Using external filters to maintain measurement sensitivity in highly dynamic measurement environments

Summary

It is often necessary to measure weak radio signals in the presence of strong radio signals. Analysis of weak radio signals requires high measurement sensitivity, but this requirement rapidly leads to overmodulation of modern measuring receivers and signal analyzers when measuring strong signals. For this reason, this Technical Note explains how to recognize and eliminate in-band and out-of-band interference. Overmodulation effects in the form of harmonics and 2nd order intermodulation products play a particularly important part in this. This Technical Note only briefly mentions odd-order intermodulation products (3rd, 5th etc.).

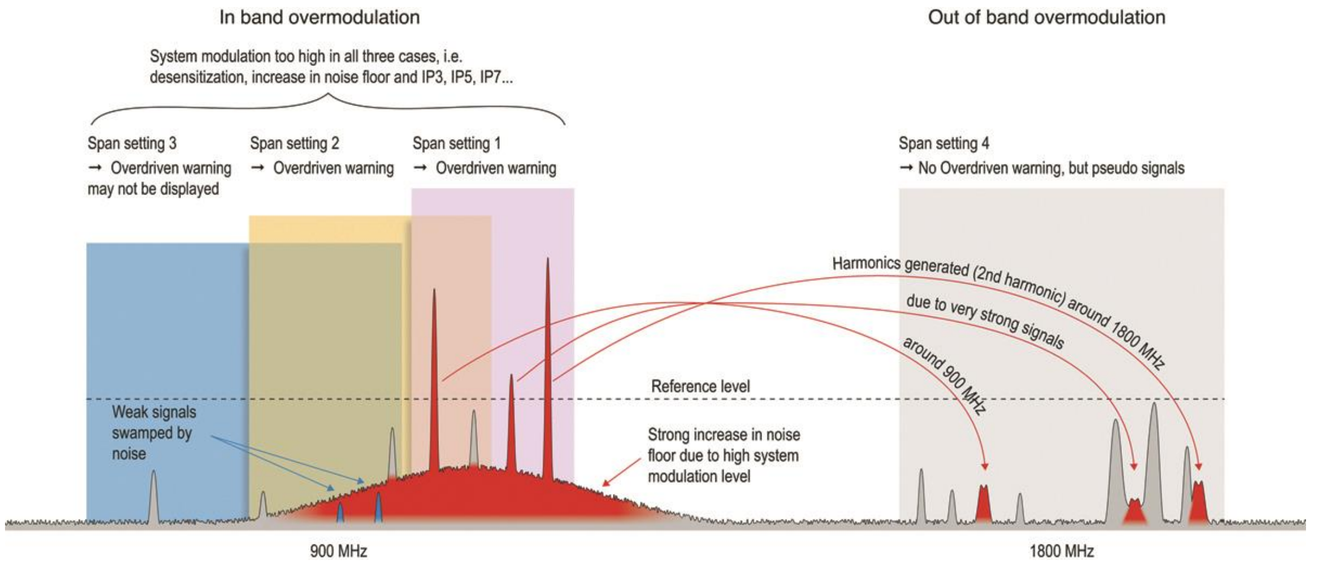

Figure 1: Simplified diagram showing the effects of high system drive levels in modern analyzers

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1 Introduction and problem

Generally, high sensitivity is desirable when analyzing radio signals: The higher the sensitivity, the lower the displayed noise floor – meaning that even weak signals can rise above it. The sensitivity of spectrum analyzers can be increased by reducing the bandwidth (RBW), the input attenuation or the reference level (RL) and by activating the preamplifier. The problem with this is that it usually prohibits capture of strong signals because they would overmodulate the analyzer. You can, of course, raise the reference level and deactivate the preamplifier in such situations, but this will raise the noise floor again.

This conflict leads to an important question: How should a receiver system be configured, and what steps should be taken if weak radio signals are to be measured where strong radio signals are present? This is referred to as a highly dynamic measurement environment in this discussion. In such an environment, the IDA, just like most of the other devices comparable with it, will be overmodulated by in band and out of band overmodulation. This is principally because of the way a super-heterodyne receiver works, being based on typical RF components such as mixers and (IF) amplifiers with limited dynamic ranges.

In band overmodulation is usually signaled on the IDA by the Overdriven warning, but out of band overmodulation is initially only be identified by the user. The two following sections explain this in detail.

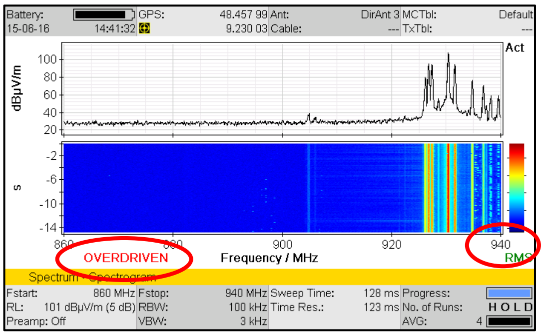

Figure 2. Overmodulated IDA: Reference level visibly exceeded within set span; Overdriven warning displayed (compare figure 1, span setting 1)

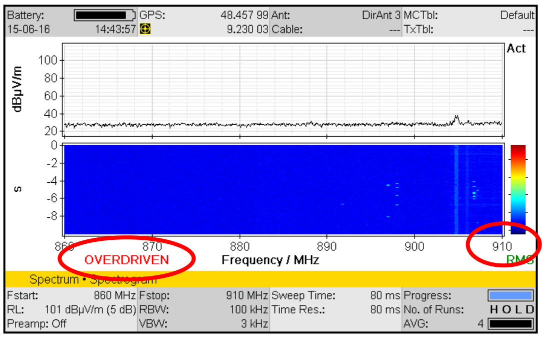

Figure 3. IDA still overmodulated as reference level exceeded outside the set span; Overdriven warning displayed (compare figure 1, span setting 2)

2 Recognizing in band overmodulation

In band overmodulation, i.e. overmodulation that occurs within or close to the specified span, is usually signaled by the Overdriven warning on the IDA. It occurs when the level of a signal exceeds the reference level (see figure 2). In band overmodulation can also be caused by signals that are outside the displayed span but are close to it (see figures 3 and 4, note F_{stop} compared to figure 2).

This happens because of the wide band signal processing used by the IDA. The reference level on the IDA must be increased and the preamplifier deactivated to avoid in band overmodulation. This of course increases the noise floor, but reduces overmodulation artifacts. Changing the direction of the antenna or moving the measurement location can also eliminate in band overmodulation.

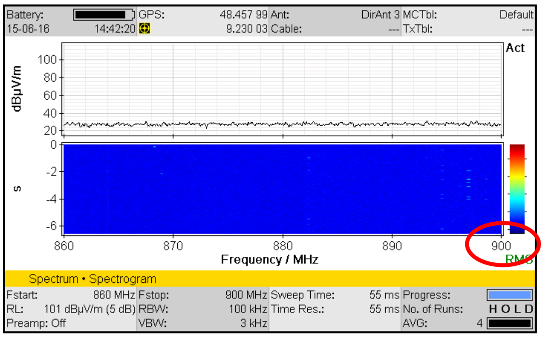

Figure 4. No Overdriven warning on IDA with the same signal as in figures 2 and 3 but different span setting; however overmodulation artifacts may be visible (increased noise floor, IP3, IP5, etc.) (compare figure 1, span setting 3)

3 Recognizing out of band overmodulation

Out of band overmodulation can occur in spectrum analyzers as well as in band overmodulation. The RF signal causing the overmodulation and the displayed span may be widely separated. Out of band overmodulation causes harmonics, i.e. whole number multiples of the frequency, which appear to be real signals. This is a completely different situation to that causing third order intermodulation products.

This section and figures 5 through 7, which describe a real scenario, illustrate the problem. Briefly stated, a strong GSM 900 signal here causes a pseudo signal at 1800 MHz in the IDA. The pseudo signal is the second harmonic, and this doubling of the frequency also doubles the bandwidth of the modulated GSM 900 signal. The Overdriven warning does not appear at first, as only the 1800 MHz frequency range is being observed.

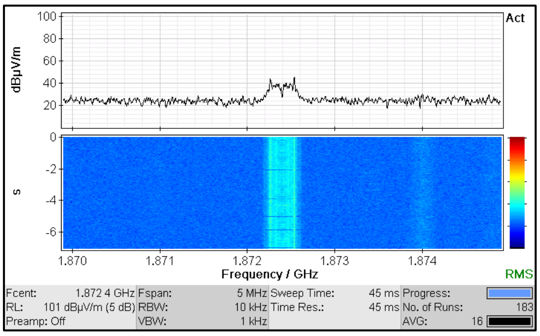

Figure 5. GSM-like signal at 1872.4 MHz with twice the bandwidth (400 kHz) compared with GSM (200 kHz) (compare figure 1, span setting 4)

Figure 5 shows a signal at 1872.4 MHz in spectrum and spectrogram views. Initially, this signal may not appear unusual, as it is in the GSM 1800 downlink frequency range (ITU Region 1: 1805 MHz - 1880 MHz) and behaves like a typical GSM signal at first glance. Only on closer examination is the over-large bandwidth of this presumed GSM signal revealed. Real GSM signals have a bandwidth of 200 kHz, yet this signal has a bandwidth of around 400 kHz as seen in figure 5. Despite this difference, the signal is seen to be very similar to a real GSM signal or broadcast channel. This is borne out by the signal characteristic in the time domain (figure 6). The GSM timeslots, around 577 µs long, can be seen; these show larger or smaller level variations depending on the modulation used (GMSK for GSM, 8-PSK for EDGE). You still do not know at this point what this signal actually is.

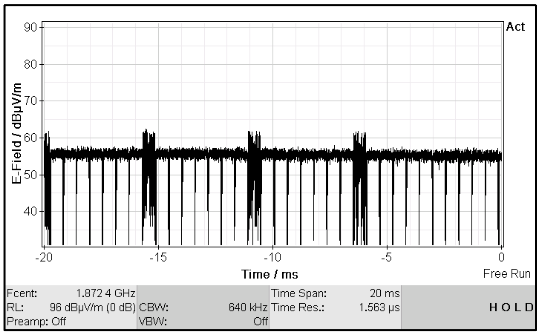

Figure 6. GSM-like pseudo signal shows a time characteristic typical of GSM

The answer is found when you check the GSM 900 frequency range, as shown in figure 7. This shows a very strong GSM 900 broadcast channel at 936.2 MHz. This signal actually causes overmodulation, and is exactly half the frequency of the pseudo signal already mentioned (1872.4 MHz), the origin of which now becomes clear. It is a harmonic generated in the IDA by the strong emission at 936.2 MHz. Confirmation of this problem is also given by a precise investigation of the signal bandwidth in comparison to a real GSM 900 signal. Figure 8 (top) on the next page first shows the frequency deviation of the real GSM 900 signal. This is around 67 kHz and can be recognized from the small peaks in the spectrum. In contrast, the frequency deviation of the pseudo signal, also recognized from its peaks, is about 134 kHz as seen in figure 8 (bottom).

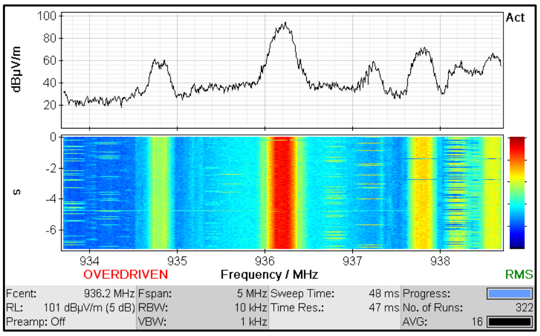

Figure 7. Signal observation at 936.2 MHz (half of 1872.4 MHz) shows a strong GSM broadcast channel that causes overmodulation

The measurement using the delta markers confirms that the suspected interference signal is a harmonic. The doubling of the frequency means this signal also has double the bandwidth. This fact is not always easy to spot without the markers because strong GSM 900 signals emerge much more strongly from the noise than their relatively weak harmonics.

You can also use the IDA Scope mode as well as the marker function to identify pseudo signals caused by overmodulation or high signal levels. Figure 9 shows how you can use the CBW to distinguish real GSM signals from pseudo GSM signals. The top left image illustrates that a CBW of 125 kHz is not sufficient to clearly display the 577 µs long GSM timeslots of the GSM 900 signal. However, a CBW of 250 kHz is enough (top right). The particular type of modulation can then also be recognized clearly.
If the 250 kHz CBW is applied to the pseudo signal though, the individual timeslots can no longer be recognized (bottom left). These only become properly visible when the CBW is increased to 400 kHz, which is the actual bandwidth of the pseudo signal (figure 9 bottom right).

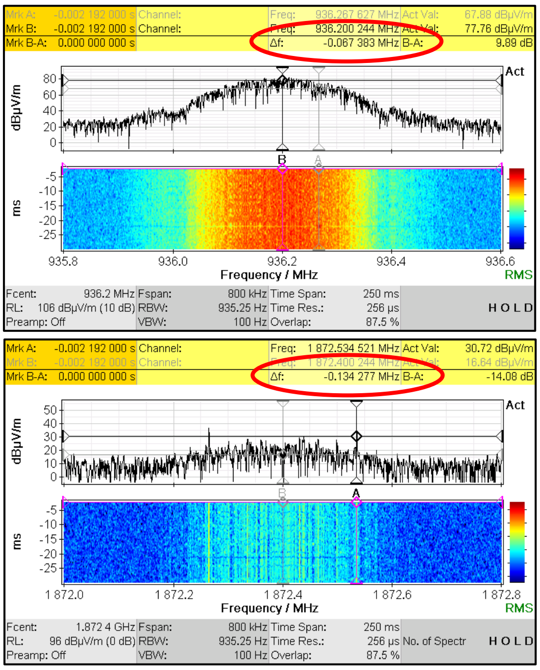

Figure 8. Distinguishing between a real GSM signal and a pseudo signal by measuring the frequency deviation

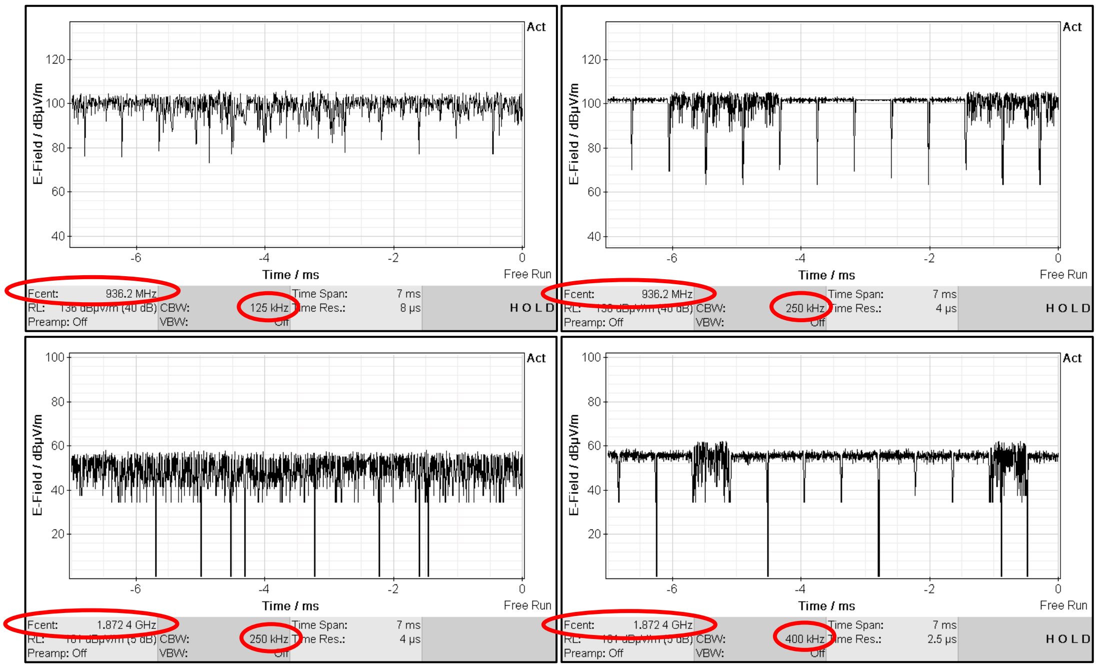

Figure 9. Distinguishing between a real GSM 900 signal and a pseudo signal (harmonic) by using different CBWs in IDA Scope mode

So far, pseudo signals have occurred in the IDA when their fundamental signals generated an Overdriven warning. However, such pseudo signals can also occur when their fundamental signals occur outside the Overdriven warning monitoring range, due to non-linearities outside the monitoring range. This is the case illustrated in figure 10. Only the resulting pseudo signal is displayed here, and its level is checked to see how it reacts to changes in the reference level. The measured level of a real signal must not change as a result of changes in the reference level! In contrast, harmonics – and therefore the pseudo signal in figure 10 – will change level because they are generated internally by active components of the analyzer. The level of the supposed GSM signal is 52 dBµV/m in figure 10 (top). Increasing the reference level by 8 dB (figure 10, bottom) results in a signal level of 44 dBµV/m, indicating a 2nd order overmodulation product. To summarize: Harmonics in the IDA can be recognized by measuring the signal bandwidth / frequency deviation, by using different CBWs in Scope mode, and by changing the reference level. They can also occur when there is no Overdriven warning displayed. It is therefore often a good idea to check neighboring and modulating frequency ranges first before making measurements using the span of interest. The preamplifier should initially be deactivated when making these overview measurements.

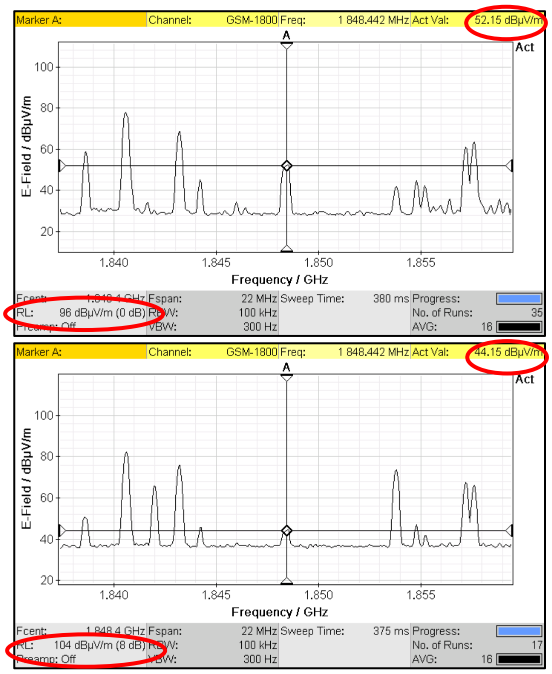

Figure 10. Recognizing harmonics or pseudo signals from level changes when the reference level is changed

4 Preventive measures and their pros and cons

It is possible to identify and avoid in band and out of band overmodulation using the information in sections 2 and 3 above, but these sections only give a general idea of how to cope in highly dynamic measurement environments. The aim in any highly dynamic environment is to be able to measure weak RF signals without sacrificing measurement sensitivity. One way of meeting this requirement is to move the actual measurement point or to alter the direction of the measuring antenna. Figure 11 illustrates the suggestion of moving the measurement point out of the main lobe of a base station and putting it in the RF “shadow” of a row of buildings. From this new position, aligning the antenna towards the row of buildings at the back gives additional protection from overmodulation. Of course, such measures are not always possible or even practical, particularly when searching for interference sources, which is why external filters are often used. These suppress strong RF signals in frequency ranges outside the range of interest, allowing the weak signals at the frequencies of interest to still be captured with high measurement sensitivity. The following section looks at this measure in more detail.

Figure 11. Changing the measurement point to avoid areas with strong RF signals

5 External filters in detail

External filters that can be attached and detached from the analyzer input allow the input sensitivity to be maintained on a frequency band selective basis. Such filters can be inserted between the antenna cable and the basic unit of the IDA. The filter specification will depend on the measurement required. Normally, the frequency range of interest is observed, and the frequencies at which strong or overmodulating signals could occur are taken into account. Modern mobile communications systems are predestined for this kind of consideration. Realistically, sensitive measurements are required for the uplink, while the downlink radiated from the base station would lead to overmodulation. The filters should therefore be specified such that the downlink signals are attenuated and the uplink signals can be measured without losses. Out of band overmodulation caused by modulating frequency bands (typically half the frequency) should be taken into account as well as the possible in band overmodulation (e.g. caused by strong RF signals in adjacent channels).

Table 1 lists the up- and downlink frequency ranges for common mobile communications systems as a guide. It is clear from this that the up- and downlink are often close together. The filter characteristic must therefore have very steep edges. This frequently results in an increase in the filter size. Though, the dimensions of an external filter are always a compromise between the desired frequency range, filter steepness, and filter size / weight.

	Uplink [MHz]	Downlink [MHz]
GSM 900	880 - 915	925 - 960
GSM 1800	1.710 - 1.785	1.805 - 1.880
UMTS	1.920 - 1.980	2.110 - 2.170
LTE 800	832 - 862	791 - 821
LTE 1800	1.710 - 1.730	1.805 - 1.825
	1.770 - 1.780	1.865 - 1.875
LTE 2600	2.500 - 2.570	2.570 - 2.690

Table 1. Uplink and downlink frequency ranges for modern mobile telecommunications systems in Germany (in MHz; as of 9 February 2016)

Figure 12 shows two example measurements without (left) and with (right) bandpass filters for the range 1710 – 1785 MHz. The images top and bottom left show obvious overmodulation and harmonics, but these are no longer present in the right hand images. Clearly, filters can be used to avoid both in band and out of band overmodulation.

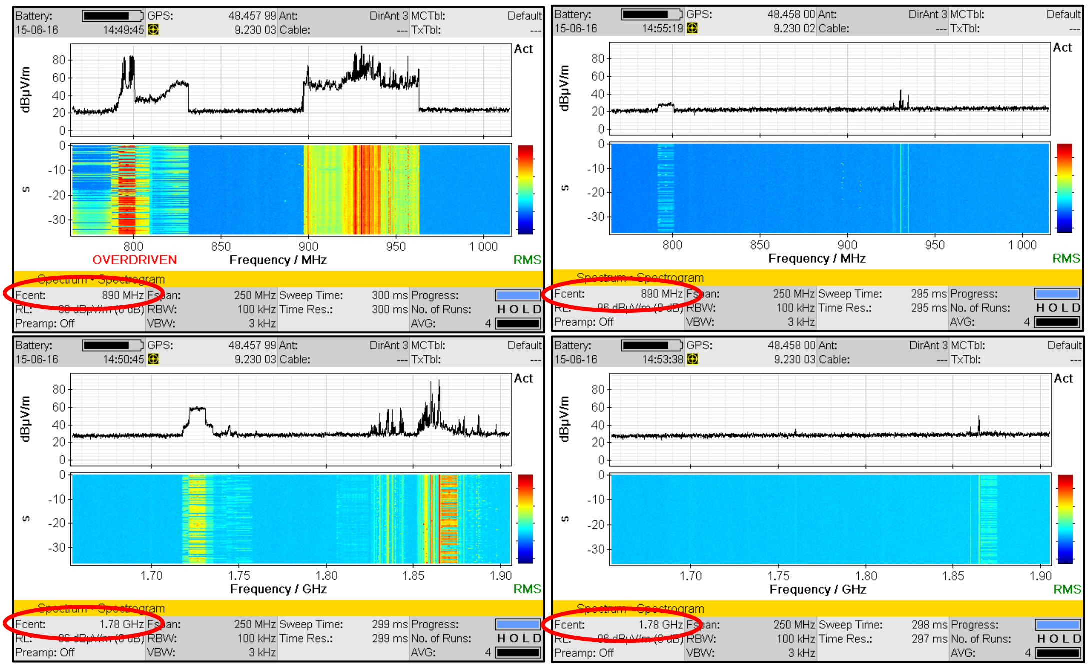

Figure 12. Uplink and downlink of various mobile telecom systems without (left) and with (right) ext. filters

6 Advantages of external filters compared to preselectors

A useful approach is to integrate preselection filters (preselectors) into the design of a spectrum analyzer. Ideally, these would only allow the frequency range of interest to pass through. Signals in other ranges that could overmodulate the system are suppressed. High quality preselectors (e.g. frequency tracking YIG filters) are often found in EMC measuring receivers. Effective tracking filters for portable measuring instruments, i.e. small size and limited power consumption but capable of high scan speeds cannot be produced using current technology. Sub octave filters represent an alternative, but the size limitation means that the attenuation characteristic is still limited. It is therefore advisable to use external filters to maintain the maximum dynamic range.

Figure 15. IDA with external filter (shown here without Velcro fastening)

7 Conclusions

The following important points need to be kept in mind when making measurements in highly dynamic environments:

- Before even starting the measurement, be aware of the measurement environment and find out what RF signals (and field strengths) are to be expected and what the measurement settings on the IDA need to be in order to detect a particular signal. The choice of the first measurement point is very important here, giving three options:
  1) Direct connection of the IDA to e.g. the interference affected antenna of a base station
     Advantage: Direct assumption of antenna orientation and gain. Disadvantage: Strong RF signals possible.
  2) Use of the complete IDA system very close to the base station
     Advantage: Similar measurement compared to the affected antenna. Disadvantage: Strong RF signals possible.
  3) Use of the complete IDA system at a certain distance from the base station
     Advantage: Avoids strong RF signals. Disadvantage: Reduced probability of detection possible.

  Wherever possible, the measurement point locations and the antenna alignment should be chosen so as to significantly attenuate strong RF signals and to avoid provoking both in band and out of band overmodulation.
- The preamplifier should always be used with caution and only after an overview measurement has been made.
- Reducing the RBW further increases sensitivity when the reference level setting has reached its limits.
- High sensitivity in the desired frequency range despite the presence of strong RF signals is possible using specifically designed external filters. The filter characteristic must be recorded in the IDA to ensure the field strength display is correct.
- Some ways to recognize overmodulation: Overdriven warning, overview measurement with large span, comparison of signal level and reference level, bandwidth measurement using the markers, characteristic vs. time with various CBWs.

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