Broadband Data Book

THE BROADBAND DATABOOK

Cable Access Business Unit
Systems Engineering

Revision 21 August 2019

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NOTES ON THE REPRESENTATION OF NUMBERS

Throughout this publication, numbers representing quantities (as distinct from dates) are printed using the conventions of English-speaking countries. That is to say, the decimal point is represented by a period (.) and numbers greater than one thousand have their digits ordered in groups of three, with a comma (,) separating each group.

Thus, the number one million, two hundred and thirty-four thousand, five hundred and sixty-seven point eight nine is written as:

1,234,567.89

It should be noted that the use of the period and the comma is reversed in many European countries. To avoid confusion, the convention originated by ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) is sometimes used. This recommends the use of the comma as an indicator of the decimal point, and a space instead of a comma to separate the groups of three digits in large numbers. By this convention, the example given above becomes:

1 234 567,89

Note, however, that the date (year) is written without commas or separators.

Section 1: INTRODUCTION

Cisco's *Broadband Data Book*, Revision 21 (August 2019), represents the latest in a series of popular and informative pocket technical guides for the cable telecommunications industry. Some new material has been added to what was available in Revision 20 (July 2016), and much of the previous material has been retained – some for historical reference purposes. Every effort has been made to ensure the accuracy of the content of this publication. Any errors and omissions are unintentional.

HOW TO USE CISCO'S BROADBAND DATA BOOK

Carrying on a tradition started years ago at Scientific-Atlanta with what was originally called *Technical Applications Data*, then *CATV Data Book*, Cisco's *Broadband Data Book* is intended to be used as a quick-reference guide for topics related to broadband network technology. The content provided here has been compiled from various sources such as product data sheets and industry standards and specifications. For more in-depth information, you are encouraged to consult the original source material as well as publications and other resources as noted.

The *Broadband Data Book* is divided into multiple sections, each focusing on a particular technology and related topics (refer to the Table of Contents), helping to simplify locating the material of interest. For example, Section 6 includes attenuation and loop resistance specifications for several makes and sizes of hardline, subscriber drop, and headend coaxial cables.

Take a few minutes to thumb through this edition of the *Broadband Data Book* and familiarize yourself with the layout and content.

Section 2: FREQUENCY CHARTS

North American Cable Channel Plan

6 MHz-wide channel allocations used in North American and some other cable networks are defined in *CTA Standard "Cable Television Channel Identification Plan" CTA-542-D R-2018 (Formerly CTA-542-D), updated February 2019*.

The original standard was developed by a joint EIA/NCTA committee, and was variously known as the EIA/NCTA, EIA, and IS-6 channel plans. The Consumer Electronics Association (now called the Consumer Technology Association) subsequently published updated versions of the standard under the designation CEA-542. Version CEA-542-D was renamed CTA-542-D after the Consumer Electronics Association changed its name to the Consumer Technology Association. The standard has since been updated to CTA-542-D R-2018.

Some in the industry still refer to 6 MHz-wide cable channels as 'EIA channels,' but that designation was deprecated many years ago. The correct terminology is 'CTA channels.'

The following related terms and definitions may be useful to the reader.

> **channel** – A portion of the electromagnetic spectrum used to convey one or more RF signals between a transmitter and receiver. May be specified by parameters such as start and stop frequencies, center frequency, bandwidth, or CTA channel number.
>
> **CTA-542-D R-2018** – A Consumer Technology Association standard that defines a channel identification plan for 6 MHz-wide channel frequency allocations in cable networks.
>
> **harmonic related carriers (HRC)** – A method of spacing channels in a cable television network defined in CTA-542-D R-2018, in which visual carriers are multiples of 6.0003 MHz.

incremental related carriers (IRC) – A method of spacing channels in a cable television network defined in CTA-542-D R-2018, in which all visual carriers except channels 5 and 6 are offset +12.5 kHz with respect to the standard channel plan. Channels 5 and 6 are offset +2.0125 MHz with respect to the standard channel plan.

single carrier quadrature amplitude modulation (SC-QAM) – The designation for legacy QAM signals carried on cable networks.

standard frequencies (STD) – A method of spacing channels in a cable television network defined in CTA-542-D R-2018. Channels 2-6 and 7-13 use the same frequencies as over-the-air channels 2-6 and 7-13. Other cable channels below Ch. 7 down to 91.25 MHz and above Ch. 13 are spaced in 6 MHz increments.

The following table includes examples of CTA-542-D R-2018 channel numbers, visual carrier frequencies, and SC-QAM center frequencies (frequencies shown in MHz).

CTA Channel	STD (analog visual carrier)	IRC (analog visual carrier)	HRC (analog visual carrier)	STD (SC-QAM center frequency)	IRC (SC-QAM center frequency)	HRC (SC-QAM center frequency)
2	55.2500	55.2625	54.0027	57.0000	57.0000	55.7500
3	61.2500	61.2625	60.0030	63.0000	63.0000	61.7500
4	67.2500	67.2625	66.0033	69.0000	69.0000	67.7500
5	77.2500	79.2625	78.0039	79.0000	81.0000	79.7500
6	83.2500	85.2625	84.0042	85.0000	87.0000	85.7500

CATV channels
(Standard frequency plan[1])

North America

CTA channel Designation[2]		Channel limits		Analog	SC-QAM[3]
new	old	bottom	top	Visual carrier	Center frequency
2	2	54.00	60.00	55.2500	57.00
3	3	60.00	66.00	61.2500	63.00
4	4	66.00	72.00	67.2500	69.00
1	A-8	72.00	76.00	NA	NA
5	5	76.00	82.00	77.2500	79.00
6	6	82.00	88.00	83.2500	85.00
95	A-5	90.00	96.00	91.2500	93.00
96	A-4	96.00	102.00	97.2500	99.00
97	A-3	102.00	108.00	103.2500	105.00
98	A-2	108.00	114.00	109.2750	111.00
99	A-1	114.00	120.00	115.2750	117.00
14	A	120.00	126.00	121.2625	123.00
15	B	126.00	132.00	127.2625	129.00
16	C	132.00	138.00	133.2625	135.00
17	D	138.00	144.00	139.2500	141.00
18	E	144.00	150.00	145.2500	147.00
19	F	150.00	156.00	151.2500	153.00
20	G	156.00	162.00	157.2500	159.00
21	H	162.00	168.00	163.2500	165.00
22	I	168.00	174.00	169.2500	171.00
7	7	174.00	180.00	175.2500	177.00
8	8	180.00	186.00	181.2500	183.00
9	9	186.00	192.00	187.2500	189.00
10	10	192.00	198.00	193.2500	195.00
11	11	198.00	204.00	199.2500	201.00
12	12	204.00	210.00	205.2500	207.00
13	13	210.00	216.00	211.2500	213.00
23	J	216.00	222.00	217.2500	219.00
24	K	222.00	228.00	223.2500	225.00
25	L	228.00	234.00	229.2625	231.00
26	M	234.00	240.00	235.2625	237.00
27	N	240.00	246.00	241.2625	243.00
28	O	246.00	252.00	247.2625	249.00
29	P	252.00	258.00	253.2625	255.00
30	Q	258.00	264.00	259.2625	261.00
31	R	264.00	270.00	265.2625	267.00
32	S	270.00	276.00	271.2625	273.00
33	T	276.00	282.00	277.2625	279.00
34	U	282.00	288.00	283.2625	285.00
35	V	288.00	294.00	289.2625	291.00
36	W	294.00	300.00	295.2625	297.00

CTA channel Designation[2]		Channel limits		Analog	SC-QAM[3]
new	old	bottom	top	Visual carrier	Center frequency
37	AA	300.00	306.00	301.2625	303.00
38	BB	306.00	312.00	307.2625	309.00
39	CC	312.00	318.00	313.2625	315.00
40	DD	318.00	324.00	319.2625	321.00
41	EE	324.00	330.00	325.2625	327.00
42	FF	330.00	336.00	331.2750	333.00
43	GG	336.00	342.00	337.2625	339.00
44	HH	342.00	348.00	343.2625	345.00
45	II	348.00	354.00	349.2625	351.00
46	JJ	354.00	360.00	355.2625	357.00
47	KK	360.00	366.00	361.2625	363.00
48	LL	366.00	372.00	367.2625	369.00
49	MM	372.00	378.00	373.2625	375.00
50	NN	378.00	384.00	379.2625	381.00
51	OO	384.00	390.00	385.2625	387.00
52	PP	390.00	396.00	391.2625	393.00
53	QQ	396.00	402.00	397.2625	399.00
54	RR	402.00	408.00	403.2500	405.00
55	SS	408.00	414.00	409.2500	411.00
56	TT	414.00	420.00	415.2500	417.00
57	UU	420.00	426.00	421.2500	423.00
58	VV	426.00	432.00	427.2500	429.00
59	WW	432.00	438.00	433.2500	435.00
60	XX	438.00	444.00	439.2500	441.00
61	YY	444.00	450.00	445.2500	447.00
62	ZZ	450.00	456.00	451.2500	453.00
63	63	456.00	462.00	457.2500	459.00
64	64	462.00	468.00	463.2500	465.00
65	65	468.00	474.00	469.2500	471.00
66	66	474.00	480.00	475.2500	477.00
67	67	480.00	486.00	481.2500	483.00
68	68	486.00	492.00	487.2500	489.00
69	69	492.00	498.00	493.2500	495.00
70	70	498.00	504.00	499.2500	501.00
71	71	504.00	510.00	505.2500	507.00
72	72	510.00	516.00	511.2500	513.00
73	73	516.00	522.00	517.2500	519.00
74	74	522.00	528.00	523.2500	525.00
75	75	528.00	534.00	529.2500	531.00
76	76	534.00	540.00	535.2500	537.00
77	77	540.00	546.00	541.2500	543.00
78	78	546.00	552.00	547.2500	549.00
79	79	552.00	558.00	553.2500	555.00
80	80	558.00	564.00	559.2500	561.00
81	81	564.00	570.00	565.2500	567.00
82	82	570.00	576.00	571.2500	573.00

CTA channel Designation[2]		Channel limits		Analog	SC-QAM[3]
new	old	bottom	top	Visual carrier	Center frequency
83	83	576.00	582.00	577.2500	579.00
84	84	582.00	588.00	583.2500	585.00
85	85	588.00	594.00	589.2500	591.00
86	86	594.00	600.00	595.2500	597.00
87	87	600.00	606.00	601.2500	603.00
88	88	606.00	612.00	607.2500	609.00
89	89	612.00	618.00	613.2500	615.00
90	90	618.00	624.00	619.2500	621.00
91	91	624.00	630.00	625.2500	627.00
92	92	630.00	636.00	631.2500	633.00
93	93	636.00	642.00	637.2500	639.00
94	94	642.00	648.00	643.2500	645.00
100	100	648.00	654.00	649.2500	651.00
101	101	654.00	660.00	655.2500	657.00
102	102	660.00	666.00	661.2500	663.00
103	103	666.00	672.00	667.2500	669.00
104	104	672.00	678.00	673.2500	675.00
105	105	678.00	684.00	679.2500	681.00
106	106	684.00	690.00	685.2500	687.00
107	107	690.00	696.00	691.2500	693.00
108	108	696.00	702.00	697.2500	699.00
109	109	702.00	708.00	703.2500	705.00
110	110	708.00	714.00	709.2500	711.00
111	111	714.00	720.00	715.2500	717.00
112	112	720.00	726.00	721.2500	723.00
113	113	726.00	732.00	727.2500	729.00
114	114	732.00	738.00	733.2500	735.00
115	115	738.00	744.00	739.2500	741.00
116	116	744.00	750.00	745.2500	747.00
117	117	750.00	756.00	751.2500	753.00
118	118	756.00	762.00	757.2500	759.00
119	119	762.00	768.00	763.2500	765.00
120	120	768.00	774.00	769.2500	771.00
121	121	774.00	780.00	775.2500	777.00
122	122	780.00	786.00	781.2500	783.00
123	123	786.00	792.00	787.2500	789.00
124	124	792.00	798.00	793.2500	795.00
125	125	798.00	804.00	799.2500	801.00
126	126	804.00	810.00	805.2500	807.00
127	127	810.00	816.00	811.2500	813.00
128	128	816.00	822.00	817.2500	819.00
129	129	822.00	828.00	823.2500	825.00
130	130	828.00	834.00	829.2500	831.00
131	131	834.00	840.00	835.2500	837.00
132	132	840.00	846.00	841.2500	843.00
133	133	846.00	852.00	847.2500	849.00

CTA channel Designation[2]		Channel limits		Analog	SC-QAM[3]
new	old	bottom	top	Visual carrier	Center frequency
134	134	852.00	858.00	853.2500	855.00
135	135	858.00	864.00	859.2500	861.00
136	136	864.00	870.00	865.2500	867.00
137	137	870.00	876.00	871.2500	873.00
138	138	876.00	882.00	877.2500	879.00
139	139	882.00	888.00	883.2500	885.00
140	140	888.00	894.00	889.2500	891.00
141	141	894.00	900.00	895.2500	897.00
142	142	900.00	906.00	901.2500	903.00
143	143	906.00	912.00	907.2500	909.00
144	144	912.00	918.00	913.2500	915.00
145	145	918.00	924.00	919.2500	921.00
146	146	924.00	930.00	925.2500	927.00
147	147	930.00	936.00	931.2500	933.00
148	148	936.00	942.00	937.2500	939.00
149	149	942.00	948.00	943.2500	945.00
150	150	948.00	954.00	949.2500	951.00
151	151	954.00	960.00	955.2500	957.00
152	152	960.00	966.00	961.2500	963.00
153	153	966.00	972.00	967.2500	969.00
154	154	972.00	978.00	973.2500	975.00
155	155	978.00	984.00	979.2500	981.00
156	156	984.00	990.00	985.2500	987.00
157	157	990.00	996.00	991.2500	993.00
158	158	996.00	1,002.00	997.2500	999.00

NOTES:

1. Incremental related carrier (IRC) and harmonic related carrier (HRC) frequency plans are excluded from this table because they are seldom encountered in today's HFC networks.
2. The 'CTA' channel numbers in the "new" column are those defined in the Consumer Technology Association standard CTA-542-D R-2018. The "old" column shows historical channel designations.
3. The center frequency is also the same as the suppressed carrier frequency (SC-QAM signals are double sideband, suppressed carrier RF signals).

CATV channels

Japan
(NTSC; standard M)

Channel width: 6 MHz							
Ch. No.	CATV	Visual	Aural	Ch. No.	CATV	Visual	Aural
1	1	91.25	95.75	C37	37	307.25	311.75
2	2	97.25	101.75	C38	38	313.25	317.75
3	3	103.25	107.75	C39	39	319.25	323.75
4	4	171.25	175.75	C40	40	325.25	329.75
5	5	177.25	181.75	C41	41	331.25	335.75
6	6	183.25	187.75	C42	42	337.25	341.75
7	7	189.25	193.75	C43	43	343.25	347.75
8	8	193.25	197.75	C44	44	349.25	353.75
9	9	199.25	203.75	C45	45	355.25	359.75
10	10	205.25	209.75	C46	46	361.25	365.75
11	11	211.25	215.75	C47	47	367.25	371.75
12	12	217.25	221.75	C48	48	373.25	377.75
C13	13	109.25	113.75	C49	49	379.25	383.75
C14	14	115.25	119.75	C50	50	385.25	389.75
C15	15	121.25	125.75	C51	51	391.25	395.75
C16	16	127.25	131.75	C52	52	397.25	401.75
C17	17	133.25	137.75	C53	53	403.25	407.75
C18	18	139.25	143.75	C54	54	409.25	413.75
C19	19	145.25	149.75	C55	55	415.25	419.75
C20	20	151.25	155.75	C56	56	421.25	425.75
C21	21	157.25	161.75	C57	57	427.25	431.75
C22	22	165.25	169.75	C58	58	433.25	437.75
C23	23	223.25	227.75	C59	59	439.25	443.75
C24	24	231.25	235.75	C60	60	445.25	449.75
C25	25	237.25	241.75	C61	61	451.25	455.75
C26	26	243.25	247.75	C62	62	457.25	461.75
C27	27	249.25	253.75	C63	63	463.25	467.75
C28	28	253.25	257.75	U13	64	471.25	475.75
C29	29	259.25	263.75	U14	65	477.25	481.75
C30	30	265.25	269.75	U15	66	483.25	487.75
C31	31	271.25	275.75	U16	67	489.25	493.75
C32	32	277.25	281.75	U17	68	495.25	499.75
C33	33	283.25	287.75	U18	69	501.25	505.75
C34	34	289.25	293.75	U19	70	507.25	511.75
C35	35	295.25	299.75	U20	71	513.25	517.75
C36	36	301.25	305.75	U21	72	519.25	523.75

NOTE:
The chrominance subcarrier is located 3.57561149 MHz above the visual carrier.

Channel width: 6 MHz							
Ch. No.	CATV	Visual	Aural	Ch. No.	CATV	Visual	Aural
U22	73	525.25	529.75	U43	94	651.25	655.75
U23	74	531.25	535.75	U44	95	657.25	661.75
U24	75	537.25	541.75	U45	96	663.25	667.75
U25	76	543.25	547.75	U46	97	669.25	673.75
U26	77	549.25	553.75	U47	98	675.25	679.75
U27	78	555.25	559.75	U48	99	681.25	685.75
U28	79	561.25	565.75	U49	100	687.25	691.75
U29	80	567.25	571.75	U50	101	693.25	697.75
U30	81	573.25	577.75	U51	102	699.25	703.75
U31	82	579.25	583.75	U52	103	705.25	709.75
U32	83	585.25	589.75	U53	104	711.25	715.75
U33	84	591.25	595.75	U54	105	717.25	721.75
U34	85	597.25	601.75	U55	106	723.25	727.75
U35	86	603.25	607.75	U56	107	729.25	733.75
U36	87	609.25	613.75	U57	108	735.25	739.75
U37	88	615.25	619.75	U58	109	741.25	745.75
U38	89	621.25	625.75	U59	110	747.25	751.75
U39	90	627.25	631.75	U60	111	753.25	757.75
U40	91	633.25	637.75	U61	112	759.25	763.75
U41	92	639.25	643.75	U62	113	765.25	769.75
U42	93	645.25	649.75				

Channel width: 8 MHz					
Ch. No.	Visual	Aural	Ch. No.	Visual	Aural
Z1	112.25	118.75	DS16	495.25	501.75
Z2	120.25	126.75	DS17	503.25	509.75
Z3	128.25	134.75	DS18	511.25	517.75
Z4	136.25	142.75	DS19	519.25	525.75
Z5	144.25	150.75	DS20	527.25	533.75
Z6	152.25	158.75	DS21	535.25	541.75
Z7	160.25	166.75	DS22	543.25	549.75
DS6	168.25	174.75	DS23	551.25	557.75
DS7	176.25	182.75	DS24	559.25	565.75
DS8	184.25	190.75	Z38	567.25	573.75
DS9	192.25	198.75	Z39	575.25	581.75
DS10	200.25	206.75	Z40	583.25	589.75
DS11	208.25	214.75	Z41	591.25	597.75
DS12	216.25	222.75	Z42	599.25	605.75
Z8	224.25	230.75	DS25	607.25	613.75
Z9	232.25	238.75	DS26	615.25	621.75
Z10	240.25	246.75	DS27	623.25	629.75
Z11	248.25	254.75	DS28	631.25	637.75
Z12	256.25	262.75	DS29	639.25	645.75
Z13	264.25	270.75	DS30	647.25	653.75
Z14	272.25	278.75	DS31	655.25	661.75
Z15	280.25	286.75	DS32	663.25	669.75
Z16	288.25	294.75	DS33	671.25	677.75
Z17	296.25	302.75	DS34	679.25	685.75
Z18	304.25	310.75	DS35	687.25	693.75
Z19	312.25	318.75	DS36	695.25	701.75
Z20	320.25	326.75	DS37	703.25	709.75
Z21	328.25	334.75	DS38	711.25	717.75
Z22	336.25	342.75	DS39	719.25	725.75
Z23	344.25	350.75	DS40	727.25	733.75
Z24	352.25	358.75	DS41	735.25	741.75
Z25	360.25	366.75	DS42	743.25	749.75
Z26	368.25	374.75	DS43	751.25	757.75
Z27	376.25	382.75	DS44	759.25	765.75
Z28	384.25	390.75	DS45	767.25	773.75
Z29	392.25	398.75	DS46	775.25	781.75
Z30	400.25	406.75	DS47	783.25	789.75
Z31	408.25	414.75	DS48	791.25	797.75
Z32	416.25	422.75	DS49	799.25	805.75
Z33	424.25	430.75	DS50	807.25	813.75
Z34	432.25	438.75	DS51	815.25	821.75
Z35	440.25	446.75	DS52	823.25	829.75
Z36	448.25	454.75	DS53	831.25	837.75
Z37	456.25	462.75	DS54	839.25	845.75
DS13	471.25	477.75	DS55	847.25	853.75
DS14	479.25	485.75	DS56	855.25	861.75
DS15	487.25	493.75			

CATV channels

Europe
(PAL; standard B/G)

Channel width: 7 and 8 MHz					
Ch. No.	Visual	Aural	Ch. No.	Visual	Aural
↓ 7 MHz channel spacing ↓			↓ 8 MHz channel spacing ↓		
E2	48.25	53.75	S21	303.25	308.75
E3	55.25	60.75	S22	311.25	316.75
E4	62.25	67.75	S23	319.25	324.75
			S24	327.25	332.75
S2	112.25	117.75	S25	335.25	340.75
S3	119.25	124.75	S26	343.25	348.75
S4	126.25	131.75	S27	351.25	356.75
S5	133.25	138.75	S28	359.25	364.75
S6	140.25	145.75	S29	367.25	372.75
S7	147.25	152.75	S30	375.25	380.75
S8	154.25	159.75	S31	383.25	388.75
S9	161.25	166.75	S32	391.25	396.75
S10	168.25	173.75	S33	399.25	404.75
			S34	407.25	412.75
E5	175.25	180.75	S35	415.25	420.75
E6	182.25	187.75	S36	423.25	428.75
E7	189.25	194.75	S37	431.25	436.75
E8	196.25	201.75	S38	439.25	444.75
E9	203.25	208.75	S39	447.25	452.75
E10	210.25	215.75	S40	455.25	460.75
E11	217.25	222.75	S41	463.25	468.75
E12	224.25	229.75			
			E21	471.25	476.75
S11	231.25	236.75	E22	479.25	484.75
S12	238.25	243.75	E23	487.25	492.75
S13	245.25	250.75	E24	495.25	500.75
S14	252.25	257.75	E25	503.25	508.75
S15	259.25	264.75	E26	511.25	516.75
S16	266.25	271.75	E27	519.25	524.75
S17	273.25	278.75	E28	527.25	532.75
S18	280.25	285.75	E29	535.25	540.75
S19	287.25	292.75	E30	543.25	548.75
S20	294.25	299.75	E31	551.25	556.75
			E32	559.25	564.75
			E33	567.25	572.75
			E34	575.25	580.75
			E35	583.25	588.75

NOTE:
The channels E2 through E69 are designated K2 through K69 in Germany.

CATV channels — Europe (cont'd)

Ch. No.	Visual	Aural	Ch. No.	Visual	Aural
↓ 8 MHz channel spacing ↓			↓ 8 MHz channel spacing ↓		
E36	591.25	596.75	E53	727.25	732.75
E37	599.25	604.75	E54	735.25	740.75
E38	607.25	612.75	E55	743.25	748.75
E39	615.25	620.75	E56	751.25	756.75
E40	623.25	628.75	E67	759.25	764.75
E41	631.25	636.75	E58	767.25	772.75
E42	639.25	644.75	E59	775.25	780.75
E43	647.25	652.75	E60	783.25	788.75
E44	655.25	660.75	E61	791.25	796.75
E45	663.25	668.75	E62	799.25	804.75
E46	671.25	676.75	E63	807.25	812.75
E47	679.25	684.75	E64	815.25	820.75
E48	687.25	692.75	E65	823.25	828.75
E49	695.25	700.75	E66	831.25	836.75
E50	703.25	708.75	E67	839.25	844.75
E51	711.25	716.75	E68	847.25	852.75
E52	719.25	724.75	E69	855.25	860.75

NOTE:
The channels E2 through E69 are designated K2 through K69 in Germany.

CATV channels

United Kingdom
(PAL; ITU-R* standard I)

Channel width: 8 MHz					
Visual	Aural	Visual	Aural	Visual	Aural
8.0	14.0	296.0	302.0	584.0	590.0
16.0	22.0	304.0	310.0	592.0	598.0
24.0	30.0	312.0	318.0	600.0	606.0
32.0	38.0	320.0	326.0	608.0	614.0
40.0	46.0	328.0	334.0	616.0	622.0
48.0	54.0	336.0	342.0	624.0	630.0
56.0	62.0	344.0	350.0	632.0	638.0
64.0	70.0	352.0	358.0	640.0	646.0
72.0	78.0	360.0	366.0	648.0	654.0
80.0	86.0	368.0	374.0	656.0	662.0
88.0	94.0	376.0	382.0	664.0	670.0
96.0	102.0	384.0	390.0	672.0	678.0
104.0	110.0	392.0	398.0	680.0	686.0
112.0	118.0	400.0	406.0	688.0	694.0
120.0	126.0	408.0	414.0	696.0	702.0
128.0	134.0	416.0	422.0	704.0	710.0
136.0	142.0	424.0	430.0	712.0	718.0
144.0	150.0	432.0	438.0	720.0	726.0
152.0	158.0	440.0	446.0	728.0	734.0
160.0	166.0	448.0	454.0	736.0	742.0
168.0	174.0	456.0	462.0	744.0	750.0
176.0	182.0	464.0	470.0	752.0	758.0
184.0	190.0	472.0	478.0	760.0	766.0
192.0	198.0	480.0	486.0	768.0	774.0
200.0	206.0	488.0	494.0	776.0	782.0
208.0	214.0	496.0	502.0	784.0	790.0
216.0	222.0	504.0	510.0	792.0	798.0
224.0	230.0	512.0	518.0	800.0	806.0
232.0	238.0	520.0	526.0	808.0	814.0
240.0	246.0	528.0	534.0	816.0	822.0
248.0	254.0	536.0	542.0	824.0	830.0
256.0	262.0	544.0	550.0	832.0	838.0
264.0	270.0	552.0	558.0	840.0	846.0
272.0	278.0	560.0	566.0	848.0	854.0
280.0	286.0	568.0	574.0	856.0	862.0
288.0	294.0	576.0	582.0	864.0	870.0

Over-the-air channels

North America
(ITU-R standard M [NTSC]
and ATSC A/53B [8-VSB])

Channel designation	Channel limits		Analog visual carrier	8-VSB suppressed carrier
	bottom	top		
Low VHF				
2	54.00	60.00	55.25	54.31
3	60.00	66.00	61.25	60.31
4	66.00	76.00	67.25	66.31
5	76.00	82.00	77.25	76.31
6	82.00	88.00	83.25	82.31
High VHF				
7	174.00	180.00	175.25	174.31
8	180.00	186.00	181.25	180.31
9	186.00	192.00	187.25	186.31
10	192.00	198.00	193.25	192.31
11	198.00	204.00	199.25	198.31
12	204.00	210.00	205.25	204.31
13	210.00	216.00	211.25	210.31
UHF				
14	470.00	476.00	471.25	470.31
15	476.00	482.00	477.25	476.31
16	482.00	488.00	483.25	482.31
17	488.00	494.00	489.25	488.31
18	494.00	500.00	495.25	494.31
19	500.00	506.00	501.25	500.31
20	506.00	512.00	507.25	506.31
21	512.00	518.00	513.25	512.31
22	518.00	524.00	519.25	518.31
23	524.00	530.00	525.25	524.31
24	530.00	536.00	531.25	530.31
25	536.00	542.00	537.25	536.31
26	542.00	548.00	543.25	542.31
27	548.00	554.00	549.25	548.31
28	554.00	560.00	555.25	554.31
29	560.00	566.00	561.25	560.31
30	566.00	572.00	567.25	566.31
31	572.00	578.00	573.25	572.31
32	578.00	584.00	579.25	578.31
33	584.00	590.00	585.25	584.31
34	590.00	596.00	591.25	590.31
35	596.00	602.00	597.25	596.31
36	602.00	608.00	603.25	602.31
37	608.00	614.00	609.25	608.31
38	614.00	620.00	615.25	614.31
39	620.00	626.00	621.25	620.31
40	626.00	632.00	627.25	626.31

Channel designation	Channel limits		Analog visual carrier	8-VSB suppressed carrier
	bottom	top		
41	632.00	638.00	633.25	632.31
42	638.00	644.00	639.25	638.31
43	644.00	650.00	645.25	644.31
44	650.00	656.00	651.25	650.31
45	656.00	662.00	657.25	656.31
46	662.00	668.00	663.25	662.31
47	668.00	674.00	669.25	668.31
48	674.00	680.00	675.25	674.31
49	680.00	686.00	681.25	680.31
50	686.00	692.00	687.25	686.31
51	692.00	698.00	693.25	692.31

NOTES:

At the time of printing of this *Databook*, all high-power over-the-air TV transmitters in the United States have made the conversion to digital transmission. Most of these transmissions use the UHF band, but some can be found in the low- and high-VHF bands. Low-power transmitters and translators may continue to broadcast analog TV signals.

The 698 MHz to 806 MHz over-the-air spectrum containing the former UHF TV channels 52-69 has been reallocated to other services such as long term evolution (LTE) and public safety communications.

A 600 MHz incentive auction concluded in early 2017, which paved the way for reassignment of UHF TV channels 38-51 for wireless services. TV broadcasters are vacating those channels and either going off the air altogether or moving to a lower-frequency channel during a multi-year, 10-phase transition schedule, slated to be complete by mid-2020.

VHF over-the-air channels

ITU-R standards B,D,I & L

Channel	BW (MHz)	Visual	Aural
Europe (standard B); 7 MHz spacing			
E2	47 – 54	48.25	53.75
E3	54 – 61	55.25	60.75
E4	61 – 68	62.25	67.75
S2	111-118	112.25	117.75
S3	118-125	119.25	124.75
S4	125-132	126.25	131.75
S5	132-139	133.25	138.75
S6	139-146	140.25	145.75
S7	146-153	147.25	152.75
S8	153-160	154.25	159.75
S9	160-167	161.25	166.75
S10	167-174	168.25	173.75
E5	174-181	175.25	180.75
E6	181-188	182.25	187.75
E7	188-195	189.25	194.75
E8	195-202	196.25	201.75
E9	202-209	203.25	208.75
E10	209-216	210.25	215.75
E11	216-223	217.25	222.75
E12	223-230	224.25	229.75
S11	230-237	231.25	236.75
S12	237-244	238.25	243.75
S13	244-251	245.25	250.75
S14	251-258	252.25	257.75
S15	258-265	259.25	264.75
S16	265-272	266.25	271.75
S17	272-279	273.25	278.75
S18	279-286	280.25	285.75
S19	286-293	287.25	292.75
S20	293-300	294.25	299.75

Australia (standard B); 7 MHz spacing			
0	45 – 52	46.25	51.75
1	56 – 63	57.25	62.75
2	63 – 70	64.25	69.75
3	85 – 92	86.25	91.75
4	94–101	95.25	100.75
5	101-108	102.25	107.75
5A	137-144	138.25	143.75
6	174-181	175.25	180.75
7	181-188	182.25	187.75
8	188-195	189.25	194.75
9	195-202	196.25	201.75
10	208-215	209.25	214.75
11	215-222	216.25	221.75

VHF over-the-air channels

ITU-R standards B,D,I & L (cont'd)

Channel	BW (MHz)	Visual	Aural
Italy (standard B); 7 MHz spacing			
A	52.5-59.5	53.75	59.25
B	61 - 68	62.25	67.75
C	81 - 88	82.25	87.75
D	174-181	175.25	180.75
E	182.5-189.5	183.75	189.75
F	191-198	192.25	197.75
G	200-207	201.25	206.75
H	209-216	210.25	215.75
H_1	216-223	217.25	222.75
H_2	223-230	224.25	229.75

Morocco (standard B); 7 MHz spacing			
M 4	162-169	163.25	168.75
M 5	170-177	171.25	176.75
M 6	178-185	179.25	184.75
M 7	186-193	187.25	192.75
M 8	194-201	195.25	200.75
M 9	202-209	203.25	208.75
M 10	210-217	211.25	216.75

New Zealand (standard B); 7 MHz spacing			
1	44 - 51	45.25	50.75
2	54 - 61	55.25	60.75
3	61 - 68	62.25	67.75
4	174-181	175.25	180.75
5	181-188	182.25	187.75
6	188-195	189.25	194.75
7	195-202	196.25	201.75
8	202-209	203.25	208.75
9	209-216	210.25	215.75
10	216-223	217.25	222.75

People's Rep. of China (standard D); 8 MHz spacing			
1	48.5-56.5	49.75	56.25
2	56.5-64.5	57.75	64.25
3	64.5-72.5	65.75	72.25
4	76.0-84.0	77.25	83.75
5	84.0-92.0	85.25	91.75
6	167-175	168.25	174.75
7	175-183	176.25	182.75
8	183-191	184.25	190.75
9	191-199	192.25	198.75
10	199-207	200.25	206.75
11	207-215	208.25	214.75
12	215-223	216.25	222.75

VHF over-the-air channels

ITU-R standards B,D,I & L (cont'd)

Channel	BW (MHz)	Visual	Aural
OIRT* (standard D); 8 MHz spacing			
R I	48.5-56.5	49.75	56.25
R II	58 – 66	59.25	65.75
R III	76 – 84	77.25	83.75
R IV	84 – 92	85.25	91.75
R V	92 – 100	93.25	99.75
R VI	174-182	175.25	181.75
R VII	182-190	183.25	189.75
R VIII	190-198	191.25	197.75
R IX	198-206	199.25	205.75
R X	206-214	207.25	213.75
R XI	214-222	215.25	221.75
R XII	222-230	223.25	229.75

Ireland (standard I); 8 MHz spacing			
I A	44.5-52.5	45.75	51.75
I B	52.5-60.5	53.75	59.75
I C	60.5-68.5	61.75	67.75
I D	174-182	175.25	181.25
I E	182-190	183.25	189.25
I F	190-198	191.25	197.25
I G	198-206	199.25	205.25
I H	206-214	207.25	213.25
I J	214-222	215.25	221.25

South Africa (standard I); 8 MHz spacing			
4	174-182	175.25	181.25
5	182-190	183.25	189.25
6	190-198	191.25	197.25
7	198-206	199.25	205.25
8	206-214	207.25	213.25
9	214-222	215.25	221.25
10	222-230	223.25	229.25
11	230-238	231.25	237.25
(12)	238-246	not defined	
13	246-254	247.25	253.25

* OIRT: Organisation Internationale de Radiodiffusion-Télévision.
This organization represented the broadcasters of Eastern European countries. In 1993 it was incorporated into the European Broadcasting Union (EBU).

VHF over-the-air channels

ITU-R standards B,D,I & L (cont'd)

Channel	BW (MHz)	Visual	Aural
France (standard L); 8 MHz spacing			
A	41 – 49	47.75	41.25
B	49 – 57	55.75	49.25
C	57 – 65	63.75	57.25
C 1	53.75-61.75	60.50	54.0
1	174.75-182.75	176.0	182.50
2	182.75-190.75	184.0	190.50
3	190.75-198.75	192.0	198.50
4	198.75-206.75	200.0	206.50
5	206.75-214.75	208.0	214.50
6	214.75-222.75	216.0	222.50

Japan (standard M); 6 MHz spacing			
J 1	90 – 96	91.25	95.75
J 2	96 – 102	97.25	101.75
J 3	102-108	103.25	107.75
J 4	170-176	171.25	175.75
J 5	176-182	177.25	181.75
J 6	182-188	183.25	187.75
J 7*	188-194	189.25	193.75
J 8*	192-198	193.25	197.75
J 9	198-204	199.25	203.75
J 10	204-210	205.25	209.75
J 11	210-216	211.25	215.75
J 12	216-222	217.25	221.75

* Channel spacing is 4 MHz

UHF over-the-air channels

ITU-R standards G, H, I, K & L

CHANNEL		BW (MHz)	VISUAL	AURAL		
Europe	P.R. China			G,H	I	K,L
UHF band IV						
21	13	470-478	471.25	476.75	477.25	477.75
22	14	478-486	479.25	484.75	485.25	485.75
23	15	486-494	487.25	492.75	493.25	493.75
24	16	494-502	495.25	500.75	501.25	501.75
25	17	502-510	503.25	508.75	509.25	509.75
26	18	510-518	511.25	516.75	517.25	517.75
27	19	518-526	519.25	524.75	525.25	525.75
28	20	526-534	527.25	532.75	533.25	533.75
29	21	534-542	535.25	540.75	541.25	541.75
30	22	542-550	543.25	548.75	549.25	549.75
31	23	550-558	551.25	556.75	557.25	557.75
32	24	558-566	559.25	564.75	565.25	565.75
33	↑	566-574	567.25	572.75	573.25	573.75
34		574-582	575.25	580.75	581.25	581.75
35	Not defined	582-590	583.25	588.75	589.25	589.75
36		590-598	591.25	596.75	597.25	597.75
37	↓	598-606	599.25	604.75	605.25	605.75
UHF band V						
38	25	606-614	607.25	612.75	613.25	613.75
39	26	614-622	615.25	620.75	621.25	621.75
40	27	622-630	623.25	628.75	629.25	629.75
41	28	630-638	631.25	636.75	637.25	637.75
42	29	638-646	639.25	644.75	645.25	645.75
43	30	646-654	647.25	652.75	653.25	653.75
44	31	654-662	655.25	660.75	661.25	661.75
45	32	662-670	663.25	668.75	669.25	669.75
46	33	670-678	671.25	676.75	677.25	677.75
47	34	678-686	679.25	684.75	685.25	685.75
48	35	686-694	687.25	692.75	693.25	693.75
49	36	694-702	695.25	700.75	701.25	701.75
50	37	702-710	703.25	708.75	709.25	709.75
51	38	710-718	711.25	716.75	717.25	717.75
52	39	718-726	719.25	724.75	725.25	725.75
53	40	726-734	727.25	732.75	733.25	733.75
54	41	734-742	735.25	740.75	741.25	741.75
55	42	742-750	743.25	748.75	749.25	749.75
56	43	750-758	751.25	756.75	757.25	757.75
57	44	758-766	759.25	764.75	765.25	765.75
58	45	766-774	767.25	772.75	773.25	773.75
59	46	774-782	775.25	780.75	781.25	781.75
60	47	782-790	783.25	788.75	789.25	789.75
61	48	790-798	791.25	796.75	797.25	797.75
62	49	798-806	799.25	804.75	805.25	805.75
63	50	806-814	807.25	812.75	813.25	813.75

ITU-R standards G, H, I, K & L (cont'd)

CHANNEL		BW (MHz)	VISUAL	AURAL		
Europe	P.R. China			G,H	I	K,L
UHF band V						
64	51	814-822	815.25	820.75	821.25	821.75
65	52	822-830	823.25	828.75	829.25	829.75
66	53	830-838	831.25	836.75	837.25	837.75
67	54	838-846	839.25	844.75	845.25	845.75
68	55	846-854	847.25	852.75	853.25	853.75
69	56	854-862	855.25	860.75	861.25	861.75
↑	57	862-870	863.25			869.75
	58	870-878	871.25			877.75
Not defined	59	878-886	879.25			885.75
	60	886-894	887.25			893.75
	61	894-902	895.25			901.75
↓	62	902-910	903.25			909.75

ITU-R standard B

CHAN	BW (MHz)	VISUAL	CHROMA	AURAL
UHF band IV				
28	526-533	527.25	531.68	532.75
29	533-540	534.25	538.68	539.75
30	540-547	541.25	545.68	546.75
31	547-554	548.25	552.68	553.75
32	554-561	555.25	559.68	560.75
33	561-568	562.25	566.68	567.75
34	568-575	569.25	573.68	574.75
35	575-582	576.25	580.68	581.75
UHF band V				
36	582-589	583.25	587.68	588.75
37	589-596	590.25	594.68	595.75
38	596-603	597.25	601.68	602.75
------- Other channels with 7 MHz spacing -------				
67	799-806	800.25	804.68	805.75
68	806-813	807.25	811.68	812.75
69	813-820	814.25	818.68	819.75

Refer to Section 3 for more information on the RF structure of the TV signal in each standard.

Section 3: RF CHARACTERISTICS OF BROADCAST TV SIGNALS

Analog transmission: General

There are many different TV standards in use around the world, defining in detail the baseband and RF structure of the signal, but for the broadband engineer and technician the key parameters are the bandwidth, the dimensions of the lower (vestigial) and upper sidebands, and the frequency and amplitude relationships of the visual carrier (luminance), color (chrominance) subcarrier, and aural carrier.

In terms of these parameters, the vast majority of TV transmissions fall into just six categories, which are illustrated in the following diagrams.

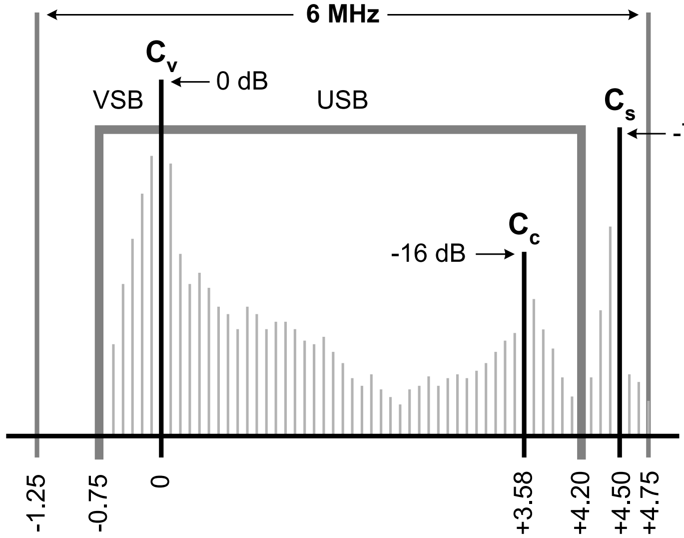
Note that these diagrams do not define such parameters as field frequency, line frequency, or color encoding technique, which distinguish the NTSC, PAL and SECAM systems.

The letters B, G, M, etc. are referred to as TV standards, and the encoding techniques (NTSC, PAL, etc.) are referred to as systems.

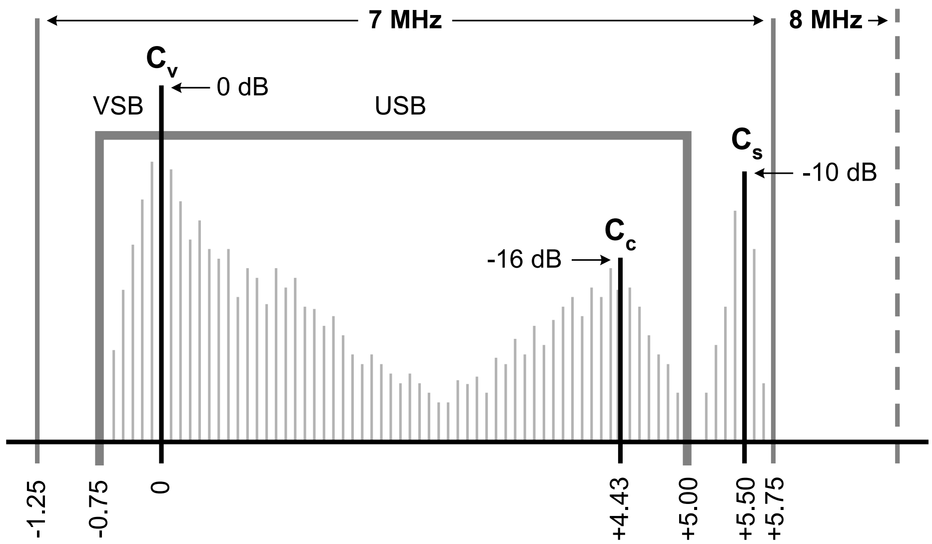
Standard:	can be used with these Systems:
B	PAL, SECAM
D	SECAM
G	PAL, SECAM
H	PAL, SECAM
I	PAL
K	SECAM
K1	SECAM
L	SECAM
M	NTSC, PAL
N	PAL

NTSC: National Television System Committee (U.S.A.)
PAL: Phase alternating line
SECAM: Séquentiel couleur à mémoire

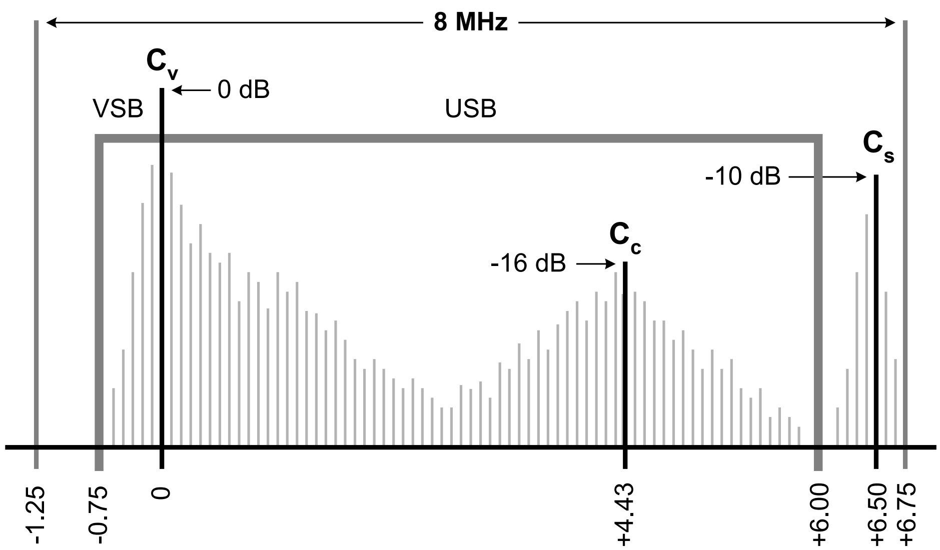
M, N



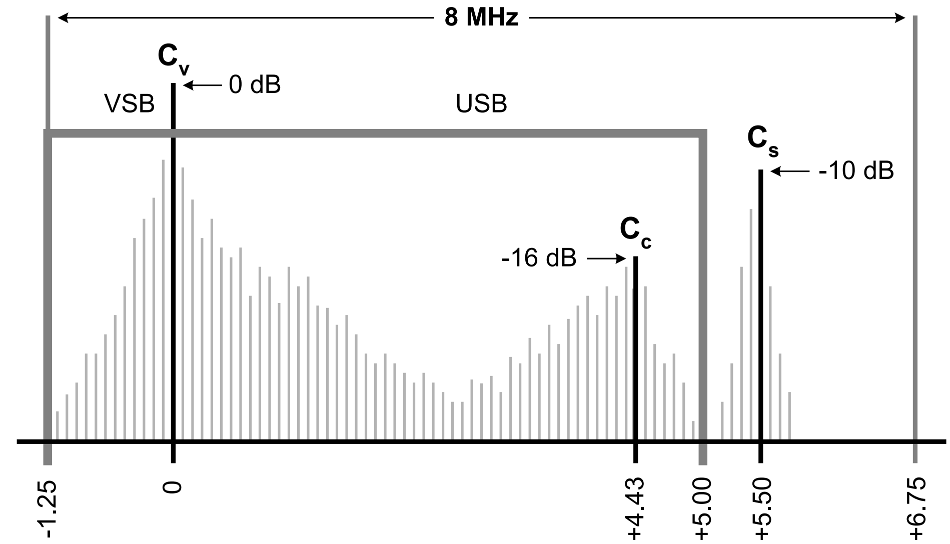
B (7 MHz)
G (8 MHz)



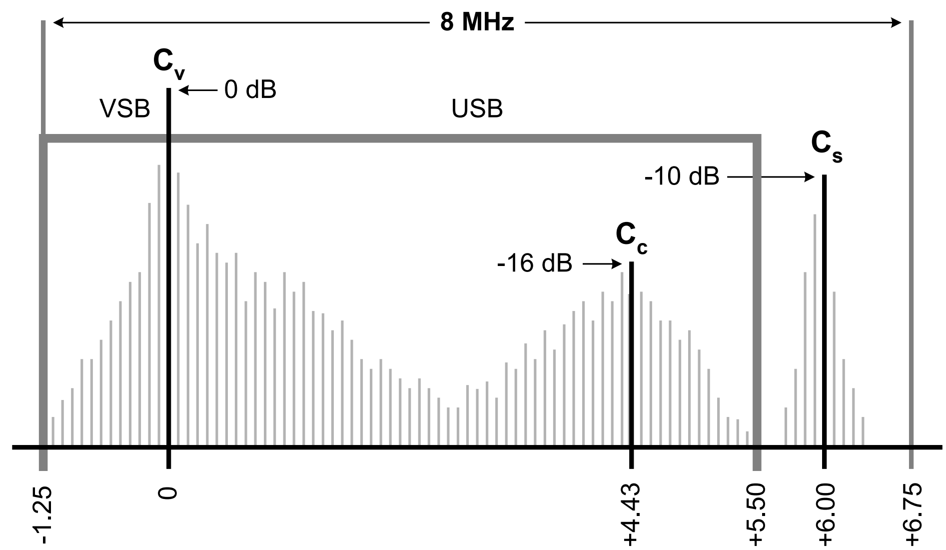
D, K



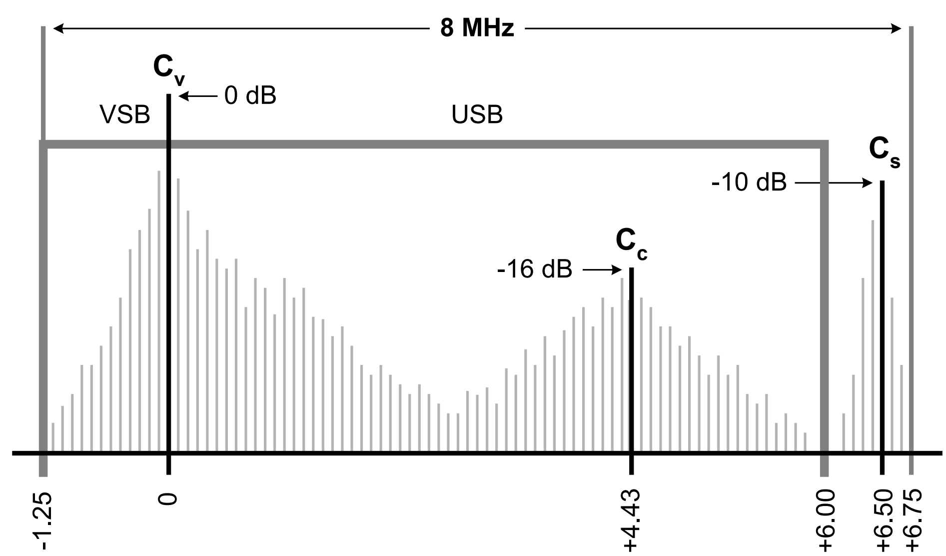
H


8 MHz
Cv
0 dB
VSB
USB
Cs
-10 dB
Cc
-16 dB
-1.25
0
+4.43
+5.00
+5.50
+6.75

I


8 MHz
Cv
0 dB
VSB
USB
Cs
-10 dB
Cc
-16 dB
-1.25
0
+4.43
+5.50
+6.00
+6.75

K1, L


8 MHz
Cv
0 dB
VSB
USB
Cs
-10 dB
Cc
-16 dB
-1.25
0
+4.43
+6.00
+6.50
+6.75

Analog transmission: Systems and Standards by Country

Country	System	Std.		Country	System	Std.
Afghanistan	PAL	D		El Salvador	NTSC	M
Albania	PAL	B/G		Equatorial Guinea	PAL	B
Algeria	PAL	B		Estonia	PAL	B/G
Argentina	PAL	N		Ethiopia	PAL	B
Angola	PAL	I		Finland	PAL	B/G
Australia	PAL	B		France	SECAM	L
Antigua & Barbuda	NTSC	M		French Guiana	SECAM	K
Austria	PAL	B/G		Gabon	SECAM	K
Azores (Portugal)	PAL	B		Germany	PAL	B/G
Bahamas	NTSC	M		Ghana	PAL	B
Bahrain	PAL	B		Gibraltar	PAL	B
Bangladesh	PAL	B		Greece	SECAM	B/G
Barbados	NTSC	M		Greenland	NTSC	M
Belgium	PAL	B/G		Granada	NTSC	M
Belize	NTSC	M		Guadeloup	SECAM	K
Bermuda	NTSC	M		Guam	NTSC	M
Bolivia	NTSC	N		Guatemala	NTSC	M
Brazil	PAL	M		Haiti	SECAM	M
Bosnia	PAL	B/H		Honduras	NTSC	M
Brunei	PAL	B		Hong Kong	PAL	I
Bulgaria	SECAM	D		Hungary	PAL	B/G
Burma (Myanmar)	NTSC	N		Iceland	PAL	B
Cambodia	SECAM	M		India	PAL	B
Cameroon	PAL	B		Indonesia	PAL	B
Canada	NTSC	M		Iran	SECAM	B
Canary Islands	PAL	B		Iraq	SECAM	B
Central African Rep.	SECAM	K		Ireland (Republic of)	PAL	I
Chad	SECAM	K		Israel	PAL	B/G
Chile	NTSC	M		Italy	PAL	B/G
China	PAL	D		Ivory Coast	SECAM	K
Colombia	NTSC	M		Jamaica	NTSC	M
Congo	SECAM	D		Japan	NTSC	M
Congo (D.R.)	SECAM	K		Jordan	PAL	B
Costa Rica	NTSC	M		Kenya	PAL	B
Cuba	NTSC	M		Korea (P.D.R.)	PAL	D
Cyprus	PAL	B/G		Korea (South)	NTSC	M
Czech Republic	SECAM	D/K		Kuwait	PAL	B/G
Denmark	PAL	B/G		Laos	PAL	M
Dominican Rep.	NTSC	M		Latvia	PAL	B/G
Ecuador	NTSC	M		Lebanon	PAL	B/G
Egypt	SECAM	B		Liberia	PAL	B
Eire (Ireland)	PAL	I		Libya	PAL	B

Analog Systems and Standards by Country (cont'd)

Country	System	Std.		Country	System	Std.
Lithuania	PAL	B/G		Saudi Arabia	SECAM	B
Luxembourg	PAL	B/G		Senegal	SECAM	K
Malaysia	PAL	B		Sierra Leone	PAL	B
Mali	SECAM	K		Singapore	PAL	B
Malta	PAL	B/G		Slovakia	SECAM	D/K
Martinique	SECAM	K		Slovenia	PAL	B/G
Mauritius	SECAM	B		Somalia	PAL	B
Mexico	NTSC	M		South Africa	PAL	I
Monaco	SECAM	L/G		Spain	PAL	B/G
Mongolia	SECAM	D		Sri Lanka	PAL	B
Montenegro	PAL	B/H		Sudan	PAL	B
Morocco	SECAM	B		Suriname	NTSC	M
Mozambique	PAL	G		Swaziland	PAL	B/G
Nepal	PAL	B		Sweden	PAL	B/G
Netherlands	PAL	B/G		Switzerland	PAL	B/G
New Zealand	PAL	B/G		Syria	SECAM	B
Nicaragua	NTSC	M		Tahiti	SECAM	K
Niger	SECAM	K		Taiwan	NTSC	M
Nigeria	PAL	B		Tanzania	PAL	I
Norway	PAL	B/G		Thailand	PAL	B
Oman	PAL	B/G		Tonga	NTSC	M
Pakistan	PAL	B		Trinidad y Tobago	NTSC	M
Panama	NTSC	M		Tunisia	SECAM	B
Paraguay	PAL	N		Turkey	PAL	B
Peru	NTSC	M		Uganda	PAL	B
Philippines	NTSC	M		Ukraine	SECAM	D
Poland	PAL	D/K		U. A. Emirates	PAL	B/G
Portugal	PAL	B/G		United Kingdom	PAL	I
Puerto Rico	NTSC	M		U.S.A.	NTSC	M
Qatar	PAL	B		Uruguay	PAL	N
Reunion	SECAM	K		Uzbekistan	SECAM	D
Romania	PAL	G		Venezuela	NTSC	M
Russian Federation	SECAM	D		Vietnam	PAL	M
Rwanda	SECAM	K		Virgin Islands (U.S.)	NTSC	M
St Kitts & Nevis	NTSC	M		Yemen (A.R.)	PAL	B
St Lucia	NTSC	M		Yugoslavia	PAL	B/H
St Vincent	NTSC	M		Zambia	PAL	B
Samoa	NTSC	M		Zimbabwe	PAL	B

Noise Measurement Bandwidth

When measuring or specifying carrier-to-noise ratio, it is important to define the bandwidth in which the noise is specified.

The bandwidths for various television systems are as shown in the following table.

System	I	B, G	K1, L	D, K	M, N
Video bandwidth*	6.75	5.75	7.25	6.75	4.95
Noise bandwidth	5.08	4.75	5.58	5.75	4.00

* including lower sideband

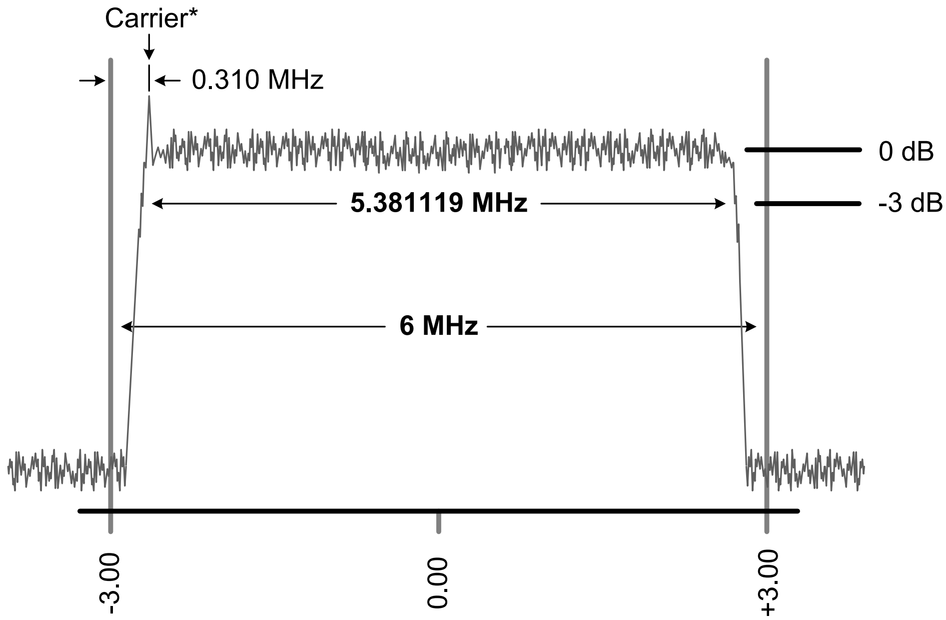
Digital transmission

Many countries have adopted standards for the terrestrial transmission of digital TV signals. In regard to the RF characteristics, these standards fall into two categories: (1) single (suppressed) carrier modulation, and (2) multiple-carrier modulation. The latter technique includes several variants on OFDM (orthogonal frequency division multiplexing). The most popular of these, in terms of the number of countries in which it has been adopted, is DVB-T (Digital Video Broadcasting – Terrestrial).

The single-carrier technique is used in 8-VSB modulation, which is defined in the ATSC standard adopted by most North American countries.

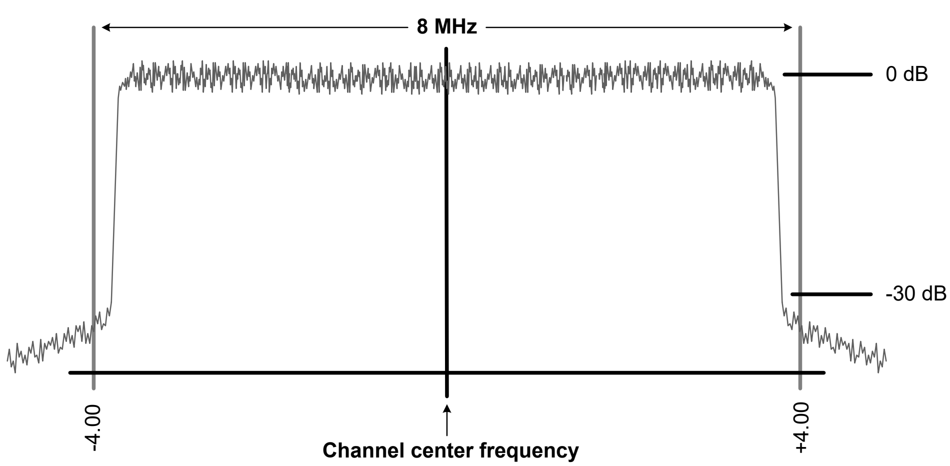
The following diagrams show the RF signal spectra for 8-VSB (6 MHz channel spacing) and OFDM (8 MHz channel spacing).

8-VSB (ATSC[1])



* The carrier in an 8-VSB transmission is suppressed, and a small pilot is added at the same frequency. This pilot will be visible on a spectrum analyzer only when the resolution (IF) bandwidth of the analyzer is much smaller than the total signal bandwidth.

OFDM (DVB-T[2])



NOTES:

1. Defined in ATSC Standard, document A/53B
2. Defined in ETSI EN 300 744

Digital transmission: Standards by Country

Country	Standard		Country	Standard
Afghanistan	N.A.		El Salvador	ATSC
Albania	DVB-T		Equatorial Guinea	N.A.
Algeria	N.A.		Estonia	DVB-T
Argentina	SBTVD-T		Ethiopia	N.A.
Angola	N.A.		Finland	DVB-T
Australia	DVB-T		France	DVB-T
Antigua & Barbuda	N.A.		French Guiana	N.A.
Austria	DVB-T		Gabon	N.A.
Azores (Portugal)	DVB-T		Germany	DVB-T
Bahamas	N.A.		Ghana	DVB-T
Bahrain	N.A.		Gibraltar	DVB-T
Bangladesh	DVB-T		Greece	DVB-T
Barbados	N.A.		Greenland	DVB-T
Belgium	DVB-T		Granada	N.A.
Belize	SBTVD-T		Guadeloup	N.A.
Bermuda	DVB-T		Guam	N.A.
Bolivia	SBTVD-T		Guatemala	ATSC
Brazil	SBTVD-T		Haiti	N.A.
Bosnia	DVB-T		Honduras	ATSC
Brunei	DVB-T		Hong Kong	DMB-T/H
Bulgaria	DVB-T		Hungary	DVB-T
Burma (Myanmar)	DVB-T		Iceland	DVB-T
Cambodia	DVB-T		India	DVB-T
Cameroon	N.A.		Indonesia	DVB-T
Canada	ATSC		Iran	DVB-T
Canary Islands	DVB-T		Iraq	N.A.
Central African Rep.	N.A.		Ireland (Republic of)	DVB-T
Chad	N.A.		Israel	DVB-T
Chile	SBTVD-T		Italy	DVB-T
China	DMB-T/H		Ivory Coast	N.A.
Colombia	DVB-T		Jamaica	N.A.
Congo	N.A.		Japan	ISDB-T
Congo (D.R.)	N.A.		Jordan	N.A.
Costa Rica	SBTVD-T		Kenya	N.A.
Cuba	N.A.		Korea (P.D.R.)	N.A.
Cyprus	DVB-T		Korea (South)	ATSC
Czech Republic	DVB-T		Kuwait	N.A.
Denmark	DVB-T		Laos	DVB-T
Dominican Rep.	ATSC		Latvia	DVB-T
Ecuador	SBTVD-T		Lebanon	N.A.
Egypt	DVB-T		Liberia	N.A.
Eire (Ireland)	DVB-T		Libya	DVB-T

Digital transmission: Standards by Country (cont'd)

Country	Standard		Country	Standard
Lithuania	DVB-T		Saudi Arabia	DVB-T
Luxembourg	DVB-T		Senegal	N.A.
Malaysia	DVB-T		Sierra Leone	N.A.
Mali	N.A.		Singapore	DVB-T
Malta	DVB-T		Slovakia	DVB-T
Martinique	N.A.		Slovenia	DVB-T
Mauritius	DVB-T		Somalia	N.A.
Mexico	ATSC		South Africa	DVB-T
Monaco	DVB-T		Spain	DVB-T
Mongolia	N.A.		Sri Lanka	DVB-T
Montenegro	DVB-T		Sudan	N.A.
Morocco	DVB-T		Suriname	N.A.
Mozambique	N.A.		Swaziland	N.A.
Nepal	N.A.		Sweden	DVB-T
Netherlands	DVB-T		Switzerland	DVB-T
New Zealand	DVB-T		Syria	N.A.
Nicaragua	SBTVD-T		Tahiti	N.A.
Niger	N.A.		Taiwan	DVB-T
Nigeria	N.A.		Tanzania	N.A.
Norway	DVB-T		Thailand	DVB-T
Oman	N.A.		Tonga	N.A.
Pakistan	N.A.		Trinidad y Tobago	N.A.
Panama	DVB-T		Tunisia	DVB-T
Paraguay	SBTVD-T		Turkey	DVB-T
Peru	SBTVD-T		Uganda	N.A.
Philippines	ISDB-T		Ukraine	DVB-T
Poland	DVB-T		U. A. Emirates	DVB-T
Portugal	DVB-T		United Kingdom	DVB-T
Puerto Rico	ATSC		U.S.A.	ATSC
Qatar	N.A.		Uruguay	DVB-T
Reunion	DVB-T		Uzbekistan	N.A.
Romania	DVB-T		Venezuela	SBTVD-T
Russian Federation	DVB-T		Vietnam	DVB-T
Rwanda	N.A.		Virgin Islands (U.S.)	N.A.
St Kitts & Nevis	N.A.		Yemen (A.R.)	N.A.
St Lucia	N.A.		Yugoslavia	DVB-T
St Vincent	N.A.		Zambia	N.A.
Samoa	N.A.		Zimbabwe	N.A.

N.A: No standard yet adopted.

Section 4: AMPLIFIER OUTPUT TILT

This section contains graphs which show the RF output levels of amplifiers with a range of tilts, using both the ‘cable’ and the ‘linear’ shapes adopted by system operators.

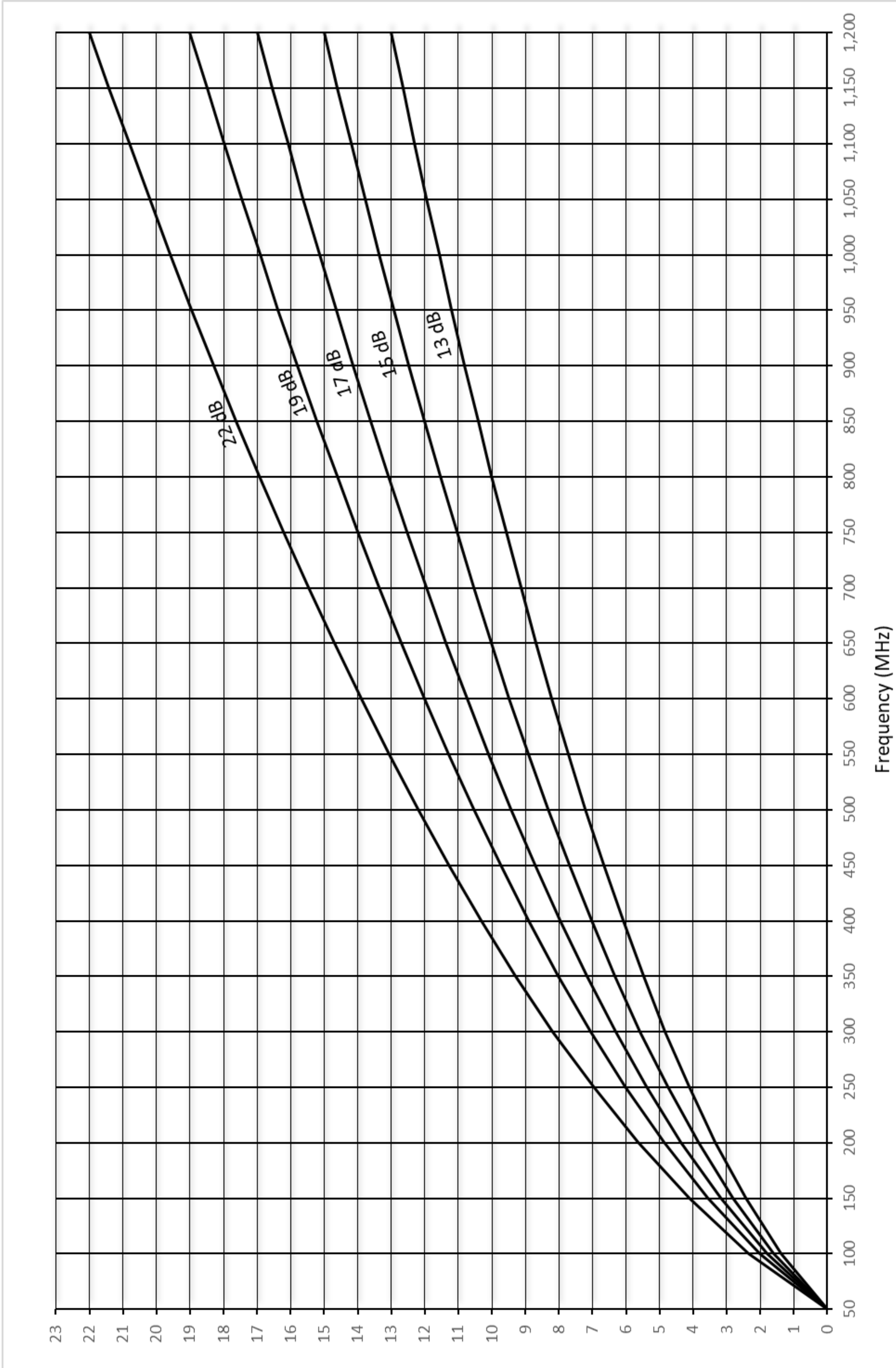
A ‘cable’ shape is designed to pre-emphasize the output of an RF amplifier to compensate for the characteristics of standard coaxial cable with foamed polyethylene dielectric. When plotted on a linear frequency scale, this characteristic exhibits a marked curvature. In recent years, the ‘linear’ shape has become popular, and as its name implies, it consists of a straight-line amplitude characteristic on a linear frequency scale.

The graphs in this section can be used as quick-reference tools in the following ways:

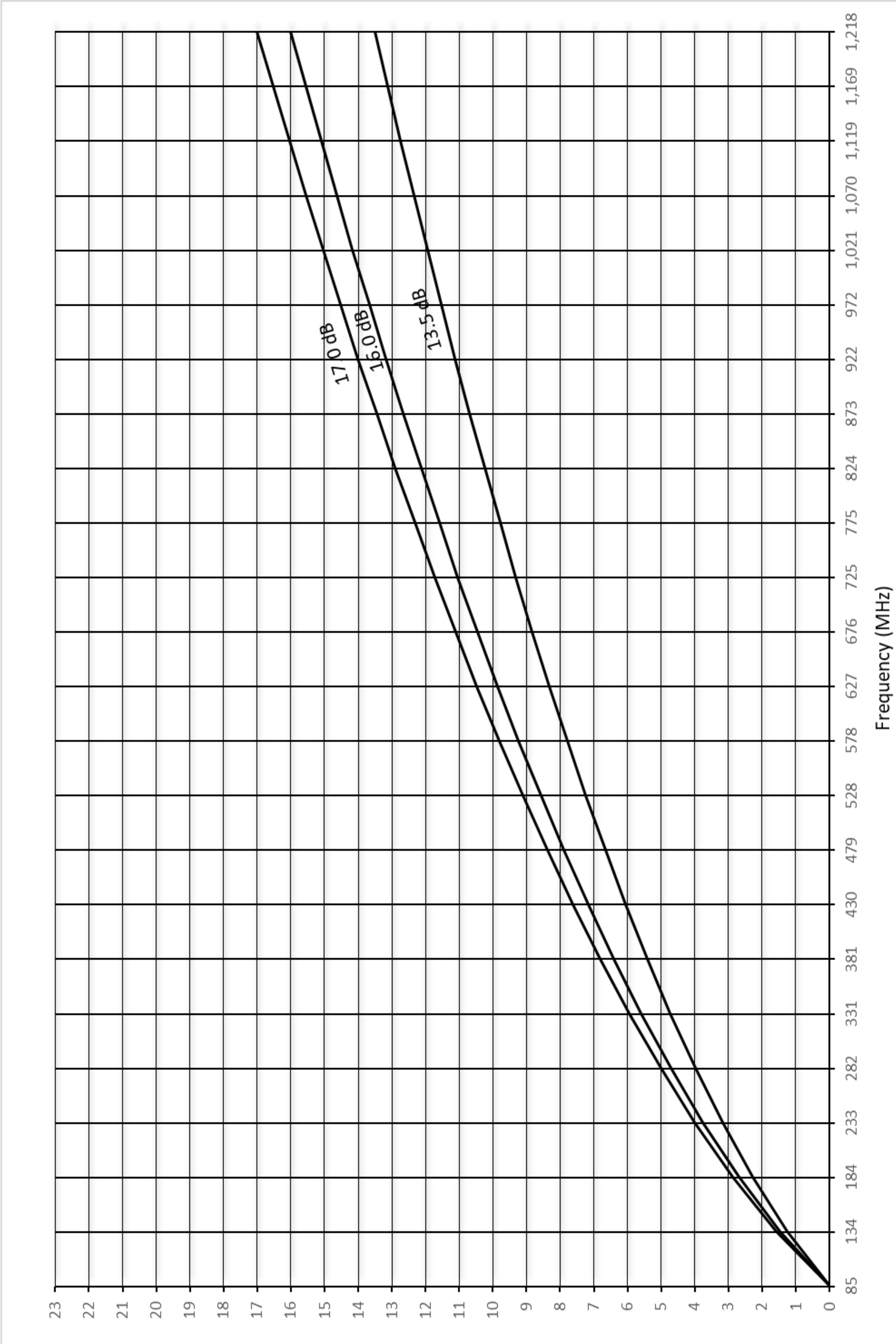
1. In existing systems, the amplitude of a signal at any frequency can be estimated.
2. When a bandwidth expansion is planned, it is common practice to maintain existing signal levels and to ‘project’ the amplifier output tilt (particularly in the feeder plant) to the new higher frequency. The graphs can be used to determine the levels of signals in the expanded frequency region.

The difference between a ‘cable’ and a ‘linear’ amplifier tilt can be significant, particularly when using a large tilt in 870 MHz or 1 GHz systems. For example, in a 1 GHz system with a 14.5 dB amplifier output tilt, the level of a signal at 550 MHz is approximately 1.5 dB greater with a ‘cable’ tilt than with a ‘linear’ tilt. This results in increased CTB and CSO distortion products.

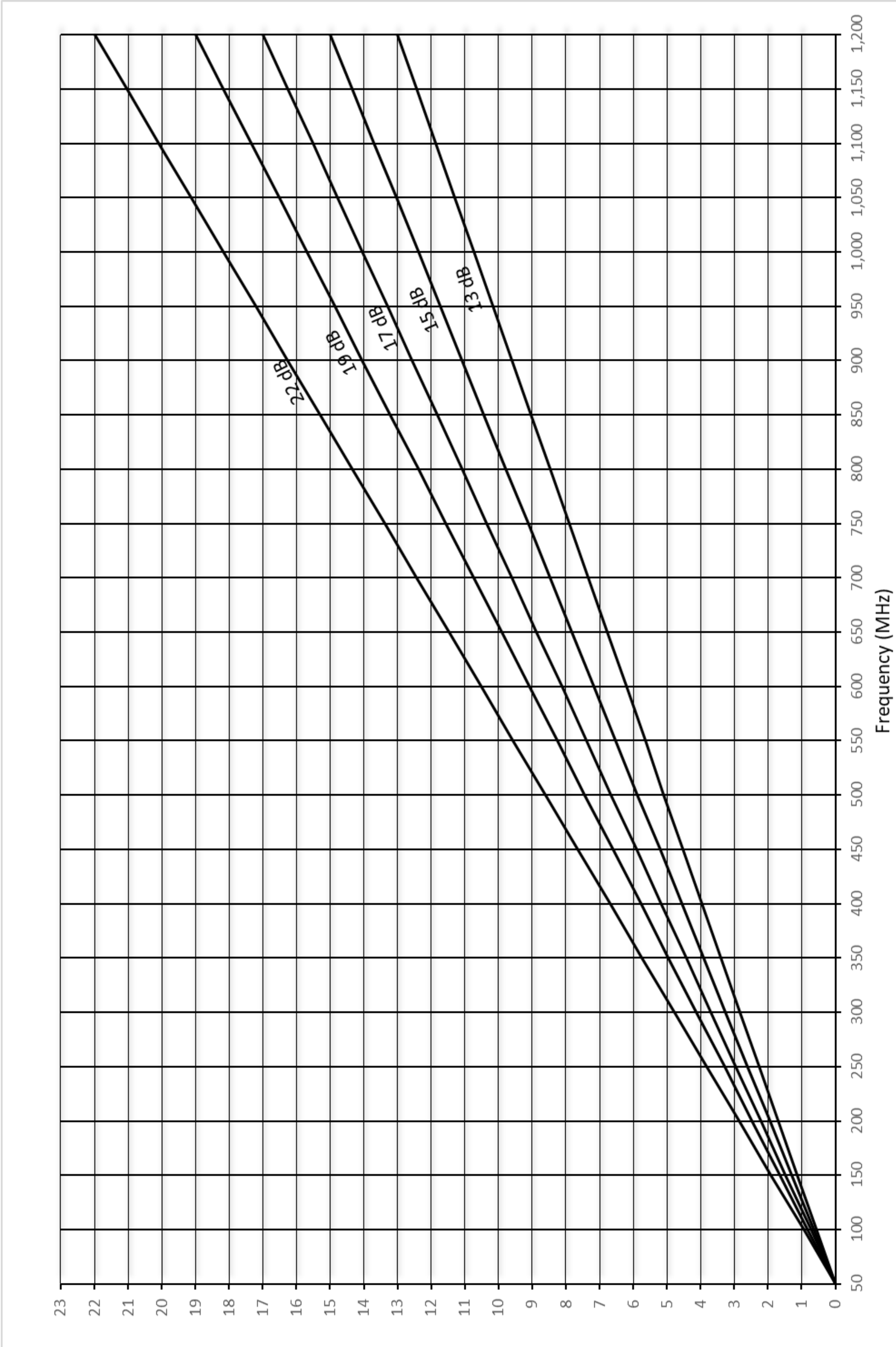
The graphs on the following pages show some of the most commonly-used output tilts. For North American systems, the graphs give overall tilt between 50 MHz and 1.2 GHz. For European systems, the range is 86 MHz to 1.2 GHz.



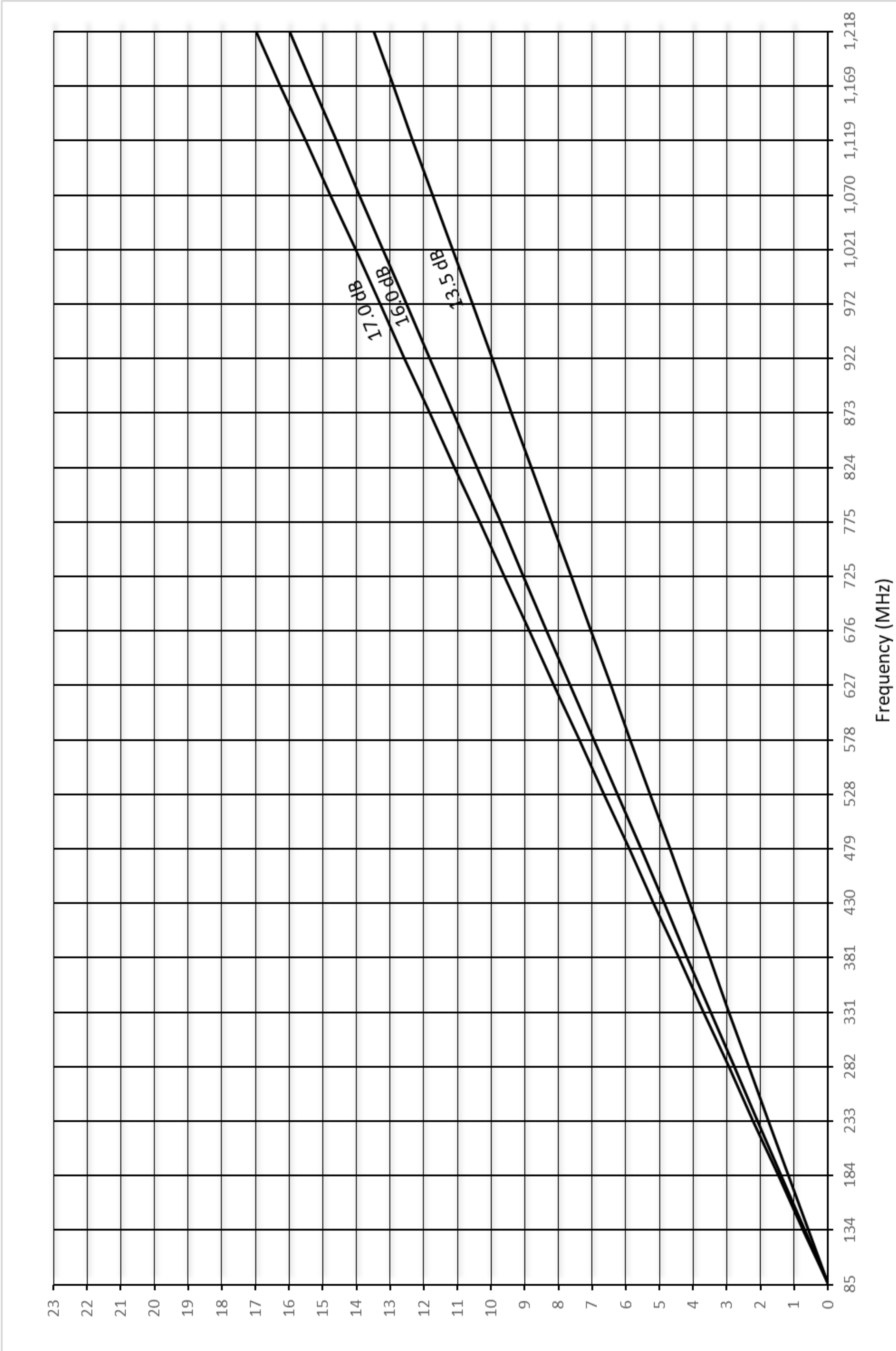
Cable tilt: North American systems



Cable tilt: European systems



Linear tilt: North American systems



Linear tilt: European systems

Section 5: RF TAPS and PASSIVES CHARACTERISTICS

The data in this section refer to Cisco outdoor taps and passives. Specifications for both 1 GHz and 1.25 GHz products are included. They are taken from Cisco published data sheets and, while every effort has been made to ensure accuracy in transcription, errors sometimes occur, and therefore these tables should be used for 'quick-reference' purposes only. For system design work, it is strongly recommended that the original data be used.

Surge-Gap™ Passives

The Cisco Surge-Gap™ series of passives are high-current devices for use in networks which may incorporate customer-premise equipment powered from the coaxial cable plant. They incorporate circuitry which allows them to tolerate voltage surges up to 6 kV.

Note that all attenuation data in this section are maximum values: these are the figures that are most commonly used in system upgrades. For new-builds or rebuilds, typical attenuation values are more common. (Refer to on-line Cisco product specifications).

Two- and Three-way Splitters (1 GHz)

Part number:		712971 2-way balanced	712972 3-way balanced	712973 3-way unbalanced	
				Low	*High*
	Frequency				
Maximum insertion loss (dB)	5	4.4	6.1	7.5	3.9
	40	4.2	5.8	7.4	3.8
	50	4.0	5.6	7.2	3.8
	450	4.2	6.1	7.8	4.1
	550	4.3	6.2	7.9	4.2
	750	4.5	6.5	8.0	4.6
	870	4.7	6.6	8.1	4.7
	1000	4.9	6.9	8.3	4.9

NOTES:

1 GHz Surge-Gap™ splitters can pass 60 V or 90 V 50/60 Hz power at 15 A.
Return loss (all ports) is typically 18 dB (15 dB worst-case).

Surge-Gap™ Passives (continued)

Directional Couplers and Power Inserter (1 GHz)

	Part number:	712968 DC-8	712969 DC-12	712970 DC-16	712974 Pwr Inserter
Maximum Insertion loss (dB)	Frequency				
	5	1.9	1.1	1.1	0.9
	40	1.8	1.1	1.0	0.6
	50	1.7	1.1	1.0	0.7
	450	1.9	1.2	1.1	0.7
	550	2.0	1.3	1.2	0.7
	750	2.2	1.5	1.4	0.8
	870	2.4	1.7	1.5	0.9
	1000	2.5	1.9	1.6	1.0
Maximum Tap loss (dB)	Frequency				
	5	9.3	13.8	17.0	
	40	9.1	13.3	16.5	
	50	9.1	13.3	16.6	
	450	9.1	13.2	16.7	
	550	9.1	13.1	16.6	
	750	9.3	13.2	17.0	
	870	9.4	13.2	17.1	
	1000	9.5	12.9	16.8	

NOTES:

1 GHz directional couplers can pass 60 V or 90 V 50/60 Hz power at 15 A.
1 GHz power inserter can pass 60 V or 90 V 50/60 Hz power at 20 A through input port; 15 A through output ports.
Return loss (all ports) is typically 18 dB (15 dB worst-case).

Two- and Three-way Splitters (1.25 GHz)

		2-way balanced	3-way balanced	*3-way* unbalanced	
				Low	*High*
Maximum Insertion loss (dB)	Frequency				
	5	4.4	6.1	7.5	3.9
	10	4.2	5.8	7.4	3.8
	40	4.0	5.6	7.2	3.8
	85	4.0	5.6	7.2	3.8
	100	4.0	5.6	7.2	3.8
	200	4.1	5.8	7.3	3.8
	550	4.3	6.2	7.9	4.2
	750	4.5	6.5	8.0	4.6
	870	4.7	6.6	8.1	4.7
	1000	4.9	6.9	8.3	4.9
	1218	5.1	7.2	8.6	5.2
	1250	5.2	7.3	8.7	5.2

Surge-Gap™ Passives (continued)

NOTES:

1.25 GHz Surge-Gap™ splitters can pass 60 V or 90 V 50/60 Hz power at 15 A.
Return loss (all ports) varies from 15 dB to 18 dB, depending on frequency.

Directional Couplers and Power Inserter (1.25 GHz)

		DC-8	DC-12	DC-16	Pwr Inserter
Maximum Insertion loss (dB)	Frequency				
	5	1.9	1.1	1.1	0.9
	10	1.8	1.1	1.0	0.6
	40	1.7	1.1	1.0	0.6
	85	1.7	1.1	1.0	0.7
	100	1.7	1.1	1.0	0.7
	200	1.8	1.1	1.1	0.7
	550	2.0	1.3	1.2	0.7
	750	2.2	1.5	1.4	0.8
	870	2.4	1.7	1.5	0.9
	1000	2.5	1.9	1.6	1.0
	1218	2.7	2.2	1.8	1.1
	1250	2.8	2.3	1.9	1.2
Maximum Tap loss (dB), ±1 dB	Frequency				
	5	8.5	12.3	16.0	
	10	8.5	12.3	16.0	
	40	8.5	12.3	16.0	
	85	8.5	12.3	16.0	
	100	8.5	12.3	16.0	
	200	8.5	12.3	16.0	
	550	8.5	12.3	16.0	
	750	8.5	12.3	16.0	
	870	8.5	12.3	16.0	
	1000	8.5	12.3	16.0	
	1218	8.5	12.3	16.0	
	1250	8.5	12.3	16.0	

NOTES:

1.25 GHz directional couplers can pass 60 V or 90 V 50/60 Hz power at 15 A.
1.25 GHz power inserter can pass 60 V or 90 V 50/60 Hz power at 20 A through input port; 15 A through output ports.
Return loss (all ports) varies from 15 dB to 18 dB, depending on frequency.

Surge-Gap™ Standard Taps

These Cisco taps are ‘symmetrical’, meaning that the attenuation between the main RF input and any of the tap ports is the same in both the downstream and upstream signal directions. They are capable of carrying a continuous through-current of 12 A, and they contain an AC/RF “make-before-break” capability, which allows technicians to pull the tap’s faceplate and perform maintenance without interrupting service to subscribers located downstream. Specifications for both the 1 GHz and 1.25 GHz models are included.

	Two-way taps (1 GHz)								
Tap value:	4	8	11	14	17	20	23	26	29
Part Number:	753370	753371	753372	753373	753374	753375	753376	753377	753378
	Maximum insertion loss:								
5 MHz		3.2	2.0	1.2	1.1	0.8	0.7	0.6	0.6
55 MHz		2.5	1.6	1.1	0.9	0.6	0.6	0.6	0.6
550 MHz		3.6	2.5	1.7	1.6	1.3	1.2	1.2	1.2
650 MHz		3.9	2.6	1.8	1.5	1.3	1.2	1.3	1.3
750 MHz		4.1	2.7	1.9	1.6	1.4	1.6	1.4	1.4
870 MHz		4.3	3.0	2.3	1.8	1.7	1.5	1.6	1.6
1000 MHz		4.6	3.6	2.7	2.2	1.9	1.8	1.8	1.8
	Tap loss tolerance (± dB):								
5 MHz	1.0	1.0	1.3	1.3	1.4	1.4	1.3	1.0	1.6
55 MHz	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
550 MHz	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.5
650 MHz	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.0	1.4
750 MHz	1.0	1.0	1.0	1.0	1.0	1.3	1.3	1.0	1.1
870 MHz	1.1	1.3	1.0	1.0	1.0	1.2	1.1	1.0	1.0
1000 MHz	1.3	1.7	1.0	1.0	1.4	1.2	1.0	1.5	1.2

Surge-Gap™ Standard Taps (continued)

	Two-way taps (1.25 GHz)						
Tap value:	4	8	11	14	17	20	23
	Maximum insertion loss:						
5 MHz		3.2	2.0	1.2	1.1	0.8	0.7
10 MHz		3.0	1.6	1.0	0.9	0.7	0.6
40 MHz		2.5	1.6	0.9	0.8	0.7	0.5
85 MHz		2.5	1.6	1.1	0.8	0.7	0.7
100 MHz		2.5	1.6	1.0	0.9	0.7	0.7
200 MHz		2.6	1.8	1.1	1.1	0.6	0.8
550 MHz		3.8	2.5	1.2	1.4	1.3	1.2
750 MHz		4.5	2.9	1.9	1.6	1.4	1.3
870 MHz		4.8	3.2	2.3	1.8	1.7	1.5
1000 MHz		5.1	3.6	2.6	2.2	1.9	1.8
1218 MHz		5.2	4.2	3.1	2.5	2.3	2.2
1250 MHz		5.4	4.3	3.2	2.6	2.4	2.3
	Tap loss (±1 dB; ±1.25 dB from 1000 MHz to 1250 MHz):						
5 MHz	4.0	8.5	10.7	13.7	16.1	19.5	22.5
10 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0
40 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0
85 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0
100 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0
200 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0
550 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.2
750 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0
870 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0
1000 MHz	4.0	8.5	11.0	14.2	17.0	20.2	23.2
1218 MHz	4.0	9.2	11.2	14.4	17.0	20.2	23.4
1250 MHz	4.1	9.5	11.5	14.5	17.5	20.4	23.5

Surge-Gap™ Standard Taps (continued)

	Four-way taps (1 GHz)							
Tap value:	8	11	14	17	20	23	26	29
Part Number:	753379	753380	753381	753382	753383	753384	753385	753386
	Maximum insertion loss:							
5 MHz		3.2	2.1	1.4	0.8	0.8	0.7	0.7
55 MHz		2.5	1.5	1.2	0.9	0.7	0.6	0.6
550 MHz		3.8	2.5	1.9	1.6	1.4	1.2	1.2
650 MHz		4.2	2.7	1.9	1.5	1.3	1.3	1.3
750 MHz		4.5	2.9	2.1	1.6	1.4	1.3	1.4
870 MHz		4.8	3.2	2.3	1.8	1.6	1.5	1.6
1000 MHz		5.1	3.6	2.7	2.1	1.9	1.9	1.9
	Tap loss tolerance (± dB):							
5 MHz	1.3	1.0	1.0	1.3	1.0	1.3	1.4	1.7
55 MHz	1.3	1.2	1.0	1.0	1.0	1.0	1.0	1.0
550 MHz	1.0	1.6	1.0	1.0	1.0	1.0	1.0	1.0
650 MHz	1.0	1.7	1.0	1.0	1.0	1.0	1.0	1.0
750 MHz	1.0	1.8	1.0	1.0	1.0	1.0	1.1	1.1
870 MHz	1.1	2.1	1.0	1.0	1.0	1.0	1.4	1.4
1000 MHz	1.5	2.8	1.3	1.0	1.3	1.5	1.5	1.5

Surge-Gap™ Standard Taps (continued)

	Four-way taps (1.25 GHz)					
Tap value:	8	11	14	17	20	23
	Maximum insertion loss:					
5 MHz		3.2	2.1	1.4	0.8	0.8
10 MHz		2.5	1.5	1.2	0.7	0.7
40 MHz		2.5	1.5	1.2	0.7	0.7
85 MHz		2.6	1.6	1.2	0.8	0.7
100 MHz		2.6	1.7	1.2	0.8	0.8
200 MHz		2.8	1.8	1.3	0.9	0.9
550 MHz		3.8	2.5	1.8	1.4	1.3
750 MHz		4.5	2.9	2.1	1.6	1.5
870 MHz		4.8	3.2	2.3	1.8	1.6
1000 MHz		5.1	3.6	2.7	2.1	1.9
1218 MHz		5.3	4.1	3.1	2.5	2.3
1250 MHz		5.4	4.2	3.2	2.6	2.4
	Tap loss (±1 dB; ±1.25 dB from 1001 MHz to 1250 MHz):					
5 MHz	7.5	12.0	13.8	16.5	19.5	22.4
10 MHz	7.5	12.0	14.0	17.0	20.0	23.0
40 MHz	7.5	12.0	14.0	17.0	20.0	23.0
85 MHz	7.5	12.0	14.0	17.0	20.0	23.0
100 MHz	7.5	12.0	14.0	17.0	20.0	23.0
200 MHz	7.5	12.0	14.0	17.0	20.0	23.0
550 MHz	7.5	12.0	14.0	17.0	20.0	23.0
750 MHz	7.5	12.0	14.0	17.0	20.0	23.2
870 MHz	7.5	12.0	14.0	17.0	20.0	23.2
1000 MHz	7.8	12.3	14.1	17.0	19.8	22.9
1218 MHz	8.2	12.6	14.5	17.1	20.0	22.9
1250 MHz	8.5	13.0	14.8	17.3	20.2	22.9

Surge-Gap™ Standard Taps (continued)

	Eight-way taps (1 GHz)						
Tap value:	11	14	17	20	23	26	29
Part Number:	753387	753388	753389	753390	753391	753392	753393
	Maximum insertion loss:						
5 MHz		3.5	2.4	1.1	0.9	0.6	0.6
55 MHz		3.1	1.9	1.0	0.8	0.6	0.5
550 MHz		4.6	2.6	1.9	1.6	1.3	1.3
650 MHz		4.7	2.7	2.0	1.6	1.4	1.3
750 MHz		5.0	2.9	2.1	1.8	1.5	1.5
870 MHz		5.2	3.2	2.4	2.0	1.8	1.7
1000 MHz		5.5	3.6	2.8	2.3	2.1	2.1
	Tap loss tolerance (± dB):						
5 MHz	1.0	1.5	1.0	1.0	1.5	1.0	1.7
55 MHz	1.3	1.0	1.2	1.0	1.0	1.1	1.0
550 MHz	1.0	1.7	1.6	1.5	1.3	1.4	1.0
650 MHz	1.0	1.9	1.4	1.3	1.0	1.0	1.0
750 MHz	1.2	2.1	1.5	1.4	1.1	1.0	1.0
870 MHz	1.8	2.4	1.8	1.4	1.1	1.0	1.0
1000 MHz	2.4	2.9	2.4	1.8	1.4	1.5	1.5

Surge-Gap™ Standard Taps (continued)

	Eight-way taps (1.25 GHz)				
Tap value:	11	14	17	20	23
	Maximum insertion loss:				
5 MHz		3.5	2.4	1.2	1.0
10 MHz		3.1	1.8	1.0	0.9
40 MHz		3.1	1.7	1.0	0.8
85 MHz		3.1	1.7	1.0	0.9
100 MHz		3.1	1.7	1.0	0.9
200 MHz		3.2	1.8	1.2	1.0
550 MHz		4.4	2.6	1.8	1.7
750 MHz		4.9	2.9	2.1	1.9
870 MHz		5.2	3.2	2.4	2.0
1000 MHz		5.6	3.6	2.8	2.3
1218 MHz		5.9	4.1	3.3	2.8
1250 MHz		6.0	4.2	3.4	2.9
	Tap loss (±1 dB; ±1.25 dB from 1001 MHz to 1250 MHz):				
5 MHz	11.0	15.0	18.0	20.0	22.5
10 MHz	11.0	15.0	18.0	20.5	23.0
40 MHz	11.0	15.0	18.0	20.5	23.0
85 MHz	11.0	15.0	18.0	20.5	23.0
100 MHz	11.0	15.0	18.0	20.5	23.0
200 MHz	11.0	15.0	18.0	20.5	23.0
550 MHz	11.0	15.0	18.0	20.5	23.0
750 MHz	11.0	15.0	18.0	20.1	22.8
870 MHz	11.5	15.0	18.0	20.1	22.7
1000 MHz	11.5	15.4	18.0	20.1	22.7
1218 MHz	12.3	15.8	18.3	20.8	23.3
1250 MHz	12.5	16.0	18.5	21.0	23.5

NOTES:

The following taps are 'self-terminating':[1]
Two-way, 4 dB
Four-way, 8 dB
Eight-way, 11 dB
Taps are capable of passing 60 V or 90 V 50/60 Hz power at 12 A.
Return loss (feeder ports): typically 18 dB (16 dB worst-case)

Note: Self-terminating taps are typically installed at ends-of-line locations. 4 dB, 8 dB, and 11 dB self-terminating taps do not have a through-port that can be terminated, because they are the electrical equivalent of two-way, four-way, and eight-way splitters respectively. As such, they do not actually terminate the feeder cable in its characteristic impedance unless all of the F ports are terminated in 75 ohms.

‘Reverse Window’ Taps (1 GHz)

These Cisco taps provide the current-carrying capability and AC/RF “make-before-break” feature of the standard units, but the highest-value taps in this series have asymmetric attenuation between the main RF input and any of the tap ports in the downstream and upstream signal directions. In HFC networks with high RF levels in the downstream path, a standard (symmetrical) tap close to an amplifier might require a CPE device (e.g., a DOCSIS cable modem) to raise its output level beyond the limit of its range. By providing lower attenuation in the upstream path, the Reverse Window tap allows a cable modem to transmit at a more reasonable level. This ability to control cable modem output levels reduces the overall range, or ‘window’ of upstream signal levels. Reverse Window taps are available with downstream tap losses of 32 dB, 29 dB and 26 dB. For all three types, the upstream attenuation is approximately 23 dB.

All taps:

	Two-way taps			Four-way taps			Eight-way taps		
Tap value:	**26**	**29**	**32**	**26**	**29**	**32**	**26**	**29**	**32**
Part Number:	753452	753453	753454	753455	753456	753457	753458	753459	753460
	Maximum insertion loss:								
5 MHz	0.6	0.6	0.6	0.7	0.7	0.7	1.0	1.0	1.0
10 MHz	0.5	0.5	0.5	0.6	0.6	0.6	0.9	0.9	0.9
40 MHz	0.5	0.5	0.5	0.6	0.6	0.6	0.8	0.8	0.8
50 MHz	0.5	0.5	0.5	0.6	0.6	0.6	0.8	0.8	0.8
100 MHz	0.6	0.6	0.6	0.6	0.6	0.6	0.9	0.9	0.9
300 MHz	0.7	0.7	0.7	0.8	0.8	0.8	1.2	1.2	1.2
450 MHz	1.0	1.0	1.0	1.1	1.1	1.1	1.4	1.4	1.4
550 MHz	1.1	1.1	1.1	1.3	1.3	1.3	1.5	1.5	1.5
750 MHz	1.3	1.3	1.3	1.5	1.5	1.5	1.8	1.8	1.8
870 MHz	1.5	1.5	1.5	1.7	1.7	1.7	2.0	2.0	2.0
1000 MHz	1.9	1.9	1.9	2.0	2.0	2.0	2.3	2.3	2.3
	Tap value (± 1 dB):								
5 MHz	22.0	22.0	22.0	22.4	22.5	22.5	22.1	22.1	22.2
10 MHz	22.7	22.7	22.7	23.2	23.2	23.2	22.7	22.7	22.8
40 MHz	23.2	23.2	23.6	23.7	23.8	24.1	23.0	23.2	23.4
50 MHz	23.3	23.5	23.8	23.7	24.0	24.3	23.1	23.3	23.8
100 MHz	23.7	24.1	24.5	24.2	24.7	25.1	23.4	23.9	24.9
300 MHz	24.0	25.1	26.1	24.9	26.1	26.7	24.2	25.4	27.0
450 MHz	24.1	25.5	27.1	25.4	27.0	28.0	24.9	26.5	28.5
550 MHz	24.2	26.0	27.9	25.8	27.7	29.0	25.1	27.1	29.4
750 MHz	24.9	27.4	29.9	26.3	28.8	30.5	25.1	27.8	30.2
870 MHz	25.7	28.7	31.2	26.4	29.1	30.9	25.2	28.1	30.8
1000 MHz	26.6	30.2	32.1	26.2	28.8	31.0	26.0	29.1	31.9

Surge-Gap™ Flexible Solution Taps

An even tighter control of the upstream signal level ‘window’ can be obtained by using the Flexible Solution Taps. These devices have an internal socket that can accept a plug-in cable equalizer, an ‘inverse’ equalizer, or a reverse attenuator. This section includes specifications for both 1 GHz and 1.25 GHz Surge-Gap™ FST models.

	Two-way taps (1 GHz)							
Tap value:	4	8	11	14	17	20	23	26
Part Number:	4013433	4013434	4013435	4013436	4013437	4013438	4018364	4018365
	Maximum insertion loss:							
5 MHz		3.2	2.0	1.2	1.1	0.8	0.7	0.6
55 MHz		2.5	1.6	1.1	0.9	0.6	0.6	0.6
550 MHz		3.6	2.5	1.7	1.6	1.3	1.1	1.2
650 MHz		3.9	2.6	1.8	1.5	1.3	1.2	1.3
750 MHz		4.1	2.7	1.9	1.6	1.4	1.4	1.4
870 MHz		4.3	3.0	2.3	1.8	1.7	1.5	1.6
1000 MHz		4.6	3.6	2.7	2.2	1.9	1.8	1.8
	Tap loss tolerance (± dB):							
5 MHz	1.0	1.0	1.2	1.0	1.0	1.0	1.0	1.0
55 MHz	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0
550 MHz	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
650 MHz	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
750 MHz	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
870 MHz	1.0	1.3	1.0	1.0	1.0	1.0	1.0	1.0
1000 MHz	1.1	1.8	1.0	1.0	1.4	1.0	1.0	1.0

Flexible Solution Taps (continued)

	Two-way taps (1.25 GHz)								
Tap value:	4	8	11	14	17	20	23	26	29
	Maximum insertion loss:								
5 MHz		3.0	2.0	1.2	1.1	0.8	0.7	0.6	0.6
40 MHz		2.2	1.4	0.9	0.8	0.7	0.5	0.6	0.6
55 MHz		2.2	1.4	0.9	0.8	0.7	0.6	0.6	0.6
70 MHz		2.2	1.4	0.9	0.8	0.7	0.6	0.6	0.6
86 MHz		2.3	1.5	1.0	0.8	0.7	0.6	0.6	0.6
102 MHz		2.3	1.5	1.0	0.8	0.7	0.6	0.6	0.6
204 MHz		2.5	1.7	1.3	1.0	0.8	0.7	0.7	0.7
258 MHz		2.7	1.8	1.3	1.1	1.0	0.9	0.9	0.9
550 MHz		3.5	2.3	1.6	1.4	1.2	1.2	1.2	1.2
650 MHz		3.8	2.7	1.7	1.5	1.3	1.3	1.3	1.3
750 MHz		4.0	2.9	1.8	1.6	1.4	1.4	1.4	1.4
870 MHz		4.3	3.1	2.1	1.2	1.7	1.5	1.6	1.6
1000 MHz		4.5	3.4	2.2	1.9	1.7	1.7	1.7	1.7
1218 MHz		4.7	3.7	2.6	2.2	2.1	2.0	2.0	2.0
1250 MHz		4.8	3.8	2.7	2.3	2.2	2.1	2.1	2.1
	Tap loss (±1.5 dB):								
5 MHz	4.0	8.5	11.0	14.0	16.5	19.5	22.5	25.5	29.0
40 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
55 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
70 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
86 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
102 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
204 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
258 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
550 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
650 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
750 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
870 MHz	4.0	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
1000 MHz	4.5	8.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
1218 MHz	4.5	9.5	11.0	14.0	17.0	20.0	23.0	26.0	29.0
1250 MHz	4.5	9.5	11.5	14.5	17.0	20.0	23.0	26.0	29.0

Flexible Solution Taps (continued)

	Four-way taps (1 GHz)						
Tap value:	8	11	14	17	20	23	26
Part Number:	4013439	4013440	4013441	4013442	4013443	4018366	4018367
	Maximum insertion loss:						
5 MHz		3.2	2.1	1.4	0.8	0.8	0.7
55 MHz		2.5	1.5	1.2	0.9	0.7	0.6
550 MHz		3.8	2.5	1.9	1.6	1.3	1.2
650 MHz		4.2	2.7	1.9	1.5	1.3	1.3
750 MHz		4.5	2.9	2.1	1.6	1.4	1.3
870 MHz		4.8	3.2	2.3	1.8	1.6	1.5
1000 MHz		5.1	3.6	2.7	2.1	1.9	1.9
	Tap loss tolerance (± dB):						
5 MHz	1.0	1.0	1.0	1.0	1.0	1.7	1.5
55 MHz	1.0	1.2	1.0	1.0	1.0	1.0	1.0
550 MHz	1.0	1.6	1.0	1.0	1.0	1.0	1.0
650 MHz	1.0	1.7	1.0	1.0	1.0	1.0	1.0
750 MHz	1.0	1.8	1.0	1.0	1.0	1.0	1.0
870 MHz	1.0	2.1	1.0	1.0	1.0	1.2	1.5
1000 MHz	1.5	2.8	1.6	1.3	1.0	1.3	1.5

Flexible Solution Taps (continued)

	Four-way taps (1.25 GHz)							
Tap value:	8	11	14	17	20	23	26	29
	Maximum insertion loss:							
5 MHz		2.9	2.0	1.3	0.9	0.7	0.7	0.7
40 MHz		2.3	1.5	1.0	0.6	0.6	0.7	0.7
55 MHz		2.4	1.5	1.0	0.7	0.6	0.7	0.7
70 MHz		2.4	1.5	1.1	0.7	0.7	0.7	0.7
86 MHz		2.4	1.6	1.2	0.8	0.7	0.7	0.7
102 MHz		2.5	1.7	1.2	0.8	0.7	0.8	0.8
204 MHz		2.7	1.8	1.3	0.9	0.9	0.9	0.9
258 MHz		2.9	1.9	1.4	1.0	1.0	1.0	1.0
550 MHz		3.7	2.6	1.9	1.5	1.4	1.4	1.4
650 MHz		3.9	2.7	1.9	1.5	1.4	1.4	1.4
750 MHz		4.4	2.9	2.0	1.5	1.5	1.5	1.5
870 MHz		4.7	3.2	2.2	1.8	1.6	1.6	1.6
1000 MHz		4.9	3.5	2.4	2.0	1.7	1.7	1.7
1218 MHz		4.9	3.8	2.8	2.2	2.0	2.1	2.1
1250 MHz		5.0	4.0	2.9	2.4	2.1	2.2	2.2
	Tap loss (±1.5 dB):							
5 MHz	8.0	12.0	14.5	16.5	19.5	22.5	26.0	29.0
40 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
55 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
70 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
86 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
102 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
204 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
258 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
550 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
650 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
750 MHz	8.0	12.0	14.0	17.0	20.0	23.0	26.0	29.0
870 MHz	8.0	12.0	14.5	17.0	20.0	23.0	26.0	29.0
1000 MHz	8.0	12.5	14.5	17.0	20.0	23.0	26.0	29.0
1218 MHz	8.5	13.0	15.0	17.0	20.0	23.0	26.0	29.0
1250 MHz	8.5	13.0	15.0	17.0	20.0	23.0	26.0	29.0

Flexible Solutions Taps (continued)

	Eight-way taps (1 GHz)					
Tap value:	11	14	17	20	23	26
Part Number:	4013444	4013445	4013446	4013447	4018368	4018369
	Maximum insertion loss:					
5 MHz		3.5	2.4	1.1	0.9	0.6
55 MHz		3.1	1.9	1.0	0.8	0.6
550 MHz		4.6	2.6	1.9	1.6	1.3
650 MHz		4.7	2.7	2.0	1.6	1.4
750 MHz		5.0	2.9	2.1	1.8	1.5
870 MHz		5.2	3.2	2.4	2.0	1.8
1000 MHz		5.5	3.6	2.8	2.3	2.1
	Tap loss (±1.5 dB):					
5 MHz	1.0	1.0	1.0	1.0	1.0	1.0
55 MHz	1.0	1.0	1.2	1.0	1.0	1.0
550 MHz	1.0	1.7	1.6	1.5	1.0	1.1
650 MHz	1.0	1.9	1.4	1.3	1.0	1.2
750 MHz	1.0	2.1	1.5	1.4	1.1	1.2
870 MHz	1.4	2.4	1.8	1.4	1.2	1.2
1000 MHz	1.8	2.9	2.0	1.8	1.6	1.6

Flexible Solution Taps (continued)

	Eight-way taps (1.25 GHz)						
Tap value:	11	14	17	20	23	26	29
	Maximum insertion loss:						
5 MHz		3.0	2.0	1.2	1.0	0.7	0.7
40 MHz		2.3	1.5	1.0	0.8	0.6	0.6
55 MHz		2.3	1.5	1.0	0.8	0.6	0.6
70 MHz		2.4	1.6	1.0	0.8	0.7	0.7
86 MHz		2.4	1.6	1.0	0.8	0.7	0.8
102 MHz		2.5	1.7	1.0	0.9	0.7	0.8
204 MHz		2.7	1.9	1.2	1.0	0.9	1.0
258 MHz		2.8	1.9	1.3	1.1	1.1	1.1
550 MHz		3.5	2.6	1.9	1.7	1.4	1.3
650 MHz		3.6	2.7	1.9	1.7	1.4	1.4
750 MHz		3.8	2.8	1.9	1.8	1.4	1.5
870 MHz		4.1	3.0	2.1	1.9	1.7	1.7
1000 MHz		4.2	3.2	2.3	2.0	1.8	1.8
1218 MHz		4.4	3.5	2.6	2.2	2.2	2.2
1250 MHz		4.6	3.6	2.7	2.4	2.4	2.4
	Tap loss (±1.5 dB):						
5 MHz	11.0	16.0	18.0	20.5	22.5	26.0	29.0
40 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
55 MHz	11.0	16.0	18.2	20.5	23.0	26.0	29.0
70 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
86 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
102 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
204 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
258 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
550 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
650 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
750 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
870 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
1000 MHz	11.0	16.0	18.0	20.5	23.0	26.0	29.0
1218 MHz	12.0	16.6	18.2	20.5	23.0	26.0	29.5
1250 MHz	12.0	17.0	18.4	20.8	23.0	26.0	29.5

Plug-in Reverse Attenuator Losses

	Attenuators for 42/54 MHz systems (1 GHz)				
Attenuator value:	0 dB*	3 dB	6 dB	9 dB	12 dB
Part Number:	F.I.*	4013485	4013486	4013487	4013488
	Tap loss increased by (dB):				
5-42 MHz		3.0	6.0	9.0	12.0
55 MHz		0.8	0.8	0.8	0.8
550 MHz		0.3	0.3	0.3	0.3
650 MHz		0.4	0.4	0.4	0.4
750 MHz		0.5	0.5	0.5	0.5
870 MHz		0.6	0.6	0.6	0.6
1000 MHz		0.8	0.8	0.8	0.8

	Attenuators for 42/54 MHz systems (1.25 GHz)				
Attenuator value:	0 dB*	3 dB	6 dB	9 dB	12 dB
	Tap loss increased by (dB):				
5-42 MHz		3.0	6.0	9.0	12.0
54 MHz		0.8	0.8	0.8	0.8
550 MHz		0.8	0.8	0.8	0.8
750 MHz		0.8	0.8	0.8	0.8
870 MHz		0.8	0.8	0.8	0.8
1000 MHz		0.8	0.8	0.8	0.8
1218 MHz		0.8	0.8	0.8	0.8
1250 MHz		0.8	0.8	0.8	0.8

	Attenuators for 55/70 MHz systems (1 GHz)				
Attenuator value:	0 dB*	3 dB	6 dB	9 dB	12 dB
Part Number:	F.I.*	4018384	4018385	4018386	4018387
	Tap loss increased by (dB):				
5-42 MHz		3.0	6.0	9.0	12.0
55 MHz		0.6	0.6	0.6	0.6
550 MHz		0.3	0.3	0.3	0.3
650 MHz		0.4	0.4	0.4	0.4
750 MHz		0.5	0.5	0.5	0.5
870 MHz		0.6	0.6	0.6	0.6
1000 MHz		0.8	0.8	0.8	0.8

Plug-in Reverse Attenuator Losses (continued)

	Attenuators for 65/86 MHz systems (1 GHz)				
Attenuator value:	0 dB*	3 dB	6 dB	9 dB	12 dB
Part Number:	F.I.*	4018388	4018389	4018390	4018391
	Tap loss increased by (dB):				
5-42 MHz		3.0	6.0	9.0	12.0
55 MHz		0.6	0.6	0.6	0.6
550 MHz		0.3	0.3	0.3	0.3
650 MHz		0.4	0.4	0.4	0.4
750 MHz		0.5	0.5	0.5	0.5
870 MHz		0.6	0.6	0.6	0.6
1000 MHz		0.8	0.8	0.8	0.8

	Attenuators for 85/102 MHz systems (1.25 GHz)				
Attenuator value:	0 dB*	3 dB	6 dB	9 dB	12 dB
	Tap loss increased by (dB):				
5-85 MHz		3.0	6.0	9.0	12.0
102 MHz		0.8	0.8	0.8	0.8
550 MHz		0.8	0.8	0.8	0.8
750 MHz		0.8	0.8	0.8	0.8
870 MHz		0.8	0.8	0.8	0.8
1000 MHz		0.8	0.8	0.8	0.8
1218 MHz		0.8	0.8	0.8	0.8
1250 MHz		0.8	0.8	0.8	0.8

* **Note:** Factory-installed attenuator.

Plug-in Equalizer Losses (1 GHz)

	Cable equalizers			Inverse equalizers			
Equalizer value:	6 dB	9 dB	12 dB	3 dB	6 dB	9 dB	12 dB
Part Number:	4022293	4022294	4022295	4018392	4018393	4018394	4018395
5 MHz	6.2	9.1	12.0	0.1	0.1	0.1	0.1
42 MHz	5.7	8.1	10.6	0.1	0.1	0.1	0.1
55 MHz	5.6	7.9	10.2	0.1	0.1	0.1	0.2
70 MHz	5.4	7.5	9.8	0.1	0.2	0.2	0.3
86 MHz	5.2	7.3	9.5	0.2	0.2	0.2	0.4
550 MHz	2.5	3.4	4.2	1.9	3.5	4.8	7.1
650 MHz	2.0	2.8	3.3	2.1	4.1	5.8	8.4
750 MHz	1.6	2.1	2.5	2.2	4.4	6.5	9.4
870 MHz	1.1	1.3	1.5	2.4	5.0	7.4	10.5
1000 MHz	0.8	0.8	0.8	2.6	5.6	8.2	11.4

Plug-in Equalizer Losses (1.25 GHz)

	Plug-In Forward Equalizer Loss													
Equalizer value (dB):	2	3	4	6	8	9	10	12	14	15	16	18	20	22
	Tap loss increase (dB), tolerance ±0.3 dB:													
5 MHz	2.6	3.6	4.5	6.5	8.3	9.3	12.1	12.1	14.0	15.0	15.9	17.7	19.6	21.5
40 MHz	2.4	3.3	4.1	5.9	7.4	8.4	9.1	10.9	12.5	13.4	14.2	15.9	17.5	19.2
55 MHz	2.3	3.3	4.0	5.7	7.3	8.2	8.9	10.6	12.2	13.1	13.8	15.4	17.1	18.7
70 MHz	2.3	3.2	3.9	5.5	7.1	8.0	8.6	10.3	11.8	12.7	13.4	15.0	16.6	18.2
86 MHz	2.2	3.1	3.8	5.4	6.9	7.7	8.41	10.1	11.5	12.4	13.0	14.6	16.1	17.7
102 MHz	2.2	3.0	3.7	5.3	6.7	7.5	8.19	9.8	11.2	12.0	12.7	14.2	15.7	17.2
204 MHz	2.0	2.7	3.3	4.6	5.8	6.5	7.07	8.4	9.6	10.4	10.9	12.2	13.4	14.8
258 MHz	1.9	2.6	3.1	4.3	5.4	6.1	6.58	7.9	8.9	9.6	10.1	11.3	12.5	13.6
550 MHz	1.5	1.9	2.2	3.1	3.3	4.2	4.45	5.3	5.9	6.4	6.7	7.4	8.2	8.9
650 MHz	1.3	1.7	2.0	2.7	3.2	3.6	3.83	4.6	5.1	5.5	5.7	6.3	7.0	7.6
750 MHz	1.2	1.6	1.7	2.3	2.7	3.1	3.25	3.9	4.3	4.6	4.8	5.3	5.8	6.3
870 MHz	1.1	1.4	1.5	2.0	2.2	2.5	2.59	3.1	3.4	3.6	3.7	4.1	4.5	4.9
1000 MHz	0.9	1.2	1.2	1.5	1.7	1.9	1.92	2.3	2.4	2.6	2.7	2.9	3.1	3.4
1218 MHz	0.7	0.9	0.8	0.9	0.8	0.9	0.85	1.0	0.9	1.0	0.9	1.0	1.0	1.0
1250 MHz	0.7	0.8	0.7	0.8	0.7	0.8	0.7	0.8	0.7	0.8	0.7	0.7	0.7	0.7

	Plug-in Forward Inverse Equalizer Loss										
Equalizer value (dB):	2	3	4	6	8	9	10	12	15	18	21
	Tap loss increase (dB), tolerance ±0.3 dB:										
5 MHz	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
40 MHz	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
55 MHz	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
70 MHz	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.5
86 MHz	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7
102 MHz	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.8	0.9	1.1
204 MHz	0.7	0.8	0.8	0.9	1.2	1.3	1.5	1.9	2.6	3.1	4.0
258 MHz	0.9	1.1	1.2	1.3	1.8	1.9	2.5	2.7	3.6	4.3	5.2
550 MHz	1.3	2.0	1.5	3.3	4.8	4.9	6.3	7.2	9.0	11.0	12.8
650 MHz	1.4	2.2	2.8	3.8	5.5	5.8	6.9	8.4	10.4	12.4	14.4
750 MHz	1.5	2.4	3.0	4.4	6.0	6.5	7.5	9.3	11.5	13.4	15.6
870 MHz	1.6	2.6	3.2	5.0	6.5	7.5	8.1	10.3	12.7	14.6	17.0
1000 MHz	1.8	2.8	3.5	5.5	7.0	8.1	8.8	11.2	13.7	15.8	18.5
1218 MHz	2.0	2.95	3.9	5.9	7.9	8.9	9.9	11.9	14.9	17.7	20.7
1250 MHz	2.0	3.0	4.0	6.0	8.0	9.0	10.0	12.0	15.0	18.0	21.0

Note: Flexible Solution Tap loss tolerances shown on previous pages are with 0 dB reverse attenuator installed. The reverse attenuator loss, forward equalizer loss, and forward inverse equalizer loss tables show the additional tap loss incurred when using the plug-in reverse attenuators, forward equalizers, and inverse equalizers.

In-Line Equalizer (with Reverse Conditioning)

This unit, identical in size to a directional coupler, provides downstream feeder equalization for 0 dB, 9 dB or 11 dB of cable. It also contains diplex filters and a reverse attenuator pad socket, allowing the user to increase the upstream through-loss in the reverse path and thus to narrow the range of transmission levels (or 'window') from cable modems.

In the following table, the through-loss (insertion loss) of the 1 GHz LEQ-RC is specified with a 0 dB reverse pad installed. Pads are the standard Cisco type, available in 1 dB steps from 1 dB to 15 dB.

If reverse conditioning alone is required, the equalizer can be bypassed.

	For 40/52 MHz systems			For 42/54 MHz systems		
Equalizer value:	Bypass mode	9 dB	11 dB	Bypass mode	9 dB	11 dB
Part Number:	-	4010310	4010311	-	4008461	4008462
5 MHz	1.0	1.0	1.0	1.0	1.0	1.0
10 MHz	1.0	1.0	1.0	1.0	1.0	1.0
40 MHz	1.3	1.3	1.3	1.0	1.0	1.0
42 MHz				1.3	1.3	1.3
54 MHz	1.3	9.6	11.4	1.3	9.6	11.4
100 MHz	1.3	9.0	10.5	1.3	9.0	10.5
450 MHz	1.3	6.0	6.7	1.3	6.0	6.7
550 MHz	1.4	5.1	5.8	1.4	5.1	5.8
650 MHz	1.7	4.5	5.0	1.7	4.5	5.0
750 MHz	1.8	3.9	4.3	1.8	3.9	4.3
870 MHz	2.0	3.2	3.5	2.0	3.2	3.5
1000 MHz	2.2	2.7	2.7	2.2	2.7	2.7

NOTES:

The LEQ-RC is capable of passing 60 V or 90 V 50/60 Hz power at 12 A.
Return loss: typically 17 dB (16 dB worst-case)

In-Line Equalizer (continued)

The following tables summarize insertion loss specifications for the Cisco 1.25 GHz Multimedia Line Equalizer/Reverse Conditioner (LEQ/RC).

	For 42/54 MHz systems			For 65/86 MHz systems		
Equalizer value:	Bypass mode	9 dB	11 dB	Bypass mode	9 dB	11 dB
5 MHz	1.0	1.0	1.0	1.0	1.0	1.0
10 MHz	1.2	1.2	1.2	1.0	1.0	1.0
40 MHz				1.0	1.0	1.0
42 MHz	1.3	1.5	1.5			
54 MHz	1.5	10.1	11.7			
65 MHz				1.5	1.5	1.5
86 MHz				1.3	9.6	11.2
100 MHz	1.5	9.5	11.0			
550 MHz	1.6	6.1	6.8	1.4	6.1	6.8
750 MHz	1.8	5.0	5.5	1.8	5.0	5.5
870 MHz	2.0	4.4	4.8	2.0	4.4	4.8
1000 MHz	2.2	3.7	4.0	2.2	3.8	4.0
1218 MHz	2.4	2.8	2.9	2.4	2.8	2.9
1250 MHz	2.5	2.7	2.7			

	For 85/102 MHz systems			For 204/258 MHz systems		
Equalizer value:	Bypass mode	9 dB	11 dB	Bypass mode	9 dB	11 dB
5 MHz	1.0	1.0	1.0	1.0	1.0	1.0
10 MHz	1.0	1.0	1.0	1.0	1.0	1.0
40 MHz	1.0	1.0	1.0	1.0	1.0	1.0
85 MHz	1.5	1.5	1.5			
102 MHz	1.5	9.4	10.9			
204 MHz				1.6	1.6	1.6
258 MHz				2.0	8.3	9.8
550 MHz	1.4	6.1	6.8	1.4	6.1	6.8
750 MHz	1.8	5.0	5.5	1.8	5.0	5.5
870 MHz	2.0	4.4	4.8	2.0	4.4	4.8
1000 MHz	2.2	3.8	4.0	2.2	3.8	4.0
1218 MHz	2.4	2.8	2.9	2.4	2.8	2.9
1250 MHz	2.5	2.7	2.7	2.5	2.7	2.7

NOTES:

The LEQ/RC is capable of passing 60 V or 90 V 50/60 Hz power at 15 A.
Return loss (all ports) varies from 15.5 dB to 17 dB, depending on frequency.

Section 6: COAXIAL CABLE CHARACTERISTICS

The data in this section are taken from the manufacturers' published data sheets. While every effort has been made to ensure accuracy in transcription, errors sometimes occur, and therefore these tables should be used for 'quick-reference' purposes only. For system design work, it is strongly recommended that the manufacturers' original data be used.

All figures in the cable loss tables represent losses at 68 °F (20 °C). As temperature varies from this reference, cable attenuation in decibels changes by approximately 1.0% for every 10 °F (5.56 °C) change in temperature.

The information provided here is intended to be representative. Space limitations prevent including all makes/types of coaxial cable used by the broadband industry.

While drop-type cables are informally called "RG-59," "RG-6," or "RG-11," the correct designations are Series 59, Series 6, and Series 11 respectively.

Trilogy Communications MC^2

Cable dia. (in):	0.440		0.500		0.650		0.750		1.00	
dB loss per 100	ft	m	ft	m	ft	m	ft	m	ft	m
Frequency (MHz)										
5	0.17	0.56	0.14	0.46	0.11	0.36	0.10	0.33	0.07	0.23
55	0.56	1.84	0.48	1.57	0.38	1.25	0.34	1.12	0.24	0.79
350	1.44	4.72	1.23	4.04	0.99	3.25	0.86	2.82	0.65	2.13
400	1.54	5.05	1.32	4.33	1.06	3.48	0.91	2.99	0.70	2.30
450	1.64	5.38	1.40	4.60	1.13	3.71	0.97	3.18	0.74	2.43
550	1.81	5.94	1.55	5.09	1.25	4.10	1.08	3.54	0.82	2.69
600	1.90	6.23	1.63	5.36	1.34	4.41	1.11	3.65	0.87	2.86
750	2.13	6.99	1.83	6.00	1.50	4.92	1.25	4.10	0.97	3.18
800	2.22	7.30	1.91	6.28	1.56	5.13	1.30	4.28	1.02	3.36
900	2.36	7.76	2.03	6.68	1.67	5.49	1.39	4.57	1.09	3.59
1000	2.49	8.19	2.15	7.07	1.77	5.81	1.47	4.82	1.16	3.82
Loop resistance per 1000	ft	m	ft	m	ft	m	ft	m	ft	m
Copper-clad aluminum center conductor	1.95	6.40	1.55	5.09	1.00	3.28	0.69	2.26	0.41	1.35

Maximum attenuation data taken from manufacturer’s data sheets. Contact manufacturer for detailed information. Note: CommScope acquired Trilogy’s MC^2 trunk and feeder cable TV products business in 2006.

Amphenol/TFC T10 cable

Cable dia. (in):	0.500		0.625		0.750		0.875	
dB loss per 100	ft	m	ft	m	ft	m	ft	m
Frequency (MHz)								
5	0.16	0.52	0.13	0.43	0.11	0.36	0.09	0.30
55	0.55	1.80	0.45	1.46	0.37	1.21	0.32	1.05
211	1.08	3.55	0.89	2.92	0.73	2.41	0.64	2.09
350	1.43	4.69	1.18	3.87	0.97	3.18	0.84	2.76
400	1.53	5.02	1.27	4.17	1.05	3.44	0.91	2.99
450	1.63	5.35	1.35	4.43	1.12	3.67	0.97	3.18
550	1.82	5.97	1.51	4.95	1.25	4.10	1.09	3.58
600	1.91	6.27	1.58	5.18	1.31	4.30	1.14	3.74
750	2.16	7.09	1.79	5.87	1.48	4.86	1.29	4.23
870	2.35	7.69	1.95	6.40	1.61	5.28	1.41	4.63
1000	2.53	8.30	2.11	6.92	1.74	5.71	1.53	5.02
1218	2.82	9.25	2.32	7.61	1.94	6.36	1.70	5.58
1800	3.51	11.52	2.90	9.51	2.43	7.97	2.13	6.99
Loop resistance per 1000	ft	m	ft	m	ft	m	ft	m
Copper-clad aluminum center conductor	1.70	5.58	1.09	3.57	0.75	2.46	0.55	1.81

Maximum attenuation data taken from manufacturer's data sheets.
Contact manufacturer for detailed information.

CommScope Parameter III

Cable dia. (in):	0.500		0.625		0.750		0.875		1.00	
dB loss per 100	ft	m	ft	m	ft	m	ft	m	ft	m
Frequency (MHz)										
5	0.16	0.52	0.13	0.43	0.11	0.36	0.09	0.30	0.08	0.26
55	0.54	1.77	0.45	1.48	0.37	1.21	0.33	1.08	0.31	1.02
211	1.09	3.58	0.92	3.02	0.74	2.43	0.66	2.17	0.62	2.03
350	1.43	4.69	1.18	3.87	0.97	3.18	0.84	2.76	0.78	2.56
400	1.53	5.02	1.27	4.17	1.05	3.44	0.91	2.99	0.84	2.76
450	1.63	5.35	1.35	4.43	1.12	3.67	0.97	3.18	0.90	2.95
550	1.82	5.97	1.50	4.92	1.24	4.07	1.08	3.54	1.01	3.31
600	1.91	6.27	1.58	5.18	1.31	4.30	1.14	3.74	1.06	3.48
750	2.16	7.09	1.78	5.84	1.48	4.86	1.29	4.23	1.21	3.97
865	2.34	7.68	1.93	6.33	1.61	5.28	1.41	4.63	1.34	4.40
1000	2.52	8.27	2.07	6.79	1.74	5.71	1.53	5.02	1.44	4.72
1218	2.84	9.32	2.33	7.63	1.95	6.40	1.70	5.57	-	-
1794	3.58	11.76	2.92	9.56	-	-	2.12	6.95	-	-
Loop resistance per 1000	ft	m	ft	m	ft	m	ft	m	ft	m
Copper-clad aluminum center conductor	1.72	5.64	1.10	3.51	0.76	2.49	0.55	1.81	0.40	1.31

Maximum attenuation data taken from manufacturer's data sheets. Contact manufacturer for detailed information.

CommScope Quantum Reach

Cable dia. (in):	0.540		0.715		0.860		1.125	
dB loss per 100	ft	m	ft	m	ft	m	ft	m
Frequency (MHz)								
5	0.14	0.46	0.11	0.36	0.09	0.30	0.07	0.23
55	0.47	1.54	0.37	1.21	0.32	1.05	0.23	0.76
211	0.95	3.12	0.74	2.43	0.64	2.10	0.49	1.61
350	1.23	4.03	0.97	3.18	0.83	2.72	0.65	2.13
400	1.32	4.33	1.05	3.44	0.88	2.89	0.70	2.30
450	1.40	4.59	1.12	3.67	0.95	3.12	0.75	2.46
550	1.56	5.12	1.25	4.10	1.06	3.48	0.84	2.76
600	1.64	5.38	1.31	4.30	1.10	3.61	0.89	2.92
750	1.85	6.07	1.49	4.89	1.24	4.07	1.01	3.31
865	2.00	6.56	1.62	5.31	1.33	4.36	1.11	3.64
1000	2.17	7.12	1.75	5.74	1.44	4.72	1.20	3.94
1218	2.45	8.05	1.90	6.22	1.66	5.43	-	-
1794	3.03	9.94	2.35	7.71	2.08	6.83	-	-
Loop resistance per 1000	ft	m	ft	m	ft	m	ft	m
Copper-clad aluminum center conductor	1.61	5.28	1.00	3.28	0.73	2.40	0.42	1.38

<u>Maximum</u> attenuation data taken from manufacturer's data sheets. Contact manufacturer for detailed information.

Amphenol/TFC Drop Cable

Cable type:	Series 6		Series 11	
dB loss per 100	ft	m	ft	m
Frequency (MHz)				
5	0.58	1.90	0.38	1.25
55	1.60	5.25	0.96	3.15
211	3.05	10.01	1.90	6.23
350	3.85	12.63	2.42	7.94
400	4.15	13.62	2.60	8.53
450	4.40	14.44	2.75	9.02
550	4.90	16.08	3.04	9.97
600	5.10	16.73	3.18	10.43
750	5.65	18.54	3.65	11.98
870	6.11	20.05	4.06	13.32
1000	6.55	21.49	4.35	14.27
1218	7.21	13.70	4.92	16.10
1800	8.87	29.10	6.04	19.80
Loop resistance per 1000	ft	m	ft	m
Copper-clad steel center conductor; dual shield	40.7	134	19.4	63

<u>Maximum</u> attenuation data taken from manufacturer's data sheets. Contact manufacturer for detailed information.

Mini-Series Quad Shield Coaxial Cable

Cable type:	Mini

dB loss per 100	ft	m
Frequency (MHz)		
5	1.00	3.28
55	2.82	9.25
211	5.30	17.39
350	6.75	22.15
400	7.25	23.79
450	7.70	25.26
550	8.54	28.02
600	8.92	29.27
750	10.01	32.84
870	10.79	35.40
1000	11.62	38.13
1218	12.89	42.29
1500	14.37	47.15

Loop resistance per 1000	ft	m
Solid copper or copper-clad steel center conductor	58.20	190.9

Maximum attenuation data taken from ANSI/SCTE 177 2018 "Specification for Braided 75 Ω, Mini-Series Quad Shield Coaxial Cable for CMTS and SDI cables."

CommScope Quad Shield F59 Headend Cable

Cable type:	Series 59

dB loss per 100	ft	m
Frequency (MHz)		
5	0.86	2.82
55	2.05	6.73
211	3.80	12.47
350	4.80	15.75
400	5.10	16.73
450	5.40	17.72
550	5.95	19.52
600	6.20	20.34
750	6.97	22.87
865	7.52	24.67
1000	8.12	26.64
1218	9.00	29.52
1794	10.90	35.77

Loop resistance per 1000	ft	m
Silver-plated copper-clad steel center conductor	26.20	85.96

Maximum attenuation data taken from manufacturer’s data sheets. Contact manufacturer for detailed information.

Amphenol/TFC Headend (Series 59) and Mini-Series Cables

Cable Type:	Series 59	
dB loss per 100	**ft**	**m**
Frequency in (MHz)		
5	0.86	2.82
55	2.05	6.73
211	3.80	12.47
350	4.80	15.75
400	5.10	16.73
450	5.40	17.72
550	5.95	19.52
600	6.20	20.34
750	6.97	22.87
870	7.57	24.84
1000	8.12	26.64
1218	8.99	29.49
1800	11.08	36.35
Loop resistance per 1000	**ft**	**m**
Silver-plated copper-clad steel center conductor	56.0	184.0

Cable Type:	Mini	
dB loss per 100	**ft**	**m**
Frequency in (MHz)		
5	0.96	3.15
55	2.73	8.96
211	5.04	16.54
350	6.51	21.36
400	6.98	22.90
450	7.37	24.18
550	8.27	27.13
600	8.66	28.41
750	9.75	31.99
870	10.53	34.55
1000	11.34	37.20
1200	12.37	40.58
3000	19.61	64.34
Loop resistance per 1000	**ft**	**m**
Copper center conductor	28.6	94.0

Maximum attenuation data taken from manufacturer's data sheets. Contact manufacturer for detailed information.

Loss Ratio Table

The following table provides the ratios of cable losses between the commonly-encountered upper frequency limits of CATV systems. Using this table, the increase in cable loss encountered during a 'drop-in' upgrade can be simply calculated. For example, if a 550 MHz system is to be upgraded to 750 MHz, and trunk amplifiers are currently spaced at 22 dB intervals, the new cable loss will be (22 x 1.19) = 26.18 dB.

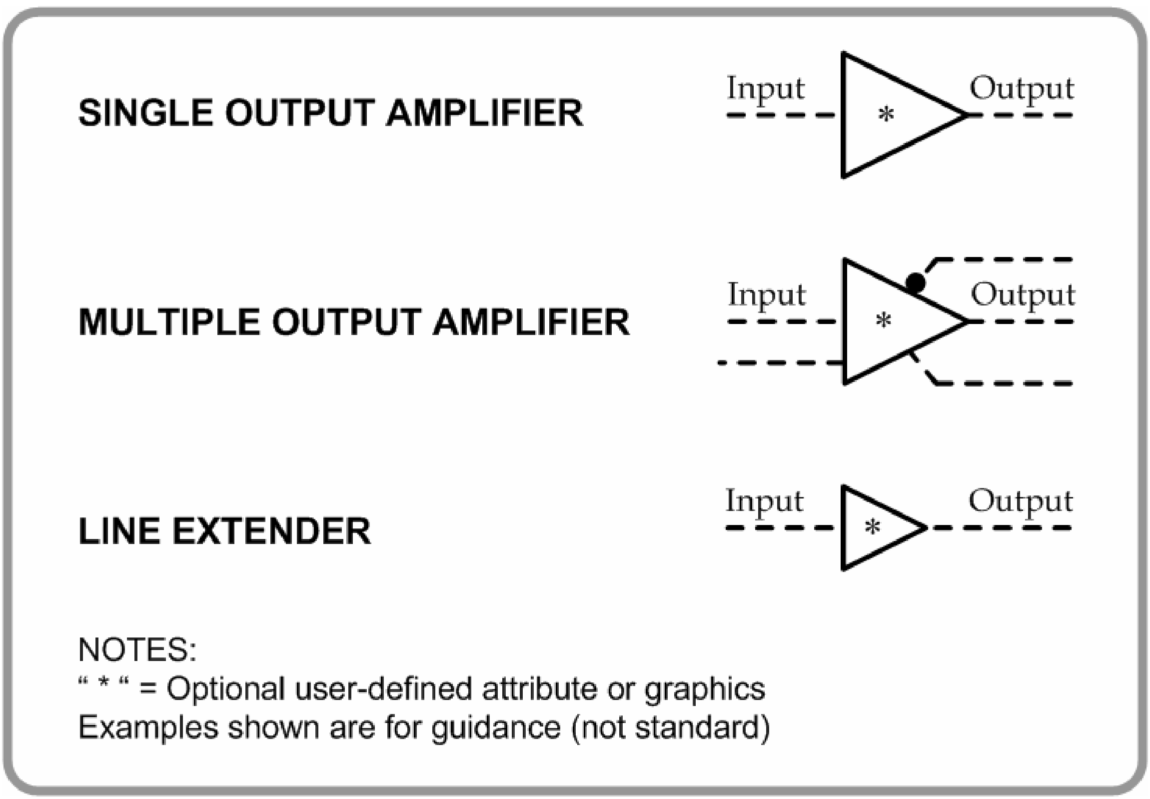
Upgrade to:	450	550	600	625	750	870	1000	1218
from								
400	1.07	1.19	1.25	1.28	1.42	1.55	1.67	1.88
450		1.11	1.17	1.20	1.33	1.45	1.56	1.76
550			1.05	1.08	1.19	1.30	1.40	1.58
600				1.02	1.13	1.24	1.33	1.50
625					1.11	1.21	1.30	1.46
750						1.09	1.18	1.33
870							1.08	1.22
1000								1.12

(Loss ratios are calculated using the CommScope Parameter III cable specifications, and taking an average over the range of cable diameters)

Section 7: STANDARD HFC GRAPHIC SYMBOLS

The following symbols are used in to identify HFC components in system design maps and schematics. They are taken from the American National Standard ANSI/SCTE 87 2017 “Graphic Symbols for Cable Systems.” Note that representative RF and optical component symbols are reproduced here. In some cases alternative symbols are shown. Refer to the aforementioned standard for the full selection of available symbols.

AMPLIFIERS (alternative symbols)

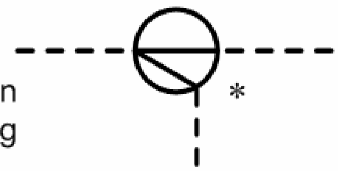


SPLITTING DEVICES (alternative symbols)

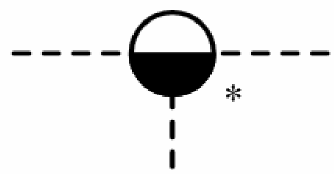
2-WAY SPLITTER

3-WAY SPLITTER
Dot shows high output leg, if unbalanced

DIRECTIONAL COUPLER
* Model or value designations are to be shown adjacent or inside symbols. The high-loss leg leaves the angular half of the symbol.



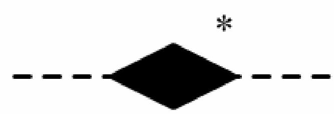
(alternate)



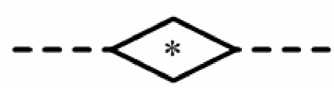
NOTES:
Indoor drop splits may have additional user-defined symbols.

LINE DEVICES

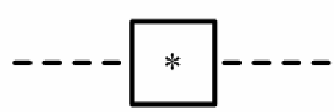
IN-LINE EQUALIZER



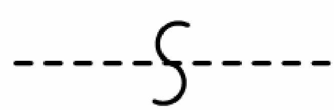
(alternate)



SPLICE

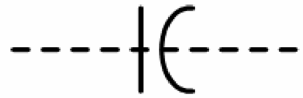


(alternate)

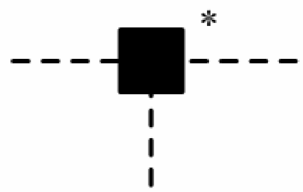


NOTES:
“ * “ = Optional user-defined attribute or graphics

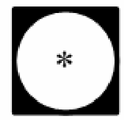
AC POWER BLOCK



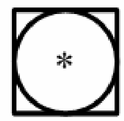
AC POWER INSERTER
“ * “ = Optional user-defined attributes



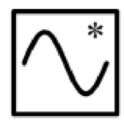
STANDBY POWER SUPPLY
“ * “ = Optional information: voltage, current, load, power supply name, status monitor



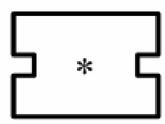
NON-STANDBY POWER SUPPLY
“ * “ = Optional information: voltage, current, load, power supply name, status monitor



(alternate)



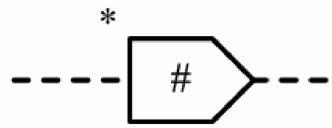
CENTRALIZED POWER SUPPLY
“ * “ = Optional information: voltage, current, load, power supply name, status monitor



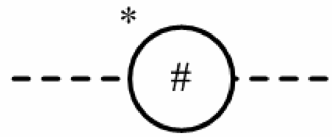
NOTES:
Additional graphics such as a circle around the symbol may also be used to designate new/existing locations

SUBSCRIBER TAPS

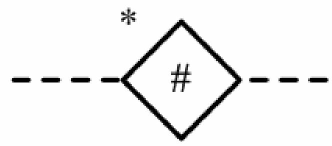
1-OUTPUT DIRECTIONAL TAP



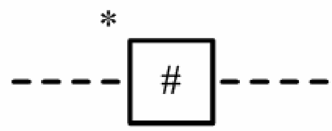
2-OUTPUT DIRECTIONAL TAP



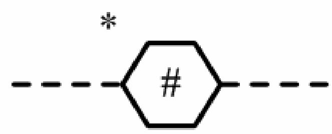
3-OUTPUT DIRECTIONAL TAP



4-OUTPUT DIRECTIONAL TAP



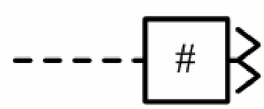
8-OUTPUT DIRECTIONAL TAP



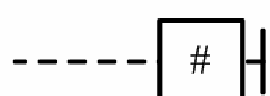
NOTES:
" # " Represents value of tap
" * " Represents value of pad, cable equalizer, addressable or telephony tap
Indoor taps may have additional user-defined symbols

LINE TERMINATORS

RF TERMINATOR
(4-output tap shown for example only)

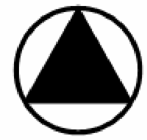


SELF-TERMINATING TAP
Applies to lowest-value tap within any family group.
(4-output tap shown for example only)
Self-terminating tap may be shown without symbol

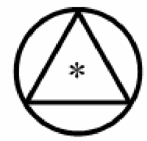


SIGNAL PROCESSING LOCATIONS

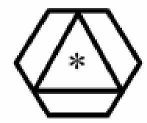
HEADEND
Location where the highest level of signal Processing takes place



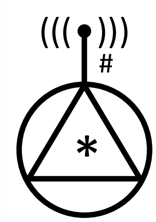
PRIMARY HUB
In multi-level networks, a signal processing location connected between the Headend and secondary hubs or nodes



SECONDARY HUB
In multi-level networks, a signal processing location connected between the primary hub and the node



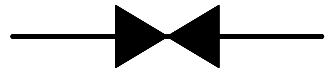
WIRELESS HUB



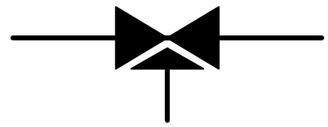
NOTES:
“ * “ = Optional user-defined attributes

OPTICAL SPLICE SYMBOLS

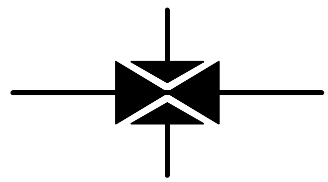
2-WAY SPLICE



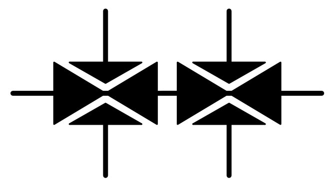
3-WAY SPLICE



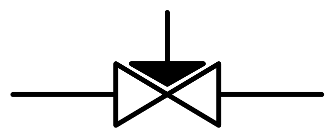
4-WAY SPLICE



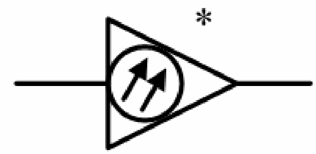
> 4-WAY SPLICE



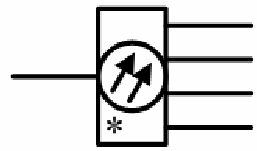
MID-ENTRY SPLICE / RING CUT



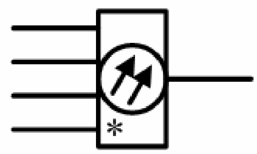
OPTICAL AMPLIFIER
“ * “ Indicates the gain (dB)



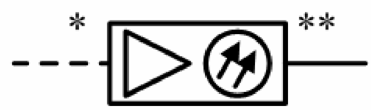
DEMULTIPLEXER
“ * “ Indicates number of outputs



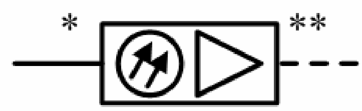
MULTIPLEXER
“ * “ Indicates number of inputs



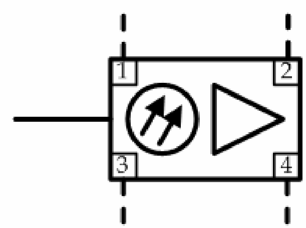
OPTICAL TRANSMITTER
“ * “ = Input RF level
“ ** “ = Output optical power

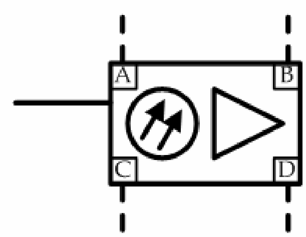


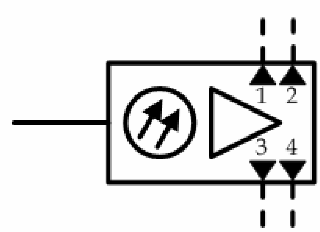
OPTICAL NODE
“ * “ = Input optical power
“ ** “ = Output RF level



(examples)

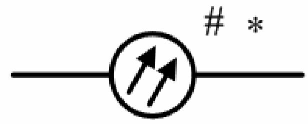






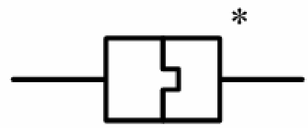
MISCELLANEOUS OPTICAL SYMBOLS

OPTICAL FIBER CABLE
“ # “ Indicates the fiber count
“ * “ Denotes user-defined attributes

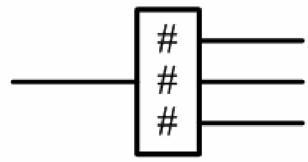


OPTICAL STORAGE LOOP
“ * “ Denotes user-defined attributes

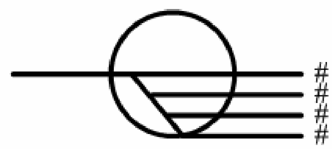
CONNECTOR
“ * “ = Connector type



SPLITTER
“ # “ = Percent or dB loss



(alternate)
Symbol shown with optional outputs
to be added as necessary



Section 8: DTV STANDARDS WORLDWIDE

NOTE: DTV (digital television) systems are deployed in several countries, in accordance with a variety of standards. Many other countries and regions are in the process of deploying such systems or are still studying the suitability of the various Standards to their local needs. Refer to the list in Section 3 of this Databook.

1. TERRESTRIAL TRANSMISSION

In the whole of North America, some Central American countries, and in South Korea, the digital terrestrial transmission RF characteristics
are defined by the ATSC (Advanced Television Systems Committee) Standard, Doc. A/53B, as amended. Information on this standard may be found at www.atsc.org and at www.atscforum.org

In this document, two transmission modes are defined. The 'terrestrial broadcast mode' uses 8-VSB (eight-level vestigial sideband), and the 'high data-rate mode' uses 16-VSB.

8-VSB supports a payload of approximately 19.28 Mbps in a 6 MHz channel, and 16-VSB supports approximately 38.57 Mbps. In both cases, the input to the transmission system consists of 188-byte MPEG-compatible transport multiplex packets; the primary difference lies in the number of transmitted levels (16 vs 8).

As shown in Section 3 of this Databook, all other countries in which a digital transmission standard has been adopted use a variant of OFDM, as specified in the DVB-T (Digital Video Broadcasting – Terrestrial) standard. DVB provides technical recommendations to the European Broadcasting Union (EBU), and the standards are formalized and published by the European Telecommunications Standards Institute (ETSI). In the case of DVB-T, the standard is ETSI EN 300 744.

Using OFDM, as defined by DVB-T, the serial bit-stream, instead of modulating a single carrier, is distributed over many closely-spaced individual subcarriers, making the transmission relatively immune to multipath distortion and narrowband interfering signals.

The standard provides for transmission in channels of 6 MHz, 7 MHz or 8 MHz bandwidth. As with the ATSC standard, MPEG-2 video and audio coding is the basis of DVB-T.

The individual carriers in the COFDM spectrum can be modulated using QPSK, 16-QAM or 64-QAM. Furthermore, the user can select from a range of convolutional code rates and inter-symbol guard intervals, giving rise to a large range of usable data rates. The lowest and highest rates for the three primary modulation schemes and for 6 MHz, 7 MHz and 8 MHz channel widths are presented in Table 8.1

Table 8.1: Ranges of usable data-rates for COFDM transmissions

	6 MHz channel		7 MHz channel		8 MHz channel	
Modulation	lowest	highest	lowest	highest	lowest	highest
QPSK	3.732	7.917	4.354	9.237	4.98	10.56
16-QAM	7.465	15.834	8.709	18.473	9.95	21.11
64-QAM	11.197	23.751	13.063	27.710	14.93	31.67

The OFDM variants are described briefly as follows:

ISDB-T

A variant of the DVB-T standard, referred to as ISDB-T (Integrated Services Digital Broadcasting - Terrestrial) has been developed in Japan by the Japanese Digital Broadcasting Experts Group (DiBEG). The major difference lies in the adoption of a data segmentation system, which allows a mixture of services such as radio, HDTV and standard-definition TV to be allocated segments of the overall bandwidth on a flexible basis. The video compression system in ISDB-T is H.262/MPEG-2 Part 2.

SBTVD-T

Sistema Brasileiro de Televisão Digital (Terrestrial) was developed by the Brazilian Telecommunications Agency, and is a variant of ISDB-T. It is therefore also called ISDB-Tb. The basic difference in the two standards lies in the fact that SBTVD-T uses H.264/MPEG-4 AVC as the video compression system.

The RF modulation method is BST-OFDM, or band-segmented transmission - orthogonal frequency division multiplexing.

DMB-T/H

This standard has been adopted by the People's Republic of China, and is also used in Hong Kong and Macau. The initialism means digital multimedia broadcast – terrestrial/handheld, and the RF modulation method is TDS-OFDM (time domain synchronous OFDM). These technologies allow reception over a wider area than is generally possible using DVB-T, and the standard also supports digital TV reception on mobile personal communication devices.

2. SATELLITE TRANSMISSION

DVB-S

The fundamental standard for satellite transmission of digital video signals is defined by DVB-S, which is the earliest of the DVB standards and the most widely accepted. It defines the modulation method as QPSK, and specifies an FEC process involving an 'inner' convolutional coding with code rates of 1/2, 2/3, 3/4, 5/6 and 7/8, and an 'outer' Reed-Solomon coding.

In Europe, the EBU passed the DVB-S recommendations to ETSI, which published the standard as ETSI EN 300 421.

In North America, ‘Modulation and Coding Requirements for Digital TV Applications Over Satellite’ is an Advanced Television Systems Committee standard, set forth in ATSC Doc. A/80. This standard is almost identical to EN 300 421, and differs primarily in the fact that it allows the transmission of arbitrary data streams, as well as MPEG-2 transport streams, and defines the use of modulation schemes other than QPSK.

Worldwide, the relevant set of recommendations is contained in the International Telecommunications Union (ITU) document ITU-R BO.1516, “Digital multiprogramme television systems for use by satellites operating in the 11/12 GHz frequency range”. This document describes four fundamental systems, with many components in common. System ‘A’ is described in an earlier recommendation, ITU-R BO.1211, which is actually the ETSI standard referred to above (ETSI EN 300 421). Systems ‘B’ and ‘C’ are described in ITU-R BO.1294 and refer to Direct Satellite Systems (DSS) services, and System ‘D’ defines the satellite component of the Japanese ISDB system. It is fully defined in ITU-R BO.1408.

Transmission rates for various satellite transponder bandwidths and convolutional code rates are shown in Tables 8.2 and 8.3, which are taken from the ETSI standard (ETSI EN 300 421), and the ATSC A/80 standard, respectively. As mentioned above, these standards are very similar and the difference in the transmission rates, shown in the two tables, is due solely to the way in which the symbol rate is defined.

In the ETSI standard, the symbol rate is obtained by dividing the 3 dB bandwidth by 1.28, whereas the ATSC standard uses a factor of 1.35. These factors are derived from the modulation roll-off, and the ATSC figure represents a more conservative assumption.

Table 8.2: Usable data-rates using DVB-S (ETSI standard)

Transponder 3 dB bandwidth (MHz)	Symbol rate (Mbaud)	Usable bit rate (Mbps), QPSK modulation				
		1/2 convol. encoding	2/3 convol. encoding	3/4 convol. encoding	5/6 convol. encoding	7/8 convol. encoding
54	42.2	38.9	51.8	58.3	64.8	68.0
46	35.9	33.1	44.2	49.7	55.2	58.0
40	31.2	28.8	38.4	43.2	48.0	50.4
36	28.1	25.9	34.6	38.9	43.2	45.4
33	25.8	23.8	31.7	35.6	39.6	41.6
30	23.4	21.6	28.8	32.4	36.0	37.8
27	21.1	19.4	25.9	29.2	32.4	34.0
26	20.3	18.7	25.0	28.1	31.2	32.8

Table 8.3: Usable data-rates using DVB-S (ATSC standard)

Available 3 dB bandwidth (MHz)	Symbol rate (Mbaud)	Usable bit rate (Mbps), QPSK modulation				
		1/2 convol. encoding	2/3 convol. encoding	3/4 convol. encoding	5/6 convol. encoding	7/8 convol. encoding
72	53.33	49.15	65.53	73.73	81.92	86.01
54	40.00	36.86	49.15	55.29	61.44	64.51
46	34.07	31.40	41.87	47.10	52.34	54.95
41	30.37	27.99	37.32	41.98	46.65	48.98
36	26.67	24.58	32.77	36.86	40.96	43.01
33	24.44	22.53	30.04	33.79	37.55	39.42
30	22.22	20.48	27.31	30.72	34.13	35.84
27	20.00	18.43	24.58	27.65	30.72	32.25
18	13.33	12.29	16.38	18.43	20.48	21.50
15	11.11	10.24	13.65	15.36	17.07	17.92
12	8.89	8.19	10.92	12.29	13.65	14.34
9	6.67	6.14	8.19	9.22	10.24	10.75
6	4.44	4.10	5.46	6.14	6.83	7.17
4.5	3.33	3.07	4.10	4.61	5.12	5.38
3	2.22	2.05	2.73	3.07	3.41	3.58
1.5	1.11	1.02	1.37	1.54	1.71	1.79

DVB-S2

As noted previously, the original DVB-S standard specified QPSK as the modulation method. A later standard, DVB-DSNG (Digital Satellite News Gathering), added 8-PSK and 16-QAM.

DVB-S2 extends the technology further by adding 16-APSK and 32-APSK options; these modulation schemes demand a higher carrier-to-noise ratio and they are intended for use in news gathering and private satellite links. The new standard also specifies a more powerful error-correction system, involving an ‘outer’ coding using BCH (Bose-Chaudhuri-Hocquenghem) and LDPC (low density parity check) ‘inner’ coding. In addition, an adaptive coding and modulation (ACM) scheme permits the transmission parameters to be modified frame-by-frame to adapt to the transmission conditions for each user. This scheme, too, is intended for use in unicast interactive services and point-to-point links.

DVB-S2 can operate with existing DVB-S receivers through the use of an optional backwards-compatibility mode.

3. CABLE SYSTEM TRANSMISSION

ALL AREAS

As with satellite and terrestrial digital video systems, the basic payload in digital cable systems is the MPEG transport stream.

Internationally, the recommendations of the ITU are definitive. The relevant document is “Recommendation ITU-T J.83 Digital multi-programme systems for television, sound and data services for cable distribution,” which describes the method of digital transmission for four television systems. Systems ‘A’ and ‘B’ are intended for deployments in Europe and North America, respectively, and are transparent to signals derived from satellite transmissions. Both define high-order quadrature amplitude modulation schemes, 64-QAM and 256-QAM, for transmission via coaxial cable. System ‘C’ is intended to be compatible with terrestrial transmissions or ISDN networks; the modulation scheme is 64-QAM or 256-QAM and is optimized for 6 MHz channels. System ‘D’ addresses specifically North American systems, and describes a 16-VSB modulation scheme.

The North American system is also defined in “ANSI/SCTE 07 2018 Digital Transmission Standard For Cable Television” (formerly SCTE DVS 031), which was ratified by ITU as Recommendation J.83, Annex ‘B’.

The European system is also defined in ETSI EN 300 429, which was ratified by ITU as Recommendation J.83, Annex ‘A’. However, the ETSI standard also allows modulation using 128-QAM and 256-QAM.

Since the most common cable modulation scheme is QAM, examples of symbol rates and data transmission rates for various orders of QAM are given in Table 8.4.

Table 8.4: Examples of raw and usable data rates (Mbps)

	6 MHz channel (ANSI/SCTE 07 2018)			8 MHz channel (ETSI EN 300 429)[1]		
Modulation	Symbol rate (Mbaud)[2]	Raw data rate (Mbps)[3]	Usable bit-rate (Mbps)[4]	Symbol rate (Mbaud)	Raw data rate (Mbps)	Usable bit-rate (Mbps)
16-QAM				6.952	27.808	25.491
64-QAM	5.057	30.342	26.970	6.952	41.712	38.236
256-QAM	5.361	42.884	38.811	6.952	55.616	50.981

NOTES:
1. Rates adjusted to produce an occupied bandwidth of 8 MHz.
2. Mbaud is the same as megasymbols per second.
3. Raw data rate is calculated by multiplying the symbol rate by the number of bits per symbol (e.g., for Annex B 64-QAM: 5.057 Mbaud x 6 bits per symbol = 30.34 Mbps; and for Annex B 256-QAM: 5.361 Mbaud x 8 bits per symbol = 42.88 Mbps)
4. Usable bit-rate is calculated after removing FEC and other overhead from the raw data rate. MPEG overhead is still included in the usable bit-rate figures.

OUT-OF-BAND

In order to support interactive video services, out-of-band control channels for set-top terminal devices must be established. These can be implemented under the existing DOCSIS standards (refer to "ANSI/SCTE 106 2018 DOCSIS Set-top Gateway (DSG) Specification" on page 8-10), or the DVB-RCC (Return Channel for Cable) standard, which is defined in the ETSI publication ETS 300 800. This standard is almost identical to DAVIC "Passband Bi-directional PHY on coax" (Digital Audio Visual Council 1.3.1 Specification part 8, "Lower Layer Protocols and Physical Interfaces." NOTE: This document is now known as ISO-16500-4).

Out-of-band messaging and signaling between a set-top controller (typically located in a headend or hub) and customer premises equipment such as set-tops and residential gateways are further defined in ANSI/SCTE 55-1 2009, ANSI/SCTE 55-2 2008, and ANSI/SCTE 106 2018.

In particular, ANSI/SCTE 55-2 2008 incorporates DAVIC 1.3.1 part 8. The parameters defined in ANSI/SCTE 55-2 2008 are applicable to Scientific Atlanta/Cisco set-tops.

Some of the signal characteristics of ANSI/SCTE 55-2 2008 are presented in the following tables. The modulation scheme for downstream and upstream transmission is differentially encoded QPSK.

Downstream transmission rates and bandwidths:

	Symbol rate (MSps)	Transmission rate (Mbps)	Channel spacing (MHz)
Grade 'A' service	0.772	1.544	1
Grade 'B' service	1.544	3.088	2

Per the specification, the downstream carrier center frequency range is 70 MHz to 130 MHz, and the RF power input range to the CPE is -18 dBmV to +15 dBmV.

Upstream transmission rates and bandwidths:

	Symbol rate (MSps)	Transmission rate (Mbps)	Channel spacing (MHz)
Grade 'A' service	0.128	0.256	0.2
Grade 'B' service	0.772	1.544	1
Grade 'C' service	1.544	3.088	2

Per the specification, the upstream carrier center frequency range is 8 MHz to 26.5 MHz, and the RF transmit power range is +25 dBmV to +53 dBmV.

ANSI/SCTE 106 2018 DOCSIS Set-top Gateway (DSG) Specification

The following is adapted from the above specification: Traditionally, the physical transport of out-of-band messaging has been carried over dedicated channels, as specified by ANSI/SCTE 55-1 2009 and ANSI/SCTE 55-2 2008.

ANSI/SCTE 106 2018 defines the applicable communications standards and protocols needed to implement an out-of-band messaging interface to compatible set-tops (that is, those with embedded cable modems) using DOCSIS as a transport. It applies to cable systems employing HFC and coaxial architectures.

Additional information can be found in the full specification, available from SCTE·ISBE.

Section 9: DIGITAL SIGNALS

Measurement of signal level

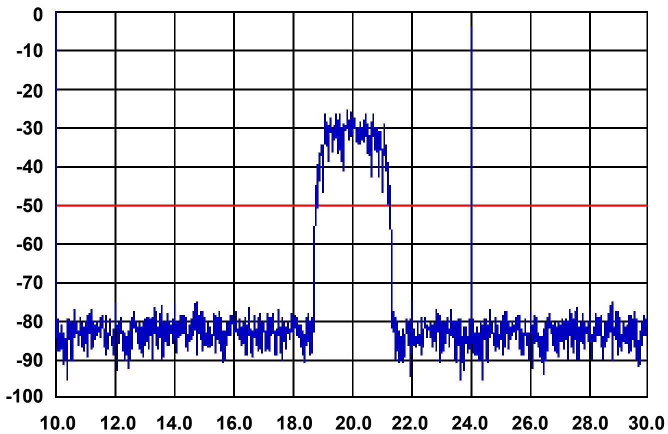
Digitally modulated RF signals have characteristics similar to those of white noise, and do not have a discernible carrier or pilot tone which can be used as a reference for signal level measurements.

A range of test equipment, from a variety of manufacturers, is available for measurements of such signals. For example, it is possible to measure signal level (called digital channel power or digital signal power), modulation error ratio (MER) and pre- and post-FEC bit error ratio (BER), and to display constellation diagrams – all at the push of a button. More advanced instruments incorporate spectrum analyzer functionality and can provide measurements of the 'traditional' HFC parameters such as CNR, CSO and CTB, in additional to the digital signal parameters.

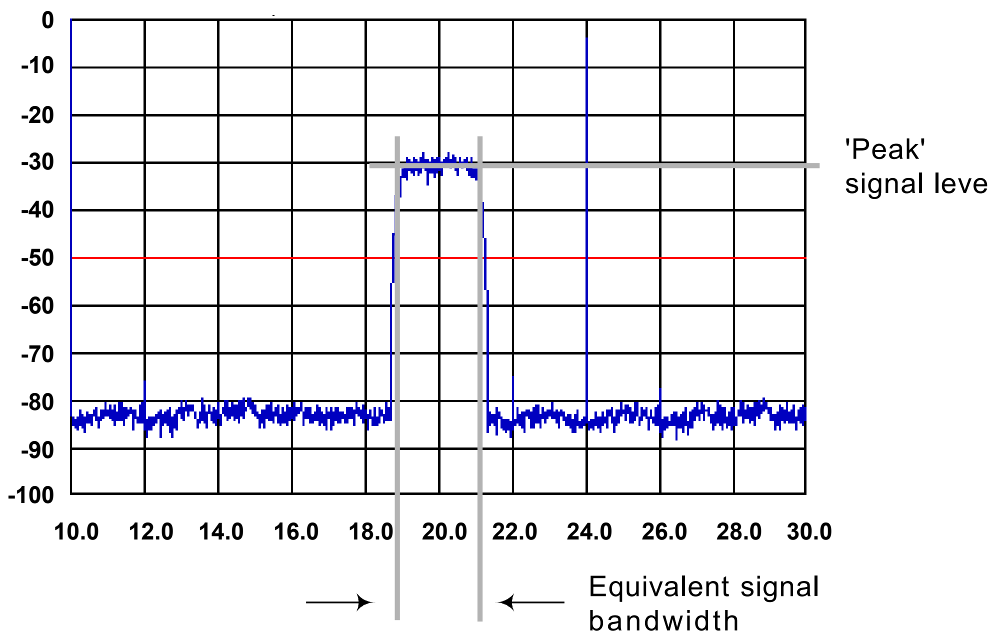
This section describes the manual measurement of digital signal level and CNR using a general-purpose spectrum analyzer. A detailed description of the procedures can be found in the CENELEC standard EN 50083-7, "System Performance", upon which the following text is based. Another useful resource is *SCTE Measurement Recommended Practices for Cable Systems, 4th Ed.*, available from the Society of Cable Telecommunications Engineers.

The digital signal should be centered in the spectrum analyzer display, with the resolution bandwidth of the analyzer set to 100 kHz. (NOTE: the resolution bandwidth of a spectrum analyzer is effectively the bandwidth of the filter in the IF stage of the instrument. It is selected either by the operator or by internal optimization software. For this reason, the resolution bandwidth is often referred to as the 'IF bandwidth' of the analyzer). The horizontal sweep should be adjusted so that the shape of the signal is clearly visible, as shown in the following diagram. (This diagram, and those that follow, were generated by software, and are not actual images of spectrum analyzer displays. This was done in order to improve clarity and avoid unnecessary clutter.

Nevertheless, the diagram is a realistic representation of a QPSK signal, having a data rate of approximately 4.6 Mbps. The horizontal scale of the display is 2 MHz per division, and the vertical scale is 10 dB per division):



The display should then be ‘smoothed’ by switching in the video filter, which effectively averages the peak-to-valley excursions of the signal:



The average power as displayed on the analyzer should now be adjusted to arrive at a true indication of signal power.

Signal level measurement (cont'd)

First, the reading given by the analyzer must be corrected to compensate for the characteristics of the analyzer's IF filter and logarithmic detector: these correction factors are usually supplied by the instrument manufacturer and included with the user guide or other relevant documentation. A correction factor of between 1.5 and 2.0 dB is typical. The result is the energy of the signal measured in the resolution bandwidth of the analyzer. This figure will be identified as P_{RBW} in the subsequent text, and the resolution bandwidth will be identified as BW_R.

Next, the total signal energy must be calculated, and this requires a knowledge of the bandwidth of the signal. As shown in the figure above, the analyzer's markers or graticule can be used to measure the bandwidth at points 3 dB below the average level. This is referred to as the 'equivalent signal bandwidth', and will be designated here as BW_E.

The total signal energy is then given by P_T, where

$$P_T = P_{RBW} + 10.\log\left(BW_E / BW_R \right)$$

It should be noted that the measurement just described is actually a measurement of the signal power PLUS the noise power, but the noise contribution can be ignored if the level of the noise outside the digital signal channel is 15 dB below the signal level, or lower.

Measurement of signal-to-noise ratio

The signal level should be measured as described above, and the value of P_{RBW} determined. Then the noise in the same channel should be measured, using the same resolution bandwidth and video filter, by turning off the signal. This figure will be designated N_{RBW}.

The signal-to-noise ratio is then S/N, where

$S/N = P_{RBW} - N_{RBW}$

Signal-to-noise ratio measurement (cont’d)

Again it should be noted that the noise level measured by this technique is actually the true noise PLUS the noise contribution of the spectrum analyser itself. The input to the analyzer should be disconnected and terminated. If the apparent noise level falls by more than 10 dB, then no correction to the measured value is necessary. If the reduction ('delta') is less than 10 dB, however, a correction to the measured value must be applied.

The following table provides a convenient listing of correction factors for a range of values of 'delta':

'delta':	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Correction:	5.35	4.33	3.02	2.20	1.65	1.26	0.97	0.75	0.58	0.46

The correction is applied by subtracting it from the measured value N_{RBW}.

It is possible to characterize the approximate signal-to-noise ratio (carrier-to-noise ratio) of a digital signal using a spectrum analyzer without applying correction factors. To do this, first ensure that the analyzer’s displayed noise floor is that of the cable network and not the instrument itself. Temporarily disconnect the RF input from the spectrum analyzer; the displayed noise floor should drop at least 10 dB (as noted above). Reconnect the RF input, and observe the height of the digital “haystack” relative to the displayed noise floor. The difference between the two, in dB, is the signal- or carrier-to-noise ratio.

Measured vs Calculated Bandwidth

The accuracy of the bandwidth measurement, as described above, can be verified by comparison with the calculated bandwidth of the digital signal.

The Nyquist bandwidth of the signal (designated here as BW_N) is equal to the symbol-rate expressed in hertz. Now the symbol-rate is the rate at which the amplitude, the phase or the frequency of the

carrier (or some combination of these characteristics) is being changed, and this is not necessarily equal to the data rate.

In the more complex modulation schemes, the digital data is 'sampled' in blocks of bits, and the numeric value of each block is then used to determine the characteristics of the carrier.

For example, in QPSK modulation, the data is sampled in blocks of two bits. There are four possible values of each sample: 00, 01, 10 and 11, so the phase of the carrier can occupy four different states. This results in a symbol rate which is exactly half the data rate, and hence the symbol rate for the hypothetical QPSK signal in the figure above is obtained by dividing the data rate of 4.6 Mbps by two, giving 2.3 Msym/s (million symbols per second). In hertz, this gives a value for BW_N of 2.3 MHz.

The following table gives the symbol rate for various signal types:

Modulation Type	Symbol rate
FSK	= bit rate
BPSK	= bit rate
QPSK	= bit rate ÷ 2
16-QAM	= bit rate ÷ 4
64-QAM	= bit rate ÷ 6
256-QAM	= bit rate ÷ 8

Assuming that the digital signal is shaped using raised-cosine filtering, and assuming that this filtering is equally distributed between transmitter and receiver, the 3 dB bandwidth of the signal, when measured by a spectrum analyzer as described above, will be approximately equal to the Nyquist bandwidth.

Recommended Levels in HFC Networks

In a typical HFC network designed for both analog and digital signals, the analog video channels are typically carried in the 50 MHz to 550 MHz range, and the remainder of the bandwidth is allocated to digital traffic, which will consist primarily of either 64-QAM, 256-QAM and DOCSIS 3.1 OFDM signals.

Cisco recommends that all downstream digital signals be carried at a level 6 dB below the corresponding analog visual carrier level*. (The 'levels' of the digital signals are as defined in the previous subsection).

Recommended Levels at the Upstream Optical Transmitter

To avoid laser clipping while obtaining the best CNR performance, two methods of calculating upstream signal levels at the input to a reverse optical transmitter are in common use:

1. 'Power sharing', based on known number of signals
2. 'Worst case' loading, based on NPR measurements

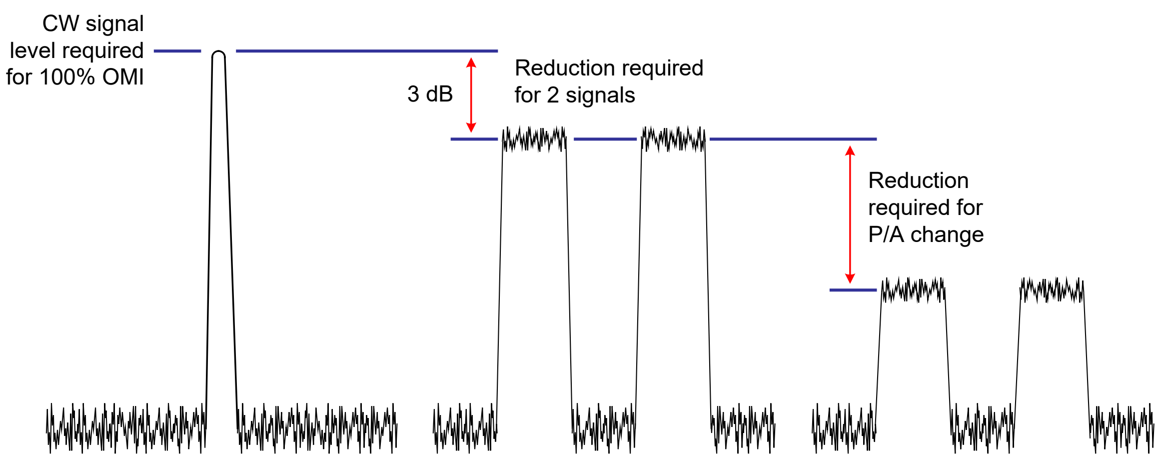
Power sharing method

If the transmitter manufacturer specifies the RF input level as a single CW tone required to produce 100% OMI, then the 'power sharing' method can be used to determine the level for a number of signals at the input. This method is also preferred when the total future traffic load of the upstream path can be predicted. For example, if the CW level for 100% OMI is 40 dBmV, then the level for two signals should be 37 dBmV.

* "Visual carrier level" must be interpreted as the peak envelope power of the analog video signal.

Recommended levels (cont'd)

Unfortunately, this calculation does not take into consideration the fact that the two signals may have a significantly different peak-to-average power ratio than the CW tone, whose PAPR is 3 dB. Therefore, if the power is measured on a spectrum analyzer, which is calibrated for true average power, the peaks of the two signals will exceed the measured value by considerably more than 3 dB.



P/A: peak-to-average ratio

For a digital signal, it is reasonably safe to say that the amplitude distribution of the signal is Gaussian (and the more signals are added, the more true this statement becomes). There is some question, however, of the figure that should be used for PAPR of a Gaussian signal. A commonly-used value is 9.5 dB.
This means that the total 'back-off' for the two signals in this example should be 3 + (9.5 – 3) = 9.5 dB.

It should be noted that there are several variants of the power sharing method. For instance, the power may be shared unequally, so that more power is allotted to those signals which have a higher CNR requirement.

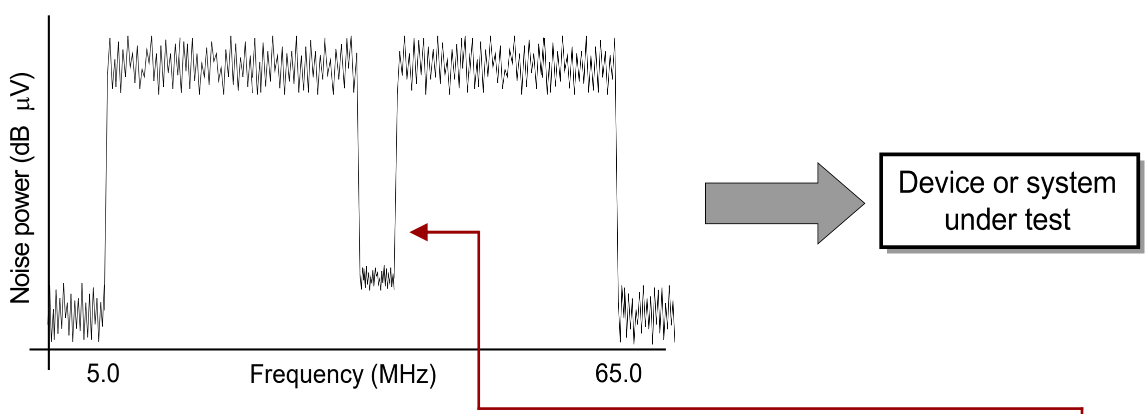
NPR method

The disadvantage of using CW tones to specify reverse transmitter performance is that a sine wave and a complex modulated signal have completely different characteristics, as explained above. If the transmitter performance specification is based on a white (Gaussian) noise measurement, this difficulty can be avoided.

The NPR method of specifying transmitter performance is based on an additive white Gaussian noise (AWGN) measurement, which is a better simulation of the traffic. It was used to measure the performance of multi-channel FDM telephone systems, before the adoption of digital transmission techniques.

The noise power ratio (NPR) test is designed to fully load a device or system with a broad spectrum of Gaussian noise, and to determine the degree of intermodulation distortion created by this noise signal, as its level is increased. Because the noise extends across the entire upstream spectrum, the test simulates the heaviest possible traffic load, and is therefore a preferred indicator of system performance when the future traffic growth is uncertain, but is expected to be high.

Band-limited white noise is applied to the input of the device or system:

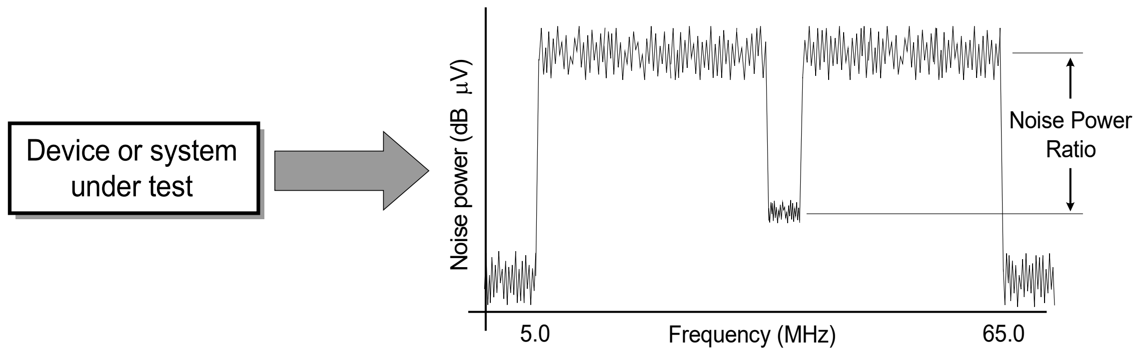


- and a band-stop filter is used to create a ‘notch’ in the noise.

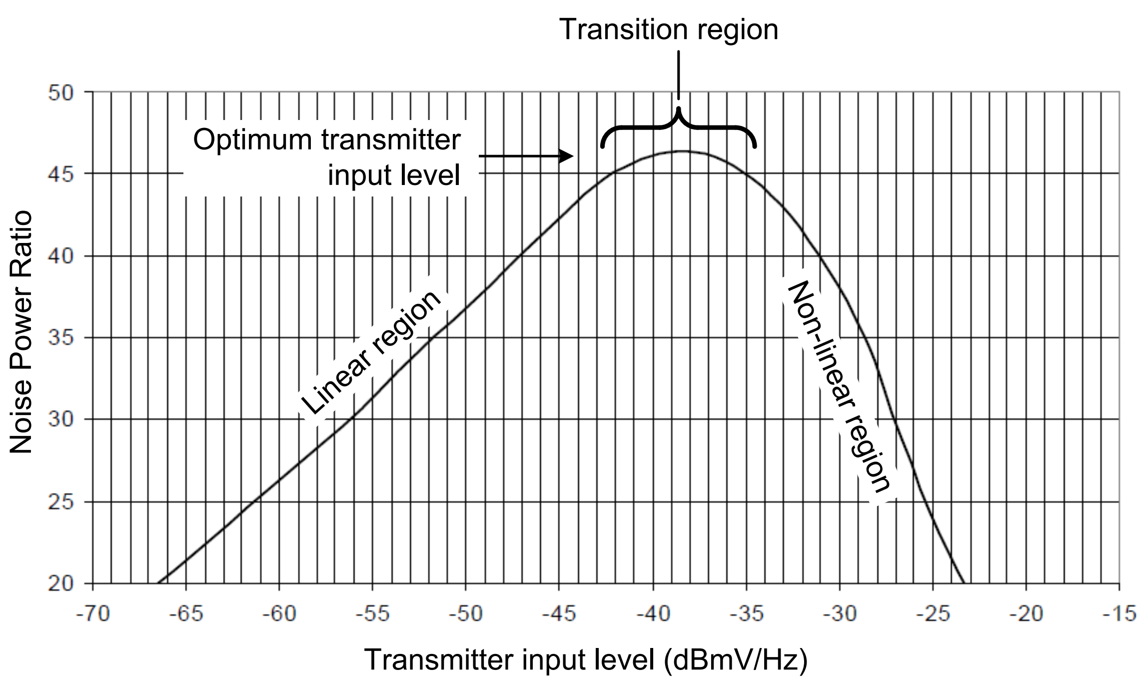
Recommended levels (cont'd)

At the output of the device or system, a spectrum analyzer is used to measure the depth of the 'notch':

The 'depth' of the notch is reduced by the presence of Intermodulation products:



A plot of the depth of the notch versus the transmitter input power results in the NPR curve:



(This is the NPR curve for a typical upstream DFB transmitter intended for use in an optical node)

Recommended levels (cont'd)

In the linear region of the curve, the NPR increases smoothly as input power in increased. This is interpreted as a linear increase in CNR as the 'carrier' (the applied noise signal) rises above the intrinsic 'noise' of the optical system.

In the transition region, the noise signal begins to cause intermodulation distortion noise and clipping of the laser, and in the nonlinear region, further increases in the level of the applied noise result in disproportionate decreases in NPR.

To determine the optimum level of any given signal, its bandwidth must be known, and then the required level can be obtained by taking the optimum input level from the NPR curve, and normalizing to the bandwidth of the desired signal.

Example: a 16-QAM signal with a bandwidth of 3.2 MHz must be carried.
The optimum input level to the transmitter, as shown by the NPR curve, is -39 dBmV/Hz. The level of the 16-QAM signal should therefore be:

$$-39 + 10\log(3{,}200{,}000) = 26.1 \text{ dBmV}$$

Whether the 'power sharing' or the 'NPR' method is used, the result of the calculation should be further adjusted to allow for changes in signal level at the input to the optical transmitter due to the effects of temperature on the upstream HFC plant and the uncertainties in the measurement of various plant parameters (cable lengths, etc.) A frequently-used value is 3 dB, which should be subtracted from the calculated level.

Section 10: STANDARD DIGITAL INTERFACES

This section describes the digital interfaces that are frequently encountered in broadband networks and in other telecommunications systems that may exchange traffic with them.

'Legacy' telecommunications systems standard interfaces

NOTE: The 'DS*n*' signals are common throughout the Americas and in some southeast Asian countries. In European and many other countries, the 'E*n*' signals are more common, while Japan has used J*n* signals. The tables on page 10-3 provide a handy summary and comparison.

DS0

Digital Signal Level 0. The telephony term for the basic channel in the digital transmission hierarchy, originally representing a single voice channel, but subsequently used also for data transmission. The data rate is 64 kbps.

DS1

Digital Signal Level 1. The telephony term for the 1.544 Mbps digital signal carried by a T1 facility*. Originally designed to accommodate 24 DS0 channels, but subsequently used also as a multiplex rate for subchannels at other data rates, and also as a 'clear channel' for services such as video teleconferencing.

DS1C

Digital Signal Level 1C. 3.152 Mbps digital signal; equivalent to two DS1 signals.

DS2

Digital Signal Level 2. 6.312 Mbps signal, equivalent to four DS-1 signals.

DS3

Digital Signal Level 3. 44.736 Mbps signal, equivalent to 28 DS-1 signals.

* The terms ‘T1’ and ‘DS1’ are frequently used interchangeably. Strictly speaking, however, ‘DS1’ refers to the electrical characteristics of the 1.544 Mbps signal, and ‘T1’ refers to the facility through which the signal travels. The term T1 was introduced by AT&T to designate a Terrestrial digital transmission system.

The ‘DS*n*’ signals are also referred to as asynchronous digital signals, to distinguish them from the later synchronous digital hierarchy (SDH) or synchronous optical network (SONET) standards.

E1

First Order Digital Signal, at 2.048 Mbps. It was designed to accommodate thirty-two 64 kbps channels but, like the DS1 signal, has also been used as a multiplex for other lower-rate channels and as a ‘clear channel’ for services such as video teleconferencing.

E2

Second Order Digital Signal, at 8.448 Mbps; equivalent to four E1 signals.

E3

Third Order Digital Signal, at 34.368 Mbps; equivalent to 16 E1 signals

E4
Fourth Order Digital Signal, at 139.264 Mbps; equivalent to 64 E1 signals.

Plesiochronous Digital Hierarchy

n	North America (T*n*)		Europe (E*n*)		Japan (J*n*)	
	Number of DS0s	Rate (Mbps)	Number of DS0s	Rate (Mbps)	Number of DS0s	Rate (Mbps)
1	24	1.544	32	2.048	24	1.544
2	96	6.312	128	8.448	96	6.312
3	672	44.736	512	34.368	480	32.064
4	4032	274.176	2048	139.264	1500	97.728

North American Digital Hierarchy

Digital Signal Level	Number of DS0s	Rate (Mbps)	Equivalent T1s
DS-0	1	0.064	N/A
DS-1	24	1.544	1
DS-1C	48	3.152	2
DS-2	96	6.312	4
DS-3	672	44.736	28
DS-3C	1344	89.472	56
DS-4	4032	274.176	168

ISDN (Integrated Services Digital Network)

ISDN is a digital telephony system that allows voice and data to be transmitted simultaneously across a network. The voice and data signals are carried on ‘bearer’ (B) channels with a data rate of 64 kbps. A ‘data’ (D) channels handles signaling at 16 kbps or 64 kbps.

Basic Rate Interface (BRI)

Consists of two B channels at 64 kbps each, and one D channel at 16 kbps. This interface is considered suitable for most individual (residential) customers.

Primary Rate Interface (PRI)

In the Americas, consists of 23 B channels at 64 kbps each, and one D channel at 64 kbps. This produces an aggregate rate which is compatible with T1 transmission facilities. In Europe and other parts of the world, the PRI consists of 30 B channels and one D channel, and is therefore compatible with first-order (E-1) transmission systems. The PRI is designed for business customers.

SONET and SDH electrical interfaces

Data rate (Mbps)	Payload rate (Mbps)	SONET designation	SDH designation
51.840	50.112	STS-1	N/A
155.520	150.336	STS-3	STM-1
622.080	601.344	STS-12	STM-4
2,488.320	2,405.376	STS-48	STM-16
9,953.280	9,621.504	STS-192	STM-64
39,813.120	38,486.016	STS-768	STM-256

If the interface designation is followed by the letter ‘c’ (for example, ‘STS-3c’), this indicates a concatenated channel. That is to say, the aggregate payload for that channel is available for a single data stream.

ASI (Asynchronous Serial Interface)

The ASI is designed as a means of transferring MPEG-2 transport streams between devices in a headend or hub. It operates at a constant data-rate of 270 Mbps; however the MPEG data is 8B/10B coded, which produces a 10-bit word for each 8-bit byte in the transport steam: this coding, plus other overhead, reduces the payload to 214 Mbps.

ASI is specified in Annex ‘B’ of the CENELEC specification EN 50083-9, and is also described in the DVB Blue Book A010. The transmission medium is 75 ohm coaxial cable, and the launch voltage is 800 mV ± 10% (p-p).

ANSI/SMPTE 259M

This is a family of digital interface specifications for video, which supports the following transmission rates:

Level ‘A’: Digital sampling of an NTSC signal at four times the chrominance subcarrier frequency ($4{\cdot}f_{sc}$), resulting in a data-rate of 143 Mbps.

Level ‘B’: Digital sampling of a PAL signal at $4{\cdot}f_{sc}$, resulting in a data-rate of 177 Mbps.

Level ‘C’: Digital sampling of a 4:2:2 component video signal (either 525-line/60 Hz or 625-line/50 Hz) with a data-rate of 270 MHz. This interface has essentially the same electrical characteristics as the DVB-ASI interface (270 MHz; 800 mV launch amplitude). It is also referred to as the ‘D1’ format, and was introduced as the standard for digital video tape recorders in the mid-1980s.

Level ‘D’: Digital sampling of NTSC or PAL 4:2:2 wide-screen (16 x 9 aspect ratio) video, with a data-rate of 360 Mbps.

SMPTE 259 is frequently referred to as ‘SDI’ (serial digital interface). As mentioned previously, the similarities between ASI and SDI are such that many pieces of equipment can handle both types of signal.

ANSI/SMPTE 292M

This standard defines the digital sampling of component (4:2:2) high-definition video (either 1080i or 720p), and transmission at a rate of 1.485 Gbps. An electrical (coaxial cable) interface is defined, with a transmission loss of up to 20 dB, and an optical interface is also possible, for distances up to 2 km. In general, SMPTE 292M is regarded as the high-definition extension of SMPTE 259M.

ANSI/SMPTE 305M

Referred to as the serial digital transport interface (SDTI). This is not a ‘physical layer’ specification; rather, it defines a data communications protocol for systems which employ the physical layer specifications of SMPTE 259M (SDI).

It allows the transport of MPEG-2 packets, as well as ‘raw’ digital data, at a rate of either 270 Mbps or 360 Mbps. (The actual payload rates are approximately 200 Mbps and 270 Mbps, respectively).

MPEG-2 packets can be transferred at high speed, to provide a ‘faster than realtime’ transmission of video files.

ANSI/SMPTE 310M

This is a synchronous serial interface, designed for short distance point-to-point applications in the video broadcasting industry, such as connecting an 8-VSB modulator to a transmitter. It carries a simple MPEG-2 transport stream at a fixed rate of either 19.39 Mbps (compatible with 8-VSB transmission) or 38.78 Mbps (compatible with 16-VSB transmission). If Series 59 coaxial cable is used, the range is approximately 300 ft.

xDSL

Digital subscriber line (DSL) comprises technologies that support the transmission of digital data over copper telephone lines. DSL includes both symmetric digital subscriber line (SDSL) and asymmetric digital subscriber line (ADSL), the latter widely used by telephone companies to provide Internet access. The following table summarizes the common ADSL technologies that have been deployed. Actual data rates depend on local loop distance between the subscriber and telephone company equipment, and the condition of the lines (crosstalk, impulse noise, presence of bridged taps, etc.).

Type	Comments
ANSI T1.413 Issue 2	Up to 8 Mbps downstream and 1 Mbps upstream
G.dmt	Up to 10 Mbps downstream and 1 Mbps upstream
G.lite	Up to 1.536 Mbps downstream and 512 kbps upstream
ADSL2	*Asymmetric digital subscriber line 2*, up to 12 Mbps downstream and 3.5 Mbps upstream
ADSL2+	*Asymmetric digital subscriber line 2 plus*, up to 24 Mbps downstream and 3.5 Mbps upstream
VDSL	*Very-high-bit-rate digital subscriber line*, up to 52 Mbps downstream and 16 Mbps upstream
VDSL2	*Very-high-bit-rate digital subscriber line 2*, sum of downstream and upstream up to 200 Mbps
G.fast	Up to approximately 1 Gbps aggregate downstream and upstream at 100 m distance

Section 11: DOCSIS SIGNAL CHARACTERISTICS

General

This section contains information on the electrical characteristics of the downstream and upstream signals in cable data transmission systems, as defined by DOCSIS® (Data-Over-Cable Service Interface Specifications). The key differences between the versions of the DOCSIS specifications, as they relate to these specific characteristics, are also presented.

Also in this section are the basic transmission characteristics of element management transponders that conform to the specifications of the Hybrid Management Sub-Layer (HMS) Subcommittee of the SCTE (Society of Cable Telecommunications Engineers).

The data were derived from the following documents:

For DOCSIS:

Version 1.0 ANSI/SCTE 22-1 2012
Version 1.1 ANSI/SCTE 23-1 2017
Version 2.0 ANSI/SCTE 79-1 2016
Version 3.0 ANSI/SCTE 135-01 2018
Version 3.1 ANSI/SCTE 220-1 2016
Downstream RF Interface Specification CableLabs CM-SP-DRFI-I15-160602

NOTE: The physical layer and the RF interface specifications for DOCSIS 3.0 are presented in two separate documents, because of the option to physically separate the CMTS and the downstream modulator.

For HMS: Hybrid Fiber Coax Outside Plant Status Monitoring – Physical (PHY) Layer Specification v1.0, ANSI/SCTE 25-1 2017

The DOCSIS specifications provide for the transmission of digital signals over broadband networks using a range of phase- and amplitude modulation schemes, the basic characteristics of which are summarized as follows. See page 11-9 for DOCSIS 3.1 information.

QPSK (Quadrature Phase Shift Keying)

The data to be transmitted is sampled in blocks of two bits, which can have four different values (00, 01, 10, 11). These blocks are transmitted by shifting the phase of a carrier among four possible states. Thus, the signaling rate (also referred to as the symbol rate and expressed in baud) is half the transmission rate (expressed in bits per second). QPSK is sometimes referred to as 4-QAM.

M-QAM (Where M = 8, 16, 32, 64, 128 or 256)

The data to be transmitted is sampled in blocks; each block is referred to as a 'symbol.' The number of bits in each symbol, and hence the range of possible values of each symbol, depends on the complexity of the modulation method, as shown in the following table:

Value of M	Bits per symbol	Range of values
8	3	0 to 7
16	4	0 to 15
32	5	0 to 31
64	6	0 to 63
128	7	0 to 127
256	8	0 to 255

Both the phase and the amplitude of a carrier are shifted to define each of the possible values representing a symbol. The signaling rate (the rate at which the phase and/or amplitude are changed) is thus a fraction of the transmission rate.

In general, the more 'compression' that is achieved by increasing the complexity of the modulation scheme, and thus transmitting more data for a given signaling rate, the more susceptible the will signal be to noise in the transmission medium.

DOCSIS signal characteristics

The following characteristics represent a very small subset of the complete signal descriptions found in the DOCSIS specification documents. Shown here are only those characteristics that have direct relevance to the broadband system technician or engineer when calculating bandwidth requirements and signal levels.

Downstream transmission rates and bandwidths (all DOCSIS versions):

	Symbol rate (Msym/s)	Transmission rate[1] (Mbps)	Channel spacing (MHz)
64-QAM	5.056941	30.341650	6
	6.952000	41.712000	8
256-QAM	5.360537	42.884296	6
	6.952000	55.616000	8

Upstream transmission rates and bandwidth (DOCSIS 1.0 and 1.1):

	Symbol rate (Msym/s)	Transmission rate[1] (Mbps)	Channel width[2] (MHz)
QPSK	0.160	0.320	0.200
	0.320	0.640	0.400
	0.640	1.280	0.800
	1.280	2.560	1.600
	2.560	5.120	3.200
16-QAM	0.160	0.640	0.200
	0.320	1.280	0.400
	0.640	2.560	0.800
	1.280	5.120	1.600
	2.560	10.240	3.200

(Only QPSK and 16-QAM are required in versions 1.0 and 1.1)

NOTES:

1. The 'transmission rate' or raw data rate is the rate at which binary digits are transported. The rate at which useful information is transmitted will always be less than this figure, because of the existence in the signal of overhead bits. In the downstream signal path, the overhead accounts for approximately 10% of the transmitted signal, and in the upstream signal path the figure is approximately 15%.
2. In the case of upstream signals, the 'channel width' is the bandwidth at the -30 dB points.

Upstream modulation methods (DOCSIS 2.0 and 3.0)

In DOCSIS versions 1.0 and 1.1, upstream transmissions from cable modems are controlled by the TDMA (time division multiple access) protocol: the CMTS 'grants' time slots to each modem during which it may transmit. Thus, several modems can use the same upstream channel, but only one modem may transmit at a time.

The same protocol is required in versions 2.0 and 3.0 (but is called advanced time division multiple access, or A-TDMA, to differentiate from versions 1.0 and 1.1). An additional optional access protocol, synchronous code division multiple access, or S-CDMA, is also specified. S-CDMA is a 'spread spectrum' transmission technology, which permits several modems to transmit blocks of data simultaneously in the same upstream RF channel. Alternatively, a single modem can use S-CDMA to greatly increase its signal's immunity to interference in the transmission channel.

Each block of data, or symbol, which the modem is preparing to transmit is first combined with a 128-bit spreading code: this generates a sequence of bits that is much longer than the length of the original data block, and is referred to as the spreading interval. The sequence of bits in the spreading interval is then transmitted upstream using one of the available modulation methods. Because the spreading interval is much longer than the original data block, the information transfer rate is greatly reduced. However, it is possible to transmit several blocks in the same RF channel, provided that each block is combined with its own unique spreading code. A total of 128 spreading codes is available.

At the CMTS, the original data is recovered by searching for the 'signature' of each spreading code embedded in the incoming data-stream.

If a modem uses all 128 spreading codes to simultaneously transmit blocks of data in a single RF channel, the resulting information transfer rate will be equal to the rate that would be achieved if TDMA were being employed. In the following tables, where 'symbol rate' and 'transmission rate' are presented, this is the assumption that has been used.

Specified modulation methods (DOCSIS 2.0 and 3.0)
A check mark (✓) indicates that the method is mandated:

	QPSK	8-QAM	16-QAM	32-QAM	64-QAM	128-QAM
TDMA	✓	✓	✓	✓	✓	
TDMA with DCM*	✓		✓			
S-CDMA	✓	✓	✓	✓	✓	
S-CDMA with TCM**	✓	✓	✓	✓	✓	✓

* Differential coding modulation
**Trellis coded modulation

Upstream transmission rates and bandwidth (DOCSIS 2.0 and 3.0)

Symbol rate (Msym/s):	0.160	0.320	0.640	1.280	2.560	5.120
Channel width (MHz):	0.200	0.400	0.800	1.600	3.200	6.400
Transmission rate (Mbps):						
using QPSK:	0.320	0.640	1.280	2.560	5.120	10.240
using 8-QAM:	0.480	0.960	1.920	3.840	7.680	15.360
using 16-QAM:	0.640	1.280	2.560	5.120	10.240	20.480
using 32-QAM:	0.800	1.600	3.200	6.400	12.800	25.600
using 64-QAM:	0.960	1.920	3.840	7.680	15.360	30.720
using 128-QAM*:	1.120	2.240	4.480	8.960	19.920	35.840

* Available only when using S-CDMA with Trellis coded modulation.

Transmission frequency ranges (MHz)

DOCSIS version:	1.x	2.0	3.0
Downstream CMTS output			
DOCSIS systems:	91 to 857	91 to 857	91 to 867[1]
Euro-DOCSIS variant:	112 to 858	112 to 858	112 to 858[2]
Downstream CM input			
DOCSIS systems:	111 to 857	111 to 857	111 to 857[3]
Euro-DOCSIS variant:	112 to 858	112 to 858	112 to 858
Upstream CMTS input			
DOCSIS systems:	5 to 42	5 to 42	5 to 42[4]
Euro-DOCSIS variant:	5 to 65	5 to 65	5 to 65[4]
Upstream CM output			
DOCSIS systems:	5 to 42	5 to 42	5 to 42[4]
Euro-DOCSIS variant:	5 to 65	5 to 65	5 to 65[4]

NOTES:

1. The CMTS may transmit over the range 57 MHz to 999 MHz.
2. The CMTS may transmit over the range 85 MHz to 999 MHz.
3. The CM may tune over the range 111 MHz to 999 MHz.
4. Operation from 5 MHz to 85 MHz is optional.

Transmission power requirements (for one RF channel)

DOCSIS version:		1.x	2.0	3.0	
Downstream CMTS output					
DOCSIS systems:		50 to 61	50 to 61	60[1]	dBmV
Euro-DOCSIS variant:		*Same as DOCSIS. Add 60 to obtain levels in dBμV.*			dBμV
Downstream CM input					
DOCSIS systems:		-15 to +15	-15 to +15	-15 to +15	dBmV
European variant, 64-QAM:		43 to 73	43 to 73	43 to 73	dBμV
European variant, 256-QAM:		47 to 77	47 to 77	47 to 77	dBμV
Upstream CMTS input					
DOCSIS systems					
	0.160 Msym/s:	-16 to +14	-16 to +14	-13 to +17[2]	dBmV
	0.320 Msym/s:	-13 to +17	-13 to +17	-13 to +17[2]	dBmV
	0.640 Msym/s:	-10 to +20	-10 to +20	-13 to +17[2]	dBmV
	1.280 Msym/s:	-7 to +23	-7 to +23	-13 to +17	dBmV
	2.560 Msym/s:	-4 to +26	-4 to +26	-10 to +20	dBmV
	5.120 Msym/s:	N.A.	-1 to +29	-7 to +23	dBmV
Euro-DOCSIS variant		*Same as DOCSIS. Add 60 to obtain levels in dBμV.*			dBμV
Upstream CM output					
DOCSIS systems					
Using TDMA	QPSK:	8 to 58	8 to 58	61[1]	dBmV
Using TDMA	8-QAM:	N.A.	8 to 55	58[1]	dBmV
Using TDMA	16-QAM:	8 to 55	8 to 55	58[1]	dBmV
Using TDMA	32-QAM:	N.A.	8 to 54	57[1]	dBmV
Using TDMA	64-QAM:	N.A.	8 to 54	57[1]	dBmV
Using S-CDMA	All modulations:	N.A.	8 to 53	56[1]	dBmV
Euro-DOCSIS variant		*Same as DOCSIS. Add 60 to obtain levels in dBμV.*			dBμV

NOTES:
1. Maximum output level (single channel) must not be less than this value.
2. Not mandatory.

Transmission power requirements[1] ('bonded' channels)
DOCSIS 3.0 only

Number of channels:	1	2	3	4	
Downstream CMTS output					
DOCSIS systems:	60	56	54	52	dBmV
Euro-DOCSIS variant:	*Same as DOCSIS. Add 60 to obtain levels in dBµV.*				dBµV
Downstream CM input					
DOCSIS systems:	-15 to +15 for each channel				dBmV
European variant, 64-QAM:	43 to 73 for each channel				dBµV
European variant, 256-QAM:	47 to 77 for each channel				dBµV
Upstream CMTS input					
DOCSIS systems					
0.160 Msym/s:	-13 to +17 for each channel[2]				dBmV
0.320 Msym/s:	-13 to +17 for each channel[2]				dBmV
0.640 Msym/s:	-13 to +17 for each channel[2]				dBmV
1.280 Msym/s:	-13 to +17 for each channel				dBmV
2.560 Msym/s:	-10 to +20 for each channel				dBmV
5.120 Msym/s:	-7 to +23 for each channel				dBmV
Euro-DOCSIS variant	*Same as DOCSIS. Add 60 to obtain levels in dBµV.*				dBµV
Upstream CM output					
DOCSIS systems					
Using TDMA — QPSK:	61	58	55	55	dBmV
Using TDMA — 8-QAM:	58	55	52	52	dBmV
Using TDMA — 16-QAM:	58	55	52	52	dBmV
Using TDMA — 32-QAM:	57	54	51	51	dBmV
Using TDMA — 64-QAM:	57	54	51	51	dBmV
Using S-CDMA — All modulations:	56	53	53	53	dBmV
Euro-DOCSIS variant	*Same as DOCSIS. Add 60 to obtain levels in dBµV.*				dBµV

NOTES:

1. Where a single RF level is given, the maximum output level must not be less than this value.
2. Not mandatory.

DOCSIS 3.1

DOCSIS 3.1 is the latest Data-Over-Cable Service Interface Specifications. CableLabs® released version I01 of the specifications in October, 2013. DOCSIS 3.1 specifications became an international standard in early December 2014 (ETSI TS 103 311). DOCSIS 3.1 specifications also are ANSI/SCTE standards (ANSI/SCTE 220-1 2016 through ANSI/SCTE 220-5 2016).

When the specification was being developed, the goals included scalability to achieve 10+ Gbps in the downstream; 1+ Gbps in the upstream; backwards compatibility with DOCSIS 3.0, 2.0, & 1.1; and better spectral efficiency (i.e., more bits per second per hertz).

DOCSIS 3.1 technology includes the following for improved performance:

- New physical layer (PHY) technology – downstream OFDM (orthogonal frequency division multiplexing) and upstream OFDMA (orthogonal frequency division multiple access)
- Better forward error correction – LDPC (low density parity check), which is more powerful than the Viterbi/Reed-Solomon FEC used in earlier versions of DOCSIS
- Time and frequency interleaving for improved data transmission robustness
- Higher modulation orders (see page 11-13)
- Expanded downstream and upstream RF spectrum usage
- Multiple modulation profiles
- 25 kHz or 50 kHz subcarrier spacings

OFDM and OFDMA signal bandwidths are not limited to legacy downstream and upstream channel bandwidths. DOCSIS 3.1 signal bandwidths are summarized in the following table:

	Minimum	Maximum
OFDM channel bandwidth	24 MHz	192 MHz
OFDM encompassed spectrum	22 MHz	190 MHz
OFDMA encompassed spectrum	6.4 MHz or 10 MHz (depending on subcarrier spacing)	95 MHz

Transmission frequency ranges

Downstream CMTS output upper band edge MUST: MAY:	1218 MHz 1794 MHz
Downstream CMTS output lower band edge MUST: SHOULD:	258 MHz 108 MHz
Upstream CMTS input MUST:	5 MHz to at least 204 MHz
Upstream CM output MUST:	5 MHz to at least 204 MHz[1]

NOTE:

1. A CM MUST support one or more of the following upstream upper band edges, as long as one of the upstream upper band edges supported is 85 MHz or greater: 42 MHz, 65 MHz, 85 MHz, 117 MHz, and/or 204 MHz.

Transmission power requirements

Downstream:

OFDM channel power is defined as the RF power per 6 MHz. In most cases the power spectral density (PSD) of the OFDM signal is set to the same PSD as the SC-QAM signals carried on the network. That is, the height of the OFDM 'haystack' will be the same as the height of SC-QAM 'haystacks' as viewed on a spectrum analyzer.

Downstream CMTS output:

- Configured by power per CTA channel – that is, per 6 MHz – and the number of occupied CTA channels for each OFDM signal. For each OFDM channel, total power = power per CTA channel + $10\log_{10}$(number of occupied CTA channels) for that OFDM channel.

- The required power per channel for N_{eq}' channels combined onto a single RF port: $P_{per\ channel} = 60 - \text{ceil}\ [3.6*\log_2(N^*)]$ dBmV

Downstream CM input:

- Total input power < 40 dBmV, 54 MHz to 1.794 GHz

- Level range = -9 dBmV to +21 dBmV in a 24 MHz occupied bandwidth. The latter is equivalent PSD to -15 dBmV to +15 dBmV per 6 MHz for SC-QAM signals.

Upstream:

All DOCSIS 3.0 requirements are still in place when operating in DOCSIS 3.0 mode.

A DOCSIS 3.1 CM's maximum transmit average power (not peak) is required to be *at least* +65 dBmV. Vendors can design their products for higher modem transmit power capability, but all spurious emissions requirements (dBc) must still be met even at the higher transmit power levels.

DOCSIS 3.1 CMs have minimum transmit power limits related to transmit grant bandwidth: no less than +17 dBmV with a 1.6 MHz grant.

Upstream OFDMA power is the RF power per 1.6 MHz. Reported upstream SC-QAM power depends on the combination of equipment. Where “Occupied bandwidth” is shown in the third column of the following table, the power reported is for the full channel bandwidth – for example, 3.2 MHz or 6.4 MHz. Note that reported SC-QAM power is per 1.6 MHz when the modem and CMTS are both DOCSIS 3.1 devices, *regardless of the signal’s actual channel bandwidth*.

CM Type	CMTS Type	SC-QAM Power
DOCSIS 3.0	DOCSIS 3.0	Occupied bandwidth
DOCSIS 3.0	DOCSIS 3.1	Occupied bandwidth
DOCSIS 3.1	DOCSIS 3.0	Occupied bandwidth
DOCSIS 3.1	DOCSIS 3.1	1.6 MHz bandwidth

Downstream Modulation Orders

	CMTS downstream transmit	Cable modem downstream receive	Bits per symbol
MUST:	16-QAM	16-QAM	4
MUST:	64-QAM	64-QAM	6
MUST:	128-QAM	128-QAM	7
MUST:	256-QAM	256-QAM	8
MUST:	512-QAM	512-QAM	9
MUST:	1024-QAM	1024-QAM	10
MUST:	2048-QAM	2048-QAM	11
MUST:	4096-QAM	4096-QAM	12
MAY:	8192-QAM	8192-QAM	13
MAY:	16384-QAM	16384-QAM	14

Upstream Modulation Orders

	Cable modem upstream transmit	CMTS upstream receive	Bits per symbol
MUST:	QPSK	QPSK	2
MUST:	8-QAM	8-QAM	3
MUST:	16-QAM	16-QAM	4
MUST:	32-QAM	32-QAM	5
MUST:	64-QAM	64-QAM	6
MUST:	128-QAM	128-QAM	7
MUST:	256-QAM	256-QAM	8
MUST:	512-QAM	512-QAM	9
MUST:	1024-QAM	1024-QAM	10
MUST:	2048-QAM	–	11
MUST:	4096-QAM	–	12
SHOULD:	–	2048-QAM	11
SHOULD:	–	4096-QAM	12

Approximate downstream transmission rates: Single 190 MHz encompassed spectrum OFDM signal (full channel, no exclusions)[1]

Modulation order	25 kHz subcarrier spacing	50 kHz subcarrier spacing
256-QAM	1.26 Gbps	1.20 Gbps
512-QAM	1.42 Gbps	1.35 Gbps
1024-QAM	1.58 Gbps	1.50 Gbps
2048-QAM	1.73 Gbps	1.65 Gbps
4096-QAM	1.89 Gbps	1.80 Gbps
8192-QAM	2.05 Gbps	1.96 Gbps
16384-QAM	2.21 Gbps	2.11 Gbps

Approximate upstream transmission rates: Single 95 MHz encompassed spectrum OFDMA signal (full channel, no exclusions)[1]

Modulation order	25 kHz subcarrier spacing	50 kHz subcarrier spacing
64-QAM	0.47 Gbps	0.46 Gbps
128-QAM	0.55 Gbps	0.53 Gbps
256-QAM	0.63 Gbps	0.61 Gbps
512-QAM	0.71 Gbps	0.69 Gbps
1024-QAM	0.78 Gbps	0.76 Gbps
2048-QAM	0.86 Gbps	0.84 Gbps
4096-QAM	0.94 Gbps	0.91 Gbps

NOTE:

1. The transmission rates in these tables are approximate, and were calculated using ‘typical’ configurations for cyclic prefix, rolloff (taper region), and other overhead. Actual transmission rates may vary from what is shown in these tables.

HMS transponder signal characteristics

The following characteristics apply to all ‘Class 2’ and ‘Class 3’ HMS transponders, which are those (as defined in the ANSI/SCTE specification) which are purposely designed to meet the HMS specifications, as opposed to new or ‘legacy’ transponders that may be upgraded to meet the specification.

Downstream characteristics:

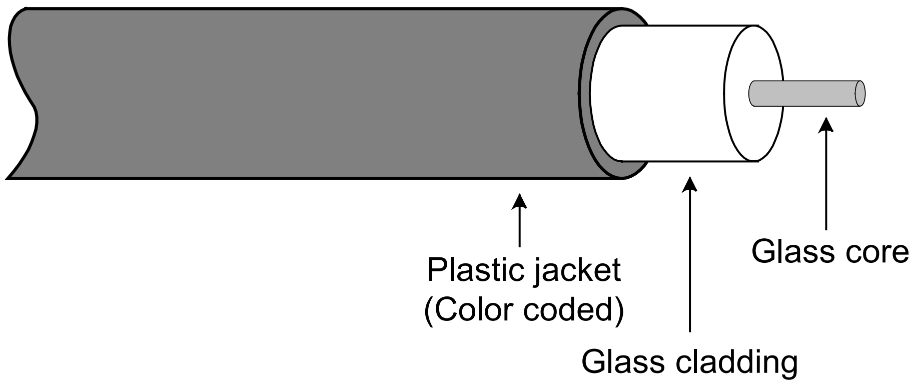
	Output of Headend transmitter	Input to transponder
Frequency	48 MHz to 162 MHz	
Signal level	+40 to +51 dBmV	-20 to +20 dBmV
Modulation	FSK	
Bit rate	38.4 kbps	

Upstream characteristics:

	Output of transponder	Input to Headend receiver
Frequency range	5 MHz to 21 MHz	
Signal level	+25 to +45 dBmV	-20 to +20 dBmV
Modulation	FSK	
Bit rate	38.4 kbps	

Section 12: FIBER CABLE CHARACTERISTICS

Mechanical Structure



A single fiber cable consists of a glass core surrounded by a concentric glass cladding; the two glasses have different refractive indices so that light is confined to the core by total internal reflection. The protective plastic jacket is color-coded so that individual fibers can be identified in multiple-fiber bundles (‘tubes’).

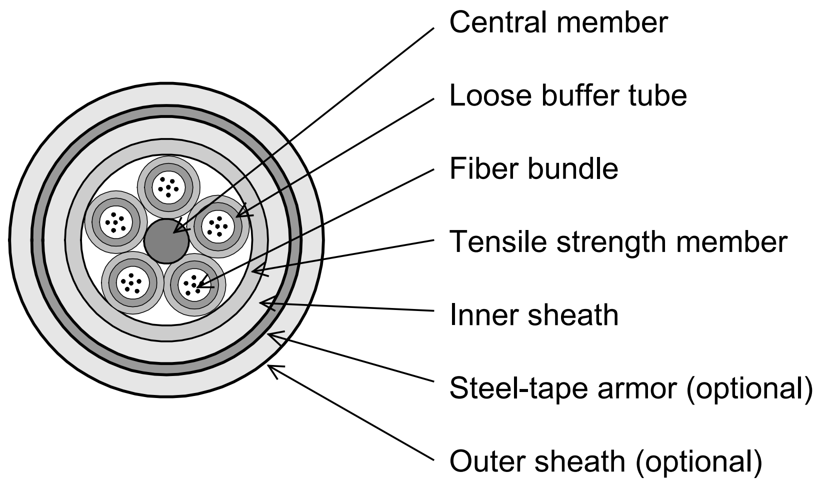
Typical dimensions of the fiber are:

Plastic jacket:	**242 µm to 250 µm**
Glass cladding:	**125 µm**
Glass core:	**50 µm to 62.5 µm (multi-mode)**
	8 µm to 9 µm (single-mode)

(‘µm’ is one micrometer, or one millionth of a meter; 250 µm is therefore the equivalent of one-quarter of a millimeter; it is frequently referred to as “micron”).
A fiber ‘pigtail’ has an additional protective plastic coating with a diameter of 900 µm, and a Kevlar sheath, bringing the total diameter up to approximately 2500 µm (2.5 mm).

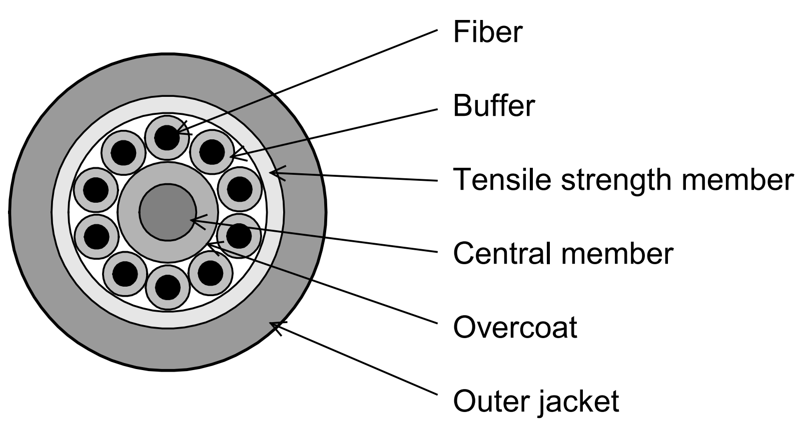
Among the principal types of multi-fiber cables are loose tube and tight-buffered cables, as illustrated in the following figures. Cable construction details and nomenclature are taken from Siecor Corporation – now Corning Incorporated – publications.

Loose Tube Cable Cross-Section



Loose tube cables contain hollow buffer tubes with one or more fibers inside each tube.

Tight-Buffered Cable Cross-Section



Tight-buffered cables have a 900 μm diameter plastic coating applied directly to each fiber.

In general, loose-tube cables are used in outdoor installations, where the isolation of the individual fibers from external stress maximizes the cable life. Tight-buffered cables have their main application in indoor environments. These cables are typically more sensitive to adverse temperatures and external forces than the loose-tube design, but are desirable because of their increased flexibility, smaller bend radius, and easier handling characteristics. (Applications information taken from Siecor Corporation – now Corning Incorporated – publications.)

Examples of other types of fiber cables not shown here include ribbon, microduct, drop, and composite (those with multiple copper conductors).

Color Coding of Fibers

For multi-fiber cables, a color coding scheme is used to distinguish individual fibers. In loose tube construction, up to 12 fibers can be placed in each tube, and they are coded as follows (in accordance with TIA-598-C "Optical Fiber Cable Color Coding"):

1. Blue
2. Orange
3. Green
4. Brown
5. Slate
6. White
7. Red
8. Black
9. Yellow
10. Violet
11. Rose
12. Aqua

Buffer tubes containing fibers are also color coded in accordance with the same standard:

1. Blue
2. Orange
3. Green
4. Brown
5. Slate
6. White
7. Red
8. Black
9. Yellow
10. Violet
11. Rose
12. Aqua

Loss Characteristics of Fiber Optic Cables

The information contained in this section, addresses only the transmission of linearly-modulated optical signals at 1310 nm and 1550 nm through single-mode fibers. In designing optical links for broadband networks, Cisco uses conservative estimates of fiber performance, and the contribution of associated optical components. Thus the information which follows should be used when specific details of actual plant performance are unknown: in many cases the true performance of an optical link will be better than that indicated by the conservative figures given here.

Loss Characteristics of Fiber Optic Cables

Fiber loss:	**0.35 dB per km** (0.56 dB/mile) at 1310 nm*
	0.25 dB per km (0.40 dB/mile) at 1550 nm
Splice loss:	**0.05 dB per km** (fusion splices)
	0.15 dB for each mechanical splice
Connector loss:	**0.25 dB** for each super FC-PC connector set
Sag & storage:	**Add 4%** to fiber length

* For standard CATV dual-window fiber. Published attenuation for Corning SMF-28e+ fiber is ≤0.35 dB/km at 1310 nm and ≤0.20 dB/km at 1550 nm.

Section 13: OPTICAL PASSIVES

Single-mode Multiband Couplers and Splitters

The data in this section represent the specifications of the fused couplers and splitters available from Cisco. Two-way splitters/
couplers are available either unconnectorized, or in LGX-compatible modules.

Fused coupler/splitter optical specifications:

Configuration	Split ratio	Maximum insertion loss (dB)* Through	Maximum insertion loss (dB)* Tap
1 : 2	50 / 50	4.00	4.00
	55 / 45	3.60	4.50
	60 / 40	3.20	5.00
	65 / 35	2.75	5.60
	70 / 30	2.55	6.30
	75 / 25	2.15	7.00
	80 / 20	1.80	8.10
	85 / 15	1.50	9.30
	90 / 10	1.30	11.25
	95 / 05	1.05	14.35
1 : 2 dual	50 / 50	4.00	4.00
2 : 2	Even	4.00	4.00
2 : 4	Even	7.70	7.70
1 : 3	Even	6.3 / 6.3 / 6.3	
	35 / 35 / 30	5.3 / 5.3 / 5.9**	
	40 / 30 / 30	4.6 / 5.9 / 5.9**	
	50 / 25 / 25	3.6 / 6.7 / 6.7**	
	40 / 40 / 20	4.9 / 4.9 / 7.8**	
	60 / 20 / 20	2.8 / 7.7 / 7.7**	
1 : 4	Even	7.60	
1 : 5	Even	8.95	
1 : 6	Even	9.90	
1 : 7	Even	10.90	
1 : 8	Even	11.20	
1 : 10	Even	13.30	
1 : 12	Even	13.50	
1 : 16	Even	14.90	

* Includes connector losses.
± 20 nm, -20 to +65 ˚C
** Typical insertion loss

The <u>theoretical</u> loss in decibels through one 'leg' of an optical coupler can be calculated from the numerical value of the loss as follows:

$$\text{Loss through port 'A' (in dB)} = 10*\log(F_A)$$

Where F_A = numerical loss, expressed as a fraction (for example; 35% becomes 0.35)

The actual optical loss through a directional coupler will be higher than the value obtained from this formula, since factors such as backscatter, polarization effects, temperature/humidity changes, aging, wavelength dependence, etc., add to the loss.

DWDM multiplexers and demultiplexers

The following table contains the performance specifications for single- and multiple-channel DWDM multiplexers and demultiplexers in the Prisma® product lines from Cisco. These devices are available with channel spacings of 100 GHz and 200 GHz, in accordance with the ITU wavelength grid.

Multiplexer and demultiplexer optical specifications:

	1 ch. OADM	4 ch	8 ch	12 ch	16 ch	20 ch	40 ch
Insertion loss, dB (typ): 100 GHz (mux/demux)	<1.1 (add/drop) < 0.8 (other)	1.5	2.4	n/a	2.4	3.0	4.0
Isolation, dB (max)	> 30 (add/drop) > 12 (other)	> 30 (adjacent channels > 40 (non-adjacent channels)					

NOTE: Losses include input/output and common connector losses

DWDM multiplexers and demultiplexers (continued)

Common specifications:

	Units	100 GHz units
Channel bandwidth at 0.5 dB	nm	$\lambda_C \pm 0.12$
Channel spacing	GHz	100
Polarization dependent loss (PDL)	dB	≤ 0.20
Polarization mode dispersion (PMD)	ps	≤ 0.15
Directivity	dB	≥ 55
Optical return loss	dB	≥ 45

NOTE: Specifications apply over a temperature range of -5 °C to +65 °C.
Operational temperature range is -40 °C to +65 °C.

CWDM multiplexers and demultiplexers

The following table contains the performance specifications for single- and multiple-channel CWDM multiplexers and demultiplexers in the Prisma® product line from Cisco. These devices use channel spacings of 20 nm, at wavelengths from 1430 nm to 1610 nm, in accordance with the ITU wavelength grid.

Multiplexer and demultiplexer optical specifications:

Center wavelength (nm)	1430, 1450, 1470, 1490, 1510 1530, 1550, 1570, 1590, 1610			
Configuration:	**1 ch. OADM**	**4 ch**	**8 ch**	**10 ch**
Insertion loss, dB*	< 1.2 (pass) < 0.8 (reflect)	2.2	3.0	3.3
Isolation, dB	> 30 (pass channel) > 12 (reflect channel)	> 30 (adjacent channels > 40 (non-adjacent channels)		

* Maximum, including connector losses

NOTE: the ‘pass’ channel is the desired add/drop channel, and the ‘reflect’ channels are all others. See explanation of parameters, also in this section.

Common specifications:

Passband	13 at -0.5 dB	nm
Passband ripple	< 0.5	dB
Uniformity	< 1.0	dB
Polarization dependent loss (PDL)	< 0.25	dB
Polarization mode dispersion (PMD)	< 0.2	ps
Thermal stability	< 0.008	nm/°C
Directivity	> 55	dB
Optical return loss	> 50	dB

Dispersion Compensation Modules

The effects of chromatic dispersion in optical fiber can be compensated by using dispersion compensation modules (DCMs) placed at intervals along the fiber route. Cisco Prisma® DCMs are available in a range of models, corresponding to different lengths of single-mode fiber.

DCM optical specifications:

Type	Dispersion at 1550 nm	Maximum loss at 1550 nm	RDS	Max. PMD
	(ps per nm)	(dB)	(nm^{-1})	(ps)
GS7000-DCM 10	-170 ± 2%	2.0	0.0035 ± 20%	0.2
GS7000-DCM 20	-340 ± 2%	2.5	0.0035 ± 20%	0.3
GS7000-DCM 30	-510 ± 2%	4.5	0.0035 ± 20%	0.4
GS7000-DCM 40	-680 ± 2%	5.0	0.0035 ± 20%	0.5
Rack Mount-DCM 20	-340 ± 2%	1.9	0.0015 – 0.0055	0.54
Rack Mount-DCM 30	-510 ± 2%	2.4	0.0015 – 0.0056	0.66
Rack Mount-DCM 40	-680 ± 2%	2.8	0.0015 – 0.0057	0.76
Rack Mount-DCM 50	-850 ± 2%	3.3	0.0015 – 0.0058	0.85
Rack Mount-DCM 60	-1020 ± 2%	3.7	0.0015 – 0.0059	0.93
Rack Mount-DCM 70	-1190 ± 2%	4.2	0.0015 – 0.0060	1.01
Rack Mount-DCM 80	-1360 ± 2%	4.6	0.0015 – 0.0061	1.08

Notes

A. RDS: relative dispersion slope
B. PMD: polarization mode dispersion
C. Includes connector losses

Each DCM is designed to compensate for a specific amount of dispersion. For example, the DCM 20 is used to compensate for 20 km of dispersion.

Modules for passive optical networks (PONs)

Single-mode Multiband Couplers/Splitters

Configuration	Split ratio	Max. Insertion loss (dB)*	Max. uniformity (dB)
1 : 2 single 1 : 2 dual 2 : 2 single	Even	4.0	0.8
1 : 4 2 : 4	Even	7.5	0.8
1 : 8	Even	10.5	1.0
1 : 16	Even	14.0	1.5
1 : 32	Even	17.8	2.0

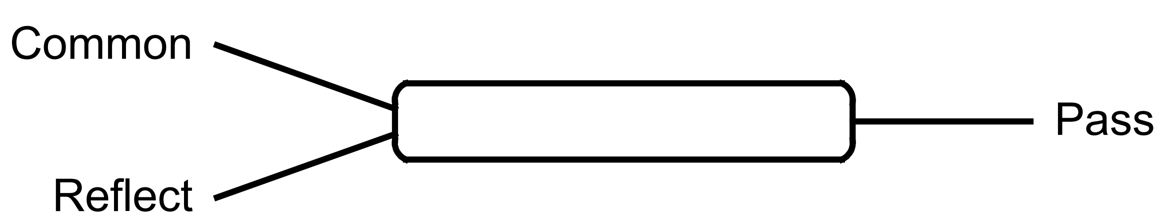
* Includes connector losses

Common specifications for couplers/splitters:

Passband	1270 - 1350 and 1480 -	nm
Operating temperature	-5 to +65	°C
Storage temperature	-40 to +85	°C
Directivity	≥ 55	dB
Optical return loss	≥ 55	dB

Explanation of component performance parameters

The following is an explanation of the parameters that are used to characterize optical passive devices in the Prisma® product-line from Cisco. A three-port DWDM filter is used as an example. The ports on such a device are identified as shown in the following figure:



3-port optical passive port nomenclature

Explanation of component performance parameters (cont'd)

If, for example, this device is designed to act as a filter for ITU channel 29, and if this and a large number of other ITU wavelengths are applied to the 'common' port, then ideally only channel 29 will emerge at the 'pass' port, and all the other wavelengths will emerge at the 'reflect' port. (The case in which optical signals travel in both directions at the 'common' port is discussed below).

Channel bandwidth

The channel bandwidth of the 'pass' port is specified in terms of the center wavelength (based on the ITU grid), and the points above and below this center at which the insertion loss in the passband is 0.5 dB greater than the minimum insertion loss.

For example, in a DWDM optical add/drop multiplexer (OADM) based on 100 GHz ITU-grid spacing, the Cisco specification for the channel bandwidth is $\lambda_C \pm 0.12$ nm, at the 0.5 dB points, where λ_C is the center wavelength on the ITU grid.

Maximum insertion loss

Referring to the performance of the 'pass' port, it is the maximum loss, relative to the theoretically perfect 0 dB loss, that occurs within the channel bandwidth.

Minimum insertion loss

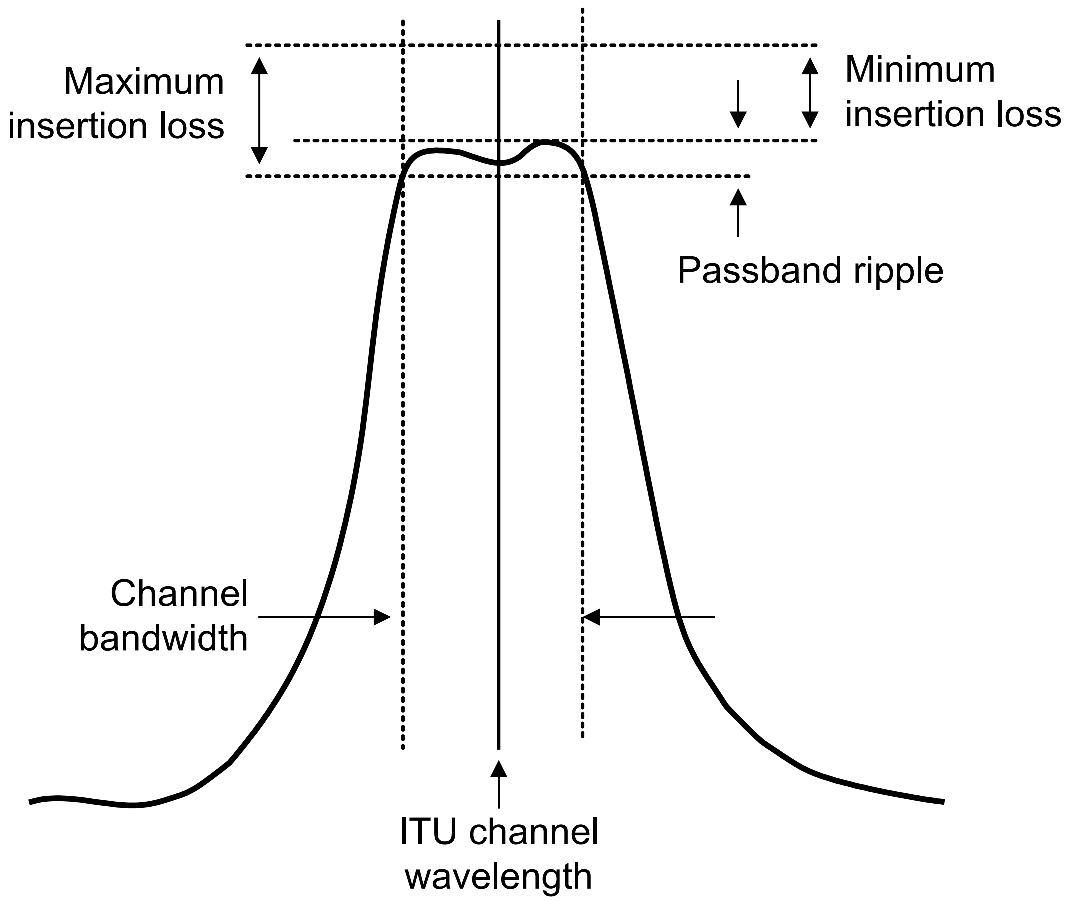
In reference to the 'pass' port, this is the minimum loss, relative to the theoretically perfect 0 dB loss, that occurs within the channel bandwidth.

Passband ripple

Again, in reference to the 'pass' port, this is the difference between the maximum and minimum insertion loss within the channel bandwidth.

The four parameters described previously are illustrated in the following diagram, which shows the optical transfer characteristic of a 3-port DWDM device from the 'common' to the 'pass' port.

Explanation of component performance parameters (cont'd)

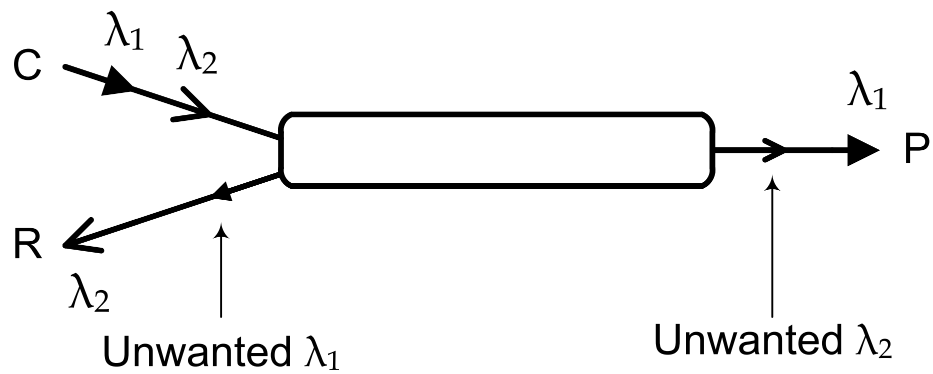


'Common' to 'pass' port spectrum for 3-port DWDM device

Uniformity
For a multiple-wavelength device, such as a 4-channel multiplexer, the uniformity defines the difference between the highest and lowest insertion losses across all channels.

Isolation (adjacent channel)
Suppose wavelengths λ_1 and λ_2, spaced 100 GHz apart on the ITU grid, enter the device at the common port, and suppose only λ_1 should exit at the 'pass' port, and only λ_2 should exit at the 'reflect' port. (See following diagram):

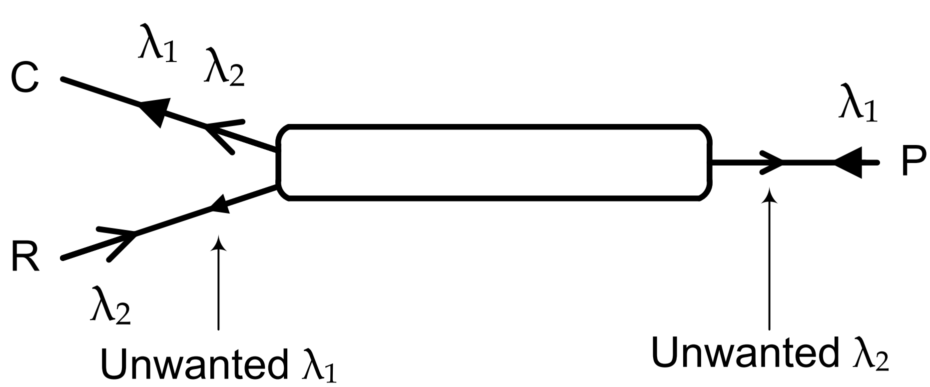
Explanation of component performance parameters (cont'd)



In practice, a residual amount of λ_2 will appear at the 'pass' port, and a residual amount of λ_1 will appear at the 'reflect' port. The ratio of the desired to the unwanted signal at each port is referred to as the <u>isolation</u> of that port.

Isolation (non-adjacent channel)
The same as the adjacent channel isolation definition, except that the wavelengths are not adjacent on the ITU grid.

Directivity
Suppose the 3-port device is being used as a low-loss wavelength combiner, as shown in the following diagram:



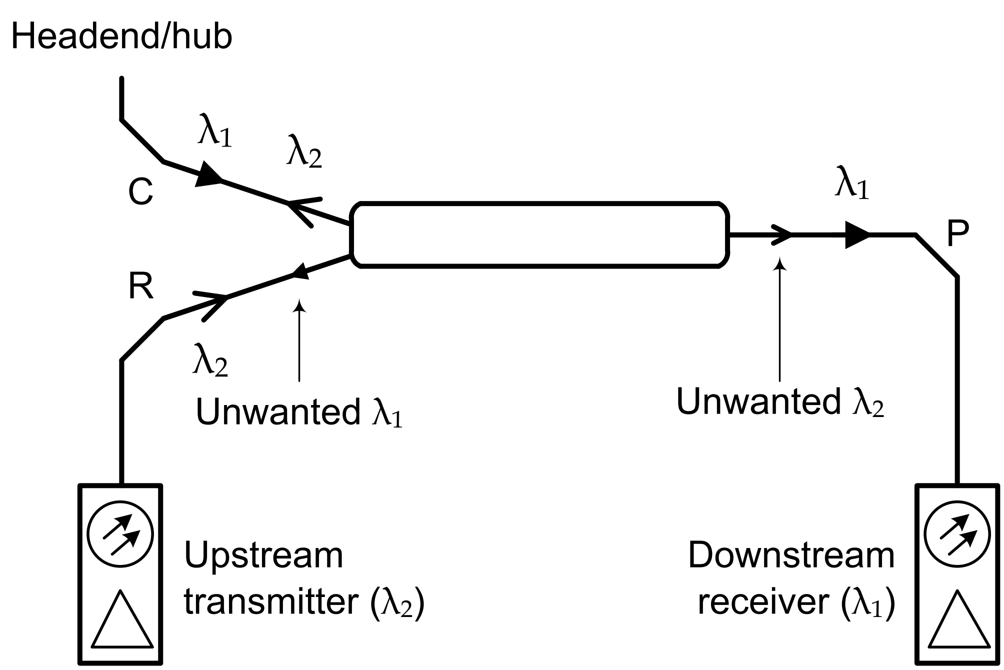
Wavelength λ_1 is applied to the 'pass' port, and wavelength λ_2 enters at the 'reflect' port. The two wavelengths may be adjacent or non-adjacent on the ITU grid.

In practice a small amount of λ_1 will appear at the 'reflect' port, and a small amount of λ_2 will appear at the 'pass' port. The attenuation (insertion loss) of λ_1 in traveling from the 'pass' to the 'reflect' port, and the attenuation of λ_2 in traveling from the 'reflect' to the 'pass' port, are defined by the directivity of the device.

(The measurement of directivity is made with the 'common' port optically terminated).

Bi-directional operation

In HFC networks with very low fiber counts, it is sometimes necessary to use only one fiber for both downstream and upstream optical communication between a hub/headend and a node. Typically, the wavelengths will be 1550 nm (downstream), and 1310 nm (upstream). Low-loss combining and splitting of these wavelengths at each end of the optical link can be accomplished using 3-port WDM devices. The following diagram shows such a device located at the node:



Explanation of component performance parameters (cont'd)

In a real implementation, a small amount of the 1310 nm upstream transmitter's output (λ_2) will be delivered to the downstream receiver: the attenuation of λ_2 through the 3-port device is defined by its directivity specification.

Also, a small amount of the 1550 nm downstream signal will be delivered to the output of the upstream transmitter, where it can increase the RIN of the laser. The actual level of λ_1 that appears at the 'reflect' port in this way can be calculated by taking the power of λ_1 at the 'common' port, and then subtracting first the insertion loss from the 'common' to the 'reflect' port and, second, the isolation between these two ports. (In the case of 1310 nm/1550 nm wavelengths, this would be the non-adjacent channel isolation).

Polarization Dependent Loss (PDL)

Within the passband of any optical device, the spectral components of an optical signal will experience different amounts of attenuation due to their state of polarization. The maximum variation in loss over all states of polarization within the device passband is the polarization dependent loss.

Polarization Mode Dispersion (PMD)

Within the passband of any optical device, the spectral components of an optical signal will experience different propagation delays through the device due to their state of polarization. The maximum signal dispersion within the device passband, over all states of polarization, is the polarization mode dispersion.

Section 14: PASSIVE OPTICAL NETWORKS

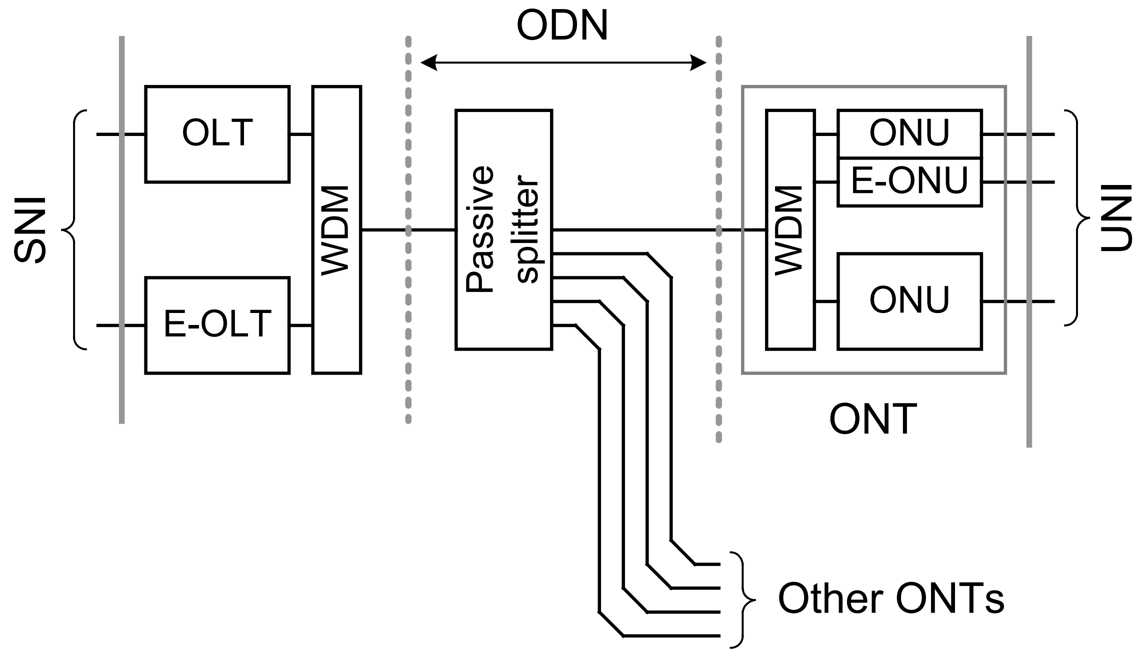
A passive optical network (PON) is a fiber-based transmission system that conveys signals between a processing or origination point, and a point at the network subscriber's premises, or at an intermediate point. A passive optical network, by definition, contains no active optical devices (amplification, re-lasing, etc.)

In this section, the structure and functionality of various types of PON are outlined, but the discussion is limited to those networks that are defined by existing or emerging international standards: proprietary implementations are not considered. The key governing PON standards are issued by the International Telecommunications Union (ITU).

These PONs are often referred to as 'FTTx' networks, where 'x' is home (H), business (B), premise (P) or curb (C). However, it is not always the case that a 'FTTx' network comprises an ITU-compliant PON. For example; a fiber-deep network based on a 'node-plus-zero' architecture (no active RF equipment beyond the node) and utilizing standard HFC components can properly be called a FTTC network.

The work of the ITU-T standards organization has been guided by the **FSAN (Full Service Access Network)** initiative. This is a group of service providers which since the mid-1990s has developed recommendations for PONs, which have been formalized in the ITU-T 983 and 984 series of standards.

The logical structure of a PON, as defined by these standards, is shown in the following diagram.



PON architecture

Definitions of terms

SNI: Service Node Interface

The interface between the domains of the access network operator and the service operator. (These operators may be a single entity; for example, in the case of a large telephone company).

UNI: User Network Interface

The interface between the domains of the access network operator and the end-user.

OLT: Optical Line Termination

The electro-optical interface between the SNI and the optical distribution network. (See ODN, next page).

E-OLT: Enhancement band Optical Line Termination

An OLT which provides additional network services via the Enhancement Band, such as broadband video.

ODN: Optical Distribution Network

A fiber-based transmission system containing only passive optical components (e.g., splitters).

ONU: Optical Network Unit

The electro-optical interface between the ODN and the copper-pair or coaxial link to the end-user.

ONT: Optical Network Termination

When a ONU includes termination ports for the end user, the combined functionality is referred to as an optical network termination. This is the configuration found in many PON implementations today: the ONT in such cases is a protected enclosure attached to the exterior of the end-user's premises, containing the electro-optical interface, the WDM components, and the connection points to which the end-user attaches customer premises equipment. (e.g., set-top terminal, telephone, modem).

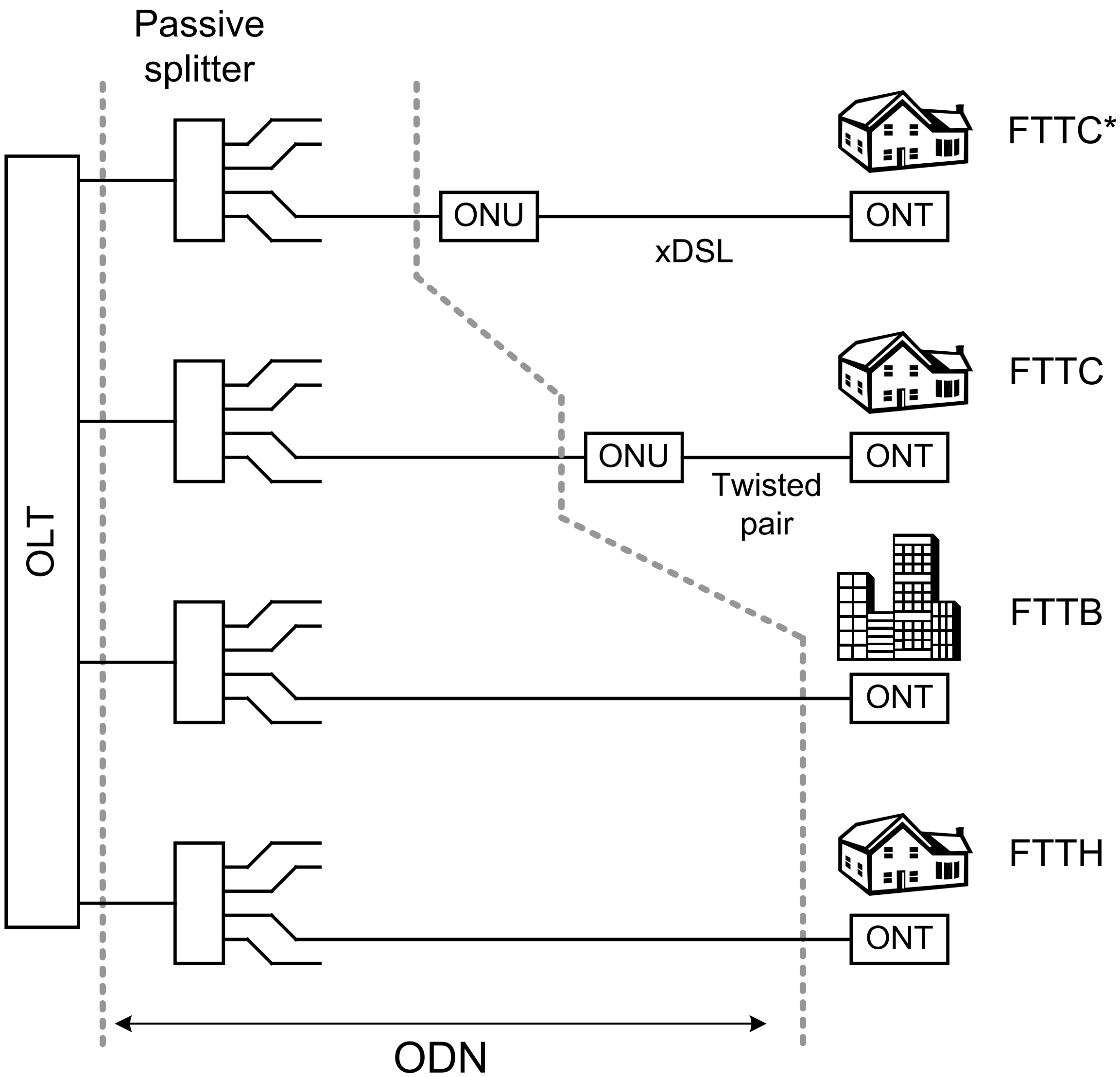
WDM: Wavelength Division Multiplexing function

As described in the following section, multiple services are carried between the OLT and the ONT using WDM, so that only a single fiber is required at each ONT.

PONs and FTTx networks

The placement of the ONU determines the overall architecture of the PON, and identifies the 'x' in 'FTTx'. The following diagram shows four different FTTx networks; for simplicity, they are all shown originating in the same OLT, which is an unlikely practical scenario.

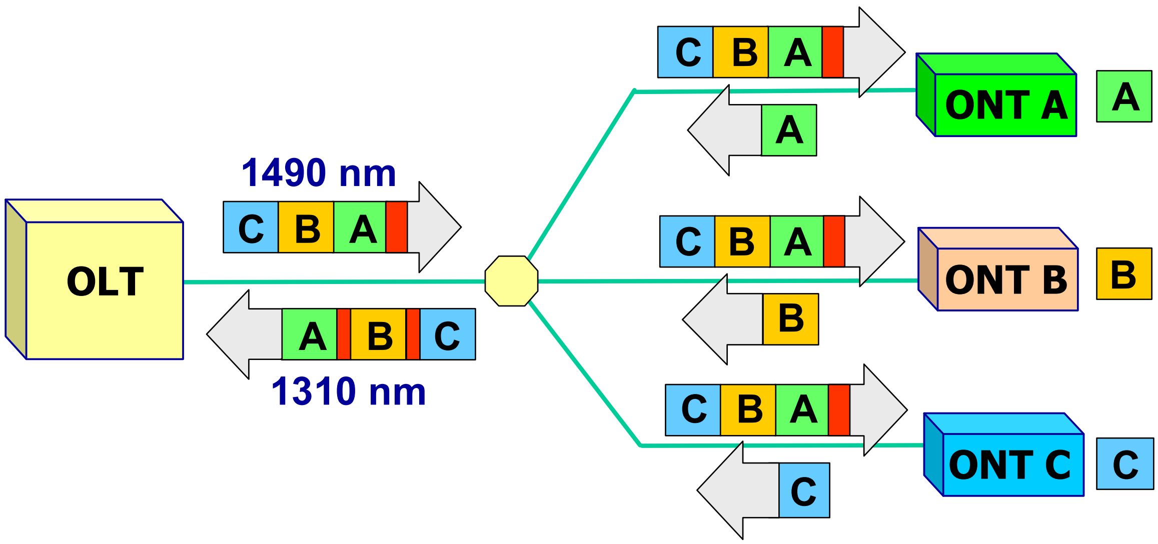
PONs and FTTx networks (cont'd)



* Refers to fiber to the cabinet, or Remote Terminal. In this example, the Remote Terminal contains DSLAMs

Practical FTTH implementation with CATV video

In these networks, the ONU is a component of the ONT, as illustrated in the previous diagram. The basic network components are as shown in the following diagram.



Practical FTTH implementation, with CATV video

Digital traffic is transmitted downstream to the end-user at wavelength λ_1, and corresponding upstream traffic is carried on the fibers at λ_2, using WDM.

Additional services such as broadband video, are carried downstream using a third wavelength, λ_3. The video traffic can consist of the 'standard' HFC spectrum of analog and digital (QAM) signals, typically occupying the 50 MHz to 1 GHz band, so that, at the customer's premises, a direct connection to a TV receiver can be made, without the need for a set-top box or terminal, assuming that many of the signals are unencrypted.

For interactive video services (for example, VoD), requests from the set-top terminal are transmitted along with the upstream digital traffic at wavelength λ_2.

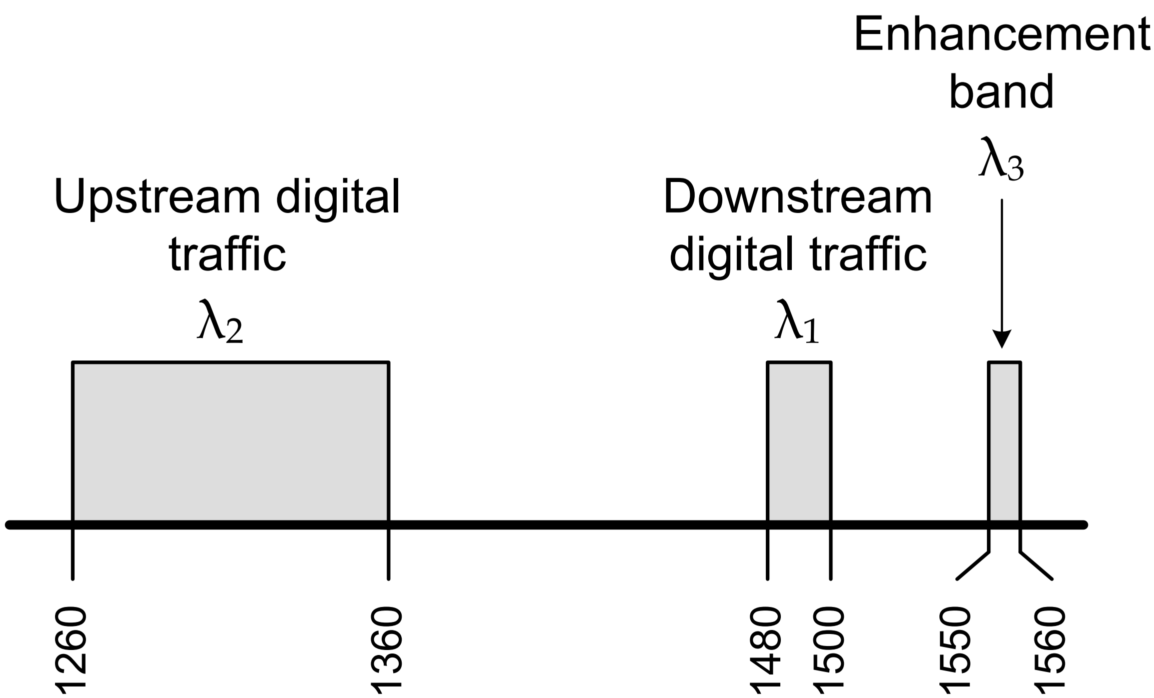
Optical wavelength allocations

Permitted optical bands for the various types of PON traffic are defined in ITU Recommendation G.983.wdm, and are summarized in the following table.

Wavelength range	Purpose
1260 – 1360 nm	Upstream digital traffic
1480 – 1500 nm	Downstream digital traffic
1539 – 1565 nm	Enhancement band 1 (Additional digital traffic)
1550 – 1566 nm	Enhancement band 2 (Video distribution)

These bands are shown schematically in the following diagram. Only the video Enhancement Band is depicted.

Optical wavelength allocations (cont'd)



Wavelength allocations

Types of PON

Several types of passive optical network are the subject of existing or proposed standards.

The following table provides a list of their key characteristics, and references to the relevant standards. The 'Data rates' are the transmission rates (not information transfer rates) for the downstream and upstream digital traffic at wavelengths λ_1 and λ_2.

Name	Standard	Data rates	
		downstream	upstream
APON	ITU-T Rec. G.983	155 Mbps 622 Mbps	155 Mbps 155 Mbps
BPON	ITU-T Rec. G.983	155 Mbps 622 Mbps	155 Mbps 622 Mbps
EPON	IEEE 802.3ah	1.25 Gbps	1.25 Gbps
GPON	ITU-T Rec. G.984	1.244 Gbps 2.488 Gbps	155 Mbps 622 Mbps 1.244 Gbps 2.488 Gbps

Definitions of terms

APON: ATM-based Passive Optical Network

The earliest PON definition, resulting from the work of FSAN in the mid-1990s, and subsequently incorporated in an ITU standard. ATM was chosen as the Layer 2 protocol for downstream and upstream digital traffic, because of its ability to handle multiple transmission formats. The ATM cells are carried in SONET/SDH frames. APON did not include a provision for 'enhanced' services such as video, and therefore the initial deployments were aimed primarily at the business market.

BPON: Broadband Passive Optical Network

Upstream and downstream digital traffic in a BPON is also carried in ATM cells; however, the upstream transmission rate may be increased to 622 Mbps (OC-12 / STM-4). For the broadband video industry, the most important modification to the earlier APON specification was the addition of an Enhancement Band which could be used for video services. BPON is predominant in current network deployments.

EPON: Ethernet Passive Optical Network

Sometimes referred to as Ethernet in the first mile (EFM). Only one symmetrical transmission rate, 1.25 Gbps is supported, using simple extensions to the standard IEEE 802.3 MAC layer. An enhancement wavelength band for video services is permitted, as in BPON, but actual deployments have focused on digital data services and a limited amount of IPTV.

GPON: Gigabit Passive Optical Network

This is the most recent ITU-T standard, and is based on work that began in FSAN in 2001. The architecture supports very high, symmetric or asymmetric transmission rates, and an Enhancement Band. Whereas EPON handles TDM (T1/E1) traffic through emulation and requires additional hardware and software to do so, a GPON supports pleisiochronous (legacy TDM) and synchronous (SONET/SDH) traffic in native format, and is therefore less likely to introduce excessive latency and jitter.

Classes of ODN

The optical distribution network of a PON, as defined by the ITU standards, is characterized by one of three ‘classes’: A, B and C.

These classes are defined by the allowable range of optical attenuation between the OLT and the ONU, as shown in the following table:

	Class ‘A’	Class ‘B’	Class ‘C’
Minimum loss	5 dB	10 dB	15 dB
Maximum loss	20 dB	25 dB	30 dB

The maximum attenuation determines the longest ‘reach’ of the optical network, and the highest ratio of the optical splitter. In the case of a BPON with the Enhancement Band allocated to CATV video, a 1:32 split is most common.

Section 15: MPEG PACKET TRANSPORT

This section contains a basic description of the structure of the data streams used for transport of Moving Picture Experts Group (MPEG) encoded video and audio data. A complete description can be found in ISO/IEC standard 13818-1 (Information technology – Generic coding of moving pictures and associated audio information: Systems), as amended.

The encapsulation of MPEG transport packets for transmission through IP-based networks is also outlined.

Notes on representation of numerical values:
Different numbering systems are identified by a suffix. ▪ A decimal number is identified by a subscript '10' ▪ A hexadecimal number is identified by a subscript '16' ▪ A binary number is identified by a subscript '2'

NOTE: A clear distinction must be made between an MPEG **program stream** and a **transport stream**. A program stream consists of a multiplexed stream of video or audio data, or both, which represents programming from a single source. It is intended primarily for use in error-free transmission environments, such as storage and retrieval of program material to/from a DVD or to/from a personal computer memory in the form of a .mpg file. This section deals exclusively with transport streams.

The result of MPEG-encoding of a video or an audio sequence is an **elementary stream,** which consists of **access units.** In the case of a video source, each access unit is an 'I', 'B' or a 'P' picture; for an audio source, each access unit consists of a short burst of compressed audio, typically a few tens of milliseconds in duration.

Elementary streams are then 'packetized' to produce **packet (or packetized) elementary streams (PES).** Within a PES, packets can contain compressed video or audio, but all represent programming from a single source. PES packets consist of a header and a payload, as shown in the figure on page 15-3. The payload can have any number of bytes up to a maximum of 64,000. The purpose and structure of the bytes in the header are as follows:

PES – packet start code

Identifies the beginning of a PES packet and always has the value 000001_{16}

Stream identifier

Identifies, and specifies the type of the data in the payload. This allows video and audio elementary streams within the same program to be distinguished from one another. 32 values are available for audio elementary streams and 16 for video.

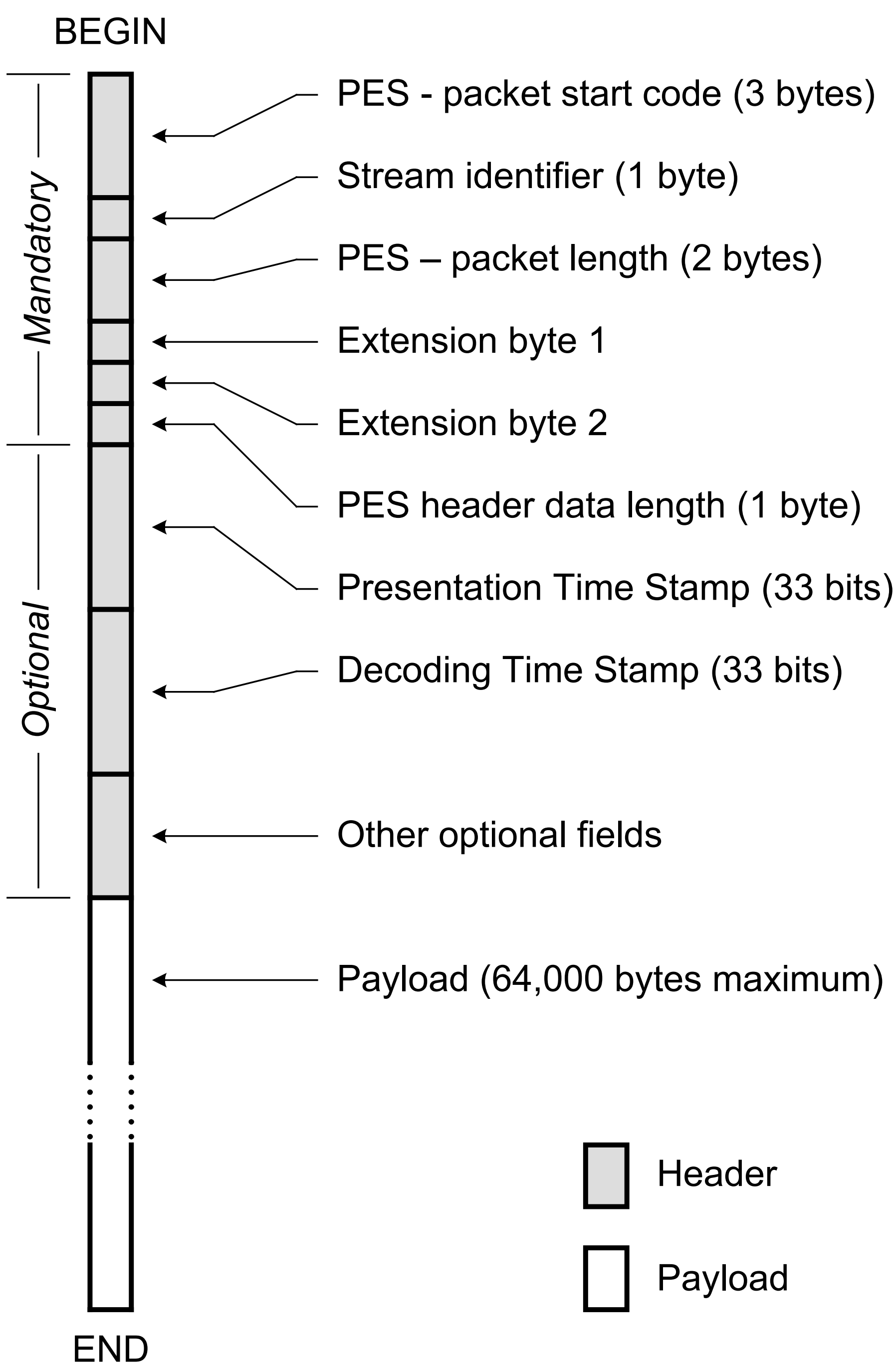
PES – packet length

Specifies the number of bytes remaining in the packet following this field.

Extension bytes 1 & 2

These fields (2 bytes total) contain flags, or 'indicator bits' to show which of several optional fields are included or excluded from the header. For example, the first two bits in extension byte 2 indicate whether the presentation time stamp or the decoding time stamp, or both, are present in the header (see the following figure). The first two bits of extension byte 1 are always set to 10_2.

Packet Elementary Stream (PES)



PES header data length

Indicates the total length of the header in bytes. This figure includes any extension (optional) fields, and stuffing bytes.

Presentation time stamp (PTS)

A 33-bit quantity, representing the number of ‘ticks’ of a 90 kHz clock. This quantity is compared with the system time clock (STC) and determines when a given presentation unit (the uncompressed version of an access unit) should be output.

Decoding time stamp (DTS)

Another 33-bit quantity, representing the number of ‘ticks’ of a 90 kHz clock. It applies only to PES packets that contain video elementary streams, and determines when a given access unit should be removed from its buffer and decoded.

Optional fields

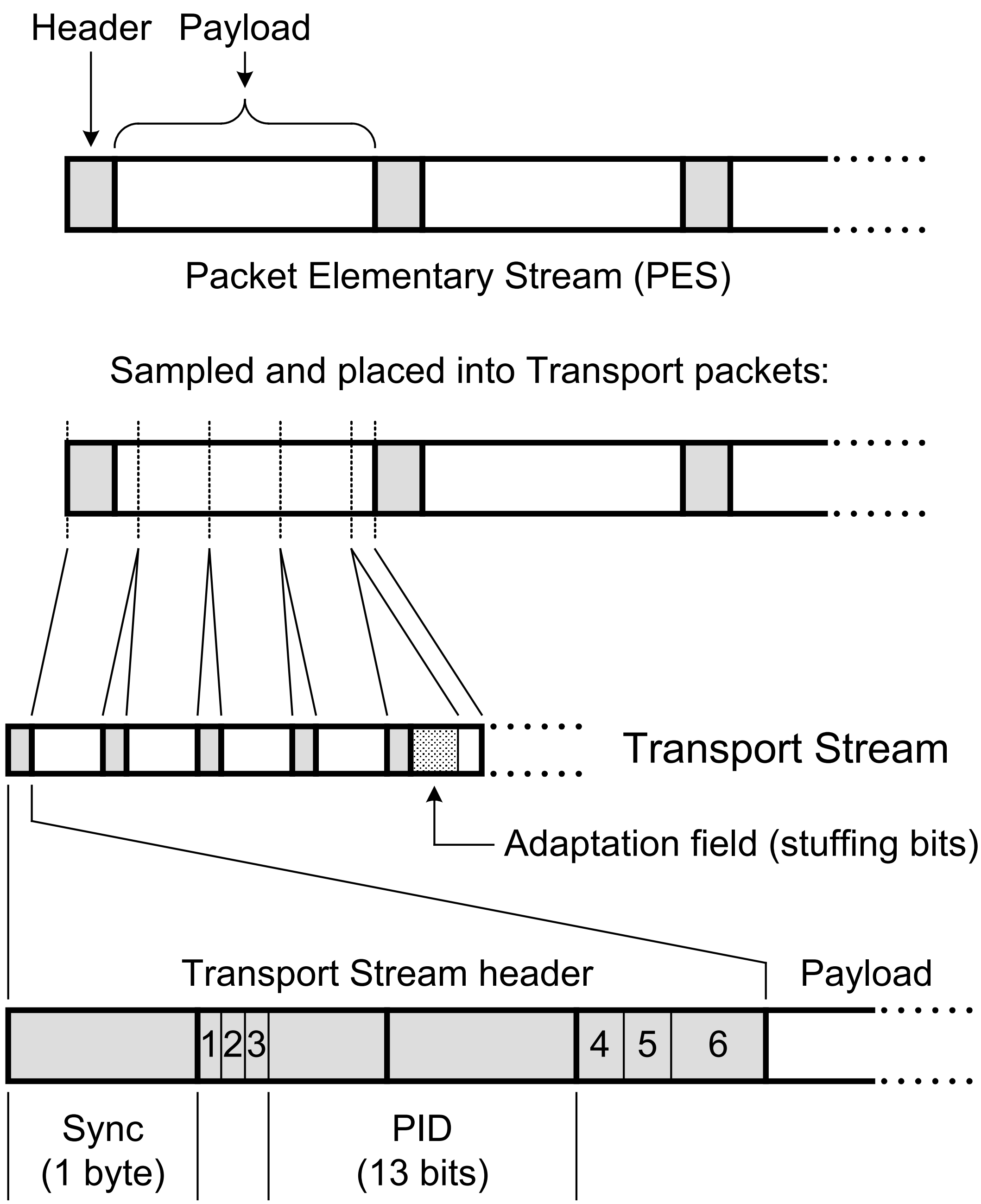
Additional information can be inserted in these fields, and its presence or absence is indicated by the flags in extension bytes 1 and 2. For example, if the **PES CRC** flag is ‘set’ in extension byte 2, a cyclic redundancy check is performed on the previous PES packet, using a 2-byte code inserted in the optional fields.

Stuffing bytes (FF_{16}) can also be inserted in the optional fields, but they must be added to all the other header bytes to compute the total PES header data length.

Payload

The payload, consisting of video or audio elementary streams of access units, can have any length up to a maximum of 64 kilobytes.

Formation of the transport Stream (TS)



The packet elementary streams are then divided into samples of 184 bytes, and placed into **transport stream (TS)** packets. Each TS packet has a header of 4 bytes, giving a total of 188 bytes for the packet.

This number of bytes was chosen because it would map into an ATM cell which, when using ATM adaptation layer type 1 (AAL 1) for constant bit-rate traffic, has a length of 47 bytes, and 4 x 47 = 188.

If a TS packet contains the last bytes of a PES packet, and not all 184 payload bytes are used, an **adaptation field** must be inserted to fill the TS packet payload. This adaptation field is placed at the beginning of the payload field and consists of stuffing bits (FF_{16}). Only one PES packet can start in any given TS payload field.

The first byte of a PES packet must become the first byte in a TS packet payload field.

The purpose and structure of the bytes in the TS header are as follows:

Sync – synchronizing burst

Consists of one byte, which always has the value 47_{16}.

Field 1

One bit: transport error indicator.

Field 2

One bit: payload unit start indicator. Indicates whether the data in the following payload field starts at the beginning of a PES packet.

Field 3

One bit: transport priority.

PID – Packet Identifier

Consists of 13 bits. The PID identifies the type of data carried in the following TS packet payload. The data, in most TS packets, will be a video or an audio PES, but it may also be a group of ‘pointers’ to other TS packets, or information regarding the structure and management of the overall transport stream. Certain values of PID are reserved for these special purposes.

Reserved PID values

With a field of 13 bits, the PID can have any one of 2^{13} values (8,192). ISO/IEC standard 13818-1 reserves 17 of these for special purposes, as follows:

PID value 0_{10}: program association table (PAT)

The program association table contains a complete list of all the programs carried in a transport stream, and the PID values of the TS packets that contain further information about each program. For example, if a hypothetical program called Interplanetary News has been assigned program number 20, then the PAT will contain an entry stating that further details of program 20 can be found in the packet that has a PID value of (for example) 300_{10}. These details are described in the following subsections. (See ‘Program Map Table’). The PAT is transmitted approximately once every 500 ms.

PID value 1_{10}: conditional access table (CAT)

If any of the elementary streams that are carried in the transport stream are scrambled, then this table must be present. It contains the PID values of TS packets where conditional access information can be found.

PID value 2_{10}: transport stream description table (TSDT)

This table provides information about the entire transport stream; for example, the type of target receiver (DVB, ATSC, etc.), or the kind of application, such as a satellite contribution link.

PID values 3_{10} to 15_{10}: reserved for future assignment

PID value 16_{10}: network information table (NIT)

This TS packet contains a pointer to the location of a unique program that is given the number 0. This program is the network information table, with a structure that can be defined by the network operator. It is optional, and can be used to give information on the physical structure of the network that carries the transport stream. For example, it may contain details of a satellite and a specific transponder, modulation scheme, etc.

The program association table, network information table, conditional access table, and program map table are referred to collectively as the **program specific information (PSI)**.

Field 4

Two bits: transport scrambling control.

Field 5

Two bits: adaptation field control.

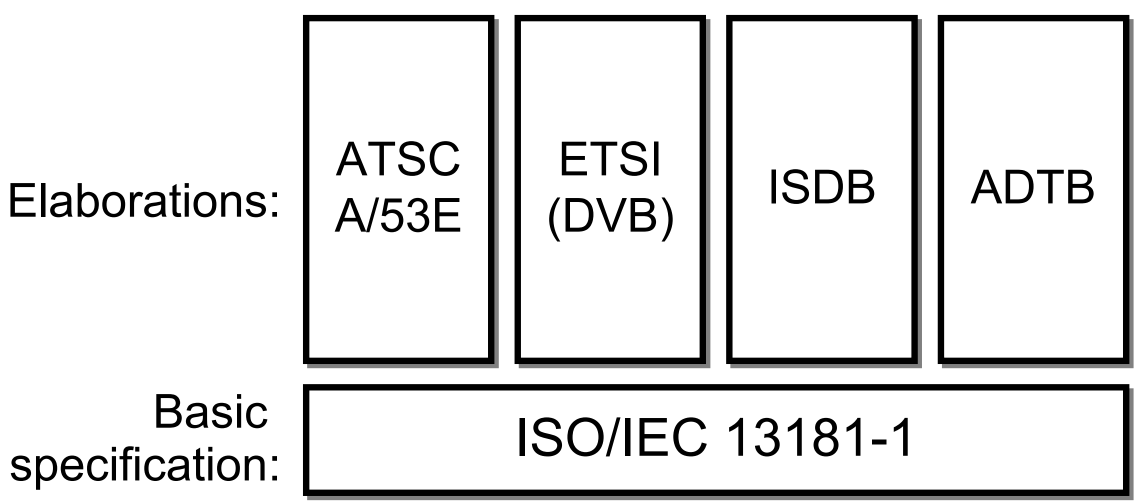
Field 6

Four bits: continuity counter. When more than one TS packet is required to carry a PES packet (that is, the PES packet is more than 184 bytes long), the continuity counter is incremented each time a block of the PES packet is encapsulated.

———————————————————

The ISO/IEC 13818-1 standard defines the 17 PID values just described. Other standards build upon this base and reserve additional PID values for specific purposes.

For example, the DVD standard ETSI EN 300 468 defines 15 further PID values. The following diagram shows the relation of the basic ISO/IEC standard to other, regional standards.



ATSC: Advanced Television Systems Committee. Applies in USA, Mexico, Canada, South Korea and Taiwan

ETSI: European Telecommunications Standards Institute. Applies in most other countries except:

ISDB: Integrated Services Digital Broadcasting (Japan and Brazil), and

ADBT: Advanced Digital Television Broadcasting (China)

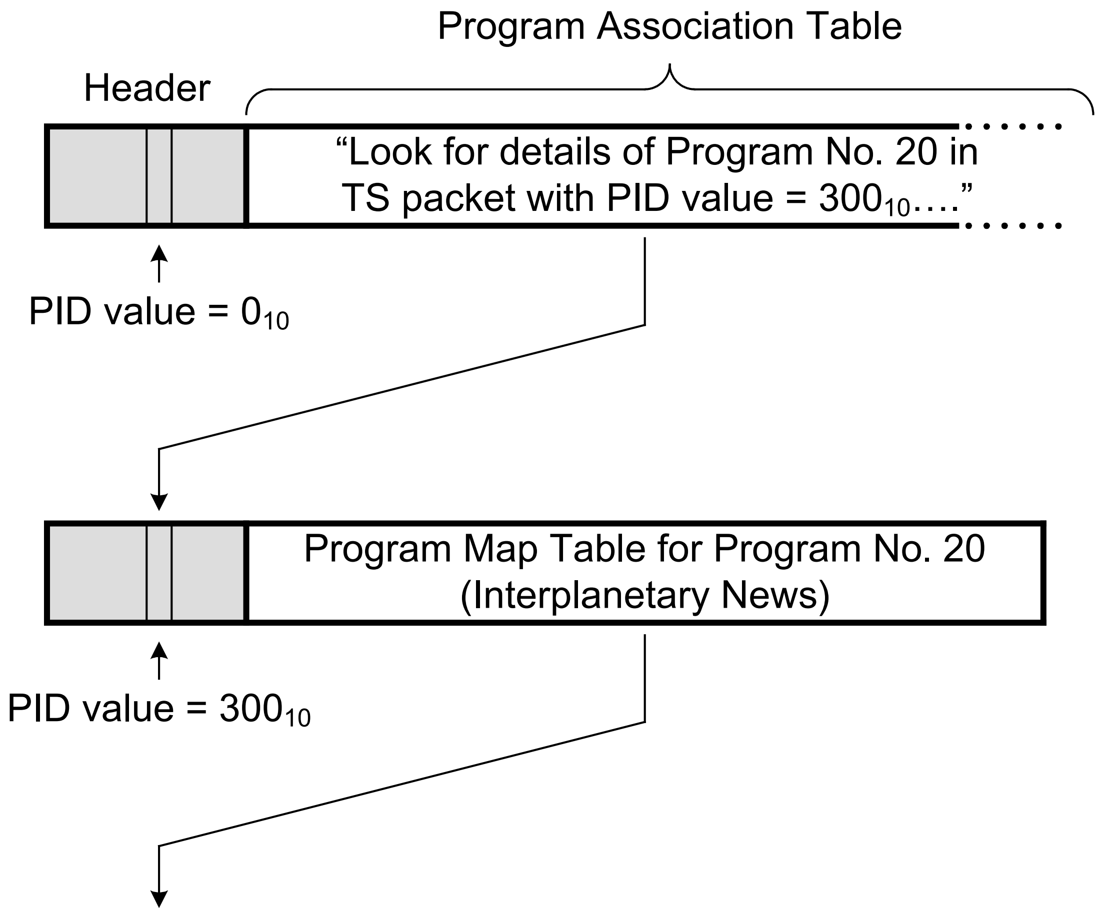
____

The program map table (PMT)

As stated previously, the transport stream packet with a PID value of 0_{10} contains the program association table (PAT).

The PAT contains ‘pointers’ to other TS packets which carry details of specific programs. These details are referred to as **program map tables.** The following diagram shows the relationships between the PAT, a typical PMT, and the program information.

Locating specific program details



PID for Program Clock Reference: 301

PID for Program 20 video: 302

PID for Program 20 audio channel 1 (English): 303

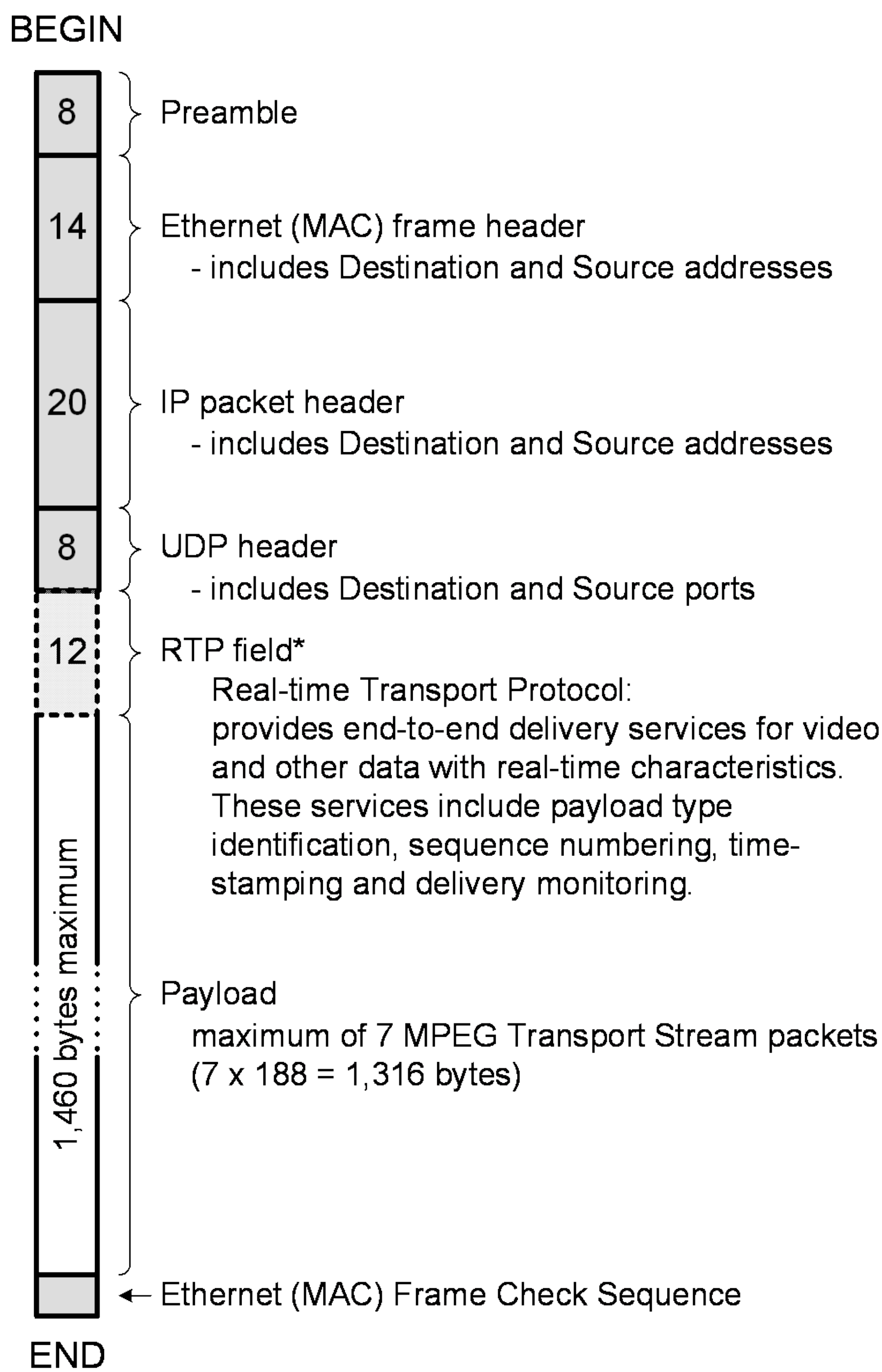
PID for Program 20 audio channel 2 (German): 304

PID for Program 20 audio channel 3 (Martian): 305

PID for Program 20 subtitles: 306

IP encapsulation

For transmission over an IP-based network which uses Ethernet as the Layer 2 protocol, MPEG TS packets are encapsulated as shown in the following diagram.



The function of each component of the entire Ethernet frame can be illustrated by considering the case of an MPEG transport stream that is being delivered to a multi-QAM modulator.

The physical (MAC address) of the multi-QAM device will be the destination address contained in the Ethernet frame header. Similarly, the IP address of the multi-QAM device will be the destination address in the IP packet header. The specific QAM modulator within the multi-QAM device will be identified by the UDP port number.

Section 16: OPTICAL WAVELENGTH DESIGNATIONS

The range of wavelengths available for optical communication via single-mode fiber today is divided into five bands, as shown in Figure 16-1. The ‘O’ (original) and ‘C’ (conventional) bands are the most frequently used, and are commonly referred to as the 1310 nm and 1550 nm bands, respectively.

Complete designations are as follows:

O-band:	Original
E-band:	Extended
S-band:	Short
C-band:	Conventional
L-band:	Long

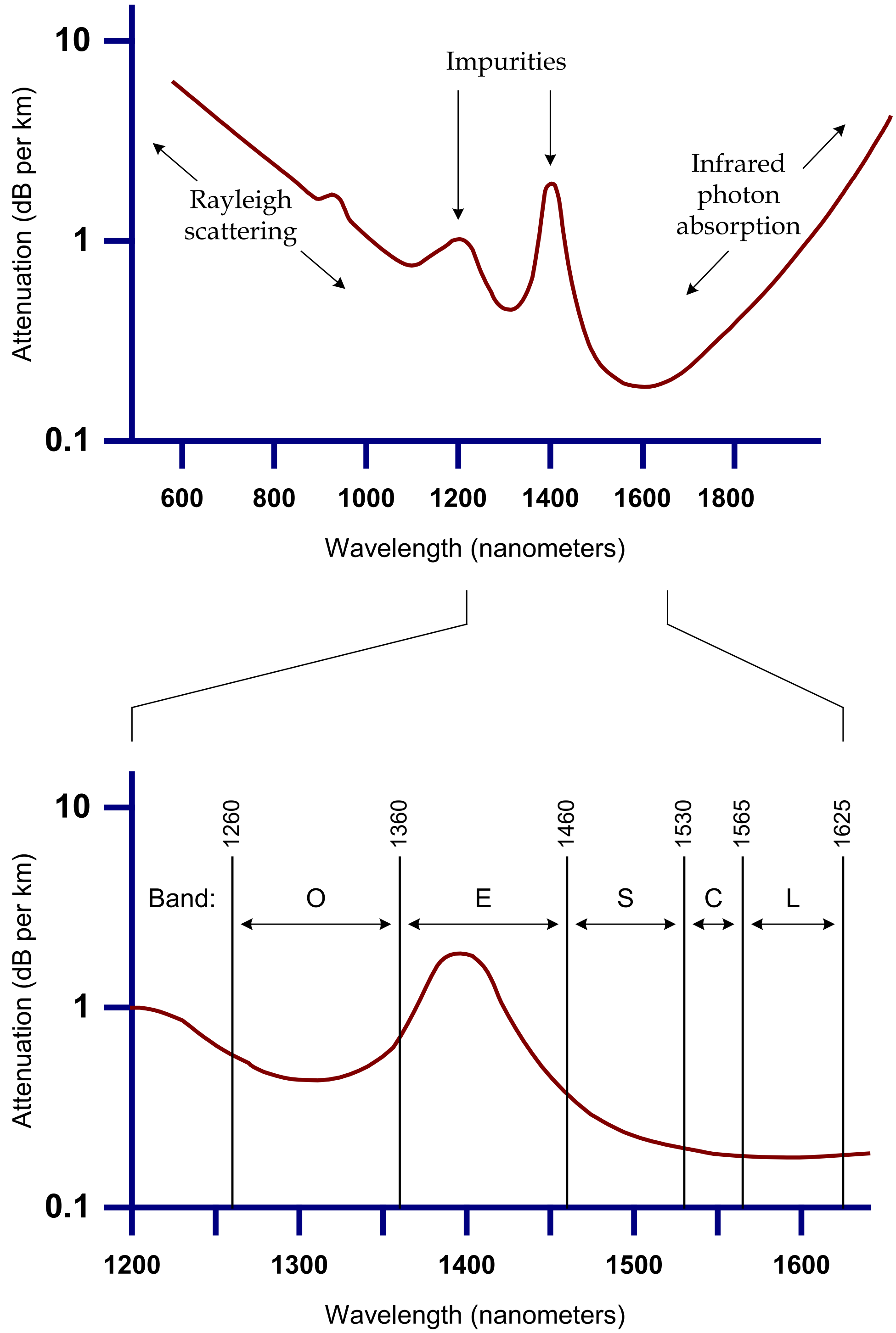
The C- and L-bands are divided into ‘red’ and ‘blue’ sections, as follows:

C-band, blue:	1525 nm to 1544 nm
C-band, red:	1547 nm to 1565 nm

L-band, blue:	1560 nm to 1584 nm
L-band, red:	1588 nm to 1620 nm

Optical channels for DWDM systems are defined by the ITU (International Telecommunications Union) in their standard G.692 (“Optical Interfaces for Multichannel Systems with Optical Amplifiers”). The channel designations are based on the frequency of the optical signal, given in terahertz (THz, or 10^{12} hertz).

In Table 16-1, the most commonly used ITU-grid channels are given. (The standard includes channels in large sections of the L- and S-bands, but they are seldom encountered in the broadband industry). It should be noted that although most manufacturers supply optical components that operate at increments of either 100 GHz or 200 GHz, a 50 GHz spacing is also possible. The table also shows the channels offered in the Cisco digital and analog optical transmission products for HFC applications.



Note: the attenuation curve represents the characteristics of SMF-28 fiber, which is most commonly encountered in existing broadband networks

Figure 16-1: Fiberoptic transmission bands

Optical wavelength designations (cont'd)

Channel No.	Frequency (THz)	Wavelength (nm)	2:1 EDR™ in Prisma II chassis or GS7000 node	Analog upstream transmitters for GS7000 and GM nodes	Analog upstream transmitters in Prisma II chassis	QAM transmitter in Prisma II chassis	iWDM Tx wavelenghts (Best 16)	iWDM Tx wavelenghts (Best 12)	iWDM Tx wavelenghts (Best 8)	iWDM Tx wavelenghts (Best 4)	iWDM Tx wavelenghts (Best top 4)	iWDM Tx wavelenghts (Best bottom 4)
10	191.0	1569.59										
11	191.1	1568.77										
12	191.2	1567.95										
13	191.3	1567.13										
14	191.4	1566.31										
15	191.5	1565.50										
16	191.6	1564.68										
17	191.7	1563.86	✓									
18	191.8	1563.05	✓									
19	191.9	1562.23	✓	✓								
20	192.0	1561.42	✓	✓		✓						
21	192.1	1560.61	✓	✓	✓	✓	✓					
22	192.2	1559.79	✓	✓		✓	✓	✓	✓	✓	✓	
23	192.3	1558.98	✓	✓	✓	✓						
24	192.4	1558.17	✓	✓		✓	✓					
25	192.5	1557.36	✓	✓	✓	✓						
26	192.6	1556.55	✓	✓		✓	✓	✓				
27	192.7	1555.75	✓	✓	✓	✓						
28	192.8	1554.94	✓	✓		✓	✓	✓	✓		✓	
29	192.9	1554.13	✓	✓	✓	✓						
30	193.0	1553.33	✓	✓		✓						
31	193.1	1552.52	✓	✓	✓	✓						
32	193.2	1551.72	✓	✓		✓						
33	193.3	1550.92	✓	✓	✓	✓	✓	✓	✓	✓	✓	
34	193.4	1550.12	✓	✓		✓						
35	193.5	1549.32	✓	✓	✓	✓						
36	193.6	1548.51	✓	✓		✓	✓	✓				

Table 16-1: ITU-grid DWDM channels

Channel No.	Frequency (THz)	Wavelength (nm)	2:1 EDR™ in Prisma II chassis or GS7000 node	Analog upstream transmitters for GS7000 and GM nodes	Analog upstream transmitters in Prisma II chassis	QAM transmitter in Prisma II chassis	iWDM Tx wavelenghts (Best 16)	iWDM Tx wavelenghts (Best 12)	iWDM Tx wavelenghts (Best 8)	iWDM Tx wavelenghts (Best 4)	iWDM Tx wavelenghts (Best top 4)	iWDM Tx wavelenghts (Best bottom 4)
37	193.7	1547.72	✓	✓	✓	✓						
38	193.8	1546.92	✓	✓		✓						
39	193.9	1546.12	✓	✓	✓	✓	✓	✓	✓		✓	
40	194.0	1545.32	✓	✓		✓						
41	194.1	1544.53	✓	✓	✓	✓						
42	194.2	1543.73	✓	✓		✓						
43	194.3	1542.94	✓	✓	✓	✓						
44	194.4	1542.14	✓	✓		✓	✓	✓	✓			✓
45	194.5	1541.35	✓	✓	✓	✓						
46	194.6	1540.56	✓	✓		✓						
47	194.7	1539.77	✓	✓	✓	✓						
48	194.8	1538.98	✓	✓		✓	✓	✓	✓			✓
49	194.9	1538.19	✓	✓	✓	✓						
50	195.0	1537.40	✓	✓		✓						
51	195.1	1536.61	✓	✓	✓	✓						
52	195.2	1535.82	✓	✓		✓	✓	✓	✓	✓		✓
53	195.3	1535.04	✓	✓	✓	✓						
54	195.4	1534.25	✓	✓		✓	✓					
55	195.5	1533.47	✓	✓	✓	✓						
56	195.6	1532.68	✓	✓		✓						
57	195.7	1531.90	✓	✓	✓	✓	✓	✓				
58	195.8	1531.12	✓	✓		✓						
59	195.9	1530.33	✓	✓	✓	✓						
60	196.0	1529.55	✓				✓	✓				
61	196.1	1528.77	✓				✓					
62	196.2	1527.99					✓	✓	✓	✓		✓

Table 16-1 (continued): ITU-grid DWDM channels

Optical wavelength designations (cont'd)

The frequency and the wavelength of an optical signal are related by the approximate formulas:

$$\text{Wavelength (in nm)} = \frac{299800}{\text{Frequency (in THz)}}$$

$$\text{Frequency (in THz)} = \frac{299800}{\text{Wavelength (in nm)}}$$

It may also be noted that the channel number can be derived from the frequency by taking the 'units' and the 'tenths' from the frequency in terahertz. For example:

Channel 59 is at a frequency of 19[5].[9] THz, and

Channel 37 is at a frequency of 19[3].[7] THz

Section 17: HFC PERFORMANCE CALCULATIONS

This section provides definitions and methods of calculation for the two principal classes of signal impairment in HFC systems: non-linear distortions and noise.

The products of non-linear distortions are discussed in terms of their creation by, and their effects upon standard analog video signals, and therefore this information is relevant only to HFC systems which carry a significant number of such signals. Digital (QAM) signals also generate non-linear distortion products and can be impaired by them; but these products, unlike the clusters of ‘beats’ generated by analog signals, appear indistinguishable from noise and so cannot be identified and measured independently from noise using available instrumentation. It is common practice for manufacturers to describe the effects of adding a digital ‘tier’ in terms of the apparent increase in noise across the spectrum.

Thermal noise is an intrinsic property of the system, and so can be described by its effect on both analog and digital (QAM) signals in terms of the carrier-to-noise ratio (CNR).

Non-Linear Distortions: definitions

Composite Triple Beat (CTB)

‘Triple beat’ distortion components result from harmonics and interactions of the form:

$3f_1$
$f_1 \pm f_2 \pm f_3$
$2f_1 + f_2$
$2f_1 - f_2$

where f_1, f_2 and f_3 are the frequencies of any three input signals. It will be seen that, in a large-capacity network, the number of such combinations which fall inside the network pass-band is very large.

The totality of all the spurious signals that result from these combinations is referred to as the composite triple beat, and triple-beat groupings generally lie at, or close to, the video carriers.
Therefore:

> Composite triple beat is defined as the ratio (in decibels) of the visual carrier peak envelope power to the peak of the aggregate distortion signal lying at the visual carrier frequency.

This parameter is measured with unmodulated visual carriers, and with the carrier in the channel of interest turned off.

Broadband equipment manufacturers specify the CTB performance of their amplifiers at a specific output level. Changing the output level by raising or lowering the level at the inputs of the internal gain blocks will cause the CTB to change.

Composite Second Order (CSO)

Another category of unwanted signal components produced by an amplifier consists of the 'second order' beat components, which result from harmonics and interactions of the form:

$2f_1$
$f_1 + f_2$
$f_1 - f_2$

where f_1 and f_2 are the frequencies of any two input signals. The number of such combinations in a large-capacity network is less than that produced by third-order distortions, but is nevertheless significant. The totality of all the spurious signals that result from these combinations is referred to as the composite second order beat, and CSO groupings generally lie at either 0.75 or 1.25 MHz above and below the visual carriers. Therefore:

> Composite second order is defined as the ratio (in decibels) of the visual carrier peak envelope power to the peak of the aggregate distortion signal lying at ±0.75 MHz or ±1.25 MHz relative to the visual carrier frequency.

This parameter is measured with unmodulated visual carriers.

As in the case of composite triple beat, broadband equipment manufacturers specify the CSO performance of their amplifiers at a specific output level.

Cross Modulation (XMOD)

Non-linearities in amplifiers also give rise to cross modulation, which is the unwanted modulation of any particular visual carrier by the signals being carried in other channels in the system. Because each video channel contains a constant, high-level signal component at the horizontal line frequency (15.734 kHz in the NTSC system), this is the most noticeable component of cross modulation. Therefore:

> Cross modulation is defined as the ratio of the peak-to-peak amplitude of the modulation, on the test carrier (caused by the signals on other carriers), to the peak level of the carrier.

It is usually measured on an unmodulated carrier, with all other carriers in the system being synchronously modulated to a depth of 100% by a square-wave at the horizontal line-rate.

The cross modulation performance of a single amplifier is specified at a given output level, and changes as that level is raised or lowered.

Hum Modulation

This form of distortion is a result of the unwanted modulation of a particular visual carrier by components of the system power supply. Therefore:

> Hum modulation is defined as the ratio (in decibels) of the peak visual carrier power to the peak of the unwanted modulation sidebands at 50 Hz or 60 Hz and harmonics (depending on power-line frequency), relative to the visual carrier frequency.

In practice, hum modulation is measured as the percentage depth of modulation of a visual carrier, using an oscilloscope, then converted to decibels.

To convert percentage modulation to decibels:

$$\text{Hum modulation in dB} = 20 \times \log\left(\frac{M}{100}\right)$$

Where M = modulation depth expressed as a percentage.

Non-Linear Distortions: single amplifier performance

Effect of Changing Output Level

If amplifier output level is changed, but tilt remains as specified in the manufacturer's recommendations, then the following modifications to amplifier performance must be made:

$$CTB_{new} = CTB_{ref} - 2 \times (L_{new} - L_{ref})$$ *(CTB given as a positive number)*

Where CTB_{new} = new composite triple beat, and
CTB_{ref} = reference (old) composite triple beat

$$CSO_{new} = CSO_{ref} - (L_{new} - L_{ref})$$ *(CSO given as a positive number)*

Where CSO_{new} = new composite second order, and
CSO_{ref} = reference (old) composite second order

$$XMOD_{new} = XMOD_{ref} - 2 \times (L_{new} - L_{ref})$$ *(XMOD given as a positive number)*

Where $XMOD_{new}$ = new cross modulation, and
$XMOD_{ref}$ = reference (old) cross modulation

Thus, it can be seen that all distortions are worsened when amplifier output level is raised.

Effect of Changing Tilt

If amplifier tilt is changed, but output level at the high-frequency end of the spectrum remains as specified in the manufacturer's recommendations, then modifications to amplifier performance must be made. *The following formulas are based on empirical data.* In all cases, 'tilt' is assumed to be positive; that is, the signal level at the high-frequency end of the spectrum is greater than that at the low-frequency end. An increase in tilt is therefore equivalent to a decrease in the signal level at the low-frequency end.

$$CTB_{new} = CTB_{ref} + 0.8 \times (T_{new} - T_{ref})$$ *(CTB given as a positive number)*

Where CTB_{new} = new composite triple beat, and
CTB_{ref} = reference (old) composite triple beat

$$CSO_{new} = CSO_{ref} + 0.33x(T_{new} - T_{ref})$$

(CSO given as a positive number)

Where CSO_{new} = new composite second order, and
CSO_{ref} = reference (old) composite second order

$$XMOD_{new} = XMOD_{ref} + 0.5x(T_{new} - T_{ref})$$

(XMOD given as a positive number)

Where $XMOD_{new}$ = new cross modulation, and
$XMOD_{ref}$ = reference (old) cross modulation

In summary, all distortions are improved when amplifier output tilt is increased.

Non-Linear Distortions: cascade performance

Identical Amplifiers and Operating Levels

For a cascade of identical amplifiers, all operating with the same output level and tilt, end-of-line (EOL) performance can be easily calculated as follows:

For composite second order,

$$CSO_{EOL} = CSO_{AMP} - 10x\log(N)$$

(CSO is given as a positive number)

Where N = number of amplifiers in cascade

For composite triple beat, cross modulation and hum modulation,

$$CTB_{EOL} = CTB_{AMP} - 20x\log(N)$$
$$XMOD_{EOL} = XMOD_{AMP} - 20x\log(N)$$
$$HMOD_{EOL} = HMOD_{AMP} - 20x\log(N)$$

(CTB, XMOD and HMOD given as positive numbers)

Dissimilar Amplifiers and/or Operating Levels

When calculating the end-of-line performance for a cascade of different amplifier types, or identical amplifiers which operate with different output levels and tilts, a more complex calculation is required.

For composite second order,

$$\text{CSOEOL} = -10\,\text{x}\log\left[10^{\left(\frac{-CSO_1}{10}\right)}+10^{\left(\frac{-CSO_2}{10}\right)}+10^{\left(\frac{-CSO_3}{10}\right)}+\bullet\bullet\right]$$

Where CSO1, CSO2, CSO3 etc. are the composite second order performance figures for the separate amplifiers in the cascade.

NOTE: It is assumed that CSO is expressed in positive numbers.

And,

For composite triple beat, cross modulation and hum modulation,

$$\text{CTBEOL} = -20\,\text{x}\log\left[10^{\left(\frac{-CTB_1}{20}\right)}+10^{\left(\frac{-CTB_2}{20}\right)}+10^{\left(\frac{-CTB_3}{20}\right)}+\bullet\bullet\right]$$

$$\text{XMODEOL} = -20\,\text{x}\log\left[10^{\left(\frac{-XMOD_1}{20}\right)}+10^{\left(\frac{-XMOD_2}{20}\right)}+10^{\left(\frac{-XMOD_3}{20}\right)}+\bullet\bullet\right]$$

$$\text{HMODEOL} = -20\,\text{x}\log\left[10^{\left(\frac{-HMOD_1}{20}\right)}+10^{\left(\frac{-HMOD_2}{20}\right)}+10^{\left(\frac{-HMOD_3}{20}\right)}+\bullet\bullet\right]$$

Where are the CTB, XMOD and HMOD performance figures for the separate amplifiers in the cascade.

NOTE: It is assumed that CTB, XMOD and HMOD are expressed as positive numbers.

Noise: definition

All amplifiers generate noise, and a broadband network is also susceptible to noise from external sources. The combined noise level is measured relative to video carrier level:

Carrier-to-noise ratio (CNR) is defined as the ratio (in decibels) of the visual carrier peak envelope power to the average noise power, normalized to a specified bandwidth.

The noise performance of a single amplifier is most commonly specified as the noise figure:

To convert noise figure (NF) to CNR:

$$CNR = 65.2 - 10.\log(\Delta f) + L_i - NF$$

Where Δf = measurement bandwidth in MHz

L_i = amplifier input level (dBmV)

and the temperature is assumed to be 68 °F (20 °C)

Values of Δf for a number of different television systems are as follows:

System	I	B, G	K1, L	M, N
Video bandwidth*	6.75	5.75	7.25	4.95
Noise measurement bandwidth	5.08	4.75	5.58	4.00

* Includes lower sideband

Example: for an amplifier with a noise figure of 9 dB and an NTSC input signal at a level of +20 dBmV, the resultant CNR at 68 °F is
65.2 - 6 + 20 – 9 = 70.2 dB (always expressed as a positive quantity, in dB).

Noise: single amplifier performance

Effect of Changing Output Level

If amplifier output level is changed, but tilt remains as specified in the manufacturer's recommendations, then the following modifications to amplifier performance must be made:

$$CNR_{new} = CNR_{ref} + (L_{new} - L_{ref})$$

(CNR given as a positive number)

Where CNR_{new} = new carrier-to-noise ratio;
CNR_{ref} = reference (old) carrier-to-noise ratio;
L_{new} = new amplifier output level, and
L_{ref} = reference (old) amplifier output level

Thus, it can be seen that carrier-to-noise ratio is improved when amplifier output level is raised.

Effect of Changing Tilt

If amplifier tilt is changed, but output level at the high-frequency end of the spectrum remains as specified in the manufacturer's recommendations, then modifications to amplifier performance must be made. 'Tilt' is assumed to be positive; that is, the signal level at the high-frequency end of the spectrum is greater than that at the low-frequency end. An increase in tilt is therefore equivalent to a decrease in the signal level at the low-frequency end.

Carrier-to-noise ratio at the high frequency end of the spectrum remains unchanged. At the low-frequency limit,

$$CNR_{new} = CNR_{ref} - (T_{new} - T_{ref})$$

(CNR given as a positive number)

CNR_{new} = new carrier-to-noise ratio;
CNR_{ref} = reference (old) carrier-to-noise ratio;
T_{new} = new amplifier output tilt, and
T_{ref} = reference (old) amplifier output tilt.

In summary, carrier-to-noise ratio at low frequencies is worsened when amplifier output tilt is increased.

Noise: amplifier cascade performance

Identical Amplifiers and Operating Levels

For a cascade of identical amplifiers, all operating with the same output level and tilt, end-of-line performance can be easily calculated as follows:

$$CNR_{EOL} = CNR_{AMP} - 10x\log(N)$$ *(CNR given as a positive number)*

Where N = number of amplifiers in cascade

Dissimilar Amplifiers and/or Operating Levels

When calculating the end-of-line performance for a cascade of different amplifier types, or identical amplifiers which operate with different output levels and tilts, a more complex calculation is required:

$$CNREOL = -10x\log\left[10^{\left(\frac{-CNR_1}{10}\right)}+10^{\left(\frac{-CNR_2}{10}\right)}+10^{\left(\frac{-CNR_3}{10}\right)}+\bullet\bullet\right]$$

Where CNR_1, CNR_2, CNR_3 etc. are the carrier-to-noise performance figures for the separate amplifiers in the cascade.

Noise in Optical Links

This sub-section provides formulas for the calculation of CNR in optical systems. The contribution of optical amplifiers (EDFAs) is given, but of course would be excluded in 1310 nm systems. Worked examples are also presented.

Laser Noise

The relative intensity noise (RIN) produced by a laser is caused by the spontaneous emission of photons, and results in the production of non-coherent light.

The CNR due to laser RIN is given by the formula:

$$CNR_{RIN} = \frac{m^2}{2.B.(RIN)}$$

where
m is the single-channel modulation index, and
B is the noise measurement bandwidth (4 MHz for NTSC systems)

In decibel notation,

CNR_{RIN} = 20.log(m) – 10.log(2.B) – (RIN)

With a typical loading of 78 NTSC channels and 33 QAM signals, the per-channel OMI will be 3.58% (=0.0358). Therefore,

CNRRIN = 20.log(0.0358) – 10.log(8.106) – (RIN)

and for a typical laser the RIN is −160 dB/Hz, therefore

CNRRIN = -97.95 + 160 = 62.05 dB

EDFA Noise

Noise in an optical amplifier is also produced by the spontaneous emission of photons, and is referred to as amplified spontaneous emission (ASE).

The CNR due to ASE is given by the formula:

$$CNR_{EDFA} = \frac{SNR_{IN}.m^2}{2.B.F}$$

where
SNR_{IN} is the amplifier input signal-to-noise ratio, and
F is the amplifier noise factor.

The input signal-to-noise ratio is given by: $SNR = \frac{\lambda.P_{IN}}{2.h.c}$

Laser Noise (cont'd)

where
λ is the laser wavelength in meters,
P_{IN} is the EDFA optical input power in watts,
h is Planck's constant (6.63×10^{-34} J.s), and
c is the velocity of light (3×10^{8} $m.s^{-1}$)

Therefore SNRIN = $\frac{(1.55 \times 10^{-6}).P_{IN}}{2.(6.63 \times 10^{-34}).(3 \times 10^{8})} = (3.896 \times 10^{18}).P_{IN}$

If the bandwidth (B) is 4 MHz, then CNREDFA = $\frac{(4.87 \times 10^{11}).m^{2}.P_{IN}}{F}$

The EDFA noise factor (F) is obtained from the noise figure (NF) by the identity NF = 10·log(F). Then, converting to decibel notation, and bearing in mind that 'dBm' is referenced to milliwatts,

CNREDFA = 116.87 + 20.log(m) + PIN – 10·log(103) – NF

EDFA Noise (cont'd)

A value of the noise figure for a typical EDFA is 5.5 dB, with an optical input power of +5 dBm, and with m = 0.0358,

CNREDFA = 116.87 – 28.9 + 5 – 30 – 5.5 = 57.47 dB

Receiver Noise

Step 1: determination of receiver responsivity

The responsivity, ρ, of a receiver in amperes per watt is given by

$$\rho = \frac{\eta . q . \lambda}{h.c}$$

where
η is the quantum efficiency of the detector,
q is the electron charge in coulombs,
λ is the wavelength in meters,
h is Planck's constant (6.63×10^{-34} J.s), and
c is the velocity of light (3×10^{8} $m.s^{-1}$)

Assuming a typical value for η of 0.8, the responsivity will be

$$\rho = \frac{0.8 \times (1.60 \times 10^{-19}).(1.55 \times 10^{-6})}{(6.63 \times 10^{-34}).(3 \times 10^{8})} = \underline{1.0 \ A.W^{-1}}$$

Step 2: determination of receiver shot noise

The receiver shot noise is due to the random occurrence of photons and electrons and is given by:

$$CNR_{shot} = \frac{m^2 . \rho . P_{IN}}{4 . q . B}$$

where ρ is the receiver responsivity, as determined in Step 1, and
m, P_{IN}, q, and B are as previously defined.

Then CNRshot = $$\frac{m^2 .(1.0).P_{IN}}{4.(1.6 \times 10^{-19}).(4 \times 10^{6})} = (3.91 \times 10^{11}).m^2 .P_{IN}$$

Receiver noise (cont'd)

Expressed in decibel notation, and recalling that 'dBm' is referenced to milliwatts,

CNRshot = 115.92 + 20.log(m) + PIN – 10.log(103)

For a typical input power of 0 dBm, and a per-channel modulation index of 0.0358,

CNRshot = 57.0 dB

Step 3: determination of receiver thermal noise

The receiver thermal noise is generated in the resistor and amplifier following the detector, and is given by:

$$CNR_{therm} = \frac{(m.\rho.P_{IN})^2}{2.i_n^2.B}$$

where i_n^2 is the 'thermal noise equivalent current' of the amplifier, and m, ρ, P_{IN}, and B are as previously defined.

The thermal noise in the amplifier immediately following the photodetector is characterized by a quantity called the 'thermal noise equivalent current'; it has the dimensions of picoamperes per √Hz, or $pA.Hz^{-½}$

In the formula just given, however, the current is assumed to be expressed in amperes, and so a factor of 10^{-12} must be included. A typical value for a transimpedance amplifier with a GaAsFET input stage is 7.0 $pA.Hz^{-½}$

Using the values of ρ and B from previous pages,

$$CNRtherm = \frac{m^2.(1.0)^2.P_{IN}^2}{2.(7.0 \times 10^{-12})^2.(4 \times 10^6)} = (2.55 \times 10^{15}).m^2.P_{IN}^2$$

If P_{IN} is expressed in dBm, then for P_{IN}^2 a correction factor of 10^{-6} must be included. If the modulation index is 0.0358, and the optical input power is 0 dBm, then, in decibel notation:

CNRtherm = 10.log(2.55 x 1015) + 20.log(0.0358) + 0 – 10.log(106)
= 65.14 dB

Overall Noise

The CNR for a complete optical link can then be calculated by combining the figures for the transmitter, the optical amplifier and the receiver:

CNRtotal =

$$10.\log\left[10^{-\left(\frac{CNR_{RIN}}{10}\right)}+10^{-\left(\frac{CNR_{EDFA}}{10}\right)}+10^{-\left(\frac{CNR_{shot}}{10}\right)}+10^{-\left(\frac{CNR_{therm}}{10}\right)}\right]$$

Using the examples given above, the overall CNR would be:

$$10.\log\left(10^{-6.205}+10^{-5.747}+10^{-5.700}+10^{-6.361}\right)=10.\log\left(4.84\,x\,10^{-6}\right)$$

= <u>53.15 dB</u>

> NOTE: When calculating CNR in a multi-wavelength system, the CNR is calculated separately for each wavelength. The 'optical power' referred to in the previous formulas refers to the power of a single wavelength, not the aggregate power.

Combined performance of optical and RF systems

So far in this section it has been assumed that, in order to calculate the combined effect of noise and distortions from many individual active devices, either a '10 x log' or a '20 x log' combining rule should be used, depending on the parameter under consideration. Specifically:

CNR and CSO: Combine on a '10 x log' basis
CTB, XMOD and HMOD: Combine on a '20 x log' basis

When the combined performance of optical and RF links must be calculated, it is clear that CNR should be computed on a '10 x log' basis, but there can be disagreement regarding the rules for distortions. (For example, '15 x log' for CTB). <u>This should be kept in mind when comparing calculations from different sources</u>.

Composite power calculations

Composite power of 'tilted' signals

For a group of N uncorrelated signals, whose power, expressed in logarithmic units, varies linearly from the lowest to the highest, so that the difference between the lowest and the highest (the tilt) is T, with the highest designated as P_H,

the total power, P_T, is given by:

$$P_T = P_H - T - 10.\log\left\{\frac{1- 10^{N.i}}{1- 10^{i}}\right\}$$

Where
PT and PH are expressed in dBm or dBmV, and $i = \frac{T}{10.(N-1)}$

Example:
An RF amplifier has an output consisting of 78 analog video signals, with the highest-frequency signal at a level of 48 dBmV. The tilt is 10 dB.

The value of "i" is $\frac{10}{10.(78-1)} = 0.01299$

and the total power is $48 - 10 - 10.\log\left\{\frac{1 - 10^{(78 \times 0.01299)}}{1 - 10^{(0.01299)}}\right\} \cong 62.9$ dBmV

Conversely, the power of the highest or lowest-frequency signal can be calculated from the aggregate power and the tilt. The equation above can be re-arranged thus:

$$P_H = P_T + T - 10.\log\left\{\frac{1- 10^{N.i}}{1- 10^{i}}\right\}$$

Example:
An EDFA has a total output power of 17 dBm, consisting of 8 ITU wavelengths. The power of the signal at the shortest wavelength is 2 dB less than that of the signal at the longest wavelength.

The value of "i" is $\frac{2}{10.(8-1)} = 0.02857$

The power of the signal at the longest wavelength is

$$17 + 2 - 10.\log\left\{\frac{1 - 10^{(8 \times 0.02857)}}{1 - 10^{(0.02857)}}\right\} \cong 8.9 \text{ dBm}$$

Adjustments to optical transmitter input levels for different analog/digital channel mixtures

The data sheets that describe the performance of Cisco optical transmitters include recommended signal input levels for various ‘reference’ channel lineups of analog and digital (QAM) signals. If the actual lineup differs from these references, it is possible to calculate new input levels that will maintain optimized noise and/or distortion performance.

The general principle is that the aggregate power at the input should remain unchanged. This is applicable to both direct and indirectly modulated transmitters. However, the following points should be noted:

1. The noise and distortion performance of the optical link, when the new signal levels are applied, may not precisely match the figures in the data sheet, particularly when the new channel lineup is significantly different from the reference lineup.

2. Some optical transmitters (e.g., the ‘SuperQAM’ transmitters), can be programmed to optimize their performance for different numbers of input channels. In such cases, the calculations presented on the next page should not be used to determine new input levels.

3. It is assumed that the signal spectra of the analog and the digital channels at the transmitter input are ‘flat’; that is, all analog signals are equal in level, and all digital signals are equal in level.

The <u>change</u> in the input level (measured by taking any single analog or digital signal) is given by the equation:

$$P_C = 10.\log\left[N_{A1}.10^{\left(\frac{d}{10}\right)} + N_{D1}.10^{\left(\frac{m}{10}\right)}\right] - 10.\log\left[N_{A2}.10^{\left(\frac{d}{10}\right)} + N_{D2}.10^{\left(\frac{m}{10}\right)}\right]$$

Where

N_{A1} is the number of analog channels in the reference lineup,
N_{D1} is the number of digital channels in the reference lineup,
N_{A2} is the number of analog channels in the new lineup,
N_{D2} is the number of digital channels in the new lineup,
d is the difference in level between analog and digital signals, and
m is the average reduction in power of an analog carrier when video modulation is applied.

In almost all cases, d = 6 dB. Repeated measurements have shown that "m" is approximately equal to 3 dB, with 'live' video.

Example:
For a Cisco 1310 nm Prisma II optical transmitter, an input level (analog carrier) of 15 dBmV is recommended, when the traffic consists of 78 analog channels and 75 digital (QAM) channels.

The actual traffic will consist of 30 analog channels and 123 digital channels. The change in input level is then:

$$P_C = 10.\log\left[78.10^{(0.6)} + 75.10^{(0.3)}\right] - 10.\log\left[30.10^{(0.6)} + 123.10^{(0.3)}\right]$$

$$= 10.\log[460.168] - 10.\log[364.849]$$

$$= 1.01 \text{ dB}$$

In other words, the input level (as measured by one analog or one digital signal) can be increased by about 1 dB.

If “d” is always equal to 6 dB, and “m” is always equal to 3 dB, then the formula can be simplified, so that the change in input level is:

$$P_C = 10.\log[2.N_{A1} + N_{D1}] - 10.\log[2.N_{A2} + N_{D2}]$$

Section 18: BROADBAND PARAMETERS

The Decibel

The decibel (dB) provides a means of representing large power ratios as manageable, small numbers, and allows the overall gains and losses in a module or a network to be calculated by addition and subtraction, rather than by multiplication and division.

The original unit was the bel (named after Alexander Graham Bell), and the decibel is one-tenth of a bel. Thus, the ratio of two power levels is calculated as follows:

Ratio of power P_1 to power P_2, in dB:

$$= 10*\log\left(\frac{P_1}{P_2}\right)$$

If voltage, rather than power levels are known, and provided that the impedance is constant, the power ratio can be calculated as follows:

Ratio of power produced by voltage V_1 to power produced by voltage V_2, in dB:

$$= 20*\log\left(\frac{V_1}{V_2}\right)$$

Power and Voltage Conversion

dBmV

‘0 dBmV’ defines the power (13.33 nW) produced when a voltage of 1 mV (rms) is applied across a defined impedance (75 ohms in the broadband industry). That is, dBmV is a unit of power expressed in terms of voltage.

Therefore, a measurement of 'x dBmV' in a defined impedance indicates that the power being measured is x dB greater than that produced when a voltage of 1 mV is applied across the same impedance.

To convert x dBmV to millivolts:	Signal level in millivolts = $10^{\left(\frac{x}{20}\right)}$

dBµV

Similarly, a measurement of 'x dBµV' in a defined impedance indicates that the power being measured is x dB greater than that produced when a voltage of 1 µV (rms) is applied across the same impedance.

To convert x dBµV to microvolts:	Signal level in microvolts = $10^{\left(\frac{x}{20}\right)}$

To convert dBmV to dBµV, add 60 to the dBmV reading:

x dBmV = (x+60) dBµV

mW

To determine the power, in milliwatts, which is represented by a reading in dBmV, assuming an impedance of 75 ohms:

To convert x dBmV to milliwatts:

$$\text{Signal power in milliwatts} = \frac{10^{\left(\frac{x}{10}\right)}}{75 * 1000}$$

dBm

A measurement of ‘x dBm’ indicates that a particular signal has a power of x dB greater than (or ‘above’) 1 milliwatt. A negative dBm value indicates that the signal is less than (‘below’) 1 milliwatt.

To convert x dBm to milliwatts:

$$\text{Signal power in milliwatts} = 10^{\left(\frac{x}{10}\right)}$$

Power expressed in dBmV can be converted to power expressed in dBm, as follows (the impedance is assumed to be 75 ohms):

To convert x dBmV directly to dBm:

$$\text{Signal power in dBm} = 10 * \log\left[\frac{10^{\left(\frac{x}{10}\right)}}{75 * 1000}\right]$$

The inverse operation is also possible:

To convert x dBm directly to dBmV:

$$\text{Signal level in dBmV} = 10 * \log\left[75 * 1000 * 10^{\left(\frac{x}{10}\right)}\right]$$

Alternatively, to convert dBmV to dBm (assuming 75 ohms), subtract 48.75 from the value in dBmV. For example, 10 dBmV = -

38.75 dBm. To convert dBm to dBmV (again, assuming 75 ohms), add 48.75 to the value in dBm. For example, 5 dBm = 53.75 dBmV.

Impedance Mismatch

It frequently happens that the input impedance of a measuring device (spectrum analyzer, signal level meter, etc.) does not match the impedance of the system under test. In such a case, a correction must be made to the reading displayed on the instrument.

$$\text{Correction (in dB)} = 10 * \log\left(\frac{Z_i}{Z_S}\right)$$

Where z_i is the impedance of the instrument, and Z_S is the impedance of the system under test.

Field Strength (leakage)

Signal leakage from a broadband network is often measured using dedicated leakage detection equipment, typically with an integrated antenna. In some cases leakage is measured using a resonant half-wave dipole antenna connected to an instrument such as a spectrum analyzer or signal level meter. If the latter method is used, the instrument's reported value in dBmV must be converted to field strength in microvolts per meter (μV/m). First, compensate for the loss of the interconnecting cabling and external bandpass filter (if used), and gain of a preamplifier (if used) to determine the signal level at the dipole's terminals. The field strength is given by the following formula.

$$\mu V/m = 21 * F * 10^{\frac{dBmV}{20}}$$

where *F* is the frequency in MHz of the signal being measured, and *dBmV* is the signal level at the dipole's terminals.

If the field strength in microvolts per meter is known, that value is converted to signal level in dBmV at the dipole's terminals with the following formula.

$$dBmV = 20\log\left[\frac{\left(\frac{\mu V/m}{0.021 * F}\right)}{1000}\right]$$

Field strength is expressed in decibel microvolts per meter (dBμV/m) in many areas outside of North America. Conversion between microvolts per meter and decibel microvolts per meter is done with the following formulas.

$$dB\mu V/m = 20log(\mu V/m)$$

$$\mu V/m = 10^{\frac{dB\mu V/m}{20}}$$

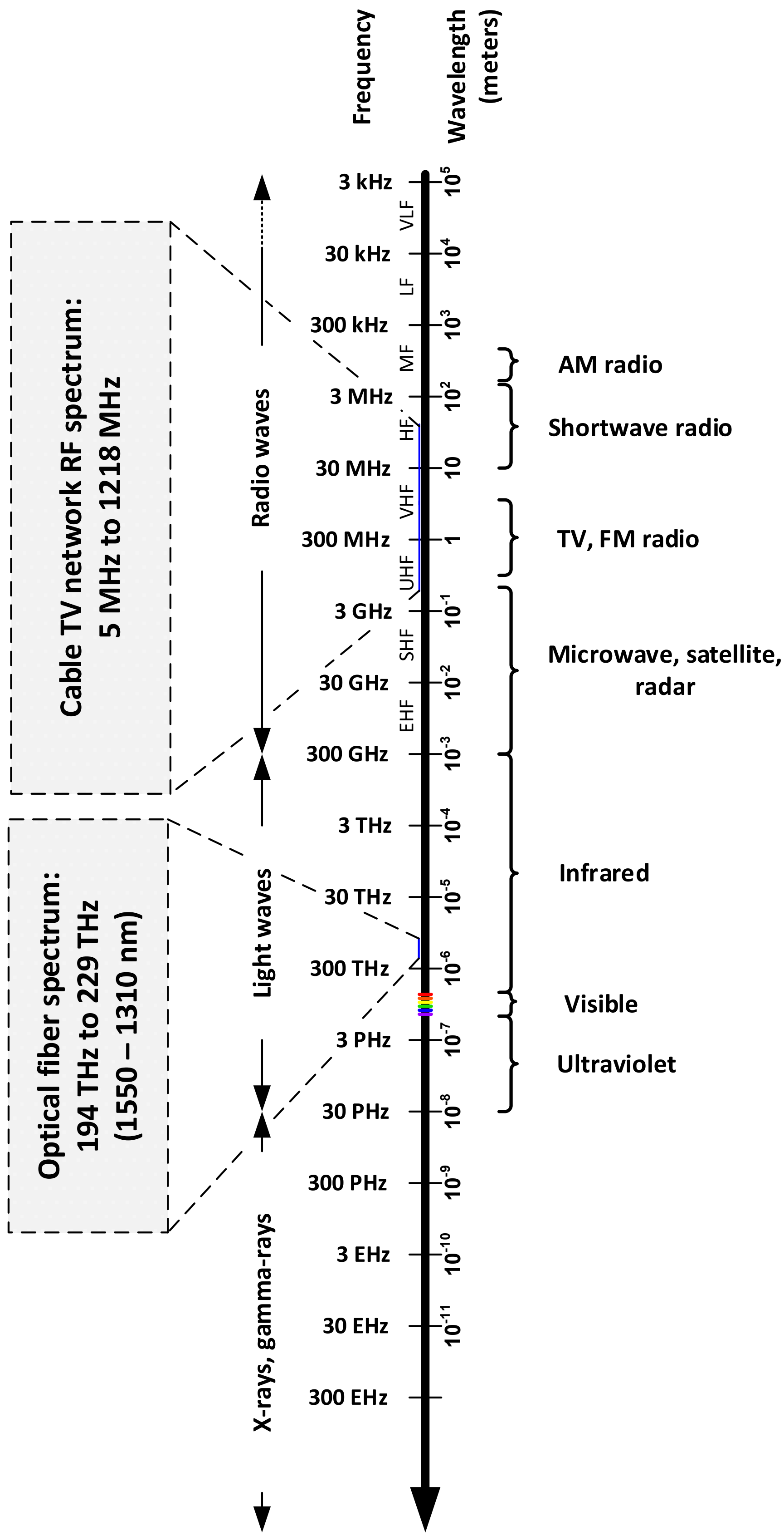
The table on the following page provides conversions between field strength in μV/m and signal level in dBmV at the terminals of a resonant half-wave dipole antenna for frequencies and channels commonly used for signal leakage monitoring and measurement.

Field strength vs. dipole level in dBmV[1]

CTA Ch.[2]	Center Freq. (MHz)	5 µV/m	15 µV/m	20 µV/m	50 µV/m	150 µV/m
98	111	-53.37	-43.83	-41.33	-33.37	-23.83
99	117	-53.83	-44.29	-41.79	-33.83	-24.29
14	123	-54.26	-44.72	-42.22	-34.26	-24.72
15	129	-54.68	-45.13	-42.64	-34.68	-25.13
16	135	-55.07	-45.53	-43.03	-35.07	-25.53
138 MHz	138	-55.26	-45.72	-43.22	-35.26	-25.72
17	141	-55.45	-45.91	-43.41	-35.45	-25.91
18	147	-55.81	-46.27	-43.77	-35.81	-26.27
88	609	-68.16	-58.61	-56.12	-48.16	-38.61
612 MHz	612	-68.20	-58.66	-56.16	-48.20	-38.66
89	615	-68.24	-58.70	-56.20	-48.24	-38.70
108	699	-69.35	-59.81	-57.31	-49.35	-39.81
109	705	-69.43	-59.89	-57.39	-49.43	-39.89
110	711	-69.50	-59.96	-57.46	-49.50	-39.96
111	717	-69.58	-60.03	-57.53	-49.58	-40.03
112	723	-69.65	-60.11	-57.61	-49.65	-40.11
113	729	-69.72	-60.18	-57.68	-49.72	-40.18
114	735	-69.79	-60.25	-57.75	-49.79	-40.25
115	741	-69.86	-60.32	-57.82	-49.86	-40.32
116	747	-69.93	-60.39	-57.89	-49.93	-40.39
117	753	-70.00	-60.46	-57.96	-50.00	-40.46
118	759	-70.07	-60.53	-58.03	-50.07	-40.53
119	765	-70.14	-60.60	-58.10	-50.14	-40.60
120	771	-70.21	-60.66	-58.16	-50.21	-40.66
121	777	-70.27	-60.73	-58.23	-50.27	-40.73
122	783	-70.34	-60.80	-58.30	-50.34	-40.80
123	789	-70.41	-60.86	-58.37	-50.41	-40.86
124	795	-70.47	-60.93	-58.43	-50.47	-40.93
125	801	-70.54	-61.00	-58.50	-50.54	-41.00
126	807	-70.60	-61.06	-58.56	-50.60	-41.06

1. Each dBmV value in columns 3-7 of the table represents the power delivered to the terminals of a lossless resonant half-wave dipole antenna for the channels/frequencies shown, when the dipole is located in an ambient field strength equal to one of the µV/m values listed in the table’s first row. It is further assumed that the terminals of the dipole are terminated by a load equal to the antenna’s radiation resistance (approximately 73 ohms for a half-wave dipole). For example, a field strength of 20 µV/m at 129 MHz (Ch. 15) will produce a signal level of -42.64 dBmV at the terminals of a resonant half-wave dipole.
2. The center frequency of each channel (e.g., 141.00 MHz for CTA Ch. 17) was used to calculate the dBmV values in the table.

Electromagnetic Spectrum



ITU Radio Bands

Band #	Abbreviation	Name	Frequency
1	ELF	extremely low frequency	3 Hz to 30 Hz
2	SHF	super low frequency	30 Hz to 300 Hz
3	ULF	ultra low frequency	300 Hz to 3000 Hz
4	VLF	very low frequency	3 kHz to 30 kHz
5	LF	low frequency	30 kHz to 300 kHz
6	MF	medium frequency	300 kHz to 3000 kHz
7	HF	high frequency	3 MHz to 30 MHz
8	VHF	very high frequency	30 MHz to 300 MHz
9	UHF	ultra high frequency	300 MHz to 3000 MHz
10	SHF	super high frequency	3 GHz to 30 GHz
11	EHF	extremely high frequency	30 GHz to 300 GHz
12	THF	tremendously high frequency	300 GHz to 3000 GHz

IEEE Radar Bands

Band	Frequency Range
HF	0.003 GHz to 0.03 GHz
VHF	0.03 GHz to 0.3 GHz
UHF	0.3 GHz to 1 GHz
L	1 GHz to 2 GHz
S	2 GHz to 4 GHz
C	4 GHz to 8 GHz
X	8 GHz to 12 GHz
Ku	12 GHz to 18 GHz
K	18 GHz to 27 GHz
Ka	27 GHz to 40 GHz
V	40 GHz to 75 GHz
W	75 GHz to 110 GHz
mm or G	110 GHz to 300 GHz

EU, NATO, US ECM Bands

Band	Frequency Range
A	0 to 250 MHz
B	250 MHz to 500 MHz
C	500 MHz to 1 GHz
D	1 GHz to 2 GHz
E	2 GHz to 3 GHz
F	3 GHz to 4 GHz
G	4 GHz to 6 GHz
H	6 GHz to 8 GHz
I	8 GHz to 10 GHz
J	10 GHz to 20 GHz
K	20 GHz to 40 GHz
L	40 GHz to 60 GHz
M	60 GHz to 100 GHz

Free space wavelength formulas

Assumptions:

Speed of light in a vacuum = 299,792,458 meters per second, or 983,571,056.43 feet per second
λ = wavelength
$\lambda/2$ = half wavelength
$\lambda/4$ = quarter wavelength
f_{MHz} = frequency in megahertz

Formulas:

$\lambda_{meters} = 299.792458/f_{MHz}$
$\lambda/2_{meters} = 149.896229/f_{MHz}$
$\lambda/4_{meters} = 74.948115/f_{MHz}$

$\lambda_{feet} = 983.571056/f_{MHz}$
$\lambda/2_{feet} = 491.785528/f_{MHz}$
$\lambda/4_{feet} = 245.892764/f_{MHz}$

$\lambda_{inches} = 11{,}802.852677/f_{MHz}$
$\lambda/2_{inches} = 5901.426339/f_{MHz}$
$\lambda/4_{inches} = 2950.713169/f_{MHz}$

Example 1: What is the free space wavelength, in feet, of a 450 MHz RF signal?

Solve with the formula $\lambda_{feet} = 983.571056/f_{MHz}$

λ_{feet} = 983.571056/450 MHz
= 2.19 feet

Example 2: A cable operator would like to use a half wave dipole antenna for signal leakage measurements. What is the length, in inches, of a dipole for 133.2625 MHz? Assume the dipole's physical length is ~95% of its free space value.

Solve with the formula $\lambda/2_{inches} = 5901.426339/f_{MHz}$

$\lambda/2_{inches}$ = 5901.426339/133.2625 MHz
= 44.28 inches

44.28 inches x 95% = 42.1 inches

Cable Loss Ratio

The ratio of the attenuation in coaxial cable, expressed in dB, at two frequencies is approximately equal to the square root of the ratio of the frequencies:

$$\text{Approximate cable loss ratio} = \sqrt{\left(\frac{F_H}{F_L}\right)}$$

Example: A 100 ft. length of 0.500 inch coaxial cable has a loss of 1.32 dB at 300 MHz. What is the loss at 600 MHz?

$$\text{Approximate cable loss ratio} = \sqrt{\left(\frac{600}{300}\right)} = \sqrt{2} = 1.414$$

Therefore the approximate loss at 600 MHz is 1.32 x 1.414 = 1.87 dB.

Exact Cable Loss Ratio

A more accurate determination of cable loss ratio can be obtained from the formula:

$$L_f = \frac{L_0}{1+\alpha}\left\{\sqrt{\frac{f}{f_0}} + \alpha\left(\frac{f}{f_0}\right)\right\}$$

Where L_f = loss, in dB, at the desired frequency;
L_0 = loss, in dB, at the reference frequency;
α = cable shape factor;
f_0 = reference frequency in MHz, and
f = desired frequency in MHz

Cable shape factor (α) is a parameter associated with a particular type and manufacturer of cable. In practice, the value of α is determined empirically.

BER (Bit Error Ratio)

In a digital communications link, bit error ratio is defined as the ratio of the number of defective (errored) bits received to the total number of bits transmitted:

$$BER = \frac{\text{Number of defective bits}}{\text{Number of bits transmitted}}$$

For example, if a BER test-set displays a reading of 2.3e-8, this means that the bit error ratio is 2.3×10^{-8} or 0.000000023. Note: Most field instruments that report BER (e.g., pre-FEC and post-FEC BER) are reporting the estimated bit error ratio.

The bit error rate is calculated by taking the reciprocal of the bit error ratio. In the above example, a bit error ratio of 2.3e-8 means that errors are being received at the rate of one defective bit in every 4.35×10^{7} bits received,

$$\text{because } \left(\frac{1}{2.3 \times 10^{-8}} = 4.35 \times 10^{7} \right)$$

When measuring BER, and particularly when testing for very low error rates, it is advisable to allow a sufficiently long measurement interval in order to obtain a statistically meaningful result. As a general guideline, the measurement interval should be one order of magnitude greater than the interval in which one error may be expected.

For example, if a bit error rate of one defective bit in 10^{8} bits is expected (bit error ratio = 1.0e-8), and the transmission rate is 1.544 Mbps, then one error may be expected every 64.8 seconds. (10^{8} divided by 1.544×10^{6}). Therefore, to obtain a statistically meaningful result an interval of 648 seconds (10.8 minutes) should be allowed. It is understood that, for very low error rates, this procedure may not be practicable.

MER (Modulation Error Ratio)

The signal-to-noise ratio (or carrier-to-noise ratio) is often used as a measure of the potential impairment in a digital signal. However, SNR or CNR, as measured on a conventional spectrum analyzer, does not provide information about phase disturbances in the signal, which are critical in the case of phase/amplitude modulation schemes such as QAM.

A better parameter is modulation error ratio. In the constellation diagram of a QAM signal, there is a ideal 'spot', defined by the I and Q coordinates, for each possible vector $\left(I_j, Q_j\right)$.

In a practical system, this ideal point is seldom hit exactly, due to several imperfections in the transmission link, such as quantizing error, rounding errors, noise, and phase jitter. This deviation of a real vector from the ideal spot in the signal constellation can be expressed as an error vector $\left(\delta I_j, \delta Q_j\right)$.

Mathematically, MER is equal to the root mean square magnitude of the ideal vector points divided by the root mean square magnitude of the error vectors.

Therefore,

$$MER = \frac{\sqrt{\frac{1}{N} \cdot \sum_{j=1}^{N} \left(I_j^2 + Q_j^2\right)}}{\sqrt{\frac{1}{N} \cdot \sum_{1=j}^{N} \left(\delta I_j^2 + \delta Q_j^2\right)}}$$

Expressed in decibel notation, this becomes:

$$\mathrm{MER(dB)} = 10.\log\left\{\frac{\frac{1}{N}.\sum_{j=1}^{N}\left(I_j^2 + Q_j^2\right)}{\frac{1}{N}.\sum_{j=1}^{N}\left(\delta I_j^2 + \delta Q_j^2\right)}\right\}$$

The DVB project uses MER as the figure of merit test for modulation quality.

EVM (Error Vector Magnitude)

EVM is related to MER in that it is a measure of the deviation of the vectors of a phase/amplitude modulated signal from the ideal points in the constellation. It is defined as the root mean square magnitude of the error vectors divided by the maximum ideal vector magnitude, and is expressed as a percentage:

$$\mathrm{EVM}(\%) = \frac{\sqrt{\frac{1}{N}.\sum_{j=1}^{N}\left(\delta I_j^2 + \delta Q_j^2\right)}}{S_{max}} \times 100$$

OMI (Optical Modulation Index)

Optical modulation index is a measure of the degree of modulation of the optical carrier by an RF signal. It is defined mathematically as the ratio of the peak RF modulating current to the average modulating current:

$$OMI = \frac{I_{rf,peak}}{I_{mod}}$$

The RF modulating current, $I_{rf,peak}$, can be written as:

$$I_{rf,peak} = \frac{V_{rf,peak}}{75\Omega} = \frac{\sqrt{2}.V_{rf,rms}.k}{75\Omega}$$

where $V_{rf,rms}$ is the input to the laser matching circuit, and k is the laser match factor. The average laser drive current, I_{mod}, can be written as:

$$I_{mod} = \frac{P_{opt}}{\varepsilon}$$

where P_{opt} is the average output optical power, and ε is the laser slope efficiency. Therefore the OMI, m, can be written as:

$$m = \frac{\sqrt{2}.V_{rf,rms}.k.\varepsilon}{P_{opt}.75\Omega}$$

The OMI is directly proportional to laser input voltage, and therefore if the input voltage changes by a certain ratio, the OMI will change by the same ratio:

$$m \;\alpha\; V_{rf,rms}, \text{ therefore } \frac{m_1}{m_2} = \frac{V_1}{V_2}$$

If V_1 and V_2 are expressed in terms of dBmV, then

$$\frac{m_1}{m_2} = \frac{10^{\left(V_1/20\right)}}{10^{\left(V_2/20\right)}} \quad \text{or} \quad \frac{m_1}{m_2} = 10^{\left(\frac{V_1 - V_2}{20}\right)}$$

Conversely, a change in OMI will require a change in drive voltage:

$$V_1 - V_2 = 20.\log\left\{\frac{m_1}{m_2}\right\}$$

The OMI referred to in the preceding text is the per channel OMI; another useful parameter is the composite rms OMI, denoted by the symbol μ. The approximate value of μ is given by:

$$\mu = m.\sqrt{\frac{N}{2}}$$

where N is the number of channels. This approximation is only valid when N is substantially greater than 10 and when the channels are of equal amplitude. For a smaller number of channels, the composite OMI is additive on a peak voltage basis, for the worst case.

Reference Charts

Return loss conversion

Return Loss, *R* (dB)	Voltage Standing Wave Ratio (VSWR), *r*	Reflection Coefficient, *ρ*	Mismatch Loss (dB)
0	∞	1.000	∞
1	17.391	0.891	6.868
2	8.724	0.794	4.329
3	5.848	0.708	3.021
4	4.419	0.631	2.205
5	3.570	0.562	1.651
6	3.010	0.501	1.256
7	2.615	0.447	0.967
8	2.323	0.398	0.749
9	2.100	0.355	0.584
10	1.925	0.316	0.458
11	1.785	0.282	0.359
12	1.671	0.251	0.283
13	1.577	0.224	0.223
14	1.499	0.199	0.176
15	1.433	0.178	0.140
16	1.377	0.158	0.110
17	1.329	0.141	0.088
18	1.288	0.126	0.069
19	1.253	0.112	0.055
20	1.222	0.100	0.044
21	1.196	0.089	0.035
22	1.173	0.079	0.027
23	1.152	0.071	0.022
24	1.135	0.063	0.017
25	1.119	0.056	0.014
26	1.106	0.050	0.011
27	1.094	0.045	0.009
28	1.083	0.040	0.007
29	1.074	0.035	0.005
30	1.065	0.032	0.004
31	1.058	0.028	0.003
32	1.052	0.025	0.003
33	1.046	0.022	0.002
34	1.041	0.020	0.002
35	1.036	0.018	0.001
36	1.032	0.016	0.001
37	1.029	0.014	0.001
38	1.025	0.013	0.001
39	1.023	0.011	0.001
40	1.020	0.010	0.0004
∞	1.000	0	0

dBm - milliwatts

dBm	mW	dBm	mW
-19	0.0126	6	3.9811
-18	0.0158	7	5.0119
-17	0.0200	8	6.3096
-16	0.0251	9	7.9433
-15	0.0316	10	10
-14	0.0398	11	12.589
-13	0.0501	12	15.849
-12	0.0631	13	19.953
-11	0.0794	14	25.119
-10	0.1	15	31.623
-9	0.1259	16	39.811
-8	0.1585	17	50.119
-7	0.1995	18	63.096
-6	0.2512	19	79.433
-5	0.3162	20	100
-4	0.3981	21	125.89
-3	0.5012	22	158.49
-2	0.6310	23	199.53
-1	0.7943	24	251.19
0	1	25	316.23
1	1.2589	26	398.11
2	1.5849	27	501.19
3	1.9953	28	630.96
4	2.5119	29	794.33
5	3.1623	30	1000

dBmV - dBµV - dBm conversion (75 ohms)

dBmV	dBµV	dBm	dBmV	dBµV	dBm
-60	0	-108.75	-18	42	-66.75
-59	1	-107.75	-17	43	-65.75
-58	2	-106.75	-16	44	-64.75
-57	3	-105.75	-15	45	-63.75
-56	4	-104.75	-14	46	-62.75
-55	5	-103.75	-13	47	-61.75
-54	6	-102.75	-12	47	-60.75
-53	7	-101.75	-11	49	-59.75
-52	8	-100.75	-10	50	-58.75
-51	9	-99.75	-9	51	-57.75
-50	10	-98.75	-8	52	-56.75
-49	11	-97.75	-7	53	-55.75
-48	12	-96.75	-6	54	-54.75
-47	13	-95.75	-5	55	-53.75
-46	14	-94.75	-4	56	-52.75
-45	15	-93.75	-3	57	-51.75
-44	16	-92.75	-2	58	-50.75
-43	17	-91.75	-1	59	-49.75
-42	18	-90.75	0	60	-48.75
-41	19	-89.75	1	61	-47.75
-40	20	-88.75	2	62	-46.75
-39	21	-87.75	3	63	-45.75
-38	22	-86.75	4	64	-44.75
-37	23	-85.75	5	65	-43.75
-36	24	-84.75	6	66	-42.75
-35	25	-83.75	7	67	-41.75
-34	26	-82.75	8	68	-40.75
-33	27	-81.75	9	69	-39.75
-32	28	-80.75	10	70	-38.75
-31	29	-79.75	11	71	-37.75
-30	30	-78.75	12	72	-36.75
-29	31	-77.75	13	73	-35.75
-28	32	-76.75	14	74	-34.75
-27	33	-75.75	15	75	-33.75
-26	34	-74.75	16	76	-32.75
-25	35	-73.75	17	77	-31.75
-24	36	-72.75	18	78	-30.75
-23	37	-71.75	19	79	-29.75
-22	38	-70.75	20	80	-28.75
-21	39	-69.75	21	81	-27.75
-20	40	-68.75	22	82	-26.75
-19	41	-67.75	23	83	-25.75

dBmV - dBμV - dBm conversion (cont'd)

dBmV	dBμV	dBm	dBmV	dBμV	dBm
24	84	-24.75	45	105	-3.75
25	85	-23.75	46	106	-2.75
26	86	-22.75	47	107	-1.75
27	87	-21.75	48	108	-0.75
28	88	-20.75	49	109	0.25
29	89	-19.75	50	110	1.25
30	90	-18.75	51	111	2.25
31	91	-17.75	52	112	3.25
32	92	-16.75	53	113	4.25
33	93	-15.75	54	114	5.25
34	94	-14.75	55	115	6.25
35	95	-13.75	56	116	7.25
36	96	-12.75	57	117	8.25
37	97	-11.75	58	118	9.25
38	98	-10.75	59	119	10.25
39	99	-9.75	60	120	11.25
40	100	-8.75	61	121	12.25
41	101	-7.75	62	122	13.25
42	102	-6.75	63	123	14.25
43	103	-5.75	64	124	15.25
44	104	-4.75	65	125	16.25

dBmV conversion (75 ohms)

dBmV	RMS voltage	RMS current	Average power
-60	1.000 µV	13.333 nA	13.333 fW
-59	1.122 µV	14.960 nA	16.786 fW
-58	1.259 µV	16.786 nA	21.132 fW
-57	1.413 µV	18.834 nA	26.603 fW
-56	1.585 µV	21.132 nA	33.492 fW
-55	1.778 µV	23.710 nA	42.164 fW
-54	1.995 µV	26.603 nA	53.081 fW
-53	2.239 µV	29.850 nA	66.825 fW
-52	2.512 µV	33.492 nA	84.128 fW
-51	2.818 µV	37.578 nA	105.910 fW
-50	3.162 µV	42.164 nA	133.333 fW
-49	3.548 µV	47.308 nA	167.857 fW
-48	3.981 µV	53.081 nA	211.319 fW
-47	4.467 µV	59.558 nA	266.035 fW
-46	5.012 µV	66.825 nA	334.918 fW
-45	5.623 µV	74.979 nA	421.637 fW
-44	6.310 µV	84.128 nA	530.810 fW
-43	7.079 µV	94.393 nA	668.250 fW
-42	7.943 µV	105.910 nA	841.276 fW
-41	8.913 µV	118.833 nA	1.059 pW
-40	10.000 µV	133.333 nA	1.333 pW
-39	11.220 µV	149.602 nA	1.679 pW
-38	12.589 µV	167.857 nA	2.113 pW
-37	14.125 µV	188.338 nA	2.660 pW
-36	15.849 µV	211.319 nA	3.349 pW
-35	17.783 µV	237.104 nA	4.216 pW
-34	19.953 µV	266.035 nA	5.308 pW
-33	22.387 µV	298.496 nA	6.682 pW
-32	25.119 µV	334.918 nA	8.413 pW
-31	28.184 µV	375.784 nA	10.591 pW
-30	31.623 µV	421.637 nA	13.333 pW
-29	35.481 µV	473.085 nA	16.786 pW
-28	39.811 µV	530.810 nA	21.132 pW
-27	44.668 µV	595.578 nA	26.603 pW
-26	50.119 µV	668.250 nA	33.492 pW
-25	56.234 µV	749.788 nA	42.164 pW
-24	63.096 µV	841.276 nA	53.081 pW
-23	70.795 µV	943.928 nA	66.825 pW
-22	79.433 µV	1.059 µA	84.128 pW
-21	89.125 µV	1.188 µA	105.910 pW
-20	100.000 µV	1.333 µA	133.333 pW
-19	112.202 µV	1.496 µA	167.857 pW

dBmV conversion (cont'd)

dBmV	RMS voltage	RMS current	Average power
-18	125.893 µV	1.679 µA	211.319 pW
-17	141.254 µV	1.883 µA	266.035 pW
-16	158.489 µV	2.113 µA	334.918 pW
-15	177.828 µV	2.371 µA	421.637 pW
-14	199.526 µV	2.660 µA	530.810 pW
-13	223.872 µV	2.985 µA	668.250 pW
-12	251.189 µV	3.349 µA	841.276 pW
-11	281.838 µV	3.758 µA	1.059 nW
-10	316.228 µV	4.216 µA	1.333 nW
-9	354.813 µV	4.731 µA	1.679 nW
-8	398.107 µV	5.308 µA	2.113 nW
-7	446.684 µV	5.956 µA	2.660 nW
-6	501.187 µV	6.682 µA	3.349 nW
-5	562.341 µV	7.498 µA	4.216 nW
-4	630.957 µV	8.413 µA	5.308 nW
-3	707.946 µV	9.439 µA	6.682 nW
-2	794.328 µV	10.591 µA	8.413 nW
-1	891.251 µV	11.883 µA	10.591 nW
0	1.000 mV	13.333 µA	13.333 nW
1	1.122 mV	14.960 µA	16.786 nW
2	1.259 mV	16.786 µA	21.132 nW
3	1.413 mV	18.834 µA	26.603 nW
4	1.585 mV	21.132 µA	33.492 nW
5	1.778 mV	23.710 µA	42.164 nW
6	1.995 mV	26.603 µA	53.081 nW
7	2.239 mV	29.850 µA	66.825 nW
8	2.512 mV	33.492 µA	84.128 nW
9	2.818 mV	37.578 µA	105.910 nW
10	3.162 mV	42.164 µA	133.333 nW
11	3.548 mV	47.308 µA	167.857 nW
12	3.981 mV	53.081 µA	211.319 nW
13	4.467 mV	59.558 µA	266.035 nW
14	5.012 mV	66.825 µA	334.918 nW
15	5.623 mV	74.979 µA	421.637 nW
16	6.310 mV	84.128 µA	530.810 nW
17	7.079 mV	94.393 µA	668.250 nW
18	7.943 mV	105.910 µA	841.276 nW
19	8.913 mV	118.833 µA	1.059 µW
20	10.000 mV	133.333 µA	1.333 µW
21	11.220 mV	149.602 µA	1.679 µW
22	12.589 mV	167.857 µA	2.113 µW
23	14.125 mV	188.338 µA	2.660 µW

dBmV conversion (cont'd)

dBmV	RMS voltage	RMS current	Average power
24	15.849 mV	211.319 µA	3.349 µW
25	17.783 mV	237.104 µA	4.216 µW
26	19.953 mV	266.035 µA	5.308 µW
27	22.387 mV	298.496 µA	6.682 µW
28	25.119 mV	334.918 µA	8.413 µW
29	28.184 mV	375.784 µA	10.591 µW
30	31.623 mV	421.637 µA	13.333 µW
31	35.481 mV	473.085 µA	16.786 µW
32	39.811 mV	530.810 µA	21.132 µW
33	44.668 mV	595.578 µA	26.603 µW
34	50.119 mV	668.250 µA	33.492 µW
35	56.234 mV	749.788 µA	42.164 µW
36	63.096 mV	841.276 µA	53.081 µW
37	70.795 mV	943.928 µA	66.825 µW
38	79.433 mV	1.059 mA	84.128 µW
39	89.125 mV	1.188 mA	105.910 µW
40	100.000 mV	1.333 mA	133.333 µW
41	112.202 mV	1.496 mA	167.857 µW
42	125.893 mV	1.679 mA	211.319 µW
43	141.254 mV	1.883 mA	266.035 µW
44	158.489 mV	2.113 mA	334.918 µW
45	177.828 mV	2.371 mA	421.637 µW
46	199.526 mV	2.660 mA	530.810 µW
47	223.872 mV	2.985 mA	668.250 µW
48	251.189 mV	3.349 mA	841.276 µW
49	281.838 mV	3.758 mA	1.059 mW
50	316.228 mV	4.216 mA	1.333 mW
51	354.813 mV	4.731 mA	1.679 mW
52	398.107 mV	5.308 mA	2.113 mW
53	446.684 mV	5.956 mA	2.660 mW
54	501.187 mV	6.682 mA	3.349 mW
55	562.341 mV	7.498 mA	4.216 mW
56	630.957 mV	8.413 mA	5.308 mW
57	707.946 mV	9.439 mA	6.682 mW
58	794.328 mV	10.591 mA	8.413 mW
59	891.251 mV	11.883 mA	10.591 mW
60	1.000 V	13.333 mA	13.333 mW
61	1.122 V	14.960 mA	16.786 mW
62	1.259 V	16.786 mA	21.132 mW
63	1.413 V	18.834 mA	26.603 mW
64	1.585 V	21.132 mA	33.492 mW
65	1.778 V	23.710 mA	42.164 mW

Section 19: WEIGHTS and MEASURES

The following tables provide conversions between U.S. units and their metric equivalents. Metric units are defined by the SI (*Le Système International d' Unités*, or International System of Units), which came into effect in October 1960.

The tables are by no means exhaustive. They include only those weights and measures which are related, directly and indirectly, to the broadband industry.

Length (general)

metric to U.S.		
1 millimeter (mm)		= 0.0394 inch
1 centimeter (cm)	= 10 mm	= 0.3937 inch
1 meter (m)	= 100 cm	= 1.0936 yard
1 kilometer (km)	= 1000 m	= 0.6214 mile

U.S. to metric		
1 inch (in)		= 25.400 mm
1 foot (ft)	= 12 in	= 30.48 cm
1 yard (yd)	= 3 ft	= 0.9144 m
1 mile (mi)	= 1760 yd	= 1.6093 km

(The SI *base unit* of length is the meter)

Length (optics)

1 angstrom (Å)	= 10^{-10} m	
1 nanometer (nm)	= 10^{-9} m	= 10 Å
1 micrometer (μm)	= 10^{-6} m	= 1000 nm

(The micrometer is frequently referred to as the 'micron')

Area

metric to U.S.

1 square centimeter		= 0.1550 sq inch
(cm^2)	= 10^4 cm^2	= 10.7639 sq foot
1 square meter (m^2)		= 1.1960 sq yard
	= 10^6 m^2	= 247.105 acre
1 square kilometer (km^2)	= 100 hectare	= 0.3861 sq mile

U.S. to metric

1 square inch (in^2)		= 6.4516 cm^2
1 square foot (ft^2)	= 144 in^2	= 0.0929 m^2
1 square yard (yd^2)	= 9 ft^2	= 0.8361 m^2
1 acre (ac)	= 4840 yd^2	= 4046.86 m^2
		= 0.4047 hectare
1 square mile (mi^2)	= 640 ac	= 259 hectare

(The SI *derived unit* of area is the square meter)

Mass

metric to U.S.

1 gram (g)		= 0.0353 ounce
1 kilogram (kg)	= 1000 g	= 2.2046 pound
1 tonne (t)	= 1000 kg	= 2204.6 pound
		= 0.9842 ton

(The ‘tonne’ is sometimes referred to as the ‘metric ton’)

U.S. to metric

1 ounce (oz)		= 28.35 g
1 pound (lb)	= 16 oz	= 0.4536 kg
1 ton	= 2240 lb	= 1016.05 kg
		= 1.0161 tonne

(The SI *base unit* of mass is the kilogram)

Volume

metric to U.S.

1 cubic centimeter (cm^3)		= 0.0610 cu. inch
		= 0.0338 fl.
1 deciliter (dl)	= 100 cm^3	ounce
1 liter (l)	= 1000 cm^3	= 3.3814 fl.
		ounce
		= 2.1134 pints*
1 cubic meter (m^3)	= 1000 l	= 0.2642 gallon*
		= 0.0353 cu. foot
		= 35.3147cu. foot
		= 1.3079 cu. yard

U.S. to metric

1 cubic inch (in^3)		= 16.3871 cm^3
1 fluid ounce	= 1.8047 in^3	= 29.5735 cm^3
1 pint (pt)*	= 16 fl. ounce	= 4.7318 dl
		= 0.4732 l
1 gallon (gal)*	= 8 pint*	= 3.7854 l
1 cubic foot (ft^3)	= 7.4844	= 28.3168 l
1 cubic yard (yd^3)	gallon*	= 0.7646 m^3
	= 27 cu. foot	

* These are U.S., not Imperial volumes.

(The SI *derived unit* of volume is the cubic meter, although the liter is more popular)

Moment of force (torque)

metric to U.S.	
1 newton meter (N·m)	= 0.737562 lb·ft

U.S. to metric	
1 pound-foot (lb·ft)	= 1.35581 N·m

(Not to be confused with *foot-pound-force*, or ft·lbf or ft·lb, a unit of work or energy. One pound-foot is the torque produced by a one-pound force acting at the end of a one-foot crank.)

International System of Units

The following tables are from the National Institute of Standards and Technology Special Publication 811, 2008 Edition, *Guide for the Use of the International System of Units (SI)*. Care should be taken to ensure that the correct case (upper or lower) is used, to avoid confusion (e.g., SI prefixes M = mega, m = milli).

SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	µ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

SI base units

Base quantity	Name	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

International System of Units (cont'd)

Examples of SI derived units

Derived quantity	Name	Symbol
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
wave number	reciprocal meter	m^{-1}
mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
amount-of-substance concentration	mole per cubic meter	mol/m^3
luminance	candela per square meter	cd/m^2
mass fraction	kilogram per kilogram, which may be represented by the number 1	kg/kg = 1

International System of Units (cont'd)

SI derived units with special names and symbols

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian [(a)]	rad	-	$m \cdot m^{-1} = 1$ [(b)]
solid angle	steradian [(a)]	sr [(c)]	-	$m^2 \cdot m^{-2} = 1$ [(b)]
frequency	hertz	Hz	-	s^{-1}
force	newton	N	-	$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	N·m	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C	-	s·A
electric potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	V·s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius	°C	-	K
luminous flux	lumen	lm	cd·sr [(c)]	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	lm/m^2	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
activity (of a radionuclide)	becquerel	Bq	-	s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent [(d)]	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$
catalytic activity	katal	kat		$s^{-1} \cdot mol$

Notes

(a) The radian and steradian may be used advantageously in expressions for derived units to distinguish between quantities of a different nature but of the same dimension; some examples are given in Table 5.

(b) In practice, the symbols rad and sr are used where appropriate, but the derived unit "1" is generally omitted.

(c) In photometry, the unit name steradian and the unit symbol sr are usually retained in expressions for derived units.

(d) Other quantities expressed in sieverts are ambient dose equivalent, directional dose equivalent, personal dose equivalent, and organ equivalent dose.

Examples of SI derived units whose names and symbols include SI derived units with special names and symbols

Derived quantity	Name	Symbol
dynamic viscosity	pascal second	Pa·s
moment of force	newton meter	N·m
surface tension	newton per meter	N/m
angular velocity	radian per second	rad/s
angular acceleration	radian per second squared	rad/s^2
heat flux density, irradiance	watt per square meter	W/m^2
heat capacity, entropy	joule per kelvin	J/K
specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg·K)
specific energy	joule per kilogram	J/kg
thermal conductivity	watt per meter kelvin	W/(m·K)
energy density	joule per cubic meter	J/m^3
electric field strength	volt per meter	V/m
electric charge density	coulomb per cubic meter	C/m^3
electric flux density	coulomb per square meter	C/m^2
permittivity	farad per meter	F/m
permeability	henry per meter	H/m
molar energy	joule per mole	J/mol
molar entropy, molar heat capacity	joule per mole kelvin	J/(mol·K)
exposure (x and γ rays)	coulomb per kilogram	C/kg
absorbed dose rate	gray per second	Gy/s
radiant intensity	watt per steradian	W/sr
radiance	watt per square meter steradian	$W/(m^2 \cdot sr)$
catalytic (activity) concentration	katal per cubic meter	kat/m^3

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