Understanding Preselection in EMI Receivers

Application Note

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1 Introduction

EMI (electromagnetic interference) testing differs from traditional spectrum analysis in numerous ways, but the most important differentiator between them lies in the nature of the signals that are being measured. In traditional spectrum analysis, we are normally measuring signals that we (or rather our device under test) are generating. In other words, we are measuring **known** signals. In most cases we have control over both the signal's content or modulation, as well RF-level parameters such as frequency, level, crest factor, etc. We can easily configure or adjust our device under test and our measurement setup such that measurements are reliable and repeatable, with minimum uncertainty and distortion.

In EMI testing, however, we are normally measuring signals that are **unknown**. In fact, the main purpose of EMI testing is detecting, measuring, and locating signals whose basic RF parameters such as frequency, level, periodicity, etc. are not known or knowable a priori. This creates an obvious problem in terms of optimizing our measurement setup and avoiding inaccurate or erroneous results – how do we choose the "correct" settings when we do not know even the most basic parameters of the signals that we wish to measure?

This is particularly important in EMI testing. Limited time and resources can be wasted looking for spurious emissions that are being generated within our measurement setup, not by the equipment under test (EUT) itself. A failure to detect and mitigate actual spurious emissions from the EUT can cause a device to fail compliance testing (time-consuming and costly) or create serious issues if the device is placed in a "real-world" environment.

Most of the problems involved in accurately detecting and quantifying spurious or unwanted emissions in EMI testing are related to the unpredictable and/or rapidly changing level of the measured signal(s). Controlling the level of signals presented to our instrument, or more precisely, to the first mixer in our instrument, is critically important for all types of EMI testing. **Preselection** is the most effective means of ensuring accurate and reliable results during EMI testing.

2 About Mixers

2.1 About Mixers

In order to understand preselection, we first have to understand what mixers are and how they are used in both spectrum analyzers and EMI receivers. A mixer is a device that combines, or "mixes", two signals to produce the sum and difference frequencies of those two signals. For example, if a mixer combines an input tone at 200 MHz and a local oscillator 300 MHz, then the output of our mixer will also contain signals at the sum, 500 MHz, and the difference, 100 MHz, of these two frequencies. [Figure 1]
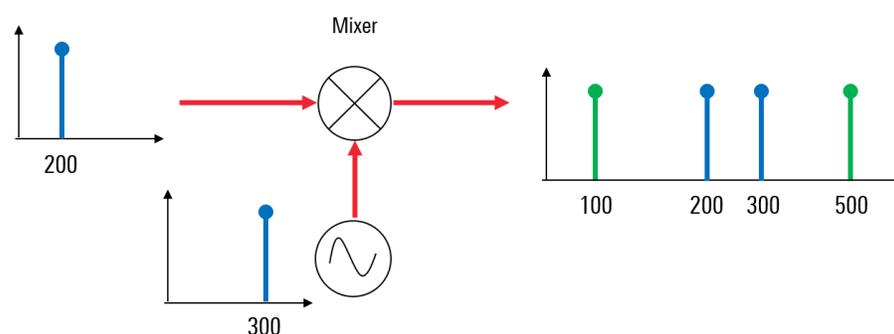
Figure 1 - Basic mixer principle

The reason that mixers are used to translate signals in frequency is for ease of processing: higher frequency RF signals are almost always more challenging to work with than lower frequency signals. By using mixers we can convert input signals over a wide frequency range to a single frequency and then process those signals with fixed filters or amplifiers with fixed bandwidths.

Since the mixer is usually one of the first components in an instrument's signal processing chain, it is typically exposed to ALL signals present at the RF input. Even if we set our measurement range or span to only a limit frequency range, say, 30 to 1000 MHz, the mixer will still be exposed to RF power outside of this frequency range. In many instruments dynamic range be changed using an input attenuator and/or a preamplifier to lower or raise signal level. [Figure 2]
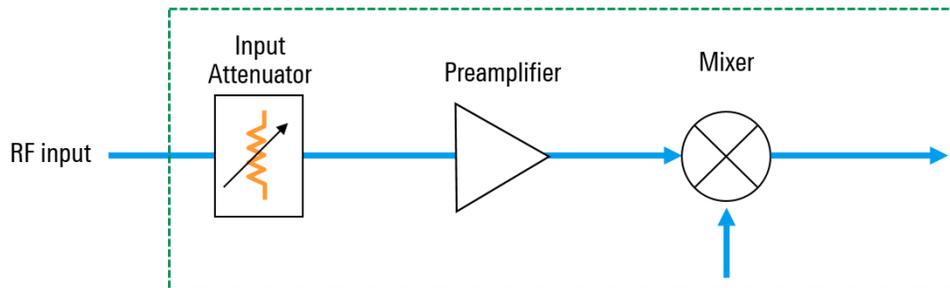
Figure 2 - Controlling mixer input level

Why are we so concerned about protecting the mixer? There are really two main reasons: compression, and spurious mixing products.

Like all active devices, mixers are subject to compression. As long as the input power level is below a device-specific threshold, the mixer is said to be operating in its linear region. In the linear region, the output of the mixer should contain only the (undistorted) input signals and their sum and difference signals. However, as the input power level increases beyond a device-specific threshold, the mixer will go into compression. Figure 3 shows how the relationship between input power and output power remains linear (constant slope) only up to a certain input power level. After this level is reached, the output power "flattens out" and the mixer is said to be "in compression."
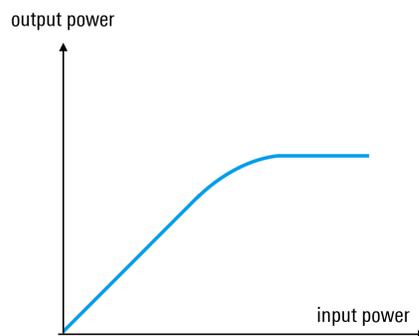

Figure 3 - Gain curve: linear region and compression

2.2 Mixers and Compression

Compression has several consequences, the most important of these being incorrect amplitude results and the generation of spurious products. [Figure 4] Mixer compression is particularly problematic because, in many cases, the mixer may be in compression without any warning from the measuring instrument, such as an IF or RF overload indication. The lack of an overload warning from our instrument does not

mean that we have no spurious products due to mixer compression – signal distortion can occur long before an overload indication is presented to the user. It is especially important to remember that the signals causing mixer compression may be outside of our current measurement range or span. A high-powered signal can cause mixer compression even if we do not see that signal on our instrument's display.
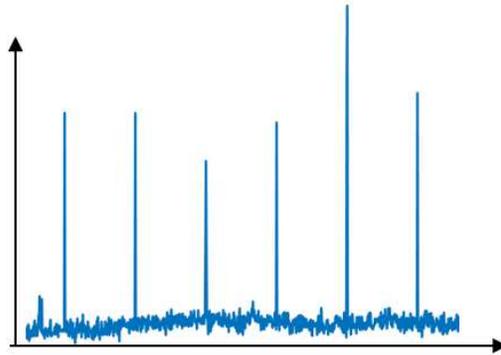
Figure 4 - Spurious products created by mixer compression

There are basically two general categories of mixers: active and passive. As the names imply, active mixers are made from active components such as transistors, and passive mixers are made from passive components such as diodes. Although passive mixers usually introduce some loss, active mixers typically provide some amplification, something known as conversion gain. Mixers therefore are liable to the same compression effects typically seen in amplifiers: gain increases linearly with increasing input power. However, as we saw above, at some point the gain curve "flattens out" and conversion gain is no longer linear. The result is that the actual mixer output levels are different than the expected mixer output levels. In most cases, this incorrect amplitude is lower than the excepted levels, but can be higher in some cases, depending on the idiosyncrasies of a particular mixer's design.

A mixer in compression can also generate distortion in the form of spurious products, such as harmonics and intermodulation products. In many applications, and especially in EMI measurements, these spurious signals are a significant issue – we want to be sure that the signals that are displayed and which we are measuring are actually coming from the equipment under test, not from the measurement instrument itself.

Spurious or "phantom" signals can also occur due to the mixing of products in an uncompressed mixer. A mixer, by its very nature, is designed to produce the sum and difference products of two input signals. Normally, this mixing occurs between the input signal and the local oscillator, but a combination of two or more signals at the input can also lead to mixing products. For example, if we look at the span 200-400 MHz [Figure 5], we do not see any signals, including the ones at 150 and 500 MHz. However, when these signals pass through a mixer, these two tones will combine and a tone will appear at 350 MHz – the difference frequency, even though no such tone was present at the input of the instrument.
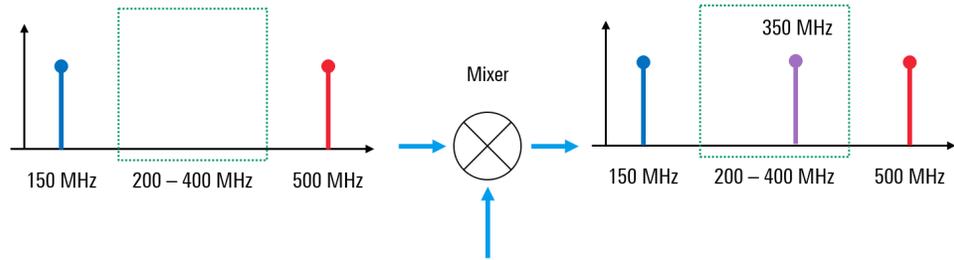
Figure 5 - Spurious product created in uncompressed mixer

2.3 Protecting the Mixer

Given how important it is to protect the mixer, how is this done in practice? One previously mentioned solution is the use of input attenuation. [Figure 6] Input attenuation is easy to implement, and input attenuators are available in almost every type and category of spectrum-measuring instruments. However, using a broadband input attenuator can also be problematic. The input attenuator affects all signals equally – it cannot be used to attenuate signals only at certain frequencies. If we increase input attenuation, we may lose the ability to "see" smaller or weaker signals, and in many cases it is precisely these smaller signals that we are interested in.
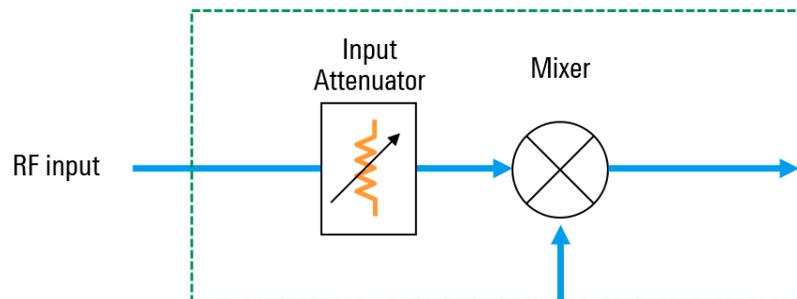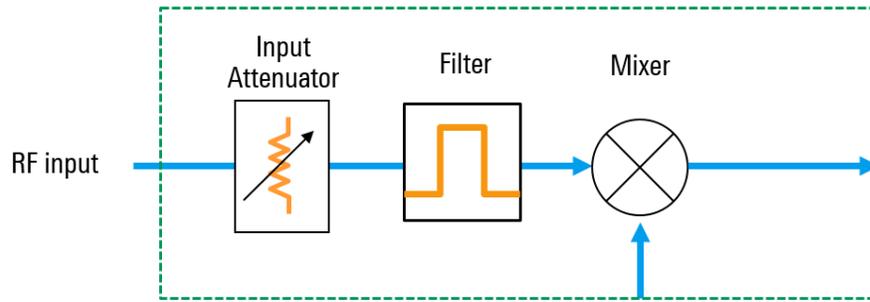

Figure 6 - Protecting the mixer with input attenuation

The next step would therefore be a frequency-selective attenuator – in other words, a filter. By placing a filter in front of the mixer, we can reduce the probability of overload and undesired mixing. [Figure 7]

Figure 7 - Protecting the mixer with a (fixed) filter

But how do we implement filtering over the wide range of frequencies typically covered by EMI testing? A tunable filter might be a possibility, but this does not work well when scanning – something done quite often in EMI testing. A better solution would be to use a bank of filters and pick the appropriate filter based on the current frequency. We can define the number of filters and their respective passbands such that we cover all or most of our instrument's range. This filter bank is called a preselector.

3 About Preselection

3.1 What is a preselector?

A preselector is a type of "tracking" filter that can be used to limit the range of input frequencies that are presented to the mixer. Preselectors are usually implemented as an automatic, electronically switched bank of filters. The preselector selects or adjusts which filter to use based on the current frequency on the instrument. The preselector automatically switches from one filter to another when the operating frequency changes, and this is done transparently without any user intervention. Note that even though most preselectors are implemented as a bank of filters, a preselector could also be implemented using a single, tunable filter. Due to the way a preselector operates, the input frequency range is essentially subdivided into several subranges, one per filter. There is however a practical limit on the number and minimum width of these filters, since the preselector filters must still be wide enough to pass any desired signals or signals of interest.
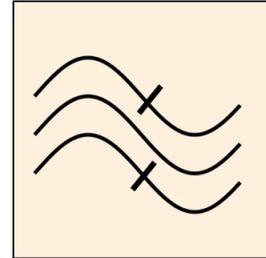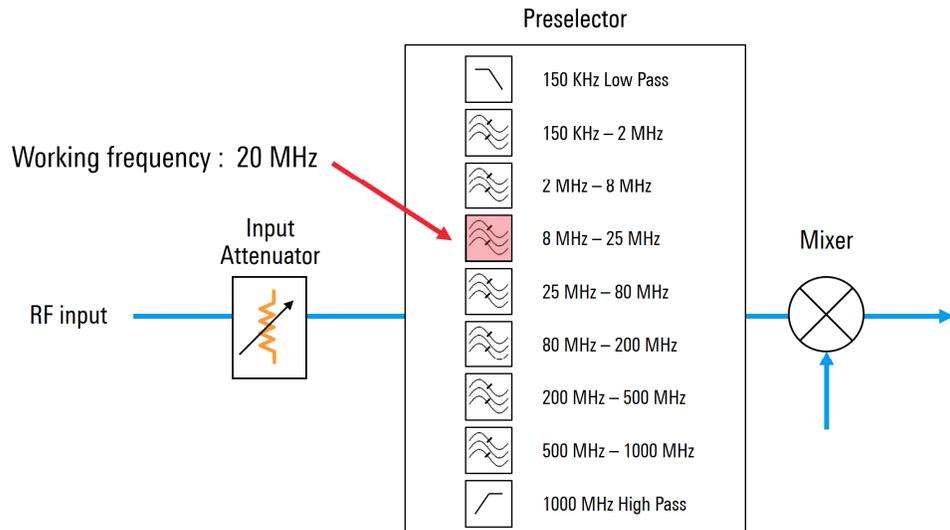

Figure 8 - Preselector symbol

## 3.2 How does a preselector work?

Without a preselector, input power at all frequencies is passed to the mixer regardless of working frequency. Imagine placing a preselector in front of the mixer. Our preselector [Figure 9] is implemented as a bank of filters, with each filter only passing a certain range of frequencies. Our instrument automatically chooses which of these filters to use based on our current or working frequency. For example, if our current measurement frequency is 20 MHz, a bandpass filter covering 8 - 25 MHz is used. If our instrument is scanning over a range of frequencies, the preselector automatically switches between filters at the appropriate times during the scan.

Preselector

- 150 KHz Low Pass
- 150 KHz – 2 MHz
- 2 MHz – 8 MHz
- 8 MHz – 25 MHz
- 25 MHz – 80 MHz
- 80 MHz – 200 MHz
- 200 MHz – 500 MHz
- 500 MHz – 1000 MHz
- 1000 MHz High Pass

Working frequency : 20 MHz

RF input

Input Attenuator

Mixer

Figure 9 - Preselector concept

Remember that without preselection, our mixer is exposed to all signals, even those that are outside of our given span. For example, we might choose our span such that we only see a single signal [Figure 10], but the mixer still sees the sum of power from all the other signals as well – signals that we do not even see on our instrument display.
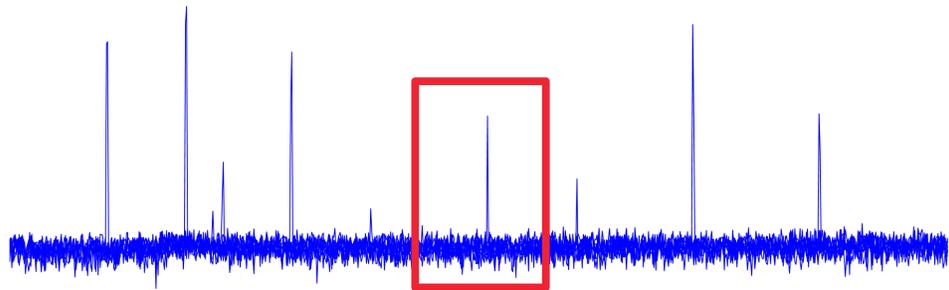
Figure 10 - Signals outside of displayed / configured span (red)

If we enable preselection, signals outside of the preselector bandwidth will be attenuated or removed. The green box in Figure 11 represents our preselection filter bandwidth, which helps prevent signals outside of its passband from reaching the mixer. Preselector filter bandwidths are usually wider than the typical span, so there could be signals that lie between the preselector bandwidth (green) and the span (red). These signals could still cause problems, but preselection **greatly** reduces the probability and severity of issues due to out-of-span signals.
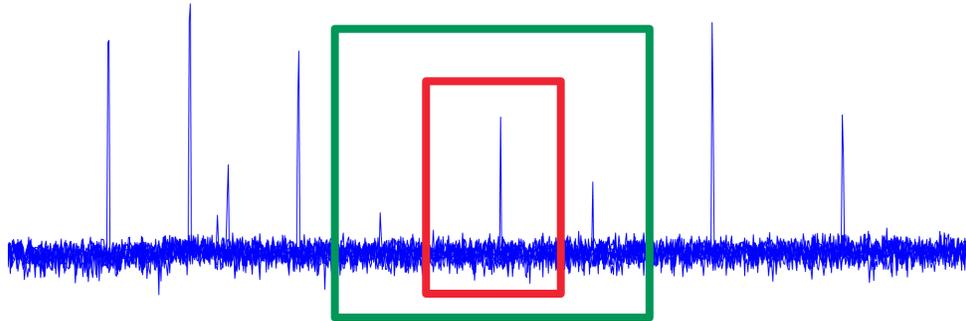
Figure 11 - Preselector (green) enabled

3.3 Pros and Cons of preselection

The main advantage of preselection is, of course, that it reduces the probability of invalid results due to compression and/or the creation of spurious mixing products. There are, however, a few things to keep in mind when using preselection. First, a preselector can increase the time needed perform a sweep or scan compared to that same measurement without a preselector. There are two reasons for this: the first is the amount of time needed to switch between filters in a filter bank or adjust a tunable filter. The second is the settling time needed for the filter. Less serious considerations include any insertion loss introduced by the preselector as well as the fact that like all filters, the passband in our preselection filters will not be entirely flat. That said, in the vast majority of cases, the advantages of preselection far outweigh the potential disadvantages.

3.4 Where are preselectors used?

Recall that there are two basic categories of spectrum measuring instruments. These are spectrum analyzers and EMI receivers.

Traditional swept-tuned spectrum analyzers are primarily used to make measurements of known signals. In other words, to characterize signals that we are intentionally generating. As we mentioned earlier, the user of a spectrum analyzer is typically controlling all of the signals that are present in the measurement setup, so there is little or no need for preselection: most spectrum analyzers do not have the type of preselector described in this paper. When preselection is available on a spectrum analyzer, it can usually be switched on and off by the user.

Figure 12 - Swept spectrum analyzer

As we know, EMI receivers are intended to characterize unknown signals, that is, signals that the user is neither intentionally generating nor can control. Given that we do not have control over, or potentially even knowledge of, the signals that may be appearing at the receiver input, preselection is more or less a necessity for these applications because it reduces the risk of overload

Figure 13 - EMI receiver

and increases the instrument's dynamic range. Preselection in an EMI receiver normally cannot be switched off, and part of the reason for this is that preselection is necessary to make the receiver – or "measurement apparatus" - comply with various EMI standards, such as CISPR 16-1-1. This will be discussed more fully later in this paper.

3.5 Preselection and EMI receivers

The main purpose of preselection is to protect the front end, or first mixer, of our measurement instrument. Recall that this is done for two reasons: to reduce the probability of mixer compression as well as to reduce the probability of spurious mixing products being generated. This happens primarily in two situations. The first situation occurs when spectral content or power is present at frequencies other than our current measurement frequency, creating an overload situation which in turn leads to distortion, amplitude inaccuracies, and reduced dynamic range. The other situation is related to CISPR 16-1-1 and involves a single, short duration pulse which results in very wide spectral content at the mixer. This second situation is a somewhat special case which needs to be examined in more detail.

CISPR 16-1, one of the most important standards for EMI testing, consists of five sections. The first of the these sections, CISPR 16-1-1, places requirements on the "measuring apparatus" that is used when making compliance measurements. In other words, it specifies certain characteristics and features that a device must have (for example, detector types) in order to be used for compliance testing. CISPR 16-1-1 uses a "black box" approach, in that it defines functionality, not specific pieces of equipment or instruments, so it applies equally to both spectrum analyzers and EMI receivers. And because MIL-STD 461 also references CISPR 16-1-1 via the ANSI C63.2 standard, this means that MIL-STD testing also follows the 'measuring apparatus' requirements set forth in CISPR 16-1-1. An area of particular concern are the CISPR requirements for pulsed signals.
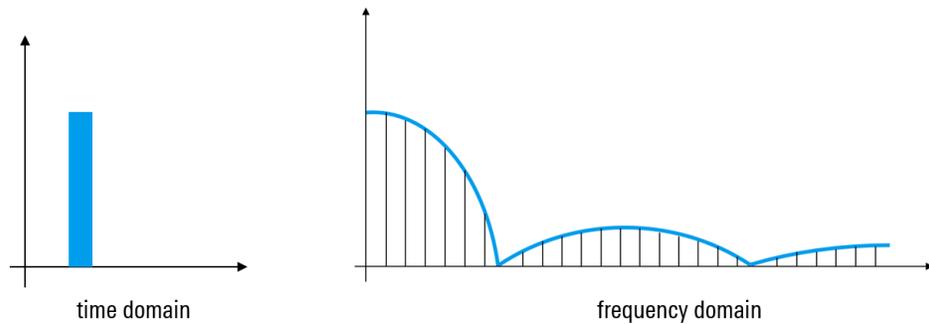
3.6 Preselection and pulsed signals

One of the tests required for CISPR compliance is testing with pulsed signals. These tests are conducted with different pulse repetition frequencies, or PRFs. [Figure 14]

$$T = \frac{1}{PRF}$$
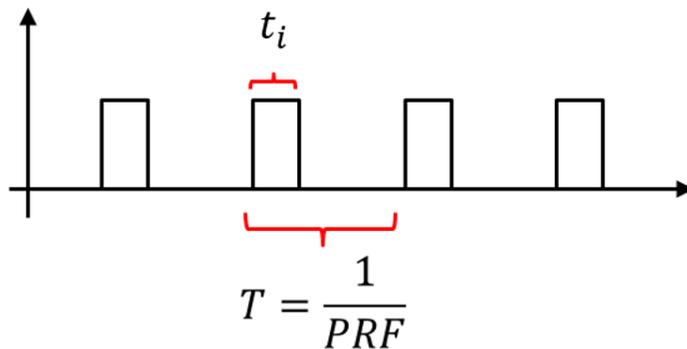
**Figure 14 - Pulsed signals and pulse repetition frequency (PRF)**

The measurement apparatus must be able to accurately measure these pulses using a quasipeak detector. This places non-trivial requirements on the instrument with regards to sensitivity, dynamic range, and noise floor. Furthermore, as the pulse repetition frequency decreases, accurate measurements become increasingly difficult – so difficult, in fact, that spectrum analyzers without preselection cannot normally measure low PRF signals with sufficient accuracy – the measured values are usually too high.

Now, let us look at how preselection can help in this case. A short, pulsed signal in the time domain corresponds to a very wide signal in the frequency domain. [Figure 15]


time domain   frequency domain

Figure 15 - Pulsed signal in time and freuqency domains

Enabling preselection "filters out" large frequency-domain components of the pulsed signal, resulting in a flattening or "smearing" of the pulse shape. [Figure 16]

time domain   frequency domain
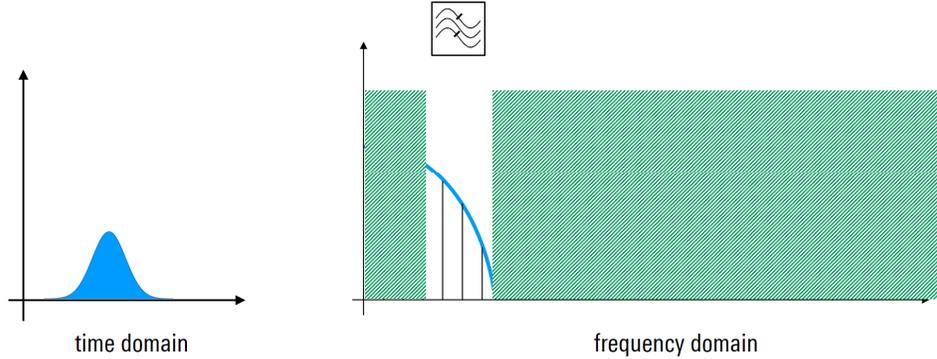
Figure 16 - Preselected pulse in the time and frequency domains

Recall that high instantaneous input voltages can overload our instrument's input – something we would like to avoid. By using a preselector to decrease the bandwidth of the signal at the mixer input, the resulting pulse takes on different shapes with lower peak voltages. The smaller the bandwidth, the lower the pulse voltage. We can quantify this mathematically by saying that the ratio of the peak pulse voltages equals the ratio of pulse to preselector bandwidth. [Figure 17]

voltage

$$\frac{E_{1\,peak}}{E_{2\,peak}} = \frac{BW_{pulse}}{BW_{preselector}}$$

Decreasing bandwidth
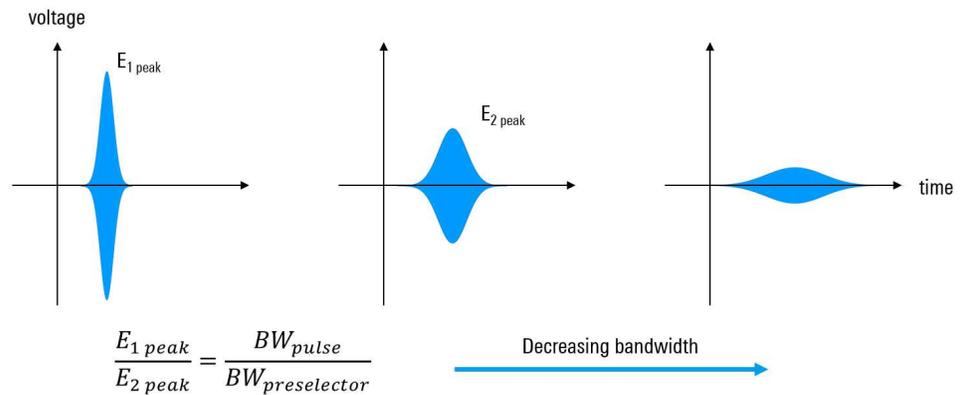
Figure 17 - Effect of preselector bandwidth on pulsed signal shape

Using preselection maintains a constant spectral density and ensures that our instrument is CISPR-compliant when measuring signals with low pulse repetition frequencies.

4 Summary

Failure to protect the mixer in a spectrum-measuring instrument can easily lead to inaccurate measurement results in two main ways: the first is overload or compression of the mixer due one or more to high power signals and the second is the creation of spurious mixing products. Both of these can, and frequently are, caused by signals that are outside of our span or current measurement range. The most effective solution to this problem is **preselection**, which is typically implemented as a switchable filter bank. Proper implementation of preselection reduces both the number and level of undesired mixer inputs, which in turn reduces overload and spurious mixing products. Preselection is essential for almost all types of EMI testing. Aside from the obvious advantage of using preselection to measure unknown and uncontrolled signals, preselection is also required by the CISPR 16-1 group of standards, and this is particularly true when making accurate and compliant measurements of pulsed signals with a low pulse repetition frequency.

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