Dynamic Sciences International, Inc.

Application Note

DSI-600 EMI TEST SYSTEM

Application Note No. 2.01

Subject: ***Pre-Amplification***

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DSI Application Note

Pre Amplifiers for EMI Receivers, Pros and Cons

Scope

This application note describes the rationale for the use of Preamplifiers with Receivers for EMI Measurements.

Background

Receivers for EMI Measurements are characterized by a long list of parameters. For our application, Sensitivity and dynamic range are of prime importance.
In order to obtain the best sensitivity and enable measurement of low-level signals, the total noise and signal attenuation in the measurement system has to be limited.

Attenuation in the signal path is typically due to cables between the sensor – antenna, current probe etc. And the Receiver input port.

Noise in the measurement system is due to the thermal noise in the system. In very sensitive systems, such as satellite communication links, systems are cooled down to very low temperatures by liquid hydrogen to limit this thermal noise. In EMI Measurements, the temperature is that of the environment.

The expression of the sensitivity of the receiving system is given by:

$$P_0 = NF + n_0 + \frac{S}{N}, dBW \qquad 1$$

NF=Noise Figure of the System
n_0=Reference noise floor
S/N=Desired signal to noise ratio

The Reference Noise n_0 is the physical measure of the thermal noise power associated with the movement of electrons in any conductor. This value is quantified by:

n_0=kTB, Watt/Hz

k=Bolzmanns Constant = $1.3*10^{-23}$ Joules/Degrees Kelvin
T=Degrees Kelvin=290^0,
B=Bandwidth of the system input port, Hz.

NF is the measure of how much noise power is added by the system
S/N is a measure of how much the signal must be above all the noise to be interpreted correctly, up to an allowable distortion or Bit Error Rate (BER).

Expressing the Reference Noise Power in dB:

$n_0 = 10\log_{10}(10^3 k\ T) = -174$dBmW/Hz

There is little to be done to limit the Reference Noise, in a given environmental temperature and given band width. We would like to add as little as possible system noise power (NF) to this value, to obtain the best possible sensitivity.

Adding Amplifiers to a Receiver

It seems almost intuitively obvious that amplifying the weak measured signal will improve the systems sensitivity. Let us examine this option in some detail, concentrating on the limiting factor of the sensitivity, noise.

The receiver may have a low noise amplifier of some sort at the input port. The noise power **P** out of this amplifier is due to the Reference Noise Power symbolized here as **T,** and the noise contributed by the amplifier itself, $\mathbf{T_N}$**,** multiplied by the gain of this amplifier, **G.**

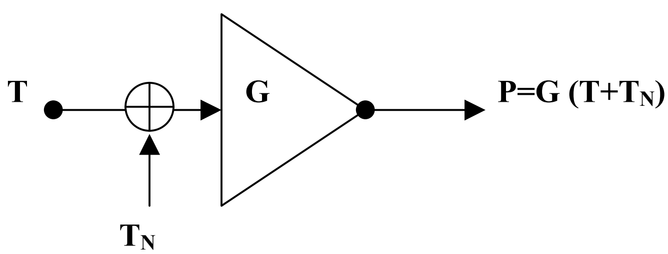

Figure 1, Noise power sources in an amplifier

Let us now define a useful parameter, the noise factor:

$$F = \frac{Practical.OutPut.Noise.Power}{Ideal.OutPut.Noise.Power} = \frac{G \cdot (T_N + T)}{G \cdot T} = \frac{T_N + T}{T} \qquad 2$$

The well known Noise Figure is related to the noise factor by:

$$NF = 10\log_{10}(F), \text{ dB}$$

Now let us add an amplifier to the input port of a receiver, by "cascading" the amplifiers, one after another in the path of the signal:

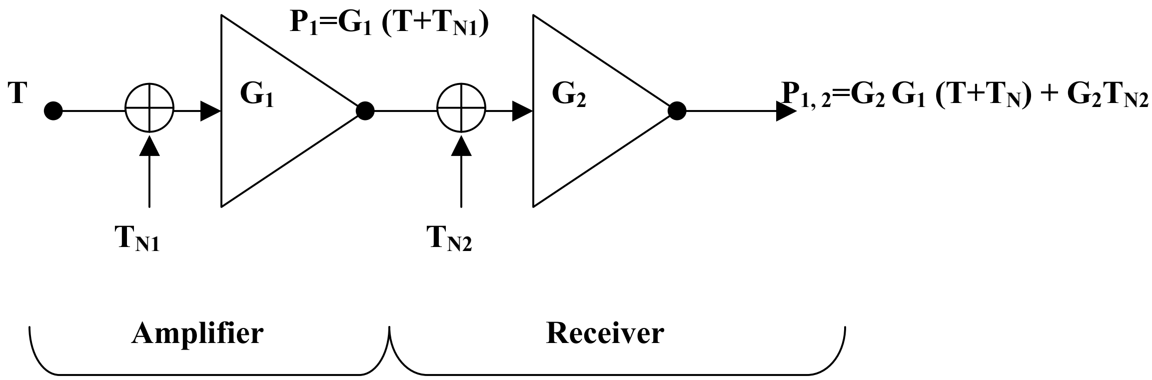

Figure 2. Cascaded Amplifiers

In this arrangement, we expect the overall sensitivity to be appreciable better than would be obtained by the receiver only. To check this, we will first assign the noise factors to the receiver, F_2 and the amplifier F_1:

$$F_1 = \frac{T_{N1} + T}{T},$$

$$F_2 = \frac{T_{N2} + T}{T}$$

And now we would like to know what the overall noise factor is:

The total noise power at the output is the sum of the noise powers from the amplifier and the receiver:

$$P_{1,2} = P_1 \cdot G_2 + T_{N2} \cdot G_2 \qquad 3$$

$$P_{1,2} = G_1 \cdot G_2 \cdot (T + T_{N1}) + G_2 \cdot T_{N2} = G_1 \cdot G_2 \cdot (T + T_{N1} + \frac{T_{N2}}{G_1}) \qquad 4$$

The amplifier "quiets" the noise of the Receiver.

The noise factor, then, of the cascaded system is:

$$F_{1,2} = \frac{T_{N1} + T + \frac{T_{N2}}{G_1}}{T} = \frac{T_{N1} + T}{T} + \frac{T_{N2}}{G_1 \cdot T} = F_1 + \frac{\frac{T_{N2} + T}{T} - 1}{G_1} = F_1 + \frac{F_2 - 1}{G_1} \qquad 5$$

This can be expanded to describe the noise factor for any number of cascaded amplifiers:

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3} \ldots. \qquad 6$$

It may be seen that each amplification stage serves to limit the noise from the following stages, which is of course, a desired effect.

As this is the case, we will choose an amplifier at the front end with as low noise factor (F_1) as possible, as it will determine the overall noise factor (F) of the system. Low noise broadband amplifiers of the type to be used in EMI measurements are expensive, so it is worth while to examine when they should be used.

As an example, let us select an amplifier with a gain of 10 and see with what receiver it will provide an overall improved sensitivity-reduced noise factor:

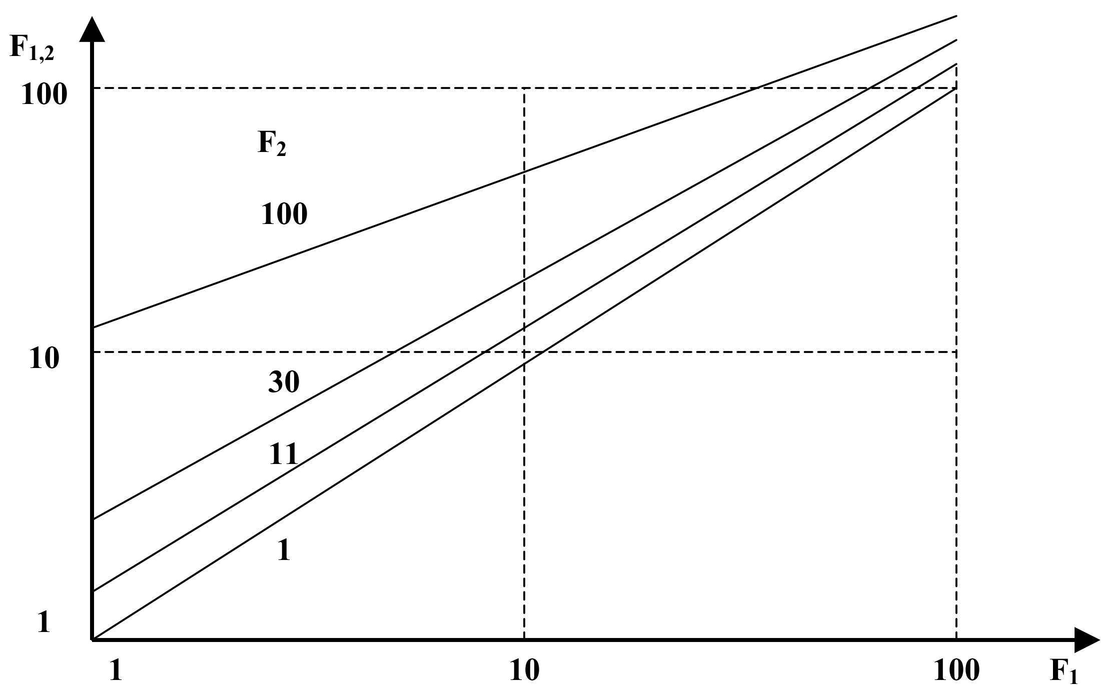

Figure 3. Over-All Noise factor of a cascaded amplifier and Receiver system

It may be seen from figure 3 that the benefit to be gained for an additional low noise amplifier is best when the noise factor of the low noise amplifier is much less (better) than that of the receiver. Other wise, when the receiver has a low noise factor=noise figure, to start with, an additional amplifier will be expensive and add little to the overall sensitivity.

Dynamic Range, and third order intercept point

An important factor in EMI measurements is the dynamic range in which measurements can be performed within the acceptable amplitude accuracy. This dynamic range is limited by the linearity of the front end of the receiver. A measure of this linearity is provided by two acceptable parameters, the 1dB compression point and the third order intercept point. Figure 4 describes these points:

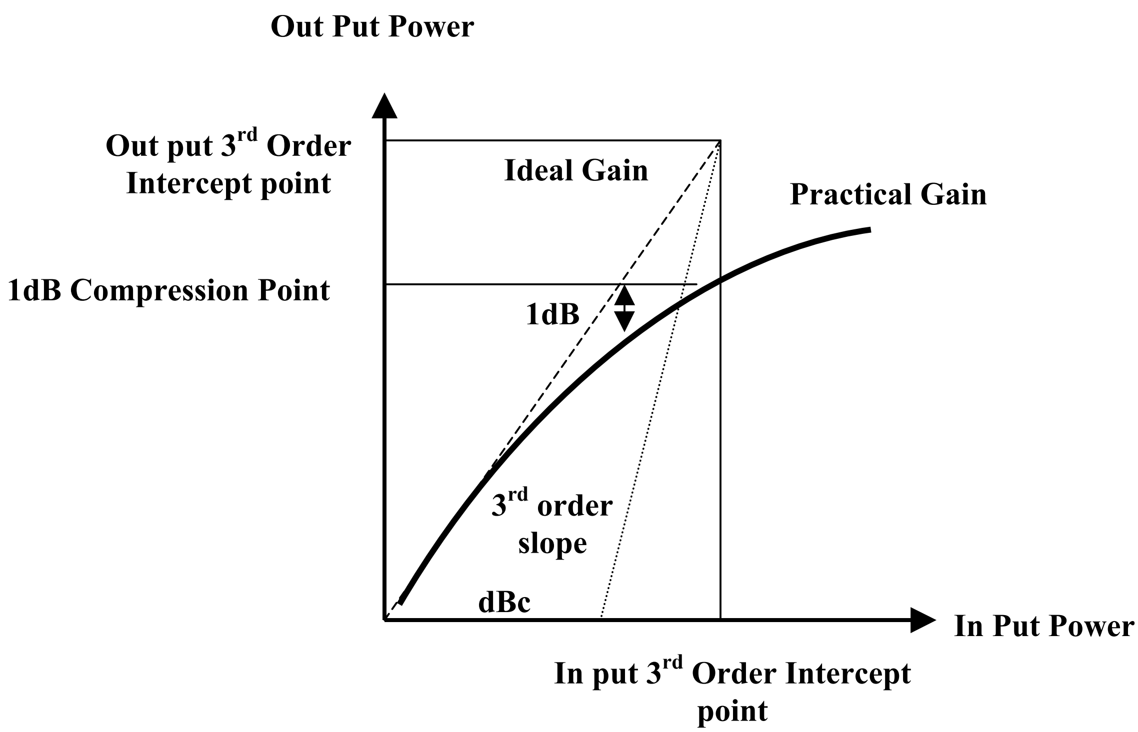

Figure 4. Non Linear identification points of an amplifier

We would like the Out-put and Input 3rd Order intercept points to be as high as possible, to obtain the highest dynamic range in measurements in EMI. To this end, a high “dBc” is desired.

The 3rd order intercept point is chosen due to the creation of 3rd order inter-modulation products due to the non linearity of the amplifier. These products are well defined in the RF telecommunication industry, with accepted measurement methods for their quantification. A description of these products is given in figure 5:

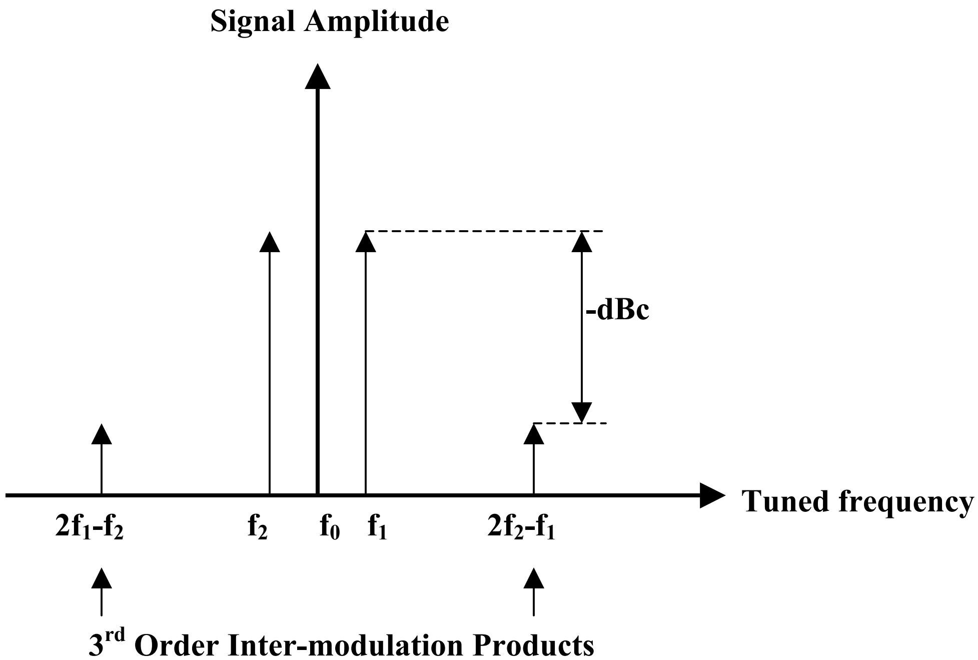

Figure 5. Inter-modulation products in an amplifier

f_1 and f_2 are undesired signals outside the pass band of the receiver, which create inter-modulation products which fall within the pass band of the receiver, and are identified as a signal.

There are many more inter-modulation products, caused by the non-linearity of the amplifier, but only the 3rd order products are depicted here, for clarity. The linearity of the amplifier is given by the degree (given by "-dBc") it discourages the creation of inter-modulation products. The larger this value is, the better the linearity and as a result, a higher dynamic range is attainable.

The next step is to quantify the effect of this non-linearity in an EMI Measurement system, and to evaluate the effect of an additional amplifier.

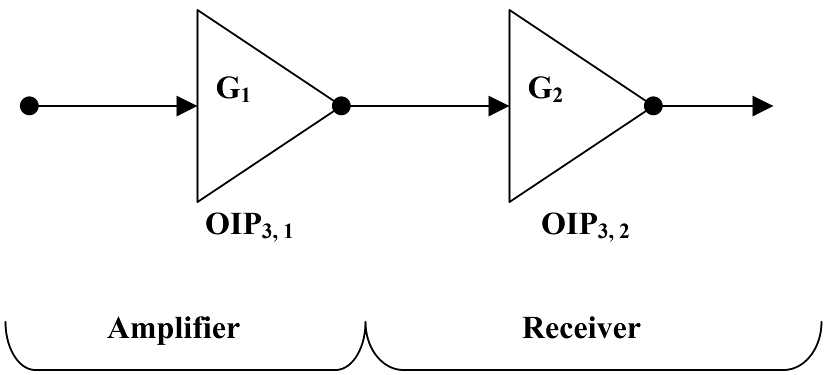

Figure 6. Cascaded Amplifier and receiver.

In figure 6 we have an amplifier connected to the input port of a receiver.
The Output 3rd Order Intercept Point of each is denoted as OIP_3 and is in units of dBm, while the Gain G is dB.

The overall 3rd order output intercept point is:

$$OIP_3 = -10\log_{10}(10^{\frac{-(OIP_{3,1}+G_2)}{10}} + 10^{\frac{-OIP_{3,2}}{10}}) \qquad 7$$

To visualize this expression more clearly, it is translated into linear, non dB terms:

$$\frac{1}{OIP_3} = \frac{1}{OIP_{3,1} \cdot G_2} + \frac{1}{OIP_{3,2}} \qquad 8$$

$$OIP_3 = \frac{OIP_{3,1} \cdot OIP_{3,2}}{OIP_{3,1} \cdot G_2 + OIP_{3,2}} \cdot G_2 \qquad 9$$

As in paralleling resistors, the result is lower than the highest value, so here the 3rd order inter-modulation output product power is less for the cascaded amplifiers than the highest value in the amplifier-receiver pair. Hence, some of the dynamic range is lost.

Of prime importance to EMI Measurements is the input dynamic range, quantified by the Input 3rd order inter-modulation Product power IIP_3:

$$IIP_3 = \frac{OIP_3}{G_1 \cdot G_2} \qquad 10$$

We may see that adding an input amplifier G_1 compromises the input dynamic range.

The dynamic range useful for EMI Measurements is called the Spurious Free Dynamic Range-SFDR:

$$SFDR = \frac{2}{3} \cdot \left[IIP_3 - 10 \cdot \log(kTB) + NF\right] = \frac{2}{3} \cdot \left[IIP_3 - MDS\right] \qquad 11$$

Where: MDS is the Minimum Detectable Signal of the measurement System.

This is depicted in figure 7:

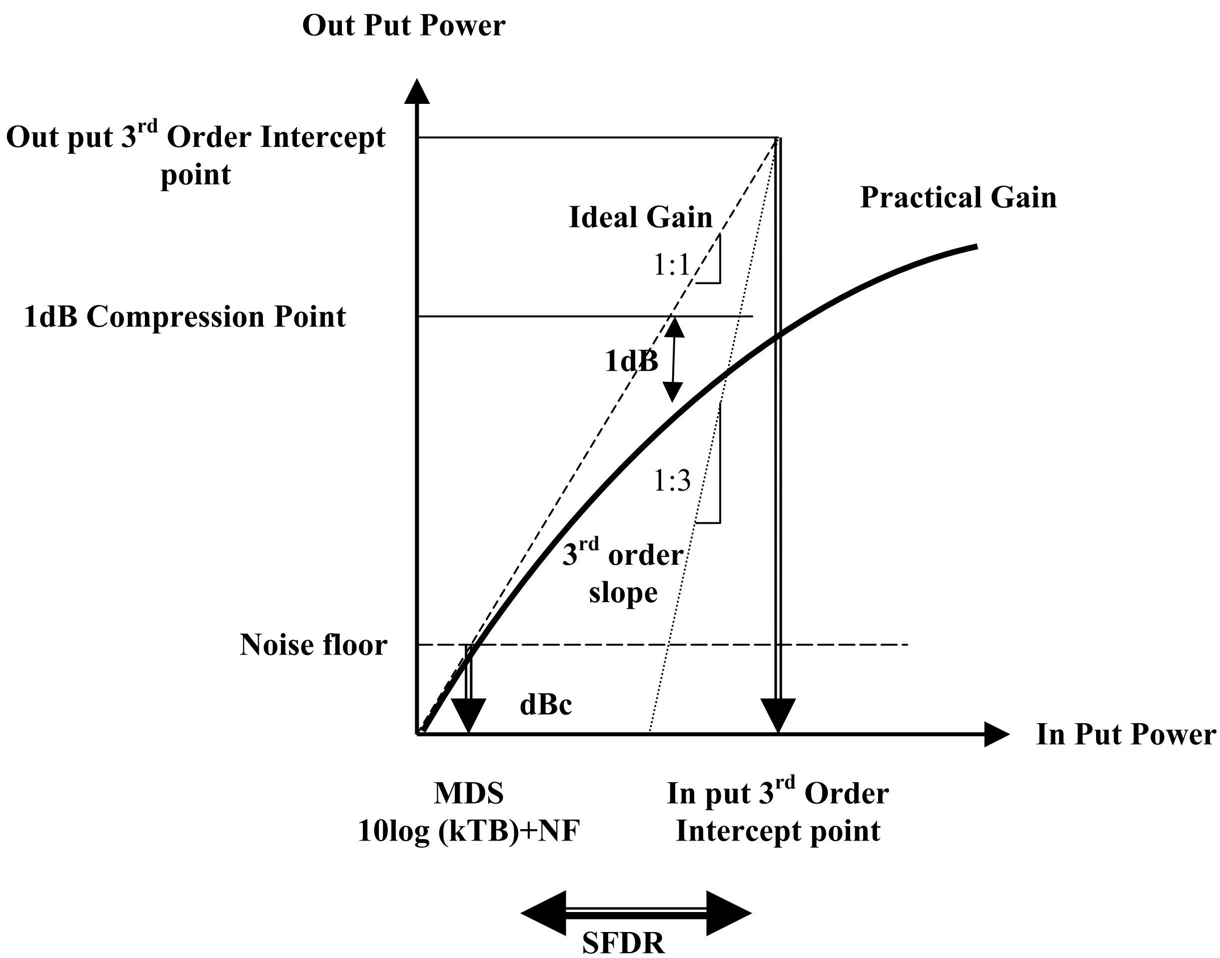

Figure 7. Dynamic Range of A measurement System

Summary:

Using preamplifiers in EMI Measurements is a mixed blessing. Low noise amplifiers can well serve to reduce noise due to cable losses at the upper microwave and mm wave bands, when installed at the antennas, and may provide a benefit to measurement systems having an inherent high noise figure.
When the prime measurement system is a receiver with a low noise figure, the benefit of using a low noise broadband and expensive amplifier is questionable.
In all cases, an additional amplifier curtails the usable dynamic range of a measurement system.

So using an amplifier with a measurement system for EMI should be evaluated in the light of the overall performance of the system, and the cost.

Practical Conclusions

DSI Quality Receivers such as the DSI-600 have an inherent low noise factor, compared to leading Spectrum Analyzers/Receivers used in the EMI Measurement market,

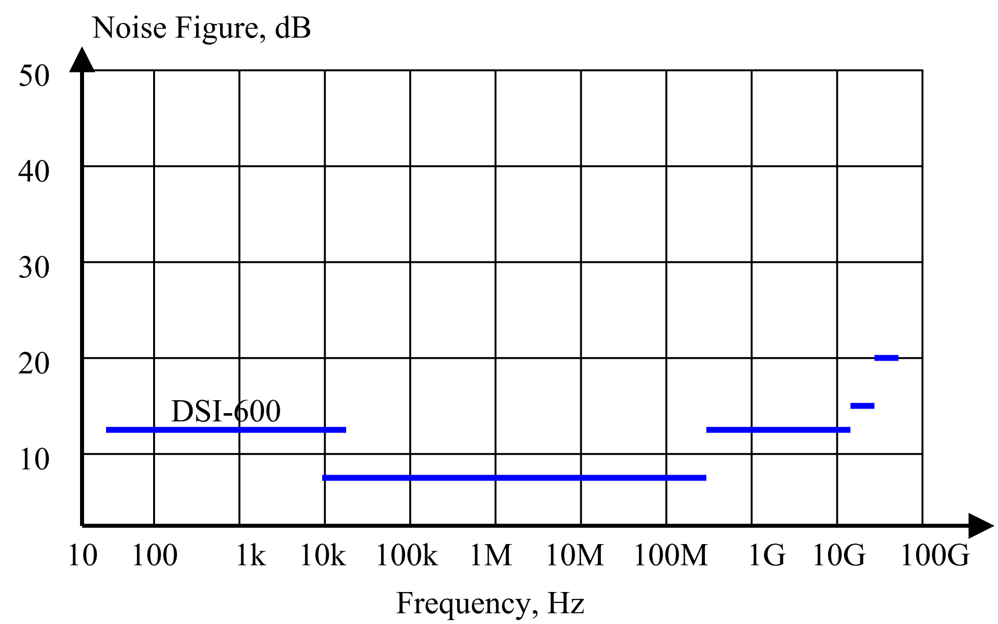

Figure 8. Noise figure of DSI-600

It is easy to see that the DSI-600 has a broad spectrum coverage and good sensitivity without additional amplifiers.

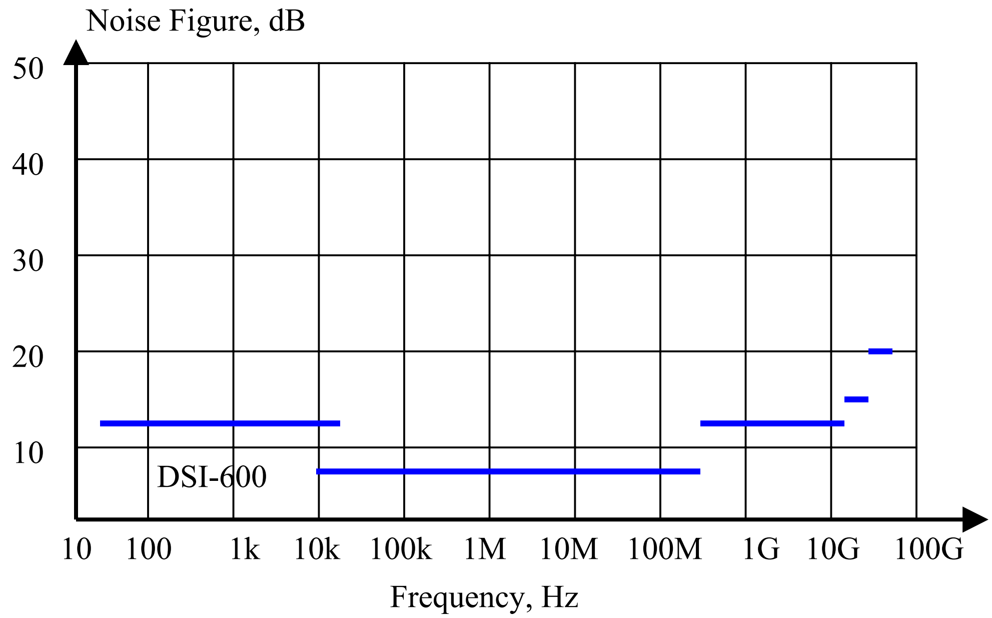

Figure 9. Noise figure of DSI-600

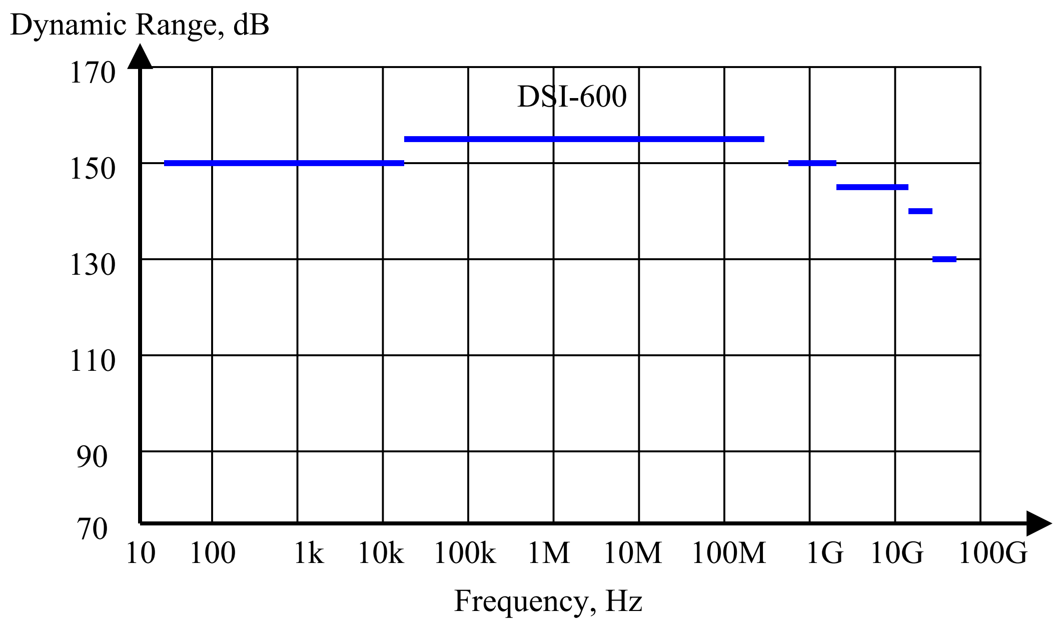

Figure 10. Dynamic Range of DSI-600

It can easily be seen that the dynamic Range of the DSI-600 is state of the art without the use of additional amplifiers.

The DSI-600 is a Quality Receiver with a low noise figure, a high sensitivity, high dynamic range, which does not require additional expensive broadband low noise amplifiers for its performance, hence providing a cost-effective solution for EMI Measurements.