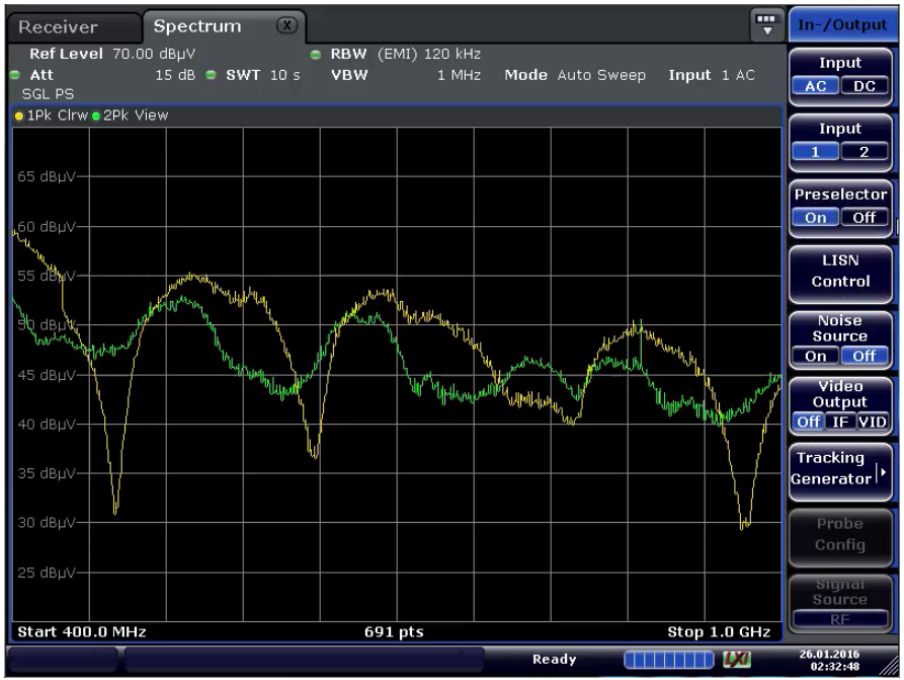
The Value of Pre-Selection in EMC Testing

Scott Niemiec
Application Engineer

ROHDE&SCHWARZ

Video Demonstrating Benefit of Pre-selection

400MHz -1GHz Sweep with RBW = 120kHz



Yellow: w/ preselection
Green: w/o pre-selection

Questions for Audience

- **Commercial and/or A&D?**
  - Commercial: CISPR, FCC, EN, etc.
  - A&D: MIL-STD461, MIL-STD464, DO-160, etc.
- **Use Spectrum Analyzers for EMC measurements?**
- **Use Receivers for EMC measurements?**
- **Know the difference between Spectrum Analyzers and Receivers?**
- **Measure time varying per the spectrum?**
- **Measure pulsed emissions? Know what pulse repetition rate?**
- **Believe you are capturing all the events in the spectrum?**
- **Feel you are accurately measuring the amplitudes of pulses?**
- **Understand the concept of pre-selection?**

Outline

- **Spectrum Analyzer vs EMI Test Receiver**
- **Pre-selection in the standards**
  - MIL-STD461 & CISPR 16-1-1
  - Time & Frequency Characteristics of Pulses
  - Pulse Requirements in CISPR 16-1-1
- **Pre-selection in a Spectrum Analyzer**
  - Image Rejection
- **Pre-selection in an EMI Receiver**
  - Overload protection
  - Ability to properly measure pulses
- **Video demonstrating the effects of pre-selection**

Spectrum Analyzer vs EMI Test Receiver

- **The application / purpose drives differences in architecture**

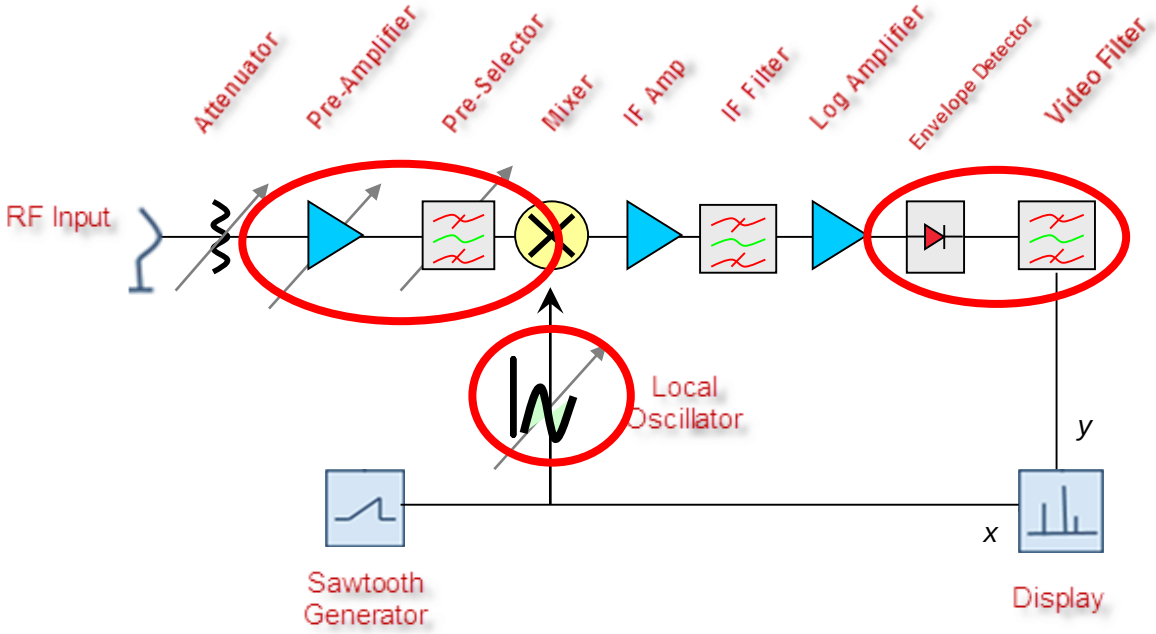
- **Spectrum Analyzer (Traditional Swept Spectrum Analyzer)**
  - Make accurate measurements of (typically) known signals for proper characterization

- **EMI Test Receiver**
  - Characterize unknown signals in repeatable manner per specification in standard

- **Main Architectural Differences**
  - Frequency Swept vs Frequency Stepped vs Time Domain Scan
  - Types of Detectors
  - Pre-selection

Spectrum Analyzer vs EMI Receiver

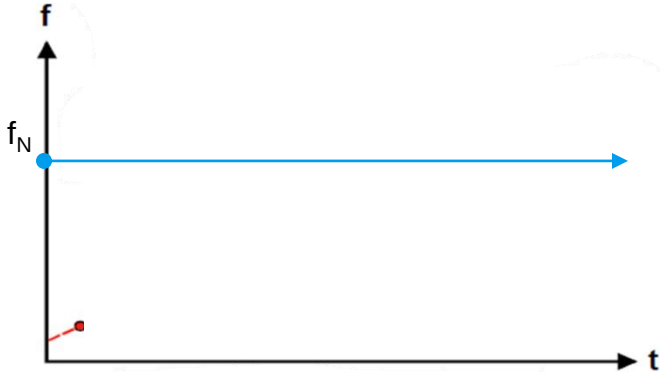
Main Architectural Differences



- Local Oscillator
- Detector Types
- Pre-selection

Spectrum Analyzer vs EMI Receiver

Frequency Swept vs Frequency Stepped

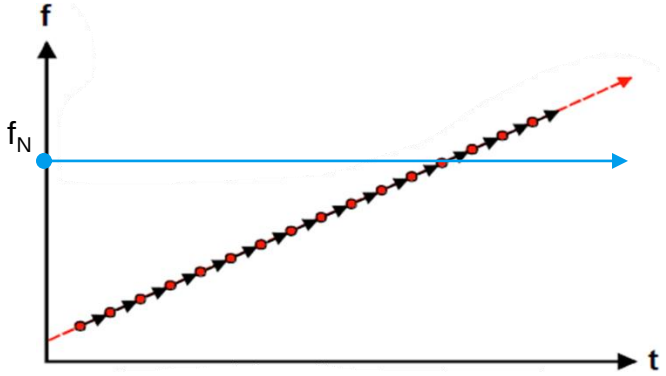


Spectrum Analyzer (Traditional Swept)

- Continuously swept across frequency range
- What is measurement time at each frequency?
  - Time = Sweep Time / Sweep Points
- What is the Spacing/Step size between measurements?
  - Step = Frequency Span / (Sweep Points -1)

Spectrum Analyzer vs EMI Receiver

Frequency Swept vs Frequency Stepped



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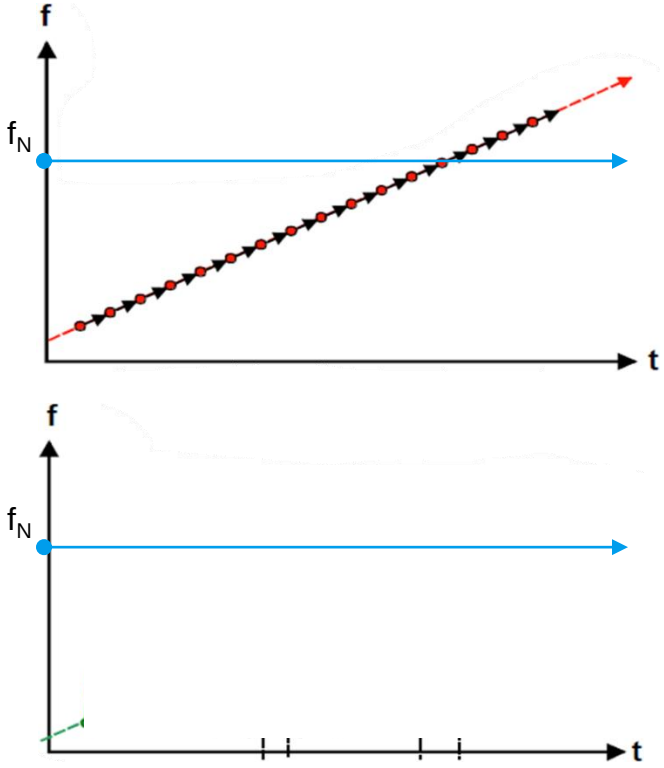

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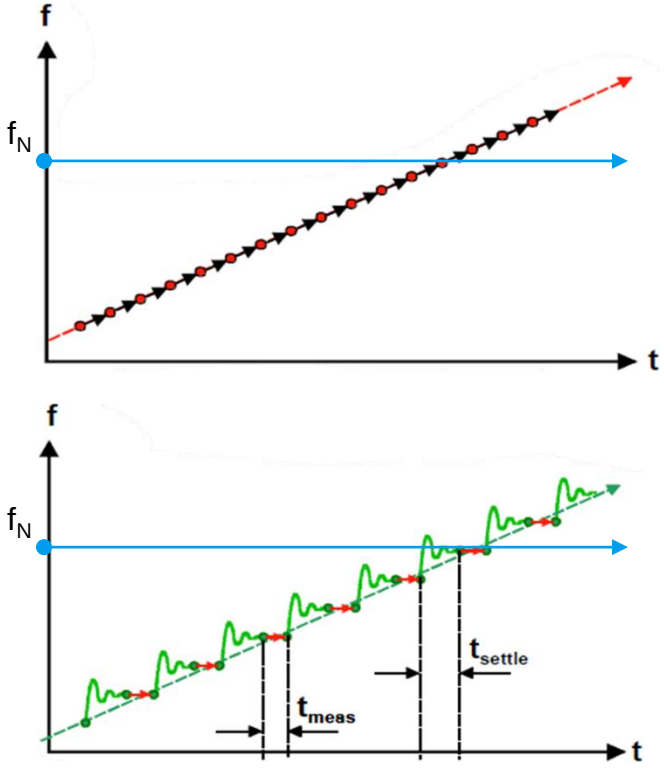
EMI Test Receiver (Tuned Receiver)

- Frequency tuned (stop) at each point
- Directly set the measurement time
- Directly set the frequency step size

- Removes most opportunities for user configuration error via user interface designed for EMI measurements

Spectrum Analyzer vs EMI Receiver

Frequency Swept vs Frequency Stepped



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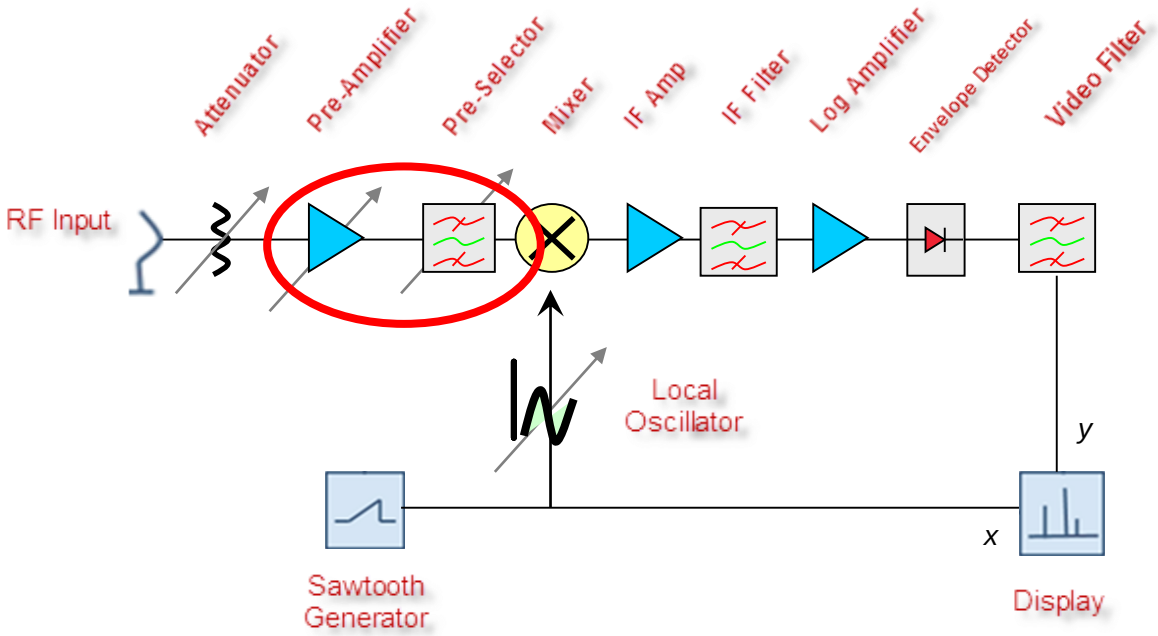
Spectrum Analyzer vs EMI Receiver

Definition of pre-selection

Pre-selection

- Any filtering before the first mixer to ‘pre-select’ the frequencies of measurement and exclude other frequencies



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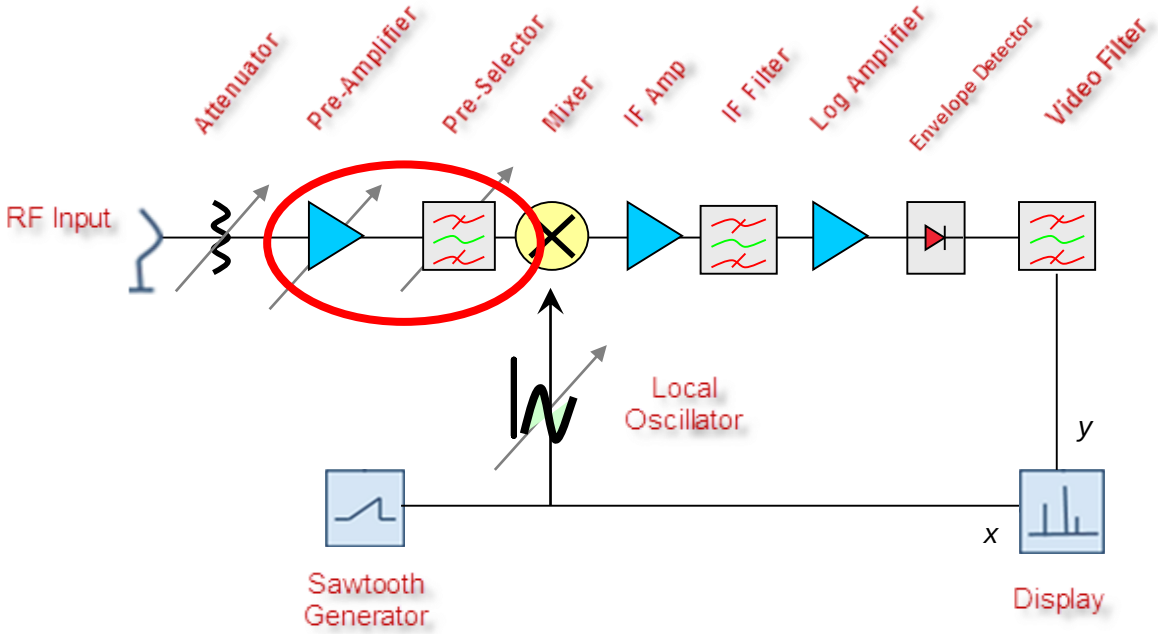
- Purpose = improve signal measurement fidelity via image rejection and harmonic rejection



Spectrum Analyzer vs EMI Receiver

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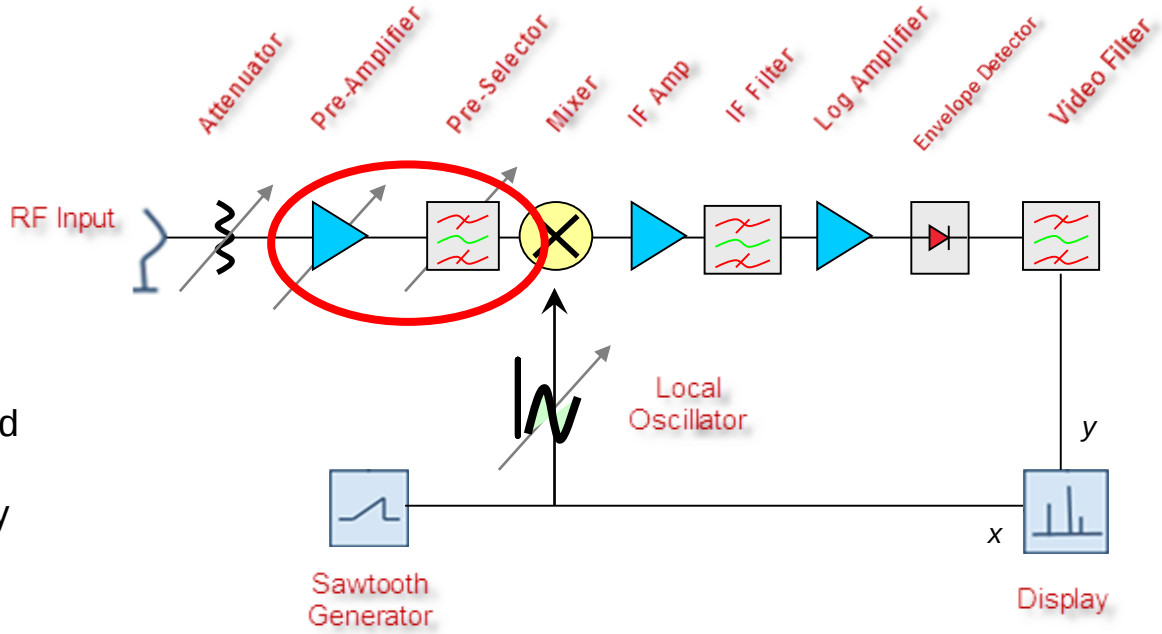
EMI Test Receiver

- Purpose = eliminate overload and increase dynamic range to make ‘measurement apparatus’ comply with standards (CISPR16-1-1)



Outline

- Video demonstrating effects of pre-selection
- Spectrum Analyzer vs EMI Test Receiver
- **Pre-selection in the standards**
  - MIL-STD461 & CISPR 16-1-1
  - Time & Frequency Characteristics of Pulses
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- CISPR 16-1-1 is the standard which puts specifications on the ‘measuring apparatus’
  - Be it spectrum analyzer, EMI test receiver, FFT analyzer
  - ‘Black box’ approach

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- MIL-STD461 indirectly references CISPR 16-1-1 requirements via ANSI C63.2
  - Therefore, even the MIL-STD community is governed by requirements in CISPR16-1-1

- CISPR 16-1-1 has requirements on the ability of the ‘measuring apparatus’ to properly measure pulses

- The pulse handling requirements translate into dynamic range and pre-selection architectural requirements of the ‘measuring apparatus’

Pre-selection in the Standards

MIL-STD461 references ANSI C63.2

MIL-STD-461G

IEEE/ASTM INTERNATIONAL

IEEE/ASTM SI 10	American National Standard for Metric Practice

(IEEE and ASTM International publish this standard jointly. Copies are available from http://www.ieee.org/ or http://www.astm.org/.)

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)/IEEE

ANSI C63.2	American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 Hz to 40 GHz Specifications
ANSI C63.14	American National Standard Dictionary of Electromagnetic Compatibility (EMC) including Electromagnetic Environmental Effects (E3)

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ANSI C63.2 references CISPR16-1-1

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1. Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

CISPR 16-1-1, Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods—Part 1-1: Radio Disturbance and Immunity Measuring Apparatus—Measuring Apparatus.[1]

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Pre-selection in the Standards

CISPR 16-1-1

INTRODUCTION

The CISPR 16 series, published under the general title *Specification for radio disturbance and immunity measuring apparatus and methods,* is comprised of the following sets of standards and reports:

- CISPR 16-1 – five parts covering measurement instrumentation specifications;
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Pre-selection in the Standards

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- Part 1-1: Measuring apparatus
- Part 1-2: Ancillary equipment – Conducted disturbances
- Part 1-3: Ancillary equipment – Disturbance power
- Part 1-4: Ancillary equipment – Radiated disturbances
- Part 1-5: Antenna calibration test sites for 30 MHz to 1 000 MHz

- **Family of CISPR product standards all reference CISPR 16-1-1**
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Pre-selection in the Standards

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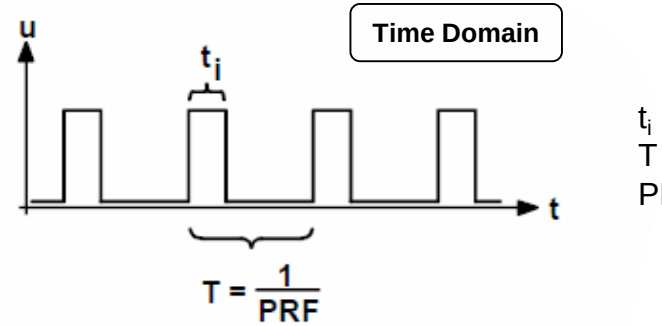
Time & Frequency Domain Characteristics of a Pulse



t_i = Width (sec)
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PRF = Pulse Repetition Frequency (Hz)

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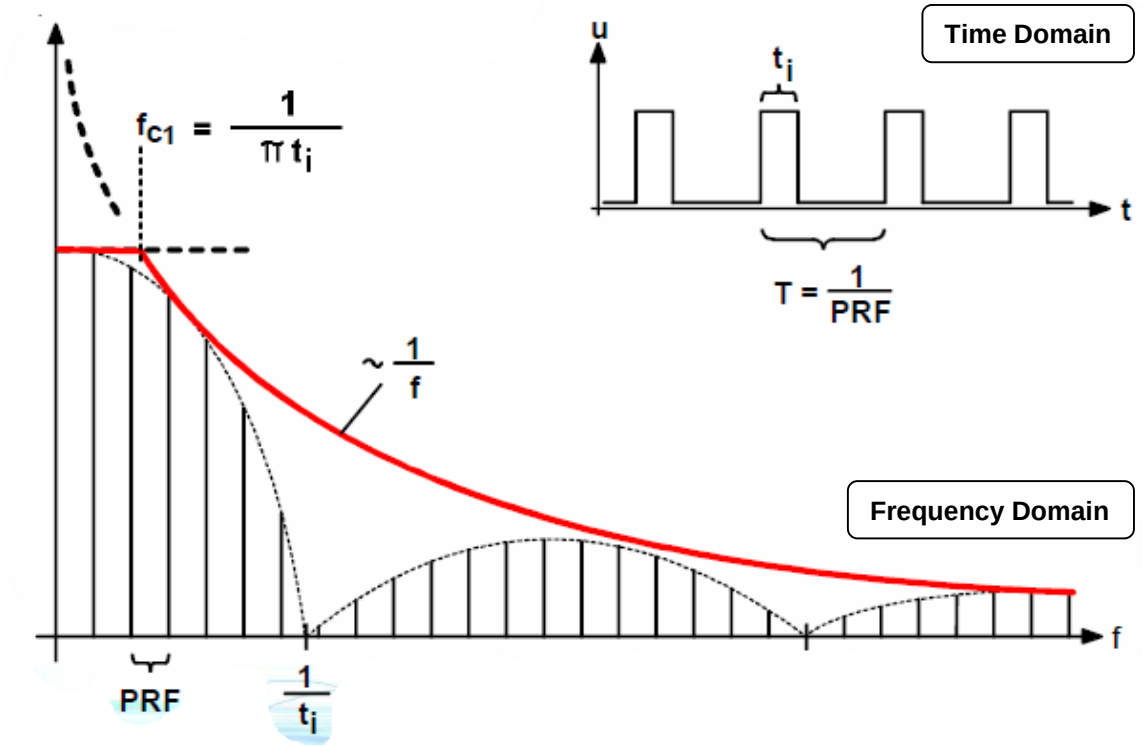

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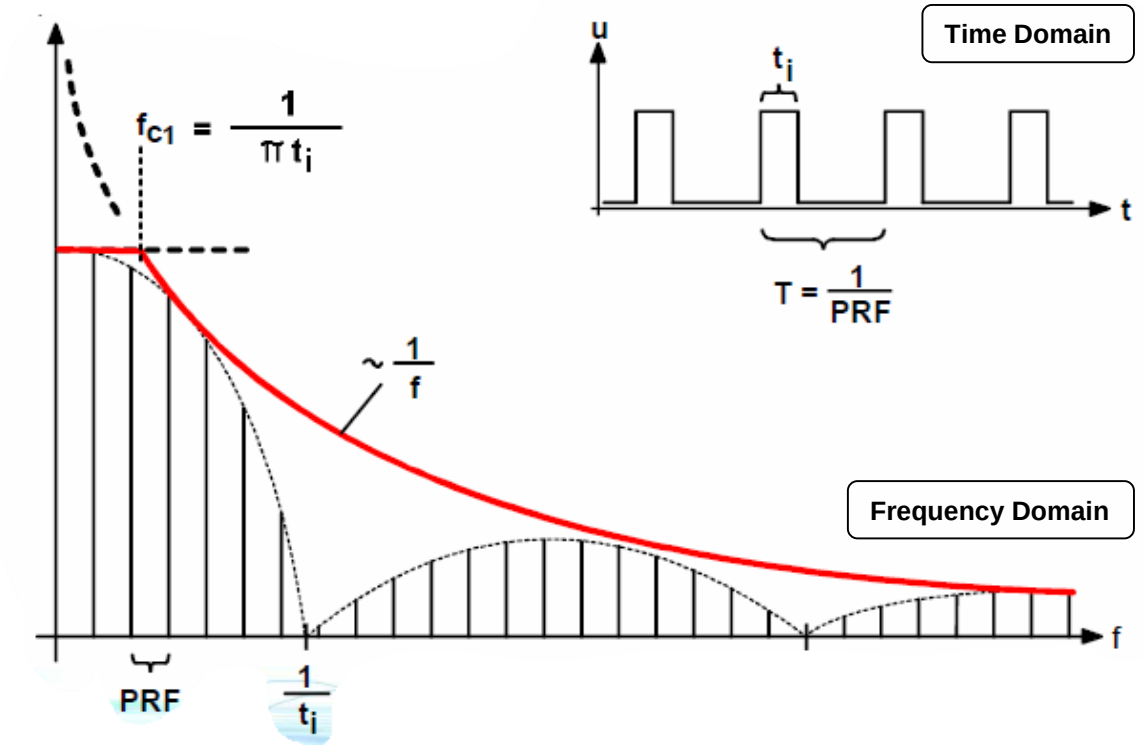

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Debug Note:
Hump in frequency sweep indicates a pulse signal.

Pre-selection in the Standards

CISPR 16-1-1

CONTENTS

Pre-selection in the Standards

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Pre-selection in the Standards

CISPR 16-1-1

Section 6 → Average Detector
Section 7 → RMS-Average detector

CONTENTS

Pre-selection in the Standards

CISPR 16-1-1

4.4 Response to pulses

4.4.1 Amplitude relationship (absolute calibration)

Referring to Table 1, the response of the measuring receiver to pulses of impulse area of a) μVs (microvolt second) e.m.f. at 50 Ω source impedance, having a uniform spectrum up to at least b) MHz, repeated at a frequency of c) Hz shall, for all frequencies of tuning, be equal to the response to an unmodulated sine-wave signal at the tuned frequency having an e.m.f. of rms value 2 mV [66 dB(μV)

Table 1 – Test pulse characteristics for quasi-peak measuring receivers (see 4.4.1)

Frequency range	a) μVs	b) MHz	c) Hz
9 kHz to 150 kHz	13,5	0,15	25
0,15 MHz to 30 MHz	0,316	30	100
30 MHz to 300 MHz	0,044	300	100
300 MHz to 1 000 MHz	0,044	1 000	100

Pre-selection in the Standards

CISPR 16-1-1

The response curve for a particular measuring receiver shall lie between the limits defined in the appropriate figure and quantified in Table 2. For spectrum analyzers without preselection, the requirements in Table 2 for pulse repetition frequencies less than 20 Hz are not applicable. The use of such instruments for compliance testing is conditional. If such spectrum analyzers are used for measurements, the user shall verify and document that the equipment under test does not emit broadband signals of pulse repetition frequencies of 20 Hz or lower. A determination of the suitability of a spectrum analyzer for testing shall be made by performing the procedure documented in Annex B of CISPR 16-2-1, Annex B of CISPR 16-2-2, or Annex B of CISPR 16-2-3.

The pulse response is restricted due to overload at the input to the receiver at frequencies above 300 MHz. The values marked with an asterisk (*) in Table 2 are optional and are not essential.

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Pre-selection in the Standards

CISPR 16-2-1

< 150.0 mV
Typically < 103.5 dBuV
< -3.50 dBm

Annex B
(informative)

Use of spectrum analyzers and scanning receivers
(see Clause 6)

B.1 Introduction

When using spectrum analyzers and scanning measuring sets, the following characteristics should be taken into account.

B.2 Overload

Most spectrum analyzers have no RF preselection in the frequency range up to 2 000 MHz; that is, the input signal is directly fed to a broadband mixer. To avoid overload, to prevent damage and to operate a spectrum analyzer linearly, the signal amplitude at the mixer should typically be less than 150 mV peak. RF attenuation or additional RF preselection may be required to reduce the input signal to this level.

Pre-selection in the Standards

5.5 Response to pulses

Up to 1 000 MHz, the response of the measuring receiver to pulses with impulse area $1{,}4/B_{imp}$ mVs (where B_{imp} is in Hz) e.m.f. at 50 Ω source impedance shall be equal to the response to an unmodulated sine-wave signal at the tuned frequency having an e.m.f. with rms value of 2 mV [66 dB(μV)]. The source impedances of both the pulse generator and the signal generator shall be the same. The pulses shall have a uniform spectrum according to Table 2. A tolerance of ±1,5 dB is permitted in the sine-wave voltage level, and this is a requirement for all pulse repetition frequencies for which no overlapping pulses occur at the output of the IF amplifier.

NOTE 1 Annexes B and C describe methods for determining the output characteristics of pulse generators for use in testing for the requirements of this subclause.

NOTE 2 At a repetition rate of 25 Hz for Band A and 100 Hz for the other bands, the relationship between the indications of a peak measuring receiver and a quasi-peak measuring receiver with the preferred bandwidth are given in Table 7.

Table 7 – Relative pulse response of peak and quasi-peak measuring receivers for the same bandwidth (frequency range 9 kHz to 1 000 MHz)

Frequency	A_{imp} mVs	B_{imp} Hz	Ratio peak/quasi-peak (dB) for pulse repetition rate	
			25 Hz	100 Hz
Band A	$6{,}67 \times 10^{-3}$	$0{,}21 \times 10^{3}$	6,1	–
Band B	$0{,}148 \times 10^{-3}$	$9{,}45 \times 10^{3}$	–	6,6
Bands C and D	$0{,}011 \times 10^{-3}$	$126{,}0 \times 10^{3}$	–	12,0
NOTE The pulse response is based on the use of the reference bandwidth only (see Table 6).				

Above 1 GHz, the required impulse area is defined using a pulse-modulated carrier at the frequency of test, since pulse generators with a uniform spectrum up to 18 GHz are not feasible. See E.6.

Table 2 – Pulse response of quasi-peak measuring receivers

Repetition frequency Hz	Relative equivalent level in dB of pulse for stated band			
	Band A 9 kHz to 150 kHz	Band B 0,15 MHz to 30 MHz	Band C 30 MHz to 300 MHz	Band D 300 MHz to 1 000 MHz
1 000	Note 4	–4,5 ± 1,0	–8,0 ± 1,0	–8,0 ± 1,0
100	–4,0 ± 1,0	0 (ref.)	0 (ref.)	0 (ref.)
60	–3,0 ± 1,0	–	–	–
25	0 (ref.)	–	–	–
20	–	+6,5 ± 1,0	+9,0 ± 1,0	+9,0 ± 1,0
10	+4,0 ± 1,0	+10,0 ± 1,5	+14,0 ± 1,5	+14,0 ± 1,5
5	+7,5 ± 1,5	–	–	–
2	+13,0 ± 2,0	+20,5 ± 2,0	+26,0 ± 2,0	+26,0 ± 2,0*
1	+17,0 ± 2,0	+22,5 ± 2,0	+28,5 ± 2,0	+28,5 ± 2,0*
Isolated pulse	+19,0 ± 2,0	+23,5 ± 2,0	+31,5 ± 2,0	+31,5 ± 2,0*

* These values are optional and not essential.

NOTE 1 The influence of the receiver characteristics upon its pulse response is considered in Annex D.

NOTE 2 The relationships between the pulse responses of a quasi-peak receiver and receivers with other detector types are given in 5.5, 6.5 and 7.5.

NOTE 3 The theoretical pulse response curves of quasi-peak and average detector receivers combined on an absolute scale are shown in Figure 1d. The ordinate of Figure 1d shows the open-circuit impulse areas in dB(μVs) corresponding to the open-circuit sine-wave voltage of 66 dB(μV) rms. The indication on a measuring receiver with an input matched to the calibrating generators will then be 60 dB(μV). Where the measuring bandwidth is less than the pulse repetition frequency, the curves of Figure 1d are valid when the receiver is tuned to a discrete line of the spectrum.

NOTE 4 It is not possible to specify a response above 100 Hz in the frequency range 9 kHz to 150 kHz because of the overlapping of pulses in the IF amplifier.

NOTE 5 Annex A deals with the determination of the curve of response to repeated pulses.

Outline

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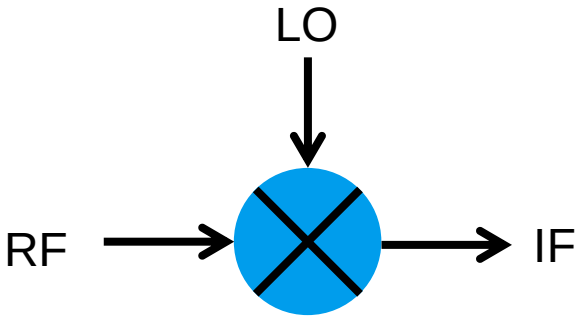
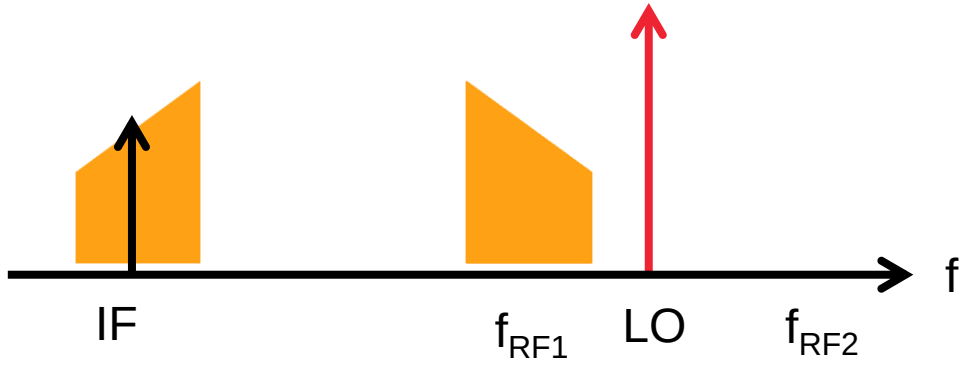
Pre-selection in a Spectrum Analyzer

The need for image rejection

- Frequency conversion
- Generation of image frequency





$f_{IF} = f_{LO} - f_{RF1}$

Pre-selection in a Spectrum Analyzer

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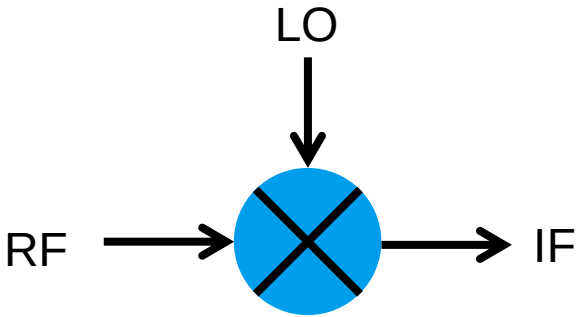
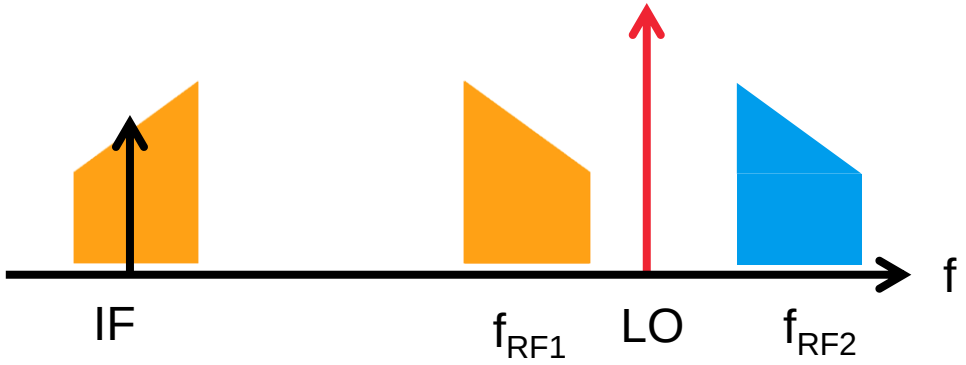




$f_{IF} = f_{LO} - f_{RF1}$

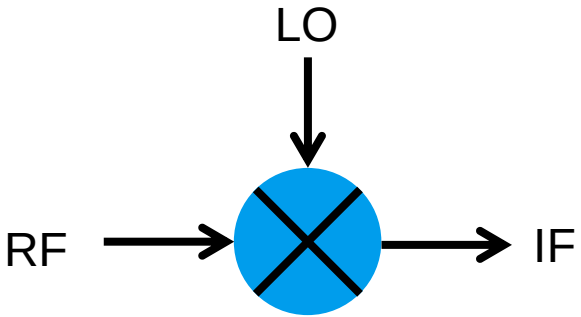
$f_{IF} = f_{RF2} - f_{LO}$

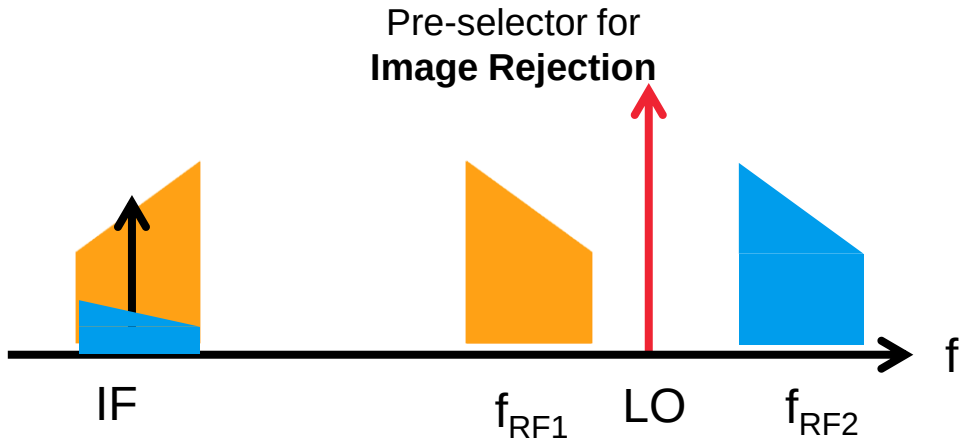
Image Frequency

Pre-selection in a Spectrum Analyzer

The need for image rejection

- Frequency conversion
- Generation of image frequency





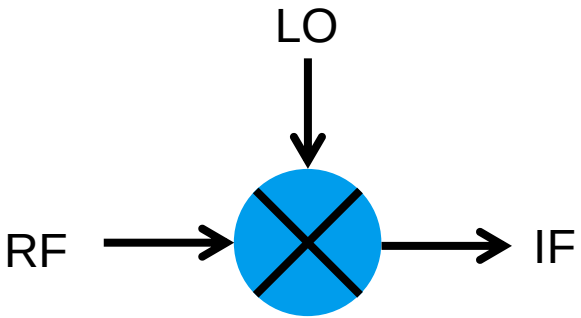
$f_{IF} = f_{LO} - f_{RF1}$

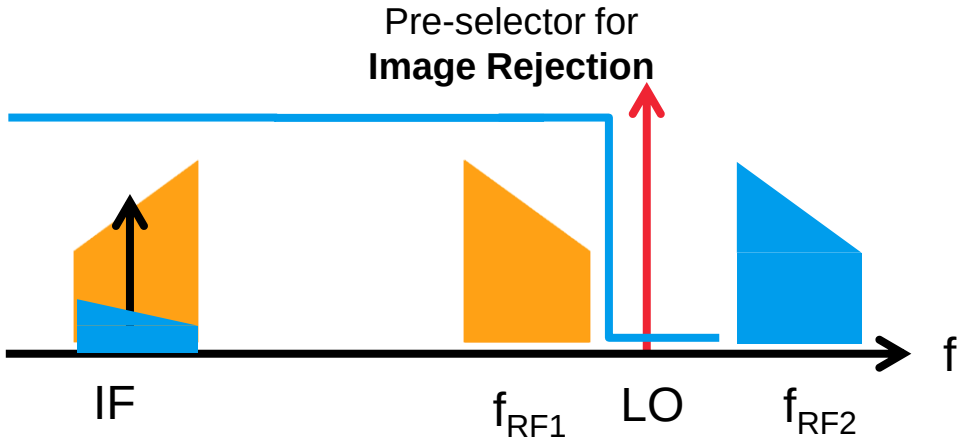
$f_{IF} = f_{RF2} - f_{LO}$

Pre-selection in a Spectrum Analyzer

The need for image rejection

- Frequency conversion
- Generation of image frequency





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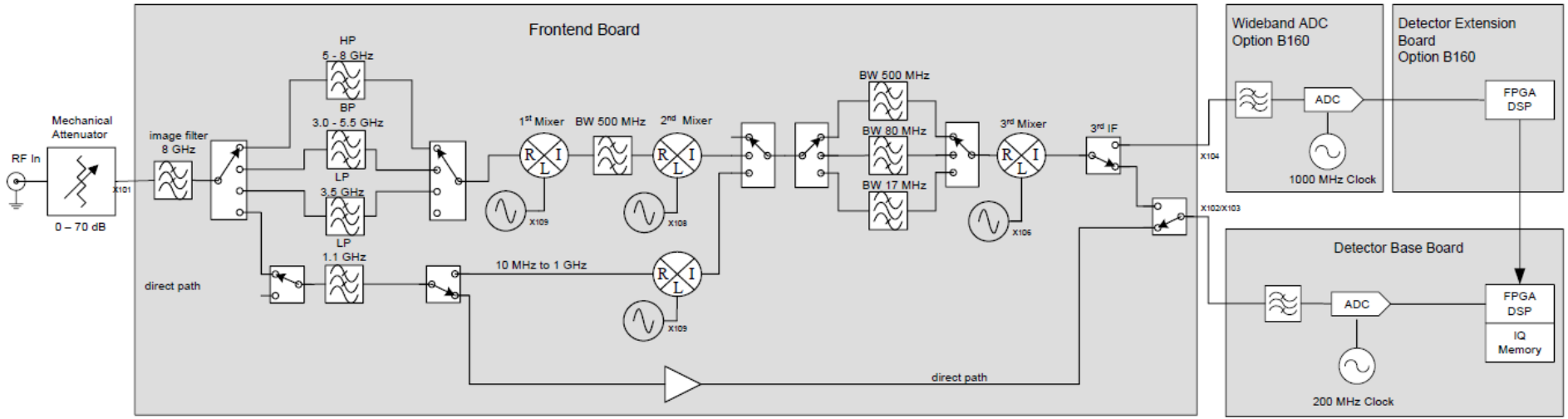
Pre-selection in a Spectrum Analyzer

FSW8 (below 8GHz)



Pre-selection in a Spectrum Analyzer

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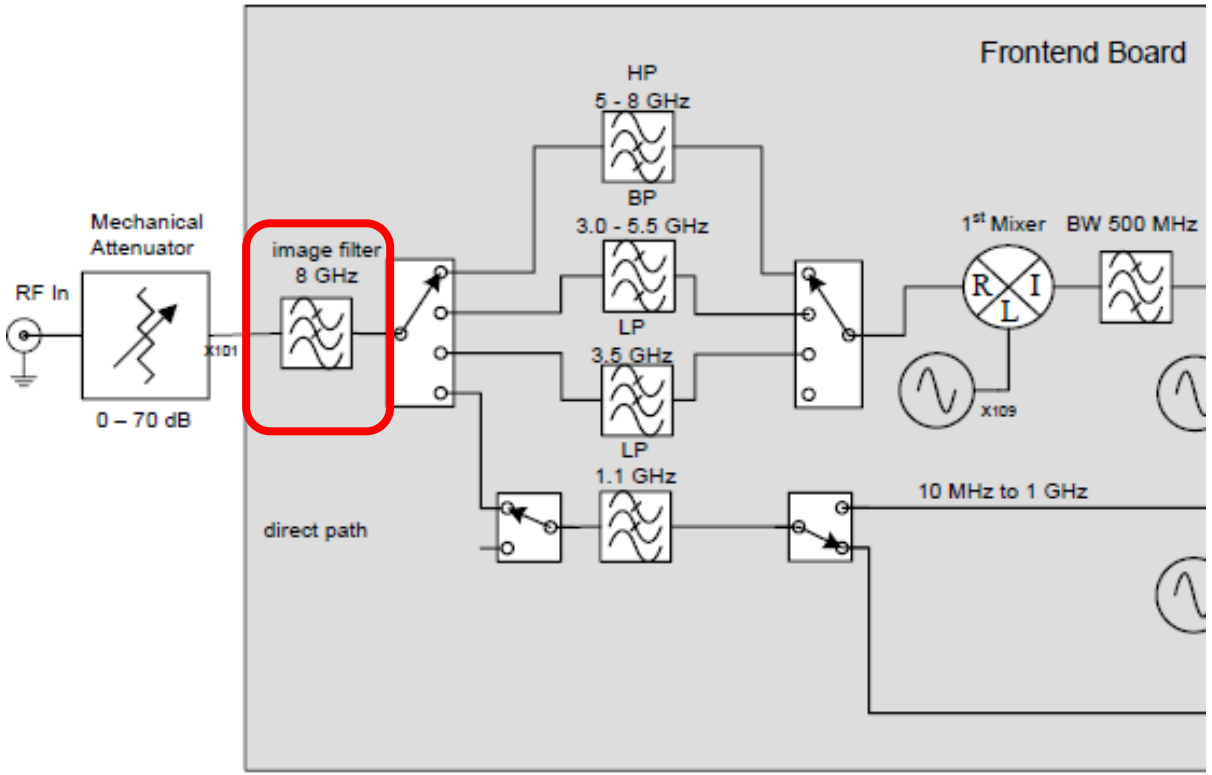
- **Image Filter 8GHz**
  - 1st IF at ~8.97GHz
  - Filters image above 8GHz
  - Low pass filter



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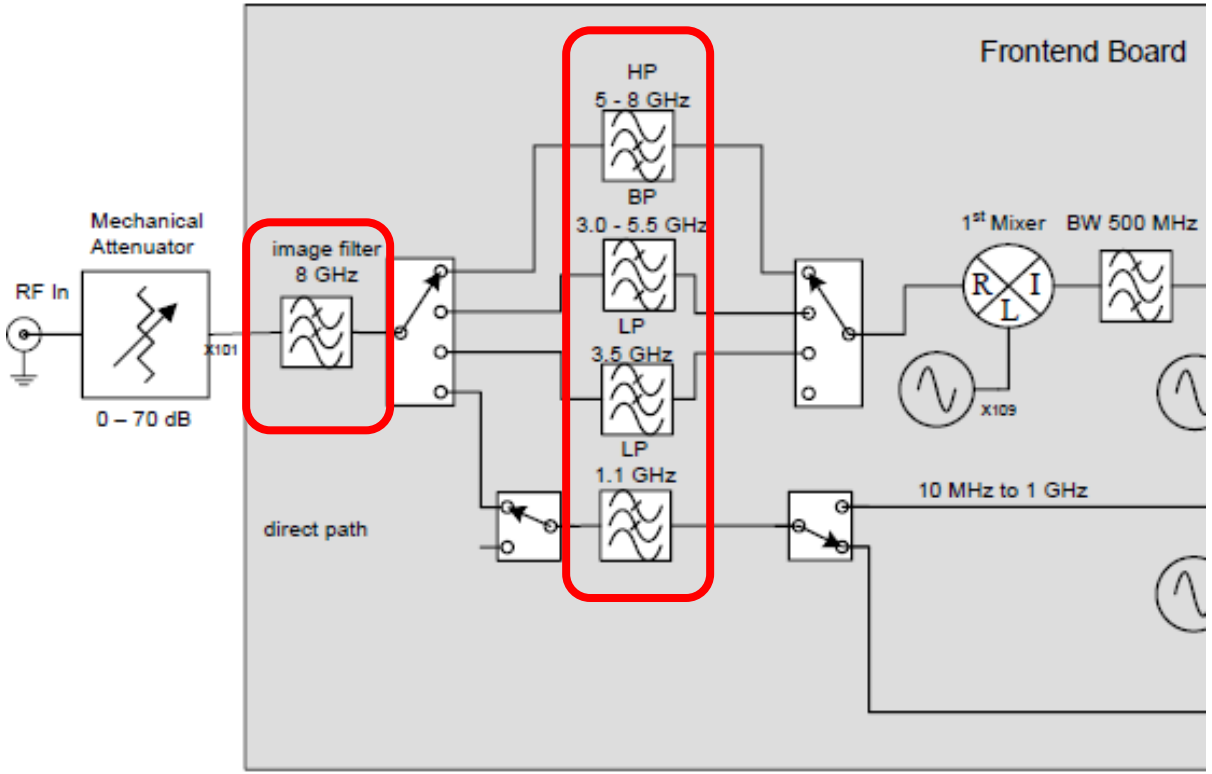
  - Designed for signal integrity concerns of input signal harmonics
  - Not designed for overload protection of the1st mixer



Pre-selection in a Spectrum Analyzer

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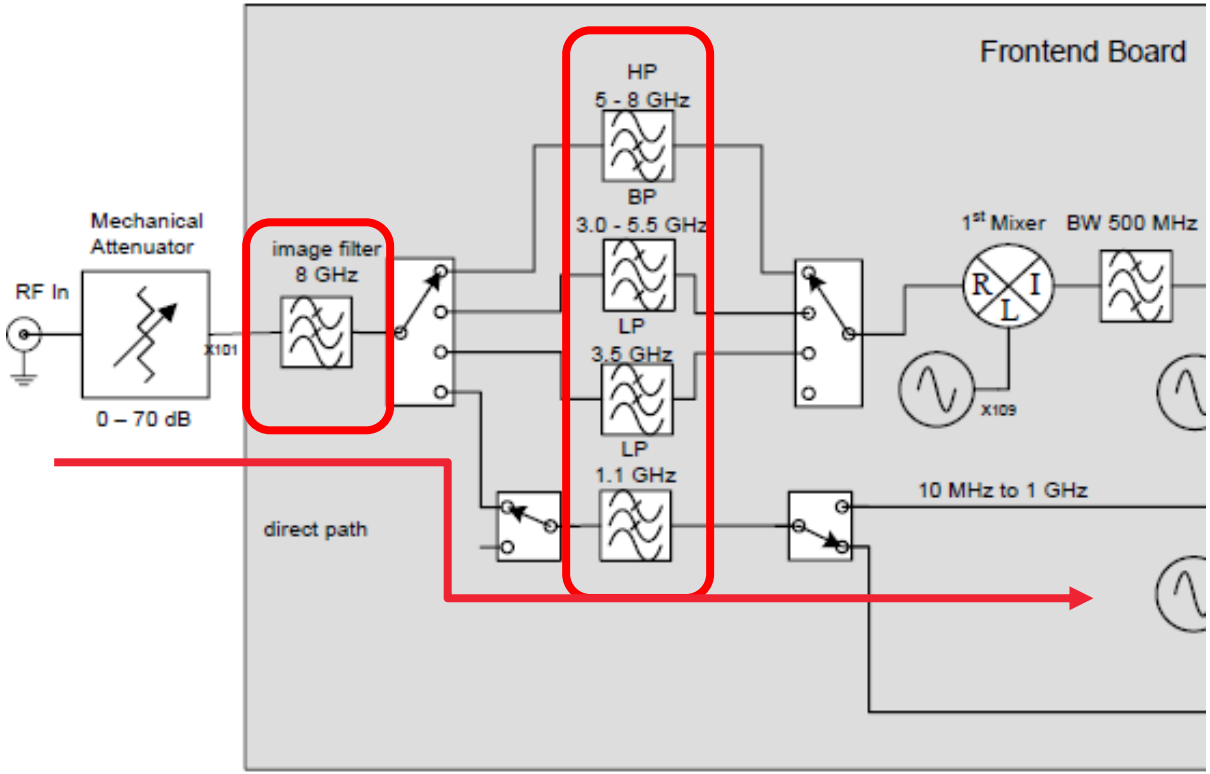
  - Not designed for overload protection of the1st mixer
- **Signal Frequencies <1GHz**
  - Only ‘pre-selection’ is 8GHz LP and then 1.1GHz LP

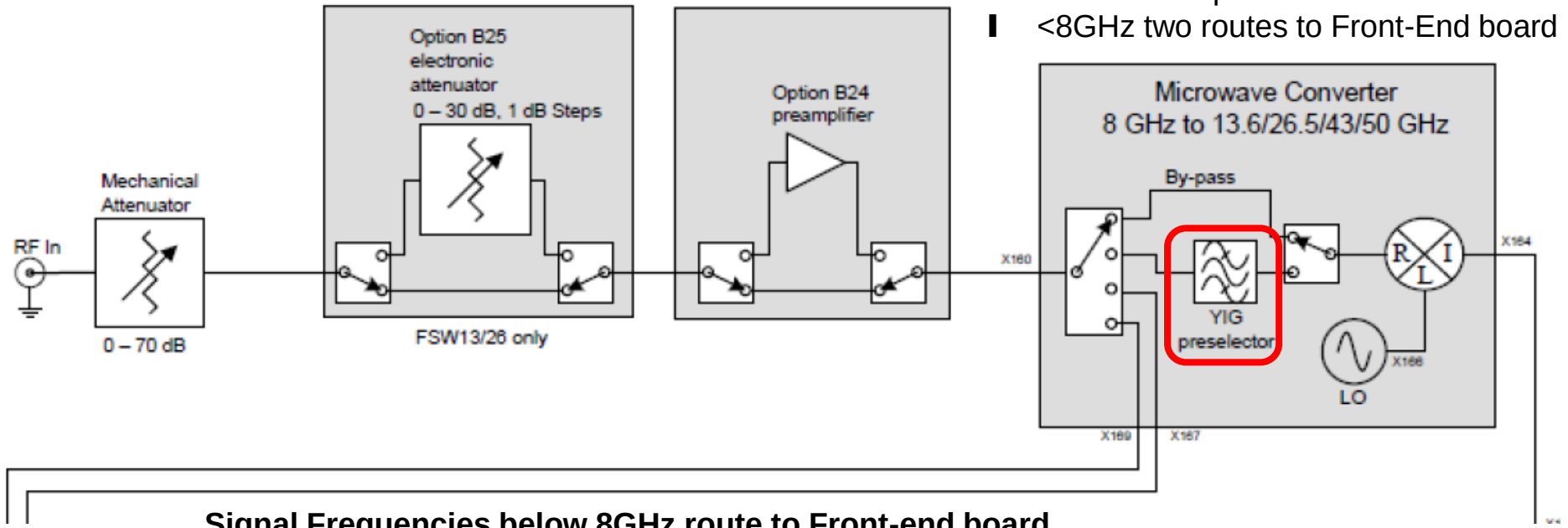


Pre-selection in a Spectrum Analyzer

FSW13/26/43/50

4 signal paths

- >8GHz YIG By-pass
- >8GHz YIG 'pre-selector'
- <8GHz two routes to Front-End board

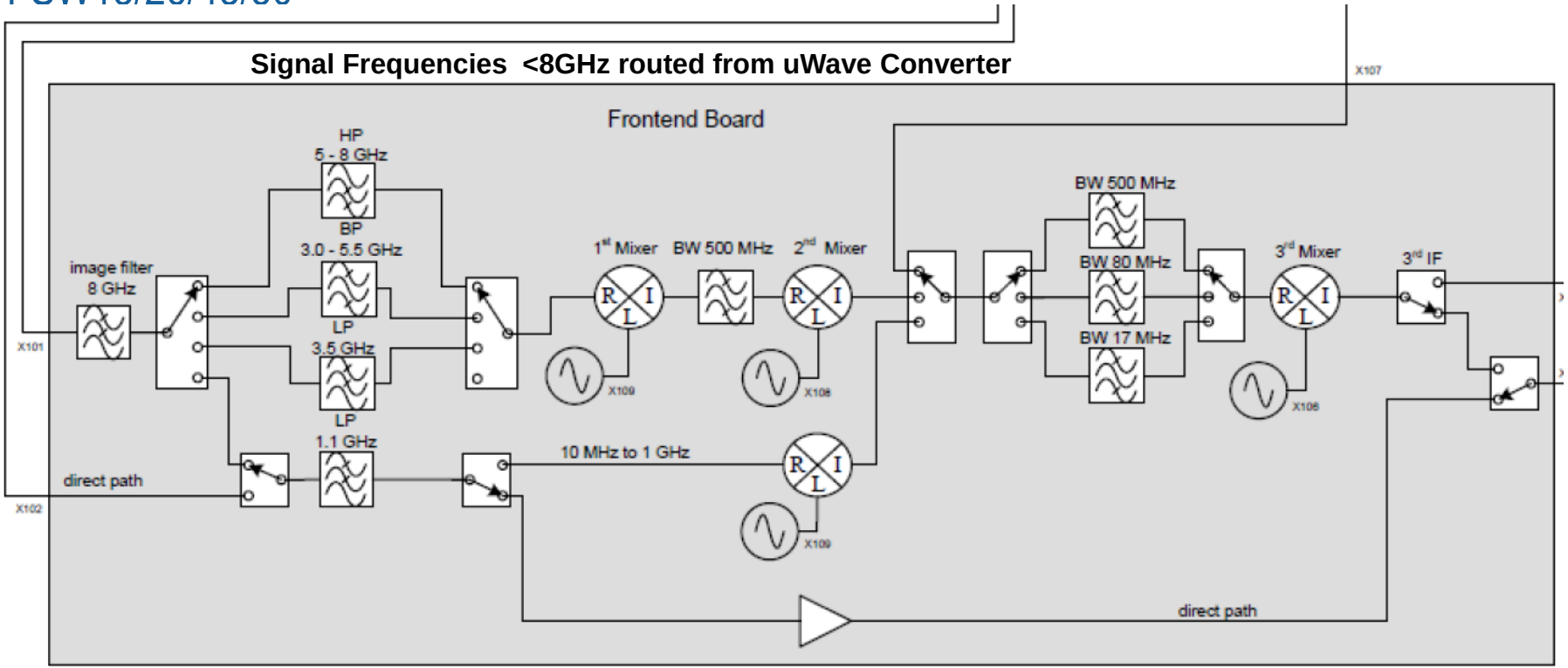


Signal Frequencies below 8GHz route to Front-end board

Pre-selection in a Spectrum Analyzer

FSW13/26/43/50

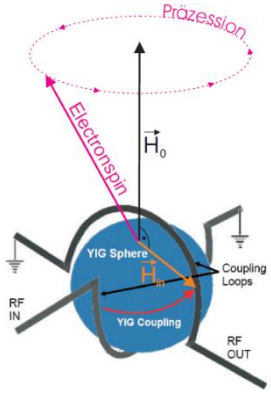
Signal Frequencies >8GHz routed from uWave Converter (already downconverted)

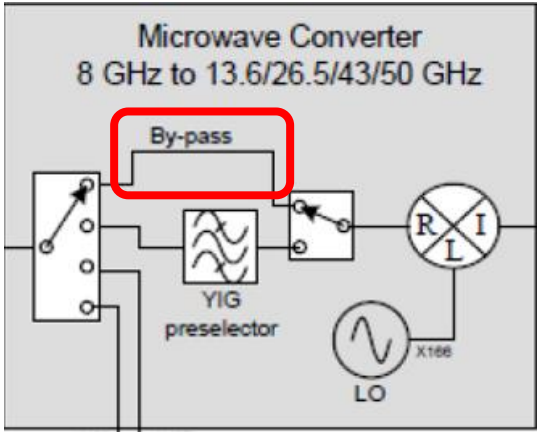


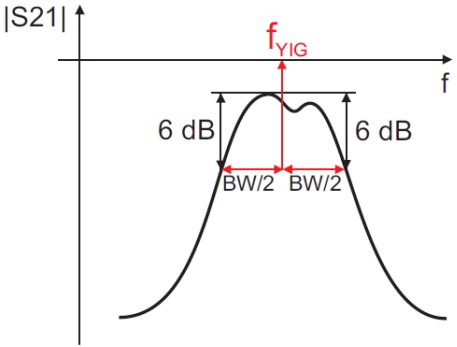
Pre-selection in a Spectrum Analyzer

YIG filters

- **What is It?**
  - YIG – Yttrium Iron Garnet
  - Tunable band-pass
  - Magnetically tuned
    - Current determines frequency
- **Purpose?**
  - Improved signal integrity by image rejection
  - Not overload protection
- **Drawbacks**
  - Limited bandwidth (~ 30 MHz)
  - Frequency Range (~ .5 – 50 GHz)
  - Level accuracy
  - Tuning speed







Outline

- Video demonstrating effects of pre-selection
- Spectrum Analyzer vs EMI Test Receiver
- Pre-selection in the standards
  - MIL-STD461 & CISPR 16-1-1
  - Time & Frequency Characteristics of Pulses
  - Pulse Requirements in CISPR 16-1-1
- Pre-selection in a Spectrum Analyzer
  - Image Rejection
- **Pre-selection in an EMI Receiver**
  - Overload protection
  - Ability to properly measure pulses
- Video demonstrating the effects of pre-selection

Pre-selection in an EMI Receiver

- **Purpose of pre-selection**
  - NOT image rejection or improved harmonic performance
  - Pre-selection protects the front end mixer
  - Helps eliminate mixer compression and overload

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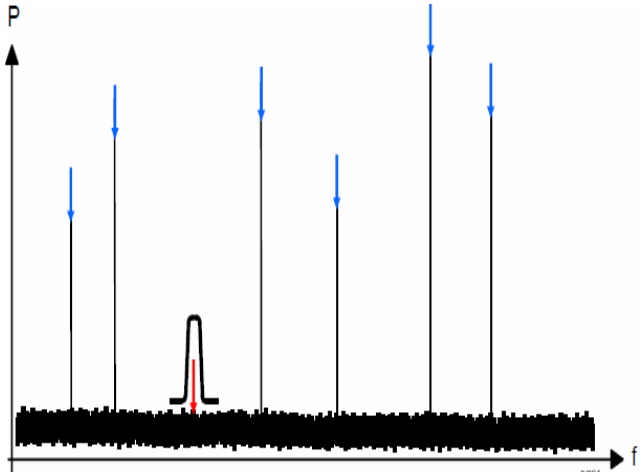
Pre-selection in an EMI Receiver



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  1) Spectral content at frequencies other than the desired measurement frequency is overloading the mixer resulting in reduced dynamic range

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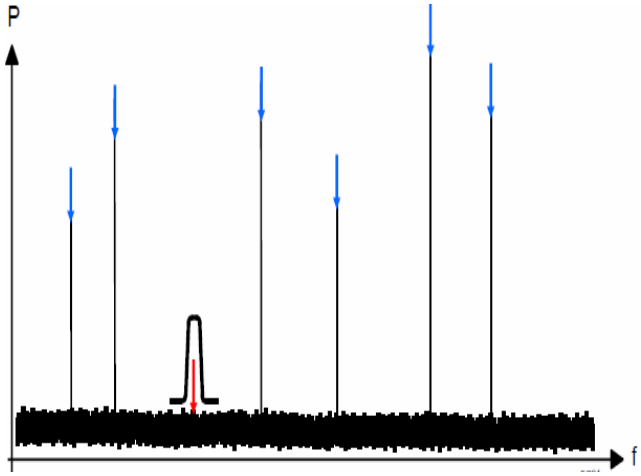
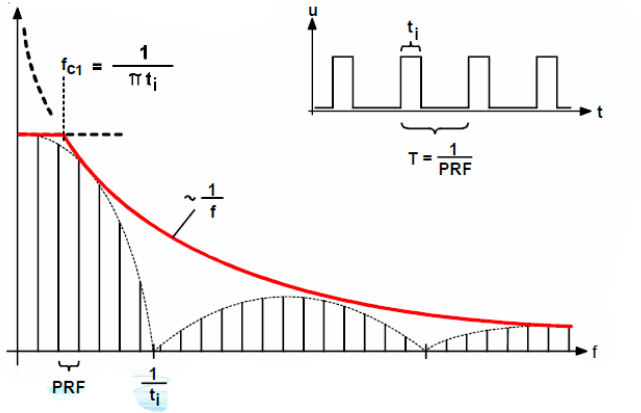
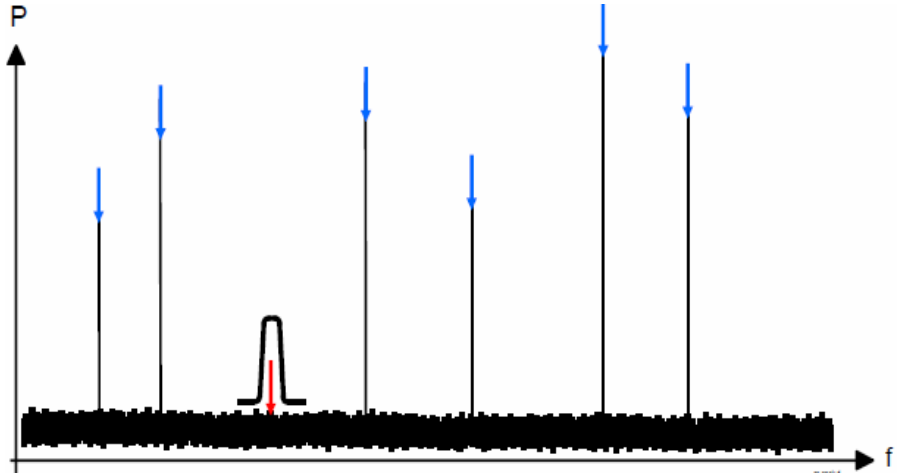
- **Two main situations where pre-selection is required**
  1) Spectral content at frequencies other than the desired measurement frequency is overloading the mixer resulting in reduced dynamic range
  2) Single short duration pulse input resulting in very wide bandwidth spectral content at the mixer





Pre-selection in an EMI Receiver

- Every signal hits the mixer
- If compressed → wrong results



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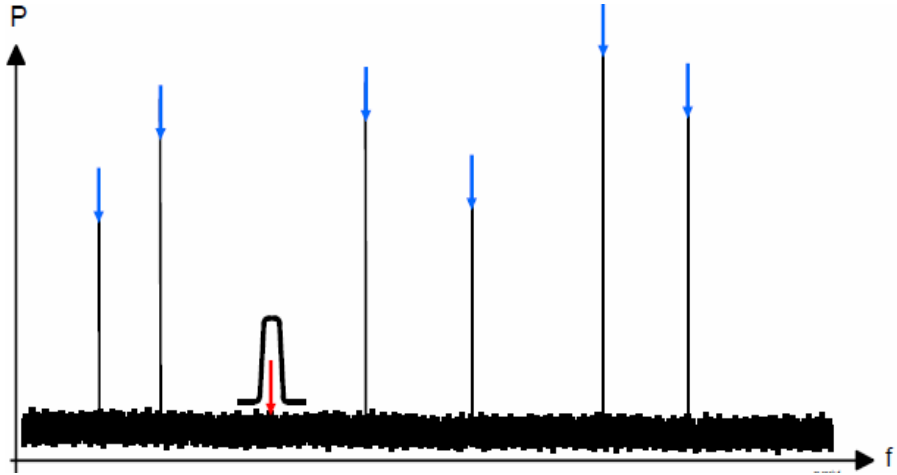

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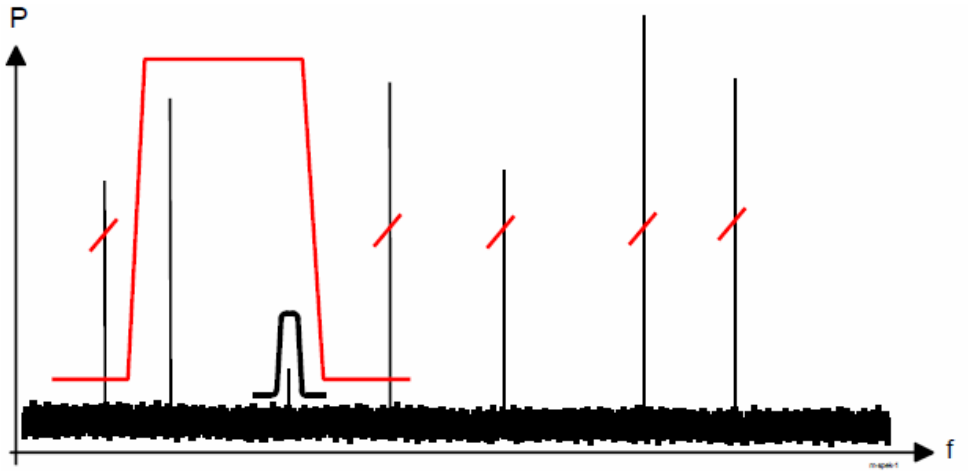
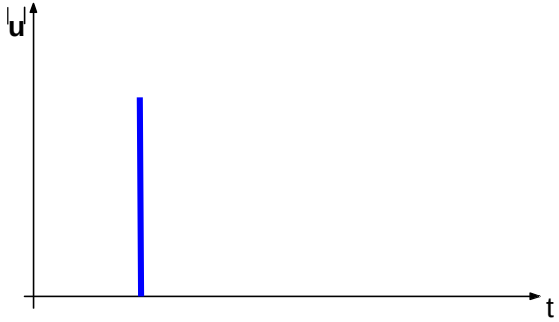


Pre-selection in an EMI Receiver

Filtering Effects in Time and Frequency

Pulse in Time Domain



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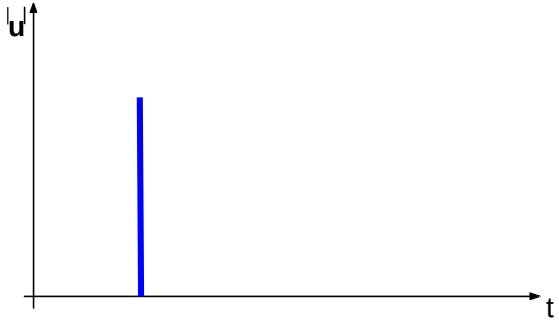
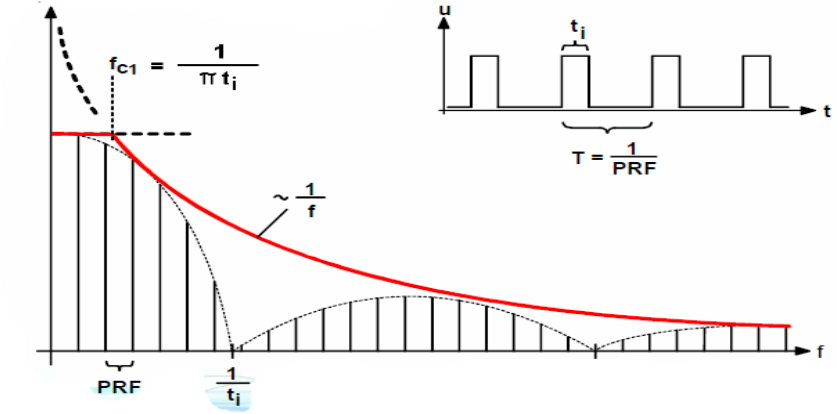


Pulse in the Frequency Domain



Pre-selection in an EMI Receiver

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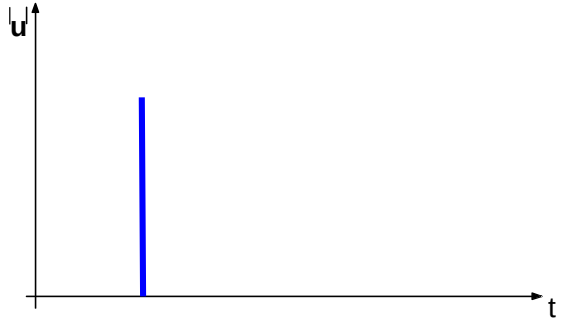

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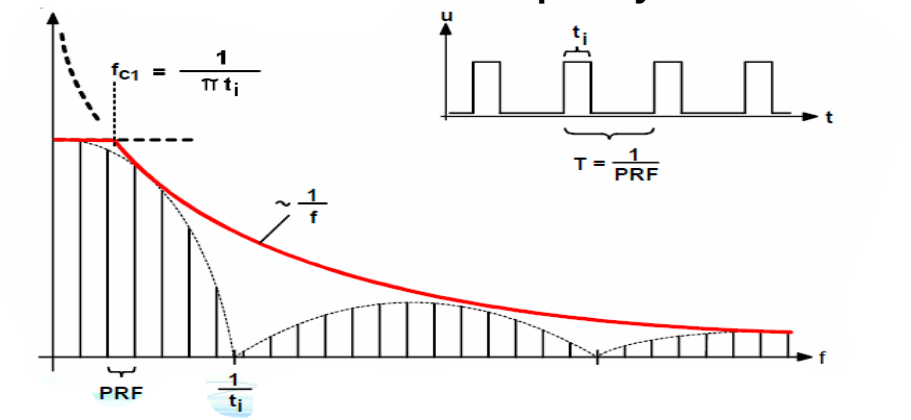
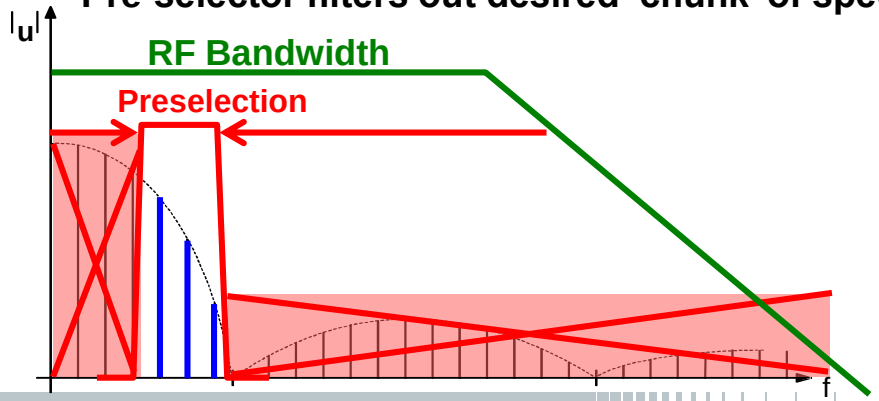


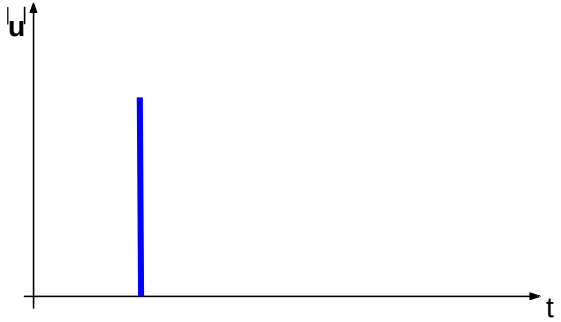
Pre-selector filters out desired ‘chunk’ of spectrum



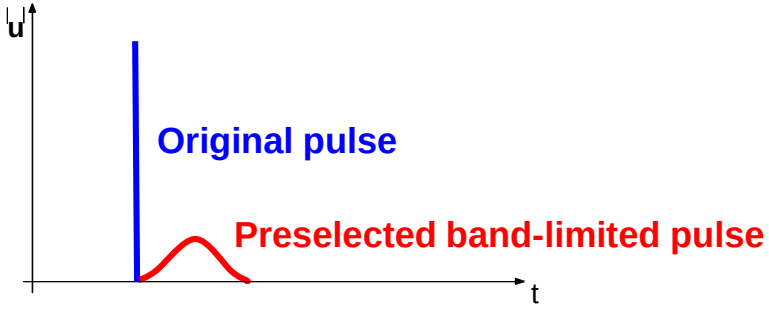
Pre-selection in an EMI Receiver

Filtering Effects in Time and Frequency

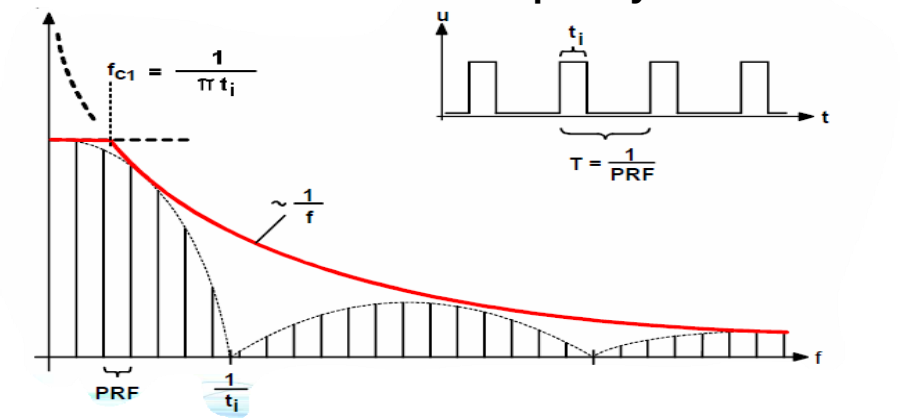
Pulse in Time Domain



Resultant Pulse in Time Domain



Pulse in the Frequency Domain



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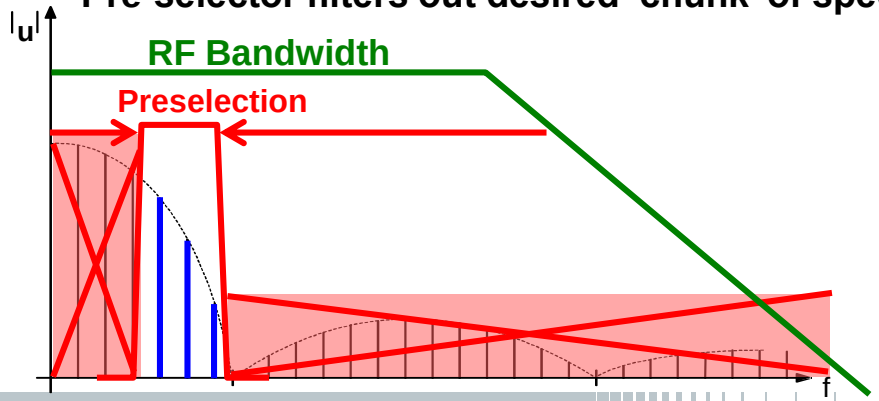
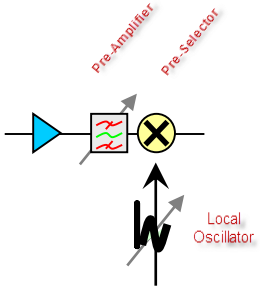
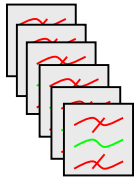


Pre-selection in an EMI Receiver

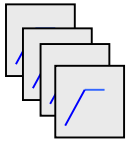
Bank of filters switched in automatically



150 KHz LPF



Fixed bandpass filters covering range 150kHz to 1005MHz



Fixed highpass filters covering range

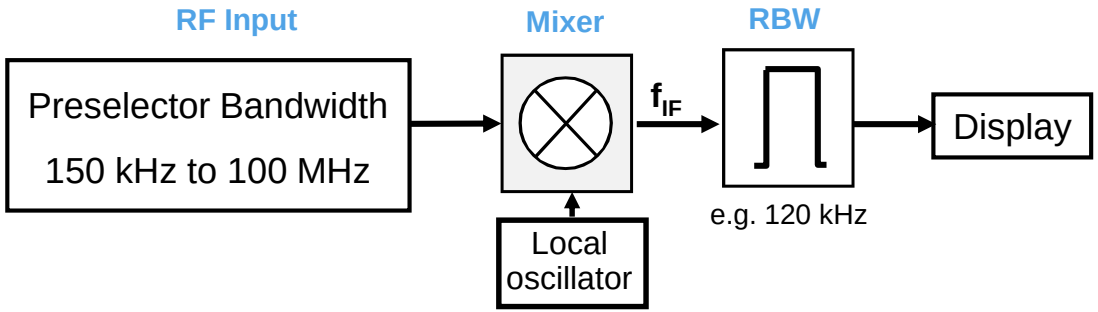
1005MHz to 7000MHz

> 7 GHz YIG filter

Preselection and preamplifier

Preselection		
State	receiver mode	always on
	analyzer mode	on/off (selectable)
Number of preselection filters		16
Bandwidths (–6 dB), nominal	10 Hz to 150 kHz	fixed lowpass filter
	150 kHz to 30 MHz	35 MHz, fixed bandpass filter
	30 MHz to 80 MHz	94 MHz, fixed bandpass filter
	80 MHz to 130 MHz	94 MHz, fixed bandpass filter
	130 MHz to 180 MHz	91 MHz, fixed bandpass filter
	180 MHz to 230 MHz	105 MHz, fixed bandpass filter
	230 MHz to 300 MHz	110 MHz, fixed bandpass filter
	300 MHz to 425 MHz	195 MHz, fixed bandpass filter
	425 MHz to 570 MHz	200 MHz, fixed bandpass filter
	570 MHz to 715 MHz	210 MHz, fixed bandpass filter
	715 MHz to 860 MHz	200 MHz, fixed bandpass filter
	860 MHz to 1005 MHz	200 MHz, fixed bandpass filter
	1005 MHz to 1750 MHz	fixed highpass filter
	1750 MHz to 2850 MHz	fixed highpass filter
	2850 MHz to 4850 MHz	fixed highpass filter
	4850 MHz to 7000 MHz	fixed highpass filter
	7 GHz to 26.5 GHz	YIG filter
Preamplifier	switchable	
Location	1 kHz to 7 GHz	in the signal path between preselection and 1st mixer
	7 GHz to 26.5 GHz	in the signal path between diplexer and preselection
Range		1 kHz to 26.5 GHz
Gain	1 kHz to 7 GHz	20 dB (nom.)
	7 GHz to 26.5 GHz	30 dB (nom.)

Necessity of Pre-Selection



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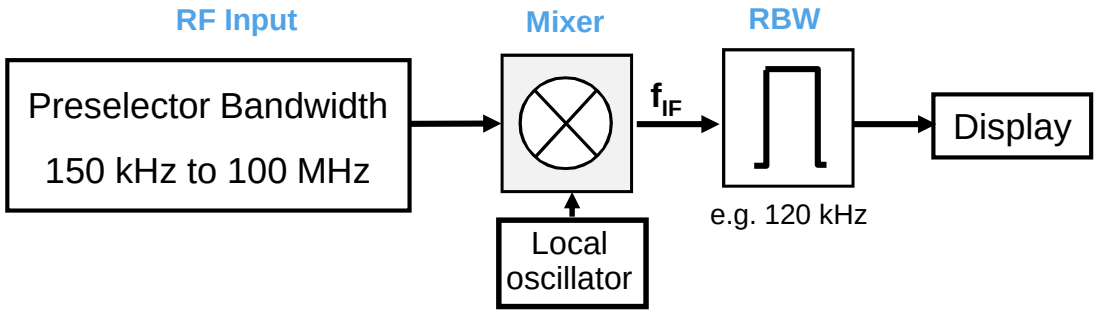

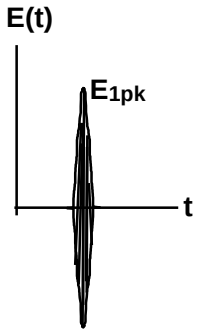

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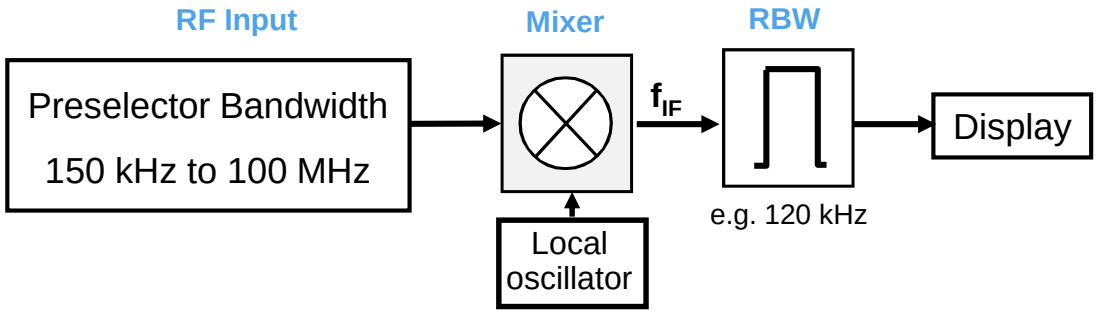

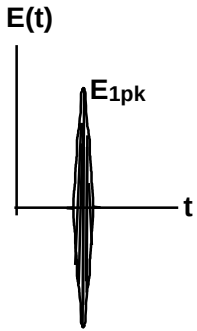

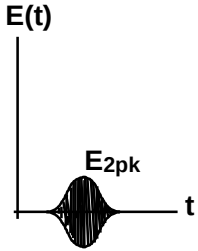

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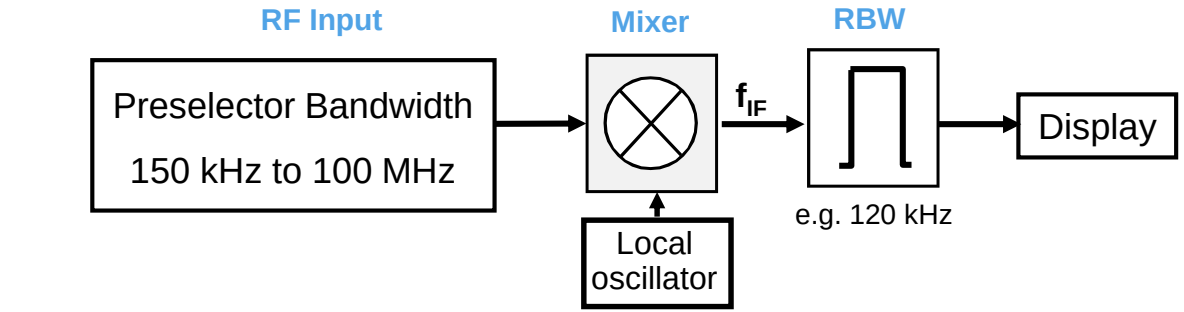

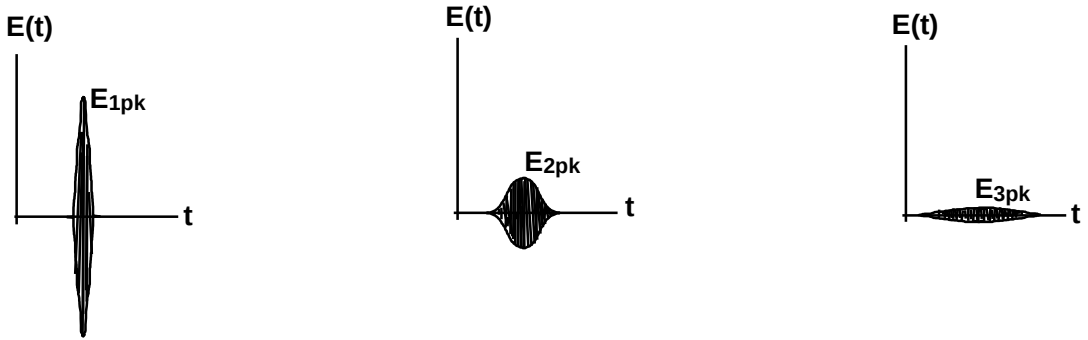

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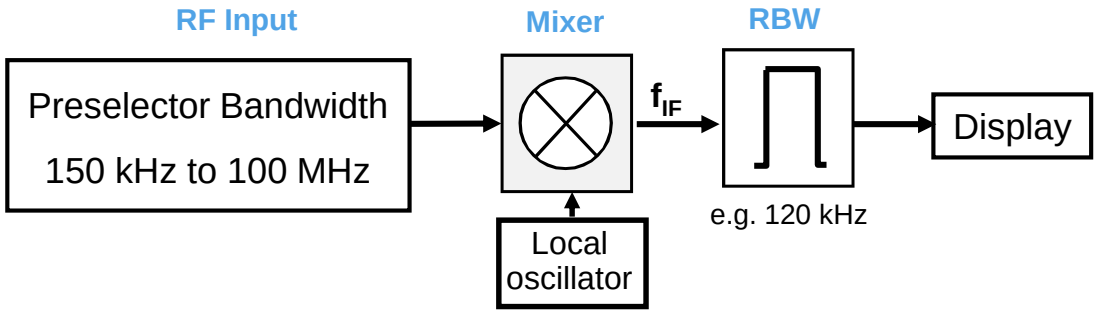
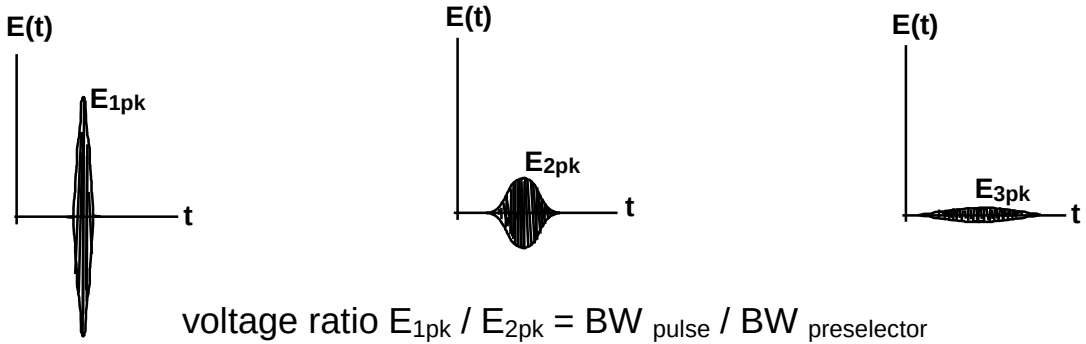
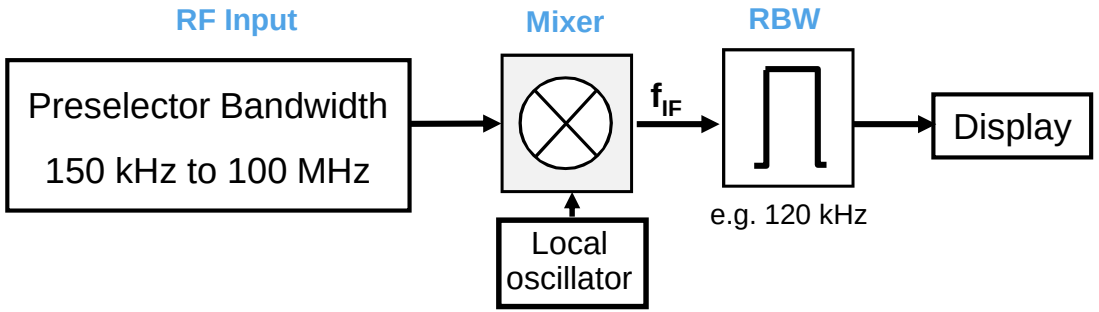


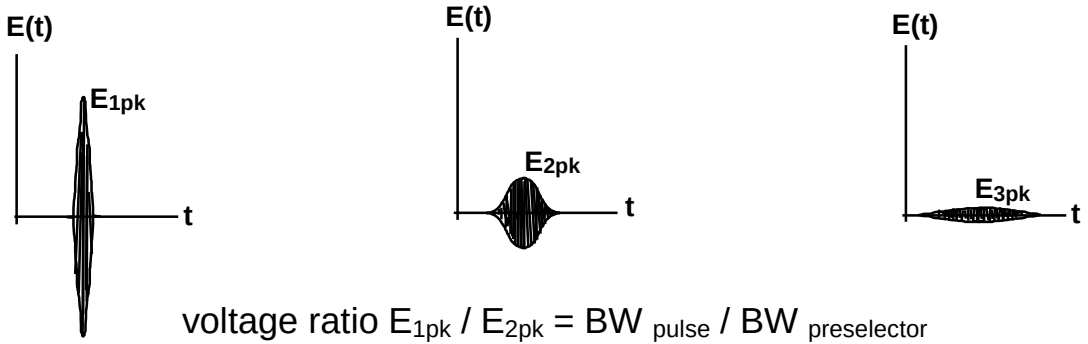


voltage ratio $E_{1pk} / E_{2pk} = BW_{pulse} / BW_{preselector}$

- constant spectral density

Necessity of Pre-Selection





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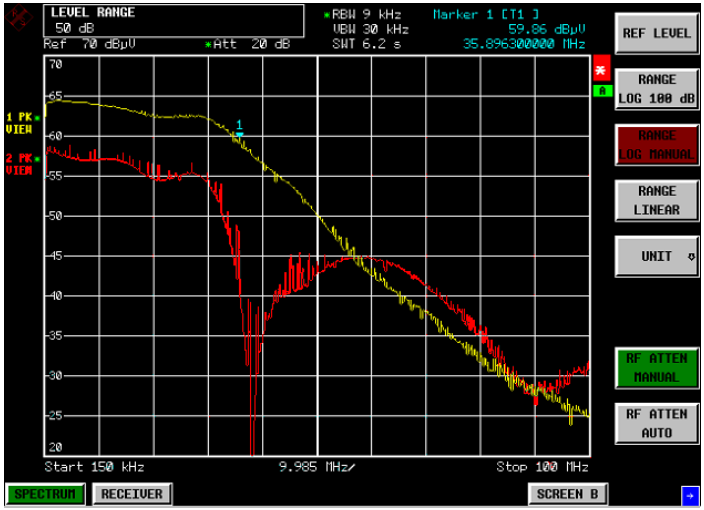
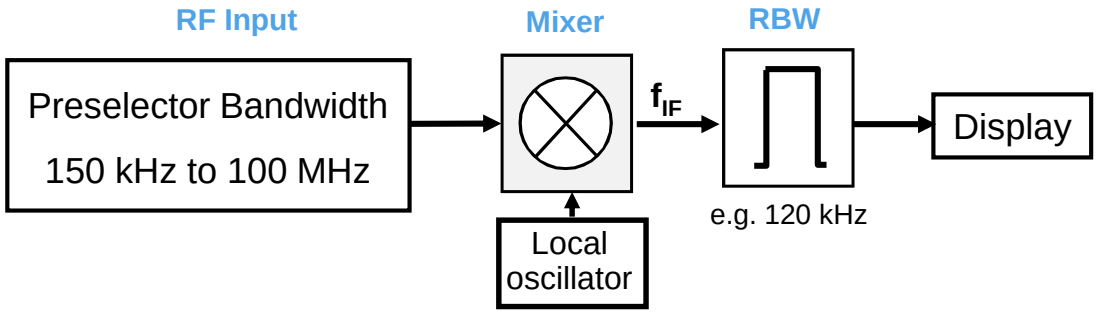
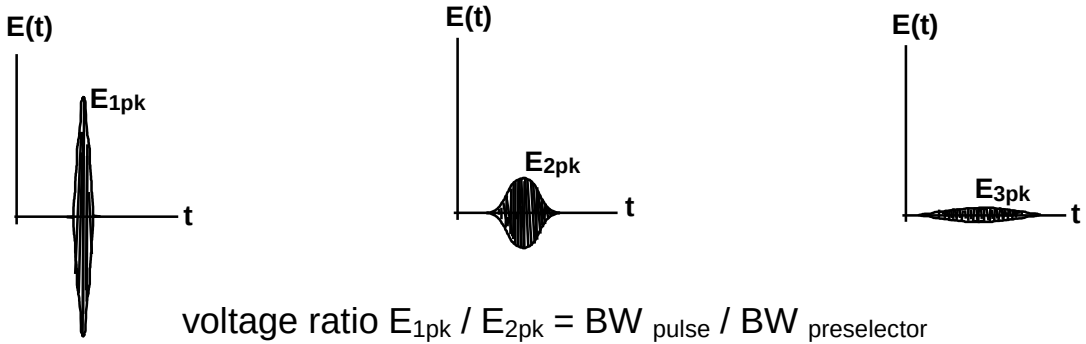


Yellow: w/ preselection
Red: w/o pre-selection

Necessity of Pre-Selection





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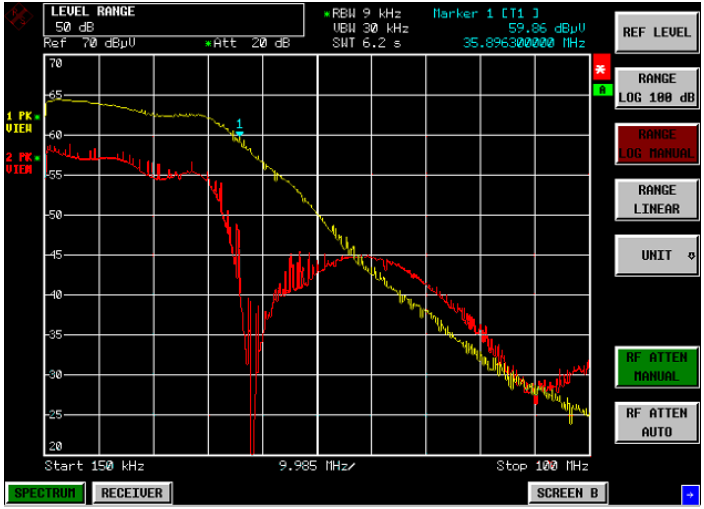
*** Debug Note**

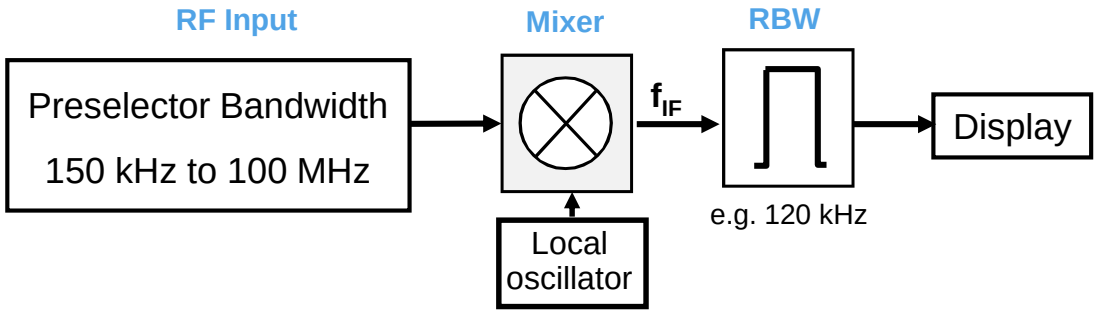
Compression can lower gain & increase noise

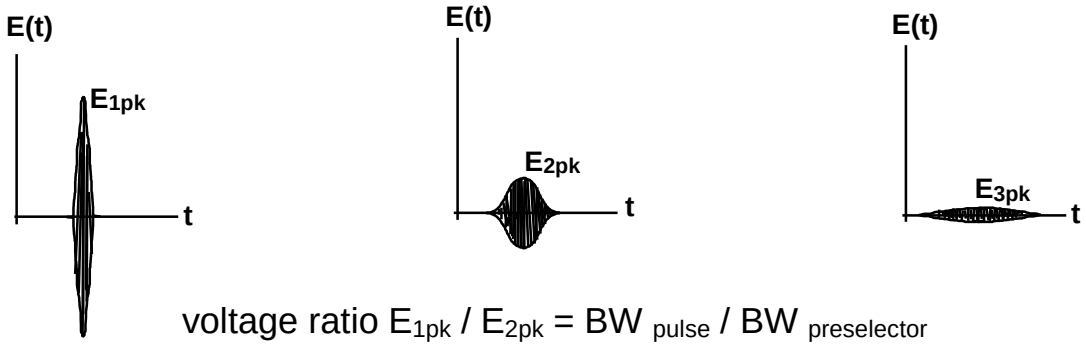


Yellow: w/ preselection

Red: w/o pre-selection

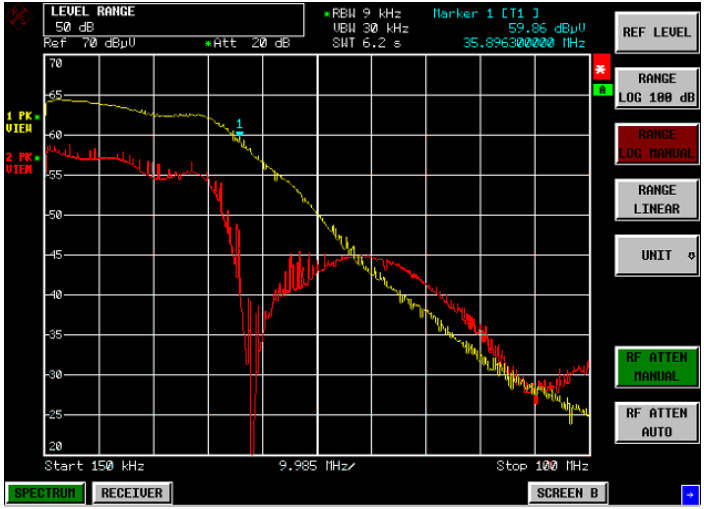
Necessity of Pre-Selection





voltage ratio E_{1pk} / E_{2pk} = BW $_{pulse}$ / BW $_{preselector}$
- constant spectral density

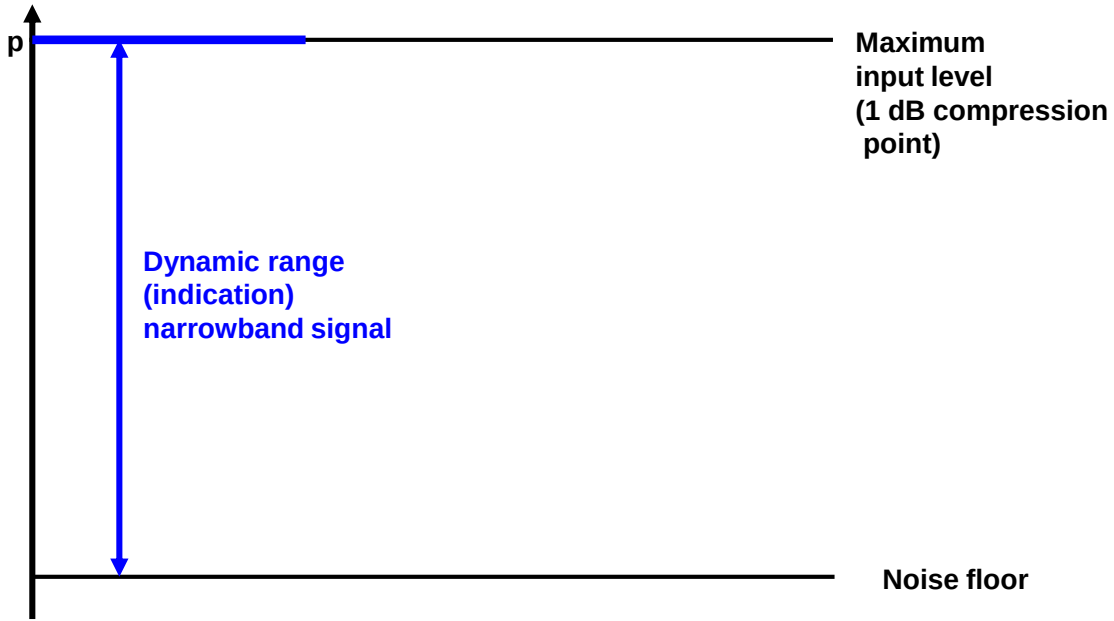
*** Debug Note**
Compression can lower gain & increase noise



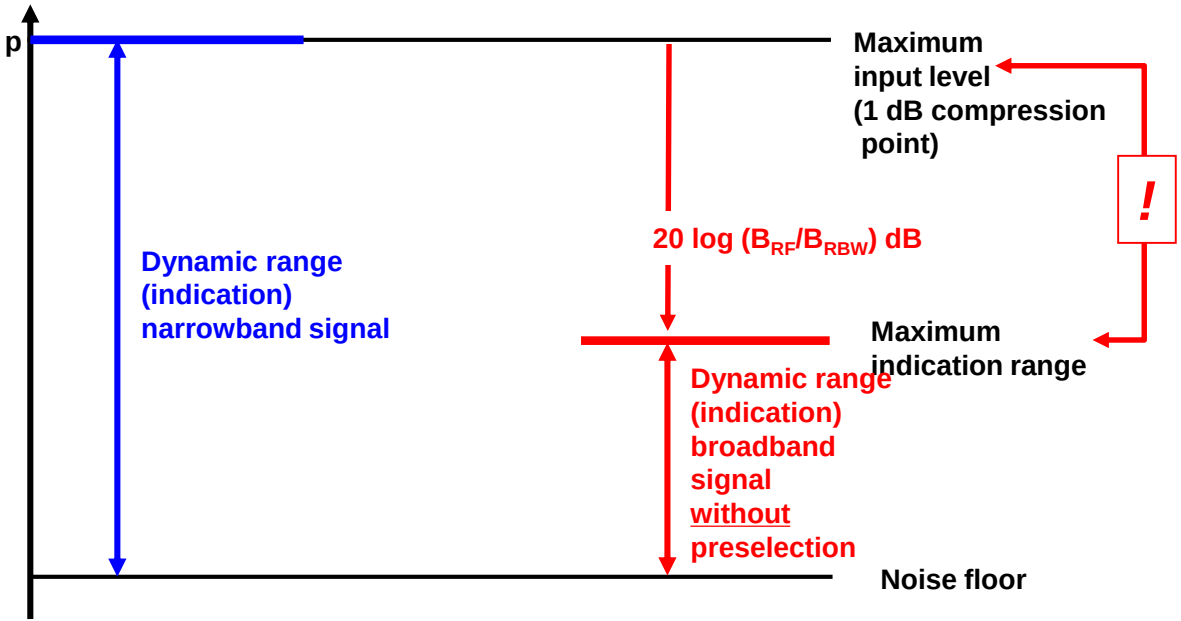
Yellow: w/ preselection
Red: w/o pre-selection

- Frontend is overloaded without preselector
- No reliable overload indication

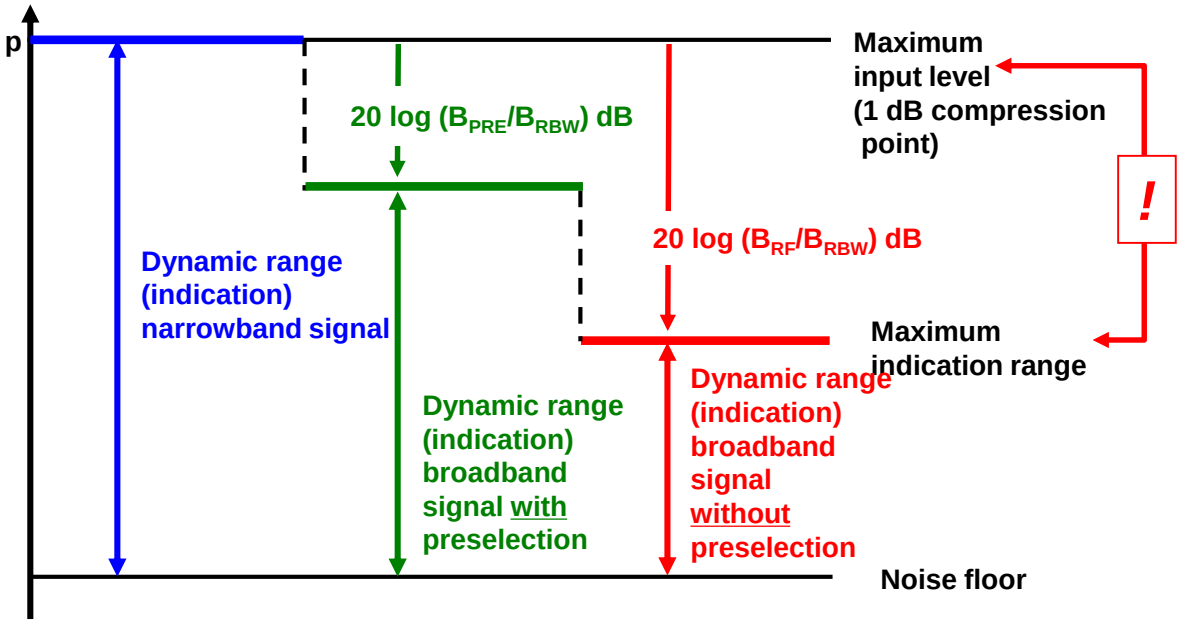
Preselector for EMI Receivers



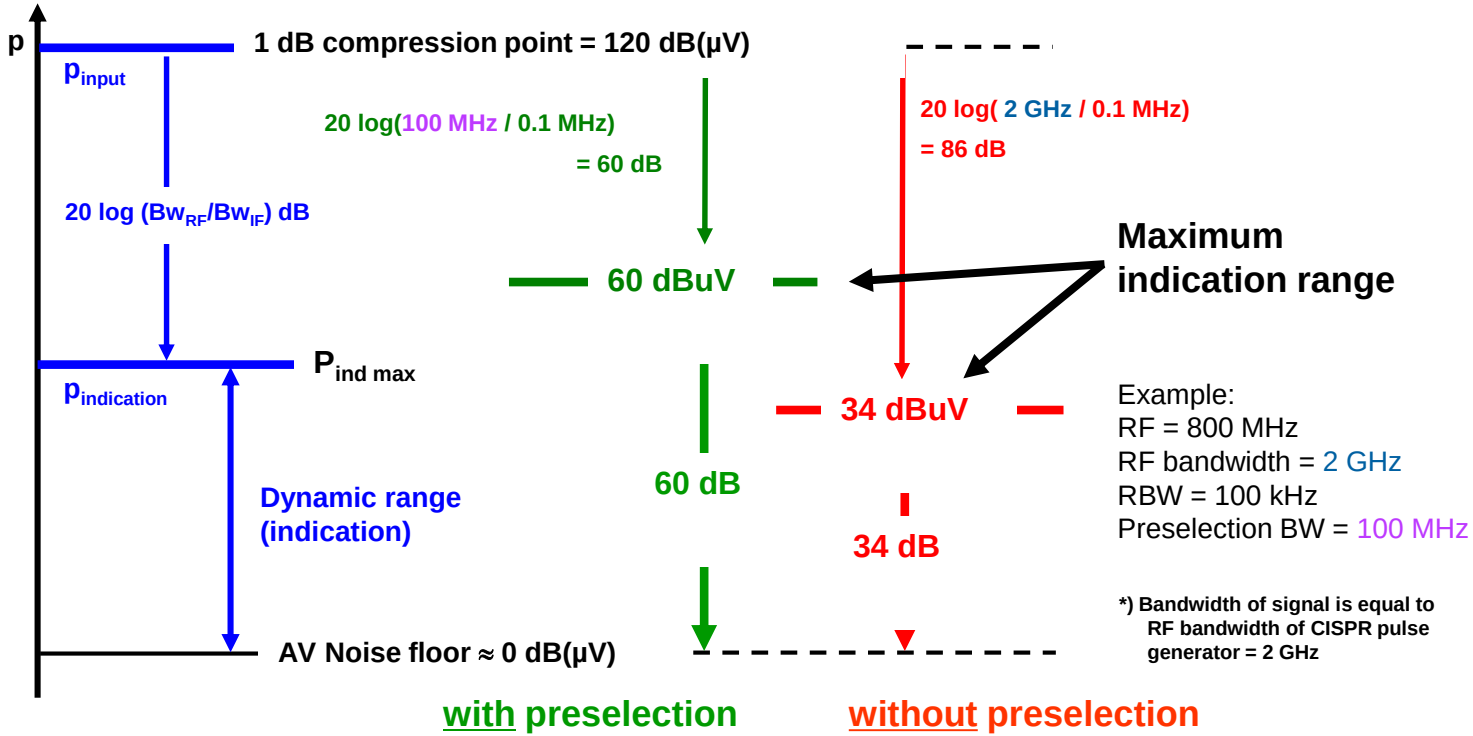
Preselector for EMI Receivers



Preselector for EMI Receivers



Preselector for EMI Receivers

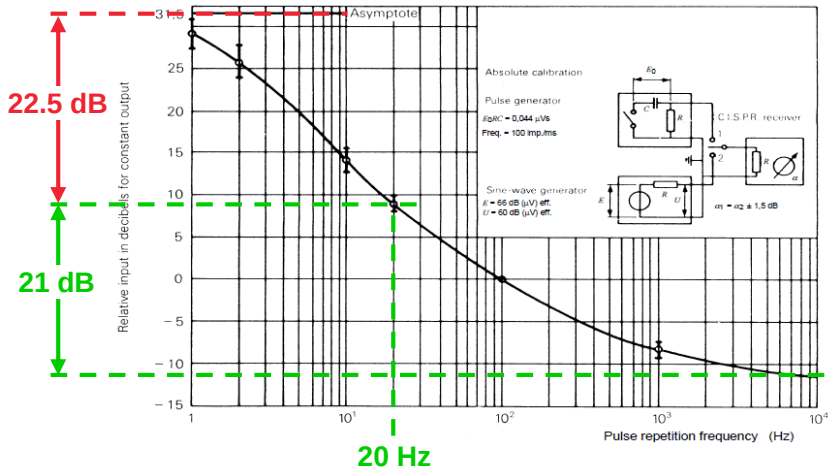


Preselector for EMI Receivers

Use of spectrum analyzer for compliance measurements

- **Requirements in CISPR 16-1-1 (3rd Ed.)**
  - The QP response of a spectrum analyzer without preselection to repeated pulses shall be identical to Figure 1 for pulse repetition frequencies equal to or greater than 20 Hz

Example for Band C/D

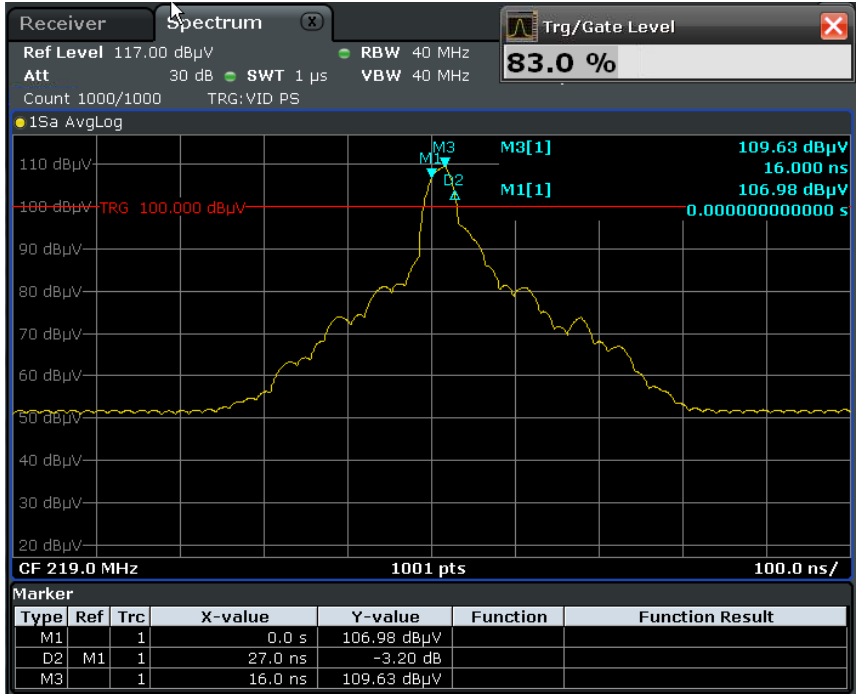


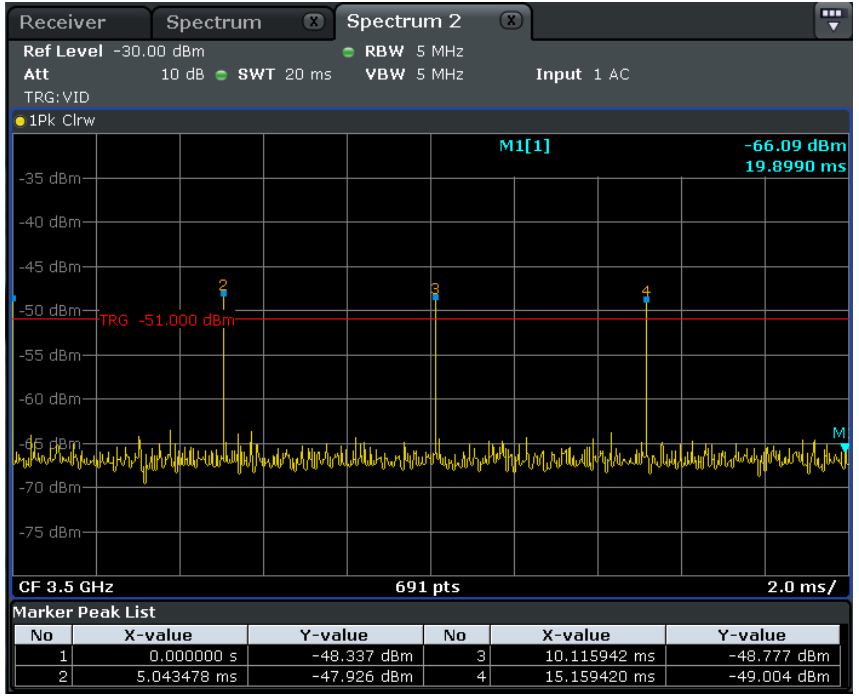
CISPR- Standard Calibration Pulse Generator

IGLK 2914 Schwarzbeck MESS-ELETRONIK

Parametrics

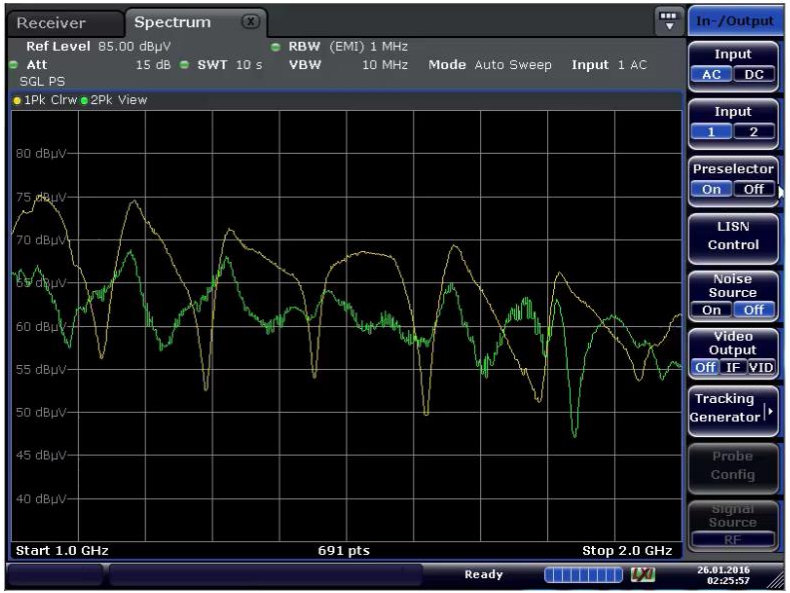
- Pulse type = CISPR 1 (9 kHz)
- Pulse Width ~ 41 ns
- PRF= 200 Hz
- Power = 56 dBuV



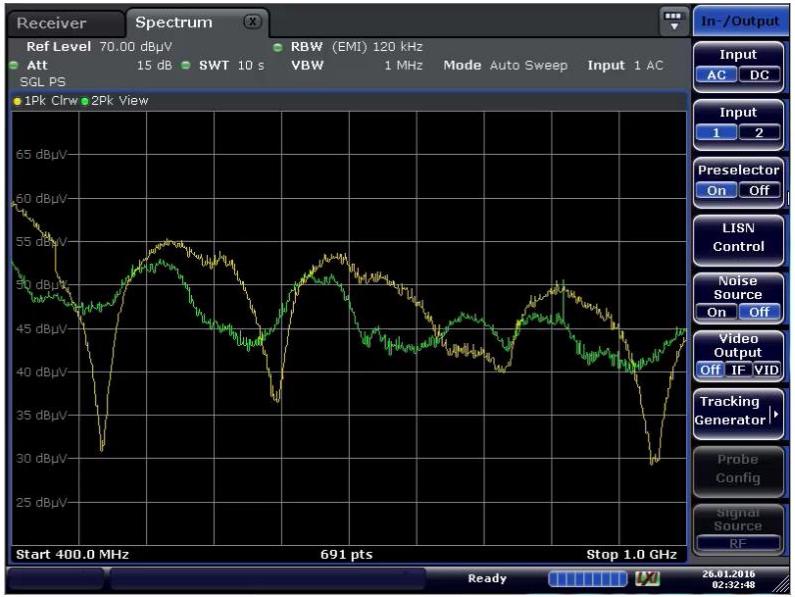


Necessity of Pre-selection

1GHz - 2GHz Sweep with RBW = 1MHz



400MHz -1GHz Sweep with RBW = 120kHz



Yellow: w/ preselection
Green: w/o pre-selection

Thank You for Your Attention

Questions?