Generating and Analyzing Complex Modulated Signals at Millimeter Frequencies

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Agilent Technologies, Inc.

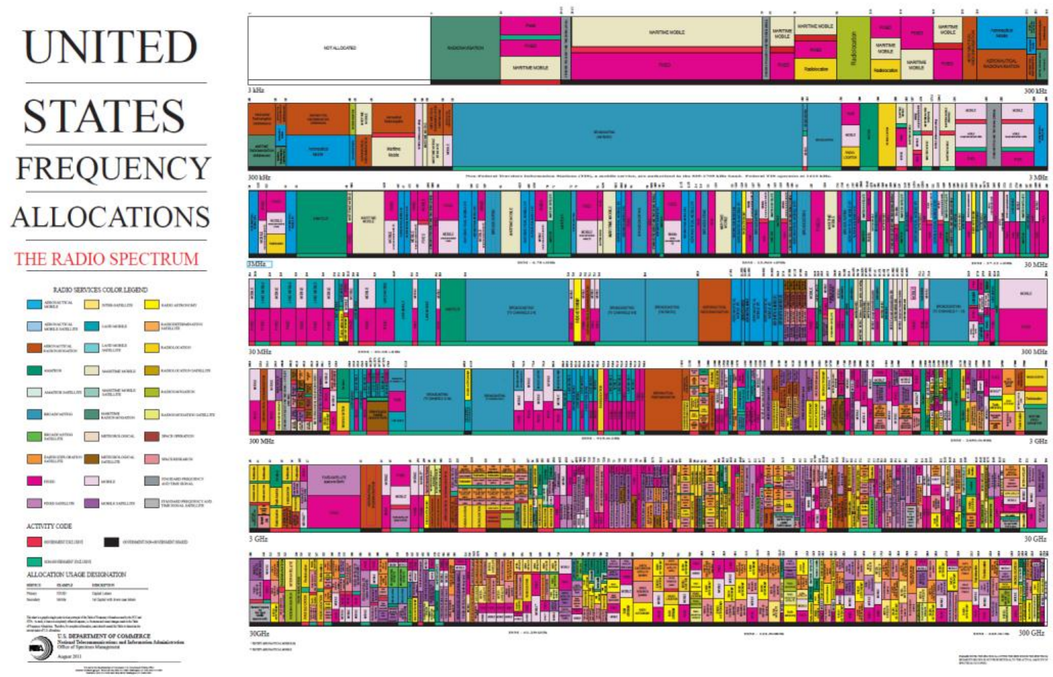
Anticipate __Accelerate __Achieve

Agenda:

- The growth of millimeter applications
- Measurement challenges at millimeter frequencies
- Signal Generation
  - Multipliers
  - Upconverters
- Signal Analysis
  - External Mixers
  - Smart Mixers
  - Frequency Extenders and Downconversion
  - Demodulation and Analysis
- Summary

Electromagnetic Spectrum is a Valuable Resource

- Ever-increasing number of wireless applications
- Spectrum auctions provide revenue for governments
- Business mergers and acquisitions can be driven by who controls what spectrum allocation
- VHF, UHF and microwave bands becoming increasingly crowded
- Greater potential for interference



Source: http://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart

One Solution: Millimeter Frequencies

Traditionally the 30 to 300 GHz spectrum (i.e., wavelength 10 ~ 1 mm)

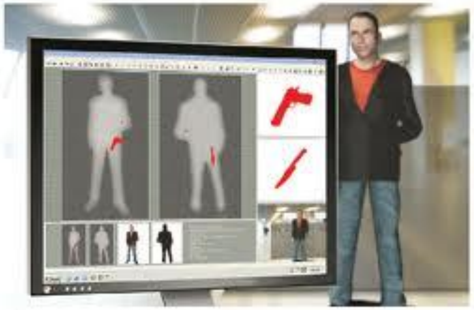
Research now extending to 500 GHz, 1 THz, and beyond

Benefits:

- Small antenna size
- High resolution
- Uncluttered spectrum & reduced interference
- Wide bandwidths
- Advantageous use of atmospheric properties

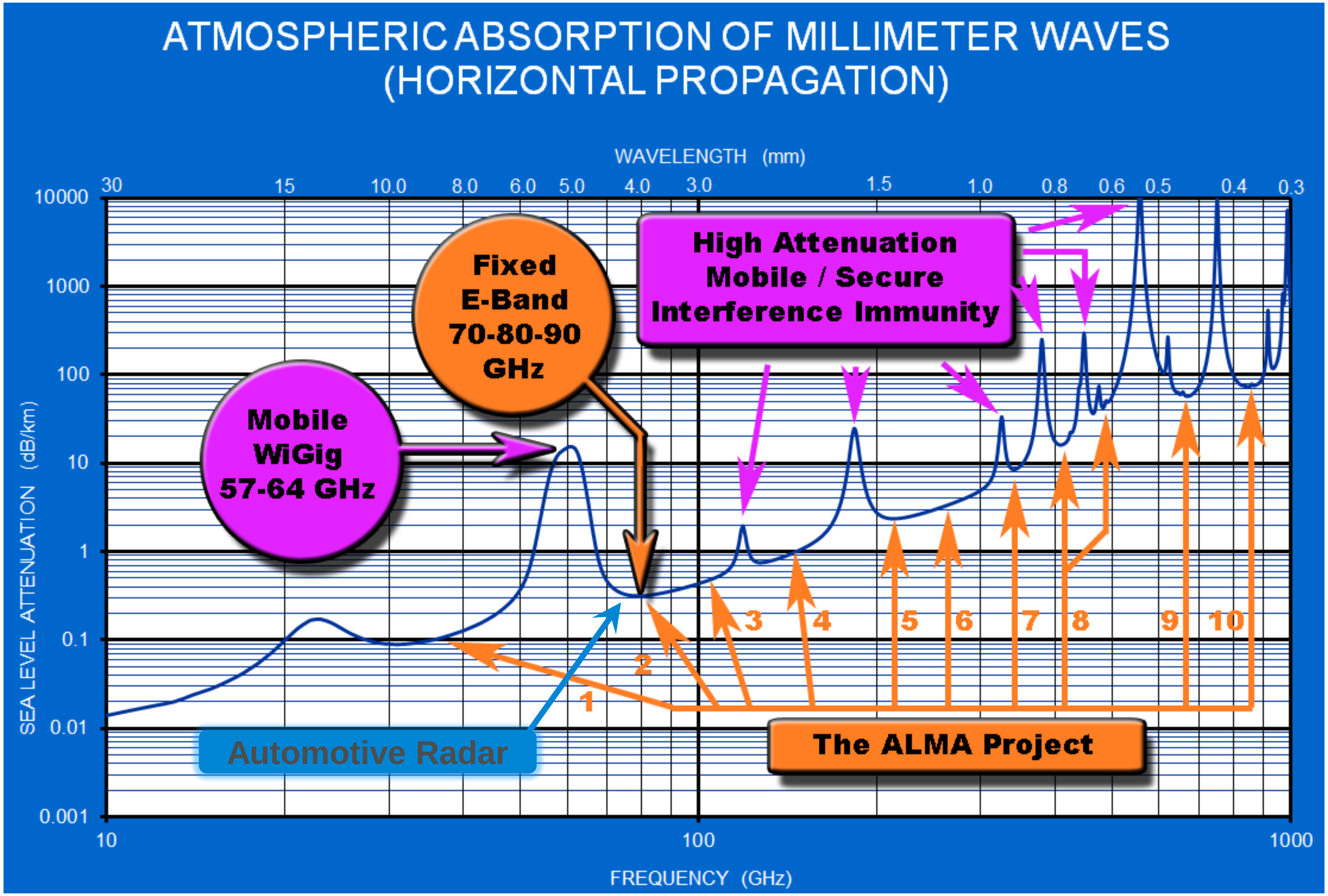
Growing Millimeter-wave Applications

- **Backhaul radio systems**
- **Automotive Radar**
- **Early next-generation wireless research (“5G”)**
- **802.11ad WiGig**
- **Aerospace/Defense**
  - Radar
  - Secure Communication systems
  - Airport Security



1. Passive millimeter-wave imaging can reveal weapons that are concealed under clothing.

Atmospheric Properties



Source: "Making Connections Beyond 110 GHz", by David J. Vondran, OML Inc., Microwave Journal, Feb 2013

Measurement Challenges at Millimeter Frequencies

- Inability to penetrate walls, foliage, etc.
- Higher losses , especially as you increase frequencies
- Smaller and more fragile cables, adapters and accessories
- Costs are high
- Lack of metrology-grade power standards above 110 GHz

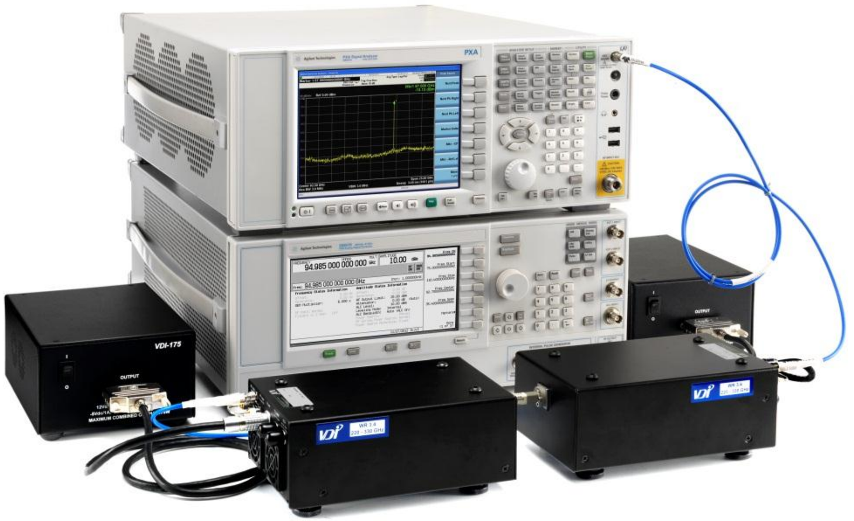
Millimeter Signal Generation

Methods of generating signals

- Multiplication
- Upconversion

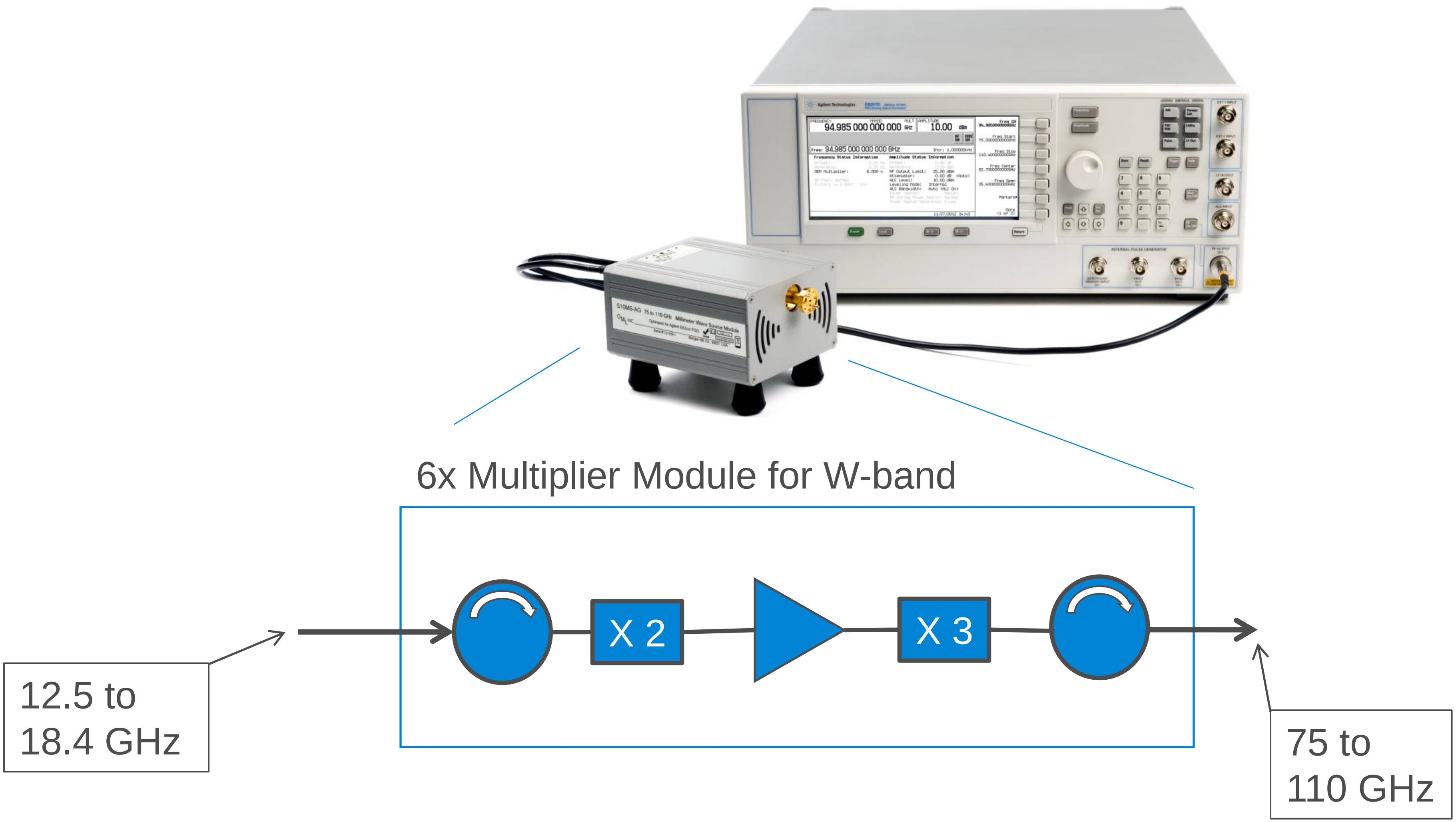
Considerations

- Frequency range requirements
- Output power requirements
- Modulation and Bandwidth requirements
- Minimizing spurious signals

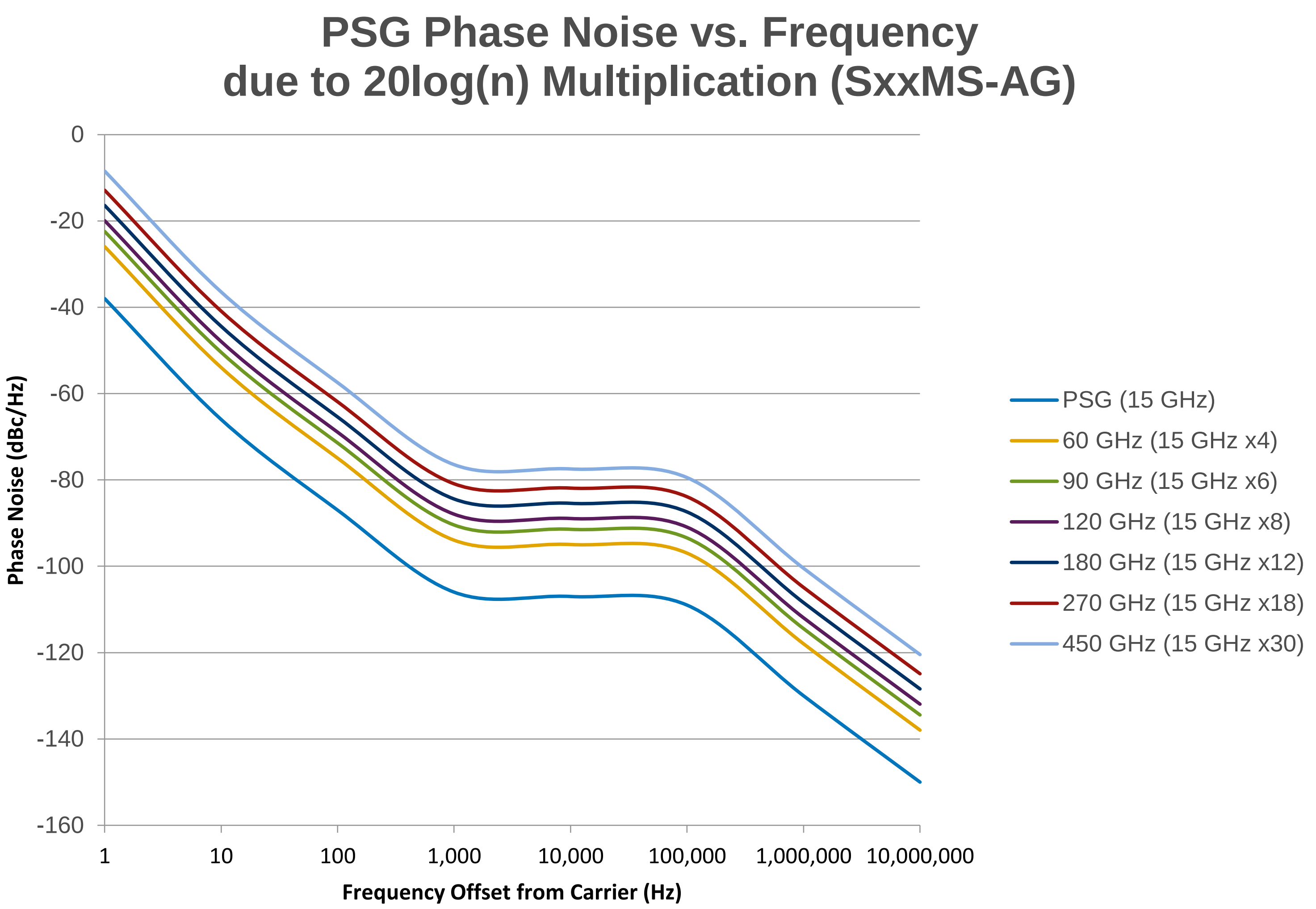


Signal Generation

Multiply a Microwave Signal to Achieve Millimeter Frequencies



Multiplication of Phase Noise



Signal Multiplication
Pros and Cons

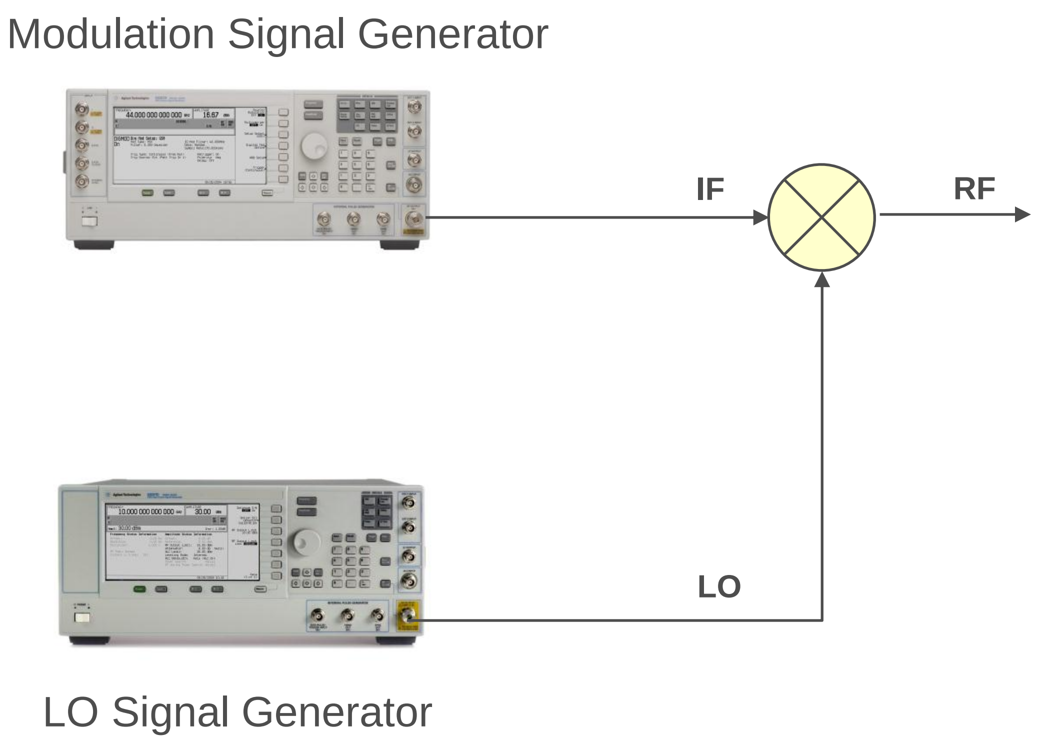
Pros

- A good choice for CW and pulse modulated signals
- Test setup simplicity
- Fixed or variable output power
- Commercially available modules from several manufacturers covering waveguide bands up to 1 THz and above

Cons

- Saturated output power
- Pulse modulation rise/fall times may be altered
- FM and ΦM deviation is multiplied by the multiplication factor
- AM modulation is severely distorted
- Not suitable for most digitally-modulated signals
- Creates harmonic, sub-harmonic and non-harmonic spurious signals, -20 dBc typ

Signal Generation
Up-converting a Microwave Signal to Achieve Millimeter Frequencies



$$F_{RF} = F_{LO} \pm F_{IF}$$

Signal Upconversion
Pros and Cons

Pros

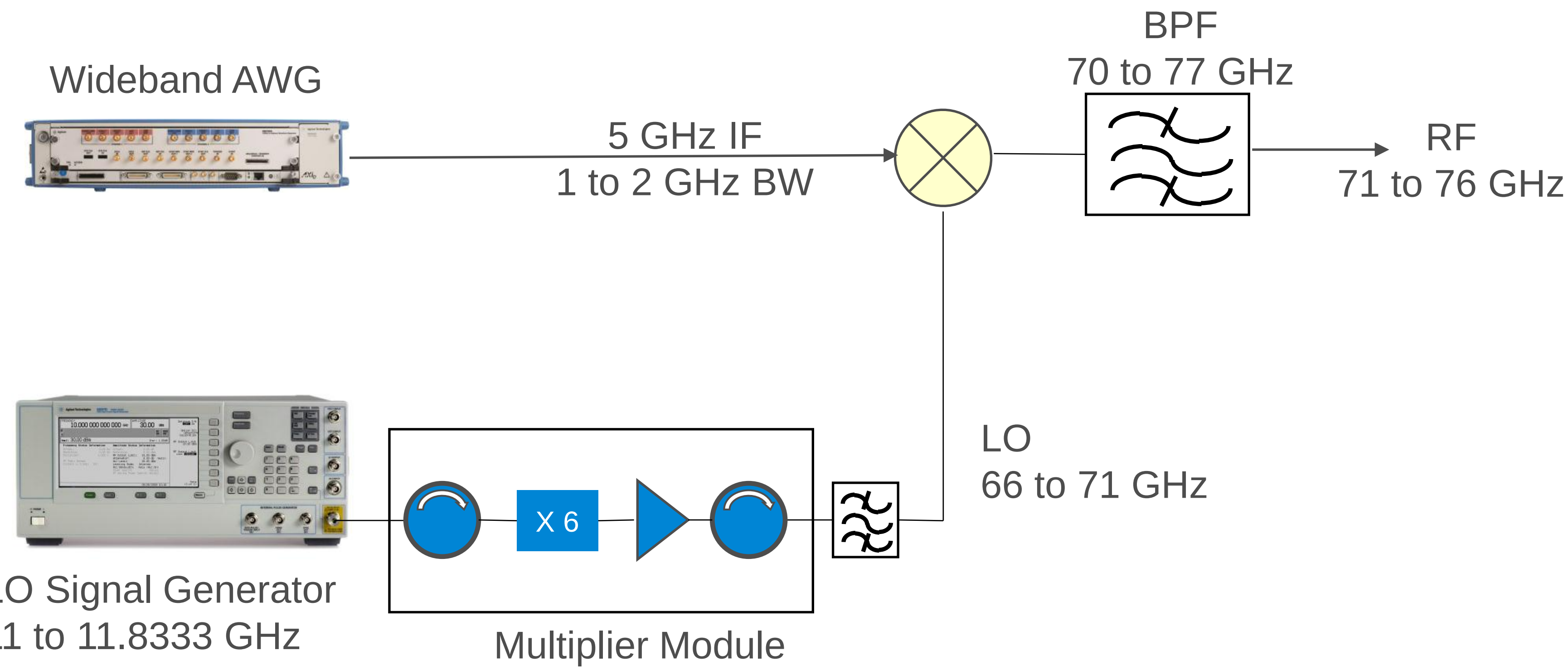
- Much better choice for modulated signals
- Can support wide bandwidth signals
- Reasonable output power

Cons

- Higher-complexity test setup – two sources required
- A well thought-out frequency plan must be established
- Limited choices among off-the-shelf upconverters
- Limited amplitude control
- Creates images, harmonic, sub-harmonic and non-harmonic spurious signals
- Filtering must be taken into account

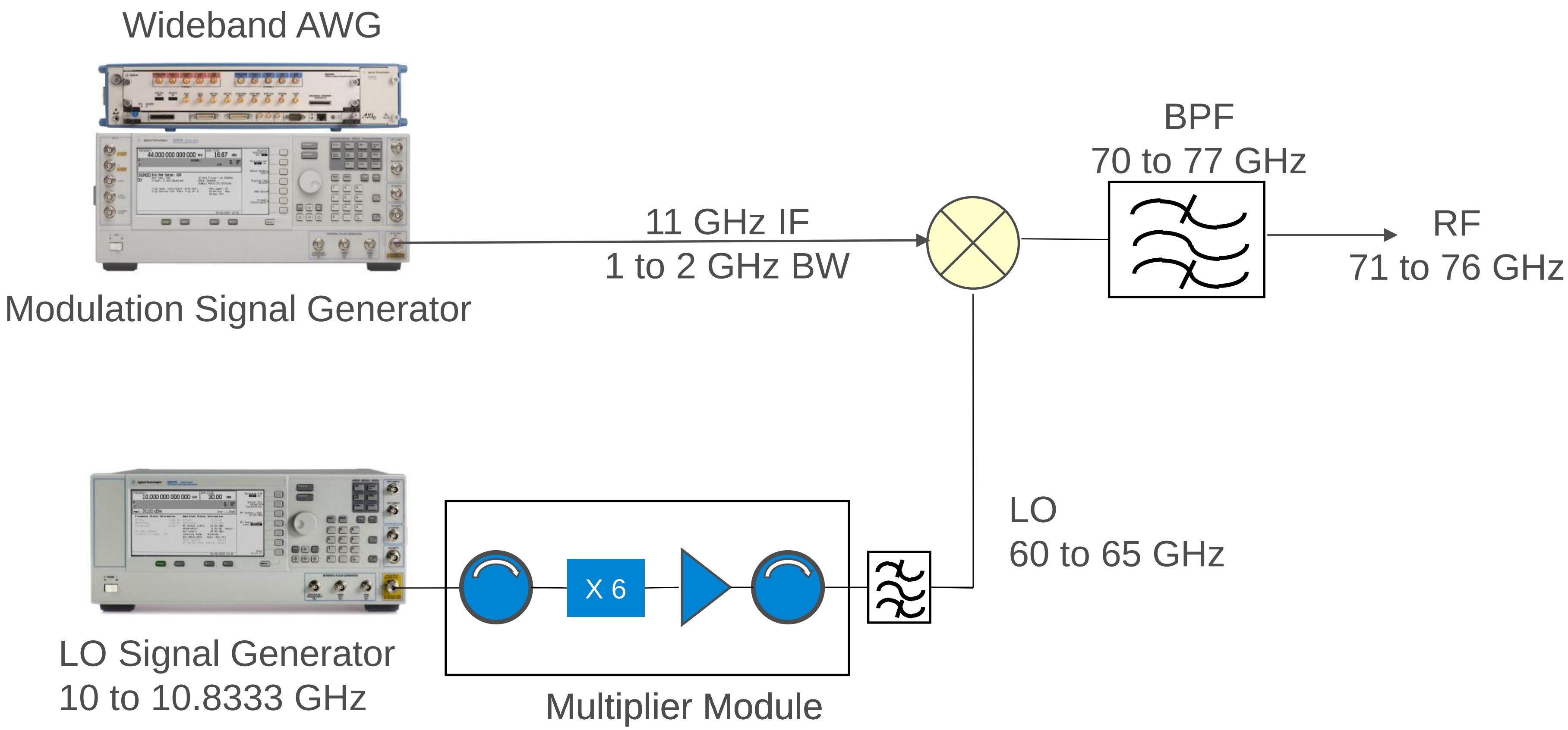
Signal Generation

Example: Generate a modulated RF signal between 71 to 76 GHz with 1 to 2 GHz Bandwidth



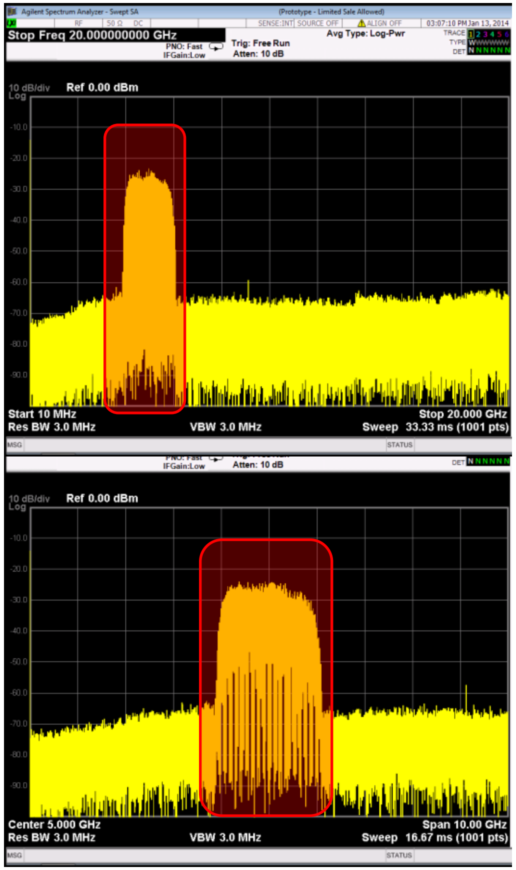
Signal Generation

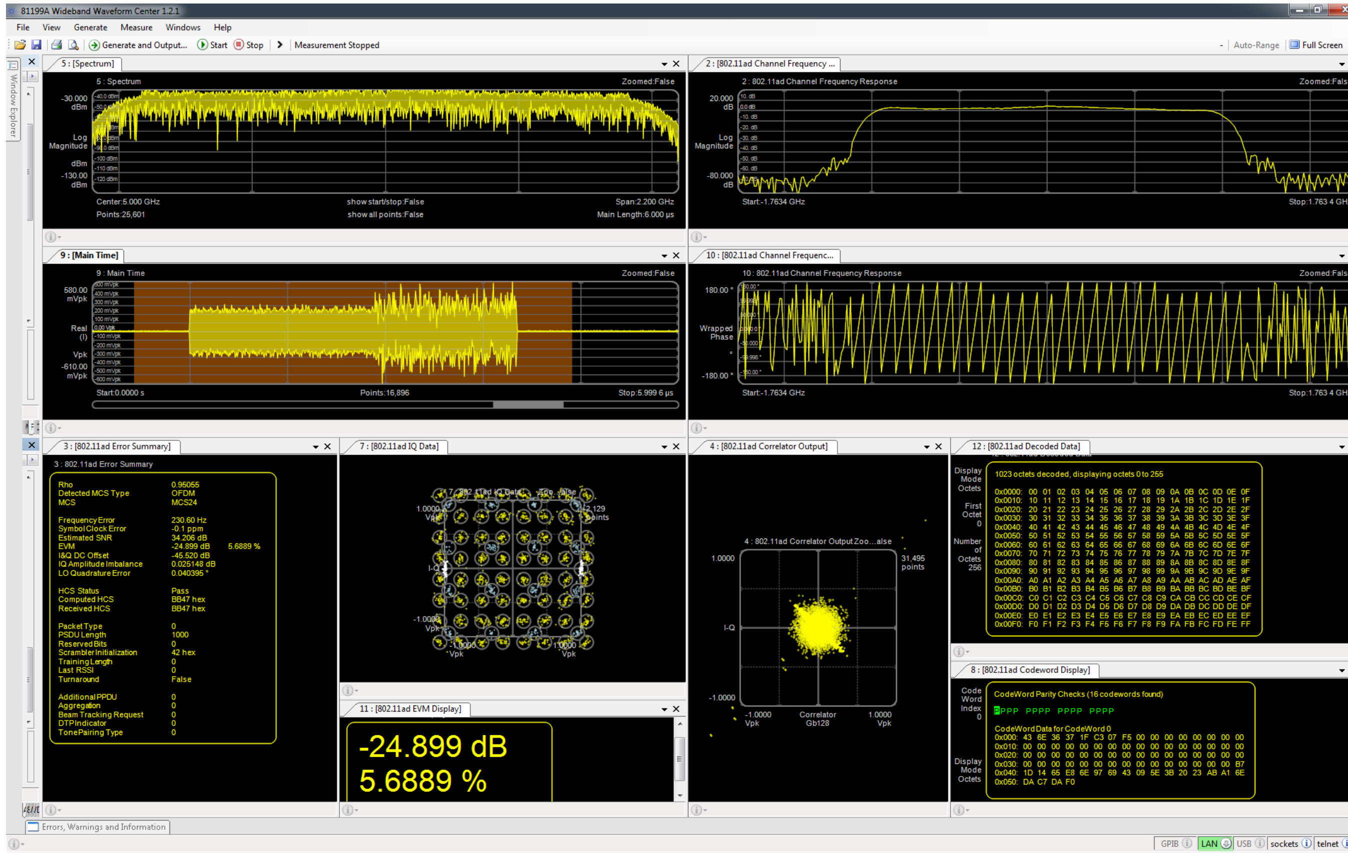
Example: Generate a modulated RF signal between 71 to 76 GHz with 1 to 2 GHz Bandwidth Using a higher IF bandwidth



802.11ad MCS24: M8190A + PSG

No calibration to correct flatness





64QAM OFDM modulated signal

Some optimization made in creating the signal for IQ Gain Imbalance

Symbol Clock Error adjusted in analysis.

EVM around 5.7% is OK, but expecting more like 3-4%. PSG modulator is the noise-limiting element.

Note cleanliness of output spectrum (PSG). Ideal for IF signal generation to 40 GHz.

Signal Generation

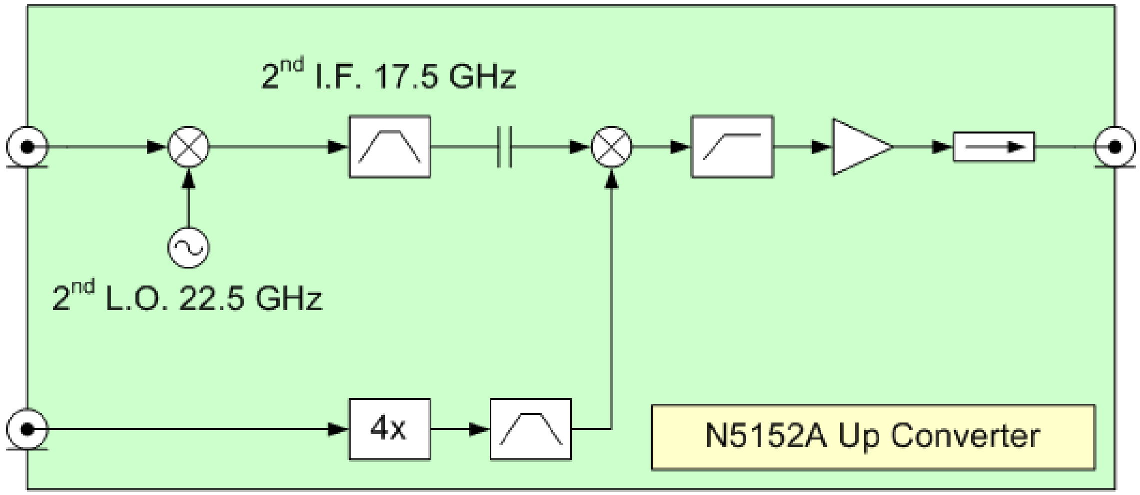
Up-converting a Microwave Signal to Achieve Millimeter Frequencies

Example:
N5152A WiGig (802.11ad)
57 – 66 GHz Upconverter

Signal Generation

Upconverting a Microwave Signal to Achieve Millimeter Frequencies

AWG input: 5 GHz IF

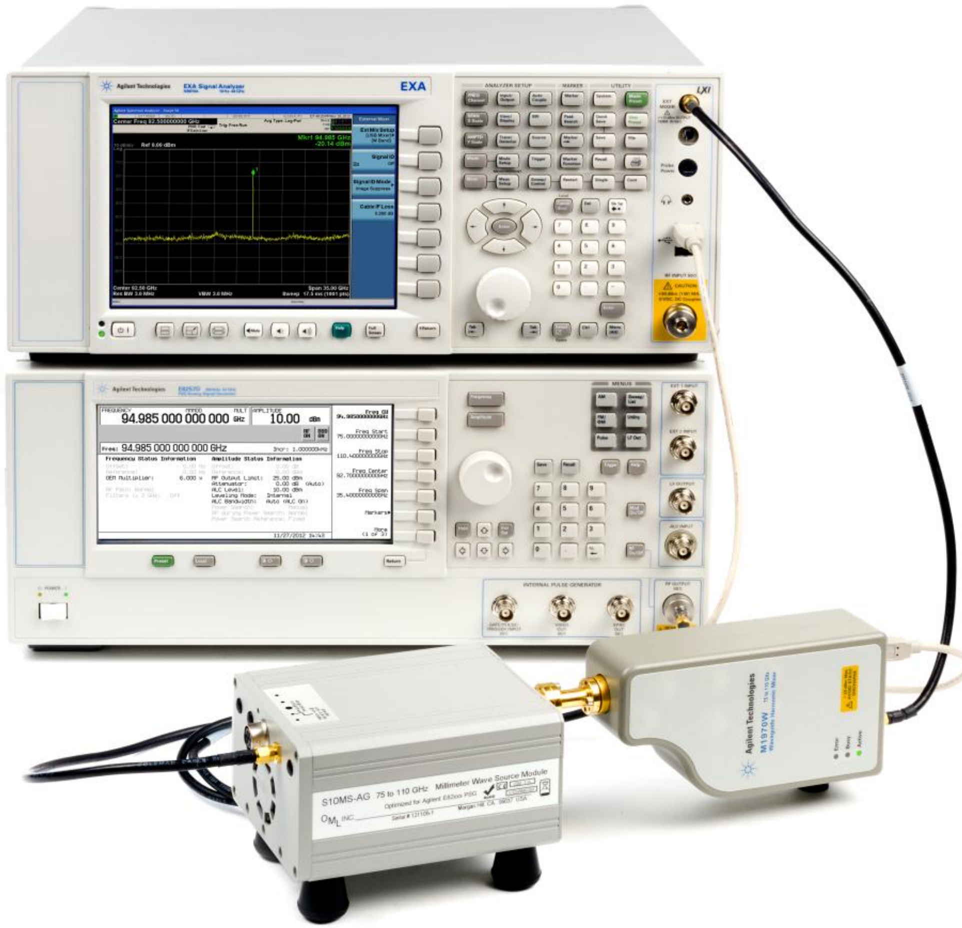


Transmitter Output:
+5 dBm
57 … 66 GHz

LO input: 10-12 GHz

WiGig (802.11ad) frequency band

Signal Analysis



Millimeter Signal Analysis

Methods of analyzing signals

- External harmonic mixers
- Smart mixers
- Downconversion

Considerations

- Frequency range requirements
- Conversion loss and sensitivity requirements
- Modulation and Bandwidth requirements
- Minimizing spurious signals

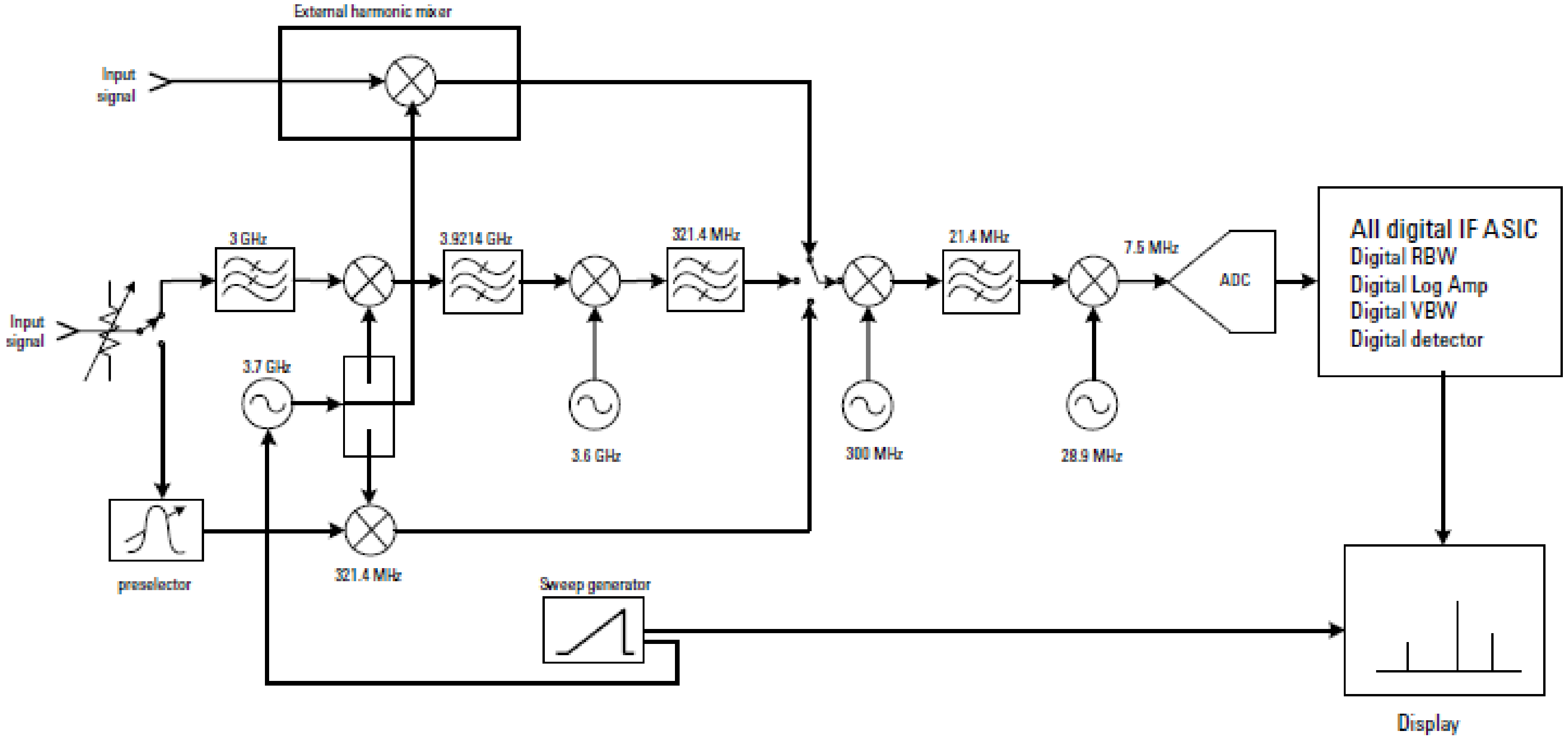
Signal Analysis

Using a Harmonic Mixer to Extend the Spectrum Analyzer Frequency Range

11970 Series tested with Agilent PSA spectrum analyzers

Agilent model number	Frequency range (GHz)	LO harmonic number	Maximum conversion loss (dB)	Nominal spectrum analyzer noise (dBm) 1 kHz BW	Frequency response (dB)	Nominal gain compression (dBm)
11970K	18 to 26.5	6–	24	–105	±1.9	–3
11970A	26.5 to 40	8–	26	–102	±1.9	–5
11970Q	33 to 50	10–	28	–101	±1.9	–7
11970U	40 to 60	10–	28	–101	±1.9	–7
11970V	50 to 75	14–	40	–92	±2.1	–3
11970W	75 to 110	18–	46	–85	±3.0	–1

Harmonic Mixing
PSA Spectrum Analyzer + 11970-Series Mixer



Signal Analysis

Using a Harmonic Mixer to Extend the Spectrum Analyzer Frequency Range

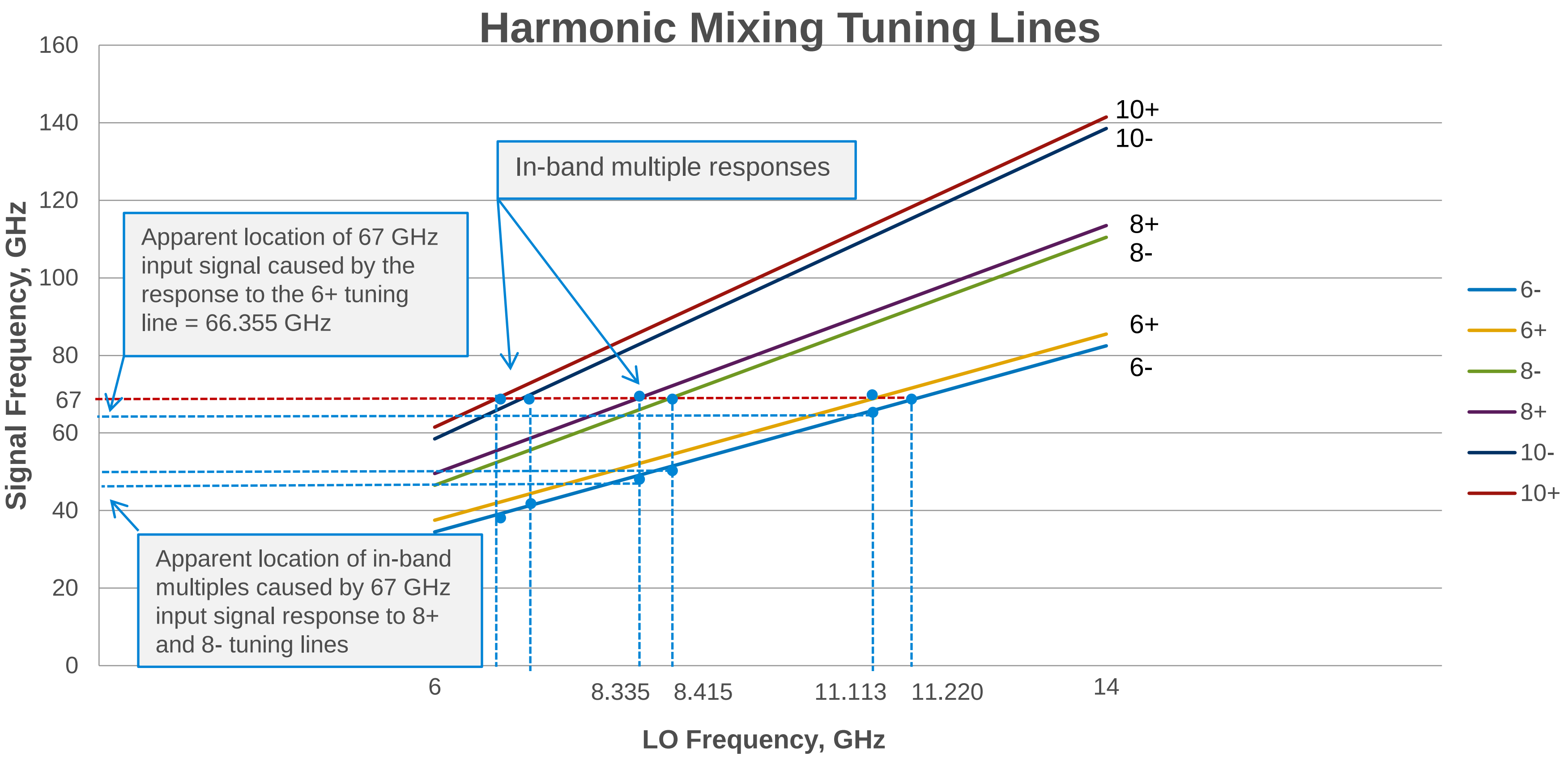
Diplexer built-in to PXA/EXA allows LO and IF signals to share the same RF cable

Some harmonic mixers require DC bias – delivered via same LO/IF coax cable

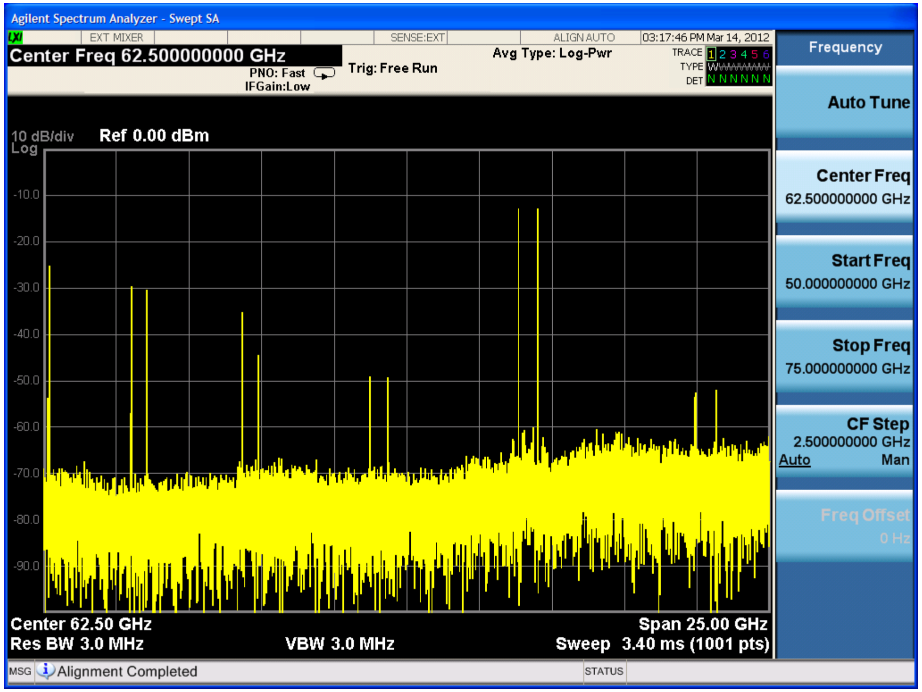
Harmonic Mixing

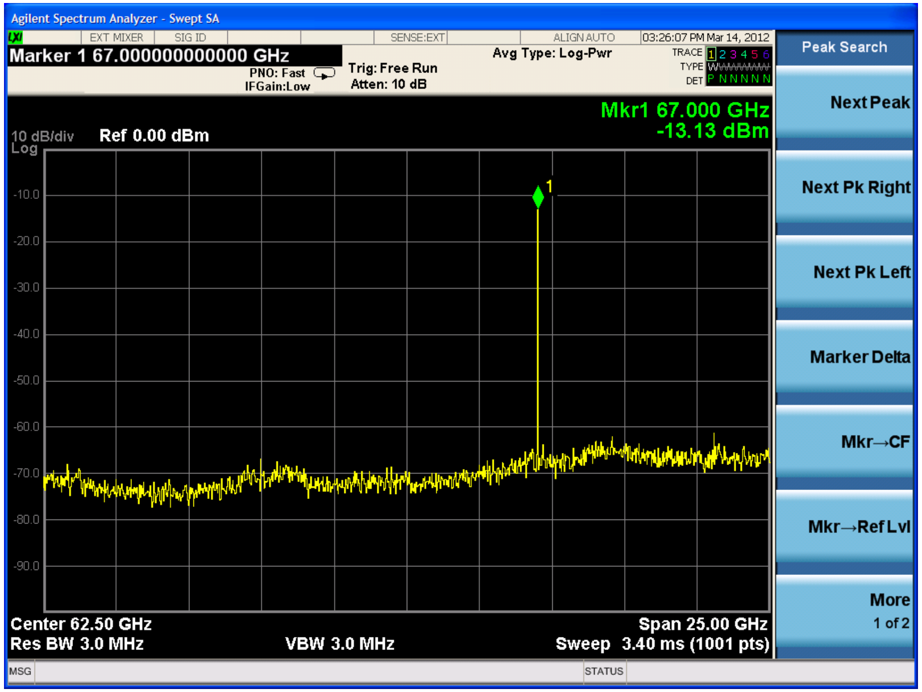
$$F_{RF} = n \times F_{LO} \pm F_{IF}$$

Where PXA IF frequency = 322.5 MHz



Signal Identification





Signal Identification OFF

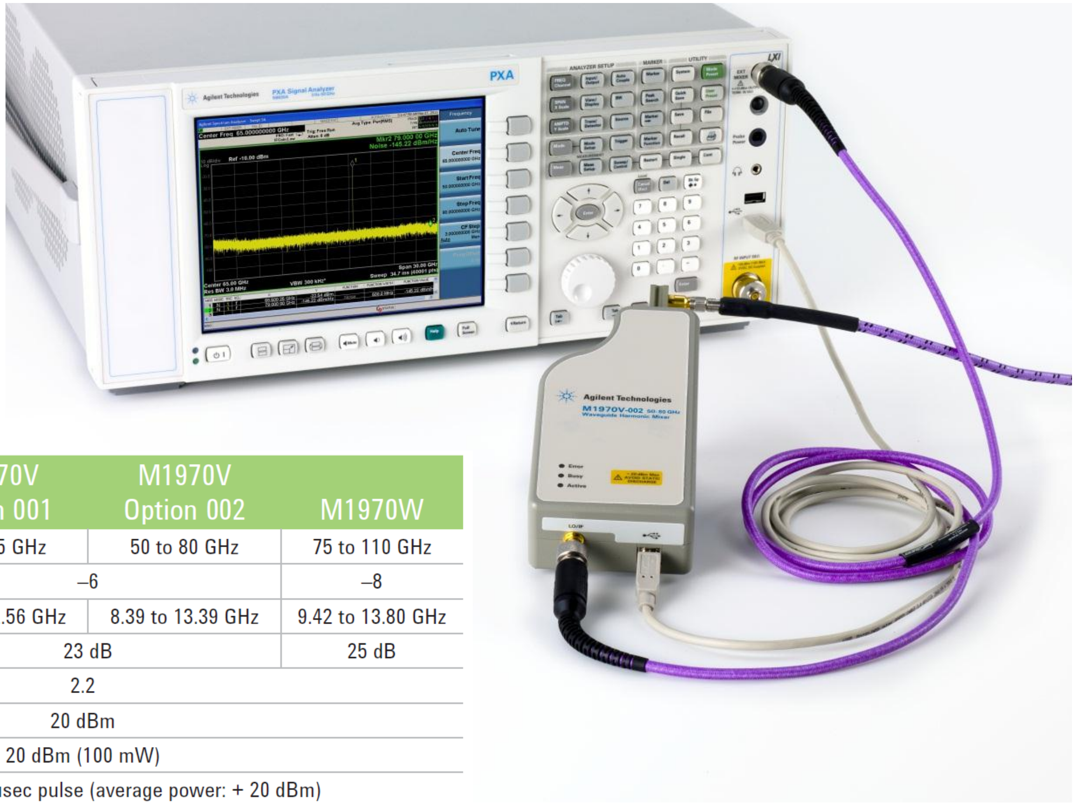
Signal Identification ON
using ***Image Suppress*** function

Signal Analysis
Phase Noise Increases at Higher Frequencies

Agilent M1970-Series Smart Mixers

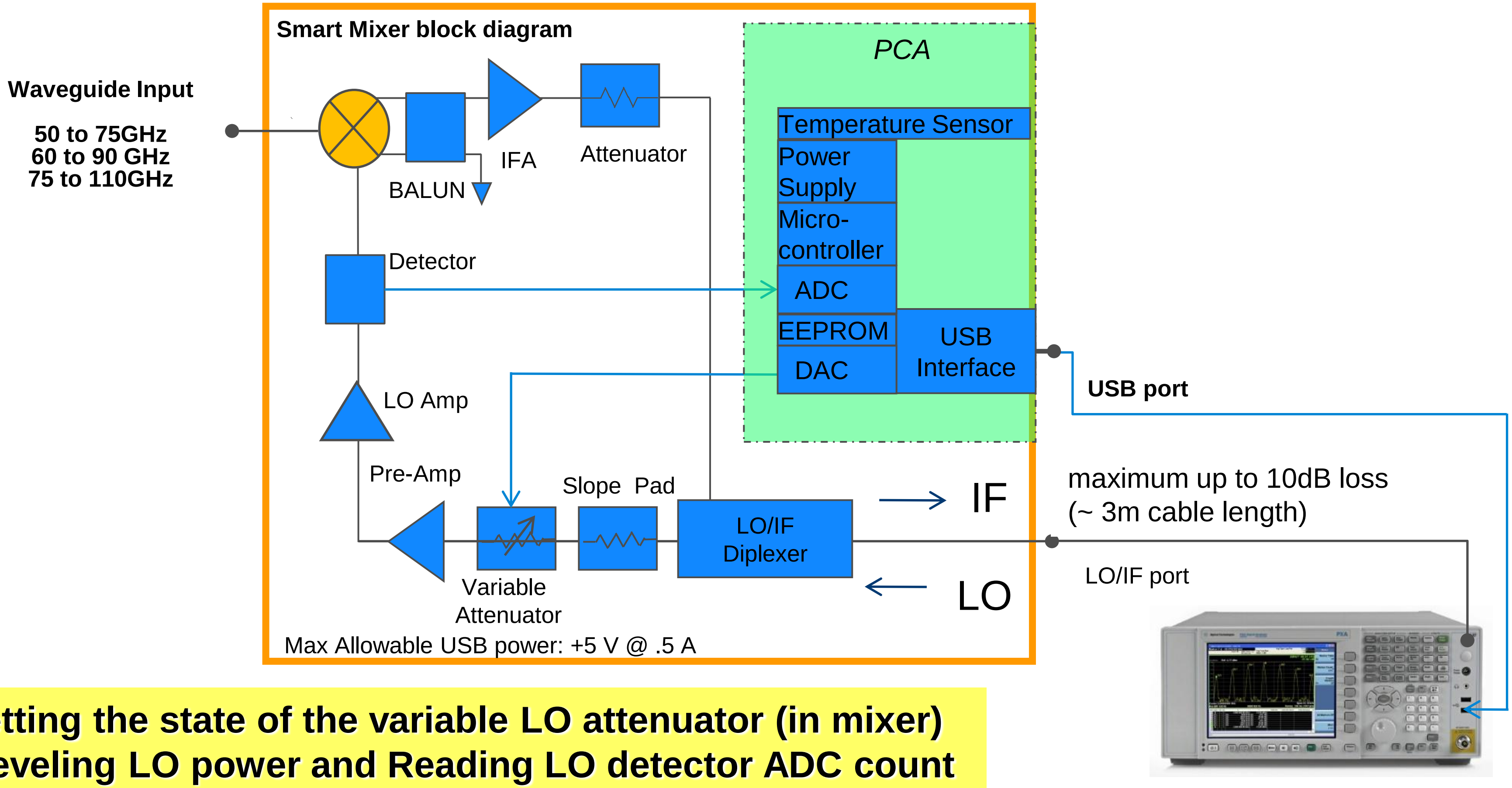
USB connection provides:

- Automatic ID
- Harmonic number
- Conversion loss data
- LO path loss



Specification	M1970E	M1970V Option 001	M1970V Option 002	M1970W
Frequency range	60 to 90 GHz	50 to 75 GHz	50 to 80 GHz	75 to 110 GHz
LO harmonic number[1]	–6/–8	–6		–8
LO input frequency range[2]	9.42 to 12.56 GHz	8.39 to 12.56 GHz	8.39 to 13.39 GHz	9.42 to 13.80 GHz
Maximum conversion loss[3]	27 dB	23 dB		25 dB
Calibration accuracy (*nominal*)[4]	2.2			
Maximum LO power	20 dBm			
Maximum CW RF input level	20 dBm (100 mW)			
Maximum RF peak pulse power	24 dBm with < 1 µsec pulse (average power: + 20 dBm)			
Odd order mixing product suppression (*nominal*)	15 dB			
Gain compression level (< 1dB) (*nominal*)	–1 dBm			
Input SWR (*nominal*)	2.6			
Noise figure (*nominal*)[5]	40 dB	36 dB		38 dB
System displayed average noise level (DANL) at 1 Hz resolution bandwidth (*nominal*)[6]	–136 dBm	–140 dBm		–138 dBm

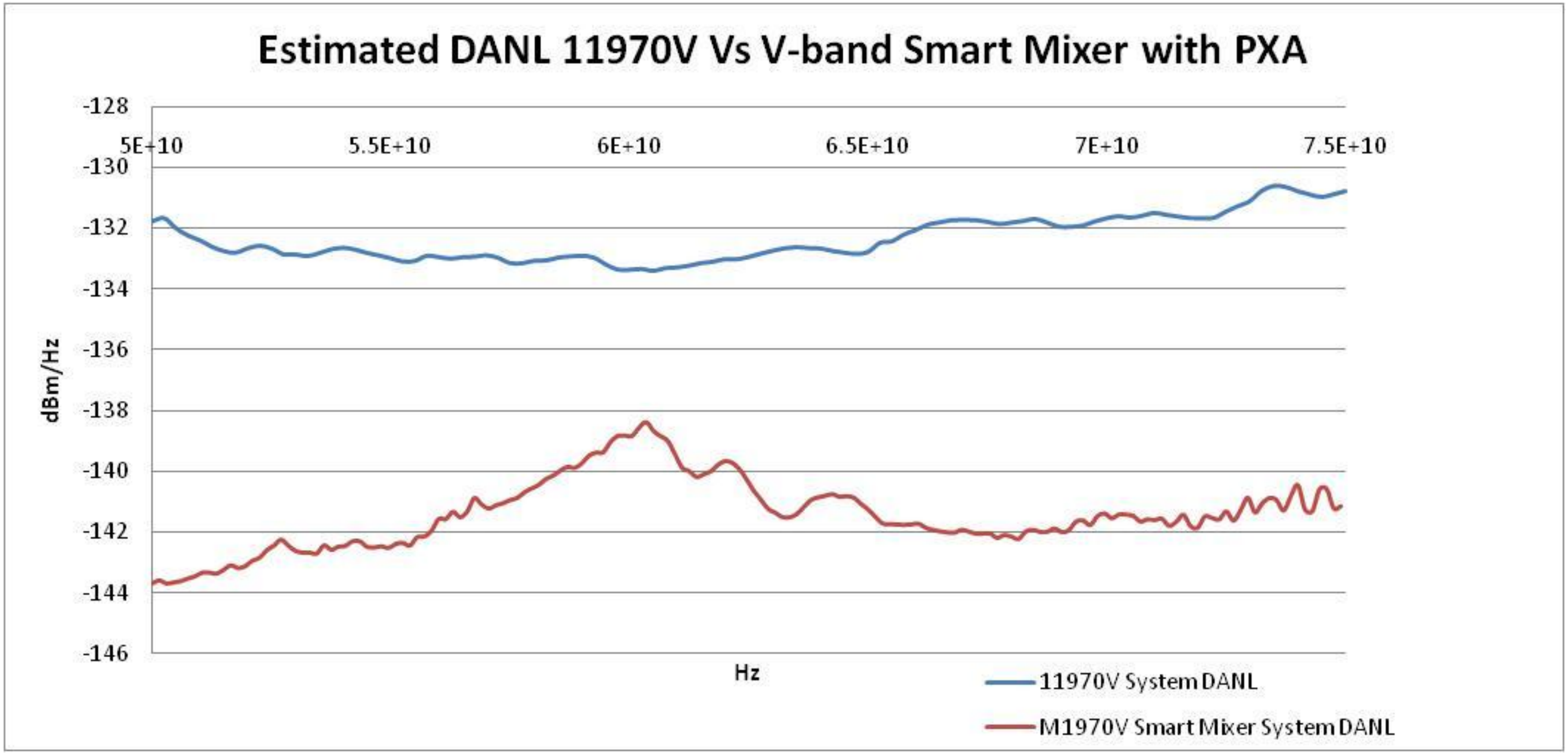
Smart Mixer Functional Block Diagram



1.Setting the state of the variable LO attenuator (in mixer)
2. Leveling LO power and Reading LO detector ADC count
3. Comparing LO detector ADC count to target ADC count
4. Store the LO power level versus LO frequency
5. Sweep thru the entire LO frequency band

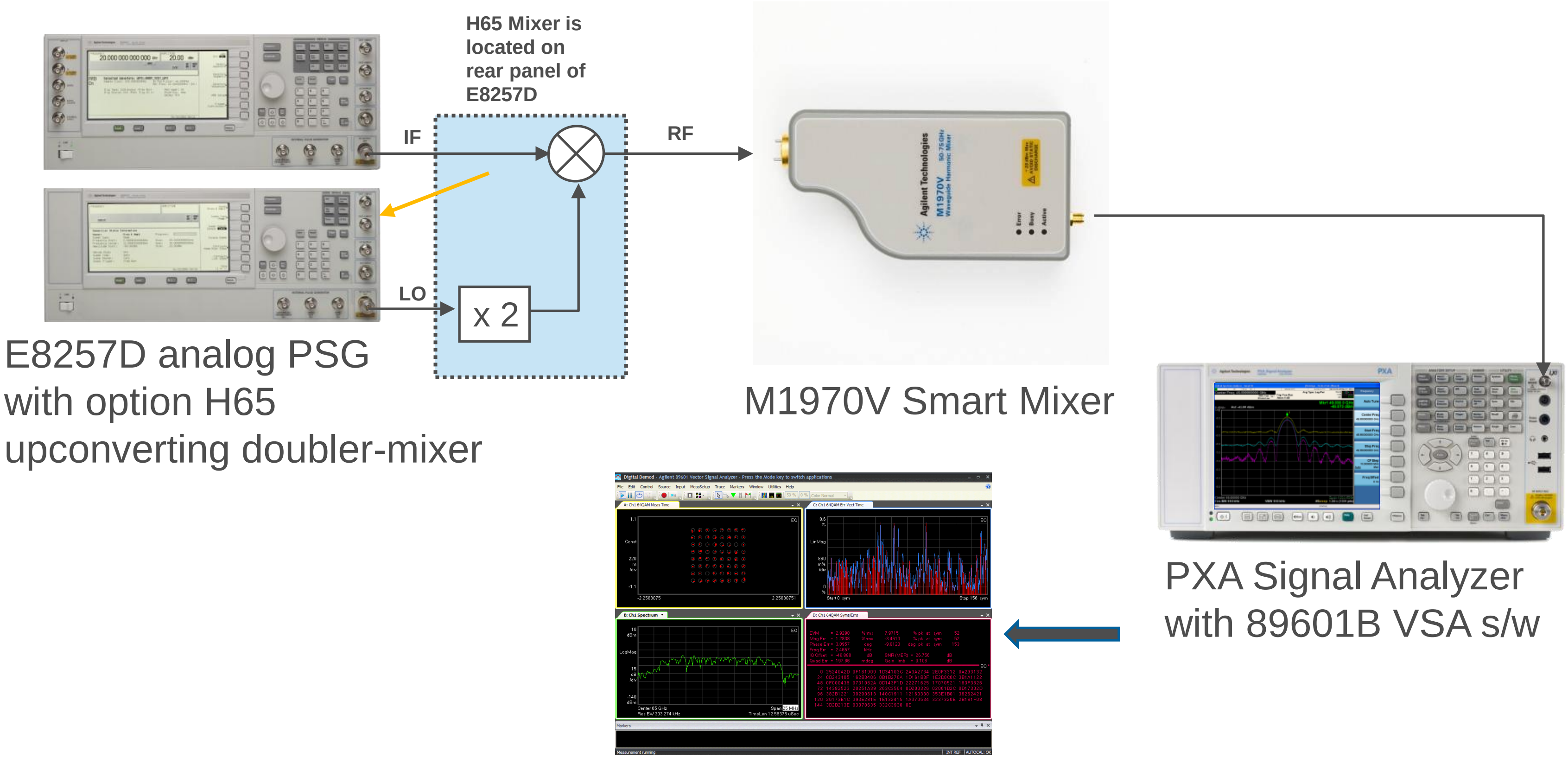
LO range: 8.3 GHz – 13.8 GHz
IF range : 100 MHz – 1 GHz

Millimeter Signal Analysis
DANL Comparison Between Traditional and Smart Mixer Designs



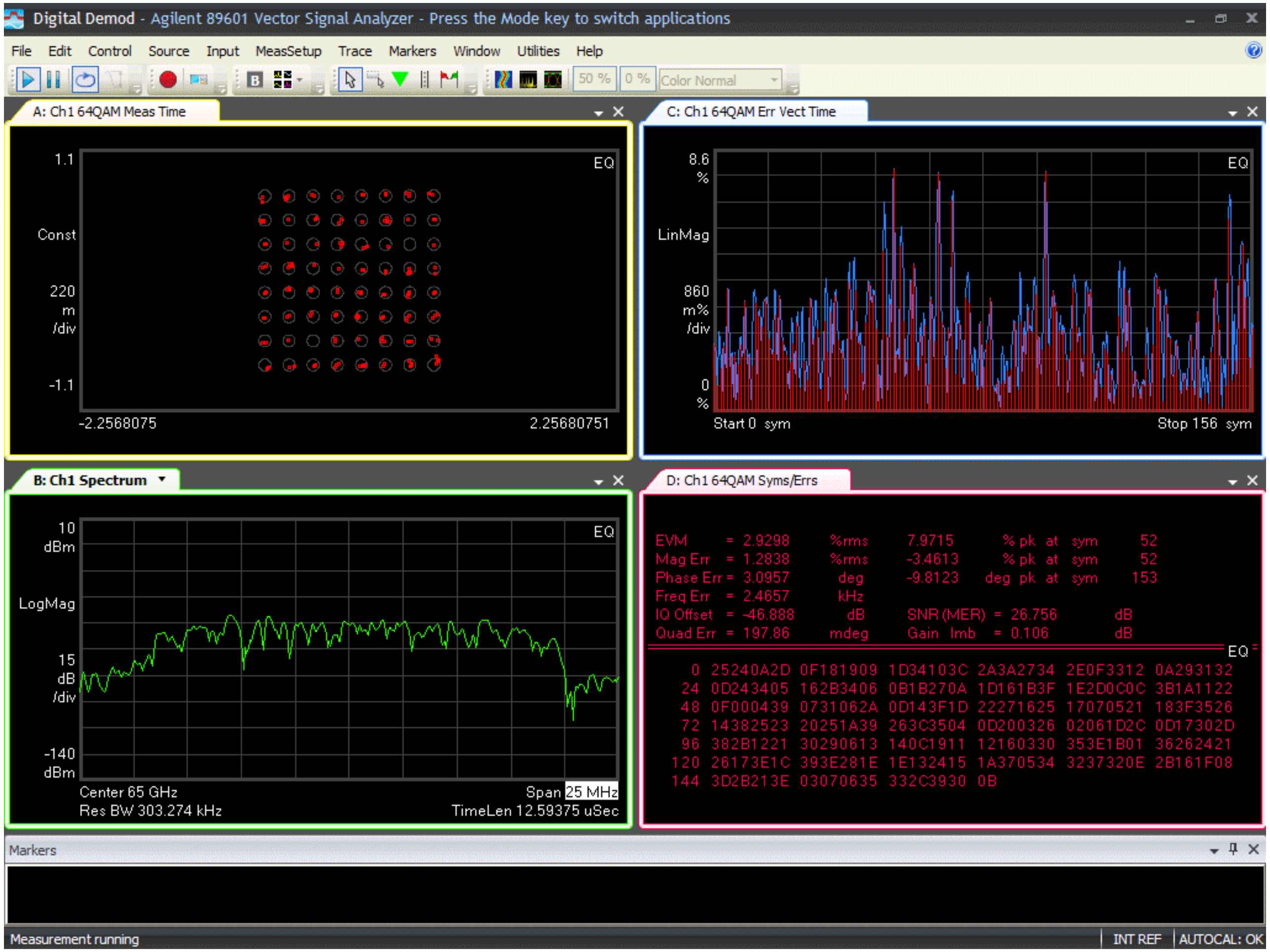
✓ ~5-12 dB improvement in DANL

Demonstration Video
Signal Generation & Analysis of a 64-QAM Signal at 65 GHz



Video Demonstration: http://www.youtube.com/watch?v=yoHbylT-9c0

Analyzing Digitally Modulated Signals



Millimeter Frequency Extenders

Multiply and amplify the spectrum analyzer LO signal prior to mixing

Lower conversion loss = better DANL

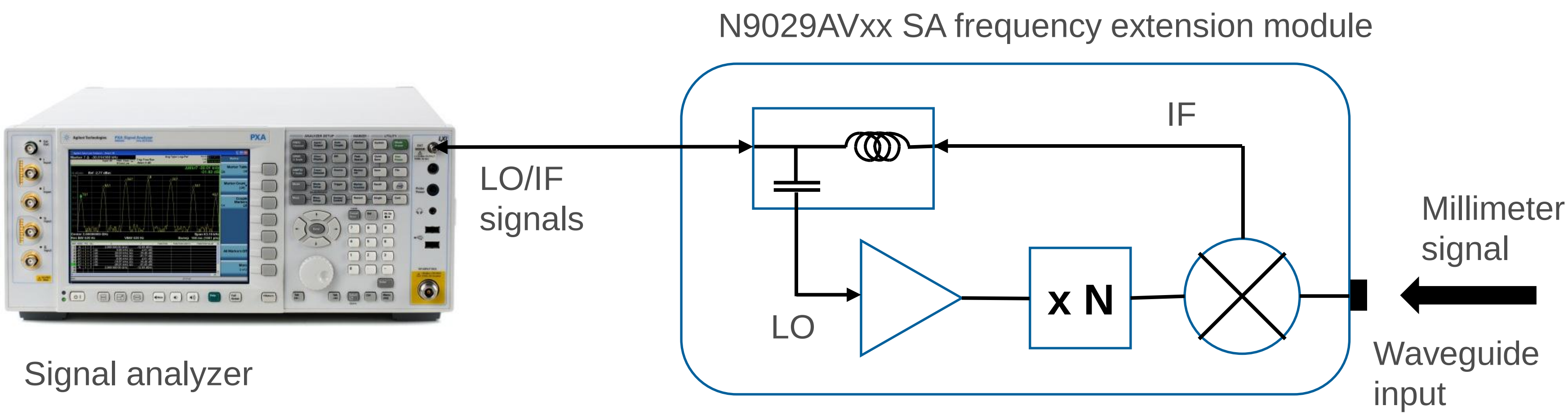
Shown:
N9029AVxx: from VDI Inc..

Waveguide Band	Frequency Range, GHz	Input	Multiplication Factor	LO Input Frequencies	Conversion Loss, dB	Max RF input Compression /Damage, dBm	DANL, dBc/Hz
WR1.0	750 - 1,100	Standard	108	6.9 - 10.2	30	-20/-10	-125
		High	36	20.8 - 30.6			
WR1.5	500 - 750	Standard	54	9.3 - 13.9	20	-20/-10	-135
		High	18	27.8 - 41.7			
WR2.2	325 - 500	Standard	36	9.0 - 13.9	17	-20/-10	-145
		High	12	27.1 - 41.7			
WR3.4	220 - 330	Standard	24	9.2 - 13.8	14	-20/-10	-145
		High	12	18.3 - 27.5			
WR5.1	140 - 220	Standard	18	7.8 - 12.2	12	-10/0	-150
		High	6	23.3 - 36.7			
WR6.5	110 - 170	Standard	24	4.6 - 7.1	12	-10/0	-150
		High	6	18.3 - 28.3			
WR8.0	90 - 140	Standard	12	7.5 - 11.7	12	-10/0	-150
		High	4	22.5 - 35.0			
WR10	75 - 110	Standard	12	6.3 - 9.2	11	-10/0	150
		High	6	12.5 - 18.3			
WR12	60 - 90	Standard	12	5.0 - 7.5	11	-10/0	-150
		High	6	10.0 – 15.0			
WR15	50 - 75	Standard	6	8.3 - 12.5	9	-10/0	-150

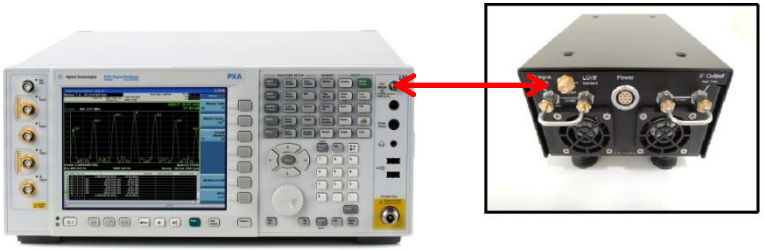
N9029AVxx SAX Frequency Extension Module

Standard Mode

- Easiest setup
- Best for CW and narrowband signals

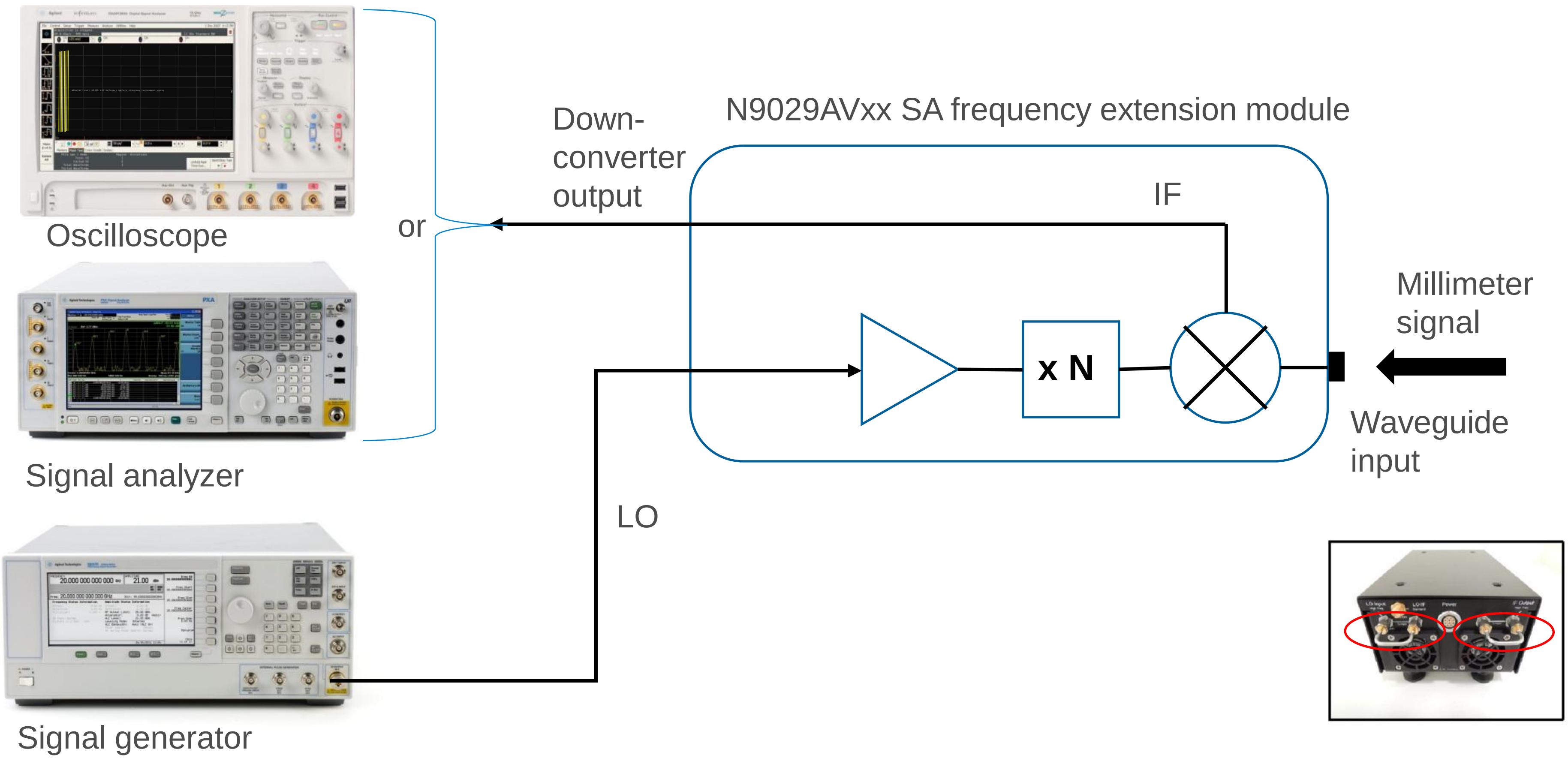


- If demodulation analysis is desired, signal bandwidth is limited to signal analyzer analysis bandwidth



N9029AVxx SAX Frequency Extension Module
Block Downconverter Mode

- Most flexible setup
- Best for wideband signals – up to 20 GHz BW

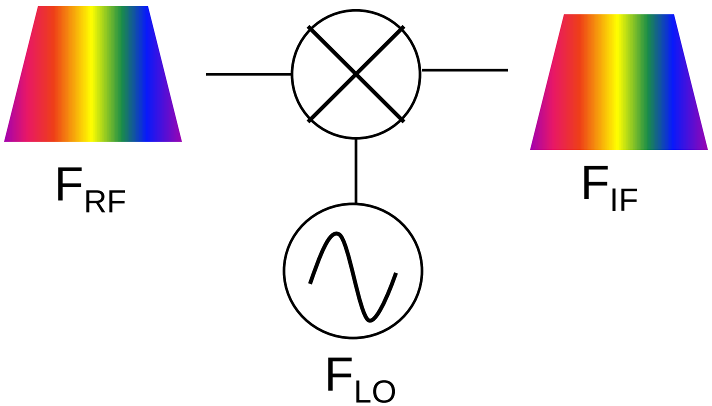


Spectrum Mirroring

- SAX frequency extenders are double side band devices
- The downconverted spectrum may or may not be inverted, depending on whether the RF > LO or if RF< LO
- If RF < LO, then the RF and IF respond inversely to frequency sweeping.
- If RF > LO, then the RF and IF will be directly proportional.

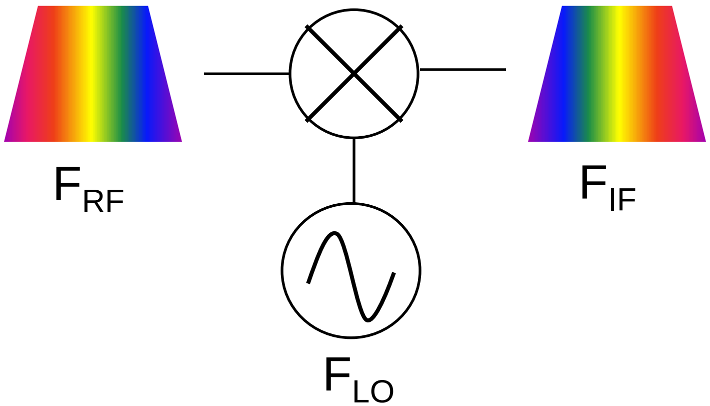
RF > LO

$F_{IF} = F_{RF} - F_{LO}$

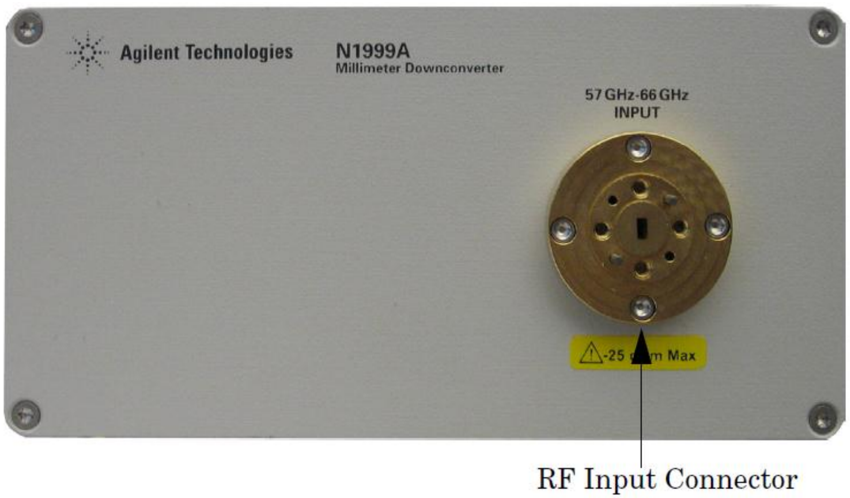


RF < LO

$F_{IF} = F_{LO} - F_{RF}$



Specialized Down Converters

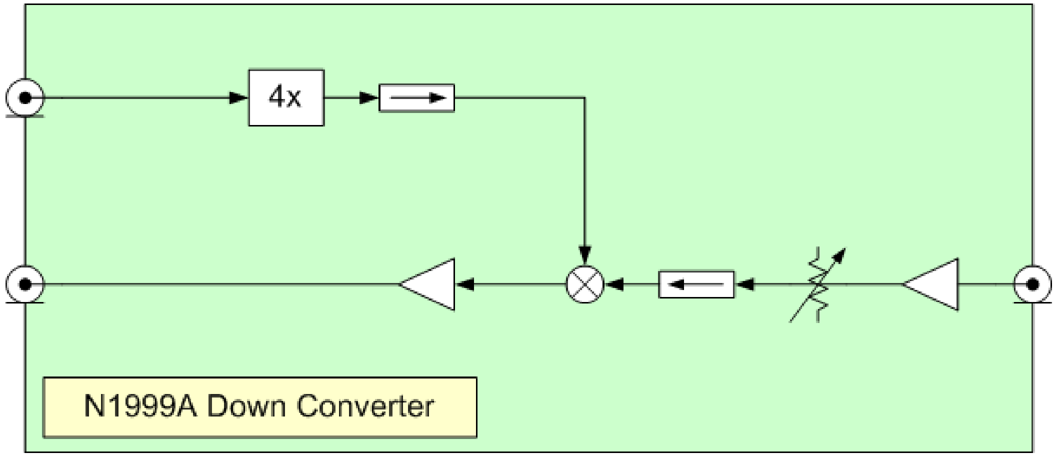


Example:
N1999A WiGig (802.11ad)
57-66 GHz Down Converter

Down Converter (N1999A)

LO input: 12.5 – 18.75 GHz

IF Output to SA or scope:
5 GHz, -7 dBm



Down Converter Input:
-50 to -20 dBm
57 … 66 GHz

Specifications (Preliminary, 25°C - 30°C)

LO Section

Input Frequency:	12.50 to 18.75 GHz
Input Power:	≤ +10 dBm
Maximum Input:	+13 dBm

RF Section

Input Frequency:	57 to 66 GHz.
Input Power:	-50 to -30 dBm
Maximum Input:	-15 dBm
IQ bandwidth:	≤ 2 GHz

IF Section

Output Frequency:	5 GHz
Output Power:	-7 dBm
IQ bandwidth:	≤ 2 GHz
Non-Harmonic Spur.:	≤ -30 dBr
Noise Figure:	> 6 dB
Dynamic Range:	≤ 30 dBr

Summary

- Several techniques exist to generate and analyze millimeter-wave signals

- The optimum technique depends on what parameters are most important for your application:
  - Performance
    - Output power
    - Signal purity & distortion
    - Sensitivity
    - Signal bandwidth
  - Budget
  - Equipment on-hand vs. acquiring new instrumentation

  - Greater use of wideband digital modulation in millimeter systems will drive greater usage of up- and down-coverters

Agilent Millimeter-Wave Solutions

For more information, contact your local Agilent sales representative or visit:

Millimeter Signal Generation:	www.agilent.com/find/SG_mmwave
Millimeter Signal Analysis:	www.agilent.com/find/SA_mmwave
Millimeter Network Analysis:	www.agilent.com/find/mmwave
M1970-Series Smart Mixers:	www.agilent.com/find/smartmixers
PSG Signal Generators:	www.agilent.com/find/psg
PXA Signal Analyzers:	www.agilent.com/find/pxa
EXA Signal Analyzers:	www.agilent.com/find/exa

Application Note: **Literature # 5991-3968EN**

Measurement Considerations for Generating and Analyzing Millimeter Wave Signals