Quality RF Services, Inc.

CATV / MATV Design Fundamentals

This section is for those of you who need the fundamentals to build an indoor (or outdoor) RF distribution system. If you are an "Old Pro" in the cable television industry, this will be a boring review. **For the "first timer" this will open your eyes to the reasons why your TV signals have snow or lines in the pictures.** **This article is just the "fundamentals" of cable television (CATV) and master antenna television (MATV) signal distribution.**

If your RF distribution network requires more than one amplifier in series, the number one cable TV rule applies. **Cable television systems consist of UNITY GAIN building blocks.** What that means is every length of cable (and the passive devices in that length of cable) is followed by an amplifier with an equal amount of RF gain and equalization to overcome the differing losses at all desired frequencies.

A piece of coaxial cable is nothing more than a piece of round wire surrounded by an insulating material (usually foam) that is then surrounded with an outer metal jacket which may consist of overlapping vinyl/foil layers, braided wire, or extruded (or welded) aluminum tubing. The object of coaxial cable is to keep electromagnetic RF carrier waves inside the cable from getting out and similar waves from the outside world from getting inside the cable. **And by the way, the term COAXIAL means the center conductor must stay in the CENTER. If you kink, or flatten the cable, it does not work as well. Damaged cable creates reflections and it will radiate and absorb signals to and from the outside world. DO NOT DAMAGE THE CABLE.**

Electromagnetic waves of different wavelengths (frequencies) can flow through a single cable at the same time. The higher the frequency of a wave, the greater the insertion loss of the cable for a given length of cable. This loss is usually expressed in decibels (dB) per 100 feet of cable here in the United States. Common cable television test equipment and signal level meters are calibrated with decibel ranges. A table of losses for popular cable types is included in this article for quick reference. The signal level losses will vary with the temperature of the cable. These data tables are published for ambient cable temperature of 70 degrees Fahrenheit. **For cables exposed to the weather, when the temperature is COLDER, the losses of the cable are LESS. On the hottest day in the summer, the cable losses are the greatest.** Cable that is buried in the ground, or indoors, will usually remain at the same temperature year round.

For ease of use and recognition, each of the different television frequencies has been assigned a channel number. The channel numbering scheme applied to these frequencies is different in over-the-air TV transmissions as received with an antenna when compared to the channel numbers and frequencies used in a cable television system. There are several different frequency plans used in cable. We will only be concerned with "standard CATV" channels in this article and not the IRC or HRC CATV RF frequency plans. **For more information of channel numbers versus actual frequencies, CLICK HERE.**

The passive splitters and directional couplers used in cable systems are called flat loss devices. Below 450 MHz (CATV channel 61) they are essentially flat in their loss characteristics. **With the newer 750 to 860 MHz RF distribution systems, the high-frequency insertion losses of these devices needs to be addressed when totaling the signal losses between amplifiers.** Passive losses for splitters, taps and directional couplers are published by the various manufacturers. Pocket-sized reference books are published by the major CATV manufacturing companies containing this type of data. A brief excerpt of this type of data is included in this article.

A splitter is a passive device with from 2 to 8 ports with equal loss to each and every port. The most common type of splitter has one input port and two output ports. It is commonly referred to as a "two-way splitter" - - meaning it has two output ports. In a perfect world of 100% efficient devices, an equal split of RF energy would result in a signal loss of 3 dB to each output port. The "real world" loss of the splitter is typically 3.5 dB to 3.8 dB at lower frequencies to as much as 5 to 5.5 dB at the highest frequencies used in CATV / MATV systems. For practical purposes, the loss of a 2-way splitter may be assumed to be 4 dB, a 4-way splitter loss can be 7.5 to 8 dB, and an 8-way splitter can be from 11 to 12 dB insertion loss to each port.

A directional coupler is a three-port or four-port passive device that does NOT evenly divide the RF signals at the output ports. Depending on the RF bandwidth of these devices, they typically have tap loss values of 8 dB, 12 dB, or 16 dB. The higher the loss to the "tap port", the lower the insertion loss to the "through port". **When a directional coupler is connected directly to a splitter in a single housing, it is called a directional tap or multi-tap.** Common tap loss values for these devices vary from 8 to 32 dB depending on configuration and number of tap ports (up to 8). **(Click here for page 2.)**

The third part of the CATV / RF distribution system consists of the active devices like modulators, signal processors and broadband amplifiers. Here are brief descriptions of each type of device:

Modulators take video and audio signals from satellite receivers, video tape machines or cameras and produce a standard modulated television channel for viewing on a television set. The signal output level from a modulator is constant and can be as much as +60 dBmV. This value is 60 decibels above ONE millivolt as measured across a 75 ohm source impedance. This value is ONE volt of RF carrier at the peak amplitude of the signal.

Signal processors (or strip amplifiers) are single channel amplifiers designed to receive a single television signal from an antenna and control its output to a steady level. This **automatic gain control (AGC) function** is essential for the success of the distribution network of broadband amplifiers. Strip amplifiers do not alter the input frequency of the received television signal - - what goes in, comes out on the same frequency. Signal processors convert received television signals to an intermediate frequency **(I.F.)** for filtering out unwanted adjacent television signals that may be present at the antenna input. Precise signal level control **(AGC)** is accomplished at this point inside the signal processor. The sound carrier RF level is reduced from the 6 to 10 dB level difference transmitted by the TV station to a level between 13 and 17 dB lower than the associated visual RF carrier. This allows adjacent TV channels to be received by a television set with no visual impairment on the viewing screen. The final stage of a signal processor converts the I.F. signal to a standard or CATV channel for distribution to the cable system. A typical maximum RF output level for a processor may also be as much as +60 dBmV.

Some types of frequency AGILE processors and modulators can also produce broadband noise across the full range of CATV frequencies. When a large number of these low-cost devices are coupled together into a single cable, the result is a noisy or "snowy picture" on all channels before leaving the headend. The best types of AGILE modulators and processors will have some type of "tracking bandpass filter" to minimize the broadband noise output. Fixed channel processors and modulators may contain an internal single-channel bandpass filter to prevent this type of broadband noise problem.

Now that we have television signal sources, all that remains is to combine them using directional couplers and splitters. When combined, the VISUAL RF carriers should all be at the same level. Each associated sound carrier should be set -15 dB in relation to the visual carrier level for that channel. The losses of the couplers and splitters may require a broadband amplifier after all the signals are combined. This will insure that we have enough RF signal level to begin signal distribution to the many television outlets in the RF distribution system.

Depending on the number of channels combined together, the coupler and splitter losses could result in a combined signal level on all channels from +10 dBmV to +30 dBmV on each channel. At +30 dBmV, the signal levels may be strong enough to feed directly into cables leaving the headend to go to other buildings. At lower signal levels, an amplifier is used to provide a signal level from +35 dBmV to +45 dBmV or more to depart the headend. The maximum signal level will vary depending on the number of channels and amplifiers in cascade in the distribution network. This is due to the inter-mixing of signals when they are passed through the active components of the amplifiers. **The most common intermodulation distortion is known as**

composite triple beat (CTB). You know you have it when you see various types of "lines" in the pictures. This may be called a "busy background" by some individuals.

When the headend amplifier output levels are established, the design of the cable distribution network can begin. **For our 750 MHz system, let us assume an output level of +40 dBmV on cable channel 118 and a level of +35 dBmV on channel 2.** There are two reasons why the amplifier output is not FLAT (equal level at all channels). The first reason is the coaxial cable that follows the amplifier has lower insertion loss at channel 2 than it has at cable channel 118. The second reason is to provide a lower ratio of CTB distortion from the amplifier with the reduced signal levels at the lower frequencies.

The choice of the type of coaxial cable to be used in the distribution system is based on the distances to be covered and whether or not the cable is aerial, direct buried, or in a conduit or other underground passage ways. Common sizes of outdoor cables are specified by the outside diameter of the metalic outer sheath of the cable. The outdoor cable sizes most used are 0.500" (1/2 inch) and 0.750 (3/4 inch). The larger cable has lower insertion loss per 100 feet of cable.

Systems that are completely inside a single building may use the extruded aluminum cable commonly used outdoors or may require special plenum types of cable in sizes known by their RG numbers: RG-11, RG-6 or RG-59. The RG-11 cable is the largest and has the lowest loss per 100 feet. The RG-59 cable is hardly used anymore in systems with bandwidths above 300 MHz, since it has the highest loss of the three types of flexible coaxial cable. **(Click here for page 3.)**

Calculating Cable and Passive Losses Between Amplifiers

The nominal cable losses per 100 feet of some popular cable sizes is given in the chart below. * The 0.412" and 1.000" cable losses are given as the maximum cable loss per 100 feet. To discover the loss of a given length of cable at specific CATV channels or frequencies, divide the length of cable in feet by 100, then multiply by the appropriate dB figure from the chart below. Doing this at the highest and lowest frequencies to be distributed will provide the losses needed to select a cable equalizer when reaching successive RF amplifiers. This topic is discussed in another article on this web site called **Fixed Equalizer Selection.** The formula for computing cable equalizer selection is explained and tables of signal level difference solutions are provided.

Cable Loss vs. Frequency	Times Fiber T10 Drop Cable Maximum Losses @ 68 deg.F			CommScope Parameter III Nominal Cable Attenuation at 68 degrees Farenheit in dB per 100 feet by cable sizes					
	RG-59	RG-6	RG-11	.412"	.500"	.625"	.750"	.875"	1.000"
5 MHz	0.77	0.57	0.36	0.20	0.16	0.12	0.10	0.09	0.08
30 MHz	1.45	1.15	0.75	0.50	0.38	0.31	0.25	0.23	0.21
50 MHz	1.78	1.48	0.93	0.63	0.50	0.40	0.33	0.28	0.27
220 MHz	3.60	2.87	1.83	1.38	1.08	0.87	0.72	0.62	0.62
300 MHz	4.27	3.43	2.17	1.63	1.26	1.02	0.85	0.73	0.72
400 MHz	4.88	4.00	2.53	1.90	1.47	1.18	0.99	0.86	0.84
450 MHz	5.30	4.28	2.69	2.05	1.56	1.26	1.06	0.91	0.90
550 MHz	5.90	4.51	3.01	2.25	1.75	1.41	1.19	1.03	1.01
600 MHz	6.18	4.98	3.16	2.36	1.83	1.48	1.23	1.08	1.06
750 MHz	6.96	5.62	3.58	2.55	2.04	1.66	1.38	1.21	1.21
865 MHz	7.54	6.09	3.90	2.84	2.20	1.77	1.49	1.30	1.34
1000 MHz	8.09	6.54	4.23	3.05	2.41	1.95	1.62	1.42	1.44

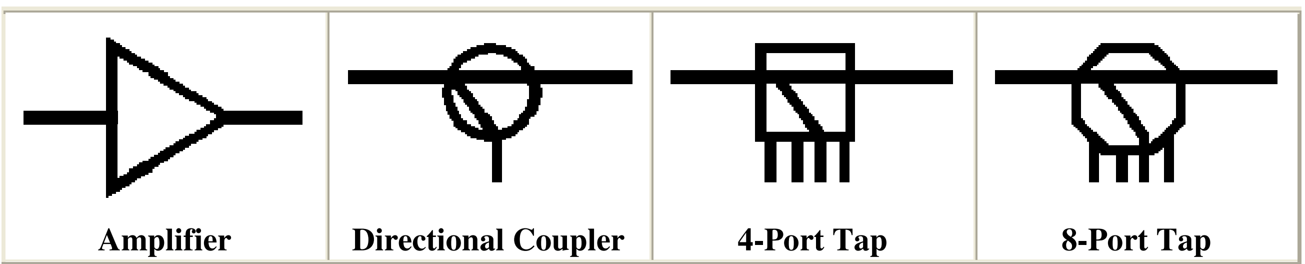
Similar cable loss data is published by CATV amplifier companies in handy pocket reference books for **Times Fiber Cable and Trilogy Communications MC^2 (M-C-squared)** coaxial cable types. The above chart is given as an example only. The user should refer to the correct cable loss charts for actual signal loss calculations.

The following table gives typical insertion losses for Scientific Atlanta SAT4G-(db) family of 4-outlet taps.										
Freq (MHz)	**-8**	**-11**	**-14**	**-17**	**-20**	**-23**	**-26**	**-29**	**-32**
5 to 10	**N/A**	**3.2**	**1.6**	**1.0**	**0.6**	**0.5**	**0.4**	**0.3**	**0.3**
11 to 300	**N/A**	**3.0**	**1.7**	**1.0**	**0.7**	**0.7**	**0.5**	**0.5**	**0.3**
301 to 400	**N/A**	**3.2**	**1.9**	**1.3**	**0.9**	**0.9**	**0.6**	**0.6**	**0.5**
401 to 450	**N/A**	**3.5**	**2.0**	**1.4**	**1.1**	**1.0**	**0.8**	**0.7**	**0.7**
451 to 600	**N/A**	**3.7**	**2.2**	**1.5**	**1.2**	**1.1**	**0.9**	**0.8**	**0.8**
601 to 750	**N/A**	**4.1**	**2.6**	**1.8**	**1.5**	**1.4**	**1.3**	**1.2**	**1.2**
751 to 900	**N/A**	**4.3**	**3.0**	**2.2**	**1.7**	**1.7**	**1.5**	**1.4**	**1.4**
900 to 1000	**N/A**	**4.7**	**3.5**	**2.5**	**2.0**	**1.0**	**1.8**	**1.6**	**1.6**
Tap Loss =	**8 dB**	**11 dB**	**14 dB**	**16 dB**	**20 dB**	**23 dB**	**26 dB**	**29 dB**	**32 dB**

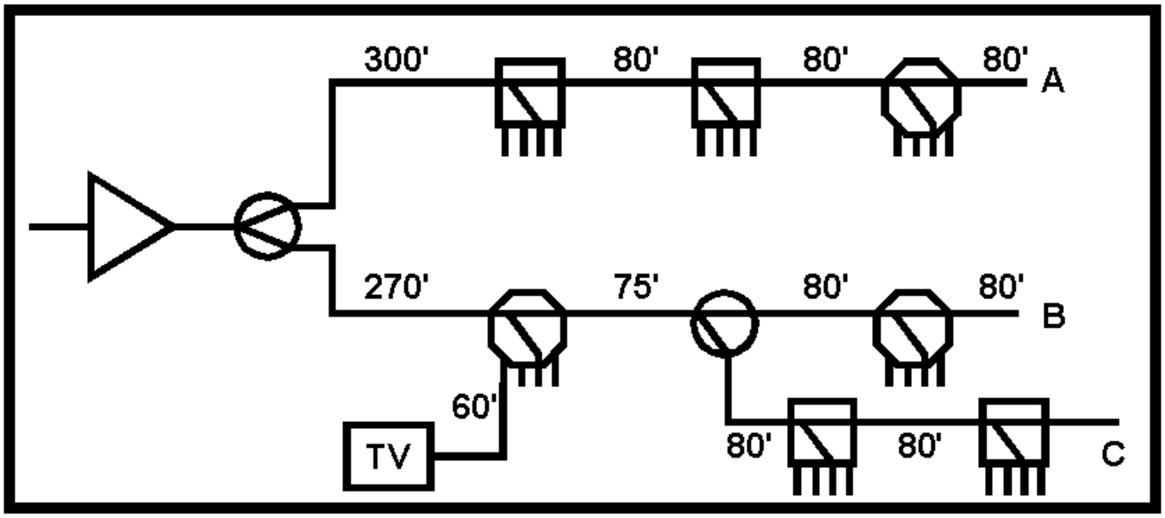
The above data table contains the insertion loss through the tap to the next cable or tap at the frequency ranges specified. The tap loss is the signal level loss that occurs from the input of the tap to each of the output ports to feed subscriber drop cables. This chart indicates the loss differences based on frequency and tap values and will vary from one tap manufacturer to another. Indoor taps that do not contain AC power passing circuitry may have better specifications. Similar charts exist for 2-port and 8-port taps as well as for inline directional couplers and 2-port and 3-port splitters. In the chart above, the 8 dB tap is a 4-way splitter and therefore has no through-port insertion loss, since all of the RF signals are directed to the 4 tap ports. **(Click here for page FOUR)**

NOW, DO THE WORK!

Now that we have seen samples of the cable loss data tables that are published by various industry cable and passive device suppliers, it is time to get the specific cable loss data and passives loss data together and do the work. First thing to do is to create a simple line drawing of the cable routes from building to building and/or within buildings. The key features should be indicated. Use a triangle to represent an amplifier providing forward gain from left to right on your chart. Use round circles to represent splitters and directional couplers in the trunk or feeder lines. Use your choice of small squares or Octaagons to represent the taps. Make these large enough to write a two-digit number inside the square or hexagon or adjacent if desired. The number will represent the tap loss value. See the graphics below for examples.



Using a combination of the symbols above, create a trunk tree diagram with the cable distances between desired cable splitter or tap locations. As each leg of the proposed distribution is drawn, the choice of splitter versus directional coupler will become evident as a result of the cable length or passive losses on each leg. Draw in the location of the required taps and whether they will need to be 2-port, 4-port, or 8-port taps at each location. When this phase of the drawing is completed, the loss of each length of cable can be calculated. **Tap values will be assigned when RF signal levels are calculated.**



Now that we have a sample layout, the RF output level of the amplifier can be added to the diagram and the signal levels in and out of each length of cable and passive device can be determined. **In the diagram above, the single TV set shown has a 60-foot length of RG-6 drop cable attached to an 8-port tap.** **The desired signal level at the TV set should be not less than 0 dBmV at any frequency.** **An ideal signal level should be around +3 dBmV to +5 dBmV.** Due to the differential slope attenuation of the coaxial cable and the passive devices, the signals arriving at the TV set may have a different strength at the highest and lowest RF channels. **This difference value (slope) should not exceed 12 dB maximum.** The smaller the slope difference, the better for the TV tuner to select the desired channel with minimum interference from the other TV channels. **(Click for PAGE FIVE)**

SIGNAL LEVELS - FILL IN THE BLANKS

A computer spread sheet is an easy way to determine RF signal losses for high and low forward RF distribution frequencies. If a two-way active design is desired, the highest and lowest return path frequency losses should also be calculated. A sample spread sheet is shown below. Remember to enter the data in a format that will account for the loss per 100-foot values given by cable manufacturers. Entering the values with the decimal point moved two places to the left will allow direct footage entries.

A	B	C	D	E	F	G
P3-500 Cable dB Loss per foot >>	**5 MHz**	**40 MHz**	**50 MHz**	**RF Level**	**750 MHz**	**RF Level**
	0.0016	**0.0044**	**0.0050**	**35**	**0.0204**	**40**
2-way splitter	**-3.8**	**-3.9**	**-3.9**	**31.1**	**-4.9**	**35.1**
300	**-0.48**	**-1.32**	**-1.50**	**29.6**	**-6.12**	**29.0**
23 dB, 4-port tap	**-0.5**	**-0.7**	**-0.7**	**28.9**	**-1.4**	**27.6**
80	**-0.13**	**-0.35**	**-0.4**	**28.5**	**-1.63**	**24.9**
20 dB, 4-port tap	**-0.6**	**-0.7**	**-0.7**	**27.8**	**-1.5**	**23.4**
80	**-0.13**	**-0.35**	**-0.4**	**27.4**	**-1.63**	**21.8**
17 dB, 8-port tap	**-1.6**	**-1.7**	**-1.7**	**25.7**	**-2.6**	**19.2**
80	**-0.13**	**-0.35**	**-0.4**	**25.3**	**-1.63**	**17.6**

The table above shows cable footage and passive device descriptions in the first column on the left. Cable losses and passive losses are shown in the second and third columns. In a spread sheet, the formula in each of these cells would be entered to multiply the cable footage in the first column by the loss per foot near the top of each frequency column. The formula in **cell B4** would take the form of **+$A4*B$2** and display the value **0.48 dB loss** as shown in the **5 MHz** column to the right of the 300 feet of cable distance in the first column. The **dollar signs** in the formula will insure that each formula copied below that cell will point to the cable distances in column A and the correct loss of the cable per foot at that frequency. **That same formula can then be copied into all the cells in that column and in columns C, D and F. When a cable footage is entered in column A, the attenuation at 5 MHz will appear in column B.** When a passive device is entered in row cell in column A, enter the insertion loss for that device at the designated frequencies, replacing the fomula in the appropriate cells **on that row in B, C, D and F columns.** With all the losses in place, the RF signal levels can be found and displayed in columns E and G.

The RF amplifier output level at 50 MHz is entered in cell E2. The 750 MHz output level is entered in cell G2. Each cell in column E and G, beginning with row 3, will have a formula which takes the signal level from the cell above and subtracts the loss of the adjacent cell to the left from the value above. The formula in cell E3 would read **+E2-D3** and display the value of 31.1 dBmV. Copy that formula in all cells below that one in column E. A similar set of formulas would be in column G to calculate the signal levels at the output of each device or after a length of cable at 750 MHz.

Looking at the chart, it becomes obvious by looking at the RF signal levels in columns E and G, that the cable and passive losses are reversing the slope output of the amplifier as the signal propogates down the signal path. This chart represents the path from the RF amplifier to the end of **cable A** as shown in the sample diagram on the previous page of this article. It appears that one more tap and a short length of cable may fit into this scenario before a second amplifier is required. Be sure that the highest frequency has at least 3 to 5 dBmV more signal than the rated noise figure of the amplifier that is going to be used. This is discussed in the technical article **"Amplifier Operational Sweet Spot."** A cable equalizer installed in the input of that next amplifier will insure a uniform carrier-to-noise ratio (C/N) for the RF signals. Choosing the correct equalizer is also covered in a technical article titled **"Fixed Equalizer Selection Theory and Chart."**

With all this said, it is time to build your own system, using real cable and passive loss data from your system as it exists or is proposed to meet the cable distances involved. It may be necessary to increase the output levels and slope of the amplifiers used in the system to meet spacing requirements. Larger cable sizes may have to be used. Lower bandwidths ease this problem, but signal levels reaching the television sets are not negotiable. Good Luck!