Reducing scepticism in emissions measurements

Familiarity with a test system design boosts confidence in laboratory test results

WHEN READING THE maximum emission level on the display of a receiver and comparing it to the limit line, how sure are you that the unit under test has passed or failed? What is your window of confidence? This article advocates familiarity with the design of the test system to provide greater confidence in test laboratory results.

INTRODUCTION

The low field strength level limits specified by auto industry emissions standards present a measurement challenge, and it is perfectly reasonable for a paying customer to ask on what engineering grounds a decision to pass or fail a product has been made. Customer confidence in the results is enhanced by the test operator's ability to display insight into the intricacies of the system design.

MEASURING FIELD STRENGTH

Figure 1 shows a typical test equipment configuration for measuring 1-to 18-GHz emission levels.

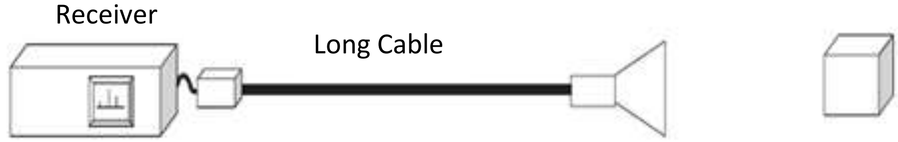


Figure 1: Typical Emissions Set-Up

The measurement system consists of an antenna to collect the emitted noise fields, a long interconnecting cable to feed the antenna voltage signals to a distant (several yards away) receiver, and a pre-amplifier to boost the signals so the receiver can discern them from noise created within the test system.

The field strength of a particular emitted signal is calculated from the equation

$$E = V + AF + C - G$$

Where E = the field strength in dBμV/m
V = the voltage indicated on the receiver display in dBμV
AF = the antenna factor of the receiving antenna in dB
C = the cable loss in dB,
And G = the amplifier gain in dB

SYSTEM FREQUENCY DEPENDENCE

None of the test components in the RF line-up feeding the receiver has a flat frequency response. This situation is commonly seen when using a network analyzer in a test bench situation as shown in Figure 2. In this case, a calibration procedure is used to normalize out the non-flat response of the test train—*i.e.* the input cable connected to the device under test is connected directly to the output cable so the entire test train can be characterized

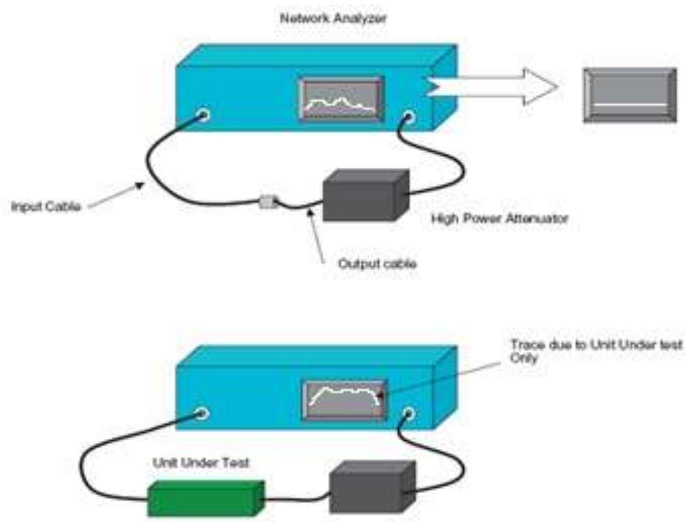


Figure 2: Normalizing a bench test setup

The network analyzer feeds the train with a swept frequency test signal, and a response plot is obtained. The plot is stored in memory and is subtracted from the display to give a flat horizontal line. The device under test is then connected between the input and output cables, and its frequency response is read directly from the screen. This approach has an inherent advantage in that there is no further need to account for the frequency response of the test line up.

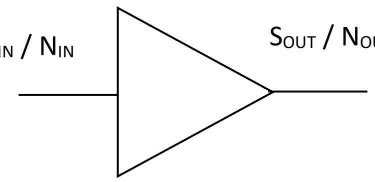
The test bench situation described has a closed loop configuration. The emissions test setup has an open loop configuration—*i.e.*, it gets its input signals via the antenna from an outside source.
With this configuration, there is no fast and simple self-correction method to compensate for the non-ideal response of the test line up. Perhaps, in the future, a field generator with constant output over frequency will exist. Meantime, correction data are input to the receiver during system calibration so that the internal processor can adjust the received signal levels prior to displaying them.

The correction data are input only once between formal system calibrations. To confirm system integrity prior to a test run, a previously measured field source such as a comb generator/antenna combination is used to confirm the performance is as previously recorded. Figure 3 shows comb generators (with integrated antennas) designed specifically for this purpose.

Figure 3: Com-Power comb generator Model CGO-5100B covering 1-18GHz (left) and Model CGO-51000 covering 1-40GHz

SYSTEM NOISE OPTIMIZATION
When dealing with small signals in the presence of noise, systems engineers in non-EMC related industries invariably place the pre-amplifier ahead of a lossy cable. For example, consider the mast-mounted receive amplifiers at cell phone base stations. To understand this choice, we need to revisit the concept of amplifier noise factor.

Noise factor F is the ratio of signal-to noise in to signal-to-noise-out.



$$F = \frac{S_{IN}/N_{IN}}{S_{OUT}/N_{OUT}}$$

The noise-in is part of the input signal. The noise-out consists of the noise from the input noise (noise-in multiplied by amplifier gain) plus the noise added by the amplifier itself.

$$N_{OUT} = GN_{IN} + N_{ADD}$$

Also

$$S_{OUT} = GS_{IN}$$

so

$$F = \frac{S_{IN}/N_{IN}}{N_{OUT}/S_{OUT}} = \frac{S_{IN}\ N_{OUT}}{N_{IN}\ S_{OUT}}$$

$$= \frac{S_{IN} . (GN_{IN} + N_{ADD})}{N_{IN}\ GS_{IN}}$$

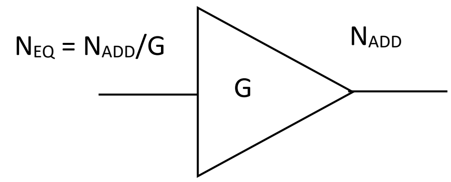
resulting in

$$F = \frac{(GN_{IN} + N_{ADD})}{GN_{IN}} \qquad (1)$$

Essentially, the noise factor is the ratio of (total-output-noise) to (noise due to the input-noise).

Friis derived the equation in a slightly different manner, allowing patterns to be recognized when the total noise figure of a cascaded amplifier system is calculated.
The trick employed is to refer the noise added by the amplifier to the input, and to call this the equivalent noise, N_{EQ}.

That is:



$$N_{EQ} = \frac{N_{ADD}}{G}$$

So

$$F = \frac{S_{IN}/N_{IN}}{S_{OUT}/N_{OUT}} = \frac{S_{IN}.N_{OUT}}{N_{IN}.S_{OUT}}$$

$$= \frac{S_{IN}.\,(GN_{IN} + GN_{EQ})}{N_{IN}\,GS_{IN}}$$

$$= \frac{(GN_{IN} + GN_{EQ})}{GN_{IN}}$$

Giving

$$F = \frac{1 + N_{EQ}}{N_{IN}} \qquad (2)$$

For a cascaded amplifier arrangement (Figure 4), the total noise factor F_T is:

$$F_T = \frac{S_{IN}/N_{IN}}{S_{OUT}/N_{OUT}} = \frac{S_{IN}.N_{OUT}}{N_{IN}.S_{OUT}}$$

$$N_{OUT} = G_1G_2N_{IN} + G_1G_2N_{EQ-1} + G_2N_{EQ-2}$$

And

$$S_{OUT} = G_1G_2S_{IN}$$

Therefore,

$$F_T = \frac{S_{IN}}{N_{IN}} = \frac{G_1G_2N_{IN} + G_1G_2N_{EQ-1} + G_2N_{EQ-2}}{G_1G_2S_{IN}}$$

$$= \frac{G_1G_2N_{IN} + G_1G_2N_{EQ\text{-}1} + G_2N_{EQ\text{-}2}}{G_1G_2N_{IN}}$$

$$F = 1 + \frac{N_{EQ\text{-}1}}{N_{IN}} + \frac{N_{EQ\text{-}2}}{G_1N_{IN}}$$

Careful study allows patterns to be recognized. The first two terms of F_T are the noise factor of the first stage (see Equation (2)).
Ignoring the G_1, the third term is the noise factor of the second stage only it does not have the 1 + in front.

That is:

$$F_2 = 1 + \frac{N_{EQ\text{-}2}}{N_{IN}} \quad \text{so} \quad \frac{N_{EQ\text{-}2}}{N_{IN}} = F_2 - 1$$

Therefore F_T can be rewritten as:

$$F_T = F_1 + \frac{F2 - 1}{G1} \qquad (3)$$

This is the Friis noise equation for two amplifiers in cascade. It states that the total noise factor is equal to the first noise factor plus the second noise factor reduced by the gain of the first stage. If F_1 is low and G_1 is very high the total noise factor will be low. Conversely, if F_1 is high and G_1 low, the total noise figure will be high.

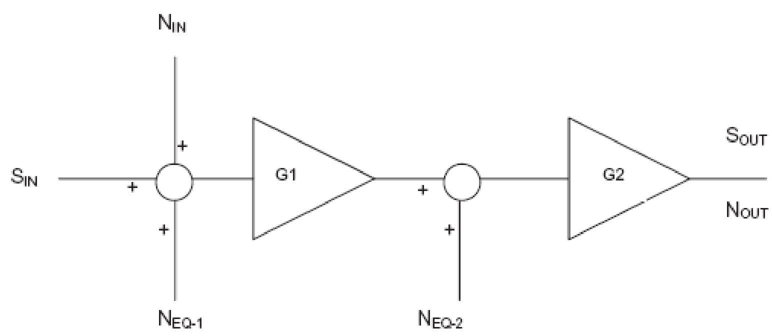


Figure 4 Two amplifiers in cascade (Use of N_{EQ})

This conclusion goes against natural intuition that pre-supposes that gain is gain, that loss is loss, and that whatever combination you put them in, the overall outcome will be the same. As regards the signal, this assumption is absolutely true. The same cannot be said of the overall noise produced. The concept is explained graphically in Figure 5. (The input noise used has value kTB where k is Boltzman's constant, T is absolute temperature in Kelvin, and B is the bandwidth). The left-hand side shows the total output noise produced by amplifier X (low-noise, high-gain) followed by amplifier Y (high-noise, low-gain). The right-hand side shows the total noise for the arrangement in reverse. It can be seen that simply reversing the order of X and Y results in a considerable change in the total noise output. Note that amplifier X has only twice the gain of Y. In actual use, the gain would be much higher. Also, Y is only twice as noisy as X. Again, in actuality, Y would usually be considerably noisier than X. In a real system, the difference in added noise will be more pronounced.

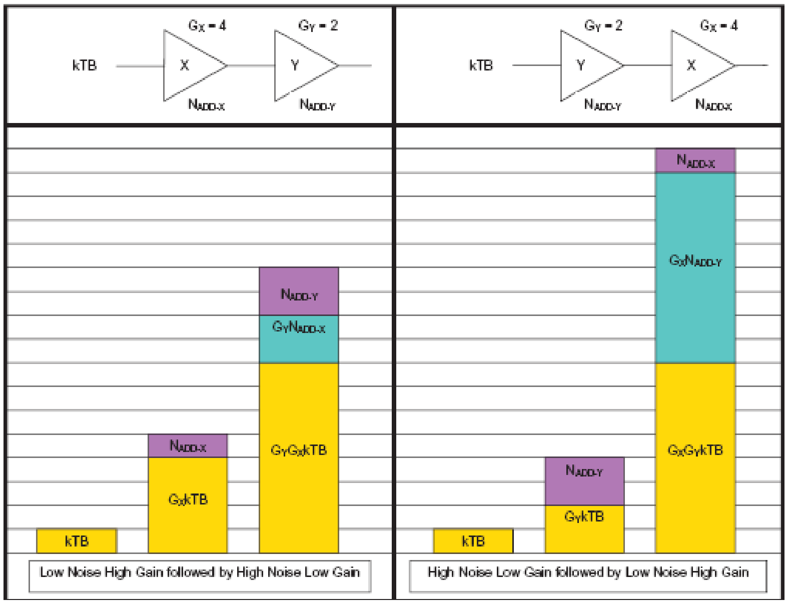
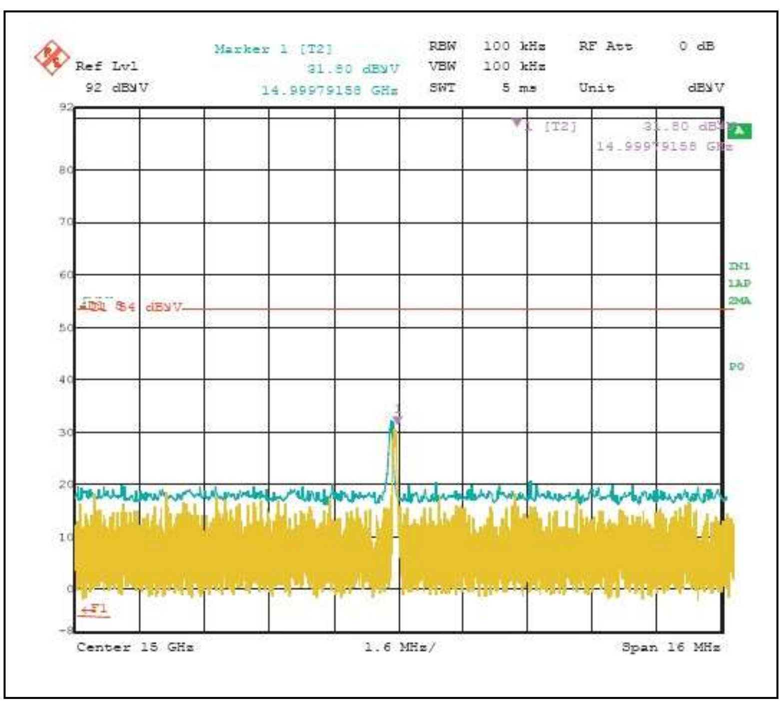


Figure 5: Total noise produced by cascaded amplifiers

How do these observations apply to an emissions test setup? To utilize the Friis noise equation, we need to assign a gain and a noise factor to the lossy cable.
The gain is easy. If the cable attenuates a high frequency signal by 10 dB, then in linear terms, this is the same as multiplying by 0.1 so the "gain" of the cable G_{CAB} is 0.1.

Regarding noise factor, Figures 6 and 7 demonstrate signal attenuation because a real cable is used in an emission test setup. It can be seen that the signal itself is attenuated, but the noise floor remains constant. Therefore, the signal-to-noise ratio has been decreased by the cable attenuation.

Figure 6: Signal level at input to cable



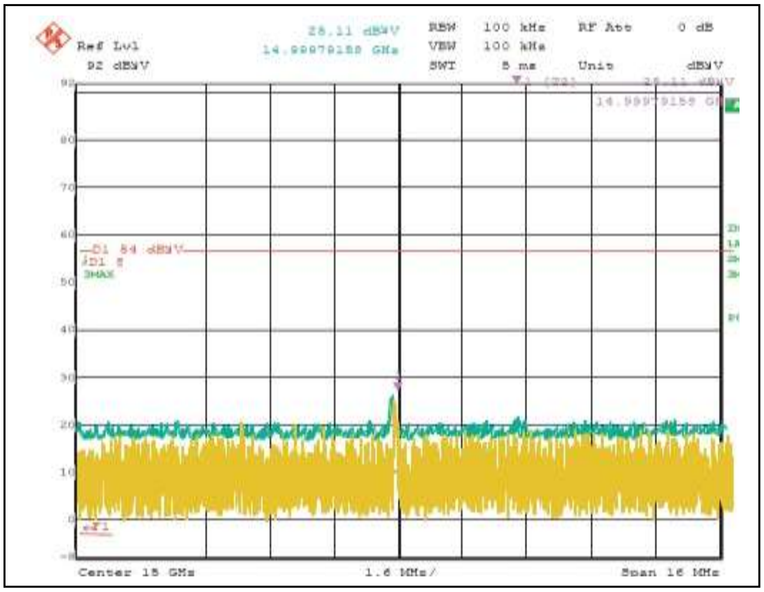


Figure 7: Signal level at output of cable

The noise factor of the cable F_{CAB} can be deduced using the initial definition of noise factor.

$$F_{CAB} = \frac{S_{IN}/N_{IN}}{S_{OUT}/N_{OUT}} = \frac{S_{IN}.N_{OUT}}{N_{IN}.S_{OUT}}$$

Noise-out equals noise-in so

$$F = \frac{S_{IN}}{S_{OUT}}$$

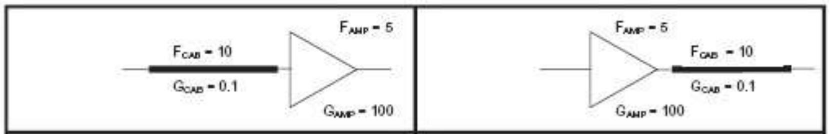
S_{OUT} is 10 dB lower than S_{IN}, which equates to one tenth of S_{IN}.

Therefore

$$F_{CAB} = 10.$$

Combining this cable with a realistic pre-amplifier that has a power gain of G_{AMP} = 100 and noise factor F_{AMP} = 5 allows us to make a realistic performance comparison between cable/amplifier and amplifier/cable combinations.

Figure 8 shows the results. For the cable/amplifier combination, the noise factor is 50.
For the amplifier/cable combination, the noise factor is only 5. In dBs this is 17 dB and 7 dB, respectively.
This 10-dB improvement ripples all the way through the test system to give an overall signal-to-noise improvement of 10 dB. At the small level of signals being monitored, this improvement is significant and well worth having, particularly when performing the initial wide sweep for emission hot spots.
A smart way of implementing the amplifier/cable solution is to integrate the two into one assembly. Two examples of this approach can be seen in Figure 9.
Note that the integrated amplifier is easily disconnected, allowing the antenna to be used in transmission mode.



$F = F1 + \frac{(F2-1)}{G1}$	$F = F1 + \frac{(F2-1)}{G1}$
$F = F_{CAB} + \frac{(F_{AMP}-1)}{G_{CAB}}$	$F = F_{AMP} + \frac{(F_{CAB}-1)}{G_{AMP}}$
$F = 10 + \frac{(5\text{-}1)}{0.1}$	$F = 5 + \frac{(10\text{-}1)}{100}$
$F = 10 + 40$	$F = 5 + 0.009$
$F = 50$	$F = 5.009$
NF = 17 dB	NF = 7 dB

Figure 8: Effect of placing pre-amplifier ahead of lossy cable

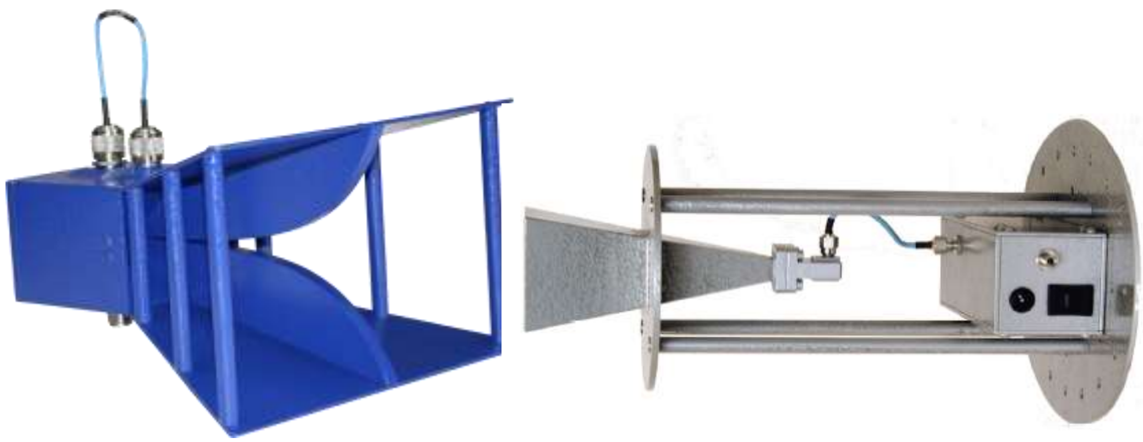


Figure 9: Com-Power active horns Model AHA-118 (1-18GHz) and Model AHA-840 (18-40GHz)

CONCLUSION

Two crucial factors are often overlooked in emissions measurements. Cable loss can adversely affect the dynamic range of the system, and that reduction in dynamic range can make it impossible for a pre-amplifier to recover signals lost in the system noise floor. The considerable advantage gained by placing a high gain, low noise amplifier at the front of a RF test train is now evident, and we see how base station designers put pre-amplifiers at the top of a mast ahead of the lossy feed cable. Once thoroughly familiar with most or all test system intricacies, EMC engineers can support pass/fail decisions from an informed standpoint. A system operator who displays ownership of a system by being thoroughly familiar with the system limitations will instil far more confidence than one who operates a system blindly. This article covers only one of the design intricacies involved in RF emissions systems. Readers new to emissions testing are encouraged to delve deeper into the system design. The system supplier is probably the richest source of design details.

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