Cables or other metal (antenna-like) structures often couple to sources of common-mode currents and end up radiating, causing product failures during compliance testing. During the troubleshooting process, it would be helpful to determine the resonance of these cables or structures to confirm they are the source of certain harmonic signals.

We could certainly measure the length of the cables or metal structures, but often, they are connected to other conductive assemblies, such as circuit boards or brackets. Because of these system inter-relationships, it's not always easy to predict the resonances within a system, and so there's always a little uncertainty as to where to start the troubleshooting process. These simple techniques may help quickly identify potential resonances within your system or product.

There are several methods for measuring resonance; (grid) dip meters, H-field probe driven by a network analyzer, or by using a pair of current probes.

While you can still purchase (grid) dip meters, I've never had great luck using them, because they don't seem to couple well to short cables or metal structures. Several years ago, my colleague, Scott Roleson (Hewlett-Packard) came up with a unique measurement method by using an h-field probe and 20 dB coupler along with a network analyzer. This was published internally within HP and also in the 1990s (References 1 and 2). High frequency measurement expert, Doug Smith, later referenced this technique in one of his "technical tidbits" (Reference 3).
Smith also developed a unique resonance measurement method using a comb generator and pair of current probes clamped around the cable in question. See Reference 4. One probe is used to inject the closely-spaced harmonics into the cable to be measured. The other is used to pick up the resonant currents (Figure 1). In fact, you don't even need commercial current probes for this test. DIY probes as shown in Reference 5 should work equally well. This is ideal if you don't have a network analyzer or spectrum analyzer with tracking generator. The little comb generators from Applied Electromagnetic Technology (AET) are perfect for this, because they can be powered from a standard USB port or battery-powered USB power source.

I have two of these comb generators - one with a 10 MHz oscillator (model USB-S-10) and a 1.8 MHz oscillator (model USB-S-1.8432). As you'll see, the model at 1.8 MHz offers a lot more resolution for typical cable lengths. These comb generators, designed by Dr. Bruce Archambeault, are available at relatively low cost from AET.

In this article, I'd like to compare both the 1.8 and 10 MHz comb generators with the tracking generator feature on the Rigol DSA815TG spectrum analyzer. The BNC cable to be measured is approximately 51 inches in length (1.3 m). Since the cable is open circuited at both ends, it ought to resonate at a half-wavelength. Using the standard formula relating frequency to wavelength, we calculate a full-wave resonant frequency in MHz = c/L(m) = 300/1.3 = 230.7 MHz, or for a half-wavelength, 115.4 MHz (in free space). Because the speed of light in a copper wire or cable is lower by factor of about 0.8, we should expect it to actually resonate at around 115.4 * 0.8 = 92 MHz.

We'll first start with the 10 MHz model comb generator (10 MHz harmonic spacing). As you can see in Figure 2, there is a large resonance about 90 MHz. It was just sheer luck that the cable resonance landed right on top of one of the comb harmonics. Otherwise, the peak would not have been nearly as distinct. Notice that the normal harmonics from the comb generator are greatly suppressed away from resonance.
Next, we'll switch in the 1.8 MHz model (1.8 MHz harmonic spacing), which injects many more harmonics. Figure 3 shows the result and you can observe several more harmonics surrounding the resonance frequency. The Q of the cable can be determined from the width and amplitude of the resonance peak. Notice, also, the peaks at twice and three times the resonance in both the figures above. Because of the much greater resolution, I recommend this model comb generator for general purpose resonance measurement.
Finally, we'll compare the results with the Rigol DSA815TG spectrum analyzer with tracking generator (Figure 4). As you can see, all three primary resonances remain right on 90 MHz. The secondary resonances may still be seen. Because not everyone has access to a network analyzer or tracking generator, the small 1.8 MHz comb generator might be handy to add to your troubleshooting toolkit.
One interesting aspect that will come in handy for troubleshooting when measuring the resonance of cables, is whether it should resonate at a quarter-wave or half-wave. In the case above with the isolated cable (disconnected at both ends), you would expect it to resonate at the half-wavelength frequency (infinite impedance at both ends). However, what would happen if we were to connect one end to a product? If we tie one end to chassis ground, we ought to expect it to resonate as a quarter-wave, due to the reflection (or image) of the cable in the chassis. Because the effective dipole is now twice as long, the resonant frequency should be half that of the disconnected cable. Figure 5 shows the new resonance at 46 MHz, approximately half that before. Theory works!

Using simple tools, you can measure the actual resonance of cables and cables attached to circuit boards or other sub-assemblies. Identifying the resonance of cables, or other structures, will help during troubleshooting of EMI issues.

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See also:

PC board resonance and the "balloon effect"

Questions on cables for EMC mitigation

Identifying emission sources and radiating structures
Using a tracking generator

Product review: Rigol DSA715TG spectrum analyzer

References


