Test & Compliance for mmWave Technology

Demystifying EMC 2020, Silverstone, February 10th

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Empowering Trust™

Agenda

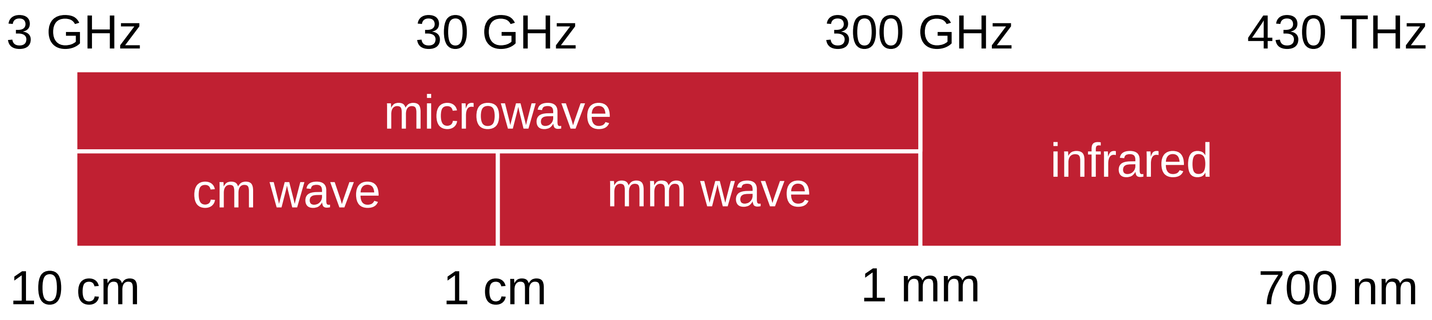
I. What & Why?
II. Technologies & Frequency Bands
III. Applicable Standards & Procedures
IV. Limitations of Traditional Test Equipment & Test Methods
V. Overcoming Limitations

What & Why?

What is mm Wave?

Millimetre Wave (also known as EHF - extremely high frequency)

- Refers to electromagnetic waves with a wavelength between 10 mm and 1 mm.
- Translates to frequencies between 30 GHz and 300 GHz
- Sits at the top of the microwave EM spectrum between cmWave (SHF) and Infrared.



Why is it being used?

- As more and more devices are incorporating wireless communication, the sub 6 GHz spectrum is becoming increasingly crowded.
- Our insatiable need for faster data is pushing wireless technology towards the Shannon limit:

$$C = B\log_2\left(1 + \frac{S}{N}\right)$$

- Available bandwidth and S/N are limited, which in turn limits the channel capacity.
- mmWave frequencies offer a large amount of uncongested spectrum, allowing for much wider channel bandwidths and higher data rates.
- This gain comes with compromise – mmwaves are highly directional, requiring line of sight propagation, and suffer from much higher free space attenuation than lower frequencies.

Technologies & Frequency Bands

Technologies & Frequency Bands

cmWave	mmWave					
26-28 GHz	39 GHz	57-71 GHz	71-76 GHz	76-81 GHz	81-86 GHz	>86 GHz
5G NR FR2		802.11ad/ay WLAN	Backhaul	Automotive Radar		
	5G?		5G?		5G?	

Technologies & Frequency Bands

5G NR FR2	802.11ad/ay WLAN	Backhaul	Automotive Radar
• Massive MIMO • Beamforming / Beam Steering	• Beamforming / Beam Steering • ≤2 / ≤8 GHz Channel Bandwidth	• ≤2 GHz Channel Bandwidth	• ≤4 GHz Chirp Bandwidth

These features all present their own measurement challenges, which will be discussed later…

Standards & Test Procedures

Applicable Test Standards

5G NR FR2	ETSI EN 301 908-24 (BS) / ETSI EN 301 908-25 (UE)*
	FCC 47CFR Part 30
	ISED Canada - TBD
802.11ad/ay WLAN	ETSI EN 302 567
	FCC 47CFR Part 15.255
	ISED Canada RSS-210 Annex J
Backhaul	ETSI EN 302 217-2
	FCC 47CFR Part 101
	ISED Canada – Various, SRSP-371.0 for 71-76/81-86 GHz**
Automotive Radar	ETSI EN 301 091 (76-77 GHz) / ETSI EN 302 264 (77-81 GHz)
	FCC 47CFR Part 95 M
	ISED Canada - RSS-251

**Early drafts v0.0.5 / v0.0.1*
***Does not follow FCC rules*

Applicable Test Procedures

5G NR FR2	ETSI TS 138 series (mirrors 3GPP 38 series)
	ANSI C63.26[1] / KDB 842590
	ISED Canada - TBD
802.11ad/ay WLAN	ETSI EN 302 567
	ANSI C63.10[1]
	ANSI C63.10[1] / ISED Canada RSS-Gen
Backhaul	ETSI EN 301 126-1
	ANSI C63.26[1,2] / FCC KDB 971168
	ANSI C63.26[1,2] / ISED Canada RSS-Gen
Automotive Radar	ETSI EN 303 396
	ANSI C63.26[1,3] / FCC KDB 653005
	ANSI C63.26[1,3] / ISED Canada RSS-Gen

(1) Update in progress, significant changes to mmWave procedures.
(2) Fixed microwave is excluded from scope of current edition, KDB 971168 provides sufficient guidance.
(3) Ground based radar is excluded from scope of current edition, KDB 653005 provides sufficient guidance.

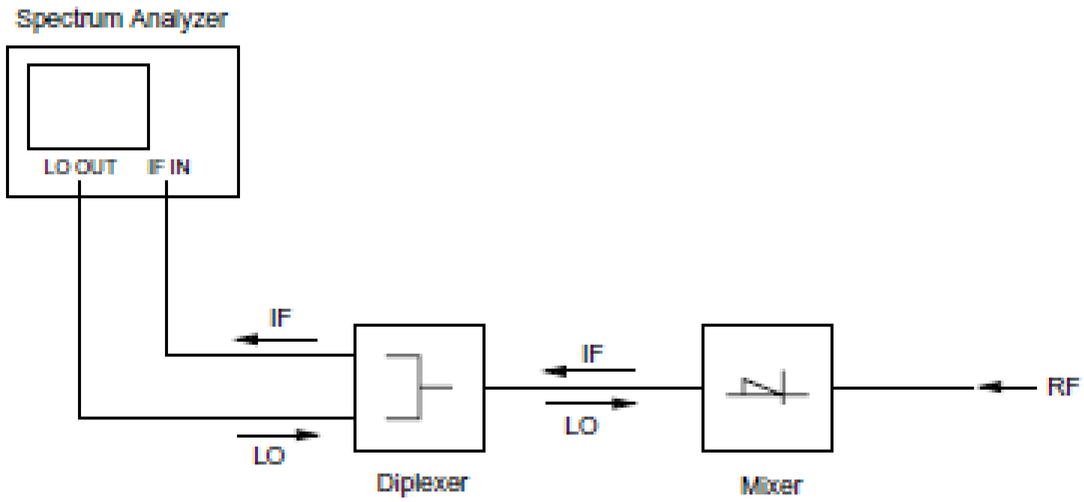
Limitations of Test Equipment & Test Methods

Harmonic Mixers

Until very recently, commercially available test receivers and spectrum analysers have been limited to an upper frequency of 50 GHz.

External harmonic mixers can be used to extend the frequency range much further into the mm wave spectrum.

A harmonic of the local oscillator (LO) generated by the receiver or analyser mixes with the incoming signal and converts it to a much lower intermediate frequency (IF) that can be measured by the receiver or analyser.



Excerpt from ETSI TS 103 052

Harmonic Mixers

Although external harmonic mixers have been the industry standard for many years, they have several drawbacks that become problematic when attempting to make compliance measurements on modern mmwave devices:

- Conversion loss –

The harmonic mixing process has an inherent loss that must be corrected for in order to reflect the actual amplitude of the input signal. The result of applying this correction is an apparent increase in the displayed noise level on the receiver or analyser, reducing the dynamic range available for measurement. Conversion loss can be 30 to 40 dB in some cases.

- Image response –

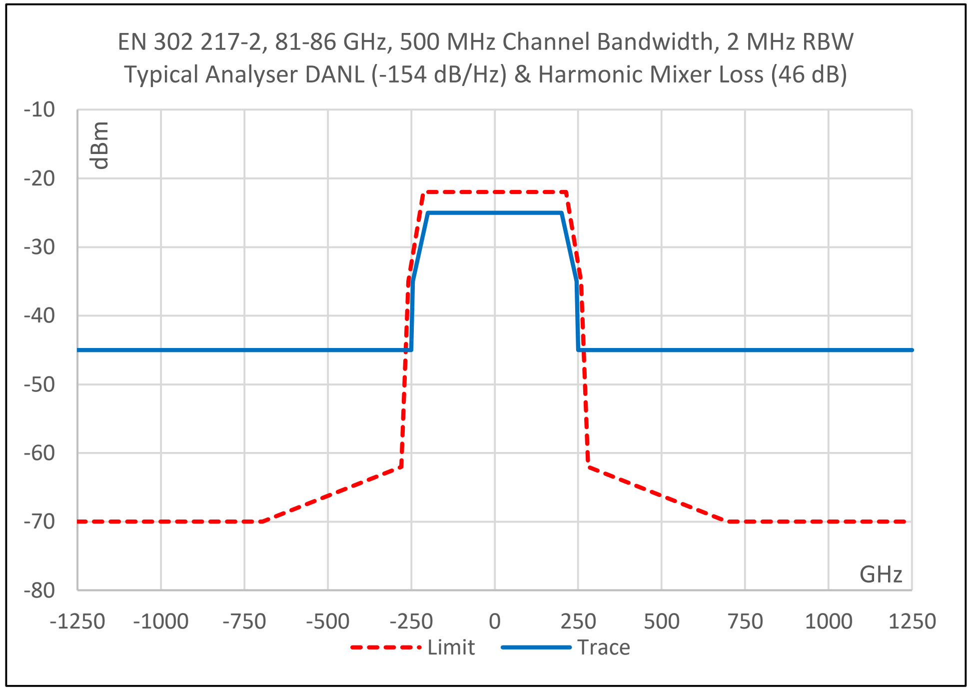
Harmonic mixing produces a pair of signals, spaced 2 x IF apart. One of these signals is the 'wanted' signal and the other is an 'image'. Many receivers or analysers employ an image suppression function, where the image can be removed by taking a second sweep with the LO harmonic frequency shifted by 2 x IF.

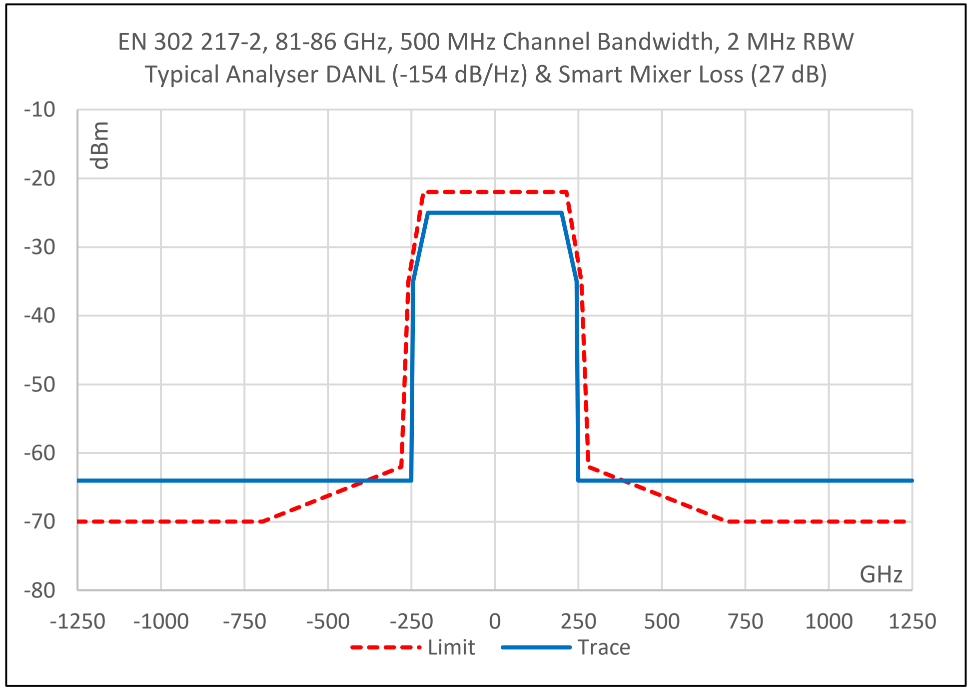
Harmonic Mixers – Conversion Loss

- Reduced dynamic range – Mask / Out of Band

The spectrum mask / out of band emissions requirements for some devices are specified as attenuation below the spectral density of the carrier.
The required attenuation is as much as 45 dB in certain cases.

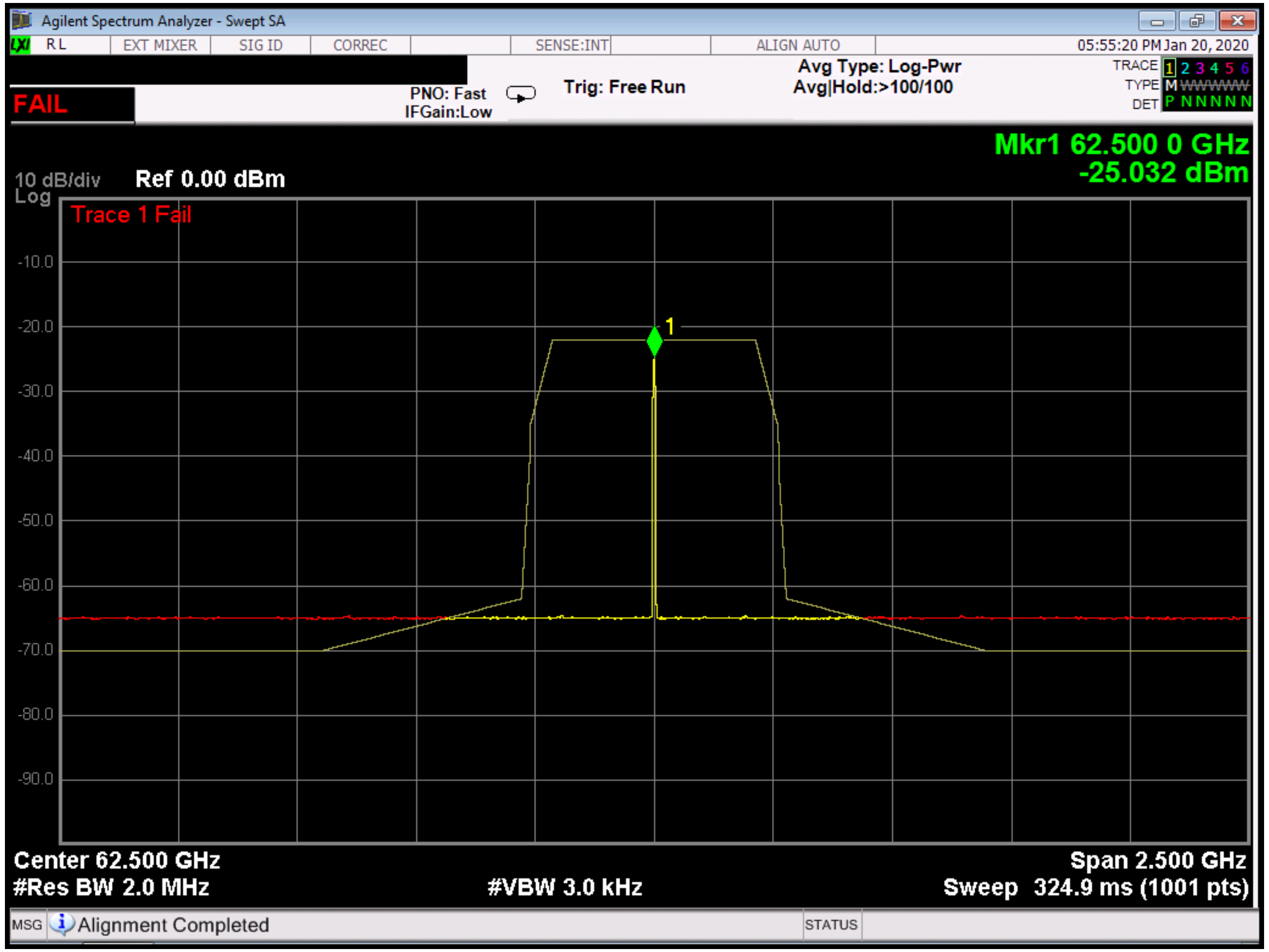
Typical spectrum analyser noise floor specifications coupled with typical mixer conversion loss figures can preclude measurement of stringent requirements such as this.





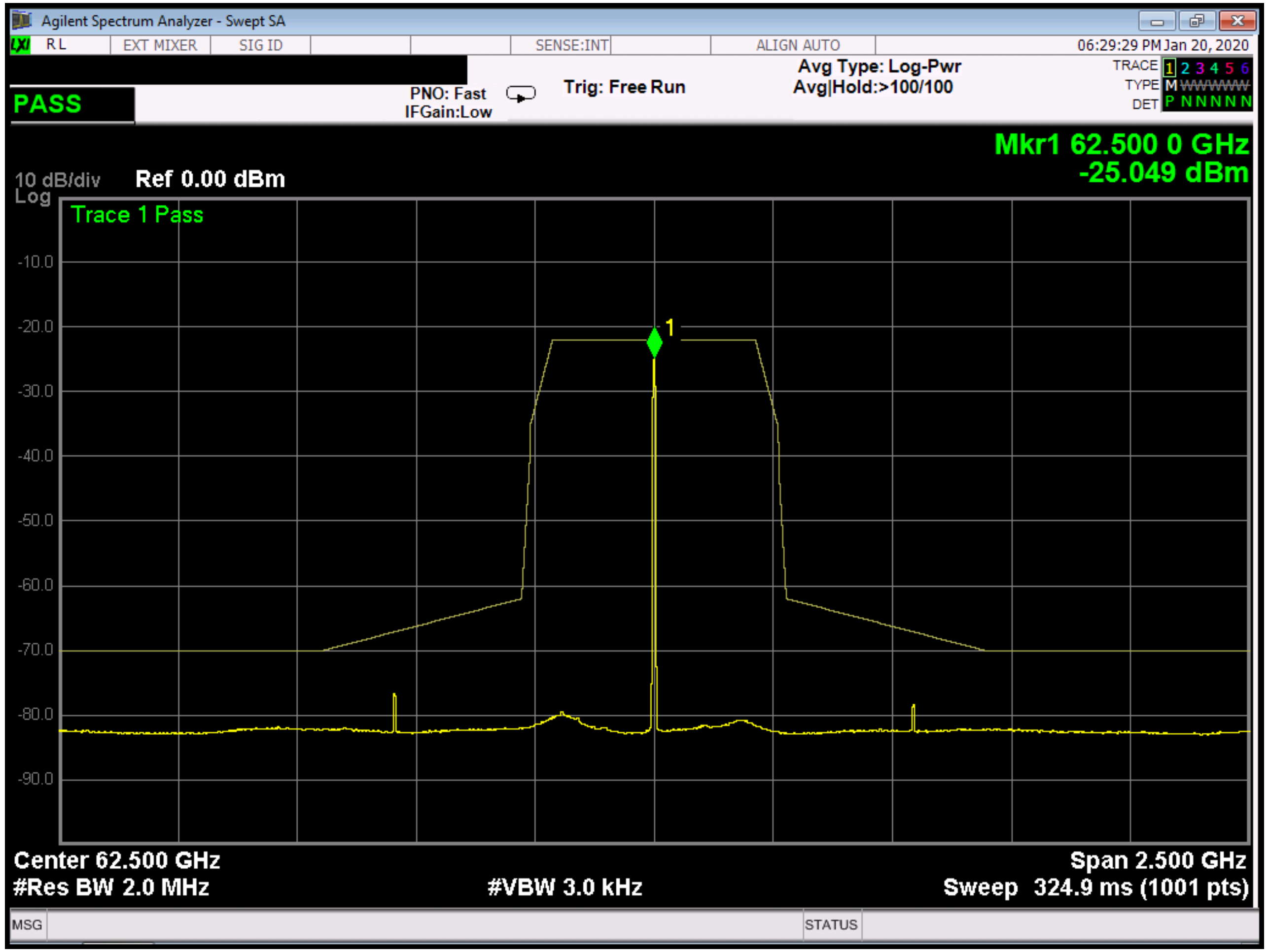
Harmonic Mixers – Conversion Loss

- Reduced dynamic range – Mask / Out of Band (Harmonic Mixer, ~35 dB Conversion Loss)



Harmonic Mixers – Conversion Loss

- Reduced dynamic range – Mask / Out of Band (Smart Mixer, ~14 dB Conversion Loss)

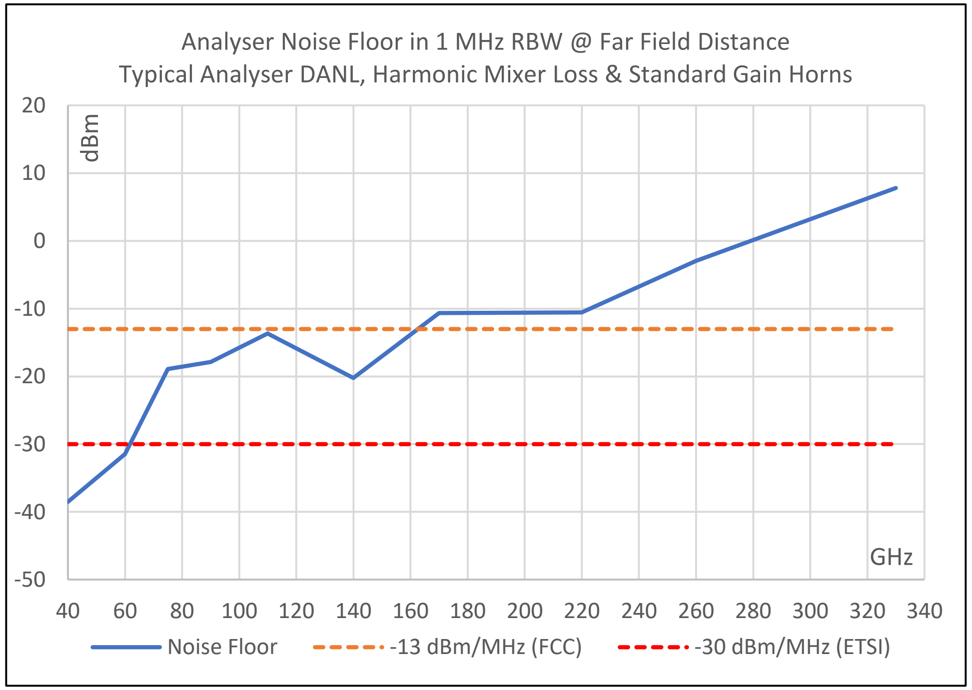


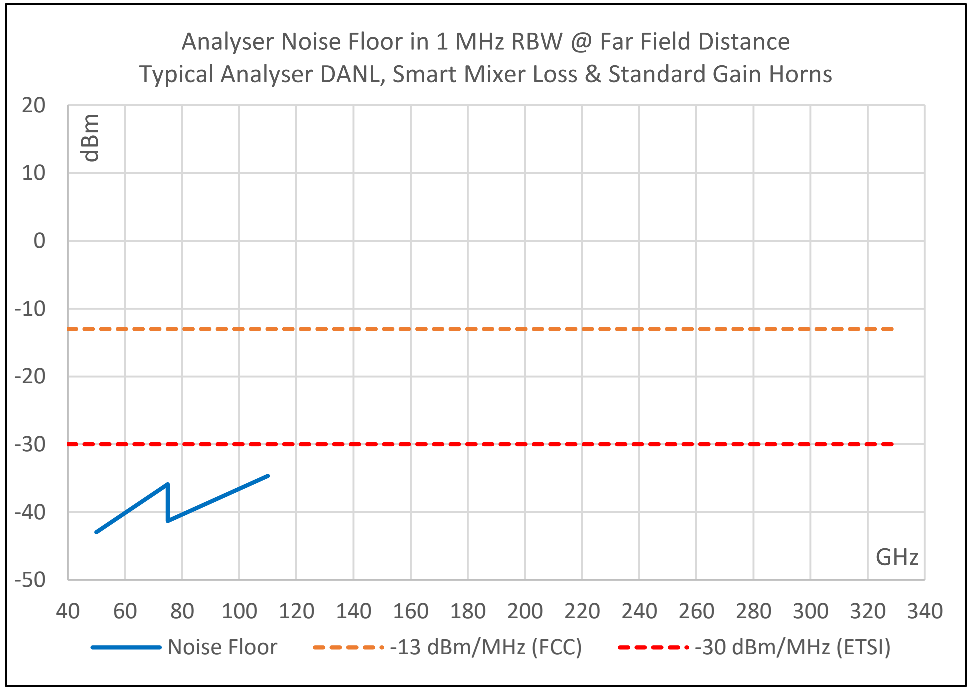
Harmonic Mixers – Conversion Loss

- Reduced dynamic range – Radiated Spurious Emissions

Along with increased free space attenuation, the far field distance also increases with frequency:
Far Field = $2D^2/\lambda$

This is offset to some extent by smaller antenna size at mm wave frequencies, however high conversion loss can still preclude measurement in the far field.





Harmonic Mixers – Conversion Loss

- Reduced dynamic range – Radiated Spurious Emissions

EN 302 567 (60 GHz WLAN) specifies a 5 m or 3 m anechoic chamber, with no further consideration given to the issue. TR 102 555 *"Technical characteristics of multiple gigabit wireless systems in the 60 GHz range, System Reference Document"* states the antenna aperture size is typically < 10 cm. To maintain a 3 m measurement distance at 66 GHz, the maximum aperture size is 8.2 cm.

EN 303 396 (60 GHz SRD, 76-81 GHz Radar) specifies the use of an anechoic chamber for far field measurement, but also notes that measurement in the far field at mm wave frequency can become impractical, allowing shorter measurement distances at the expense of increased measurement uncertainty.

ANSI C63.10 Section 9 *"Procedures for testing millimeter-wave systems"* states a preference for far field measurements, but also notes that this is not always practical, allowing the use of a 20 dB/decade distance attenuation factor which '*has been determined to be generally representative and is the default specified by the regulatory authorities*'.

Harmonic Mixers – Conversion Loss

- Reduced dynamic range – Radiated Spurious Emissions
- ETSI –

  No changes in current drafts.
- FCC –

  ANSI update activities include:

  C63.10
  (c) review and change as necessary subclause 6.6 for measurements above 40 GHz;
  (h) review and change as necessary the mm-wave test procedures;

  C63.26
  6. Procedures for millimeter wave (mmW) measurements (above 26 GHz);

  Measurement in the near field will no longer be permitted, given that measurement equipment with sufficient sensitivity is now commercially available, i.e. downconverters.

Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal ID function of a spectrum analyser takes alternating sweeps, with every other sweep using the LO harmonic shifted by 2 x IF. The lowest amplitude of 2 alternate sweeps is displayed as a composite sweep, suppressing the image.

No Signal ID:

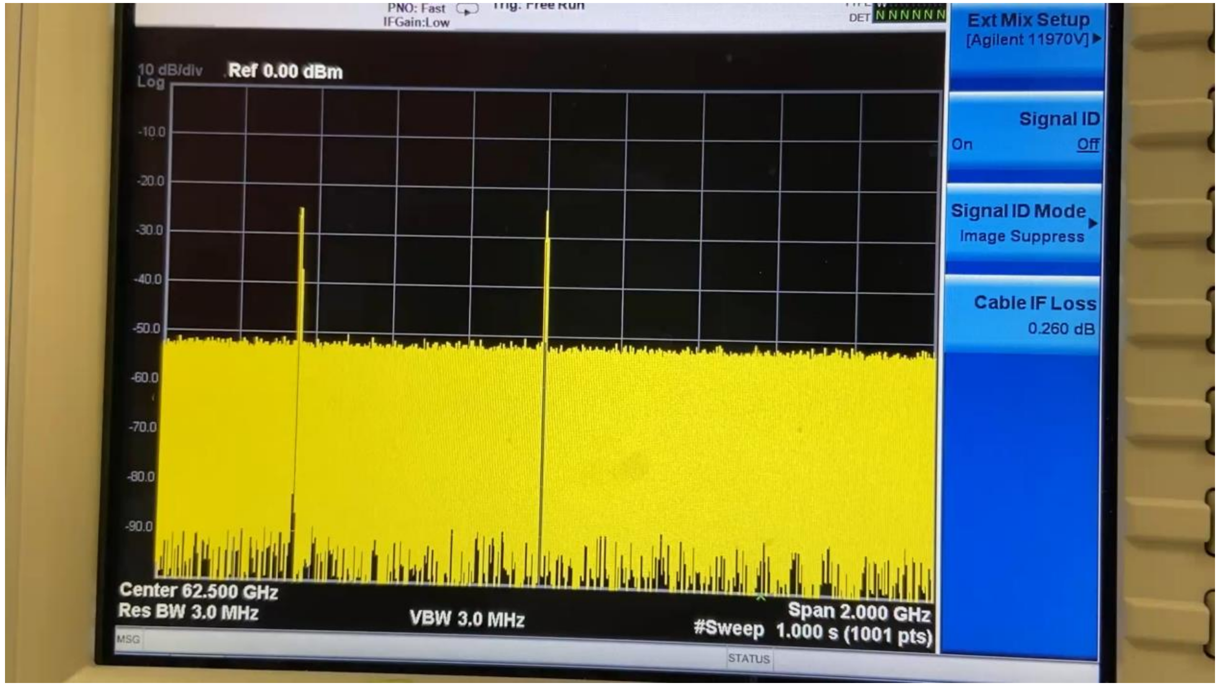


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Image Shift:

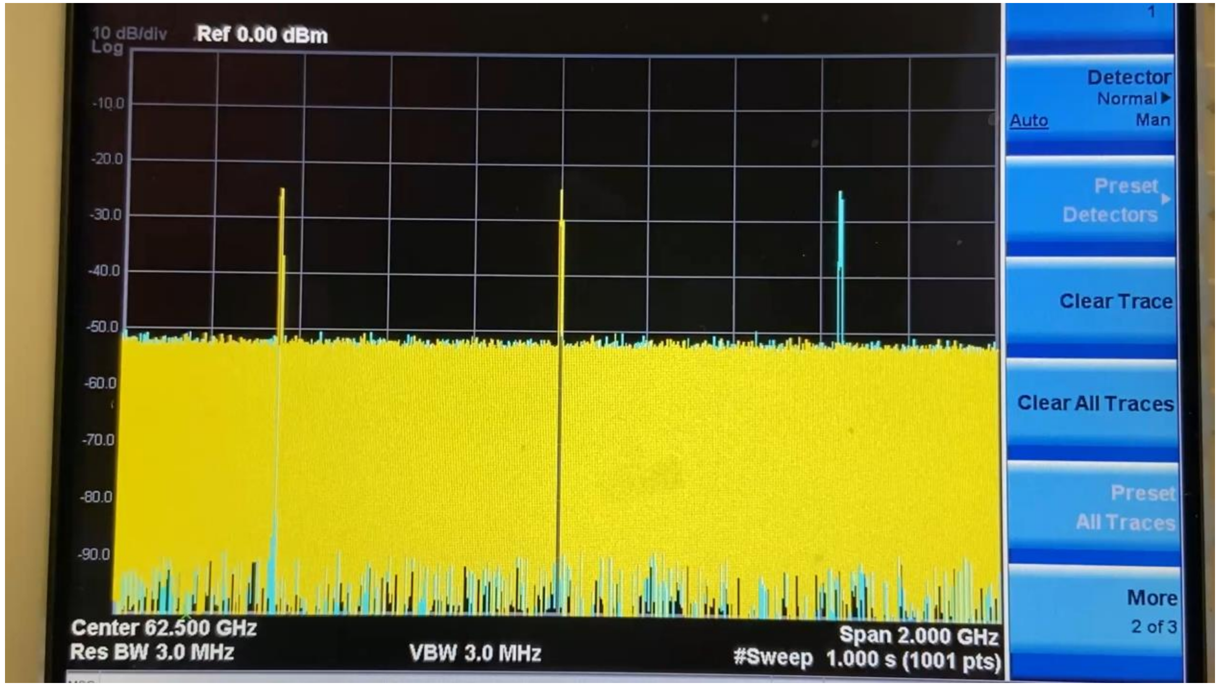

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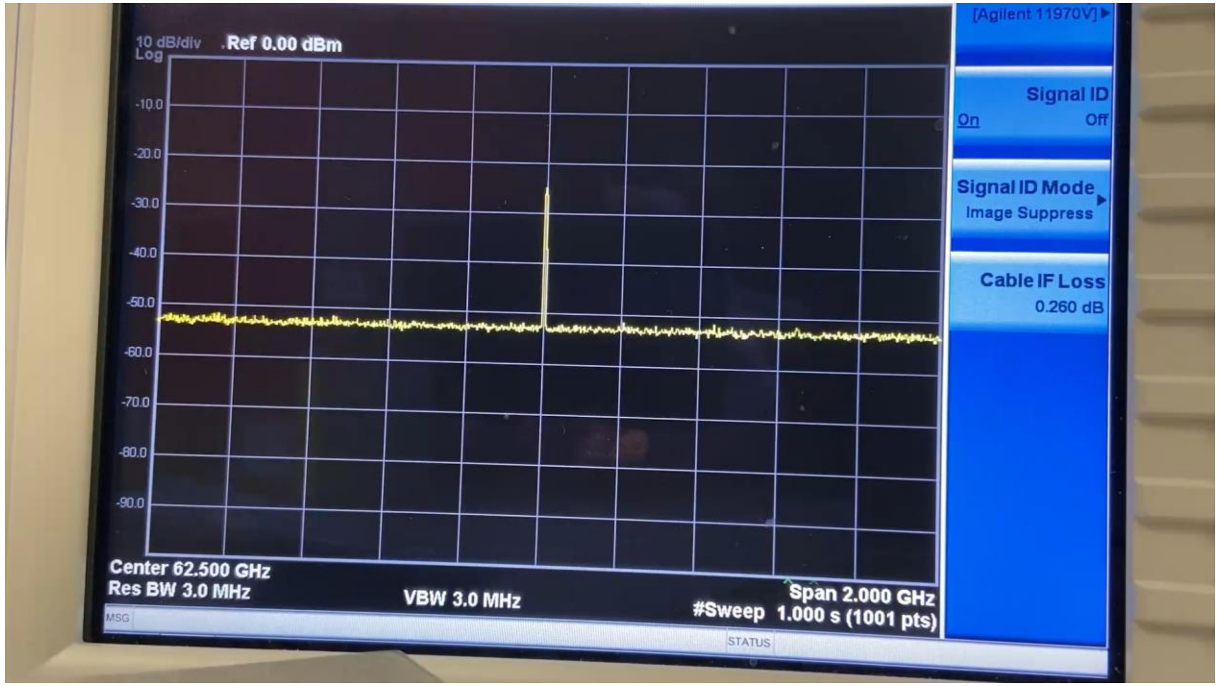
Image Suppress:



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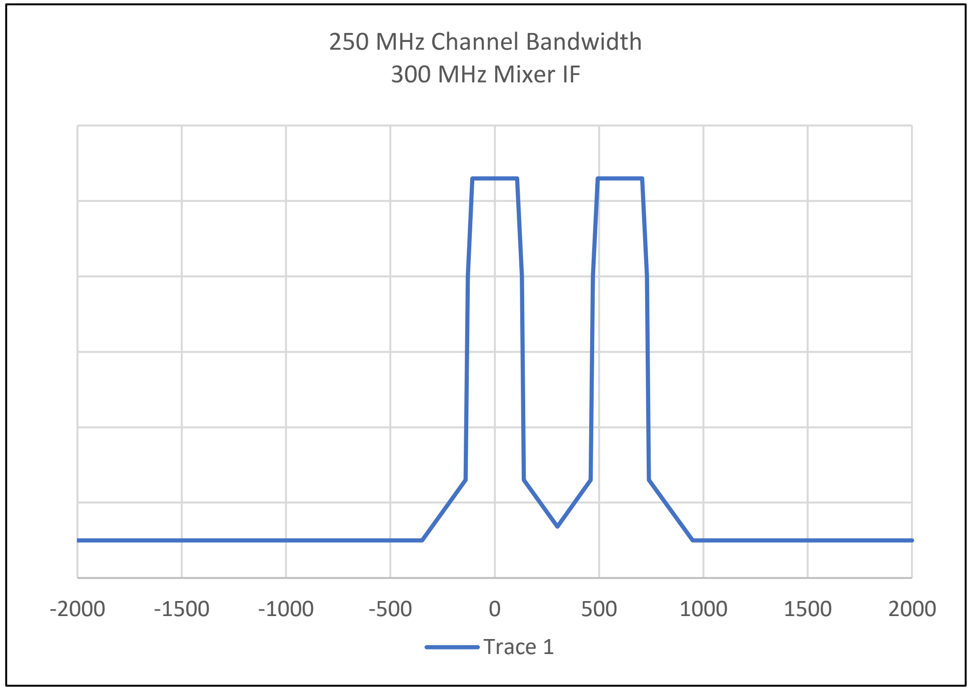
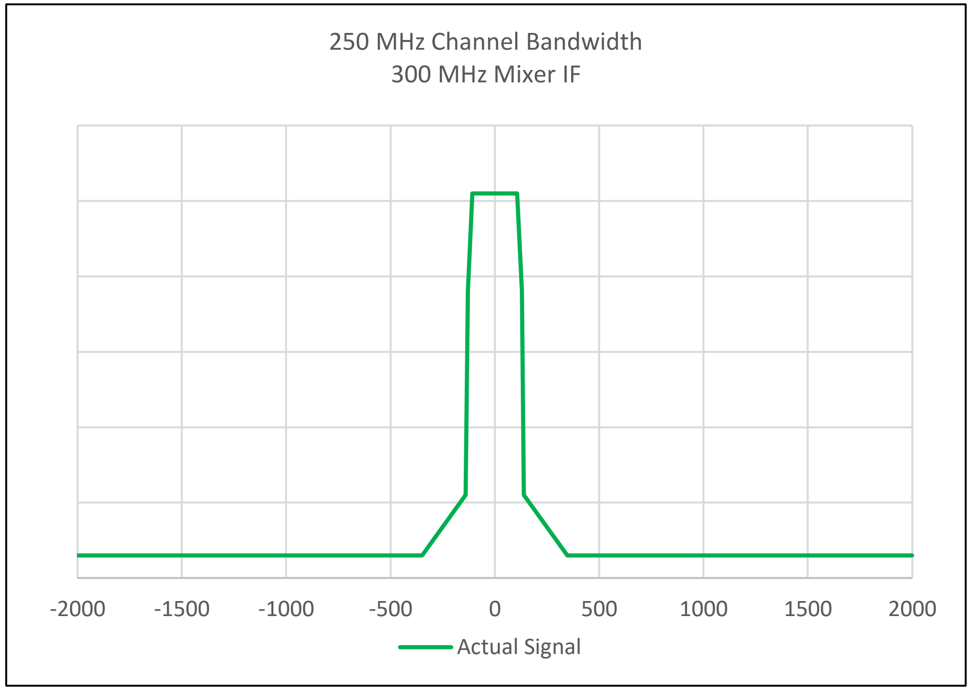
- Signal ID (Image Suppression)

The signal ID function of a spectrum analyser takes alternating sweeps, with every other sweep using the LO harmonic shifted by 2 x IF. The lowest amplitude of 2 alternate sweeps is displayed as a composite sweep, suppressing the image.

This works well for narrower channel bandwidths: ‘wanted’ and ‘image’ signals can be distinguished.





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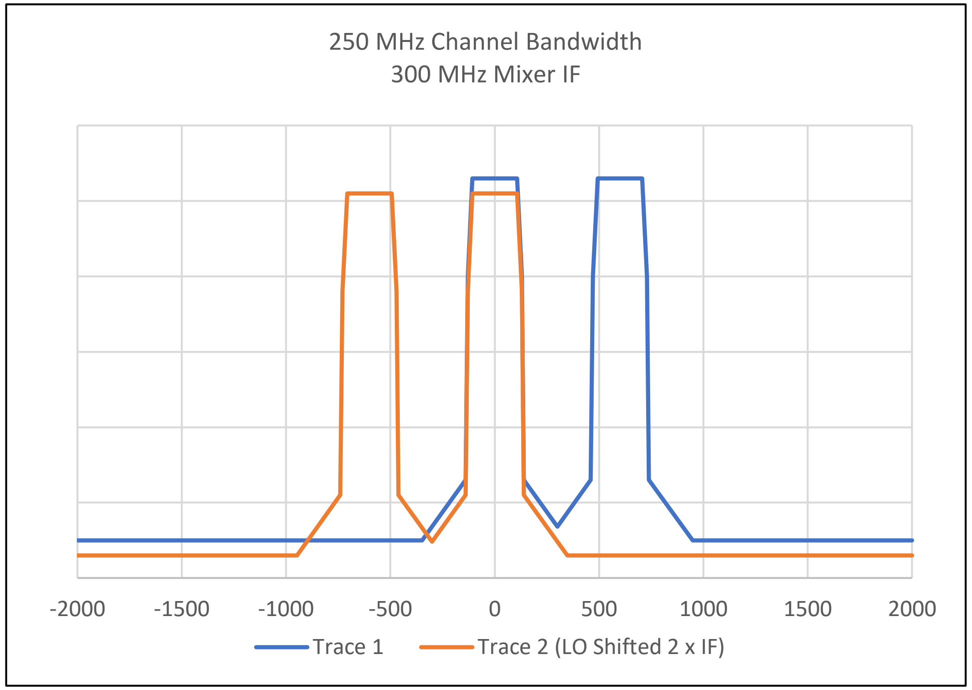
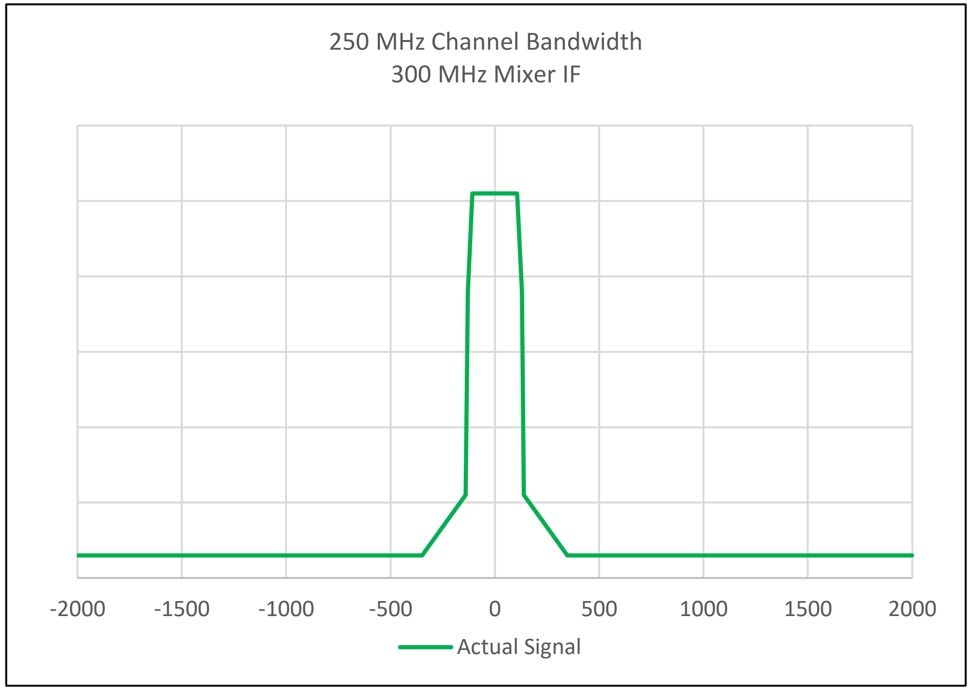
The signal ID function of a spectrum analyser takes alternating sweeps, with every other sweep using the LO harmonic shifted by 2 x IF. The lowest amplitude of 2 alternate sweeps is displayed as a composite sweep, suppressing the image.

This works well for narrower channel bandwidths: signal ID shifts LO by 2 x IF on trace 2.



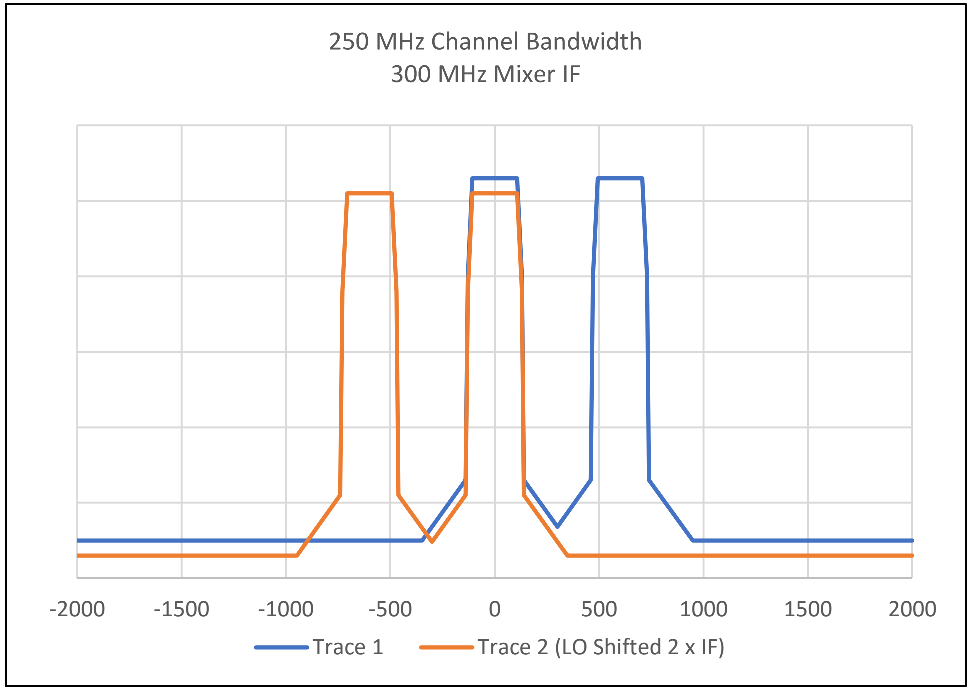


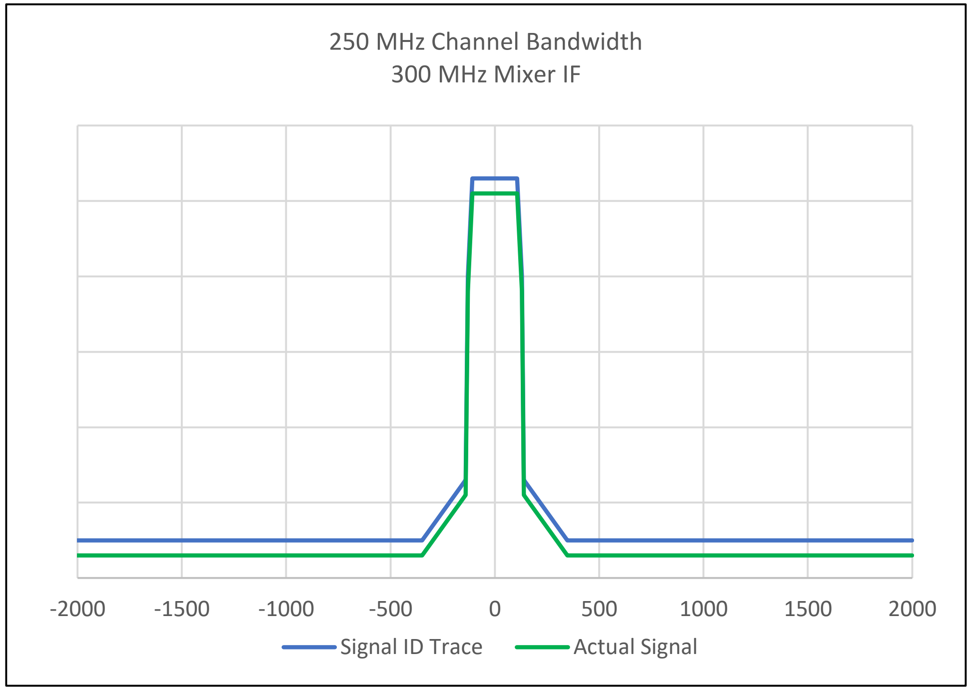
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal ID function of a spectrum analyser takes alternating sweeps, with every other sweep using the LO harmonic shifted by 2 x IF. The lowest amplitude of 2 alternate sweeps is displayed as a composite sweep, suppressing the image.

This works well for narrower channel bandwidths: composite signal ID trace matches actual signal.



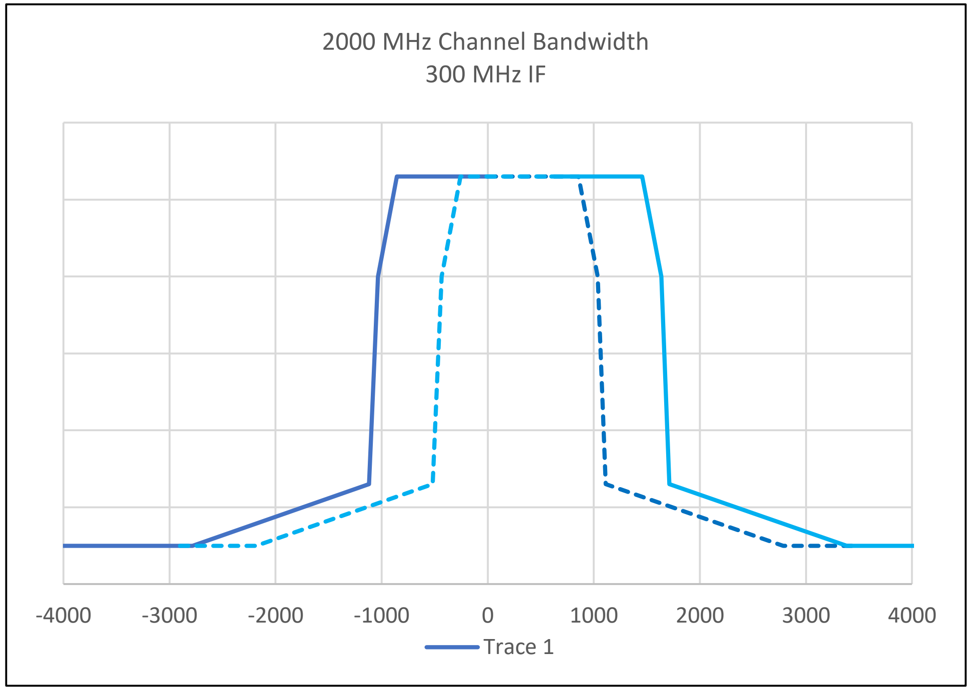


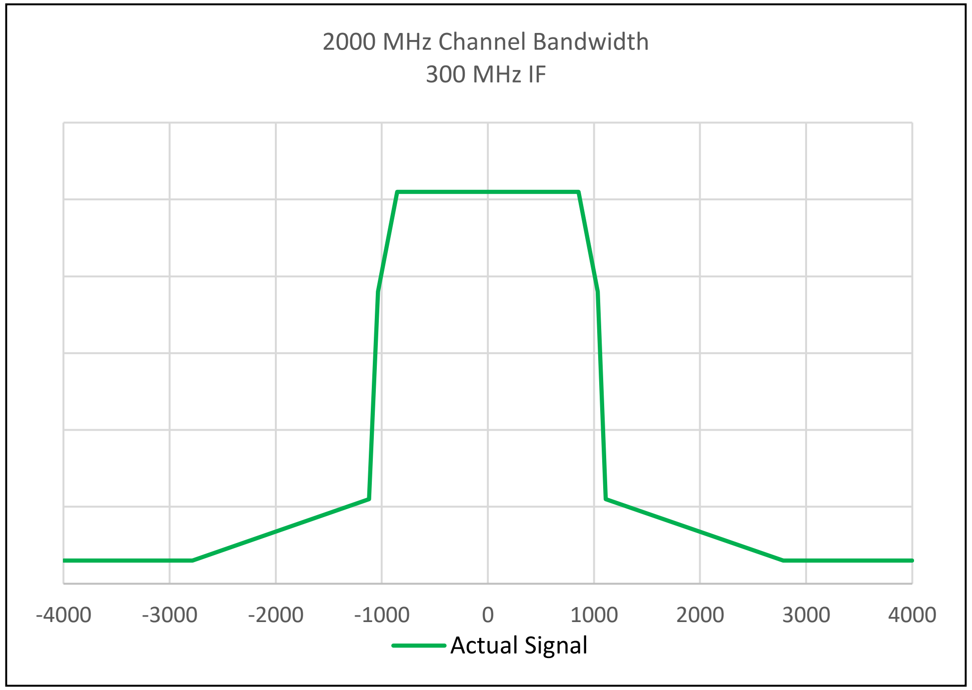
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal ID function of a spectrum analyser takes alternating sweeps, with every other sweep using the LO harmonic shifted by 2 x IF. The lowest amplitude of 2 alternate sweeps is displayed as a composite sweep, suppressing the image.

However, for channel bandwidths > 2 x IF: ‘wanted’ and ‘image’ signals overlap.



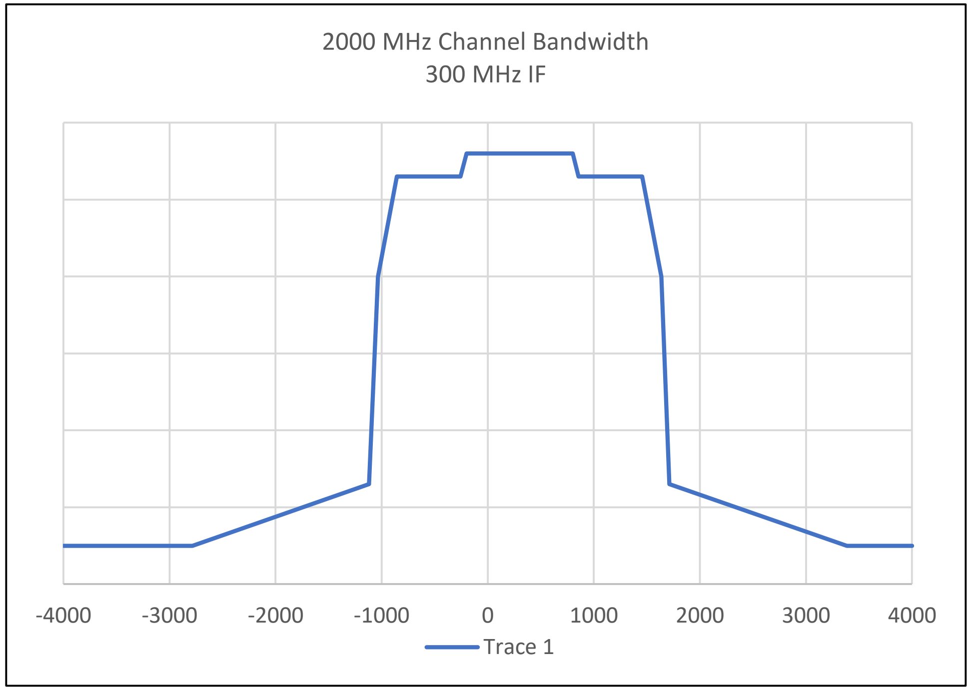


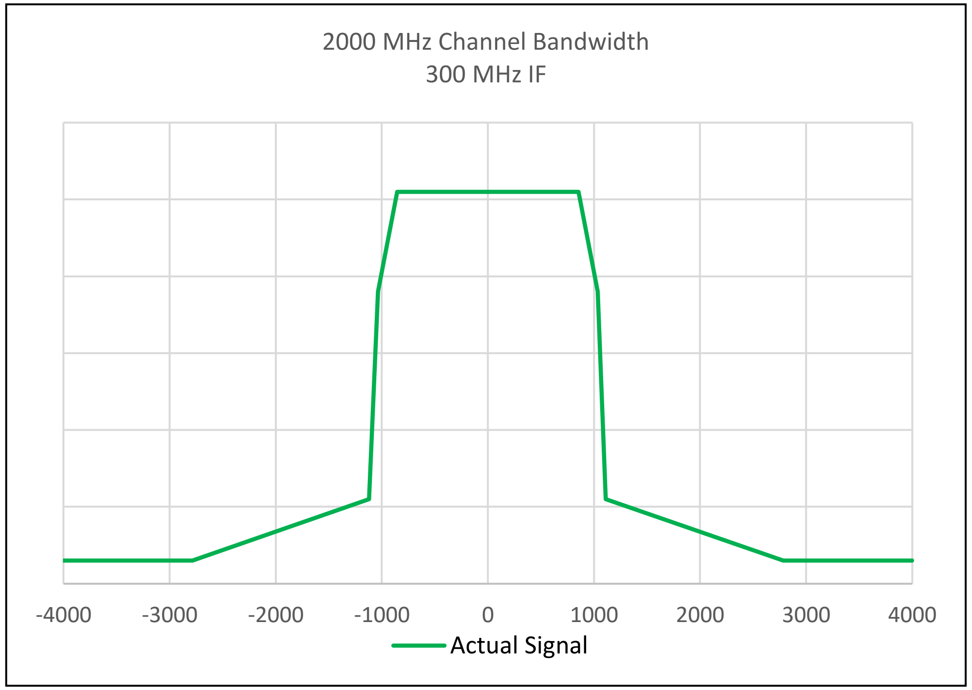
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal ID function of a spectrum analyser takes alternating sweeps, with every other sweep using the LO harmonic shifted by 2 x IF. The lowest amplitude of 2 alternate sweeps is displayed as a composite sweep, suppressing the image.

However, for channel bandwidths > 2 x IF: ‘wanted’ and ‘image’ signal amplitude sums in the overlap.





Harmonic Mixers – Image Response

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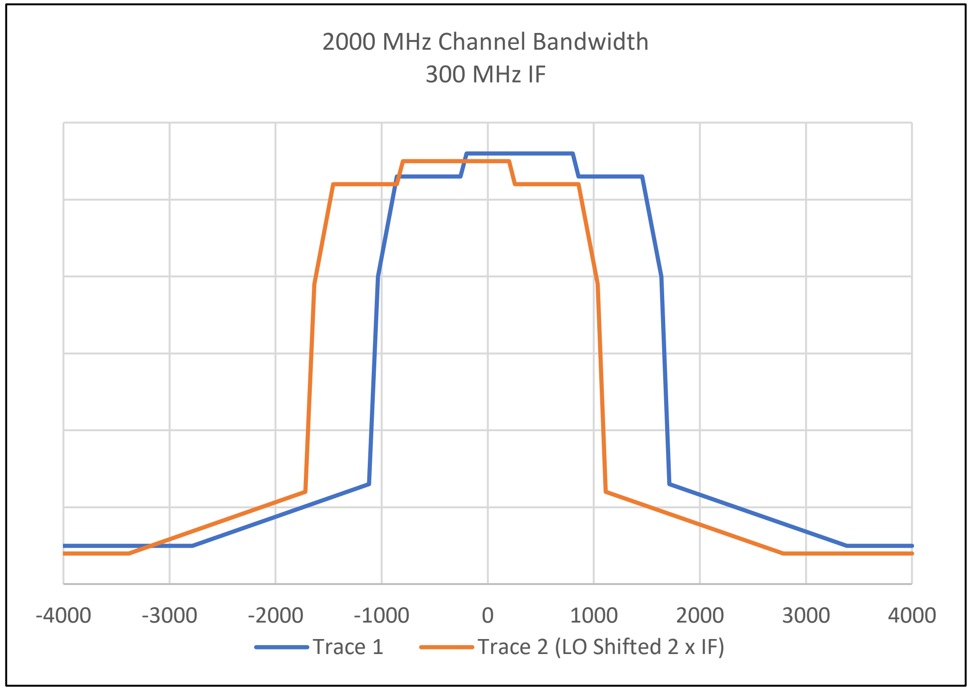
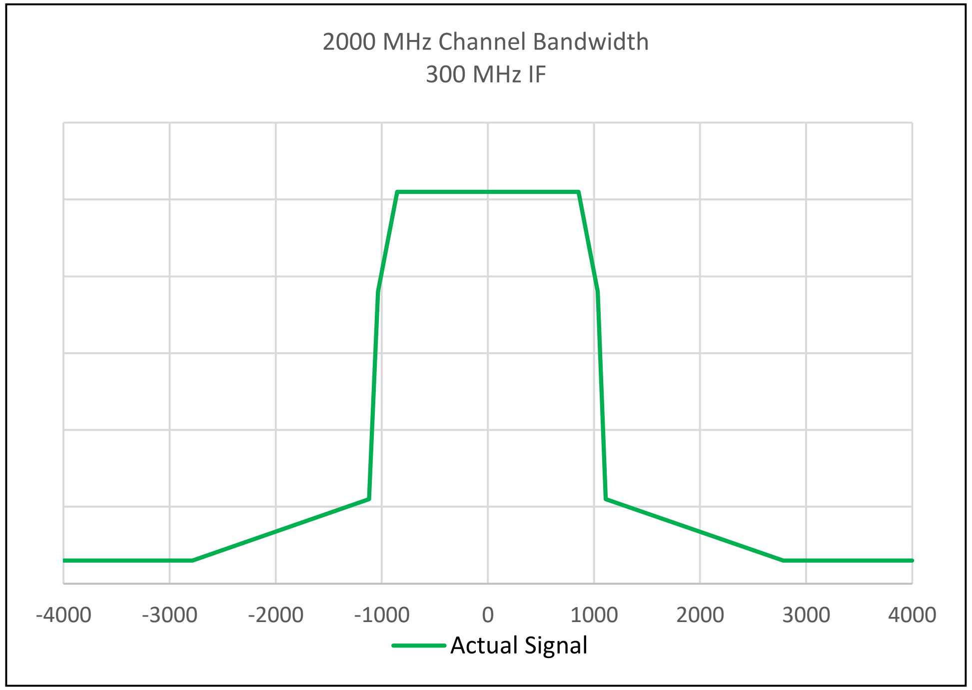
However, for channel bandwidths > 2 x IF: signal ID shifts LO by 2 x IF on trace 2.



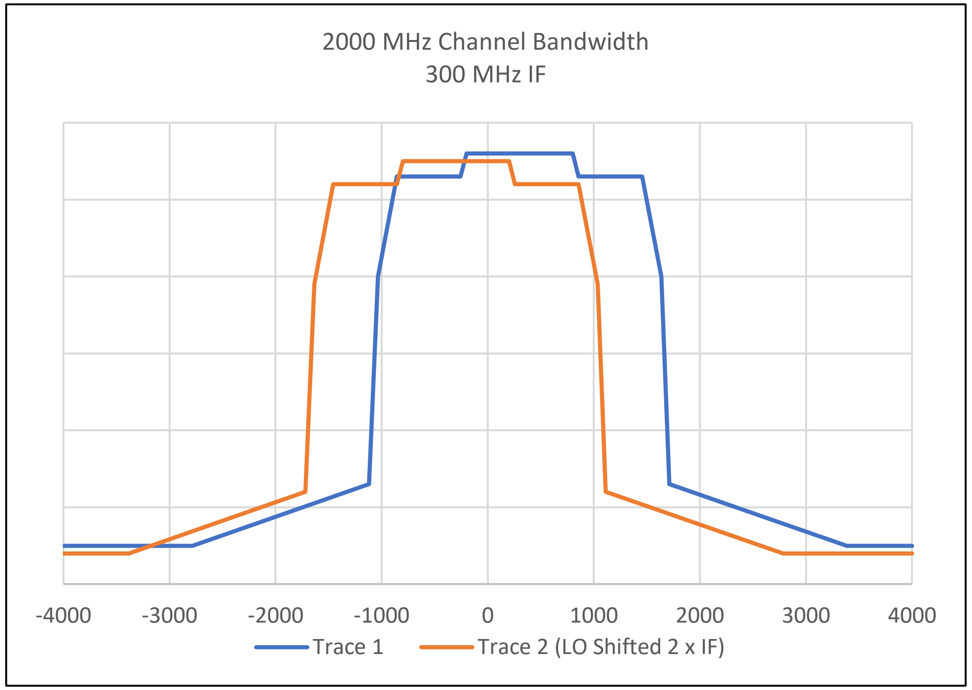


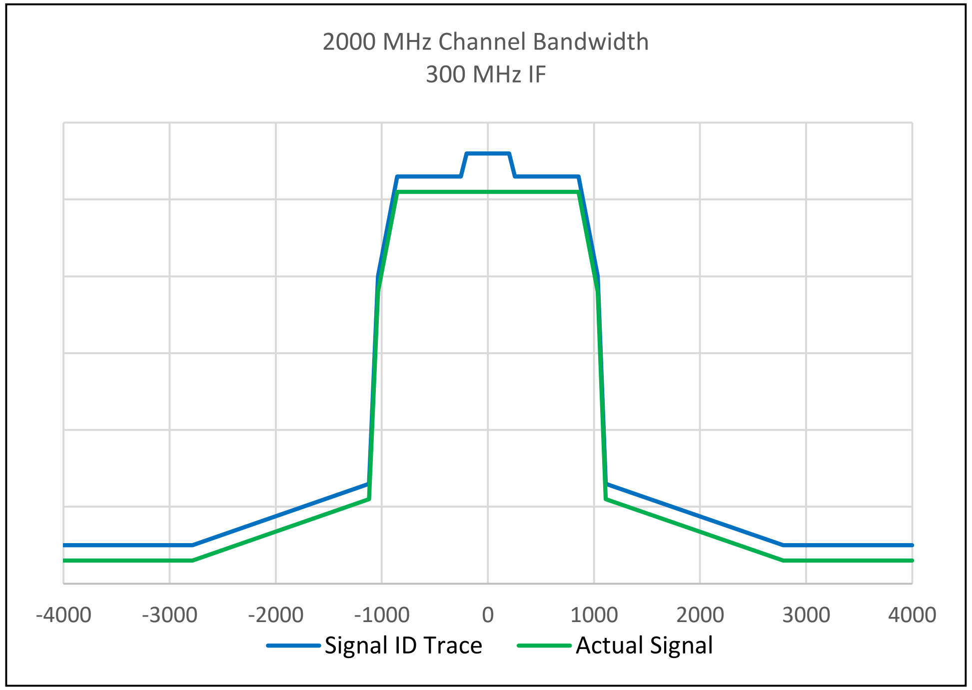
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal ID function of a spectrum analyser takes alternating sweeps, with every other sweep using the LO harmonic shifted by 2 x IF. The lowest amplitude of 2 alternate sweeps is displayed as a composite sweep, suppressing the image.

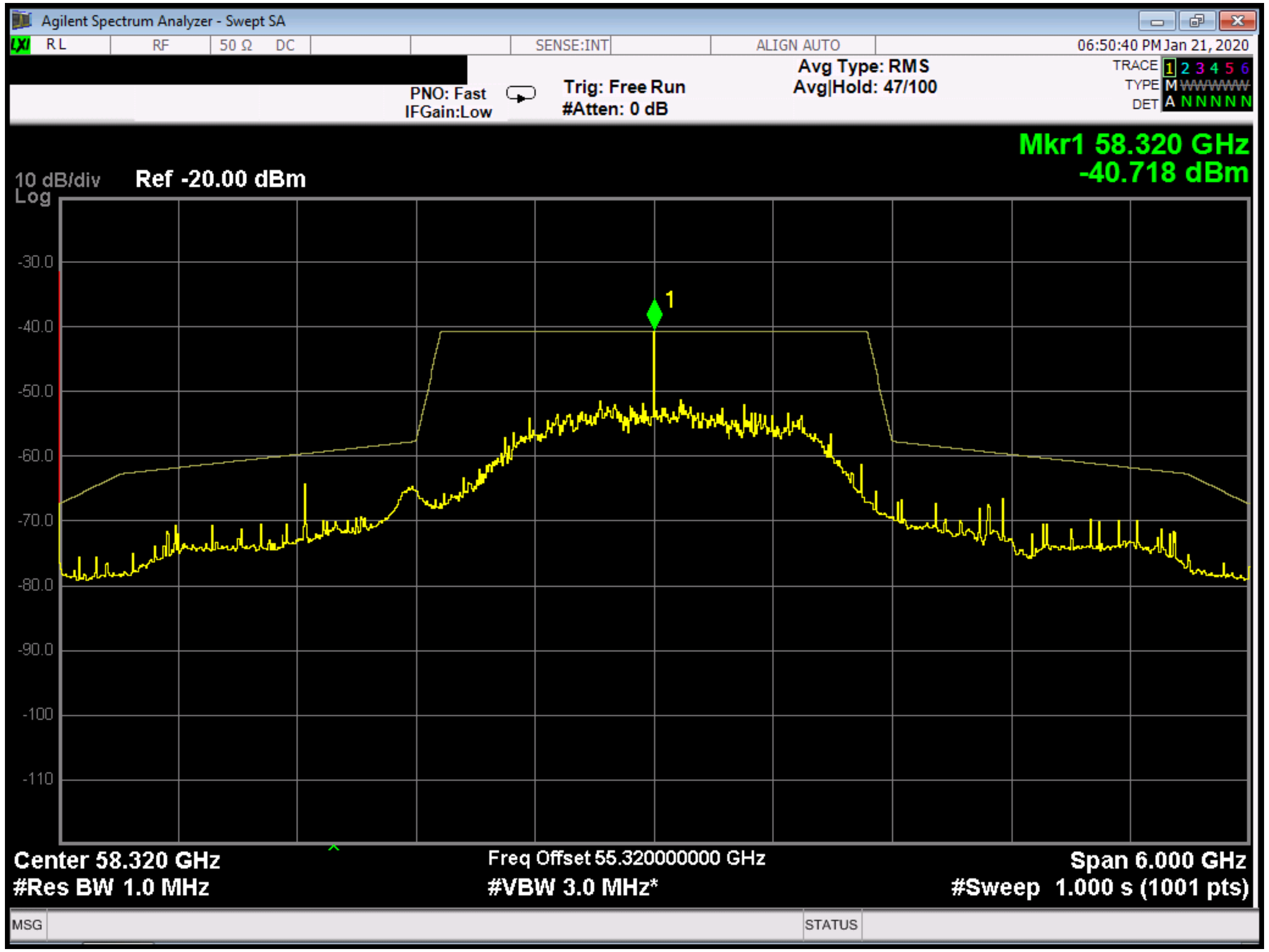
However, for channel bandwidths > 2 x IF: composite signal ID trace does not match actual signal.





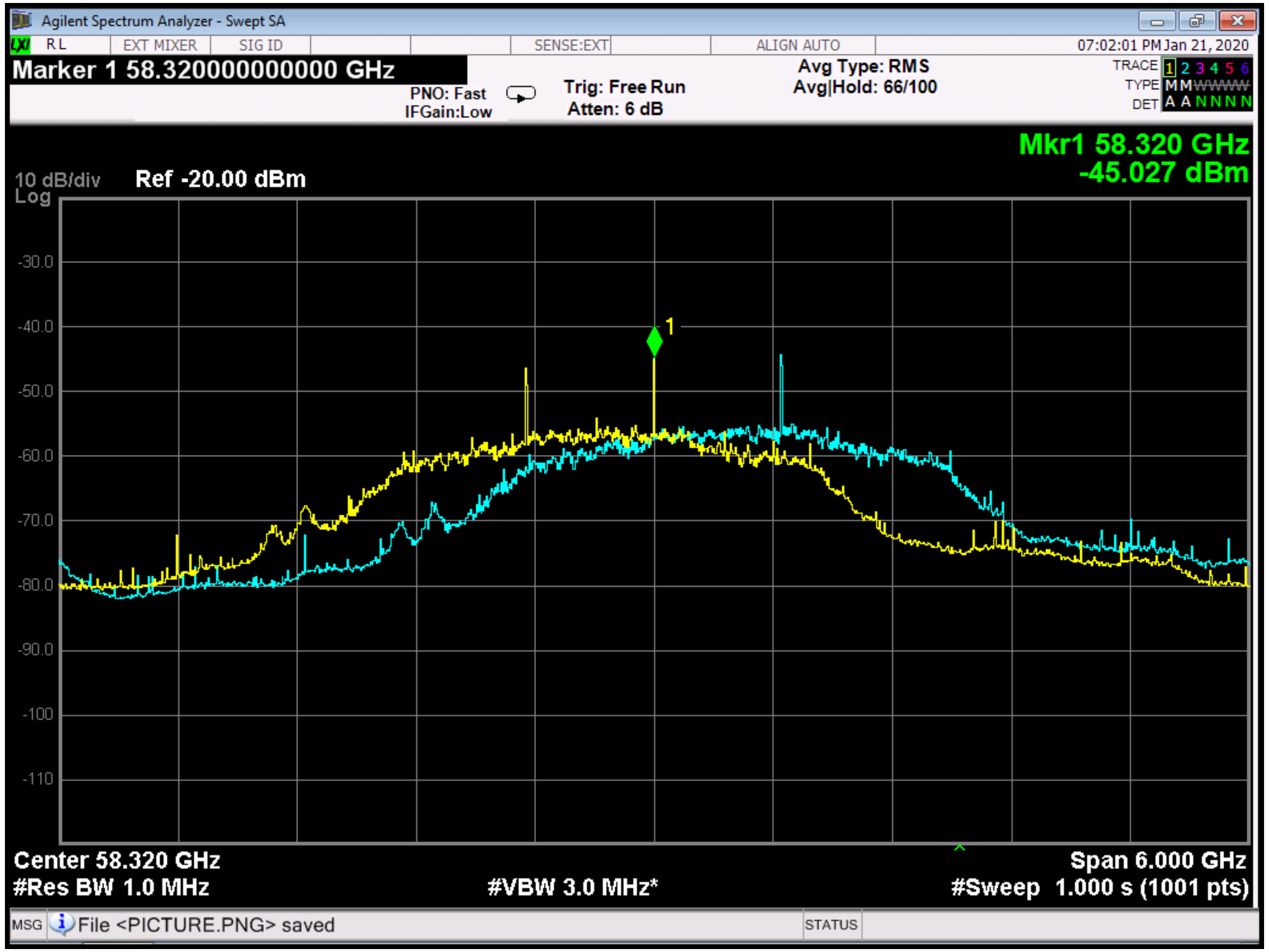
Harmonic Mixers – Image Response

- Signal ID (Image Suppression) – Actual 802.11ad Signal, 2.15 GHz Bandwidth



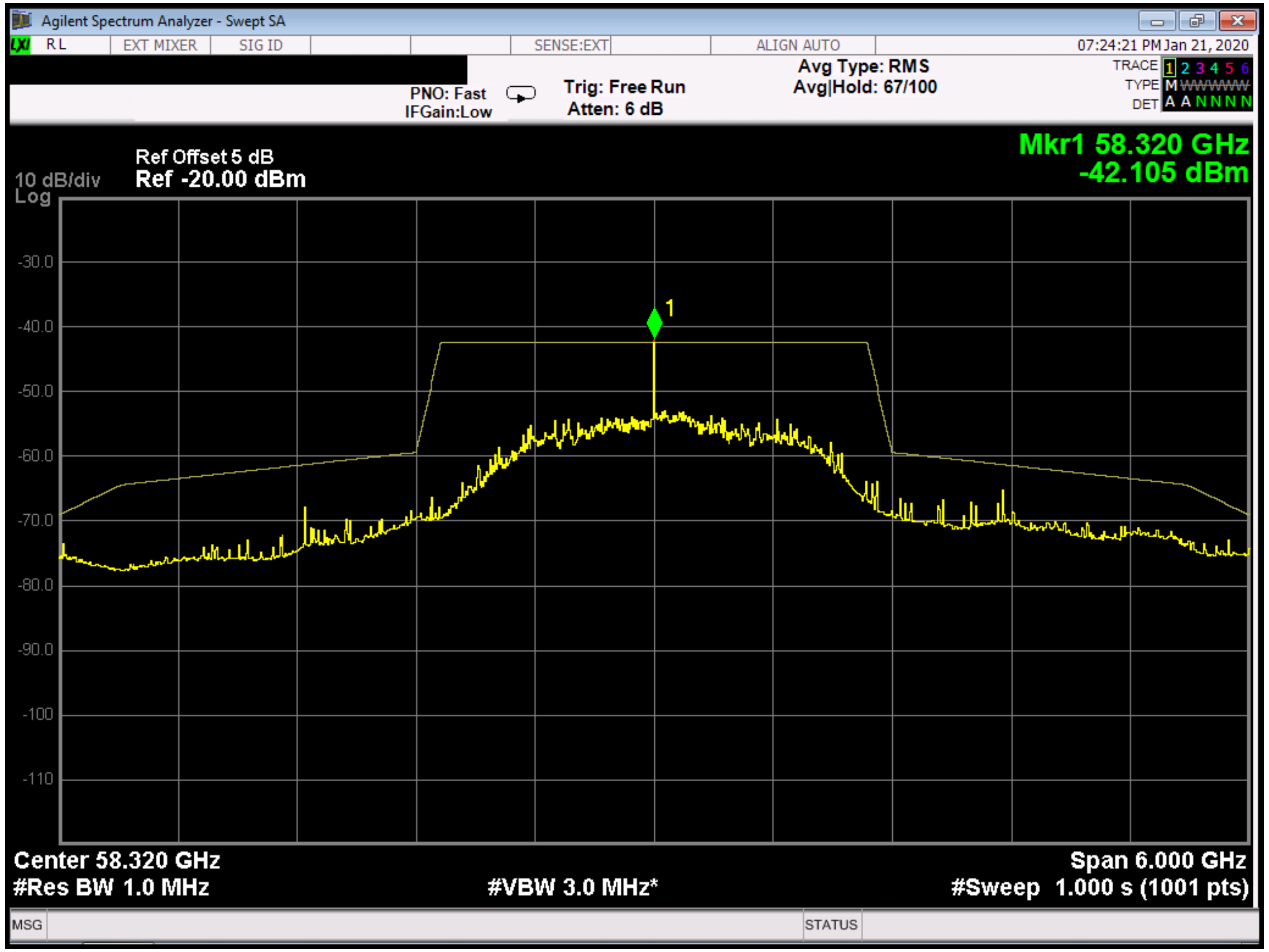
Harmonic Mixers – Image Response

- Signal ID (Image Suppression) – Measured 802.11ad Signal, 2.15 GHz Bandwidth, Image Shift



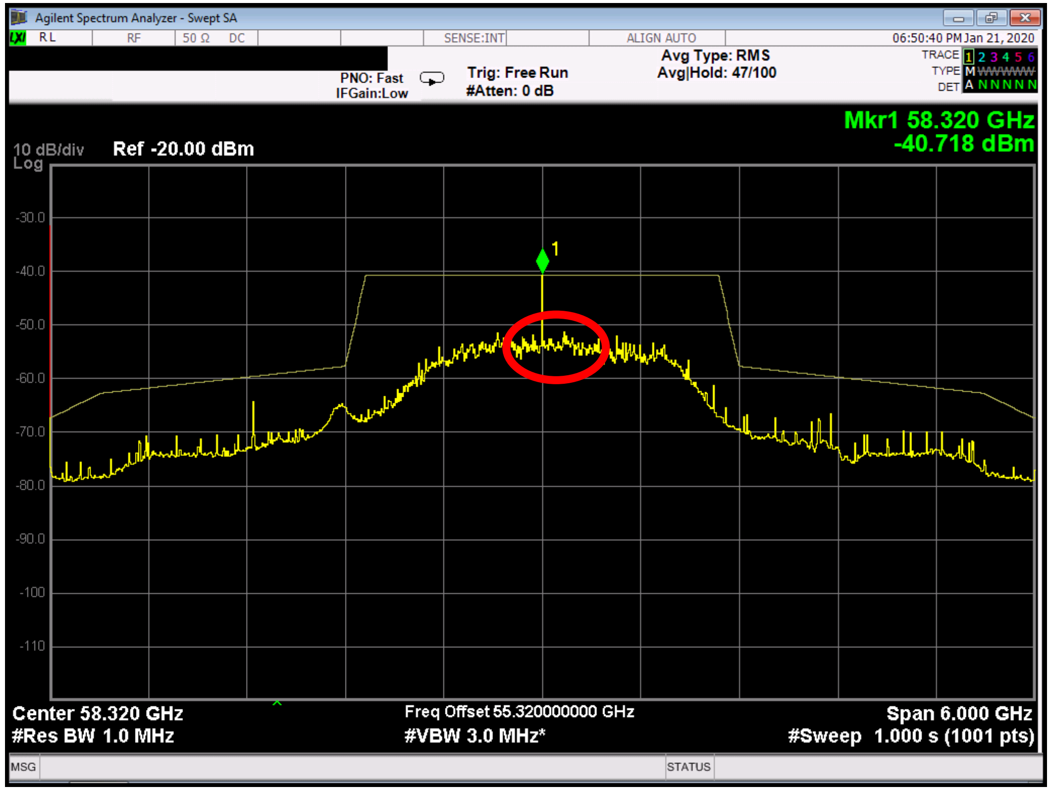
Harmonic Mixers – Image Response

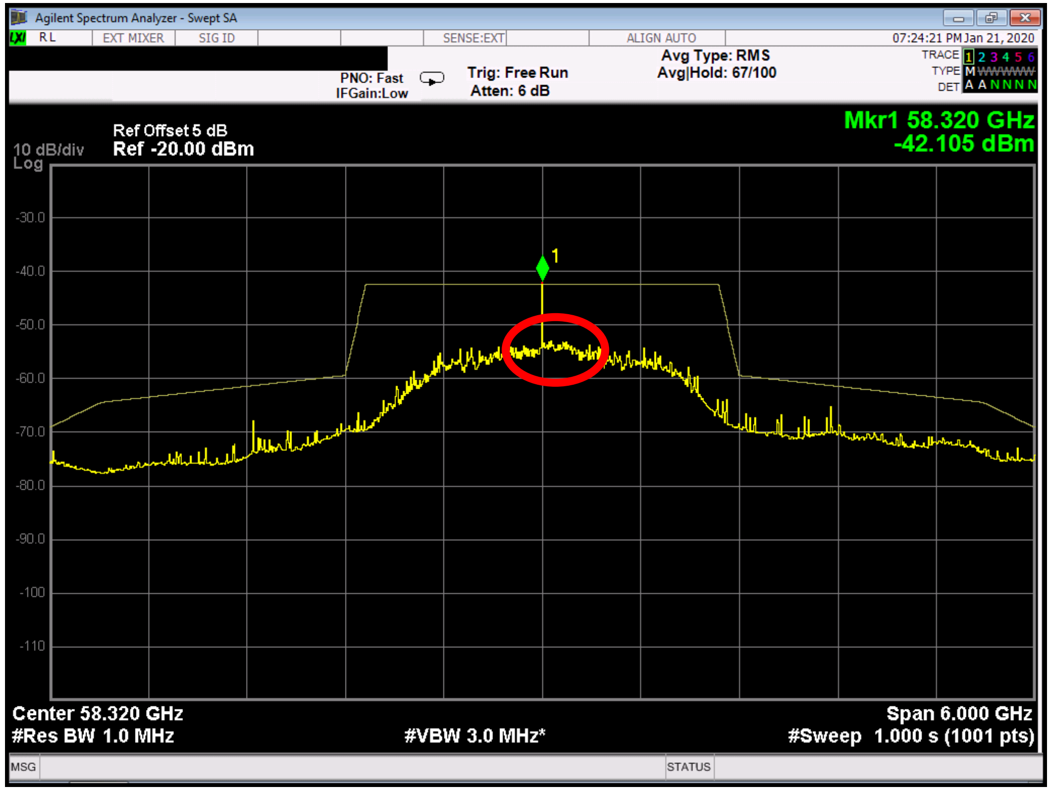
- Signal ID (Image Suppression) – Measured 802.11ad Signal, 2.15 GHz Bandwidth, Image Supress



Harmonic Mixers – Image Response

- Signal ID (Image Suppression) – Actual vs Measured 802.11ad Signal, 2.15 GHz Bandwidth



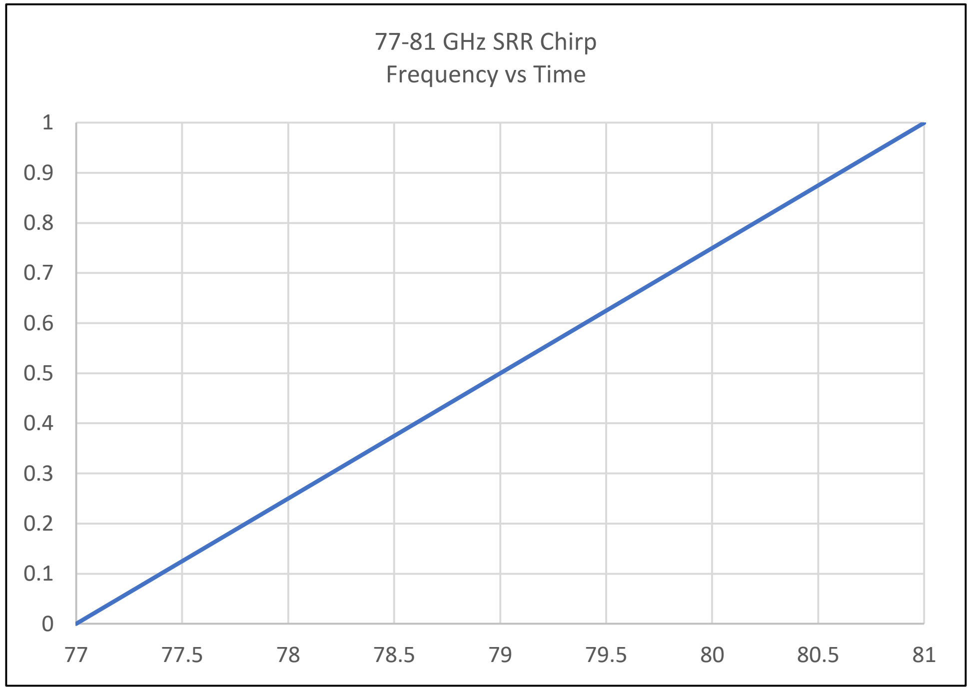


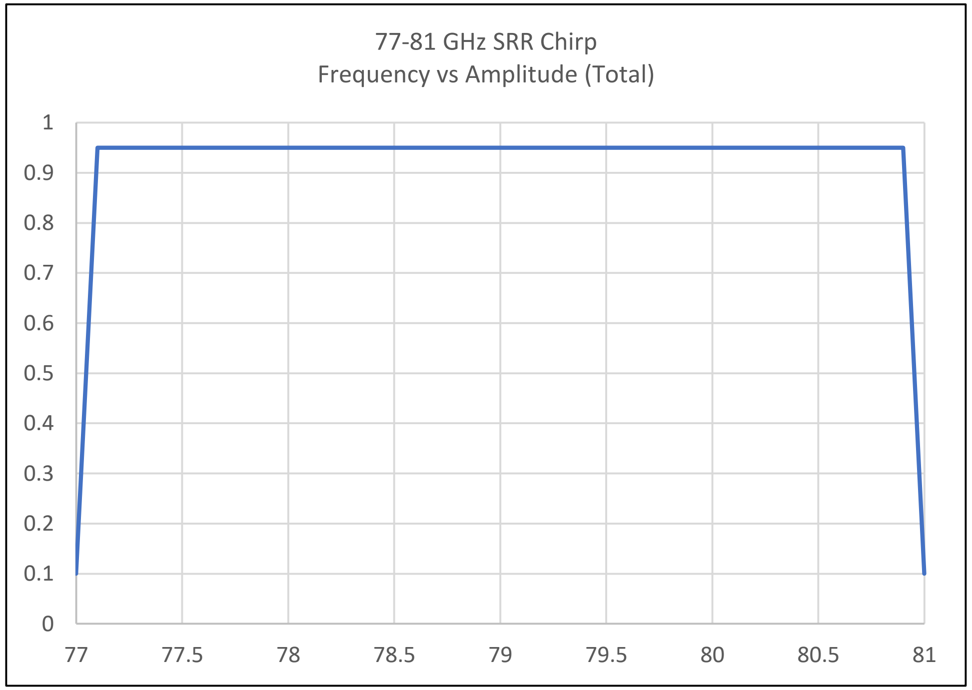
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal being measured must also be stable. A FMCW signal, such as those used in automotive radar applications, could be supressed entirely by the signal ID function.

For a 4 GHz chirp:





Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

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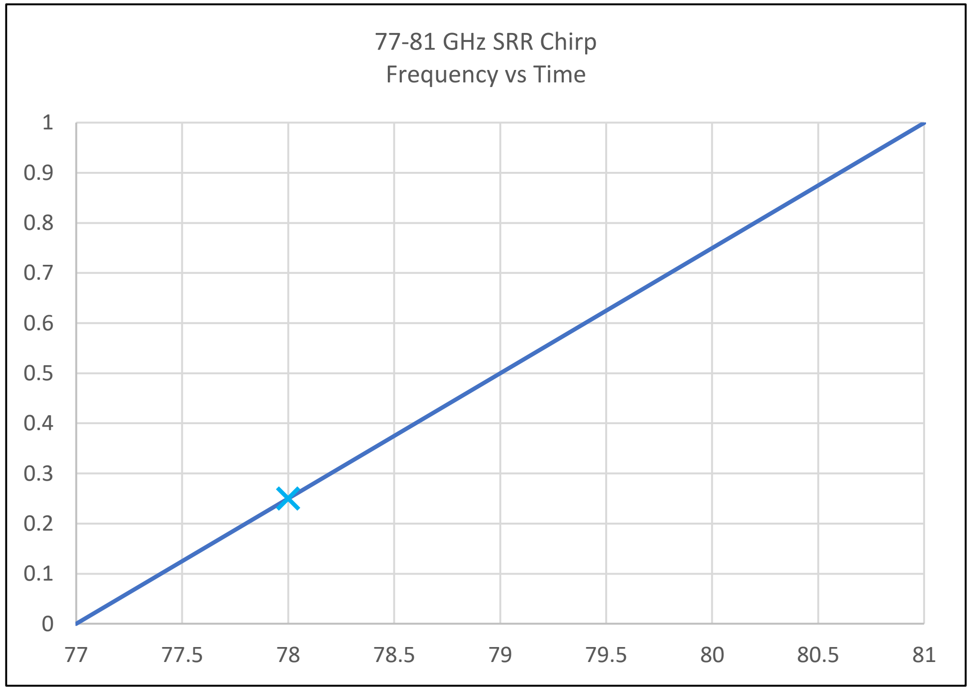
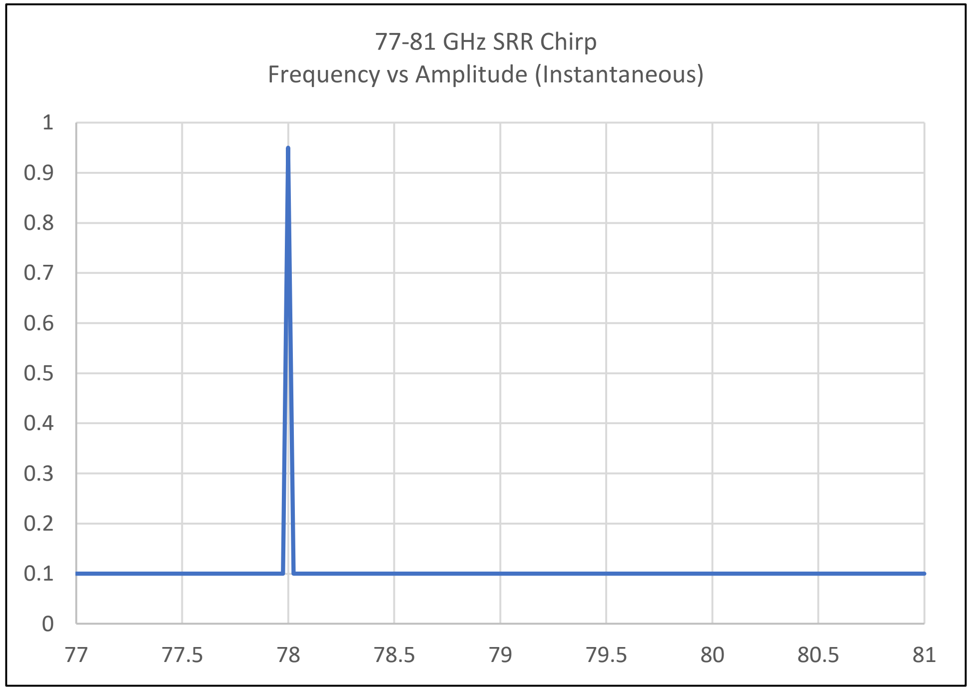
For a 4 GHz chirp: the instantaneous signal is CW.



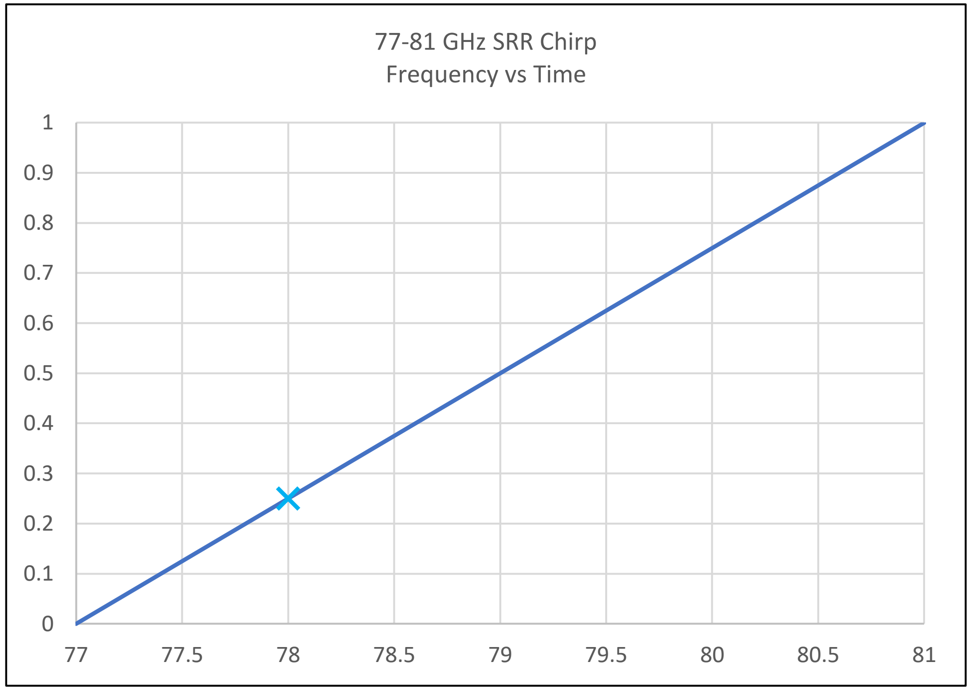


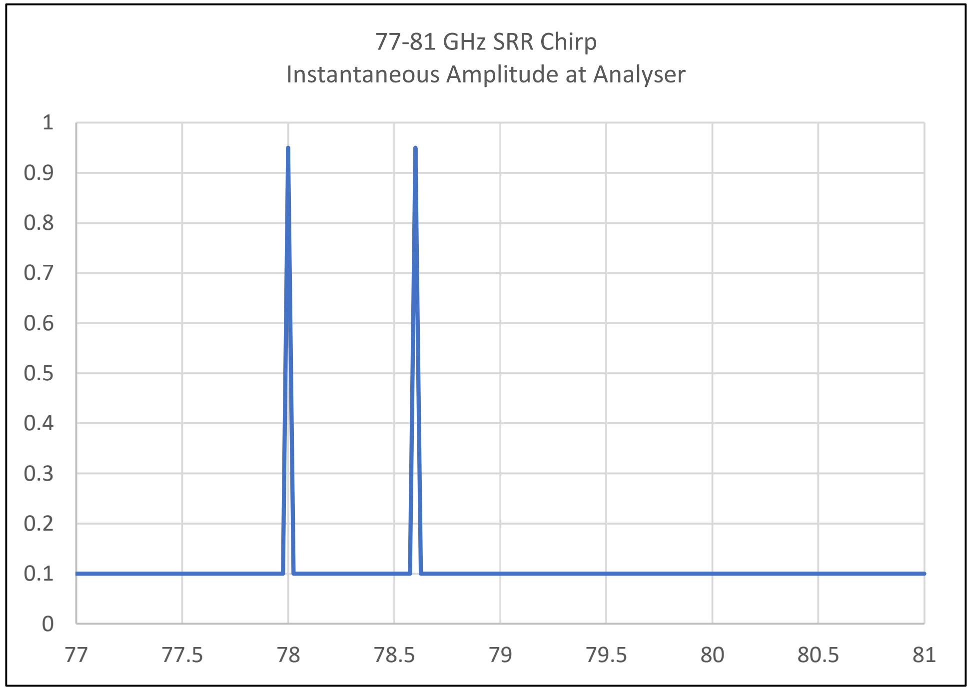
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal being measured must also be stable. A FMCW signal, such as those used in automotive radar applications, could be supressed entirely by the signal ID function.

For a 4 GHz chirp: the 'image' signal can be seen 2 x IF above the instantaneous CW signal on the 1st sweep.



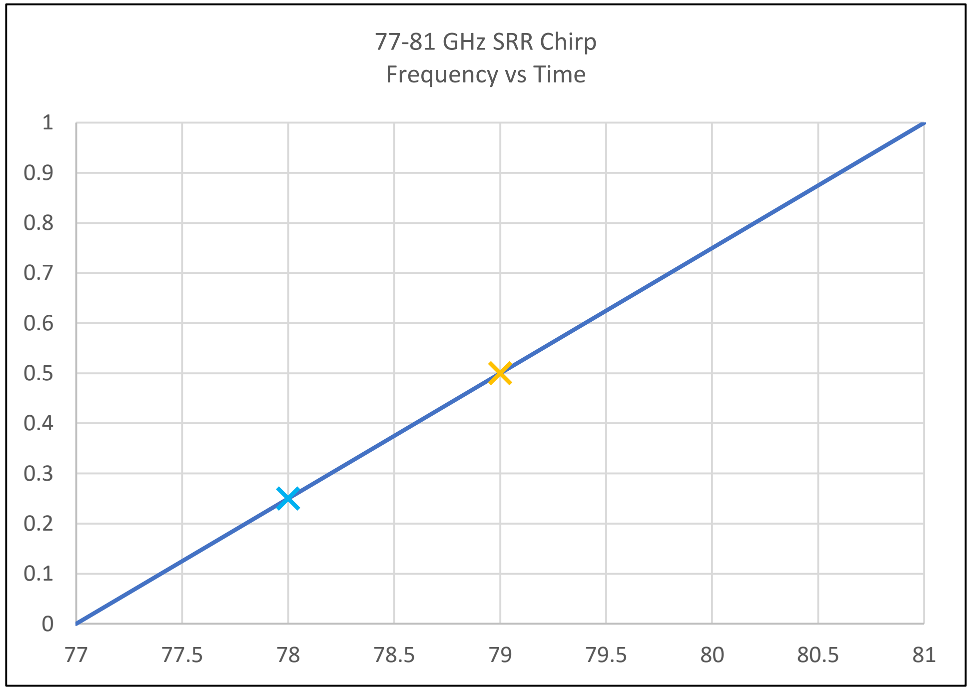


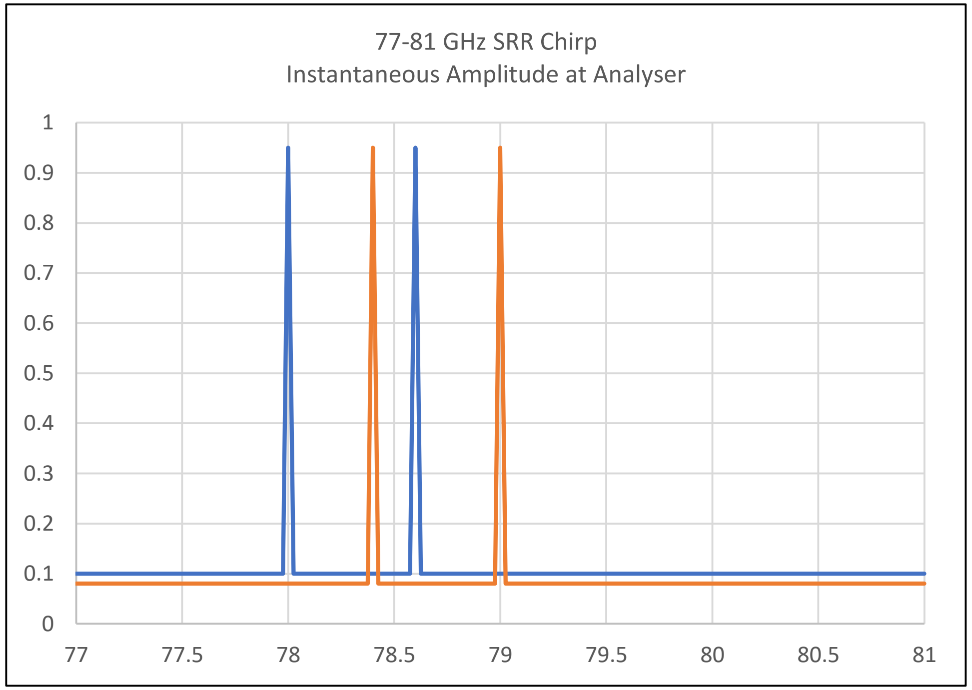
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal being measured must also be stable. A FMCW signal, such as those used in automotive radar applications, could be supressed entirely by the signal ID function.

For a 4 GHz chirp: the consecutive sweep intersects the chirp at a different point, and is shifted by 2 x IF.



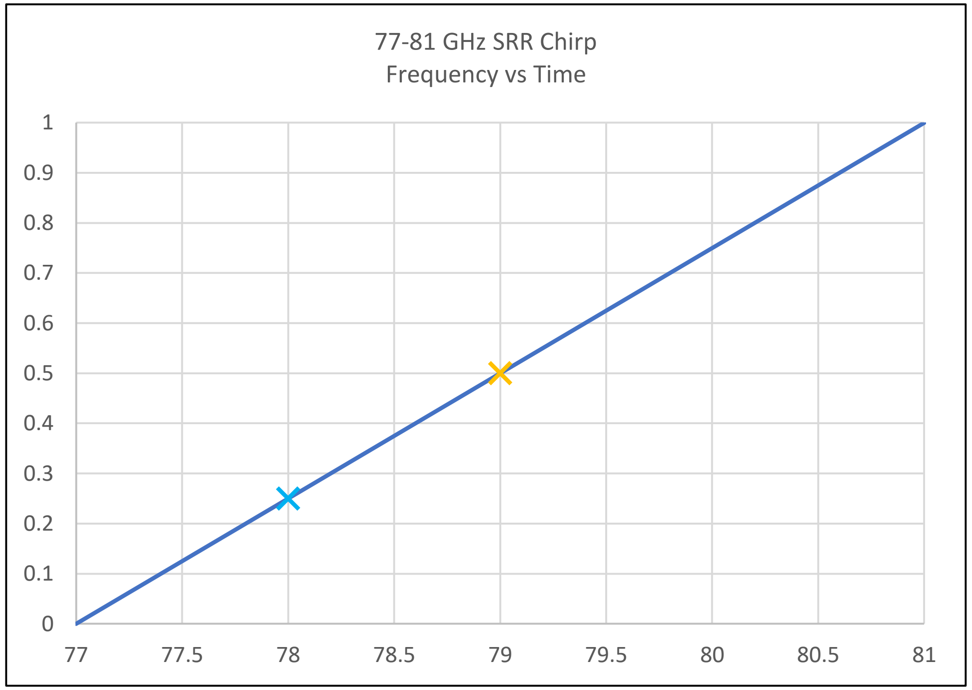


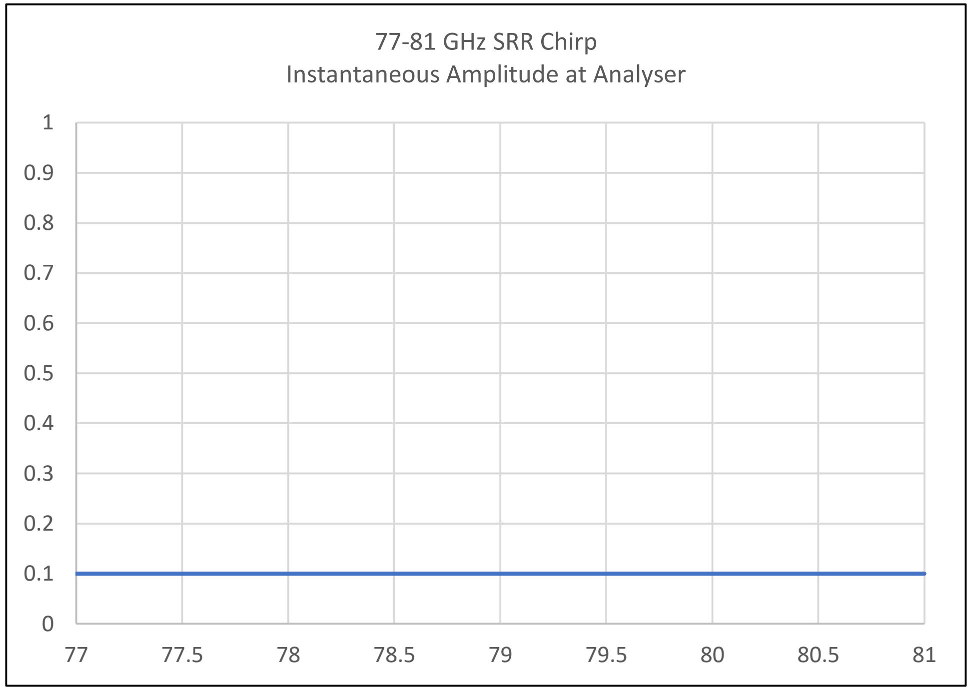
Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal being measured must also be stable. A FMCW signal, such as those used in automotive radar applications, could be supressed entirely by the signal ID function.

For a 4 GHz chirp: the composite signal ID trace shows no signal.





Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

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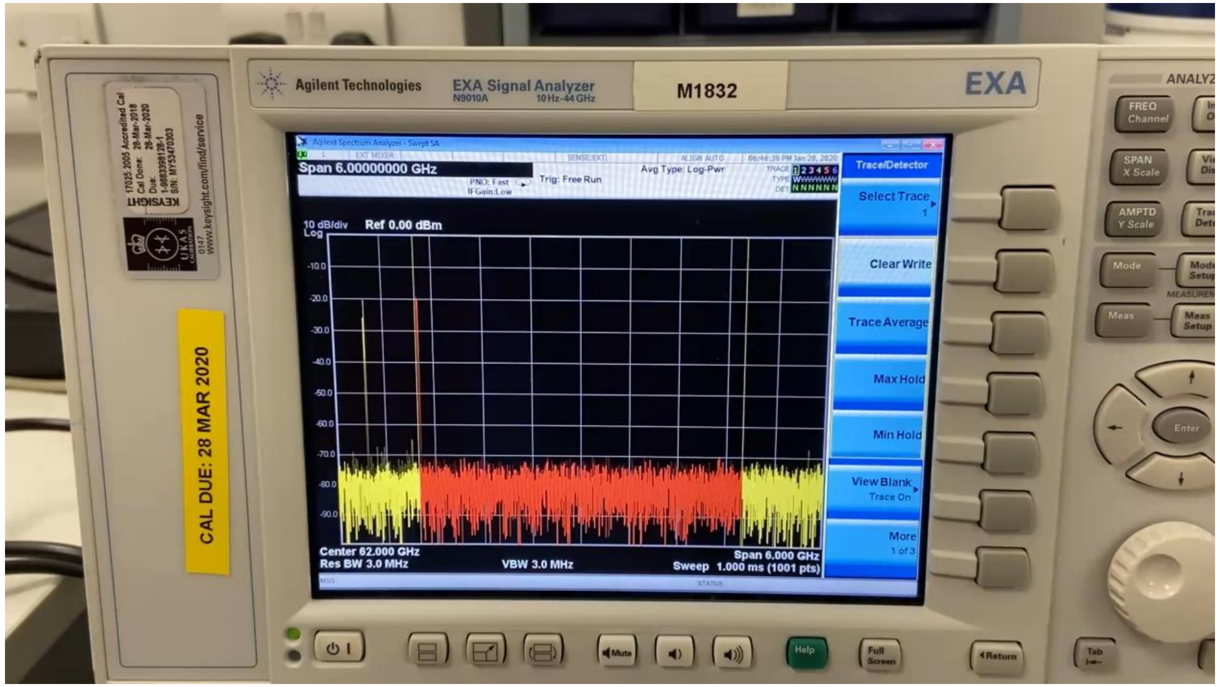
No Signal ID:

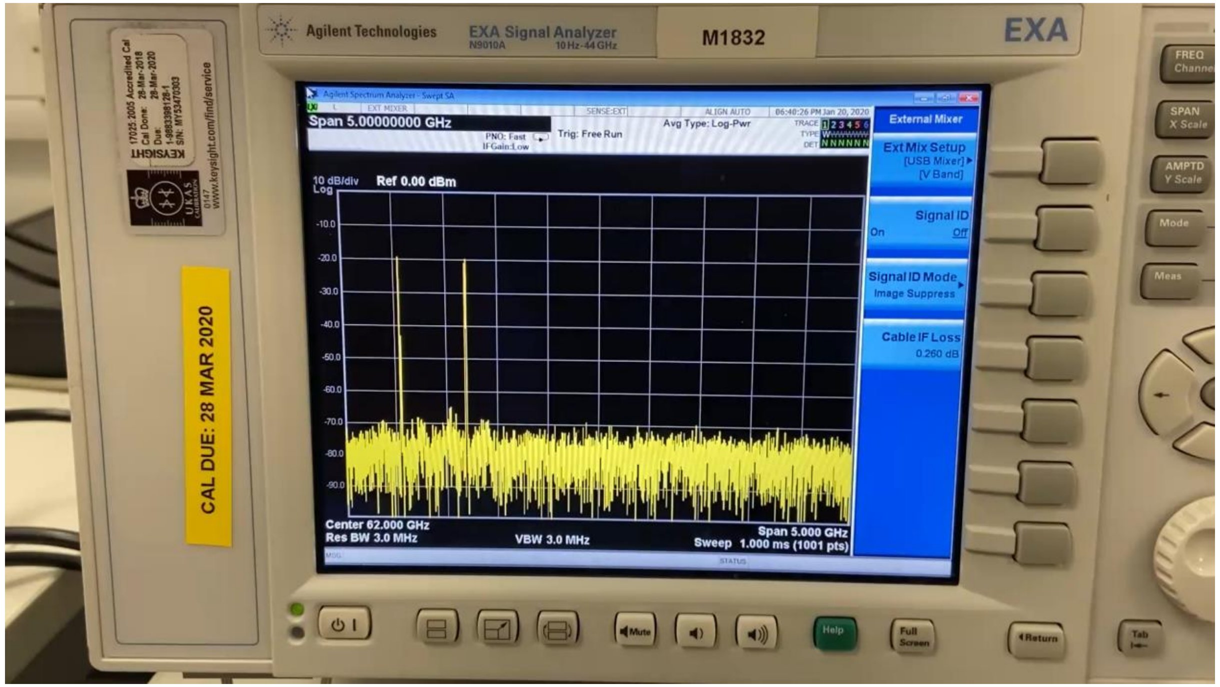


Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal being measured must also be stable. A FMCW signal, such as those used in automotive radar applications, could be supressed entirely by the signal ID function.

Image Suppress (slow chirp):



Harmonic Mixers – Image Response

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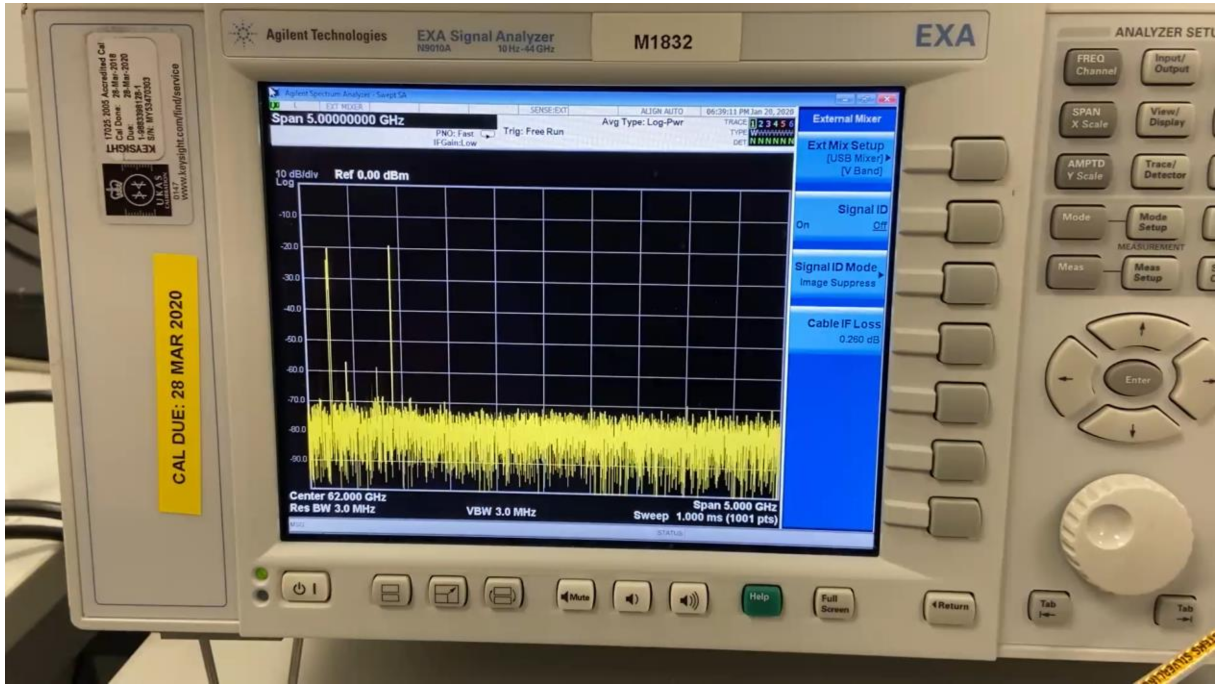
Image Suppress (fast chirp):

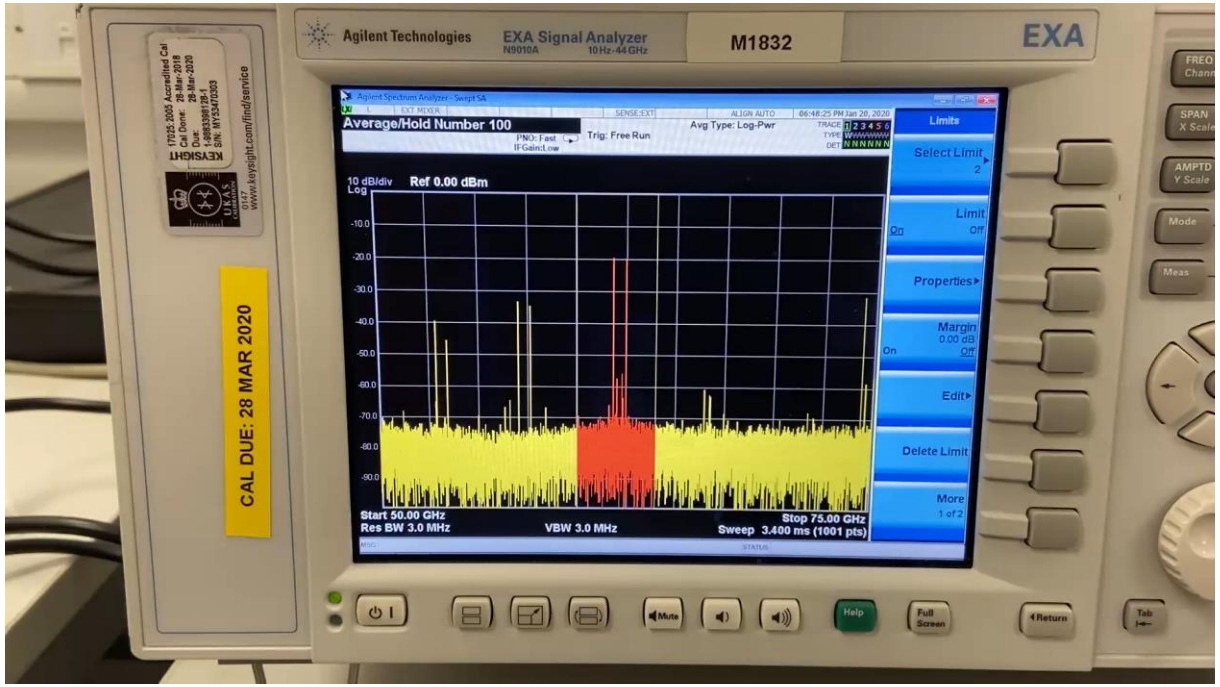


Harmonic Mixers – Image Response

- Signal ID (Image Suppression)

The signal being measured must also be stable. A FMCW signal, such as those used in automotive radar applications, could be supressed entirely by the signal ID function.

No Signal ID, Full Band:



No Conducted Measurements

- **Massive MIMO / Beam Steering / Beamforming**

At mm wave frequencies, these features can be achieved using antenna arrays integrated on chip. While this is a useful design optimisation, it prevents the use of conducted measurements.

- **TRP**

The implementation of these features in 5G NR has resulted in the need to measure TRP (total radiated power) in place of EIRP. TRP can only be accurately characterised using a radiated test methodology.

- **Receiver Testing**

Receiver tests now required under the RED need accurate calibration and control over signal levels. This is more challenging in a radiated environment, particularly with beam steering / beamforming devices.

Overcoming Limitations

Overcoming Limitations

Recap limitations:

- **Harmonic Mixers – Conversion Loss**

Correcting for high conversion loss reduces the dynamic range available for measurement.
This can prevent measurement of stringent mask / out of band requirements and measurement in the far field.

- **Harmonic Mixers – Image Response**

Wide channel bandwidths (> 2 x IF) cause image overlap, preventing accurate image suppression. Dynamic signals (i.e. FMCW) may be supressed entirely.

- **No Conducted Measurements**

Integrated antenna arrays and TRP requirements prevent conducted measurements. Accurate calibration and control over signal levels for radiated receiver tests is challenging.

- **Anechoic Chambers – Far Field Measurement**

Larger antenna array dimensions increase the far field distance, preventing measurement in a 3 m anechoic chamber. Path loss increases accordingly, reducing the dynamic range.

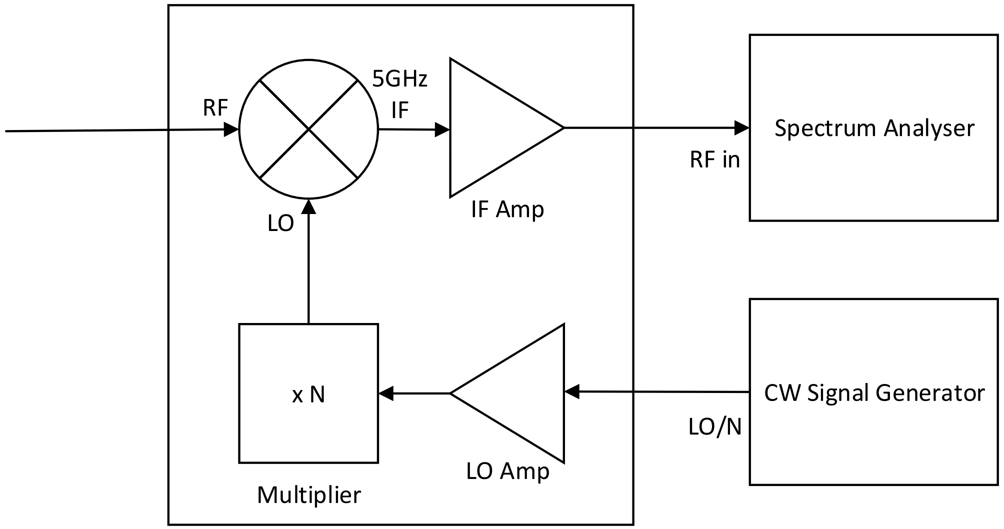
Overcoming Limitations - Harmonic Mixers

The high conversion loss and image overlap limitations of harmonic mixers can both be overcome by using a fundamental mixing downconverter.

A static LO, driven by a separate source, is amplified and multiplied up to the RF frequency ± 5 GHz. This produces an IF output at 5 GHz.

The amplification stages result in a low conversion loss (~10 dB), and the higher IF frequency allows much wider bandwidths to be measured before image overlap (2 x IF).

The image suppression function is no longer available, but mixing products can be identified manually by adjusting the LO frequency.



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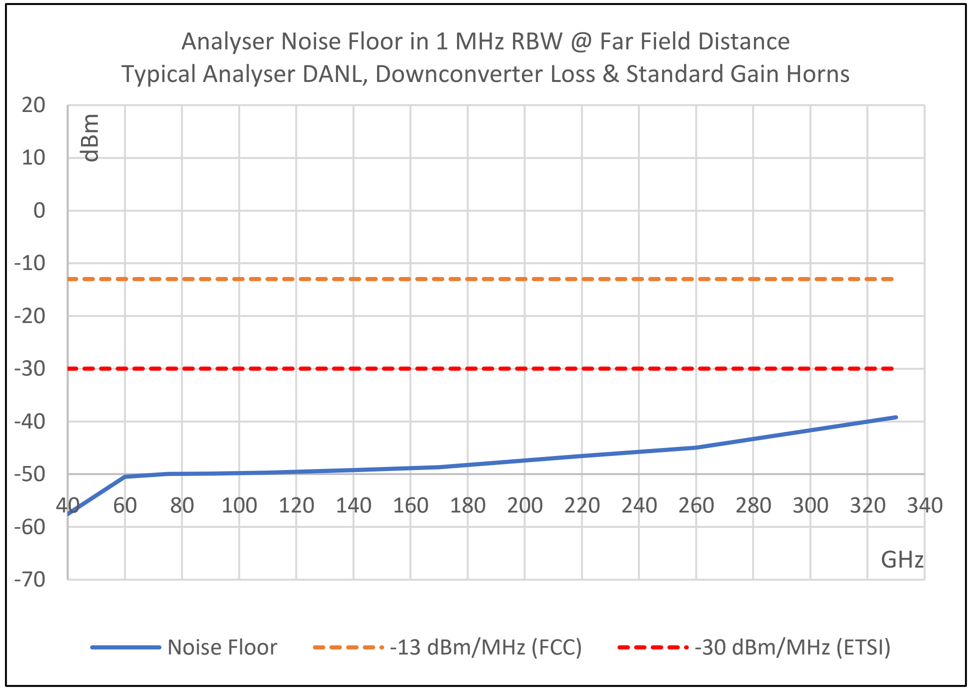

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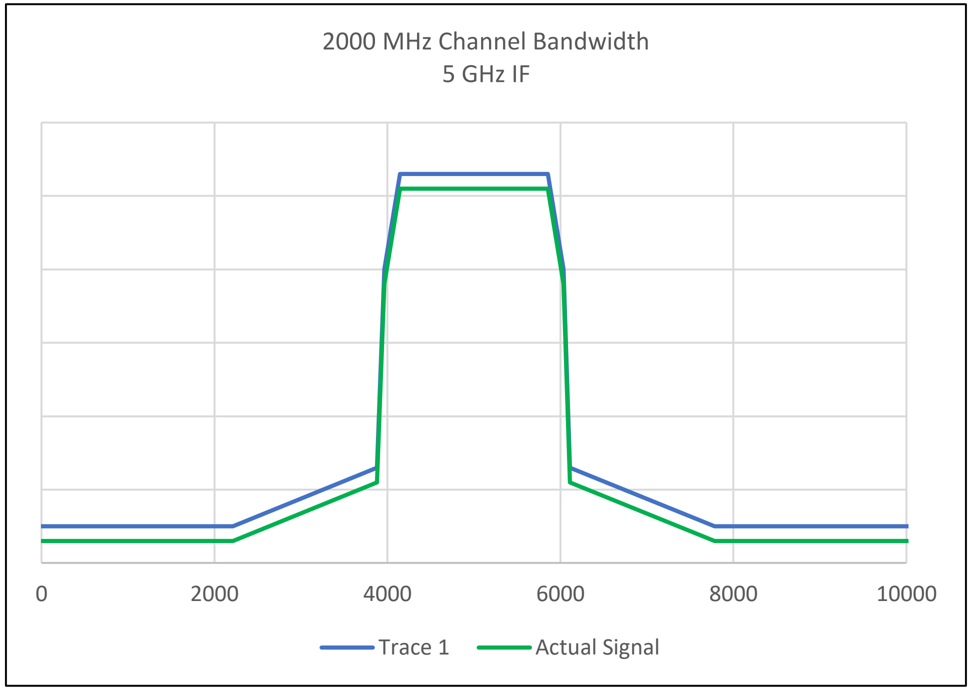

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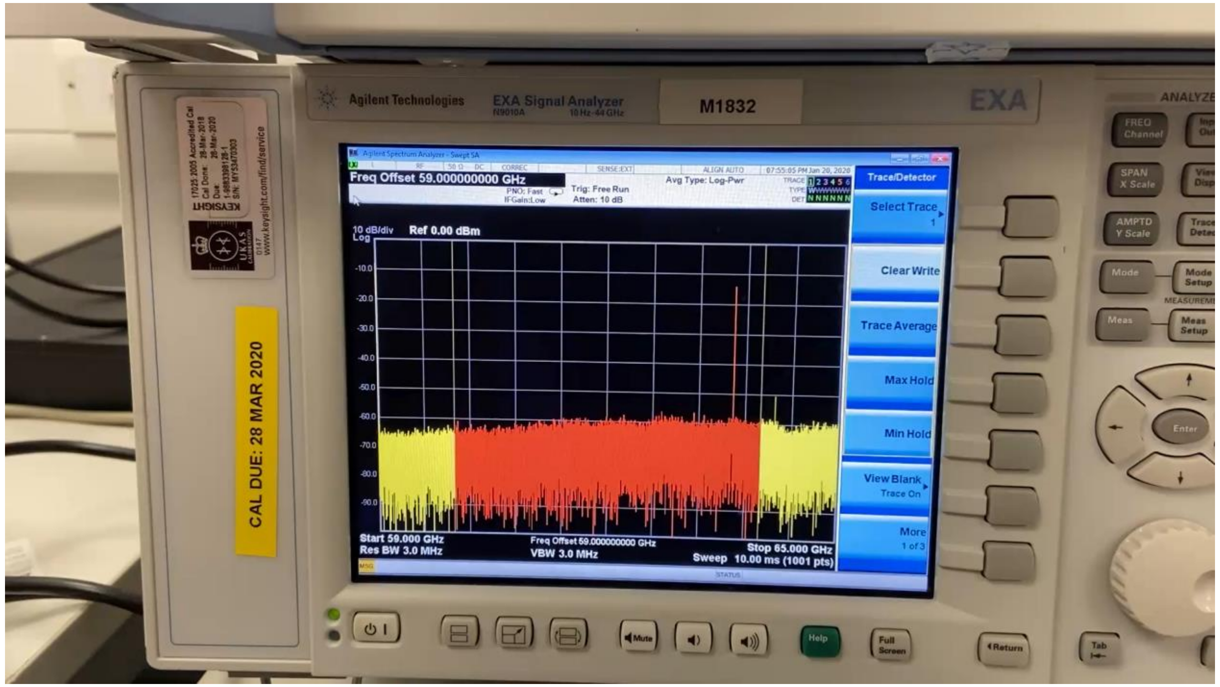


4 GHz Radar Chirp (Downconverter)

Overcoming Limitations - Harmonic Mixers

Alternatively, some high end spectrum analysers now natively support up to 110 GHz. Although these make for a simpler and more elegant solution than downconverters, there are some trade-offs to consider.

- Cost – top end analysers come with top end price tags. Downconverters may be considerably cheaper, particularly if you already have a lower frequency analyser and signal source to drive them.
- Spurious Range – downconverters may still be required to extend the range of the 110 GHz analyser to the upper spurious frequency limit (2nd harmonic for ETSI, lower of 5th harmonic or 200 GHz for FCC, 231 GHz for 76-81 GHz Radar!).
- Coaxial Insertion Loss – at 110 GHz, typical insertion loss can be 18 dB/m. Cable lengths would need to be kept short, which may be impractical for measurements in an anechoic chamber where the measurement antenna position needs to be adjusted.

Downconverters have their own drawbacks – RF input compression point and damage level are lower than harmonic mixers and spectrum analysers.

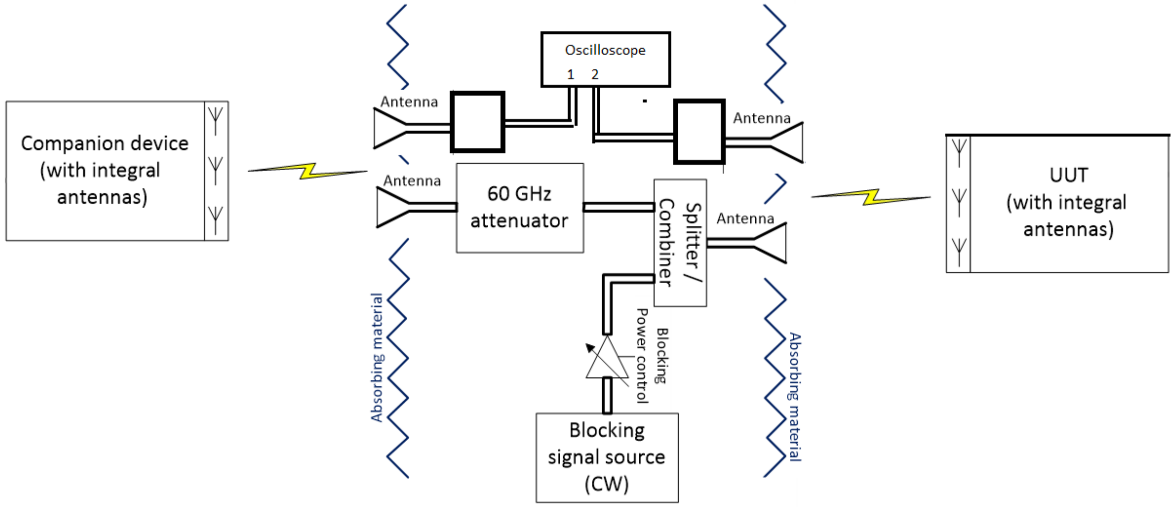
Overcoming Limitations – No Conducted Measurements

A conducted test methodology for receiver performance measurements allows for accurate calibration of losses and fine control over signal levels.

For a conducted receiver sensitivity test at 60 GHz using waveguide, a measurement uncertainty of <1.5 dB is achievable.

For the same test performed radiated, the achievable measurement uncertainty could be in excess of 5 dB.

Radiated receiver test uncertainty can be reduced by using a semi-conducted test setup, such as the adjacent channel rejection setup defined in EN 302 567:



Overcoming Limitations – No Conducted Measurements

For radar receiver tests, a semi-conducted test setup is not suitable.

Accurate and repeatable measurements can only be ensured by precise positioning of the target, interfering signal source, calibration antenna and radar sensor.

EN 301 091 and EN 302 264 do not define wanted performance criteria due to radar sensors being tailored to a range of specific applications. The target type and properties are therefore subject to manufacturer declaration.

This opens up the possibility of using a radar target simulator, now commercially available from several test equipment manufacturers. These are capable of simulating a wide range of target types and properties, and can help to ensure accurate and repeatable measurements.

Conclusion

- Although mm wave spectrum has been in use to some extent for a number of years, the latest evolution of the technology and its uses has a considerable impact on product compliance, requiring a shift in the established measurement practices.
- Test equipment manufacturers have responded quickly, keeping pace with the evolving technology.
- Standards and procedures are lagging behind, leaving key issues unaddressed in the interim.
- Seeking guidance from a Notified Body / FCC OET enquiry / ISED Canada Certification and Engineering Bureau may be the best course of action where standards and procedures are not yet in place.

Thank you

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