Basic AC System Design

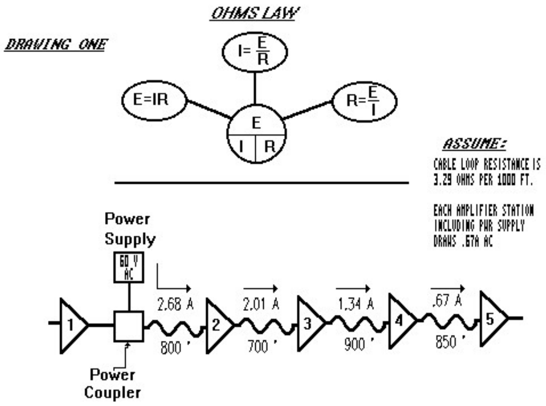
Many technicians struggle with AC design, particularly in the area of proper supply placement and loading. It can be said that AC design involves information and principles that we normally don't use in everyday cable system maintenance or operation, therefore they may seem foreign to us. Because a cable system is spread over a wide area, there are unique problems in supplying operating power to its various components. The amplifiers in a cable system are typically spaced several thousand feet from each other and cover an entire community. Each amplifier must be supplied with operating power and within a fairly narrow voltage range.

Because integrated circuit (and transistor) amplifiers operate at low DC voltages, it would seem ideal to route a low DC voltage along the coaxial cable with the TV signals. This is impractical, however, because of electrolysis/corrosion problems which result. This was verified through many attempts to do so in early cable systems of the 1950's and 60's, with less than optimal results. This tech letter takes a new look at the various system elements, then makes several sample AC designs examining various issues and overall concerns.

Basically, to determine the voltage drop that can be expected between amplifiers plus final load voltages, we must know the following information: the length of the cable, the DC loop resistance, and the amount of current carried. The design is then carried out so that the amplifier that is farthest removed from the power supply or inserter will always be supplied have it's minimum required operating voltage *under worst case conditions*.

DC Loop Resistance of Coaxial Cable: The nominal frequency of AC power is 60 Hertz. A pictorial representation of this is a sine wave in which the peaks occur at 60 times per second. At this very low frequency, there is very little difference between the loop resistance of the cable measured at DC, and the AC impedance measured at 60 Hertz. Impedance is the total opposition to current flow at some frequency other than DC. Most of the resistance in coaxial cable is in the inner conductor simply because it is smaller, but it is customary to specify the overall effect of the cable on the power supply voltage in terms of its "Loop Resistance". This is the equivalent resistance of a given length of cable and is usually stated in terms of ohms per 1000 Feet of Cable. Actual loop resistance (on a 1000' basis) will vary from a fraction of an ohm for 1"+ diameter cable, to over 50 Ohms for some drop wire types. Although support strand does in fact reduce the resistance of the outer conductor in system calculations, it is usually disregarded for several reasons. The overall amount of reduction is small, typically on the order of 5% or less; plus this reduction is not seen in underground systems.

Ohm's Law; and Cable AC Basics: Any treatise on AC powering in cable systems needs to begin with a discussion of Ohms Law. Ohms Law (E=IR) can be most simply defined by saying that, given the three basic electrical quantities (voltage, current, and resistance), current flow is directly proportional to total circuit voltage and inversely proportional to total circuit resistance (I=E/R). This is probably the single most important and basic theorem in electronics, because it explains so much of circuit operation. It is simple and easily understood, yet forms the basis for highly complicated theories and circuit/system analysis. Ohms Law is shown more fully in the top section of **Drawing One**.



If a certain level of energy is supplied to an energy absorbing device, at least part of the energy will be absorbed and dissipated in some fashion (or in some cases stored for later use). Accordingly, the amount of energy left over for use elsewhere in the circuit will be less than the amount started with. Electrically, this energy is known as power which is measured in Watts. From Ohms Law we see that for a fixed current flow and a specific fixed point of resistance, there will be a voltage drop across this resistance. The amount of energy or power absorbed by the resistance is equal to the flow of current times the voltage drop which occurs. In other words, power absorbed by a resistance equals the amount of current times the voltage drop across the resistance (P=IE). Similarly, the power absorbed in an entire system is the total of individual voltage drops in the system times the current flow through the each device. In actuality, this only occurs (all power absorbed by the load) when the load is purely resistive i.e., has no reactive components, inductive or capacitive. This condition does not really exist in a cable system, but for our discussion purposes we will assume so.

When applied to cable system architecture, we now observe that:

- ♦ Every item of electronic equipment requires a certain amount of power (P) for operation. When supplied a specific fixed voltage, the item of equipment will absorb the required amount of power by drawing sufficient current as needed.
- ♦ All electrical conductors (wire and cable) have a specific, very minute value of DC resistance, specified in ohms per foot or 1000 feet, which is inversely proportional to the diameter of the conductor.

Examining the bottom area of Drawing One, any section of cable carrying current will have some small voltage drop per unit of length. As current increases, the voltage drop increases. In this example, the DC loop resistance of the cable is 3.29 Ohms per 1000 feet of cable, and each amplifier station draws .67 amperes. Basic voltage drops in this circuit can now be computed as follows:

.00329 Ohms per foot yields sectional DC loop resistances of:
800' = 2.632 Ohms
700' = 2.303 Ohms
900' = 2.961 Ohms
850' = 2.796 Ohms

Voltage drops can now be calculated as follows:
Amp #4 to #5 = 0.67A X 2.796 Ohms = 1.87 V
Amp #3 to #4 = 1.34A X 2.961 Ohms = 3.96 V
Amp #2 to #3 = 2.01A X 2.303 Ohms = 4.62 V
PI to Amp #1 = 2.68A X 2.632 Ohms = 7.05 V
Total Cumulative Voltage Drop is **17.5 V**

With the power supply at 60V, the load voltage at Amp #5 is therefore (60 - 17.5) or 42.5 Volts AC. It is also easy to see that voltage drops close to the power supply are usually higher since *total current increases as combined towards the supply*.

Basic Power Supply Concepts: Cable AC power supplies are almost always the self-regulating constant-voltage, or Sola^{tm} type. These supplies have proven themselves over many years of field use to be very reliable, and provide limited surge and voltage variation protection. The basic circuit is one in which a transformer with a normally saturated core (at least partially saturated at all times) operates in parallel with a large value of capacitance, and hence forms a parallel resonant circuit at 60 Hertz. This circuit stores energy which then serves to buffer and limit voltage variations on the input side, preventing them from passing on to the secondary or load side. This circuit also creates a quasi-peak (or peaked square wave) waveform on its output which provides some additional benefits:

- Limits the peak voltage, which assists in compliance with local and national codes limiting voltages on communications circuits.
- Provides for a more efficient transfer of power from the source to the load.

The maximum voltage in our system and design is therefore established by our power supply design and code limitations, while the minimum is established by amplifier requirements.

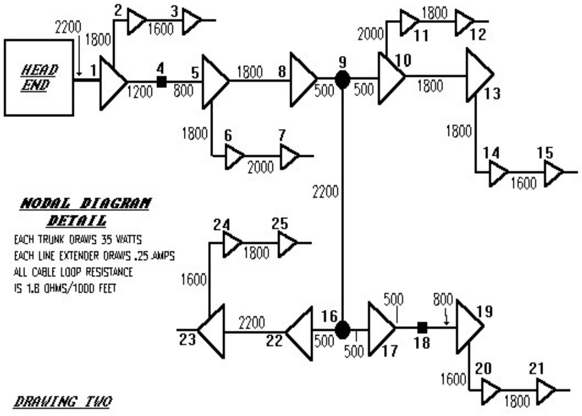
Power Inserter Considerations: There are three basic considerations involved in coupling 60 Hz operating power onto a coaxial cable that also carries (television) RF signals:

1. The RF signal on the cable must not be shorted out in the power supply transformer windings.
2. Noise and other possible interfering carriers or components that might be present on the power line must not be coupled into the cable system.
3. The configuration of the coupling device must not cause adverse reflections on the cable.

The device that actually couples the 60 Hz power onto the coaxial cable is called a power inserter, and accomplishes all of the above. It is typically housed in a splitter-type housing, but may be built into another device such as the AC power supply itself.

Amplifier Power and Current Ratings: Manufacturers rate their equipment typically by either specifying the current drain within a particular voltage range, or by specifying the power draw at a given voltage. Generally, using the power rating will result in more accurate designs, but this is dependent upon the computation technique used in the design process, and the manufacturers method of specifying power or current loading for their equipment. Assuming that you have access to a program that enables you to use power draw as the calculation method, I recommend it. Detailed individual examples of calculations using power ratings are beyond the space and scope of this article, but it is a superior method given certain caveats which will be covered.

Amplifier "Tree" or Nodal Layout: Optimal AC design layout calls for the arrangement of all amplifiers in a tree-type configuration as was shown in Drawing One. A more detailed diagram is now shown in **Drawing Two**.



DRAWING TWO

The nodal configuration should contain the following basic information:

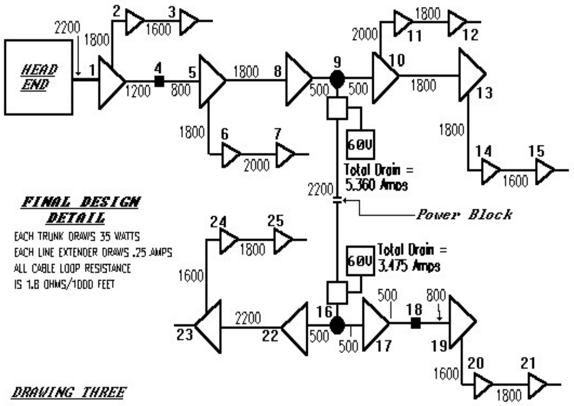
- ♦ Cable sizes, loop resistances, and distances between cable "breaks".
- ♦ The power or current drain of all devices at each point in the system where power is drawn.
- ♦ Location of all current dividing paths i.e., splitters, directional couplers, amplifiers, etc. In other words, anywhere the current can divide or route in a different direction.
- ♦ The location of any point in the system where you suspect you may wish to place an AC supply, either now or in the future. Nodal points #4 and #18 represent typical break points.
- ♦ Assignment of nodal numbers for reference on the tree design. These are for reference purposes, and use in some programs. If you are designing using "current times cable resistance techniques", the nodal or tree-type diagram is of great assistance in laying out and calculating your answers. If you have a more sophisticated approach such as the use of a computer program, the nodal layout will prove valuable in entering and tracking the design.

Basic Current and Power Calculations: Basic calculation techniques involve those demonstrated in the Drawing One example. If the equipment's' AC current rating is used, calculations will employ typical voltage drop calculation techniques as follows. Resistance values are calculated for each section of cable. Current draws are known for each device in the system that must be supplied. Voltage drops for each section of cable are then computed using the Ohms Law formulae E=IR. Be sure to include all currents passing through the section of cable when calculating the voltage drop. For example, if a section of cable has a total resistance of 4 Ohms, and has a current of 2 Amperes (.25A for the local device; 1.75A for other devices downstream) flowing through it, the voltage drop for that section of cable is 8 Volts. Once voltage drops for each section of cable are known, you may start at the supply and sum voltage drops to arrive at specific load voltages at each device. Voltages should not drop below manufacturers recommended levels for that device. If the AC power in Watts is used, an iteration calculation technique should be used that roughly approximates the following:

1. The current draw at **60 volts** for each device is calculated.
2. The approximate load voltage at each location is then calculated given the current loading on all cable lines.
3. Each devices' current draw is then re-calculated using the new load voltage at each location; given preceding voltage drops in the system. This involves the basic principle that a switching regulated device will attempt to draw constant power, therefore the current draw at the device is inversely proportional to voltage supplied.
4. Step 3 is repeated multiple times until voltages calculated on successive iterations at each device do not change by more then a very small amount, typically .001 volt.

Obviously a computer program or programmable calculator is needed for the above iterative approach. This method, when properly applied, will yield very accurate results.

Complete Calculations: **Drawing Three** shows final placement of two AC supplies in our "mini-system".



The following are printouts showing voltage and current drains at all node locations.

POWER SUPPLY AT NODE #9

NODE NO	Voltage	Current (I) Inserted	Total (I) Downstream
1	44.47	0.79	1.29
2	42.85	0.25	0.50
3	42.13	0.25	0.25
4	47.25	0.00	1.29
5	49.10	0.71	2.50
6	47.48	0.25	0.50
7	46.58	0.25	0.25
8	57.20	0.61	3.11
9	**60.00**	**0.00**	**5.36**
10	57.98	0.60	2.25
11	56.18	0.25	0.50
12	55.37	0.25	0.25
13	54.27	0.64	1.14

14	52.65	0.25	0.50
15	51.93	0.25	0.25

Total Current For Supply is 5.3605 Amps

POWER SUPPLY AT NODE #16

NODE NO	Voltage	Current (I) Inserted	Total (I) Downstream
16	**60.00**	**0.00**	**3.47**
17	58.45	0.60	1.73
18	57.43	0.00	1.13
19	55.81	0.63	1.13
20	54.37	0.25	0.50
21	53.56	0.25	0.25
22	58.43	0.60	1.75
23	53.87	0.65	1.15
24	52.43	0.25	0.50
25	51.62	0.25	0.25

Total Current For Supply is 3.4747 Amps

The above calculations assume a minimum permissible voltage to all amplifiers of 40 VAC. Given that restriction, it is not possible to have one power supply feed all amplifiers; not because the supply does not have adequate capacity (most supplies are available in many sizes, but typically are available in the 12A to 15A total capacity range), but because minimum load voltage cannot be maintained. It should also be noted that switching regulated devices are being supplied, which will draw more current as load voltage decreases! **Hence, power supply total current loading will change as the power supply location changes.** Within limits, I try to achieve final supply placement looking for minimum current drain for the area, operating the supply within its proper efficiency range, and while supplying the most devices possible. This requires a delicate balance, and it takes some experience and the proper design program (or methodology) to achieve best results.

Final Discussions and Precautions:, or "Why aren't my calculations closer to what I actually measure in the field?"

Real system voltages often vary from calculated voltages for many reasons. This can be a frustrating exercise if the designer is not aware of them, and expects to measure exactly what they designed for when they make a field trip to compare results. Conversely, if you understand these limitations and caveats, they can be incorporated into your design, or left as "headroom" for the AC design in a similar fashion to distortion calculation techniques over the years.

Reasons for variation between calculated and field levels are as follows:

1. Manufacturers typically publish current and/or power specs for their equipment which are worse case rather than nominal values.
2. Many times, actual system cable footage's are less than those indicated on system maps. This can occur for a variety of reasons, not the least of which is a common practice during strand or as-built mapping of slightly over estimating footage's when in doubt i.e., the measurement seems to be 102 feet, mapper writes down 105 feet or 110 feet.
3. Actual cable "loop resistance" values are often less than the cable manufacturers published values.
4. Many (if not most) designers layout systems using fully loaded amplifier station numbers. For example, you may use a power rating for a trunk station which includes reverse amplifiers, although the stations are installed without them.
5. Some AC voltage meters measure the quasi-peak square-wave signal with some degree of inaccuracy, usually high because of harmonic content present in the signal.

All of the above add to the following scenario. You've carefully laid out your AC design and calculated all parameters. When the system or section is built, you decide to make a field trip to compare measured parameters with computed ones. You find that actual system voltages at various locations are higher, and your total power supply current load is less than anticipated. You can consider this as headroom, or begin to recognize and allow for these various conditional parameters that will affect the overall accuracy of your design. For example, more accurate amplifier power ratings can be obtained by bench testing a large sample under varying AC load voltage conditions, developing your own ratings. This headroom in your design is not necessarily bad, unless carried to a point where it begins to affect the main supply efficiency, plus the quantity/cascade of supplies and therefore overall system reliability (downtime and outages due to power outages).

Modern AC supplies should be loaded at close to 100% of rated value for proper operational efficiency. If significantly underloaded (less than 80% to 85%), the supply's efficiency will fall off dramatically. At best, you end up paying for power which is dissipated as heat. At worst, you'll experience premature failure of supplies in your systems. If your design dictates only 5 to 6 amps at a given location, install a smaller amperage supply to maintain proper efficiency. Many power supply manufacturers now offer graduated values from 5A to 15A. You can choose the size of supply which best meets your design needs.

Mark Bowers
Cablesoft Engineering, Inc.