So what is all this impedance stuff about anyway?

• Impedance 101 (In the beginning, there was the Ohm,….)

Folks who work with video know all there is to know about impedance. Everyone knows that without termination the video is twice as hot as it should be. Just slap on a 75-ohm terminator and everything is OK. Right? Is that your final answer? BEEP… Sorry, try again! I wish things were that simple! The cheap 75-ohm termination you use for NTSC or PAL video may be garbage when used to terminate a 270 MHz serial digital video signal. Let me expound a bit further. But first, let me climb up here onto this soapbox….

Impedance is specified in ohms. This of course makes the un-informed think that impedance is resistive. An impedance of 75-ohms is equal to a 75-ohm resistor. This is sort of correct, but not entirely. What is left out of this is that impedance is a reactive value, which means that it is dependent on frequency.

The definition of Impedance as from the Webster's dictionary is: "something that impedes: HINDERANCE; as A: the apparent opposition in an electrical circuit to the flow of an alternating current that is analogous to the actual electrical resistance to a direct current and that is the ratio of effective electromotive force to the effective current B: the ratio of the pressure to the volume displacement at a given surface in a sound-transmitting medium". So the next time you need to terminate a video cable, just ask your comrade for a 75-ohm hindrance.

Try this test. Use an Ohmmeter to measure the resistance of a Hi-Fi speaker. The speaker may have an 8-ohm impedance, but measure under 2-ohms of resistance. This is because the speaker is made of a coil of wire. When an audio frequency signal is applied, the inductance of the wire blasts into affect leaving the wire's resistance in the dust.

• Impedance 102 (the impedance of a wire)

So I haven't told you anything you don't already know? Bear with me 'cause things will get more interesting as we progress.

A piece of wire has resistance and impedance. But to measure these values you need to make a closed circuit, so I should have said: a pair of wires (in a bundle) has resistance and impedance right? Wrong! A single wire has impedance referenced to ground (that is the earth you are standing on). But this is getting a little too esoteric even for me, so let's concentrate on the impedance of a pair of wires.

Here's a simple case. String a short length of zip cord (that is to say a 10 mile length of 18 gage lamp cord) out in a straight line in your home or office. Measure the resistance between the two wires. You should read an open circuit or you will pop the circuit breaker when you fix your mother's lamp next year. Now pull out your capacitor meter (everyone has one of those, right?) and measure the capacitance between the two wires. Low and behold there will be a reading. There is a formula to calculate the capacitance based on adjacent surface area of the conductors, distance between the surfaces, and dielectric constant of the insolating material between the conductors. So pull out your trusty EE fundamentals text book, plug the numbers into your HP calculator and you can come up with a number of farads for this wire to wire capacitor (OK I really mean Pico farads or microfarads).

- **Impedance 103 (to terminate or not to terminate)**

Am I putting you to sleep yet? And I am not even pulling out any mathematical formulas yet! I promise things will get more interesting to you.

Impedance is frequency dependant. If you measure that 10 miles of zip cord at 100 Hz and then again using a 1Ghz signal you WILL get a different reading. Why, you might ask? Even if you don't ask, I'm going to talk about it anyway. As the frequency of the electricity you are passing down these wires increases, the electrons passing the current get busy and don't want to travel down the center of the wire any more.

Instead they travel down the outside surface of the wire. I personally think that it is like riding in an airplane, the electrons all want a window seat. This phenomenon is called surface or skin effect. When it happens, it causes the impedance of the wire to change. Have you ever heard of Lutz wire? This is special wire ma de up of lots of small-insulated wires. This increases the surface area and decreases the resistive component of impedance for higher frequencies. Some real golden eared folks have been know to use Lutz wire in their Hi-Fi systems to improve the sound.
But I am getting away from what I really want to talk about. When the length of cable reaches and exceeds the wavelength of the signal you are passing through it, something called the "characteristic impedance" of the cable comes into play. Have you ever heard of 75-ohm coax? This is the characteristic impedance of the coax.

It is now time for you pull out your textbook on transmission lines or fundamental field theory (everyone has one of these books, don't they?). There you will find lots of stuff written about this. If you don't care to review your college calculus then I will wave my arms and say "it is obvious to the most casual observer that…" if you DO
NOT terminate a cable with its characteristic impendence then you will get reflections and standing waves on the wire! To put this into English 101 terms, all of the signal that you are passing down this wire WILL NOT get to the other end. Some of the signal will bounce of the end and be reflected back to the sender!

What makes this all the more interesting is to remember that impedance is frequency dependent. A termination that works great at 100Khz may be garbage at 1Mhz.

• Impedance 104 (have I lost my return loss?)

There is a measurement of how good a termination is. That measurement is called "return loss" and is measured in dB. In the simplest terms (the only ones that I can understand myself) return loss is the amount of signal that is reflected back down the cable. A return loss number of 20 dB means that 10% of the single is "lost" 'cause it is returned to the sender. A return loss number of 40 dB means a 1% loss of signal and so on and so on. I sure wish that the checks I send to pay my bills had a return loss spec, don't you?

Needless to say, a large return loss number is better than a smaller return loss specification. A return loss of say 100 dB would be fantastic. A point to remember when reading a manufacturer's specifications is that return loss is a measurement of impedance and so it is frequency dependent. And always remember that what is printed is most likely the best number.

• Impedance 106 (a shameless plug for SVS products)

As frequencies increase, termination becomes more and more important. In the digital world it becomes even more important. A serial digital signal has only two states (0 and 1) that will change with time. If there is not a correct termination, the signal reflections can (and do) confuse the receiver. What is sent as a 0 may be seen as a 1 and what is sent as a 1 could be interpreted as a 0. This of course is the worst that could happen. At the least the reflections will cause the transition edge of the signal to degrade. This will cause jitter in the signal, which confuses the receiver, and it's phase lock loop and will be a source of "soft" errors. The solution to this problem is to terminate your cabling.

Many equipment manufacturers design their equipment with circuit cards that install from the front of the equipment rack and have connectors on the backside of the rack. This is a great idea for servicing because if you need to swap out a circuit board that has problems there are no wires in the way. For standard analog video this works out just fine. There is not a problem with audio equipment designed with this approach either. But up the frequency of the signal to say 270 MHz or 1.5 GHz (where did I come up with these numbers anyway?) and things change.

At the frequencies of digital video, every connector in the signal path will cause a discontinuity in the impedance. This fact is unavoidable and can only be minimized by clever use of connectors and by designing special circuitry to complement the connector. So the old way of designing equipment becomes a problem. The coax cable is plugged into a connector which feeds a motherboard trace to a printed circuit card connector to the another trace and finally to the input circuitry. The output signal takes a similar convoluted path. You can count 5 impedance discontinuities in this scheme. I don't care who you are or how clever you are, designing interconnections of this type with a great return loss spec is a very daunting task.

Compare this to the Sierra Video Systems Digilinx family of modular products, or to our Yosemite series of routing switches. Both of these designs move the input buffer to a circuit that is right next to the BNC connector. We also use a connector from a vendor that actually publishes impedance specifications at digital video frequencies.

It may cost a wee bit more to do it right, but the result is error free video 'cause our return loss is in the noise!

I will admit that if you ever have to remove a module for servicing it is a bit more difficult with rear entry cards. But my question to you is how often do you actually have to remove a failed distribution amplifier module? If the design is solid and the circuit is assembled with good quality components and it is properly tested and burned in by the manufacturer, it is very rare to see a failure in the field. Sierra Video Systems equipment has a meantime between failures of over 15 years. You will be upgrading your entire facility to the new (and undefined) HDTV+2 before you will have to worry about one of our modules failing! Our equipment just keep working, and working, and working….

• Impedance 107 (what does all of this have to do with audio?)

What has all of this got to do with analog audio? Within a facility the characteristic cable impedance of audio twisted pair is meaningless. I know of very few places where the length of the audio cable approaches the wavelength of 20Khz. Where it DOES come into play is thanks to Ma Bell. Once you run your audio several miles, return loss and impedance become important. The impedance of the telephone wire is 600-ohms. So anything you used that connects to the telephone system needs to be 600-ohm terminated, or you are degrading your signal.

If your analog audio system is entirely in plant, then your audio cables are probably short compared to the wavelength of the signal. In this case terminating your cables buys you nothing, and in fact costs you a little bit. If you DO terminate, then every signal driving a 600-ohm load will draw a wee bit of current which you will pay for in your electricity bill (alright I will admit that it is a lot less than a light bulb, but it IS something). The other way to handle your analog audio distribution is to use high impedance loads and low impedance drivers. This has been the de-facto standard for in plant audio distribution for the past 20 years, and now you know why. When we move to digital audio, this changes. The wavelength of a 2MHz digital audio stream is a lot shorter that a 20KHz audio signal and your facility WILL have cable runs that are long enough to require terminations for good operation. The AES/EBU specification assumes that the impedance of the wire pair you are using is 110-ohms and all digital audio equipment is designed with this in mind. There is also a spec for digital audio using coax cable, and surprisingly this spec calls for a 75-ohm termination. What happens when there is a termination miss-match? The same thing as in digital video, the reflections foul up the edges of your digital signal at best causing jitter to increase and at worst causing a 0 to be received as a 1 (or the other way around).

Cheers!
The Doctor

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