FIG 1 Whether with built-in or external preamplifier, the EMI Test Receivers R&S ESIB represent a superior complete test system, featuring excellent RF and microwave characteristics.

EMI Test Receivers R&S ESIB 26 / R&S ESIB 40

Better system sensitivity through preamplifiers

High attenuation values significantly limit the total sensitivity of a test system in the microwave range. Only the use of a broadband low-noise preamplifier makes it possible to fulfill the high sensitivity requirements defined for measuring radiated emissions (EMI) in compliance with standards.

Measurements in line with standards mean high requirements

The attenuation values and transducer factors of cables and antennas in the microwave range are so high that they considerably limit the sensitivity of a receiving system and thus the dynamic range for measurements. One solution is to use a broadband low-noise preamplifier directly on the antenna or before the receiver input which significantly improves the total sensitivity of a test system. Only then is it possible to fulfill the high requirements placed on the sensitivity and performance of measuring instruments by test standards.

Specifications for standard-conforming EMI emission measurements in commercial applications above 1 GHz are defined in the basic standard CISPR 16-1 (1999), which also defines requirements for the measurement environment and measuring instrument characteristics up to 18 GHz. Military applications are governed by standards such as the internationally recognized MIL-STD-461 E – and specifically parts RE 102 and RE 103 (RE: radiated emission) – which requires EMI measurements up to 40 GHz.

Limit lines and transducer factors for the R&S ESIB ready for download; see page 46.

The EMI Test Receivers R&S ESIB26 and R&S ESIB40 (FIG 1) from Rohde&Schwarz offer superb RF characteristics for sensitivity and dynamic range [1]. Equipped with the R&S ESIB-B2 option [2], both have an internal preamplifier (up to 26 GHz or 40 GHz, respectively), which predestines them for measurements in line with the sophisticated MIL standard.

Calculation of noise factor and noise figure

Test systems for radiated emissions are fundamentally a cascade circuit consisting of receiving antenna, preamplifier, connecting cable and EMI test receiver, which in some cases is extended by an internal preamplifier (FIG 2). The total noise factor for this configuration can be calculated by subdividing the components into individual elements such as twoports and determining their separate contribution to the overall result.

The (dimensionless) noise factor F of a twoport is the ratio of its S/N ratio at the input (S_1/N_1) to the S/N ratio at the output (S_2/N_2):

$$F = \frac{S_1/N_1}{S_2/N_2}$$

This yields the noise figure *NF* in dB:

$$NF = 10 \cdot \lg F$$

In addition, the noise factor and gain of twoports are a function of frequency, which means that the individual values for approximate calculations can be determined only for discrete frequency points.

The total noise factor of several twoports connected in series (FIG 3) is obtained by adding together the noise factors of successive twoports while taking into consideration the gain G of each preceding port as shown in the following equation:

$$F_{\text{total}} = (F_1 - 1) + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \cdots + \frac{F_n - 1}{\prod_{i=1}^{n-1} G_i}$$

where F_i = noise factor of a given component
G_i = gain of a given component

Within the equation, the third twoport will thus have a noise factor of F_3 and a gain calculated from the two preceding values, G_1 and G_2.

Because an ideal, noise-free twoport has a noise figure of 0 dB or a noise factor of 1, its contribution to the total noise factor must yield zero. In the equation, this is expressed by:

$$F_z = F - 1$$

Calculation of total noise factor

The following example calculation of the total noise factor is based on the setup shown in FIG 2. Since a preamplifier cannot be placed in front of the receiving antenna, the first possible point of intervention is directly on the antenna output. The low-noise, broadband preamplifier must be dimensioned with respect to overload control in such a manner that it cannot be overdriven by broadband noise signal spectra and that it changes the antenna input parameters as little as possible. As a result, preamplifiers for frequencies up to 18 GHz, 26 GHz or 40 GHz are relatively expensive.

The total noise factor for all four components connected after the antenna is calculated as follows on the basis of their noise factors *F* and gain/attenuation *G*:

$$F_{\text{total}} = (F_1 - 1) + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3}$$

The numeric values in the following example calculation – e.g. for 18 GHz – are rounded up or down to obtain simple values that are easy to remember. The corresponding data sheets contain the exact specifications.

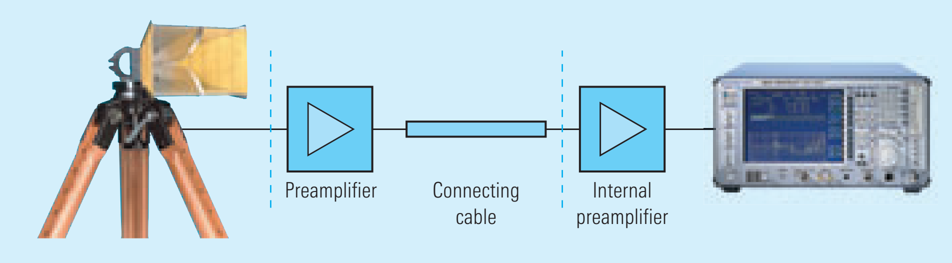

FIG 2 Practical arrangement of twoports in EMI measurements.

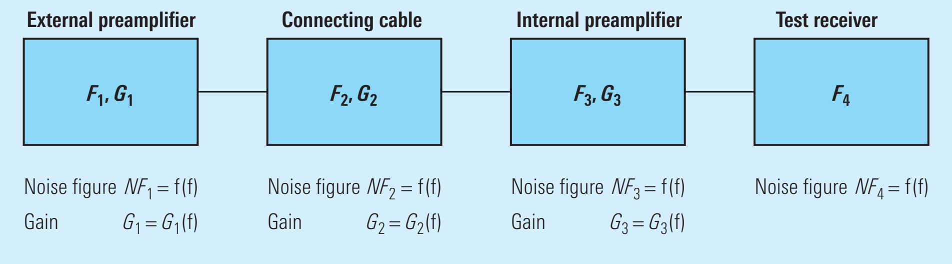

FIG 3 Cascading of several twoports.

Preamplifier

$NF_1 = 3$ dB; $F_1 = 2$;
Gain $g_1 = 30$ dB ($G_1 = 1000$)

Cable RTK 081 (FIG 4) at 18 GHz

$NF_2 = 15$ dB; $F_2 = 31.62$;
Attenuation $a_2 = -15$ dB ($G_2 = 0.03162$)

Internal preamplifier

$NF_3 = 10$ dB; $F_3 = 10$;
Gain $g_3 = 20$ dB ($G_3 = 100$)

EMI test receiver

$NF_4 = 20$ dB; $F_4 = 100$

This yields the following:

$$F_{\text{z total}} = (2-1) + \frac{31.62-1}{1000} + \frac{10-1}{1000 \cdot 0.03162} + \frac{100-1}{1000 \cdot 0.03162 \cdot 100}$$

$$= 1 + 0.03062 + 0.2846 + 0.031309 = 1.3465$$

$$F_{\text{total}} = F_{\text{z total}} + 1 = 2.3465$$

Total noise figure NF_{total} = 3.704 dB

Results from the calculation of the total noise factor

The example calculation shows that the noise of the entire circuit is determined primarily by the preamplifier characteristics. The subsequent components are largely insignificant due to the preamplifier's gain factor. Thus, the amplifier must not be overdimensioned (see also the comments regarding dynamic range on page 46).

The choice of microwave cables is also important. The cables must be chosen with regard to optimum (minimum) length and attenuation. Long cables with high attenuation significantly increase the costs for improved sensitivity with preamplifiers. Investing several hundred to a thousand euros in suitable cables can eliminate the need for better amplifiers, which can cost up to 10000 euros depending on the frequency range. Cable length can be kept to a minimum in many cases by placing the test equipment located outside the anechoic chamber in a favourable position near the test antenna.

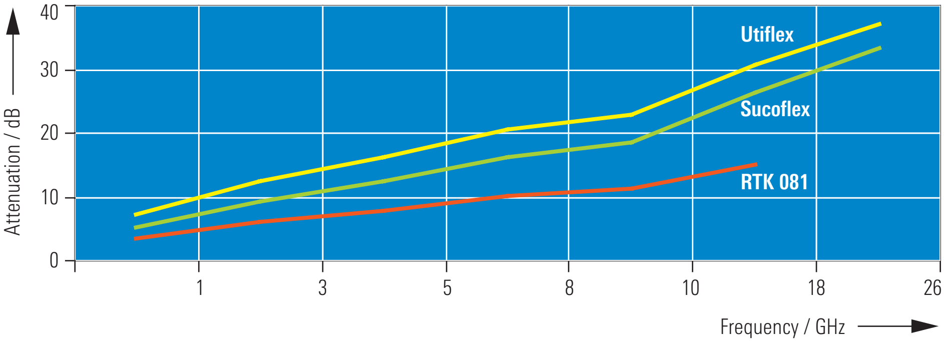

FIG 4 Attenuation of cables with a length of 20 meters.

Which amplifier for the given noise figure?

When the minimum noise figure for the entire test system is in line with the test standards, the required preamplifier gain can also be determined.

In the following example, the total noise figure desired for the test system is 5 dB. A preamplifier with a noise figure of $NF_{\text{preamp}} = 3$ dB ($F_{\text{preamp}} = 2$) is selected for the specified frequency range. The question is whether an amplifier with 10 dB or 20 dB needs to be selected (G_{preamp} 10 or 100). For example, the subsequent test receiver has a noise figure of $NF_{\text{Rx}} = 15$ dB or $F_{\text{Rx}} = 31.62$. The following is obtained when these values are used in the simplified equation with a preamplifier preceding the test receiver:

$$F_{\text{z total}} = (F_{\text{preamp}} - 1) + \frac{F_{\text{Rx}} - 1}{G_{\text{preamp}}}$$

When $G_{\text{preamp}} = 10$:

$$F_{\text{z total}} = (2-1) + \frac{31.62-1}{10} = 4.062$$

$$F_{\text{total}} = F_{\text{z total}} + 1 = 5.062$$

NF_{total} **= 7.04 dB**

When $G_{\text{preamp}} = 100$:

$$F_{\text{z total}} = (2-1) + \frac{31.62-1}{100} = 1.3062$$

$$F_{\text{total}} = F_{\text{z total}} + 1 = 2.3062$$

NF_{total} **= 3.62 dB**

This shows that a total noise figure of <5 dB can be achieved only with a 20 dB amplifier.

The criteria for using and selecting preamplifiers are thus as follows:

- The 20 dB preamplifier improves sensitivity from 15 dB to 3.6 dB, i.e. the dynamic range increases by 11.4 dB at the lower end but decreases at the upper end. The maximum permissible input level with a 20 dB preamplifier decreases by 20 dB. Thus, the total dynamic range loss is 8.6 dB. **Therefore, do not select more gain than absolutely necessary.**
- **Use an amplifier with suitable linearity.** If broadband signals have high levels and a large occupied bandwidth, a preamplifier can be overdriven. Particular attention should

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thus be paid to its linearity, especially when no preselection filters can protect the input stage of the measuring instrument.

- **Attach a preamplifier directly to the antenna** to ensure maximum increase in sensitivity.
- **Use an amplifier with calibrated gain** to minimize the measurement uncertainty of the entire system.

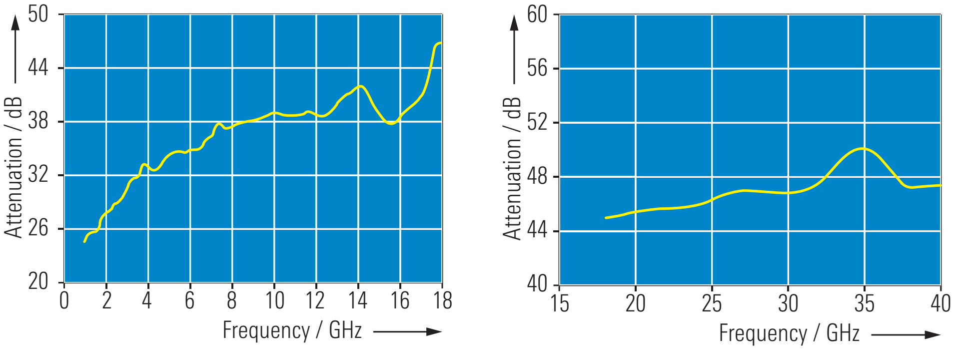


FIG 5 Typical attenna factors for horn attennas.

What is the available dynamic range?

When determining the minimum noise figure required for a complete test system, the dynamic range needs to be considered. For example, if the measurement bandwidth is 1 MHz, the noise floor increases by 60 dB in accordance with 10 log RBW / 1 Hz. Due to the antenna factor, the dynamic range decreases further by approx. 45 dB (at 18 GHz; see FIG 5).

FIG 6 shows this reduction of the dynamic range as a result of a measurement bandwidth of 1 MHz, the use of a preamplifier, allowance for antenna correction values as well as different detector types (peak or average value). The preamplifier reduces the permissible level at the test receiver input by 30 dB, i.e. by its gain. The antenna correction factors represent attenuation values that require higher IF gain, thus increasing the internal noise by the amount of the correction value, e.g. by 45 dB.

Thus, only high-quality test receivers with a basic dynamic range of approx. 100 dB can be used for sophisticated measurements in line with test standards. The Test Receivers R&S ESIB 26 and R&S ESIB 40 feature these prop-

FIG 6 Numerous factors diminish the useful dynamic range.

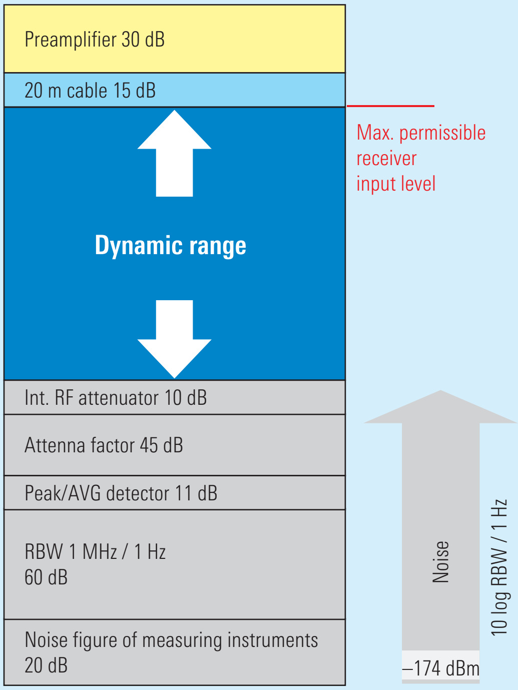
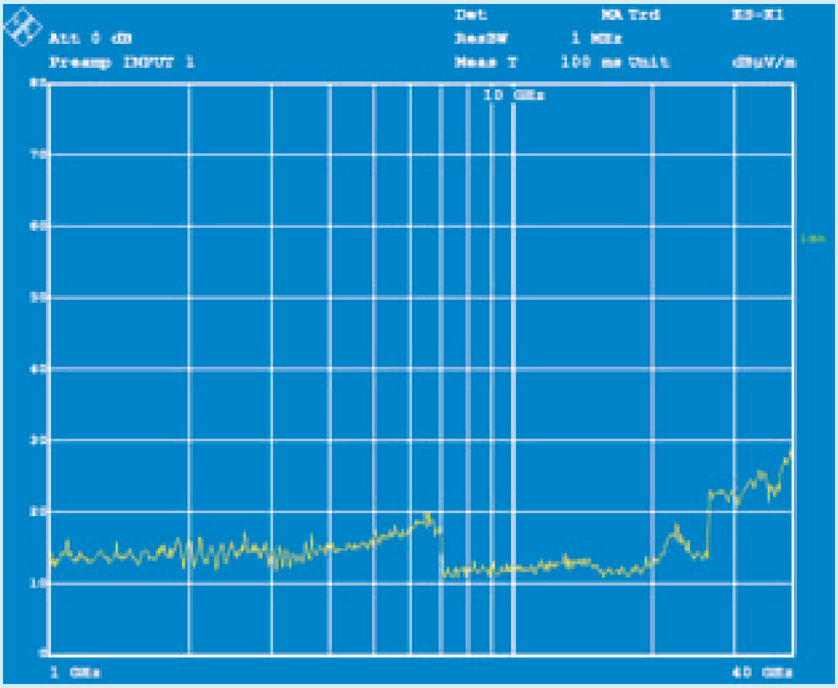


FIG 7 Noise characteristic of the EMI Test Receiver R&S ESIB 40 between 1 GHz and 40 GHz.



erties – large dynamic range and low inherent noise.

These receivers are indispensable because they offer high reproducibility of measured values and the capability to generate reports, which also makes them ideal as reference test instruments in the full compliance class, i.e. for EMC compliance testing to different standards in the certification of electrical and electronic components, instruments and systems in the civil and military area.

FIG 7 shows the typical noise characteristics of the EMI Test Receiver R&S ESIB 40 between 1 GHz and 40 GHz with an activated 20 dB preamplifier, 1 MHz measurement bandwidth and average detector. Including the correction values specified in FIG 5 for the various horn antennas yields the noise curve shown in FIG 8, recorded with a peak detector. The measurement not only meets the MIL-STD-461E RE 102-4 standard when performed with an internal preamplifier but is actually up to 10 dB below the required limit line for maximum permissible emissions. The cable selected determines whether a low-noise preamplifier with corresponding gain must be used.

Summary

To meet the strict requirements of the standards for the measurement of radiated emissions up to 40 GHz while taking into account the receiver, connecting cable and antenna, it is necessary to include dimensioning fundamentals such as the determination of noise factor described here. The criteria for cable selection and dimensioning as well as a suitable amplifier are to be determined on the basis of the parameters of the antennas and EMI test receiver that are used.

The EMI Test Receivers R&S ESIB 26 and R&S ESIB 40 with built-in preamplifier option R&S ESIB-B2 up to 26.5 GHz or 40 GHz represent a superior complete test system with excellent RF and microwave specifications. They can be used to successfully perform compliance testing to standard.

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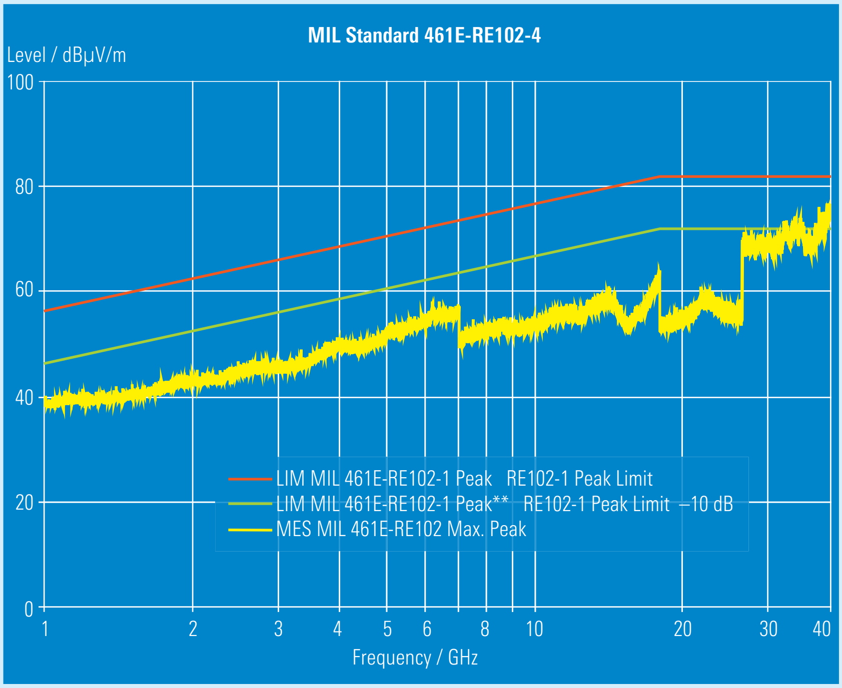
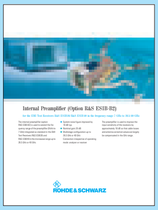
FIG 8 Noise curve (peak) at 1 MHz measurement bandwidth and attenna transducer factors.



More information and data sheet at www.rohde-schwarz.com (search term: ESIB-B2)


Data sheet
R&S ESIB


Data sheet
R&S ESIB-B2

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[1] EMI Test Receivers ESI: EMI professionals through to 40 GHz. News from Rohde & Schwarz (1999) No. 162, pp 7–9

[2] EMI Test Receivers R&S ESIB 26 / R&S ESIB 40: Internal preamplifiers for improved sensitivity above 7 GHz. News from Rohde & Schwarz (2002) No. 173, pp 28–29