The EMI-Receiver according to CISPR 16-1-1

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Requirements from the standard CISPR 16-1-1

- Frequency Ranges from 9 kHz to 18 GHz, divided into CISPR Bands A to E
- Detectors: QP, AV, PK, RMS, recently added: CAV and CRMS
- Overall Selectivity, Bandwidth
- Pulse Weighting
- Overload Capabilities
- Impedance matching at the receiver input

Evaluation of CISPR-compliance

- Signal generators with c.w. output
- Pulse generators with defined pulse area, duration and repetition frequency
- Network Analyser or comparable equipment to measure impedance matching

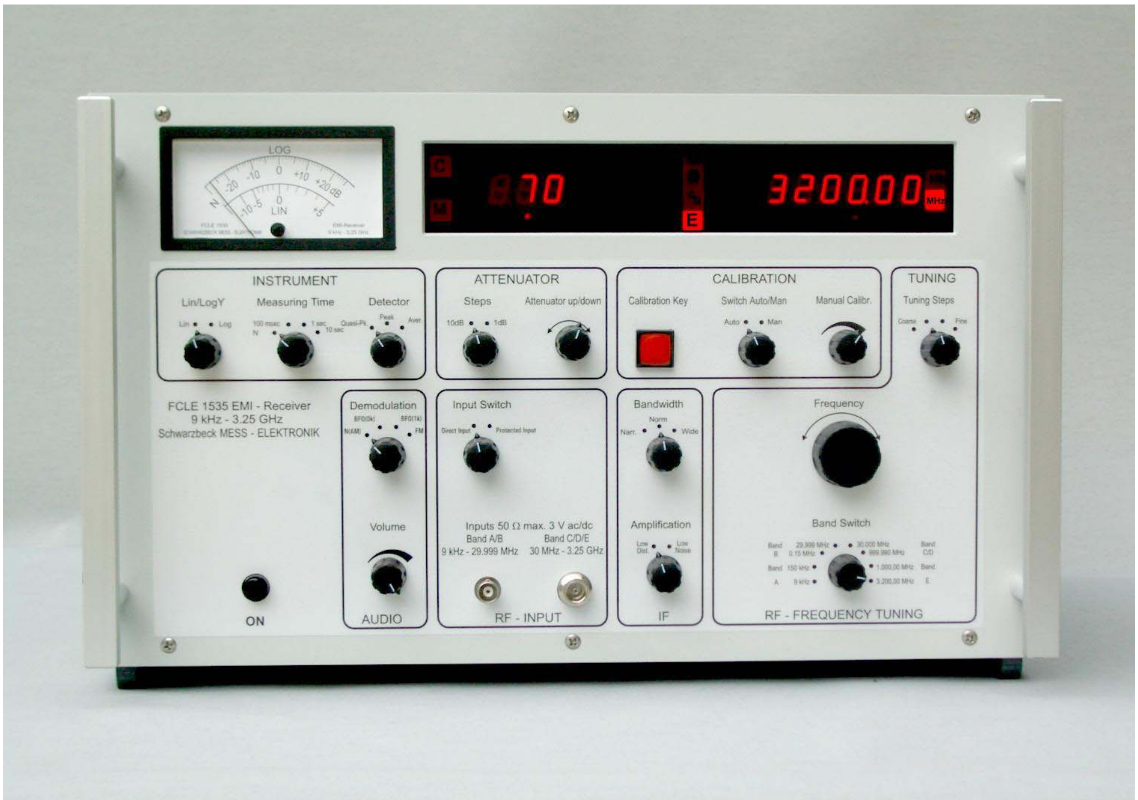


Fig. 1: EMI-Receiver FCLE 1535 covering the frequency range from 9 kHz to 3.25 GHz

The EMI-Receiver according to CISPR 16-1-1

Requirements to an EMI Receiver in practical applications

EMI-Receivers are used to measure unwanted emissions at high frequencies generated by an EuT (equipment under test). These emissions may be conducted (i.e. on the power cord) or radiated as an electromagnetic wave. Depending on the kind of emission there are different coupling devices available, which are responsible to pick up the emission and forward it to the receiver. Here is an overview about the most common coupling devices:

- LISN (Line Impedance Stabilisation Network) to measure conducted emissions, usually up to 30 MHz, sometimes up to 108 MHz. The most common LISN is a V-type, which provides the measurement of unsymmetrical disturbance voltage. The T-LISN or ISN measures the asymmetrical disturbance voltage in symmetrical data transmission systems. For rare applications there is a delta LISN which measures the differential voltage between two lines.
- Voltage Probes are used to measure the conducted unsymmetrical disturbance voltage for applications in which LISN can't be used, e.g. because of extremely high currents. The voltage probes have usually an impedance of 1.5 kΩ, a transducer of 30 dB and a maximum frequency of 30 MHz.
- Absorbing Clamps are used to measure the disturbance power on power cords from 30 MHz up to 1 GHz
- Current Clamps measure the disturbance current on single lines or line bundels. Most current clamps have a transducer of 34 dB, which corresponds to a transfer impedance of 1 Ω.
- Capacitive Voltage Probes measure the conducted asymmetrical (common mode) voltage on line bundles, typically used for data transmission.
- Loop Antennas measure the magnetic fieldstrength, usually up to 30 MHz
- Electrical Antennas are used to measure the electrical fieldstrength above 30 MHz, the most common types are Biconical Antennas, LPDA (Logarithmic Periodic Dipole Array) and Horn Antennas. The monopole antenna is mostly used below 30 MHz.

The big variety of coupling devices lead to sometimes contradictory requirements. LISNs can produce very short peak voltages, which can reach the order of 100 V or more, whereas antennas, especially at high frequencies, provide voltages in the order of some µV only! Both situations, robustness against damage and high sensitivity to measure weak signals must be covered by a good EMI-receiver. A further difficulty arises from the nature of disturbance signals: all of them are unintentional signals. They may be stable or unstable, their spectral intensity may be very high and their frequency response is generally unknown. The majority of disturbance signals has pulse characteristics, which leads to a broadband spectrum. A very important matter in all EMC applications is the reproducability of test results among different laboratories in case of dispute. Experience from approx. 50 years of EMI-measurement have shown, that the frequency range of a receiver or spectrum analyser itself is by far not sufficient to obtain comparable measurement results.

Block Diagram of an EMI Receiver

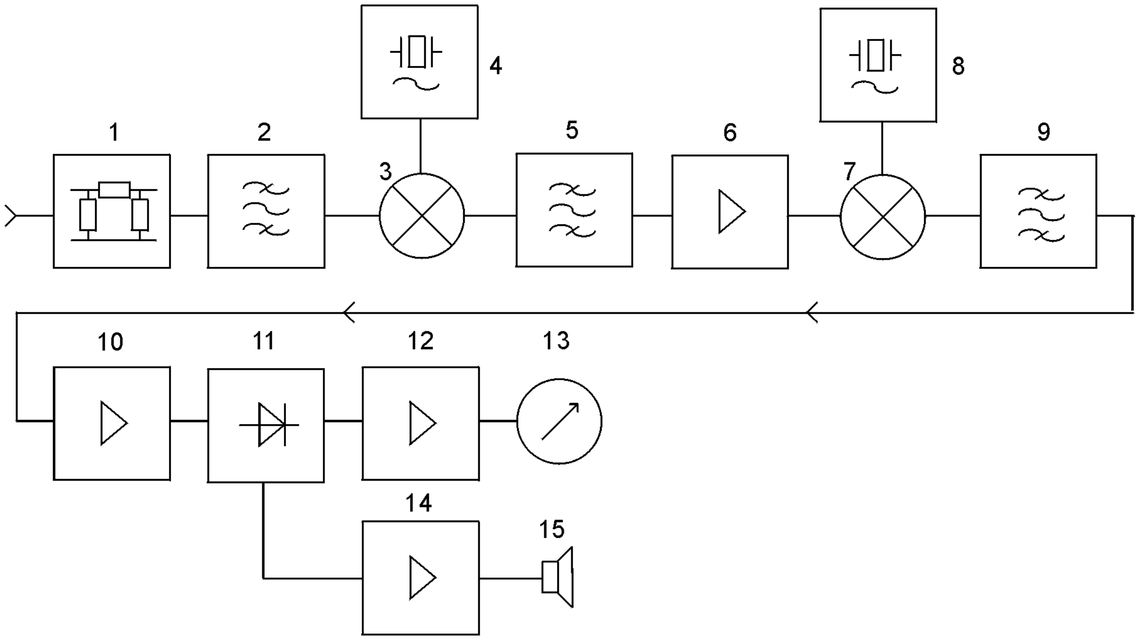


Fig. 2: Block Diagram of an EMI-Receiver (simplified)

1: Input Step Attenuator
2: Preselector
3: 1st Mixer
4: 1st Local Oscillator
5: 1st IF-Filter
6: IF-Amplifier
7: 2nd Mixer
8: 2nd Local Oscillator
9: 2nd IF-Filter
10: IF-Amplifier
11: Demodulator / Detectors
12: Display Amplifier
13: Display
14: Audio-Amplifier
15: Loudspeaker / Headphone

The main difference to a spectrum analyser are the preselection filters. The selectivity of a spectrum analyser is completely provided by the frequency conversion, the first mixer must cope with the total spectral power caused by the EuT. Even if only a small frequency range is set, the mixer gets the total energy of the broadband spectrum. The EMI-receiver with its preselection is able to reject the majority of spectral energy, only a small amount passes through to the first mixer. This avoids overload of the first mixer, which is an essential criterion to provide reliable measurement results.

The EMI-Receiver according to CISPR 16-1-1

Receiver Indication for Sine Wave Signals

PK = QP = RMS = AV (valid for unmodulated c.w.)

Unmodulated c.w. (sine wave) voltages give equal readings for all detectors and for all bandwidths. This is usually not a critical requirement for EMI-receivers or Spectrum Analysers. If there are several sine wave signals in close vicinity, the overall selectivity and the shape factor becomes important. The CISPR 16-1-1 section 4.3. specifies an accuracy for sine wave signals of +/- 2 dB for the frequency range from 9 kHz to 1 GHz. Above 1 GHz the receiver reading may deviate up to +/- 2.5 dB from the true value.

Receiver Indication for Pulse Signals

The measurement of pulses instead needs more detailed receiver specifications in order to provide good reproducability. There are several specifications, which are very important for a correct receiver reading with pulses:

- The overall selectivity (bandwidth) must be inside the specified window
- The overload factor must be sufficiently high, especially at low PRF
- The detector time constants for charging and discharging and the meter time constant must be specified

The following example will help to understand the difficulties to measure pulses in a correct way. We assume some repeated pulses in the time domain. These pulses have a duration TP. If we watch the spectrum of these pulses, we can see a large number of spectrum lines. The spacing of the spectrum lines is exactly the pulse repetition frequency PRF. The envelope of these spectrum lines has the first minimum frequency f at the inverse of the pulse duration TP. The shape of the spectrum envelope depends on the pulse shape in the time domain.

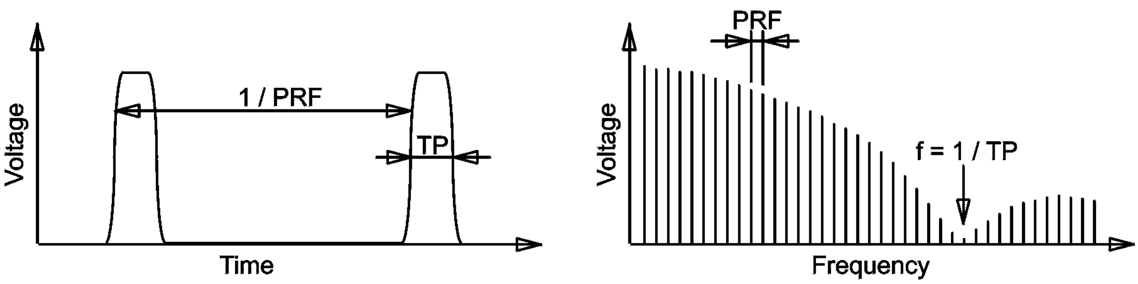


Fig. 3: Periodically repeated pulses and their spectrum

The spectrum envelope of rectangular pulses have a decay of 20 dB/decade of freuency, triangular pulses have a decay of 40 dB/decade of frequency.

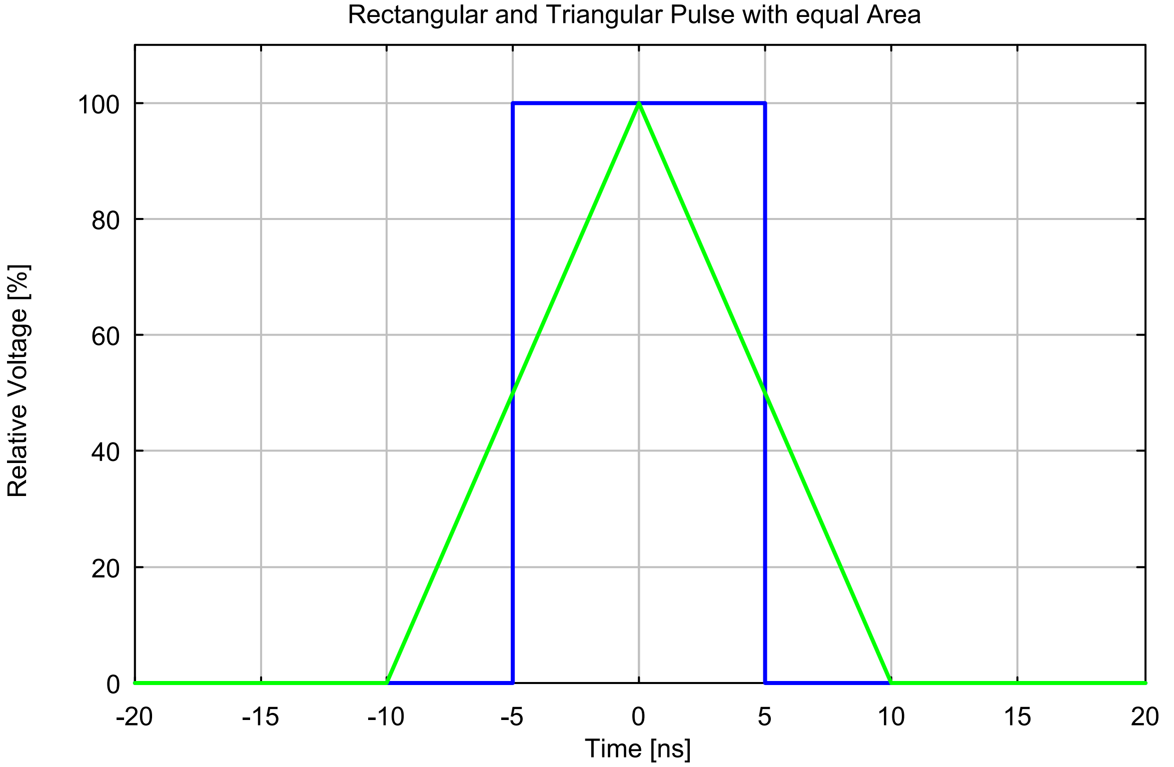


Fig. 4: Rectangular and Triangular pulse with equal area and equal duration (at 50% amplitude)

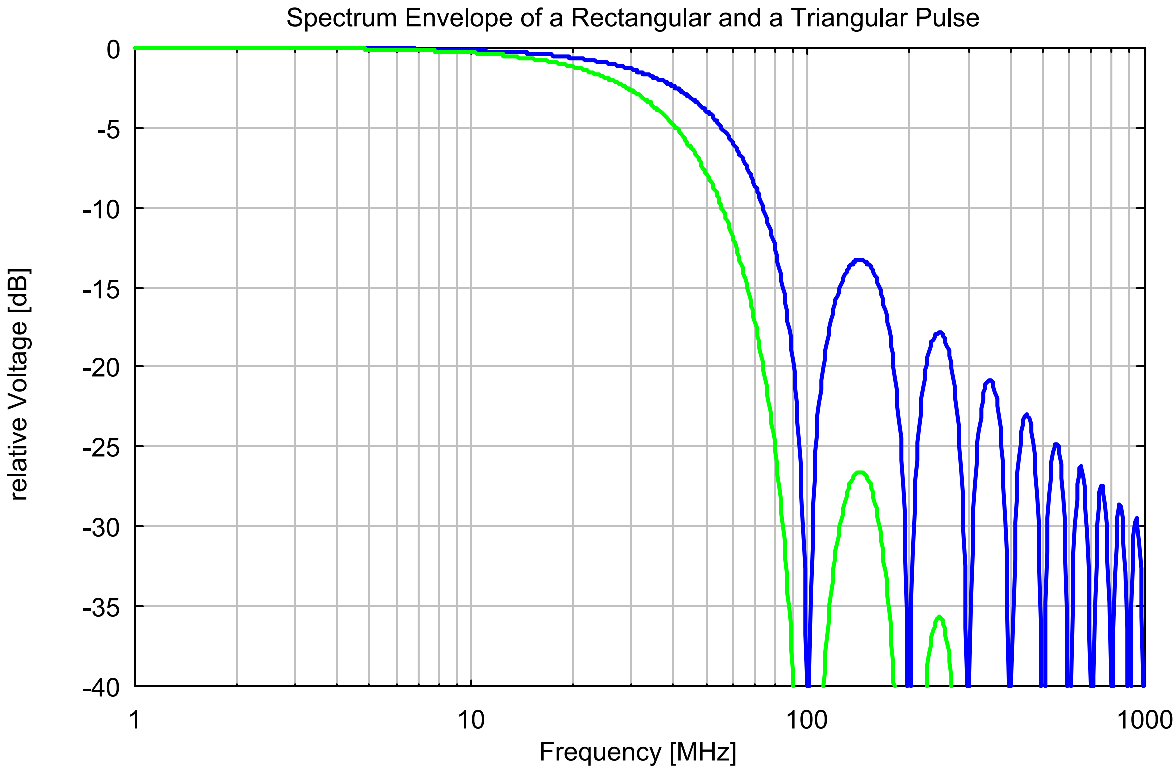


Fig. 5: Spectrum Envelope of Rectangular and Triangular pulse

The spectrum of both triangular and rectangular pulses with equal area is the same for low frequencies. In our example there is nearly no difference up to 10 MHz.

It depends on the bandwidth of the receiver and the PRF of the pulses, what kind of spectrum will appear in a measurement. In the first case there are many spectrum lines within the receiver bandwidth. The receiver is not able to resolve single spectrum lines, therefore we obtain a continuos spectrum (also called the spectrum envelope).

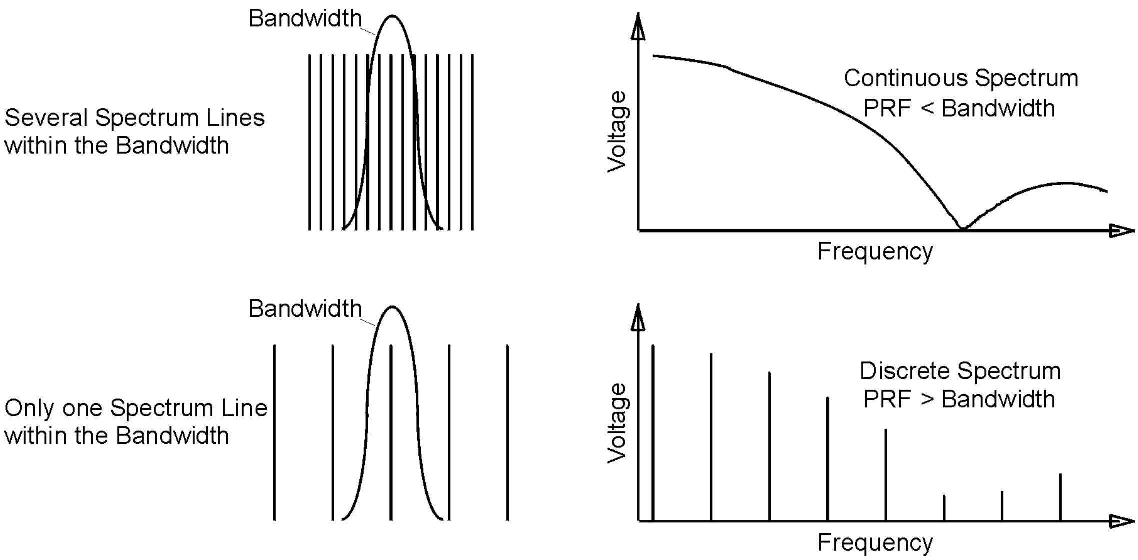


Fig. 6: Continuous and Discrete Spectra

In the second case the receiver bandwidth is narrower than the spacing of the spectrum lines (PRF). Only one spectrum line falls within the receivers selection curve. The receiver is now able to resolve each spectrum line as a discrete frequency. The envelope of these spectrum lines is still the same as above, which depends only on the pulse shape in time domain.

The mathematical relationship between time domain and frequency domain is the Fourier transform.

The overall selectivity of an EMI receiver describes the bandwidth requirements more detailed. CISPR 16-1-1 section 4.5. defines tolerance windows for the selectivity. The following plots show measured selectivity curves and their tolerance margin. The overall selectivity of a practical receiver design is finally determined by the last IF-filter.

Overall Selectivity of a CISPR 16-1-1 EMI-Receiver

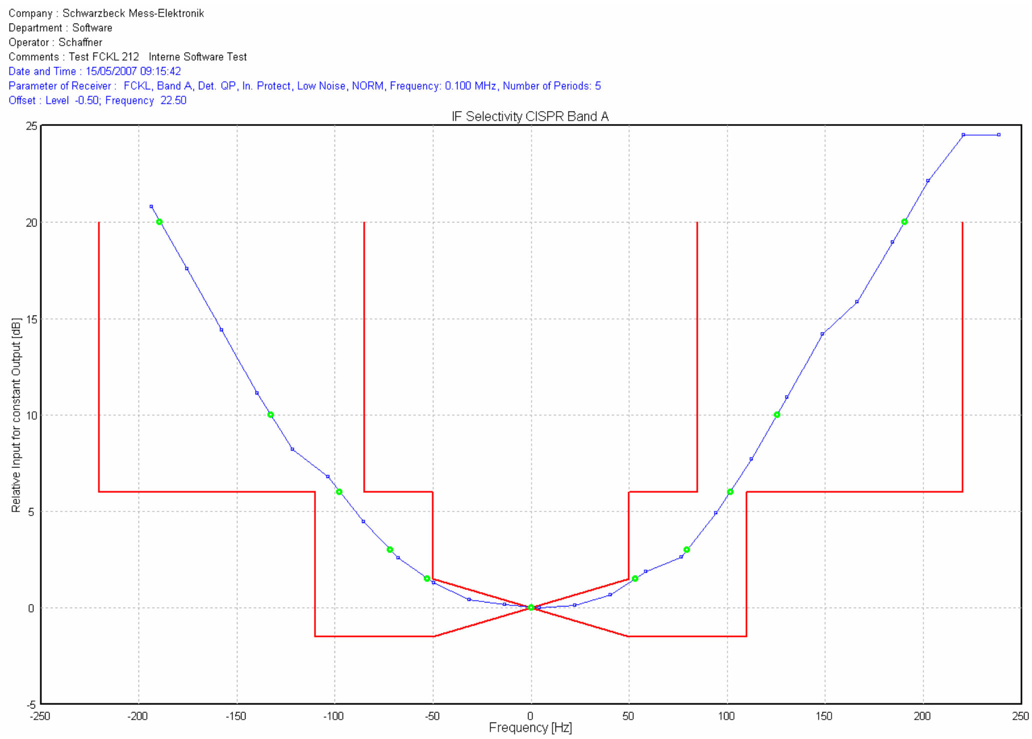


Fig. 7: Overall selectivity tolerance window and actual selectivity data in Band A

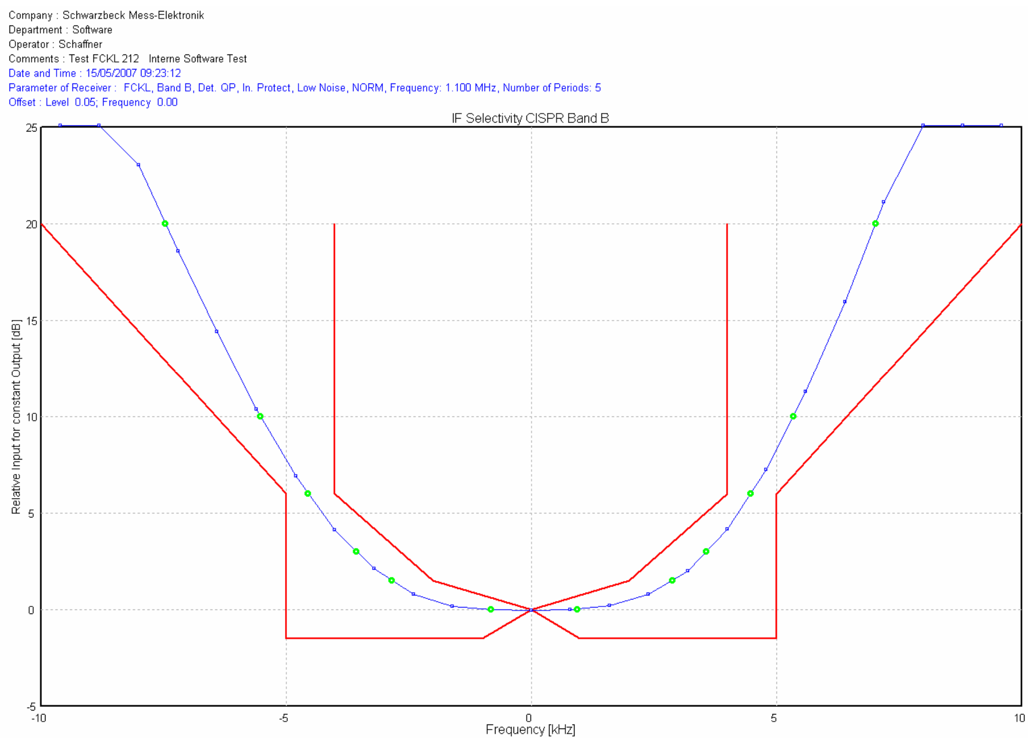


Fig. 8: Overall selectivity tolerance window and actual selectivity data in Band B

Overall Selectivity of a CISPR 16-1-1 EMI-Receiver

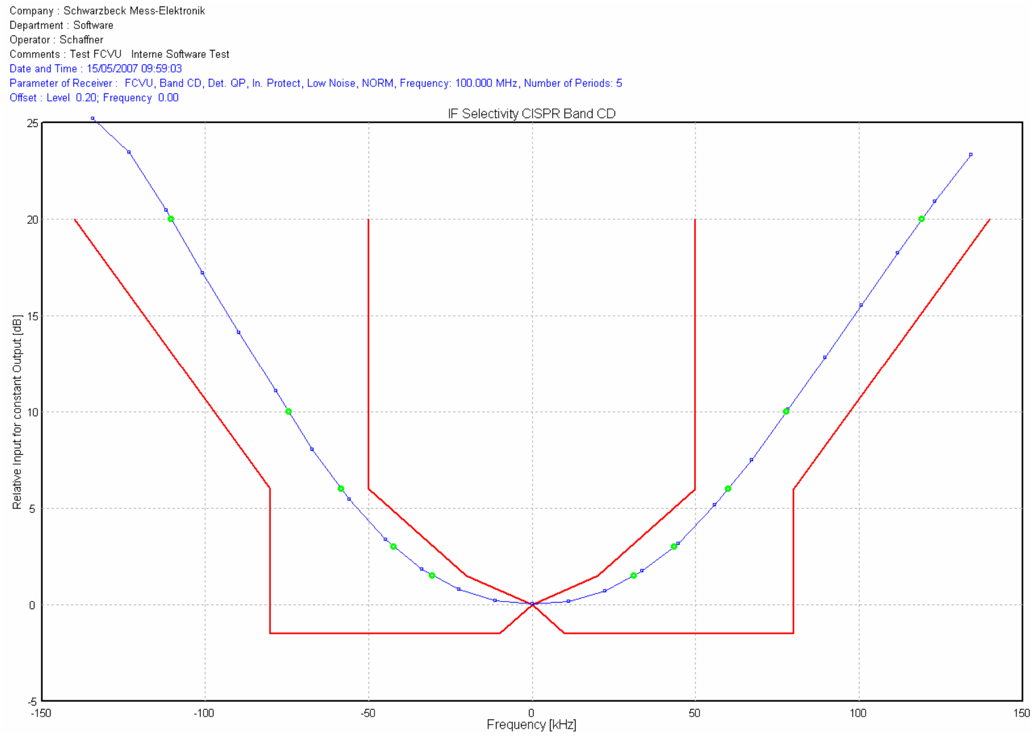


Fig. 9: Overall selectivity tolerance window and actual selectivity data in Band C/D

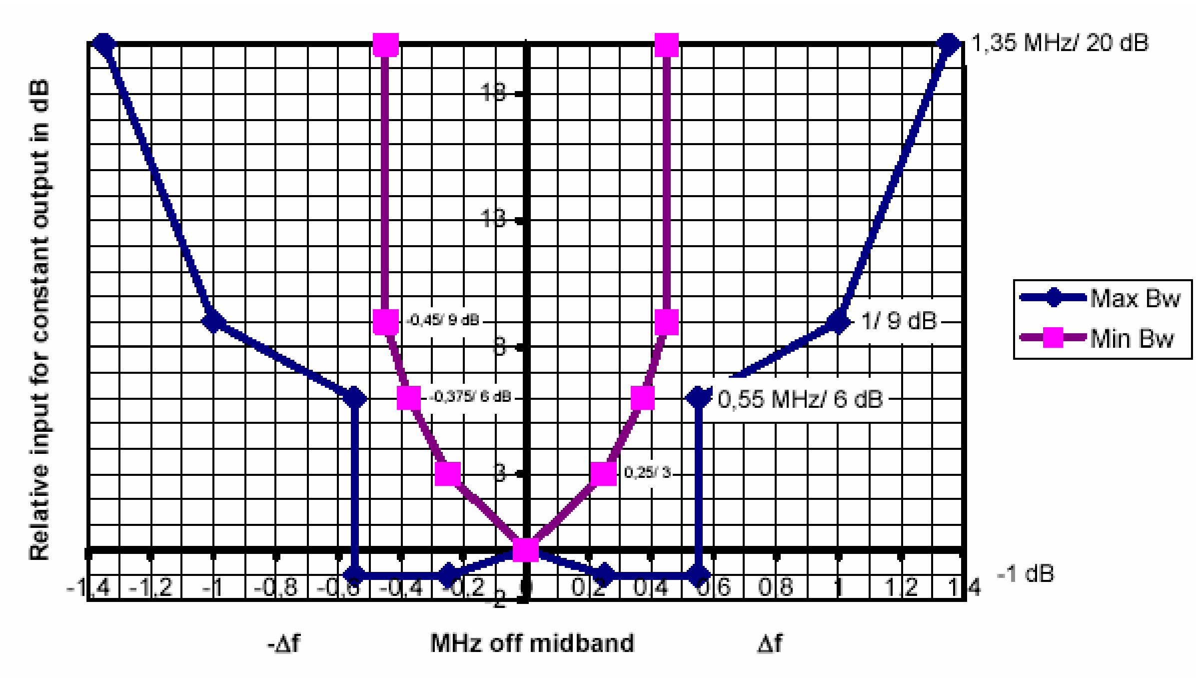


Fig. 10: Overall selectivity tolerance window in CISPR Band E

The EMI-Receiver according to CISPR 16-1-1

Pulse forming by the bandpass characteristics of an EMI-Receiver

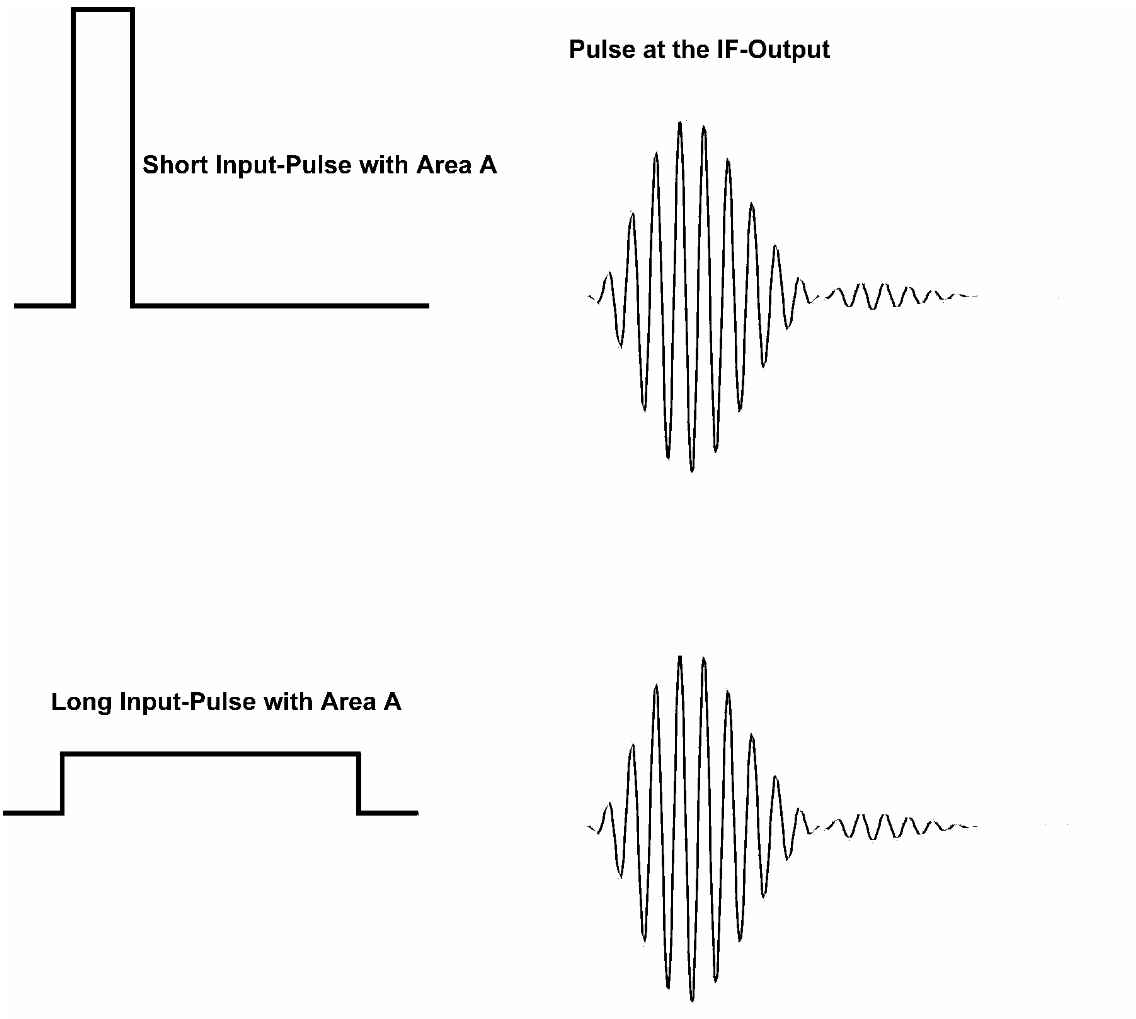
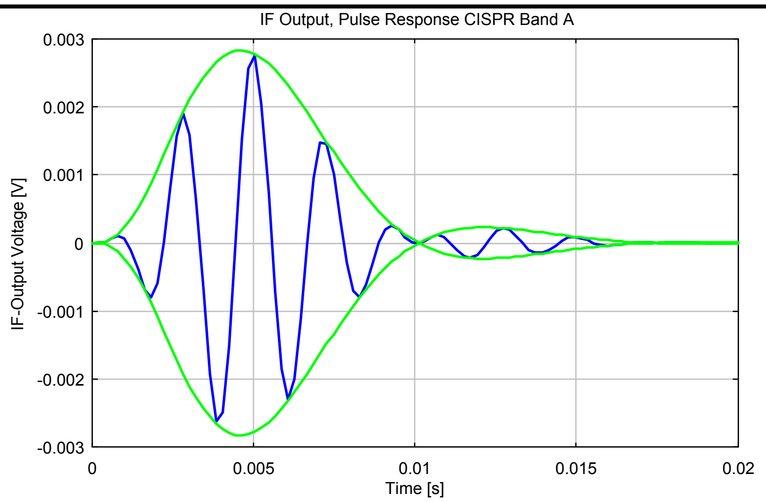


Fig. 11: Pulses with equal area produce equal IF-pulses

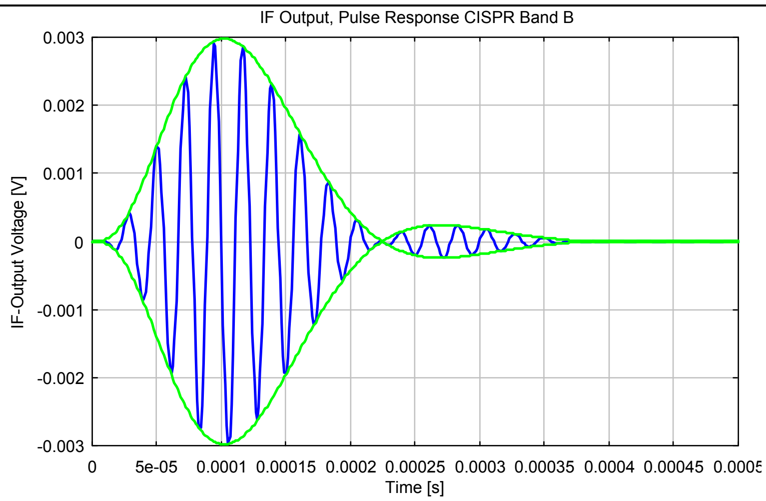
A short pulse and a long pulse with identical area (voltage multiplied with duration) create the same pulse at the IF-output of an EMI-receiver. The short pulse with the higher voltage is demanding more dynamic range of the receiver stages to be indicated in a correct way. The shorter the pulse, the more critical the situation. The bandwidth of the receiver is responsible for the duration of the IF-pulse. The inverse of the IF-pulse duration is equal to the half of the receivers' 6 dB bandwidth. The frequency of the oscillations corresponds to the IF of the receiver. The IF-pulse is amplified and forwarded to the demodulator and detector circuitry. The following diagrams show the pulse response at the IF-output for the CISPR Bands A to D.

Pulse Response
at the IF-Output of a CISPR 16-1-1 EMI-Receiver

CISPR Band A:
Pulse Area [50 Ω]: 6.75 µVs
6 dB Bandwidth: 200 Hz
Freq. Range: 9 - 150 kHz



CISPR Band B:
Pulse Area [50 Ω]: 0.158 µVs
6 dB Bandwidth: 9 kHz
Freq. Range: 0.15 - 30 MHz



CISPR Band C/D:
Pulse Area [50 Ω]: 0.022 µVs
6 dB Bandwidth: 120 kHz
Freq. Range: 30 - 1000 MHz

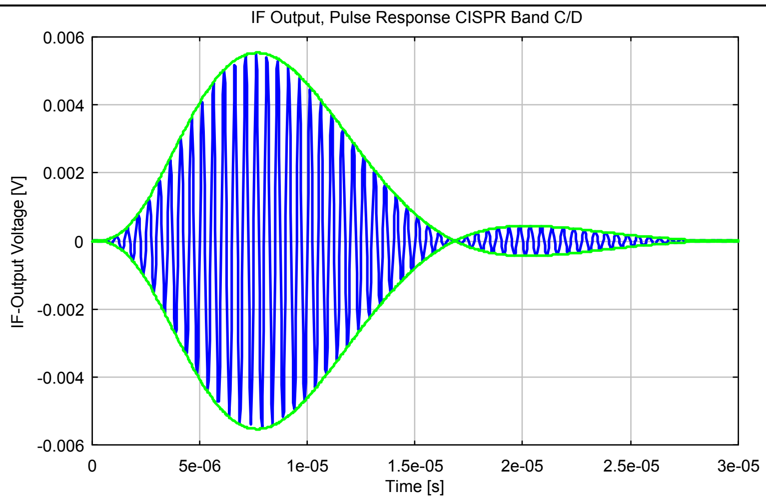


Fig. 12-14: Pulse Response at the IF-Output for CISPR Bands A to D

The EMI-Receiver according to CISPR 16-1-1

A very important rule, applicable to all CISPR Bands is the following:

$$PK > QP > RMS > AV \qquad \text{(valid for pulse signals)}$$

The reason for this rule will be explained now:

Demodulation

The demodulator D has to rectify the oscillating IF-pulse. Depending on the detector in use, the rectified pulse charges a combination of resistor Rc and capacitor C, which represent the charging time constant. The combination of a further Resistor Rd and the Capacitor C forms the discharging time constant of the detector. After having passed the detector, the signal is amplified and indicated with a meter needle, which also comes with a (mechanical) time constant. The dynamic characteristics (response to repeated pulses) of the receiver is determined by these time constants. In case of modern computer controlled receivers the mechanical time constant of the meter needle is replaced by an electrical circuitry.

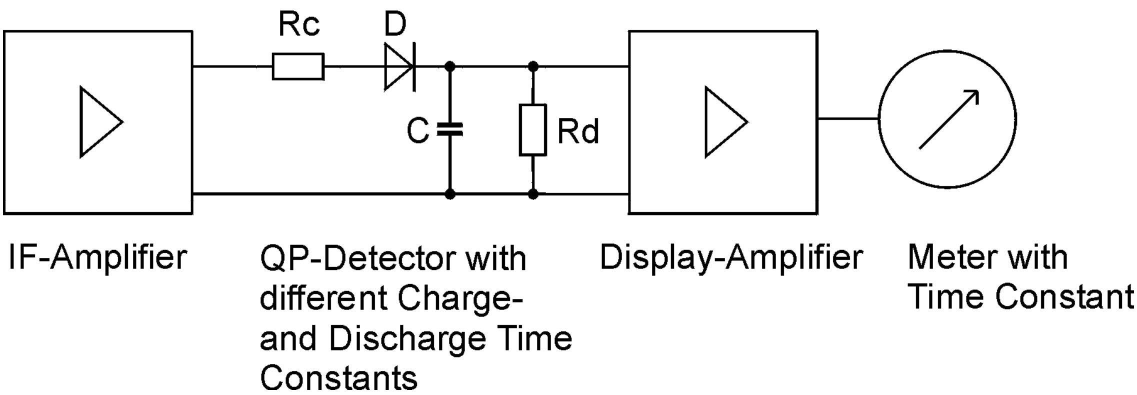


Fig. 15: Demodulator and detector circuit with display amplifier and meter

Peak Detector (PK)

A peak indication can be achieved with an extremely short time constant for charging and a very long time constant for discharging. With this combination of time constants the detector is able to follow the signal immediately and to hold the value for a long time. Therefore the Peak detector is independent of the pulse repetition frequency (PRF).

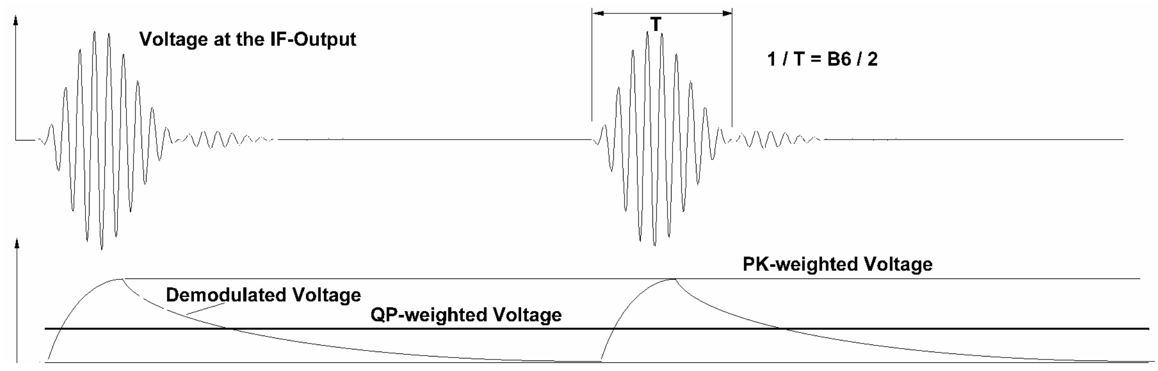


Fig. 16: Repeated IF-pulses and demodulated voltage, PK and QP-weighted voltages

Quasipeak Detector (QP)

The Quasipeak detector has a short charging time constant (1 ms in Bands B/C/D, 45 ms in Band A), which allows a fast charging, and a relatively long discharging time constant (500 ms in Band A, 160 ms in Band B and 550 ms in Band C/D). It is obvious that the PRF will have a significant influence on the QP-reading. The more pulses appearing within a certain time, the higher the QP-reading will be. The charge and discharge time constants and the meter time constants lead to the QP-Pulse weighting characteristics as described in CISPR 16-1-1 Table 3. The area of voltage and time of the standard pulse is defined in section 4.4.1. These pulses are repeated with 100 Hz repetition frequency (Band A: 25 Hz) and their RMS output value is compared with the output of a sine wave signal of 60 dBµV (1 mV). The maximum permissible deviation between QP-weighted pulse signal with 100 Hz PRF and the sine wave signal may be +/- 1.5 dB. The most critical situation is given in CISPR Band C/D: A calibration pulse with the required voltage time area of 0.022 µVs should have a flat spectrum envelope up to 1 GHz. This requires very short pulse durations in the order of less than 400 ps. A voltage of 55 V is then required to fulfill the pulse area condition. Therefore a QP-receiver must be able to handle the 55 V pulse and the 1 mV sine wave signal in the same configuration, which corresponds to a ratio of 95 dB! If the pulse repetition is reduced from 100 Hz to 1 Hz, the QP-pulse weighting curve gives a ratio of 28.5 dB less indication. In order to obtain a useful reading the RF-attenuator of the receiver must be reduced by approximately the same amount. The QP-receiver must be able to handle a dynamic range of more than 123 dB to achieve a correct indication of 1 Hz pulses and a sine wave signal which is indicated in the same way!

RMS Detector (RMS)

The RMS-detector is specified in CISPR 16-1-1 chapter 7. The RMS detector indicates proportional to the squareroot of the pulse repetion frequency. This corresponds to a RMS reading which increases by 10 dB when the PRF increases factor 10 (1 decade). It can also be expressed as an increase by 3 dB per octave (factor 2) of the PRF.

$$RMS \propto SQRT(PRF)$$
$$RMS \propto 10\ dB\ /\ Decade\ of\ PRF$$
$$RMS \propto 3\ dB\ /\ Octave\ of\ PRF$$

Average Detector (AV)

The AV-detectror is specified in CISPR 16-1-1 chapter 6. The AV-detector indicates proportional to the pulse repetion frequency. This can be expressed as an increase in AV-reading by 20 dB if the PRF increases by factor 10 (1 decade). It also corresponds to an increase by 6 dB if the PRF is doubled (octave).

$$AV \propto PRF$$
$$AV \propto 20\ dB\ /\ Decade\ of\ PRF$$
$$AV \propto 6\ dB\ /\ Octave\ of\ PRF$$

The EMI-Receiver according to CISPR 16-1-1

The Detectors defined in CISPR and their Response to repeated Pulses

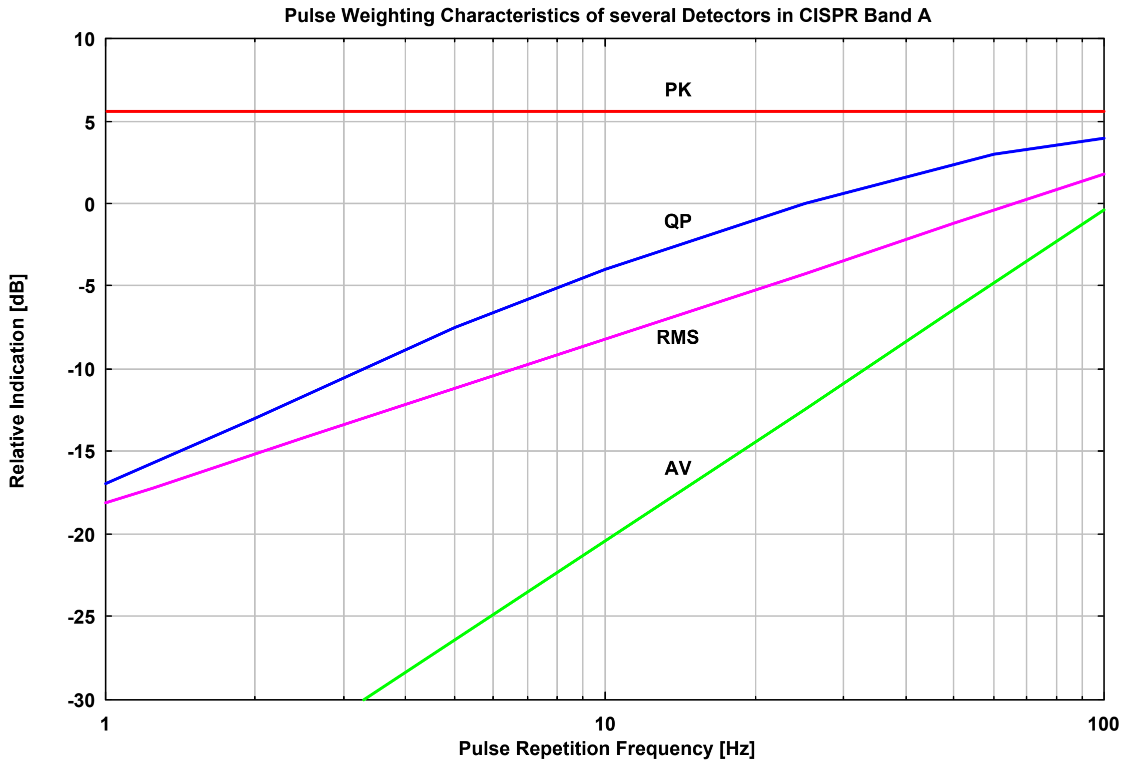


Fig. 17: Pulse weighting of PK, QP, RMS and AV detectors in CISPR Band A

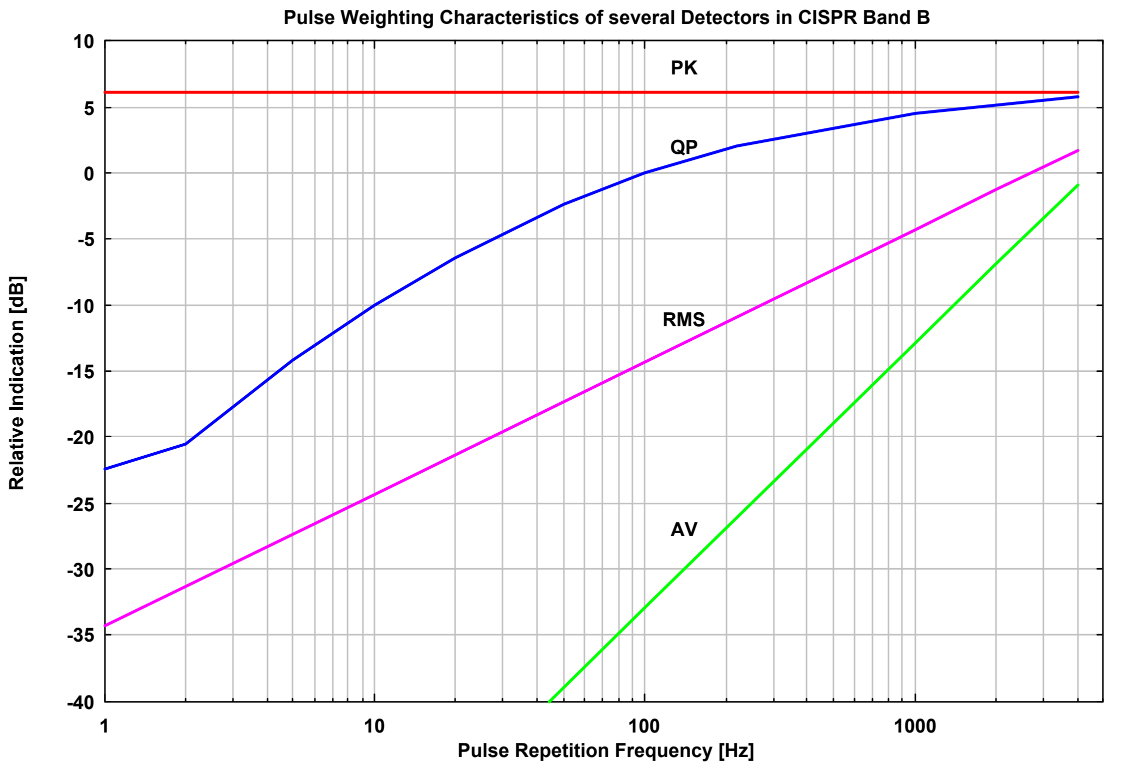


Fig. 18: Pulse weighting of PK, QP, RMS and AV detectors in CISPR Band B

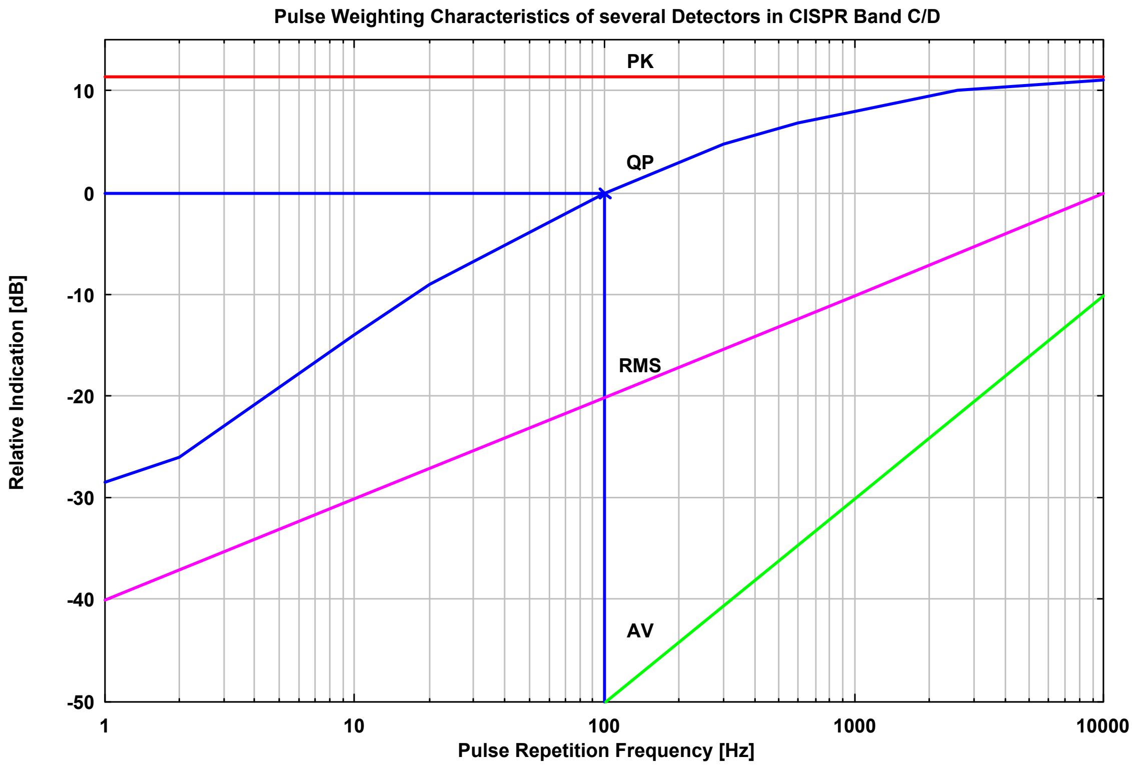


Fig. 19: Pulse weighting of PK, QP, RMS and AV detectors in CISPR Band C/D

Impedance Matching

All recent EMI receivers are operating in the 50 Ω system. The receiver input impedance should be as close to 50 Ω as possible. Otherwise standing waves will lead to measurement results, which are depending on the lengths of coaxial cables in use. This unwanted effect of measurement errors caused by standing waves can be supressed best by combining two well matched ports. In some cases this is difficult to realize, e.g. with biconical antennas at low frequencies. Therefore at least one well matched port (the receiver input) is needed to minimize errors. If there is sufficient Signal to Noise Ratio available, a fixed pad at the unmatched port can help. CISPR 16-1-1 requires a VSWR of less than 1.2 for RF-attenuation 10 dB or higher. Measurements with open inputs (0 dB RF-attenuation) for high sensitivity must fulfill a VSWR of less than 2 in CISPR Bands A to D. The frequency range above 1 GHz requires a VSWR better than 3 for the direct input and a VSWR better than 2 for 10 dB or more RF-attenuation.

The EMI-Receiver according to CISPR 16-1-1

An Overview about the most important Requirements of CISPR 16-1-1

CISPR Band	A	B	C	D	E
Frequency Range	9 kHz - 150 kHz	150 kHz - 30 MHz	30 MHz - 300 MHz	300 MHz - 1000 MHz	1 GHz - 18 GHz
Bandwidth B6	200 Hz	9 kHz	120 kHz	120 kHz	1 MHz
QP Charge Time Constant	45 ms	1 ms	1 ms	1 ms	not defined
QP Discharge Time Constant	500 ms	160 ms	550 ms	550 ms	not defined
Meter Time Constant	160 ms	160 ms	100 ms	100 ms	not defined
Overload Factor Pre-Detector	24 dB	30 dB	43.5 dB	43.5 dB	
Overload Factor DC-Amplifier	6 dB	12 dB	6 dB	6 dB	
Input VSWR (max. sensitivity)	< 2	< 2	< 2	< 2	< 3
Input VSWR (10 dB rf-attenuator)	< 1.2	< 1.2	< 1.2	< 1.2	< 2
Sine Wave Accuracy	< +/- 2 dB	< +/- 2 dB	< +/- 2 dB	< +/- 2 dB	< +/- 2.5 dB
Deviation Pulse / Sine Wave	< +/- 1.5 dB	< +/- 1.5 dB	< +/- 1.5 dB	< +/- 1.5 dB	not defined
Nominal Pulse Repetition Frequency	25 Hz	100 Hz	100 Hz	100 Hz	not defined
Pulse Area across 50 Ω as equivalent to 60 dBµV sine wave	6.75 µVs	0.158 µVs	0.022 µVs	0.022 µVs	not defined
Pulse Width	263 ns	6.18 ns	380 ps	380 ps	not defined
Pulse Amplitude	27.6 V	26.0 V	63.7 V	63.7 V	not defined
First Zero of Pulse-Spectrum	3.81 MHz	166 MHz	2.65 GHz	2.65 GHz	not defined
Ratio QP-AV	12.4 dB	32.9 dB*	50.1 dB*	50.1 dB*	not defined
Ratio QP-PK	-5.6 dB	-6.1 dB	-11.4 dB	-11.4 dB	not defined
Ratio QP-RMS	4.2 dB	14.3 dB	20.1 dB	20.1 dB	not defined

*theoretical ratios, usually AV-detection with low PRF (less than 100 Hz in Band B and 500 Hz in Band C/D) are critical in practical measurements.

Block Diagram of a CISPR 16-1-1 Calibration Pulse Generator

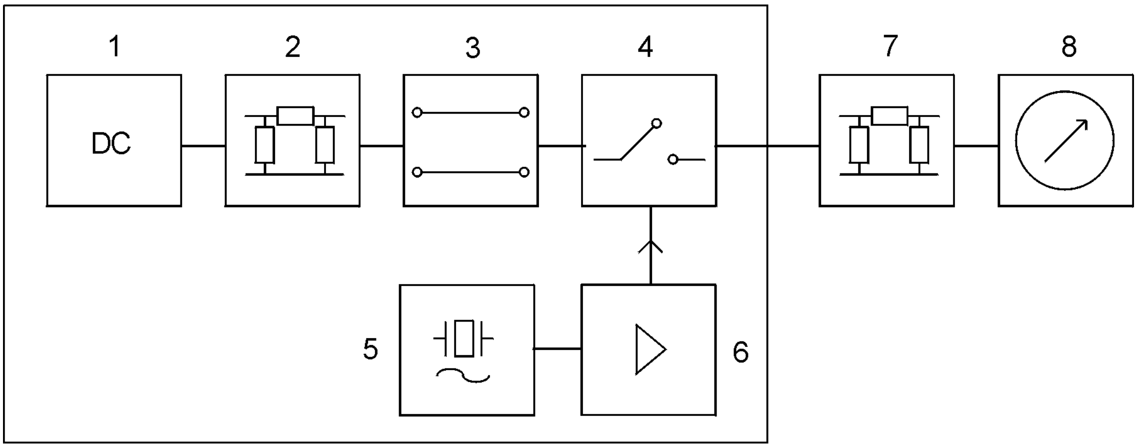


Fig. 20: Block Diagram of a CISPR 16-1-1 Calibration Pulse Generator

1: Regulated DC-Voltage Power Supply
2: DC step attenuator
3: Transmission line
4: Bounce-free discharge switch
5: Pulse repetition frequency synthesizer
6: Switch driver
7: Fixed pad (coaxial attenuator)
8: EMI-receiver under calibration