Line Level Cables in the Automotive Environment

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The automotive environment can be a very difficult one for line level cables (RCA cables). High voltage sources (the ignition) can create high level radiated noise fields. And because of the low voltage nature of automotive electrical systems, the currents flowing are very high too, leading to higher than usual issues of induced noise problems.

There has often been a recommendation of using CAT5 (Ethernet cable) as a good quality interconnect for automotive use. Some claim CAT5 to even be superior to coaxial cable. The justification given is that because of the supposedly lower inductance of the CAT5, and the twisting of the CAT5, there will be less induced noise pickup, and it will be equal in both legs, thus canceling out the noise in the system.

There are a couple of fatal flaws with these justifications: typically CAT5 has considerably HIGHER inductance than coax cable, and induced currents are not equal in unbalanced systems.
One can check the first fact - the level of inductance - with very simple math. You only need the characteristic impedance and capacitance of the cable, and both of these are typically given for your cable.

The characteristic impedance is:

$$Zo = v(L/C)$$

Where

Zo is the nominal characteristic impedance
L is the inductance, in Henrys
C is the capacitance, in Farads

Manufacturers nearly always list Zo and C for you; as such, solving for L is extremely easy!

$$L = Zo^2 * C$$

Consider a common coaxial microphone cable from Belden, Belden 8412. The characteristic impedance is 10.2 Ohms, and the capacitance is 30 pF/foot. This means the inductance is a very low 3.1 nH (nanoHenries) per foot.

Now look at a common CAT5 cable also from Belden, Belden 1583E. The characteristic impedance is 100 Ohms, and the capacitance is 49 pF per foot. This yields an inductance of 490 nH per foot, or over 150 times HIGHER than Belden 8412!

Given that a higher inductance does indicate a higher susceptibility to induced noise problems, it becomes clear that CAT5 - especially as compared to the common 8412 cable - is considerably worse from an induced current noise standpoint.

The other justification often given is that noise induced on the cable will be equal on the two strands, because of the twisting of the cables. However, this is not the case in unbalanced systems! In unbalanced systems - like all RCA based car audio systems - you have unequal terminating impedances on the two lines (signal and ground). As such, you get different induced currents based upon a given field strength.

Only in a balanced system, where you have the same terminating impedance, would you have equal currents. Having different currents means you will have higher noise, since there will be an induced voltage added to the cable (thanks to Ohm's Law).

Along these lines, we conducted a few tests to show the advantages of coax over CAT5.

CABLES

Cables will only be tested in unbalanced connection mode, since this is the vast majority (99%+) of all car audio installs. Single ended RCA connections are used. Balanced systems are in the extreme minority, and still are used to convert the single ended/unbalanced connections of the head deck and other electronics to each other.

COAX
For the coax, I used 4 runs of Belden 8412. The shield on the outside was ground, the center conductors were connected in parallel at each end.

On the far end, I installed a 47 kOhm load installed from the center to shield at one end of each cable run.

On each end of the cable, I used a 150 Ohm resistor to connect the shield to ground.

CAT5
For the CAT5, I used a single run of standard CAT5 cable. The shields were the striped conductors, the solid conductors carried the signals.

On the far end, I installed a 47 kOhm load from each signal to each shield.

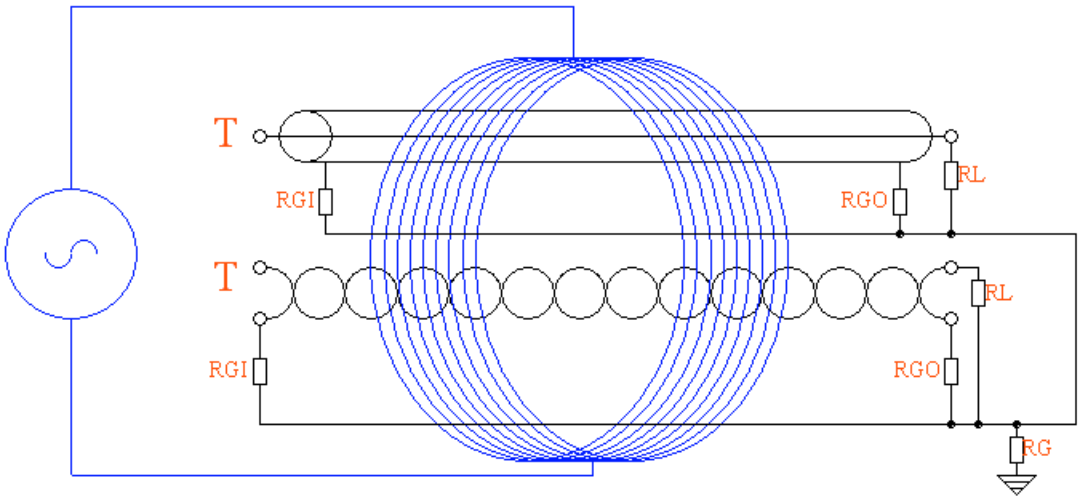
On each end of the cable, a 150 Ohm resistor connected each shield to ground.

INDUCED TEST

I ran all 5 cables (4 coax and 1 CAT5) through the center of a high power inductor. This inductor was the voice coil of a Brahma subwoofer, with the voice coils wired in series (raw voice coil, out of the driver).

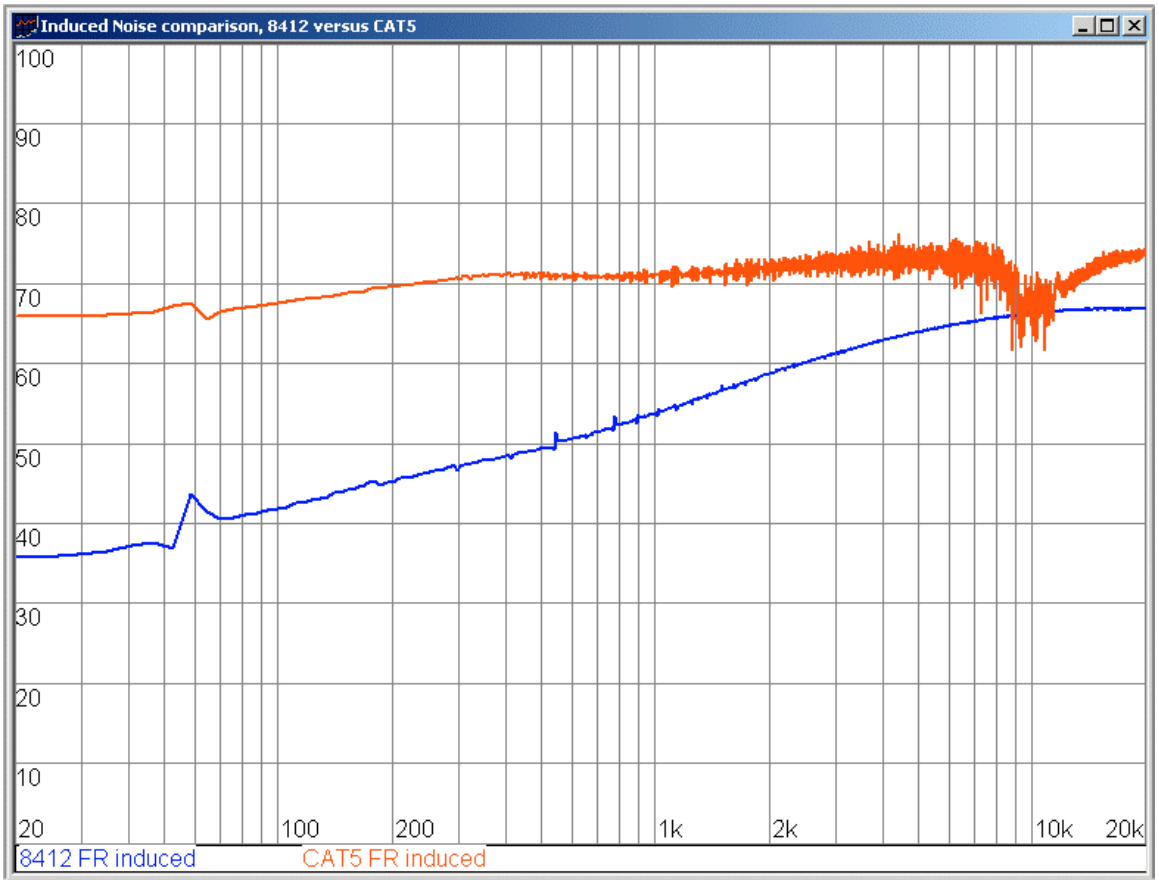
I used Praxis to generate a CHIRP sweep from 20 Hz to 20 kHz. This sweep was sent to a QSC PLX3402 amp, which was connected to the inductor.

I connected the probe line for Praxis (stimulus measurement) to the signal sent to the QSC. The mic line (output measurement) was connected to the near end signal, referenced to ground (point T).



In this manner I was able to sweep a 20 Hz to 20 kHz signal into a magnetic field, then measure the induced signal pickup in the cable. I could get the rejection of the signal across all frequencies, and would get a measured "induced" frequency response of each cable.

The results of the measurement are here:



The blue line is for the 8412; the red line is for the CAT5. As we can see, the 8412 enjoys a healthy 10+ dB better rejection at all frequencies below 3 kHz; at the low end (100 Hz) there is over 26 dB better rejection of the induced currents/signal.

Even at the high end of things, 20 kHz, the 8412 has a good 6 dB lower pickup than the CAT5.

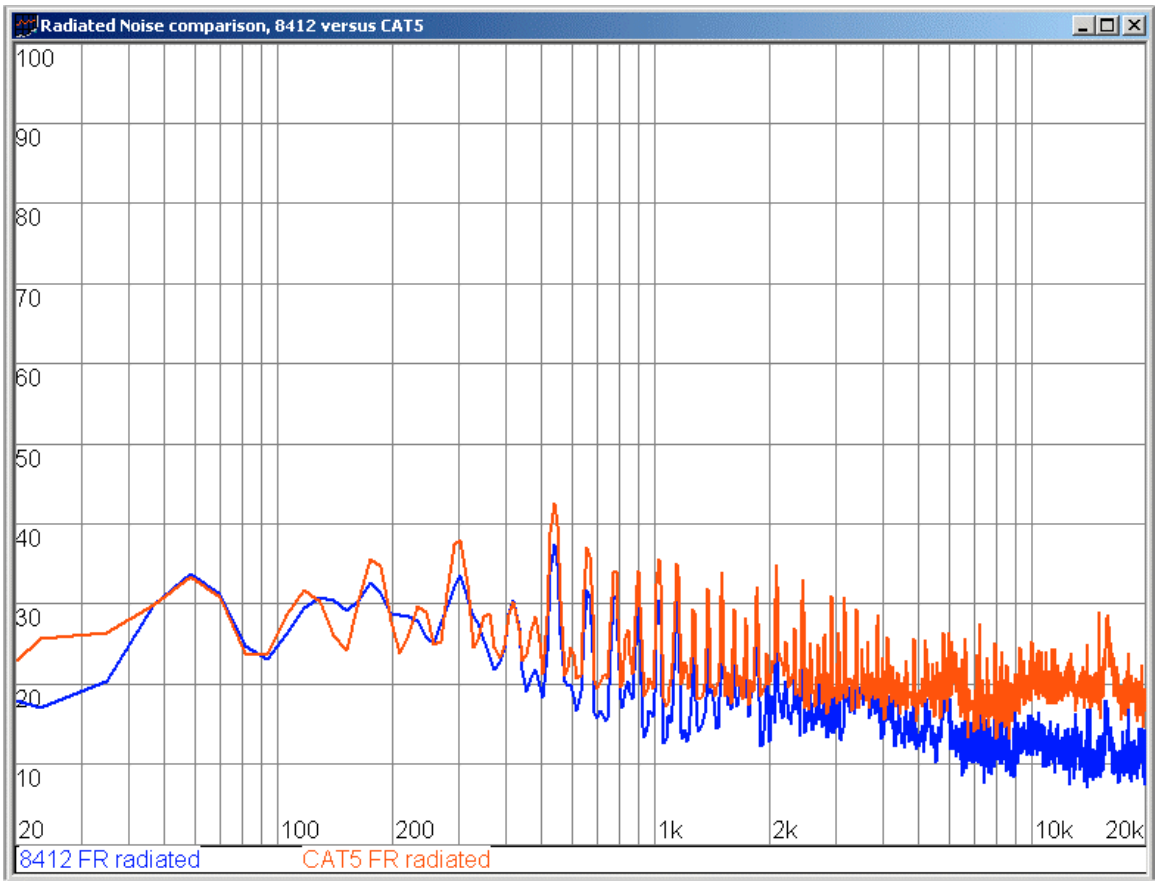
CONCLUSION: for rejection of induced noise, a decent quality coax (note that 8412 is available for $0.30 in 100 foot lengths) is vastly superior to CAT5. In the deeper frequencies from 20 Hz to 50 Hz (corresponding to 1200 to 3000 RPM), the 8412 enjoys more than 30 dB better rejection.

RADIATED TEST

Since induced current isn't the only source of noise, I also tested radiated noise issues. For this test I stretched all cables in a bundle across the hood of my truck (a 1999 Ford Ranger XLT with the 2.5L four cylinder engine). The cables ran from the center of the bottom of the windshield to just above the top center of the license plate.

Then I placed the Praxis system into a standard RTA mode (16384 point RTA/FFT collection). The engine was left idling, and the near end of each cable was connected to the test gear. The radiated noise pickup was measured.

The results of the measurement are here:



The blue line is for the 8412; the red line is for the CAT5. As we can see, the two cables are nearly equal down in the deep end of the spectrum (below 300 Hz). Above 300 Hz, the 8412 begins to show superior rejection of noise, and in fact in the top octave (from 10 kHz to 20 kHz) the 8412 has a solid 8-10 dB advantage in noise rejection, as compared to the CAT5.

CONCLUSION: for rejection of radiated noise, a decent quality coax cable is superior to CAT5. In the higher end of the spectrum (above 1 kHz), the advantage grows from 3 dB to as much as 10 dB, which would have the effect of lowering the system noise floor by up to 3 to 10 dB.

CONCLUSIONS

Overall, the 8412 coax showed superior performance to the CAT5, at all frequencies in the audible spectrum. This advantage is quite large, ranging from more than 30 dB for a large portion of the induced bandwidth, to 6+ dB for the top two octaves of the radiated noise spectrum.