Cable Capacitance Effects

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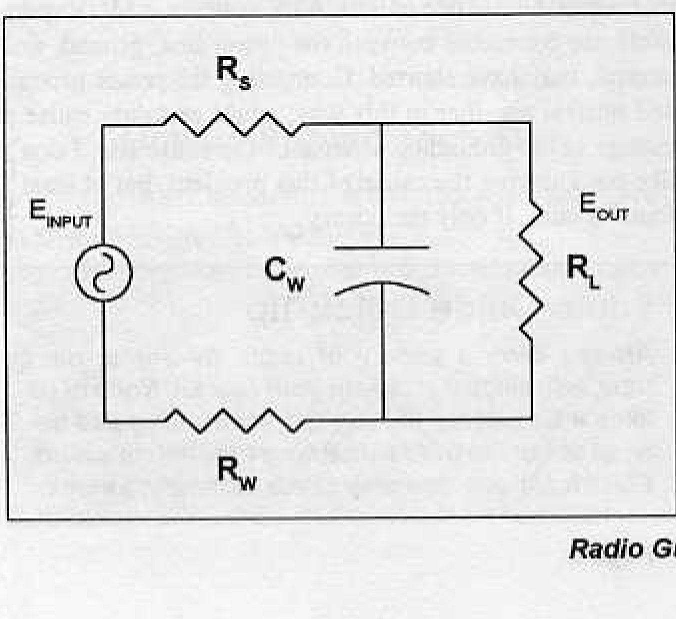
Sometimes when you are writing, you are so busy thinking about what you are trying to say that you don't say it well. You think you explained it thoroughly, but when you have a chance to clear your mind, and come back to it later, you find that you weren't as clear as you thought. This happened in the December issue of Radio Guide (Impedances and Audio — Part 2). Let's try it again.

I was talking about the problems of driving long lengths of audio cable with modern amplifiers, and mentioned that you would get high-frequency roll-off under certain circumstances. Unfortunately, I was not clear on those circumstances.

Any amplifier will have a finite output source impedance. Most solid state amplifiers (including integrated circuits) have a low output impedance, typically in the order of only a few ohms. However, due to the high gain-bandwidth product of most IC amplifiers, the capacitance of longer lengths of cable will create a phase shift in the feedback, that may create a high-frequency oscillation in the circuit. The length of the cable required for this to happen may be quite critical, and you may not run across this in most instances. However, if you happen to get just the right conditions, the results could be very disturbing if not catastrophic.

To reduce the effect of cable capacitance the designers will often place a small amount of resistance in series between the amplifier output and the load. This will tame the oscillation and instability from the cable capacitance, but creates other ill effects. The equivalent circuit of an amplifier with a series resistor and a long length of cable is shown below:

Equivalent Ciruit



R_S is the source impedance of the driving amplifier. R_W is the series resistance of the wire. C_W is the total capacitance of the wire, and R_L is the load resistance. Normally the series resistance of the wire is quite low, only a few ohms.

Let's look at an actual example. We have about 750 feet of Belden 8723, which is a two-pair shielded cable. The specifications of the wire are 15 ohms/1000', 35 pF/foot from conductor to conductor, and 62 pF/foot from any conductor to the shield. In our example we measured a total loop resistance of 23.6 ohms. This translates to about 786 feet of cable. If we measure the capacitance we see 25,000 pF from conductor to conductor in the same pair, which translates to about 714 feet. The differences can be attributed to inaccuracies in the measuring equipment. We will put a 10K load on the end of the wire, which is typical of most modern bridging inputs. If we drive this wire with a plain op-amp circuit (NE5534), a frequency response check shows a slight rise at 20 kHz, which indicates the possibility of an instability in the circuit. If we insert only 100 ohms of series resistance, the response drops by about 1.5 dB. If we increase the value of the load resistance, the roll-off will decrease a bit. Raising the resistance in series with the amplifier output will increase the roll-off.

If we know all the parameters of the circuit, we can predict the amount of roll-off we will have at any frequency. The circuit reduces to a simple three resistor voltage divider with a capacitor across the center resistor. The voltage is applied across the entire divider and the output is measured across the center resistor. If the capacitance did not exist, the formula to determine the output voltage would be:

$$E_{OUT} = E_{INPUT} \times \frac{R_L}{R_S + R_L + R_W}$$

To get the loss in dB, the formula would be:

$$\text{Loss(dB)} = 20\log\frac{E_{OUT}}{E_{INPUT}}$$

To account for the capacitor, the center resistor (R_L) would be replaced by the parallel combination of the capacitive reactance and the resistor. The capacitive reactance is:

$$X_C = \frac{1}{2\Pi f C}$$

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The parallel combination of the capacitive reactance and the resistor is:

$$Z = \frac{X_C R_L}{X_C + R_L}$$

We could work through all of this to give you the complete equation in one, but I will leave that up to you.

If you look at the original equation you will note a few things:

1. The lower the source resistance the less the roll-off.

2. The lower the load resistance the less the roll-off, but the lower the output level.

3. The lower the capacitance (shorter cable lengths) the less the roll-off.

Unfortunately you do not always have control over some or all of these parameters.

There are a number of ways to get around these problems, and some are more effective than others. One method is to use a small power amplifier as a line driver. This type of circuit will provide relatively large amounts of current to the load while still maintaining stability. The disadvantage to this technique is more complexity and perhaps more cost to the circuit. Keep in mind that for an amplifier to deliver large amounts of current to the load, its internal impedance must be very low. That is the real trick to making this method work.

Another technique is simple and low in cost, but very effective. This technique takes the feedback for the op-amp from the point where the series resistor joins the line. Doing this, effectively lowers the output impedance of the circuit to almost zero while maintaining stability for the op-amp. Until recently you had to build this type of circuit from discrete op-amps and resistors, but now Analog Devices has the SSM-2142 available. This circuit provides proper drive for most realistic lengths of cable, while maintaining stability. It also drives either balanced or unbalanced loads with virtually no change in performance.

This brings us to the subject of balanced lines. A balanced line is one in which neither side of the line is grounded. Both sides of a balanced line must be at the same potential and fed with an out-of-phase signal. The circuitry at the receiving end of the line responds to the difference between the two sides of the line. Since most interfering signals that would be induced on the line would be in phase with each other (common-mode), they are canceled at the receiving end.

In the real world, there are a few problems with balanced lines. If anything happens to upset the balance of the circuit, the rejection of the interfering signals will be compromised. Typically this would be caused by unequal wire resistance on the two sides (bad connections or an open side) or unequal impedances to ground from either side of the line (short to ground or an inadvertent load). Another problem that can happen is a mis-match in the gain from the two sides of the line to the point where they are combined. This most commonly occurs with a transformerless circuit. To build a common-mode receiver from discrete op-amps and resistors requires resistor matching better than 1% for good operation. Also, the common-mode characteristics of most op-amps deteriorates with increasing frequency, so you have less rejection of unwanted signals where it is most important.

Again, Analog Devices has a circuit to solve this problem. It is their SSM-2141, and solves the above problems with laser trimming of the resistors on the chip. Simply plug it in and it works!

These IC's from Analog Devices are just some of the many audio circuits they have available. If you would like to get more information on their audio circuits, contact **Analog Devices at One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106**. They have a data book for audio and a very good book of applications for audio. Their phone number is **(617) 329-4700**.

One good application of these circuits is to convert unbalanced hi-fi equipment inputs and outputs to balanced lines for broadcast use. A number of companies have similar circuits available but they are made with discrete op-amps and resistors. These IC's make it simpler and less subject to inaccuracies from resistor tolerances. Professional Audio Services has a kit available made with the Analog Devices chips. For more information contact **Professional Audio Services, 34 North Madison Ave., LaGrange, IL 60525**. The phone number is **(708) 482-4142**. As you use the circuits and look at the books you will probably come up with other uses. As you do, you may want to share the ideas with other Radio Guide readers, as Tech Tips.

Radio Guide Quick-Tip

CB Radio is not dead! It's an excellent substitute for cellular phone, and a heck of a lot cheaper. It's great for extended work, the air time is free, and it's easy to have multiple units on line, for DA work.