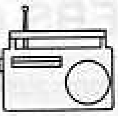
Impedances and Audio — Part 2



Gordon S. Carter — Owner, Professional Audio Svc., LaGrange, IL & C.E. WFMT, Chicago

Last time we looked at impedance matching and the need for it in tube and transformer circuits. This time we will look at the more modern transistor and op-amp circuit, and how impedance is dealt with in them. While we may not specifically say so, remember that whatever we say about transistor circuits also applies to op-amp circuits.

Transistors are essentially a current-operated device. The actual output impedance of most transistor audio circuits is very low, usually less than 100 ohms, depending on circuit topology. (Circuit topology refers to the specifics of the circuit design. You usually do not have to worry about the specifics of the topology, as a user, as long as the circuit specifications are given.)

Many modern circuits have output impedances of around 20 ohms, and power amplifier designs may have actual output impedances of around 0.1 ohm. Since the voltage applied to the load of a device will remain fairly constant, as long as the load is greater than ten times the source impedance, this type of circuit can be used at audio impedances as a constant-voltage source.

One great advantage of this type of circuit is that you can connect a number of moderate loads to it without reducing the output voltage. For instance, if the load impedance of the following devices is 10K, you can connect 10 loads in parallel and still be presenting a 1K load to the source. If the source impedance is 100 ohms, you have only reduced the voltage applied to the load by one tenth. In other words, if the unloaded output of the circuit is 1 volt, you will still have 0.9 volts delivered to the load with ten, 10K loads in parallel.

So far in this article we have been talking about delivering voltage to a load, while previous articles have talked about power. Remember that matching impedances provides maximum transfer of power, which is essential for transformers and some other devices. Delivering voltage to a load, with minimal current, does not provide maximum transfer of power, but may be acceptable if the devices are designed to operate in a voltage mode. This includes almost all modern audio amplifiers.

The low impedance source, high impedance load system, otherwise known as a bridging system, quickly solves the problem of connecting multiple loads to a single source, and even the problem of matching impedances (you just don't). The hi-fi industry standardized on this type of system years ago. All loads are greater than 10K, while the sources are usually less than 100 ohms. Everything works fine as long as your interconnects are short, as in a typical hi-fi system.

However, don't try this with long lengths of cable. Typical audio cable has a capacitance of about 20 pF per foot. Some of the newer low-capacitance cables are less, but this seems to be typical. Don't think that just because you pay a lot of money for the cable, it is low-capacitance. Check the specifications. You may be surprised. "But it is only 20 pF," you may say. "That's not much."

Let's take a closer look. For sake of argument we will use a 50 foot piece of cable, which is not unusual in a broadcast environment. The total capacitance in the cable is 50 x 20 pF, which is 1000 pF or .001 uF. At a frequency of 10 kHz, this works out to be a capacitive reactance of 15,915 ohms. If the impedance of the load at the end of the cable is 10K, the voltage applied to the load will be 4.23 dB lower than the voltage at 1 kHz.

$$X_C = \frac{1}{2\Pi F_C C} \qquad X_C = \frac{1}{(2)(6.28)(10{,}000)(.000000001)}$$

$$X_C = 15{,}915$$

$$V_L = V_S \cdot \frac{R_L}{R_L + R_S} \qquad V_L = 1 \cdot \frac{15{,}915}{15{,}915 + 10{,}000}$$

$$V_L = 1 \cdot \frac{15{,}915}{25{,}915} = 0.61$$

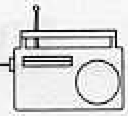
$$dB = 20\text{Log}\,\frac{V_1}{V_2} \qquad dB = 20\text{Log}\ 0.61 = 4.23$$

As you can see, this could be a problem if you are trying to maintain high fidelity in your system. In fact, this would not even meet the FCC requirements for frequency response for a proof. Besides reducing the frequency response of your system, the transient response would also be affected, further reducing your audio quality. Another potential problem is the fact that most transistor circuits do not like to work into a capacitive load. They become unstable and may oscillate under some conditions.

There are ways to deal with this type of problem. Unfortunately much of the equipment on the market today does not. It is not uncommon to see the output of an op-amp directly connected to the output terminals of a device. There may be a series resistor between the amplifier and the output terminals, but this only addresses the stability issue and does nothing to reduce the high-frequency roll-off we have just described. It also raises the apparent source impedance of the device, thus reducing the number of loads that can be applied.

(continued on page 5)

Impedances — Part 2



(continued from page 4)

Reducing the impedance of the load will reduce the affect of the line capacitance on the signal, but will require more current from the driving amplifier to maintain the same voltage. This could be done by simply adding a lower value resistor across the load, but it will do nothing to reduce the actual capacitive load on the amplifier to improve stability.

One of the best ways to address these problems is to use a feedback technique that senses the effect of the load, including the cable capacitance, and then compensates for it in the driving amplifier. While this technique is not a cure-all (eventually you will run out of output capability in your amplifier) it does a reasonable job of dealing with strange loads. I have seen a typical NE5532 output stage, using this technique, be able to drive over 300 feet of typical audio cable and still pass a very clean 1 kHz square wave. The frequency response is virtually flat to beyond 20 kHz, and the amplifier is stable.

Unfortunately, as I said before, very few manufacturers have adequately addressed this problem in their designs. If you are going to be using long cable runs, be sure to check the equipment you are going to use with the cable before you install it. You may save yourself endless hours of frustration.

In summary, if you are using transformers or other impedance sensitive devices, be sure to properly match your impedances. If you are using transformerless devices you can usually bridge the loads. Be sure to check the specification of the equipment before you hook it up, to make sure you are doing it right. Also, if you are using more than just a few feet of cable, be sure your equipment will work properly with the cable attached.

You may have to install a distribution amplifier (careful, they have the same potential problems with capacitance) or change the type of wire you are using or deal with the problem in some other manner.

When in doubt, check the instruction book or run your own tests. You may save yourself a lot of work and trouble in the end.