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INTERNATIONAL STANDARD

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INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE
COMITÉ INTERNATIONAL SPÉCIAL DES PERTURBATIONS RADIOÉLECTRIQUES

BASIC EMC PUBLICATION
PUBLICATION FONDAMENTALE EN CEM

AMENDMENT 2
AMENDEMENT 2

Specification for radio disturbance and immunity measuring apparatus and methods –
Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus

Spécifications des méthodes et des appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques –
Partie 1-1: Appareils de mesure des perturbations radioélectriques et de l'immunité aux perturbations radioélectriques – Appareils de mesure

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FOREWORD

This amendment has been prepared by subcommittee CIS/A: Radio-interference measurements and statistical methods, of IEC technical committee CISPR: International special committee on radio interference.

The text of this amendment is based on the following documents:

FDIS	Report on voting
CIS/A/1070/FDIS	CIS/A/1075/RVD

Full information on the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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4.4.1 Amplitude relationship (absolute calibration)

Add, after the existing first paragraph, the following new text:

When external preamplifiers are used, refer to Annex J for applicable requirements.

7.5.2 Amplitude relationship

Add, after the existing paragraph and Note, the following new text:

When external preamplifiers are used, refer to Annex J for applicable requirements.

Add, after the existing Annex I, the following new annex:

Annex J
(normative)

Requirements when using an external preamplifier with a measuring receiver

J.1 General

Using an external preamplifier at the input of a measuring receiver shall be considered carefully as, while it improves system sensitivity, it may invalidate the system's compliance with the overload requirements of this standard. Further, an external preamplifier may invalidate the usability of a spectrum analyzer without preselection for the measurement of impulsive signals with pulse repetition frequencies down to 20 Hz using the quasi-peak detector as specified in 4.4.2.

Therefore the operator of a measuring system that includes an external preamplifier shall determine the limitations of the system and shall apply linearity checks for the test system. Automated measurement results with external preamplifiers need to be verified using a final manual linearity check. The information given in this annex provides guidance for the user of emission measurement systems.

J.2 Considerations for optimum emission measurement system design

Internally, measuring receivers are designed to achieve optimum sensitivity while avoiding overload. Built-in preselection in the measuring receiver avoids overload by impulsive signals. In spite of preselection, measuring receivers usually have no linearity reserve for quasi-peak measurements of a single pulse above the specified indication range. Missing preselection in measuring receivers causes problems with quasi-peak detection of impulsive signals with low PRF.

The use of an external broadband preamplifier shall be considered only after all other possible measures for improving the system sensitivity have been exhausted, e.g. using measuring receivers with built-in preamplifiers, using antennas of sufficient gain, or using low loss connecting cables. An external preamplifier need only be added when the disturbance limit and all of the emissions expected and emissions to be measured are very close to the system noise level, e.g. for compliance with Class 5 radiated disturbance limits of CISPR 25 [17]. If high emission signals or high ambients are expected, external preamplifiers are not recommended.

From experience, external preamplifiers are not needed for radiated disturbance measurements to Class B limits of CISPR 11, CISPR 22 [16] and CISPR 32 [18], either at 3 m or at 10 m measurement distance, when measuring receivers with built-in preamplifiers including preselection and low-loss antenna cables are used. The same situation applies for radiated disturbance measurements to CISPR 14-1, CISPR 15 [15], and the generic emission standards, as well as for disturbance power measurements.

External preamplifiers are not recommended for conducted disturbance measurements below 30 MHz; their use may cause harmonics in the presence of high-level disturbance at frequencies below 150 kHz, where many emission standards do not specify disturbance limits.

If an external preamplifier is added for improved sensitivity, the following needs to be considered:

a) preamplifiers have a wide bandwidth, i.e. they are susceptible to overload by impulsive signals and high level narrowband signals;

b) preamplifiers may produce intermodulation products and harmonics; this is especially important when measurements are made on an OATS and/or in the presence of radio transmission equipment;

c) preamplifiers increase the signal level at the receiver input and thus may overload the receiver input stages, a condition which cannot be avoided entirely by the receiver's built-in preselection;

d) the gain in sensitivity will be less than the gain in signal level, thus limiting the dynamic range of the preamplifier/receiver combination;

NOTE 1 The gain in sensitivity is understood as the difference between the noise figure without preamplifier and the system noise figure with preamplifier.

e) for maximum sensitivity in the frequency range above 1 GHz, the preamplifier is mounted/connected directly to the measurement antenna;

f) use of an external preamplifier requires that an accurate gain versus frequency characterization be accounted for in the measurement result;

g) the uncertainty of the gain as a function of temperature and aging, as well as the additional mismatch uncertainty between the preamplifier output port and the receiver input port, shall be included in the uncertainty budget for the measurement; the input impedance shall, as far as possible, comply with the requirements for the measuring receiver and shall be included in the uncertainty budget;

h) for CISPR Band E, a system consisting of an external preamplifier and a measuring receiver shall be designed such that it cannot be overloaded by signals of lower frequency bands, and/or by any signal whose out-of-band or spurious signals are to be measured; e.g. the ISM signal of a microwave oven shall not drive the system into overload.

The gain in sensitivity is determined using the following quantities and equations:

$$F = \frac{P_{\mathrm{ie}}}{kT_0 B} \text{ and,} \tag{J.1}$$

$$\text{for an amplifier, } F = \frac{P_{\mathrm{o}}}{gkT_0 B} \tag{J.2}$$

where

F is the noise factor, with 10 lg$F$ = noise figure (often denoted by the symbol NF);

P_{ie} is the equivalent noise input power;

P_{o} is the noise output power;

g is calculated from the gain, G = 10 lg$g$, respectively $g = 10^{G/10}$

k is Boltzmann's constant = 1,38 × 10^{-23} Ws/K and kT_0 = 4 × 10^{-21} W/Hz

T_0 is the absolute reference room temperature (293 K);

B is the noise bandwidth (e.g. of the measuring receiver).

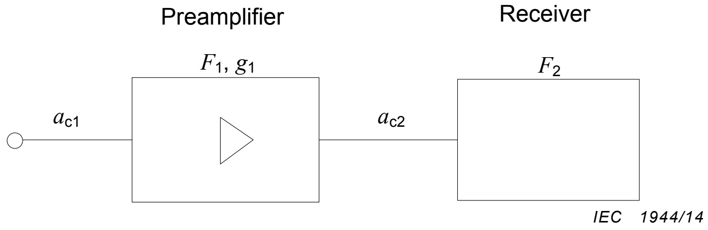


Figure J.1 – Receiver with preamplifier

In Figure J.1, assuming that the cable attenuation a_{c2} = 0 dB, then

$$10\lg F_{tot} = a_{c1} + 10\lg\left(F_1 + \frac{F_2 - 1}{g_1}\right) \qquad \text{(J.3)}$$

where F_{tot} is the noise factor of the system at the input cable with a_{c1}.

If $a_{c2} \neq 0$ dB, then the preamplifier gain factor g_1 in Equation (J.3) has to be replaced by $10^{(G_1 - a_{c2})/10}$. Cable attenuation $a_{c1} \approx 0$ dB is achieved by mounting and/or connecting the preamplifier directly to the antenna. If $a_{c1} \neq 0$ dB, then the cable attenuation a_{c1} adds to the system noise figure as shown by Equation (J.3).

State-of-the-art preamplifiers typically have noise figures of 3 dB or less, corresponding to a noise factor of F_1 = 2. Receivers with built-in preamplifiers typically have noise figures around 8 dB, corresponding to a noise factor F_2 = 6,3. This high noise factor is due to attenuation caused by preselection and other internal insertion losses of the receiver. Receivers without built-in preamplifiers typically have noise figures around 15 dB, corresponding to a noise factor F_2 = 31,6.

NOTE 2 The noise figure 10 lgF_2 of a measuring receiver can be determined from the indicated noise level using

$$10\ \lg F_2 = V_{Nav} + 67 - 10\ \lg B_N - w_{Nav}$$

where

V_{Nav} is the receiver noise floor with linear average detection, in dB(μV);

B_N is the noise bandwidth of the measuring receiver, in Hz;

w_{Nav} is the noise weighting factor for linear average detection, in dB.

EXAMPLE If V_{Nav} = –10,7 dB(μV), B_N = 85 kHz (for B_6 = 120 kHz), and w_{Nav} = –1 dB, then the noise figure 10 lgF_2 = 8 dB.

The quantity w_{Nav} is the difference between the indications of the linear average detector and the r.m.s. detector for Gaussian noise [19]; values for quasi-peak detection w_{Nqp} are approximately 4 dB for Band B, and 6 dB for Bands C/D; for peak detection w_{Npk} is up to 12 dB, depending on measurement time.

The noise bandwidth B_N is close to the 3 dB bandwidth B_3 of the measuring receiver. A rough approximation is given by B_N = 1,1 B_3. See [19] for details about specific filter implementations.

Considering a given preamplifier noise figure of 3 dB, it will be acceptable to achieve a system noise figure 10 lgF_{tot} = 4 dB, corresponding to a noise factor of 2,51. This requires that $(F_2 - 1)/g_1$ = 0,51, or $g_1 = (F_2 - 1)/0{,}51$.

- For receivers with a built-in preamplifier, the resulting gain is g_1 = 10,39, or G_1 = 10,2 dB.

- For receivers without a built-in preamplifier, the resulting gain is g_1 = 60, or G_1 = 17,8 dB.

For a receiver without a built-in preamplifier, as described above, an external preamplifier with a noise figure of 3 dB and a gain of 10 dB will give a system noise figure of 7 dB.

From the preceding examples, it can be seen that an improvement in sensitivity of 4 dB requires a signal gain of around 10 dB for a receiver with a built-in preamplifier. For a receiver without a built-in preamplifier, an improvement in sensitivity of 11 dB requires a signal gain of almost 18 dB, and an improvement of 8 dB requires a signal gain of 10 dB. It is evident that a system noise figure of 3,5 dB cannot easily be achieved with a preamplifier noise figure of 3 dB, because an excessive preamplifier gain would be necessary. Refer to Table J.1 for example noise figures.

Because it will severely limit the system's linearity performance, it is not advisable to use preamplifiers with a gain of 30 dB or more.

Table J.1 – Examples of preamplifier and measuring receiver data and resulting system noise figures

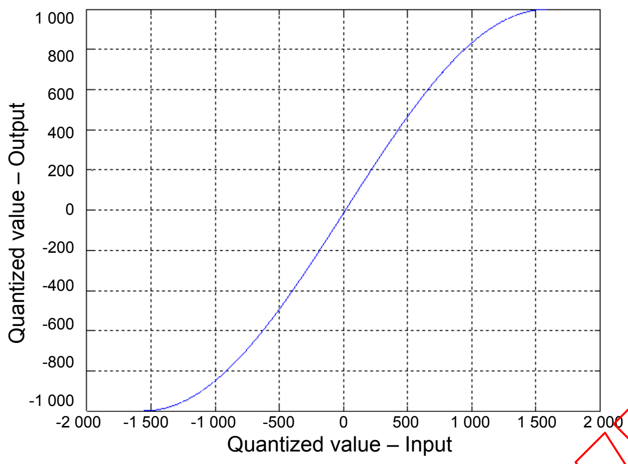
Preamplifier				Measuring receiver		System
Noise factor	Noise figure	Gain factor	Gain	Noise factor	Noise figure	Noise figure
F_1	10 lgF_1 dB	g_1	G_1 dB	F_2	10 lgF_2 dB	10 lgF_{tot} dB
2	3	10,4	10,2	6,3	8	4
2	3	10	10	31,6	15	7
2	3	60	17,8	31,6	15	4

J.3 Linearity specifications and precautions in measurement

The dynamic range of preamplifiers is defined by the 1 dB compression point, 3 dB compression point, and saturation point. To avoid distortion caused by the input signal, the signal should ideally stay below the 1 dB compression point during the entire measurement time.

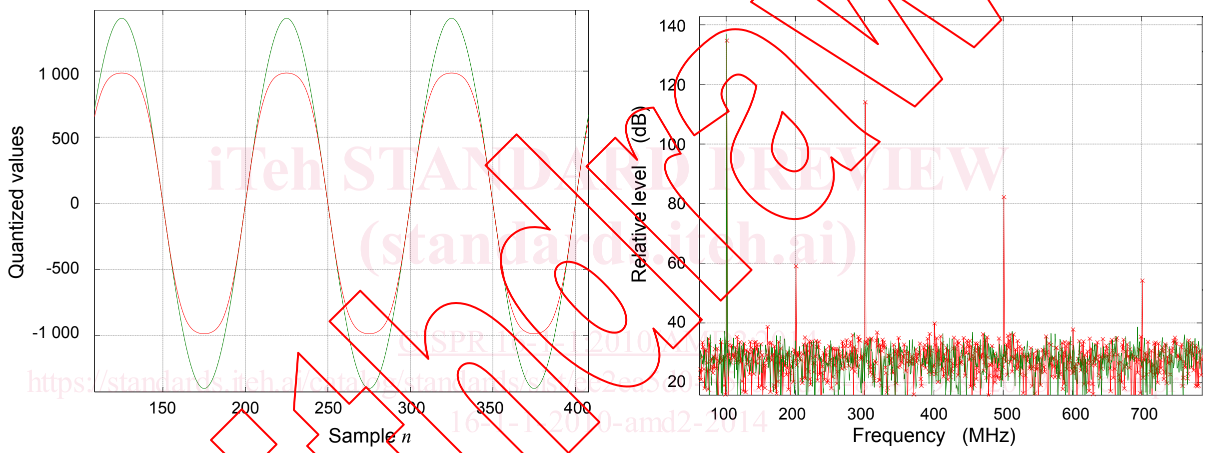
An example screenshot of the transfer function of an amplifier is shown in Figure J.2. The response of such an amplifier using a sinusoidal signal in time domain and frequency domain is shown in Figure J.3. The numbers on the axes in Figures J.2, J.3 and J.4 are generic in nature (quantization values) and do not represent specific units.

Figure J.3 shows that the sinusoidal signal is distorted in time domain, which is due to the nonlinear effects of the preamplifier. The frequency domain display shows that the level is decreased at 100 MHz, and that further harmonics exist. A corresponding simulation for a broadband pulse is shown in Figure J.4.



IEC 1945/14

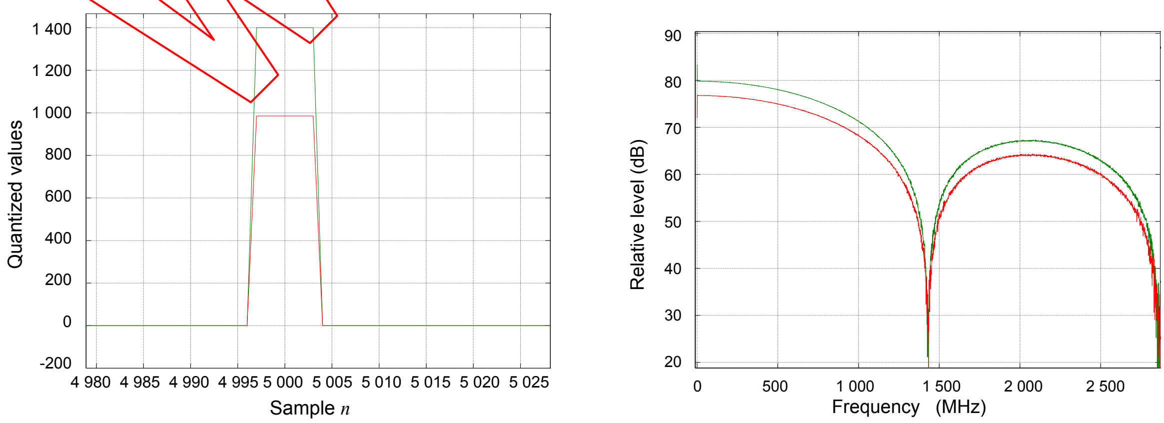
Figure J.2 – Transfer function of an amplifier



IEC 1946/14 IEC 1947/14

Green = normalized input signal; red = output signal

Figure J.3 – Response for a sinusoidal signal



IEC 1948/14 IEC 1949/14

Green = normalized input signal; red = output signal

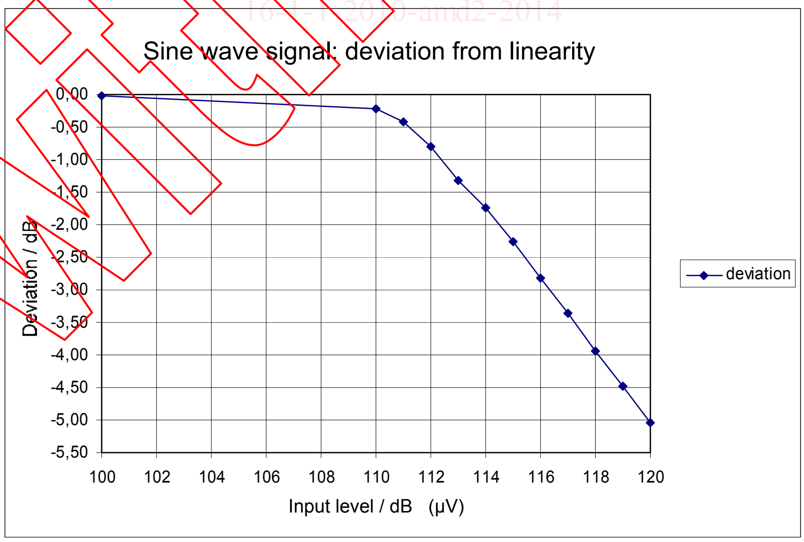
Figure J.4 – Response for an impulse

Comparing Figures J.3 and J.4, it can be seen that the saturation level in the time domain is exactly the same. However in the frequency domain the effects of saturation of the external preamplifier are different. For the impulsive signal, the amplitude level is decreased, invalidating the measurement result. For sinusoidal signals, the amplitude of the fundamental is decreased, while further harmonics are generated by the nonlinear effect of the external preamplifier; the measurement result is also invalidated.

The performance of the system, i.e. system noise level and overload capability, will depend on the characteristics of both the preamplifier and the measuring receiver. For narrowband signals, generally the 1 dB compression point of the preamplifier output exceeds the 1 dB compression point of the measuring receiver input. Preselection of the measuring receiver will improve system linearity for the measurement of broadband impulsive signals. Therefore, two types of systems are taken into consideration: systems with, and without, preselection at the measuring receiver input.

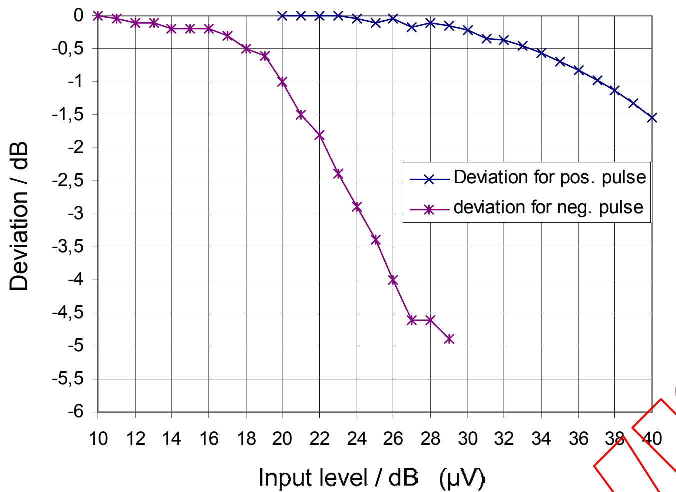
A broadband overload detector, which is effective at the input of some measuring receivers without preselection, is used to detect signal levels at the 1 dB compression point of the first mixer, to alert the user of linearity problems. The overload detector can also be used as an indicator to assure valid measurement results. Similar overload detection is recommended for wideband FFT based measuring systems to avoid over-range of the wideband A/D converter (see J.4).

Further precautions for measurements include a prediction of the available overload factor for the measurement of impulsive disturbances. Apart from gain versus frequency and noise figure, the 1 dB compression point of the preamplifier and the complete system, consisting of preamplifier and measuring receiver, shall be specified. For CISPR Bands C/D, the relationship between the 1 dB compression point for sine wave signals and the peak value of the broadband CISPR pulse signal with a bandwidth of 2 GHz gives a bandwidth factor F_{bw} of 85 dB [F_{bw} = 20 lg(2 000/0,12)]. Figures J.5 and J.6 show the deviations from linearity of a preamplifier with a 1 dB compression point of 112 dB(µV), for an unmodulated sine wave and impulsive signals.



IEC 1950/14

Figure J.5 – Deviation from linear gain for an unmodulated sine wave (example)



NOTE Using F_{bw}= 85 dB, the peak value of the positive pulse signal with a PRF of 100 Hz is at around 37 dB(µV) +12 dB + 85 dB = 134 dB(µV), i.e. around 22 dB above the 1 dB compression point of Figure J.5. 12 dB is the quasi peak weighting factor, i.e. the difference between peak and quasi peak for a PRF of 100 Hz.

Figure J.6 – Deviation from linear gain for a broadband impulsive signal as measured with the quasi-peak detector (example)

The flatness of the deviation curve for positive pulses in Figure J.6 is misleading, because the amplifier nonlinearity is masked by the amplifier's own intermodulation products. This effect can be demonstrated using a band-stop filter with a notch depth of greater than 40 dB (band-stop filter as specified in 4.6 of this standard) at the input of the preamplifier. For an acceptable operation (error contribution less than 1 dB by intermodulation), the notch depth shall remain at least 20 dB during the intermodulation test. The value of 20 dB is obtained with quasi-peak measurements at a PRF of 100 Hz; the PRF of 100 Hz is a compromise.

Ideally the 20 dB notch depth would be needed for quasi-peak measurements at all PRFs. This is shown in Figure J.7 for the preamplifier used above with 10 dB gain, where the 20 dB depth is retained as long as the peak level of the input signal is less than 37 dB(µV), and the peak level of the output signal is less than 46 dB(µV) (blue curve). For a PRF of 100 Hz, a peak level of 37 dB(µV) corresponds to a quasi-peak level of 25 dB(µV). Thus while the 1 dB compression point for the broadband impulsive signal in Figure J.6 "positive pulse" looks like being at 37 dB(µV) quasi-peak, the preamplifier is already overloaded. The input signal should be at least 12 dB lower, i.e. at 25 dB(µV) quasi-peak, to avoid excessive intermodulation.

In Figure J.6 the "positive pulse" also shows that a simple overload test with a switchable 10 dB attenuator at the preamplifier input may not properly indicate the overload in case of impulsive signals, because the output level can still follow the input level, while the preamplifier input signal is up to 20 dB above the 1 dB compression point. The simple test may work for sine wave signals. A better characterization of the system with respect to impulsive signals is obtained using the band-stop filter intermodulation test. If the band-stop filter intermodulation test is not available, the 1 dB compression point of the preamplifier, referred to its input, should be used to characterize the system.

NOTE The band-stop filter intermodulation test is intended to characterize the system, e.g. done by the system provider. It would be impractical to use a band-stop filter test in each EMC test lab during an emission test.

Note that during the band-stop filter intermodulation test, it shall be assured that the measuring receiver used as an indicator at the output of the preamplifier is not overloaded. Figure J.8 shows that the notch depth result from a CISPR intermodulation test of a measuring receiver with preselection still exceeds 30 dB with an input signal (quasi peak) of 55 dB(µV), which corresponds to an input level (quasi peak) of 45 dB(µV) to a 10 dB preamplifier. Using a measuring receiver with built-in broadband preamplifer may not show the linearity of the external preamplifier correctly, due to overload of the measuring receiver, as shown in Figure J.9 and J.10, whereas with preselection the output will be linear.

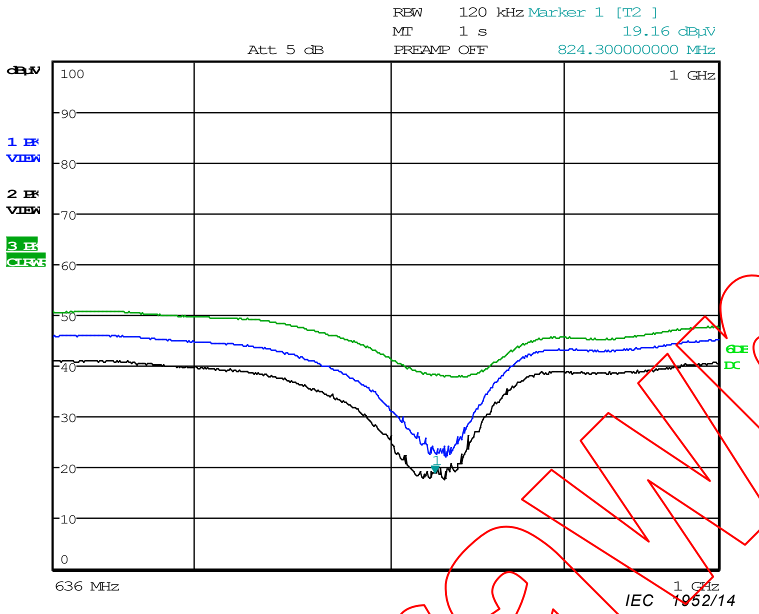


Figure J.7 – Screenshot of a band-stop filter test for a preamplifier at around 818 MHz

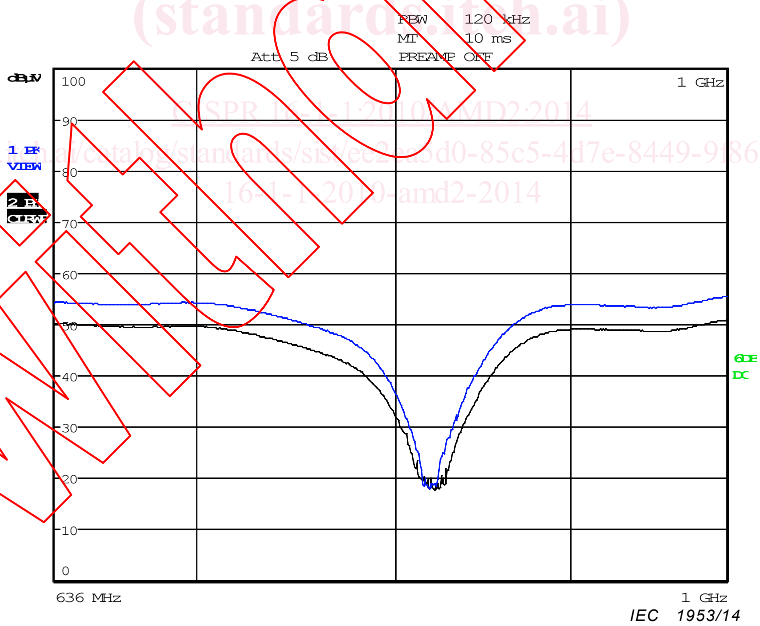


Figure J.8 – Band-stop filter test result with the measuring receiver at 818 MHz