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MINISTRY OF EDUCATION,
YOUTH AND SPORTS

Basics of spectrum analyzer measurement

Study material for practicals of the subject KEI/EMC2

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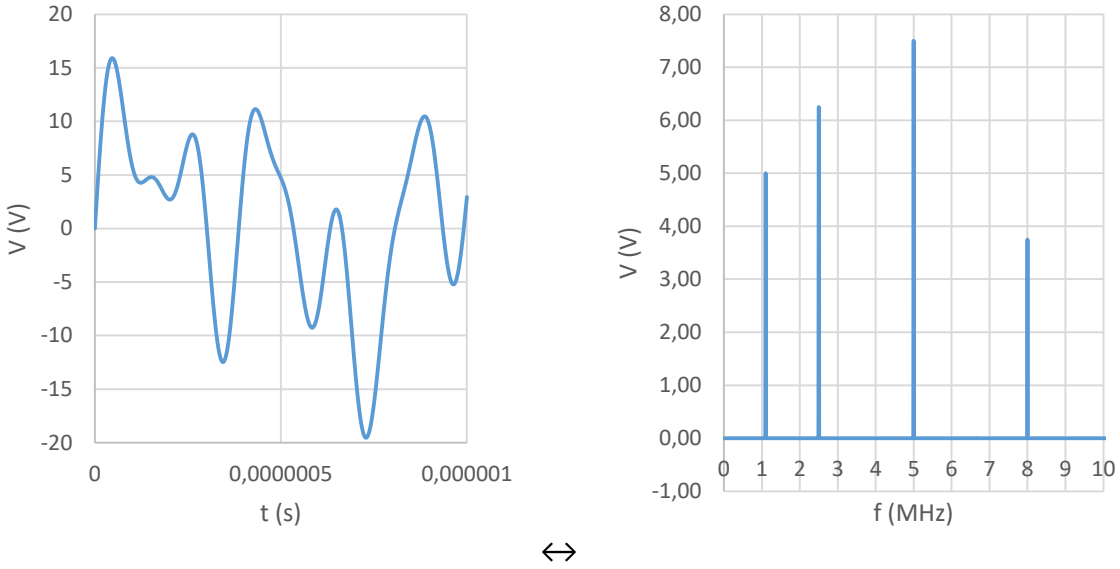
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1 Time domain signals measurement

The measurement of electrical signals is usually performed in the time (U = f(t)) and in the frequency domain (U = f(f)). Both measurement results represents the same signal, which shows Fig. 0.



↔

Obr 0: Time and frequency domain of measured signal

Spectrum analyzers are often used to measure signals (not only) in electromagnetic compatibility. These devices measure the power level (or voltage, recalculated by input impedance) dependence on the frequency L = f(f).

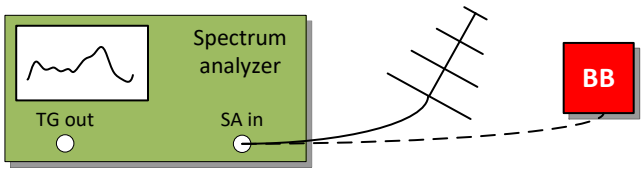


Fig. 1. Spectrum analyzer measurement – block diagram

The input signal is connected to the input of the spectrum analyzer during the measurement. This signal is processed by input stage of the analyzer. The super-heterodyne spectrum analyzers are used according to the large frequency range (f.e. 9 kHZ – 6 GHz and more). The simplified block diagram of the super-heterodyne spectrum analyzer is shown in Fig. 2. The modern spectrum analyzers use multiple mixing. There exist also analyzers used FFT (usually marked like real-time) which use digital processing of the input signal. These analyzers are usually limited frequency range – only a part from whole frequency range could be measured in the real time (current analyzers have bandwidth from tens to hundreds of MHz). The complete digital analyzers (FFT) are used for audio measurements.

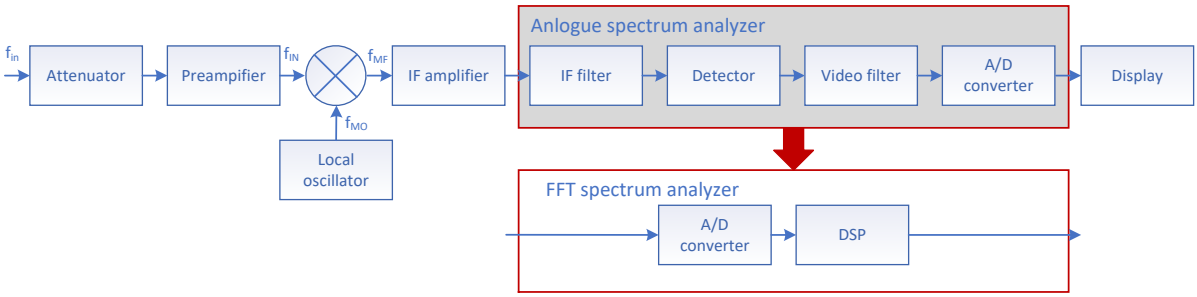


Fig. 2. Block diagram of super heterodyne spectrum analyzer

1.1 Basic parameters of measurement

Frequency range of measurement (SPAN) equals to difference of stop and start frequency: SPAN = $f_{STOP} - f_{START}$. There are two way how set the SPAN:

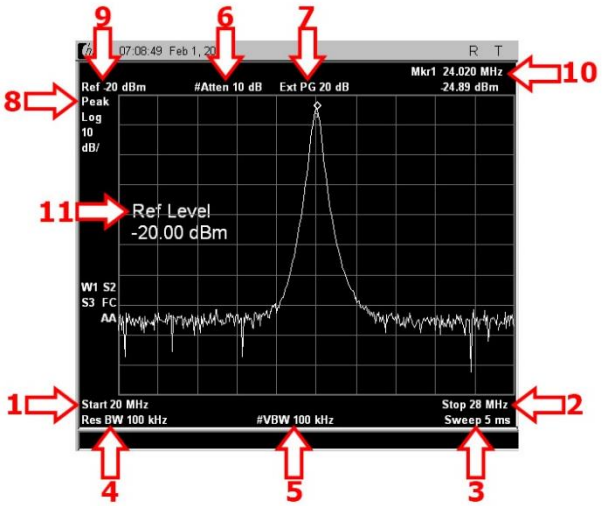
1. direct setting of starting and ending frequency (f_{START} a f_{STOP}),
2. setting by center frequency (f_{CENTER}) and frequency range (SPAN). Visible frequency range then is $f_{CENTER} \pm \frac{1}{2} \cdot \mathrm{SPAN}$.

Measured level range – in most cases set logarithmically – level in dB – dBm for power, dbµV are most usable unit in EMC. The visible range is also given by the reference level and by the scale.

Frequency resolution is defined mostly by the RBW. There is really important to say, that the visible spectrum depends to the analyzer setting and it may not match the actual input signal.

Sweep Time is the time for measurement of one window, i.e. it is the time which is needed for tunig of local oscillator from f_{START} to f_{STOP}. Sweep time is also dependent on RBW a VBW:

Typical screen on spectrum analyzer is shown in Fig. 3.



1 – start frequency
2 – stop frequency
3 – sweep time
4 – RBW
5 – VBW
6 – attenuation
7 – gain of external preamplifier
8 – detector type
9 – reference level
10 – marker (f a L)
11 – actual menu setting

Fig. 3. Typical screen of spectrum analyzer

1.2 Spectrum analyzer fundamentals

The input signal fin is connected at the RF input parts – attenuator and preamplifier (usually is necessary to buy the preamplifier like an option). These input circuits correct the input signal to the level which can be connected to the mixer – the input signal can be amplified or attenuated – this is really important in the term of mixer damage (or mixer overloading). The dependence of input circuits is shows in Fig. 4.

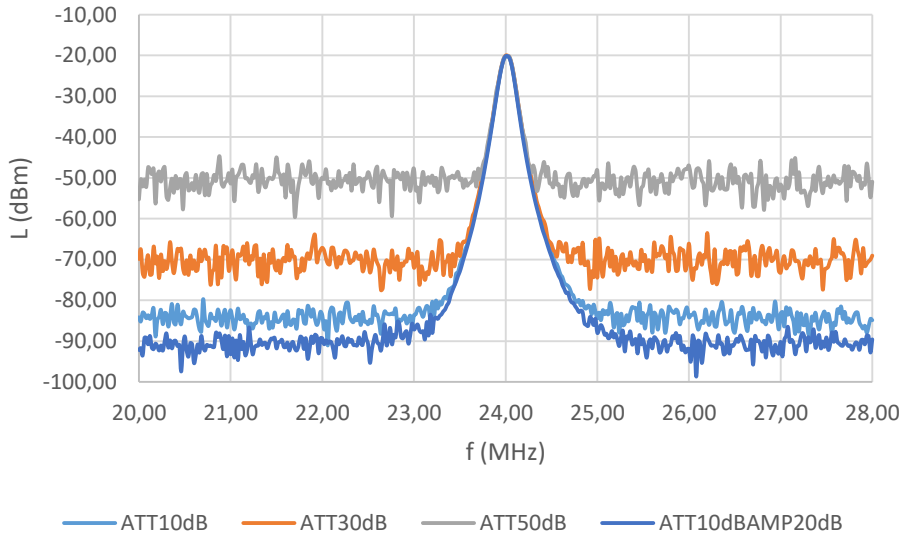


Fig. 4. Influence of attenuator and preamplifier on the measured level

NOTE: Maximum input level
The maximum value of the input signal connected to the analyzer input is really important according to the protection of the input circuits – especially on the mixer (input circuits with mixer are called as frontend). The maximum level is given by manufacturer (usually in dBm, f.e. +30 dBm) and there is possible that the input stage can be damaged. The DC voltage is also important in the input of analyzer, the zero DC voltage is often required (especially for analyzer with low frequency range). The external DC block is recommended to connect at the input in this situation. The ESD recommendations are also necessary during input cable connection and during handling with the device.

The mixer processes signals from input stage and from the local oscillator with frequency f_{MO}. This oscillator is usually tunable in the large frequency range, the sweep time is given by setting of frequency range and by RBW + VBW. It can be calculated by equation:

$$\mathrm{SweepTime} = k \cdot \frac{\mathrm{SPAN}}{\mathrm{RBW} \cdot \mathrm{VBW}} \Big|_{\mathrm{RBW} \geq \mathrm{VBW}},$$

where *k* represents the filter constant (depends on the type of the filter) – is equals k = 2,5 ÷ 3 for analogue filters and k is near to one for digital filters.

The measurement error for the same measurement time and different RBW is shown in Fig. 5.

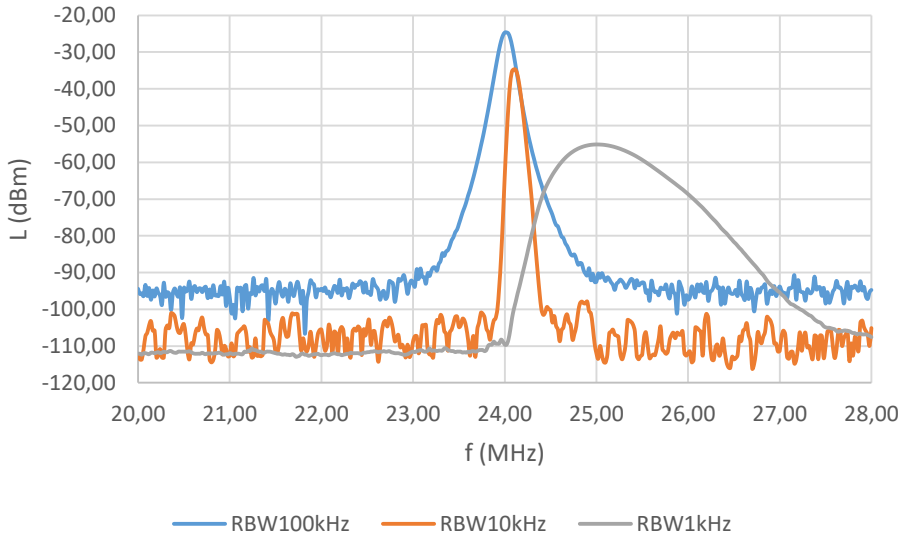


Fig 5. Influence of RBW on measurement with constant sweep time (5 ms)

The output signal f_{MF} from the mixer is equals to:

$$f_{MF} = |m \cdot f_{MO} \pm n \cdot f_{IN}|,$$

and it is amplified by intermediate-frequency amplifier and then is connect to the input of intermediate-frequency filter (IF, bandpass filter) that is tuned to the fixed frequency (most often on $f_{MF} = f_{MO} – f_{IN}$).

The intermediate-frequency filter bandwidth is really important parameter, it is usually marked BW or RBW (sometimes IFBWs. RBW is given by 3 dB drop for spectrum analyzers (6 dB drop for EMI receivers, this type of filter can be call as “EMI res” or “CISPR”) and the influence of the filter on the input signal is shown in Fig. 6. The selectivity is higher for CISPR filters (the definition can be found in CISPR 16).The definition of filter selectivity is

$$S_{MFF} = \frac{B_{60\,dB}}{B_{3(6)dB}},$$

where $B_{3\,(6)\,db}$ represents the filter bandwidth for 3 dB drop (or 6 dB for EMI receivers) and $B_{60\,dB}$ is the filter bandwidth for 60 dB drop .

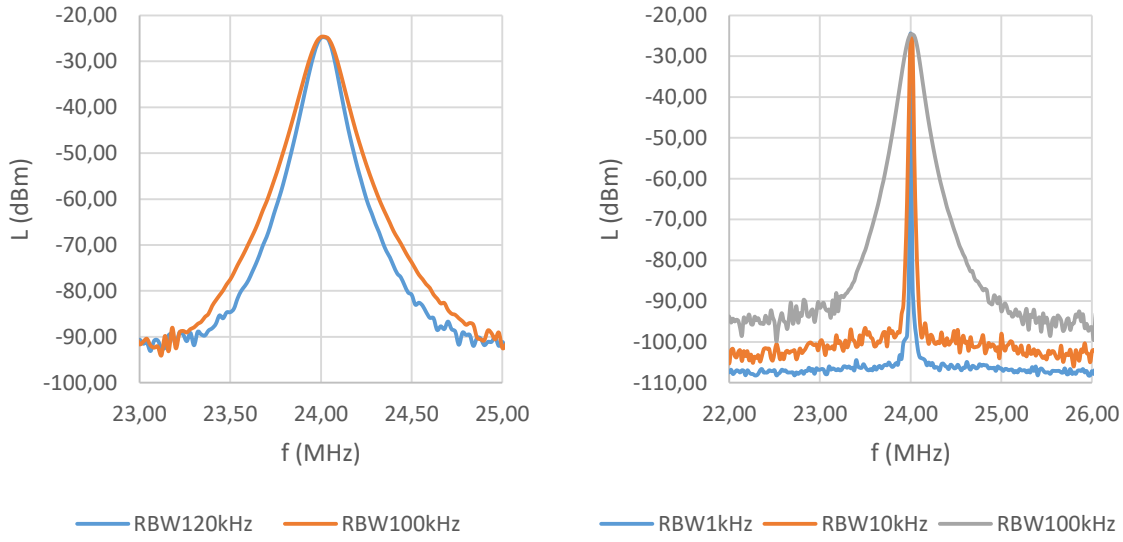


Fig. 6. Influence of RBW on measured signal

The detector follows the IF (name "demodulator" is usually used in the telecommunications) that evaluates the input signal by defined function. The peak detector is commonly used, less often the average detector and rms detector (these types in most cases do not meet the CISPR16 parameters for EMC measurements).

The video filter adjusts the signal behind the detector – its effect is visible especially for small signals (at the noise level) measurement – the SN ratio can be improved by the video filter bandwidth (VBW). The average function shows similar results (see Fig. 7). VBW influences the sweep time of the analyzator, similarly like a RBW (the narrower bandwidth increasing the sweep time).

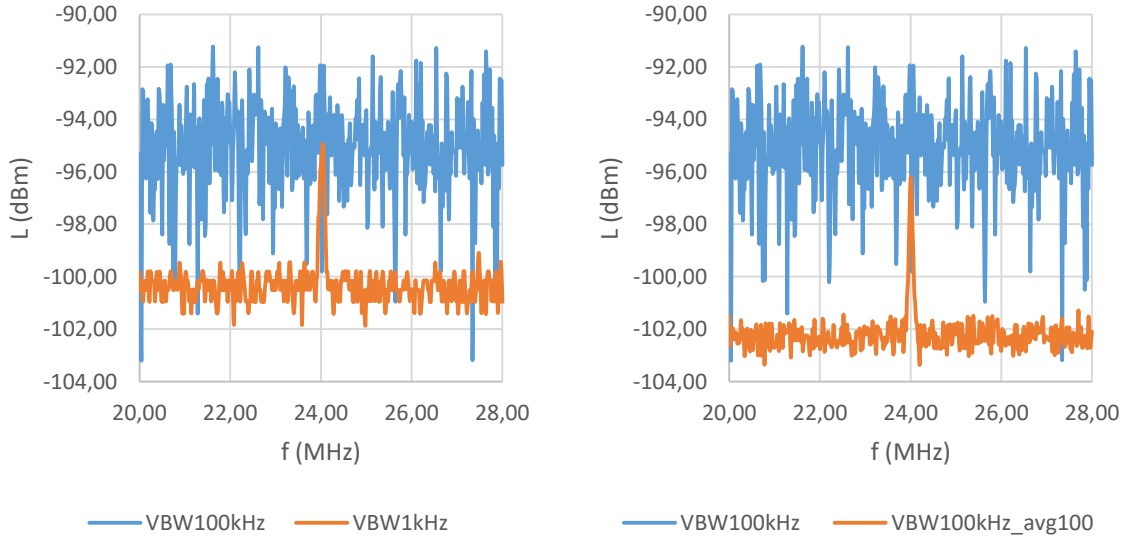


Fig 7. Influence of VBW / average on measured signal
(sweep time = 5 ms|$_{\text{VBW = 100 kHz}}$; 100 ms|$_{\text{VBW = 1 kHz}}$; 10 s|$_{\text{VBW = 100 kHz + avg 100 samples}}$)

Today, the signal from video filter is converted by an AD converter into a usable format for display visualization. In the past, the signal was visualized at tube screen – the local oscillator was coupled to the horizontal beam deflection and it causes visibility of the whole measured spectrum.

1.3 Insertion loss measurement

Attenuation of transmission line (or filter attenuation = insertion loss) is really easy to measure with a spectral analyzer with a tracking generator. The tracking generator is coupled to the local oscillator and there is possible to smoothly measure in the set frequency range.

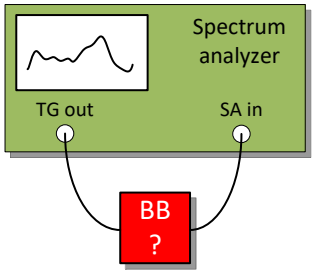


Fig 8. Insertion loss measurement – block diagram

The correct settings of SA and TG are crucial before attenuation:

- frequency range,
- measuring points,
- output level of the TG,
- RBW.

Increasing of measuring points makes sense only for saving / transferring of measured data to the computer for example. The display resolution usually represents the minimum number of measuring points (approx. 400 – 600 points). The output level should be set to the maximum – for example to the 0 dBm (if it is possible). If the lower level is used, the dynamic range decreasing directly with the TG level due to normalization of the trace. This is shown in Fig. 9.

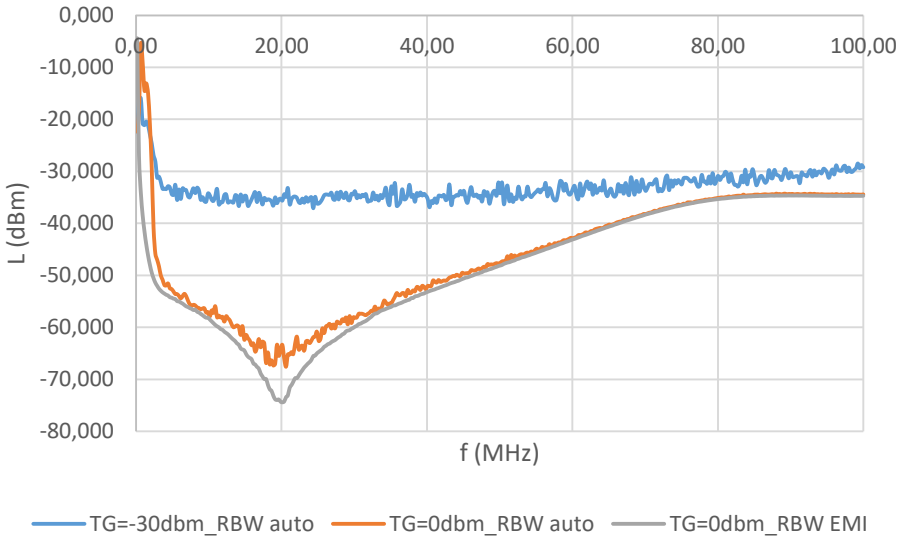


Fig 9.: Insertion loss measurement for different settings of TG output level and RBW

The dynamic range of measurement can be increased by the RBW (lower RBW represents higher dynamic range). But the sweep time increases with lower RBW.

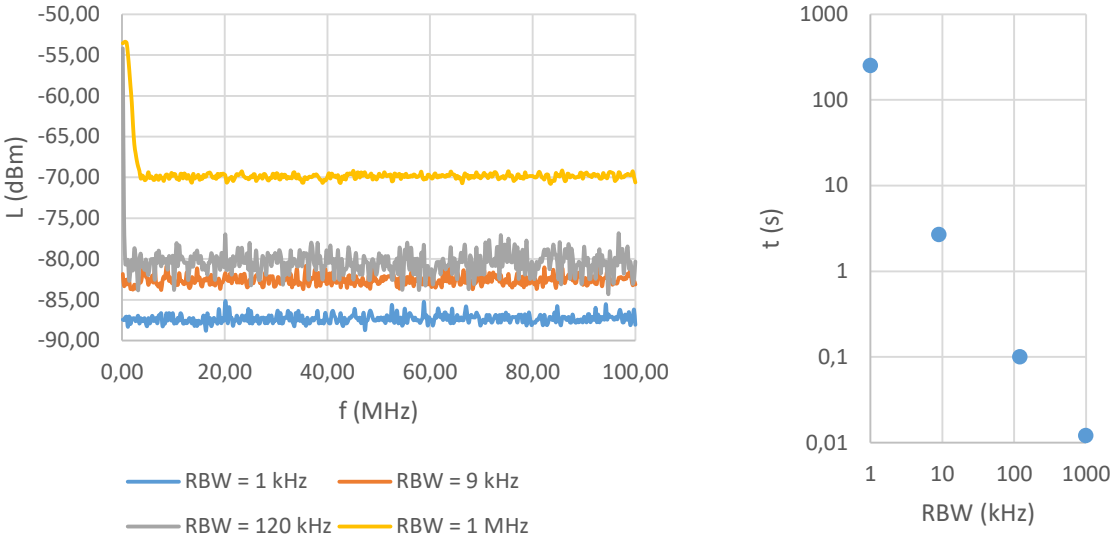


Fig. 10: dynamic range explanation

Calibration (normalization) of measured trace

A calibration is usually used for minimizing the influence of transmission line (attenuation of cables, bulkheads, etc.). There exist a different types of calibrations (especially in the case for measurement with vector analyzer), that represents calibration profile (or calibration plane) – defined condition for measurement. The most commonly used calibration type is OSM (Open – Short – Match). In this case, the defined impedance (in the form of calibration set) is connected to the measuring point(s).

The correct measurement is possible after the successful calibration process.

The term normalization is used for insertion loss measurement using spectrum analyzer with a tracking generator.

The normalization is only a mathematical process that for defined frequency range and number of measuring points moves all data to level 0 dBm. From this, every change in spectrum analyzer setting needs new normalization (for example for change of the frequency range). The re-calibration is also required for measurement with VNA (if some changes are performed).

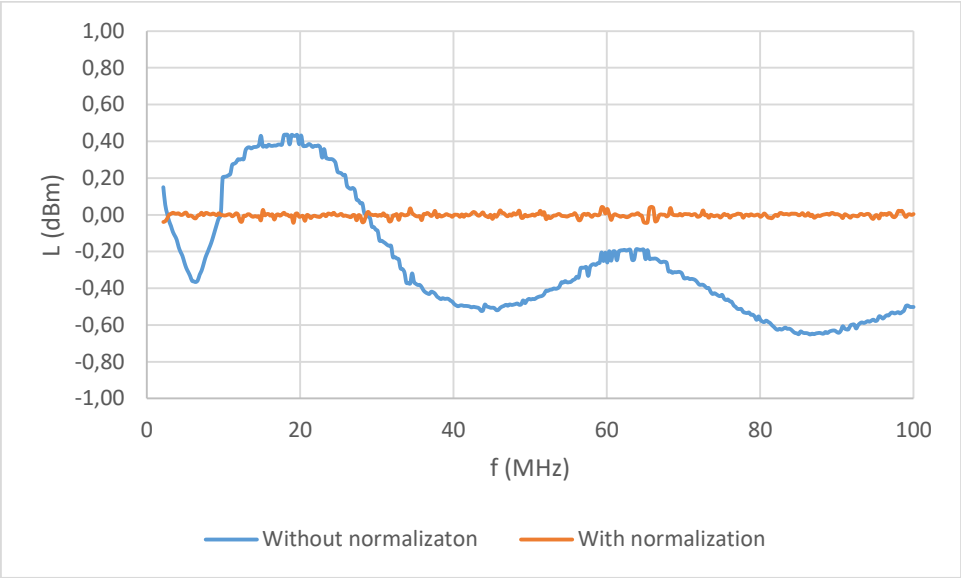


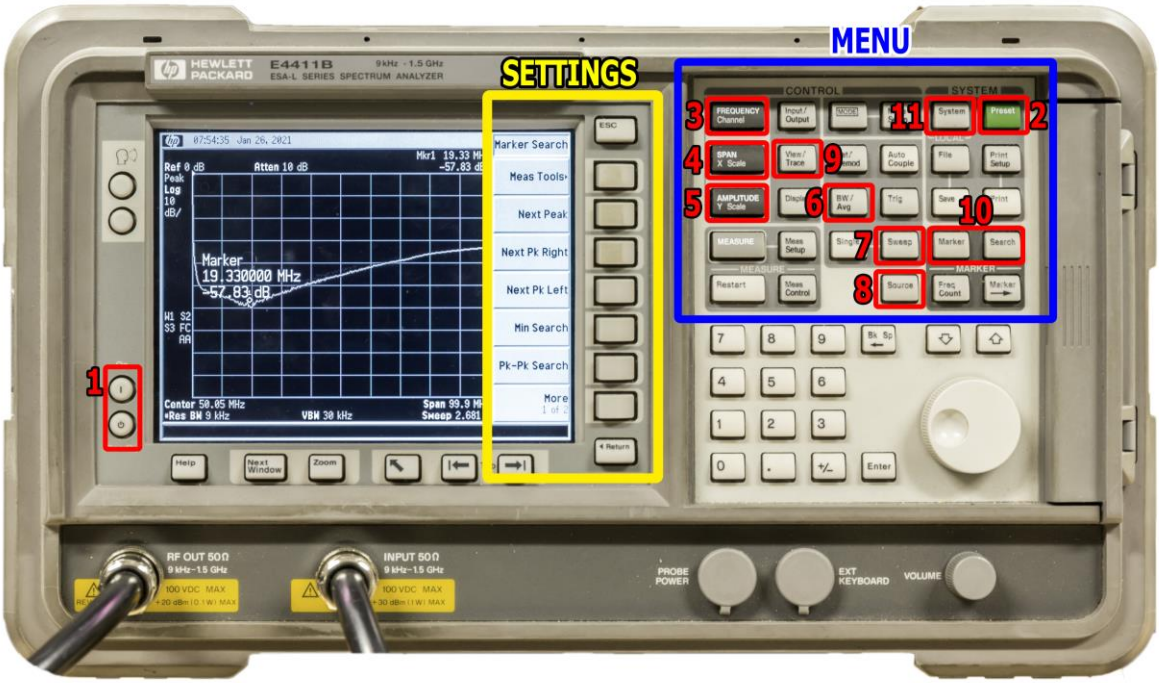
Fig. 11: Attenuation of the input cables for insertion loss measurement – with and without normalization

NOTE: Comparative measurement
In the case of comparative measurement, the normalization is not necessary to use – there the one of samples can be established like a reference value for measurement and the difference with others could be used like a “normalization”.

2 Setting of laboratory equipments

2.1 Spectrum analyzer HP E4411B

1. Frequency range setting:
    a. Menu Frequency – set start a stop
2. RBW setting
    a. Menu BW/Avg – set
3. Measuring point setting – NOTE: Increasing the of measuring points makes sense only for saving / transferring of measured data to the computer – this SA has only 401 measuring points, there is not possible to change it
4. Turning on and setting of tracking generator
    a. Menu source – Amplitude (set the output level) - On
5. Connect all cables – use dummy part for inductor measurement –
    a. Menu View / Trace – More – Normalize – Normalize On
6. Connect the measured component. The attenuation is visible on the screen = -1x gain (measured level)

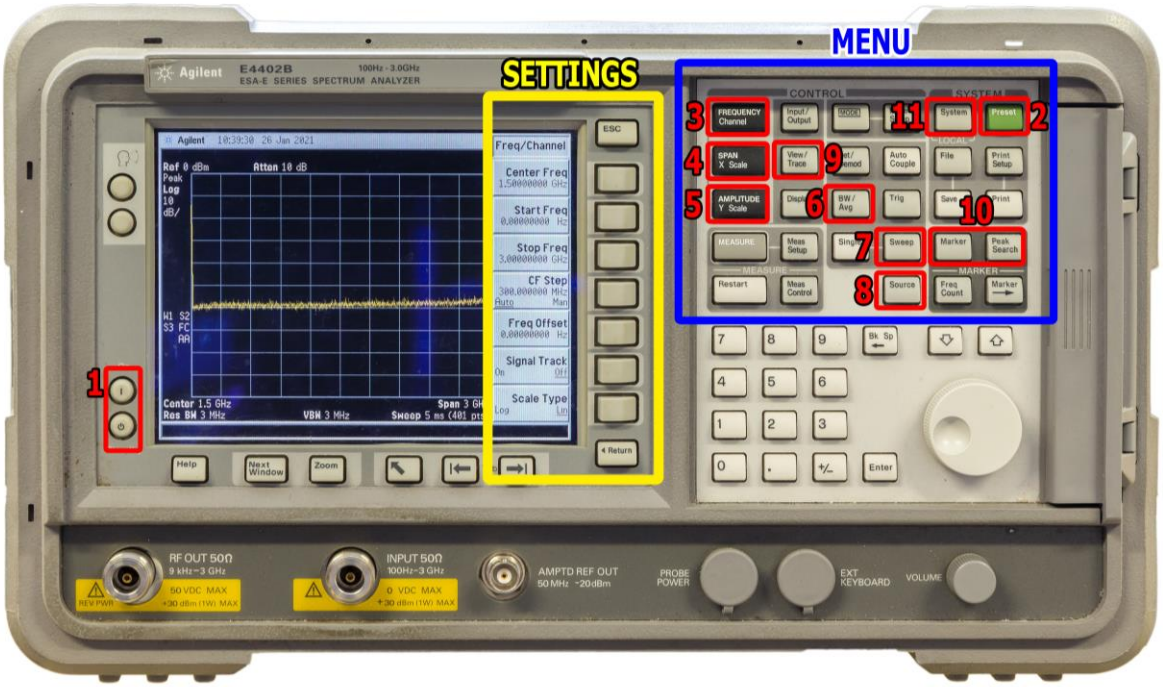


1 – Power button
2 – Preset – default setting
3 – Frequency range setting
4 – SPAN setting
5 – setting of y axis
6 – RBW setting
7 – Measuring points number / sweep time setting
8 – Tracking generator settings
9 – Trace and normalization settings
10 – Markers
11 – System information

Fig. 12: Spectrum analyzer HP E4411B

2.2 Spectrum analyzer Agilent E4402B

1. Frequency range setting:
    a. Menu Frequency – start a stop
2. RBW setting
    a. Menu BW/Avg – set
3. Measuring point setting – NOTE: Increasing the of measuring points makes sense only for saving / transferring of measured data to the computer – default 401 points
    a. Menu Sweep - Point
4. Turning on and setting of tracking generator
    a. Menu source – Amplitude (set the output level) - On
5. Connect all cables – use dummy part for inductor measurement –
    a. Menu View / Trace – More – Normalize – Stor Ref – Normalize On
6. Connect the measured component. The attenuation is visible on the screen = -1x gain (measured level)

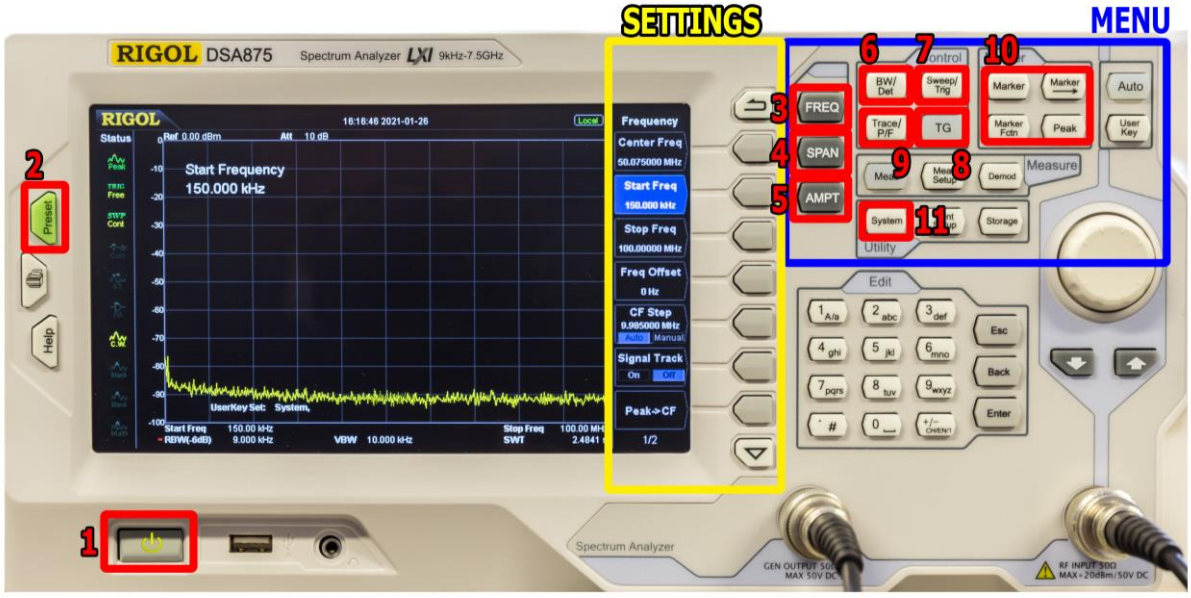


1 – Power button
2 – Preset – default setting
3 – Frequency range setting
4 – SPAN setting
5 – setting of y axis
6 – RBW setting
7 – Measuring points number / sweep time setting
8 – Tracking generator settings
9 – Trace and normalization settings
10 – Markers
11 – System information

Fig. 13: Spectrum analyzer Agilent E4402B

2.3 Spectrum analyzer Rigol DSA 875 / 815

1. Frequency range setting:
    a. Menu Frequency – start a stop
2. RBW setting
    a. Menu BW/Det – set (EMI/Gauss)
3. Measuring point setting (for DSA875 only)– NOTE: Increasing the of measuring points makes sense only for saving / transferring of measured data to the computer – default 601 points
    a. Menu Sweep – page 2/2 - Points
4. Turning on and setting of tracking generator
    a. Menu TG – TG Level (set the output level) - On
5. Connect all cables – use dummy part for inductor measurement –
    a. Menu TG – Normalize – Stor Ref – Normalize On
6. Connect the measured component. The attenuation is visible on the screen = -1x gain (measured level)

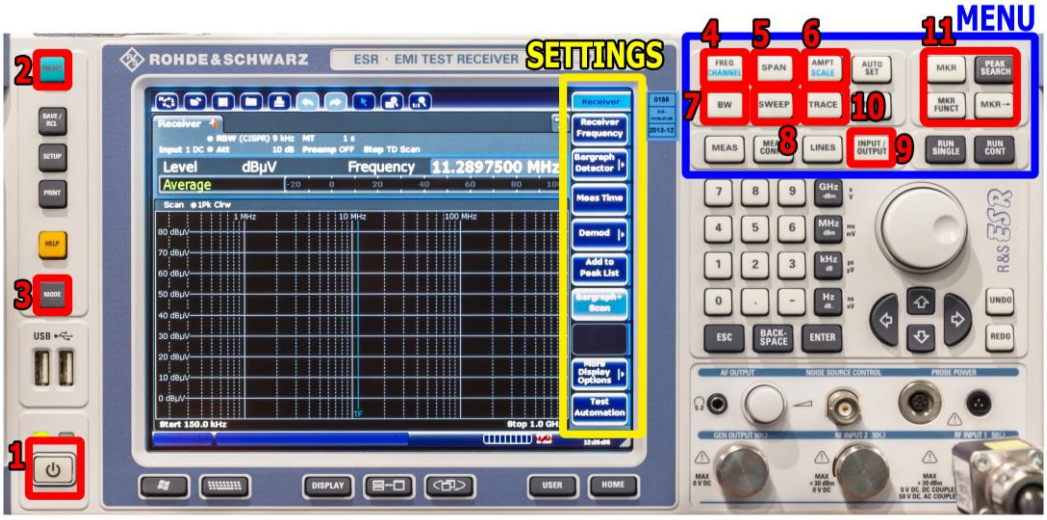


1 – Power button
2 – Preset – default setting
3 – Frequency range setting
4 – SPAN setting
5 – setting of y axis
6 – RBW setting
7 – Measuring points number (for DSA875 only) / sweep time setting
8 – Tracking generator settings
9 – Trace settings
10 – Markers
11 – system information

Fig. 14: Spectrum analyzer Rigol DSA 875

2.4 EMI receiver R&S ESR – spectral analysis setting

1. Setting of spectral analysis function
    a. Mode – Spectrum
2. Setting of dBm unit
    a. Menu AMPT / SCALE – Unit – dBm
3. Frequency range setting:
    a. Menu FREQ / CHANNEL – Start a Stop
4. RBW setting
    a. Menu BW – Filter Type – 3 dB Bandwidth or CISPR only set – Res BW Manual set
5. Measuring point setting – NOTE: Increasing the of measuring points makes sense only for saving / transferring of measured data to the computer – default 691 points
    a. Menu Sweep – Sweep Points (691 default)
6. Turning on and setting of tracking generator
    a. Menu INPUT / OUTPUT – Tracking Generator – Source Power (set the output level) – Source RF Internal – On
7. Connect all cables – use dummy part for inductor measurement –
    a. Menu Input / Output – Tracking Generator – Source Cal – Calibrate Transmission / Calibrate Reflection Short / Calibrate Reflection Open (select the type, in most cases Transmission) – Normalize
    b. Normalize – Stor Ref – Normalize On
8. Menu TRACE – SELECT TRACE (max. 3) – Clear/Write; Max Hold; Average; View; Blank;
9. Connect the measured component. The attenuation is visible on the screen = -1x gain (measured level)

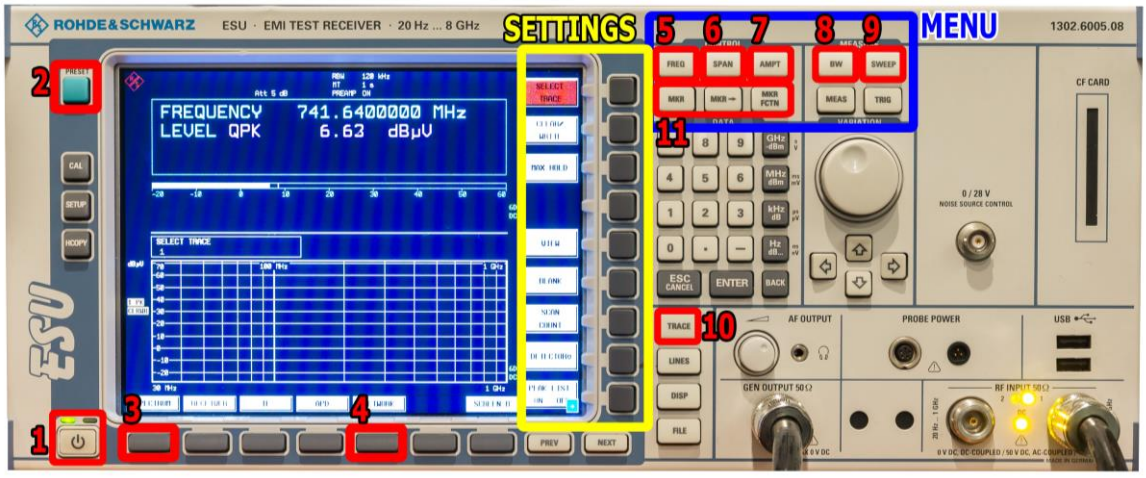


1 – Power button
2 – Preset – default setting
3 – Mode setting of the receiver
4 – Frequency range setting
5 – SPAN setting
6 – setting of y axis
7 – RBW setting
8 – Measuring points number / sweep time setting
9 – Tracking generator settings
10 – Trace settings
11 – Markers

Fig. 15: EMI receiver R&S ESR7

2.5 EMI receiver R&S ESU – spectral analysis setting

1. Setting of spectral analysis function with tracking generator
    a. Mode – Spectrum
2. Setting of dBm unit
    a. Menu AMPT – Unit – dBm
3. Frequency range setting:
    a. Menu Freq – Start a Stop
4. RBW setting
    a. Menu BW – Filter Type (set your choice, NORMAL 3 dB or EMI 6 dB) – RES BW MANUAL <value>
5. Measuring point setting – NOTE: Increasing the of measuring points makes sense only for saving / transferring of measured data to the computer – 625 default
    a. Sweep – SWEEP POINTS (625 default)
6. Turning on and setting of tracking generator
    a. Menu Network – Source Power (set the level) – Source ON
7. Connect all cables – use dummy part for inductor measurement –
    a. Menu Network – Source Cal – Cal Trans / Short / Open (select the type, in most cases trans) – Normalize
8. Menu TRACE – SELECT TRACE (max. 3) – CLEAR/WRITE; MAX HOLD; AVERAGE;VIEW; BLANK
9. Connect the measured component. The attenuation is visible on the screen = -1x gain (measured level)



1 – Power button
2 – Preset – default setting
3 – Spectrum analyser function
4 – Tracking generator settings
5 – Frequency range setting
6 – SPAN setting
7 – setting of y axis
8 – RBW setting
9 – Measuring points number / sweep time setting
10 – Trace settings
11 – Markers

Fig. 16: EMI receiver R&S ESU8