DRIVING LOOOONG CABLES

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Microphone or line level cables may appear to be foolproof compared to loudspeaker cables. However, they are not. In particular you can easily encounter high frequency losses or worse. The following shows you how to analyze what happens with longer length cables. As with all good engineering, these calculations are based on maximum or worst case conditions. Some of the numbers have been rounded off for the sake of clarity. In addition, there is no scientific notation: numbers are "spelled out" with all those zeros. Although cable lengths are in feet, metric lengths can be easily substituted.

A hidden point in this article is that creating or getting the most out of audio systems requires doing some math and there is no substitute for this. In case you are a bit "math challenged", examples using real numbers are shown in each case to help you use the formulas. You can substitute your own values to figure out your own particular situation. Also note how two of the most common electrical formulas show up: Ohms Law and the Reactance formula.

dBu figures are referenced to 0 dBu = 0.775V

LOW LEVEL SIGNALS

For low level signals there are 3 things to consider when driving long cables.

1. The length of the cable
2. The cable capacitance between the conductors
3. The output impedance of the device driving the cable

The output impedance and the cable capacitance simply form a low pass filter. You can calculate the high frequency cutoff (-3 dB point) of the cable by using the standard formula for capacitive reactance (Pi is that circle number: 3.14159265359.... etc.):

-3 dB Frequency = 1 / (Capacitance x Output Impedance x 2 x Pi)

Or in this case:

-3 dB Frequency = 1 / (cable length x capacitance per unit length x output Z x 2 x Pi)

For example, suppose you have a 100 Ohm microphone on a 500 foot cable:

-3 dB Frequency = 1 / (500 ft x 32 pf per foot x 100 Ohms x 2 x 3.14)

-3 dB Frequency = 1 / (500 x .000000000032 x 100 x 2 x 3.14) = 100 kHz

This may appear to be far more than adequate. However, the low level, high frequency cut-off (or more precisely, the small signal bandwidth) of all cables in a system should be at least 200 kHz. Briefly, the

reason for this is that each piece or equipment in an audio system, including each interconnect cable, has an upper frequency limit. As such, regard each piece as a low pass filter. When you connect this equipment together, you are connecting a chain of low pass filters in series. This results in a single, multi-pole, low pass filter with a high frequency cut-off that is lower than any of the individual pieces of equipment and cables. By using cable with a small signal bandwidth of 200 kHz, it will not contribute significantly to this low pass filtering, thus ensuring it will have little or no effect on the electronic performance of the system.

If you examine the formula, you will see that the output impedance of device driving the cable can have a profound effect. Suppose the driving device were a distribution amplifier with two 300 Ohm build-out resistors (not untypical for such devices). Its output impedance would be 600 Ohms. In the above example, the cable cut-off would be only 17 kHz!

HIGH LEVEL SIGNALS

For line level signals that are much higher voltage, other factors must be taken into account and these things make matters much worse than for low level signals. Because of the higher voltage levels, you need appreciable current to "charge" the cable capacitance. You must take into account the current to do this and, as one is "charging" a capacitor, the time needed to do this. The time is directly related to the highest frequency you want the system to be capable of handling. The results will surprise you. Unfortunately, there are no shortcuts or rules of thumb to figuring this out. You need to do the math. Here is how the math works.

First:

Calculate the slew rate of the signal (how fast the voltage has to change). This is related to the highest frequency you want the cable to pass. Assume this is 30 kHz at full output (a good number to use for a system calculation) and that you have a typical line level device with a +24 dBu or 12.3 volts RMS maximum output.

Calculate the peak voltage of the device:

Peak = Square root of 2 x RMS

Peak = 1.41 x RMS

For the example device:

Peak = 1.41 x 12.3 = 17.4 volts

Calculate its Slew Rate with this formula:

Slew Rate = 2 x Pi x Frequency x Peak Voltage

Thus for the example device:

Slew Rate = 2 x 3.14 x 30,000 x 17.4 = 3,278,160 volts per second or 3.28 volts per microsecond (3.28V/us).

Second:

Calculate the current required to charge the cable capacitance. The formula is:

Current = Cable Capacitance x Slew Rate

Thus for the 300 foot, 32 pf/ft cable, and the +24 dBu device at 30 kHz this is:

I = 300 x 0.000000000032 x 3,278,160 = 0.031 amps = 31 milliamps

(So you don't have to count them, that's 10 zeros after the decimal point and before the 32)

Third:

Compare this to the output capability of your device. The example +24 device is specified to drive its full output into 600 Ohms. The peak current for this is calculated using Ohms Law:

Current = Volts / Resistance

Or in this case:

Peak Current = Peak Volts / Load

Thus for the example device:

Peak Current = 17.4V / 600 Ohms = .029 amps or 29 milliamps

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This means the cable needs more current than the device is specified to deliver. In this case the device will run into slew rate limiting using 300 feet of this cable. This will cause high frequency distortion (specifically intermodulation distortion) near its full output.

THE EFFECT OF THE LOAD

Virtually all modern audio equipment from microphones to loudspeakers is designed to operate as constant voltage equipment. This means that from no-load to full-load conditions, the voltage output for a given audio signal will not change. For example, a signal processor is rated to drive a maximum 600 Ohm load. You put a sine wave signal through it and with no load on the output measure the output level. If you then put a 600 Ohm load on it, the output level should not appreciably change. A constant voltage circuit means the ratio of the load to the output impedance of the device driving it is at least 10:1. Up to this point much higher ratios have been assumed where the load is a bridging load and does not draw any current from the driving device. Nonetheless, it WILL draw some current along with that needed for the cable. For example suppose the load is 10,000 Ohms (10k Ohms). Using Ohms Law and the device's peak voltage:

Peak Current = 17.4V / 10,000 Ohms = 1.7 or about 2 milliamps.

Thus the current available for the cable is: maximum device current - load current:

29 - 2 = 27 milliamps.

So we can calculate further that the device has 27/31 = 87% of the current needed to charge the cable capacitance. So simply calculate 87% of 300 feet: 0.87 x 300 = 260 feet. This is the longest cable you can use with this device for these conditions to avoid slew rate limiting in the driving device.

Take this a step further, suppose your load is four 10k Ohm amplifiers = 2,500 Ohms load. Now your device must deliver more current. Calculate what you need to drive this load using Ohms Law again:

Peak Current = 17.4 V / 2500 Ohms = .007 amps or 7 milliamps

Subtract that from the total current available from the device to find what you have left for the cable:

29 - 7 = 22 milliamps.

31 milliamps is needed to charge the capacitance in 300 feet of cable and there is only 22 milliamps available from the driving device.

22 / 31 = 71% and 71% of 300 = 0.71 x 300 = 213 feet

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Thus, 213 feet is the maximum cable length you can use under these conditions to avoid slew rate limiting in the driving device.

NOTE: This is a maximum calculation meaning you are calculating that the device is being pushed to its limit. If you want to allow for a safety margin for this limit you would have to reduce the maximum cable length calculated. In this last calculation if you built in a 20% safety margin, the maximum allowable length is reduced to about 170 feet (80% of 213 feet). That is just over half of the 300 feet of cable you started with.

Foolproof? Plug-and-play? Definitely not.

ANOTHER CALCULATION

Suppose you have a device and want to know the longest length of a certain cable that you can drive with it. These two formulas give you the answer:

Maximum Cable Capacitance = Peak Device Current / Slew Rate

Length = Maximum Cable Capacitance / Cable Capacitance per unit length

The answer will be the length in whatever the unit length is in (meters or feet)

Example (using our same +24 dBu device with the 10 k load and same cable type):

Maximum Cable Capacitance = 0.027 / 3,278,160 = 0. 000000008236

Length = 0.000000008236 (= 8236 pf) / .000000000032 (= 32 pf) = 257 feet

This is about what was calculated above for 27 milliamps: 260 feet - the slight difference is because some numbers were rounded.

"TERMINATING" LONG CABLE RUNS

There is still a common practice of putting 600 Ohm or similar terminating resistors at the end of long lines. You can now see a very good reason for NOT putting them there. Once you get over even a few feet of cable your driving device will slew limit well below its maximum output because it is using all its rated current to drive the terminating resistor. Furthermore, it is incorrectly assumed that such a termination lowers the impedance across the line. Actually, the output impedance of the driving device will control the "line impedance". If you have a device with a 50 Ohm output impedance then you have 50 Ohms across the line. If you put a 600 Ohm resistor at the other end the impedance across the line would change to 47 Ohms - not an appreciable difference. Therefore its effects on the line are insignificant. However, it IS very significant in terms of causing the driving device to deliver large amounts of current into a resistor. This will cause the driving device's output to heat up, reach maximum distortion, and generally work very hard to drive the terminating resistor while doing absolutely no useful audio work. Lastly, audio cables are not "transmission lines". Transmission line theory applies only to situations the length of the cable approaches at least 1/4 the wavelength of the highest frequency. For 20 kHz of electrical signal that equals about 2.3 miles (3.7 km). How far did you say your FOH is from your amplifiers on stage?

SOLUTIONS FOR INCREASING CABLE LENGTH

Here are several solutions for increasing the cable length. All of these solutions involve terms used in the calculations. Putting this another way: you must change the value of some term used in the calculations to use a longer cable. Of course you must recalculate the effect of each solution.

1. Use lower capacitance cable.
2. Use a driving device with a higher output capability (voltage and/or current).
3. Use a driving device with a lower output impedance (if its 50 Ohms that's the best you can do).
4. Reduce the load you are driving by dividing it up between outputs of a distribution amplifier.
5. Reduce the signal level over the cable run and put gain back in at the receiving end.

SUMMARY

Do not take long cables for granted. You may not be getting all the high frequency signal through them you think you are. Also, your driving device may be running into trouble due to exceeding its current capabilities trying to drive the cable at high frequencies. It can reach its slew rate limit resulting in noticeable distortion.