Calibration of measurement receivers with quasi-peak detector

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Introduction

- calibration methods generally given in standards (CISPR 16-1-1, EN 55016-1-1), some manufacturers use modified methods

  - **absolute** calibration of amplitude response - generally a signal with known spectral properties at the receiver input
  - uniform spectrum of the pulse generator needed (at least in the bandwidth of the receiver)

  - **relative** calibration of amplitude response – exact value of the spectrum amplitude not needed
  - the shape of the pulse must not change
  - the pulse repetition rate must be stable
two basic types of signals in the time-domain resulting in the same signal in the frequency domain

- pulse in the base band

- radiofrequency pulse

(see the presentation *Pulse generators – overview*)
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Calibration methods - standards

- **EN 55016-1-1 ed. 3, Annex A**: Determination of response to repeated pulses of quasi-peak and rms-average measuring receivers
  - response of the pre-detector stages
  - response of the QP voltmeter detector to output of preceding stages
- gives an overview of calculation of the time constants, selectivity curves, bandwidths etc.
- assumes calibrated pulse generator with known properties
response of the pre-detector stages

- determined solely by the IF stages
- selectivity can be obtained by an assembly of 2 critically-coupled tuned transformers (desired $B_{-6\text{dB}}$)
- equivalent low-pass filter used to calculate the envelope of this pulse

Envelope of the pulse

$$A(t) = 4\omega_0 Ge^{-\omega_0 t} (\sin \omega_0 t - \omega_0 t \cos \omega_0 t)$$

$G = \text{overall gain at tuned frequency}$
$\omega_0 = \text{angular frequency of value } (\pi/\sqrt{2})B_{-6\text{dB}}$
Calibration methods - standards

response of the pre-detector stages

• envelope of the response of two transformers to an impulse area $v\tau$

$$A(t) = (v\tau)4\omega_0 Ge^{-\omega_0 t}(\sin\omega_0 t - \omega_0 t \cos\omega_0 t)$$

• corresponding selectivity curve of equivalent LP filter ($\tau << 1/\omega_0$)

$$F(f) = G \frac{2\omega_0^2}{[(\omega_0 + j\omega)^2 + \omega_0^2]^2}$$
Calibration methods - standards

response of the pre-detector stages

• bandwidths for 3 dB and 6 dB drop

\[ B_{-3dB} = \frac{\sqrt{2^4 \sqrt{2 - 1}}}{} \omega_0 = 0.361\omega_0 \]

\[ B_{-6dB} = \frac{\sqrt{2}\omega_0}{\pi} = 0.450\omega_0 \]
Calibration methods - standards

response of the pre-detector stages

- effective bandwidth of a receiver comprised of an ideal rect. filter giving the same response as the receiver

\[
\Delta f = \int_{-\infty}^{\infty} F^2(f) df = \int_0^{\infty} 2 \left\{ \frac{2\omega_0^4}{[(\omega_0 + j\omega)^2 + \omega_0^2]^4} \right\} df = 0.375\omega_0
\]

\[B_{-3dB} = 0.963\Delta f\]
Calibration methods - standards

response of the QP detector to output of preceding stages

• connection of the detector to the IF stage must not change the amplitude or shape of the signal

• any detector reduced to
  – nonlinear element
  – series resistance
  – capacitance + discharge resistance
response of the QP detector to output of preceding stages

- electrical charge constant \( T_C \propto R_1 C \)
- electrical discharge constant \( T_D = R_2 C \)
- relationship between \( T_C \) and \( R_1 C \): indicated voltage 0.63x the final value in \( t = T_C \)
- voltage across capacitor related to the amplitude \( A \) of the RF signal applied to the detector

\[
\frac{dU}{dt} + UI(RC) = \frac{A(\sin \theta - \theta \cos \theta)}{\pi R_1 C}
\]

\[ U = A \cos \theta \]
Calibration methods - standards

response of the QP detector to output of preceding stages

- value for product $R_1C$ found by approximation

<table>
<thead>
<tr>
<th>band</th>
<th>$T_C$</th>
<th>$T_D$</th>
<th>$R_1C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>45 ms</td>
<td>500 ms</td>
<td>1 / 2.81 ms</td>
</tr>
<tr>
<td>B</td>
<td>1 ms</td>
<td>160 ms</td>
<td>1 / 3.95 ms</td>
</tr>
<tr>
<td>C+D</td>
<td>1 ms</td>
<td>550 ms</td>
<td>1 / 4.07 ms</td>
</tr>
</tbody>
</table>

$\Rightarrow$ solution for

$$\frac{dU}{dt} + UI(RC) = \frac{A(sin \theta - \theta cos \theta)}{\pi R_1C}$$
Calibration methods - standards

response of the indicating instrument to the signal from QP det.

• solution of a differential equation of a critically damped mechanical oscillator

• dependent on the discharge time $T_D$ and mechanical constant of the mechanical instrument (scale)
Calibration methods - standards

relation between indications of different detectors

Band A
Calibration methods - standards

relation between indications of different detectors

Band B
Calibration methods - standards

relation between indications of different detectors

Band C/D
Calibration methods - standards

measurement of the impulse bandwidth

- ratio of the peak value $U_p$ measured by the receiver and the spectral density $D$

\[ B_{imp} = \frac{U_p}{D} \quad [\text{MHz}; \mu\text{V}; \mu\text{V/MHz}] \]

- both $U_p$ and $D$ assumed to be RMS quantities (CW signal)
- spectral density usually not available $\Rightarrow$ 2 measurement methods recommended in CISPR 16-1-1
Calibration methods - standards

measurement of the impulse bandwidth

- method 1: comparison of responses of $B_{imp}$ to two pulses with different pulse repetition frequencies (prf)

- pulse-modulated RF signal, two different prfs

![Diagram with symbols and annotations]

- $\tau$: Pulse width (at 50% points)
- $f_p = \frac{1}{T}$: Pulse repetition frequency (PRF)
- $f_0 = \frac{1}{T_0}$: Carrier signal frequency
Calibration methods - standards

measurement of the impulse bandwidth

- method 1: comparison of responses of $B_{imp}$ to two pulses with different pulse repetition frequencies (prf)

- high prf ($f_p >> B_{imp}$): receiver can be tuned to the carrier frequency
measurement of the impulse bandwidth

- method 1: comparison of responses of $B_{imp}$ to two pulses with different pulse repetition frequencies (prf)

- low prf ($f_p \ll B_{imp}$): spectrum will appear as a broadband signal with $D = U_1 \tau$
measurement of the impulse bandwidth

- method 1: comparison of responses of $B_{imp}$ to two pulses with different pulse repetition frequencies (prf)

- example: for $B_{imp} = 1$ MHz, $f_{p1} = 30$ MHz and $f_{p2} = 30$ kHz

\[
U_2 = U_1 \tau f_{p1} \\
U_p = U_1 \tau B_{imp} \quad \Rightarrow \quad B_{imp} = f_{p1} \frac{U_p}{U_2}
\]

(product $U_1 \tau$ must be equal in both measurements)
measurement of the impulse bandwidth

- method 1: comparison of responses of $B_{imp}$ to two pulses with different pulse repetition frequencies (prf)
Calibration methods - standards

measurement of the impulse bandwidth

- method 2: comparison of the response of $B_{imp}$ to an impulsive signal with the response to a narrow BW to the same signal

- for cases when the pulse generator amplitude is dependent on prf
- same principle as method 1, instead of high prf signal, the 2nd measurement is made with a filter much narrower than the prf

$$D = \frac{U_k}{f_p}$$ measured voltage of 1 spectral line
pulse repetition frequency

$$B_{narrow} \ll f_p \ll B_{imp}$$
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- usually given in the Service (Maintenance) manual
- instrument-specific settings recommended
- example R&S ESVN40 receiver:

```
Error with pulses:

Test setup: Connect pulse generator to RF input of ESN/ESVN.
Pulse frequency: 100 Hz
Level: 80 dB\mu V/\text{MHz} \pm 0.1 \text{ dB}
Settings on the ESN/ESVN:
- RF ATT: 10 dB
- Mode: Low Noise
- Detector: QP
- OP Range: 60 dB
- Meas Time: 500 ms

Test: Check the measuring accuracy at 1 MHz and 100 MHz.
Nominal level at 1 MHz: 33 dB\mu V \pm 1 dB
at 100 MHz: 50 dB\mu V \pm 1 dB
```
Calibration methods - manufacturers

- example **R&S ESVN40** receiver (cont.):

```
**Error with sinusoidal signals:**

**Test setup:**  Connect signal generator to RF input of ESN/ESVN.
Level........................................ 90 dBµV ±0.1 dB

Settings on the ESN/ESVN:
Attenuation .............................. Auto
Mode ................................. Low Noise
Detector................................. QP
Op Range ............................... 30 dB
Meas Time.............................. 500 ms

**Test:**  Check the measuring accuracy at 1 MHz and 100 MHz.
Nominal level ............................................................... 90 dBµV ±1 dB
```
Calibration methods - manufacturers

- example R&S ESVN40 receiver (cont.):

**Quasi-peak weighting curve:**

**Test setup:** Connect pulse generator to RF input of ESN/ESVN.
- Level........................................... 80 dBµV/MHz ±0.1 dB

**Settings on the ESN/ESVN:**
- Frequency............................ 1 MHz and 100 MHz
- RF ATT................................. 0 dB
- Mode..................................... Low Noise
- Detector............................... QP
- Op Range............................. 60 dB
- Meas Time........................... 2 s

**Test:** Measure the level on the ESN/ESVN depending on the pulse frequency of the pulse generator according to the following tables. The reference value is the level at 100 Hz.
Calibration methods - manufacturers

- example R&S ESVN40 receiver (cont.):
  - IF bandwidths
  - IF gain and linearity
  - shape factor of IF filters

+ other (non-QP related) tests
Calibration methods - manufacturers

- example **R&S ESPI** receiver: use of a modulated RF pulse

<table>
<thead>
<tr>
<th>Test setup:</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Connect TTL output of function generator with pulse modulation input of the signal generator.</td>
</tr>
<tr>
<td>➢ Connect RF output of signal generator to RF input of ESPI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pulse generator settings:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Frequency: 128 MHz</td>
</tr>
<tr>
<td>- Level: -10 dBm</td>
</tr>
<tr>
<td>- Modulation: Pulse</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function generator settings:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Waveform: Pulse Continue</td>
</tr>
<tr>
<td>- Pulse width: 5 μs</td>
</tr>
<tr>
<td>- Period: 40 ms</td>
</tr>
</tbody>
</table>

pulse parameters chosen so that they satisfy the needed impulse area at the given RF frequency
• example **R&S ESPI receiver** (cont.):

**CISPR Band A**

<table>
<thead>
<tr>
<th>ESPI settings:</th>
<th>- [ <strong>BW</strong> : 200 Hz ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference measurement:</td>
<td>The measured level is indicated with the reading ‘LEVEL QP’ (= reference value $L_{Ref}$).</td>
</tr>
<tr>
<td>Measurement of weighting curve:</td>
<td>The measured level is indicated with the reading ‘LEVEL QP’ ($L_{Mes}$).</td>
</tr>
<tr>
<td>Evaluation:</td>
<td>The difference between level $L_{Mes}$ and the value recorded in the reference measurement $L_{Ref}$ is to be determined as follows: $\Delta L = L_{Mes} - L_{Ref}$</td>
</tr>
</tbody>
</table>

$f_p = 25$ (ref.), 100, 60, 10, 5, 2, 1 (**band A**)  
$f_p = 100$ (ref.), 20, 10, 2, 1 (**bands B, C/D**)
Calibration methods - manufacturers

- example **R&S ESIB** receiver, pulse generator requirements:

<table>
<thead>
<tr>
<th>CISPR bands level at frequency f</th>
<th>A, B, C/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 kHz</td>
<td>&gt; 114.6 dBμV / MHz</td>
</tr>
<tr>
<td>1.1 MHz</td>
<td>&gt; 80 dBμV / MHz</td>
</tr>
<tr>
<td>101 MHz</td>
<td>&gt; 80 dBμV / MHz</td>
</tr>
</tbody>
</table>

⇒ important to characterize the pulse generator in the whole bandwidth, as different receivers have different IF frequencies and pulse area requirements
Calibration methods - manufacturers

- example **HP 8590 EM** receiver (obsolete):

```
Parameters:
LEE ................................................. 3 ns
TRE .................................................. 3 ns
HIL .................................................... +2 V
LOL ................................................... +1.8 V
DEL ................................................... 0 ns

Output Mode: Enabled
Channel A ........................................ 50 Ω
Channel A ........................................... NORM
```
Thank you for attention