Agilent Technologies

Back to Basics: Signal Generation

Agenda

- The need for creating test signals
  - Aerospace Defense to Communications
- Generating Signals
  - No modulation
  - Analog Modulation
  - Composite Modulation
- Signal Generator Architecture
- Signal Simulation Solutions
- Summary

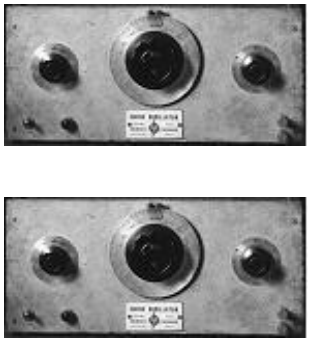
From Movies ….

Nov. 1940 - News Flash

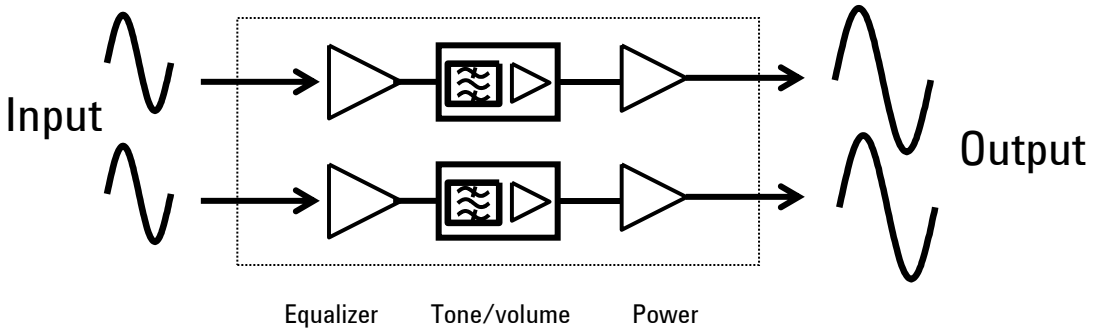
*Disney releases Fantasia with **"Fantasound"**, a new audio stereophonic sound system*

Walt Disney orders eight audio oscillators (HP 200B) for the sound production of the movie Fantasia.

The 200B was used to calibrate the breakthrough sound system of Walt Disney's celebrated animated film, Fantasia

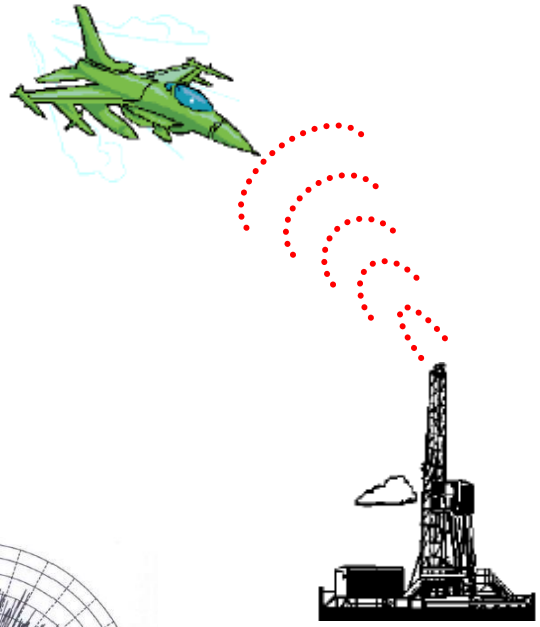


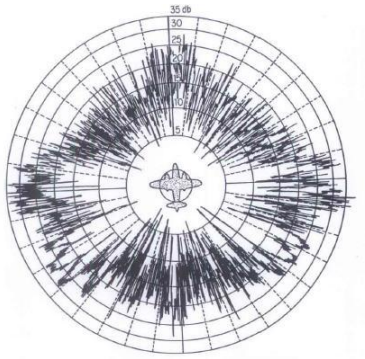
Stimulus/Response Testing

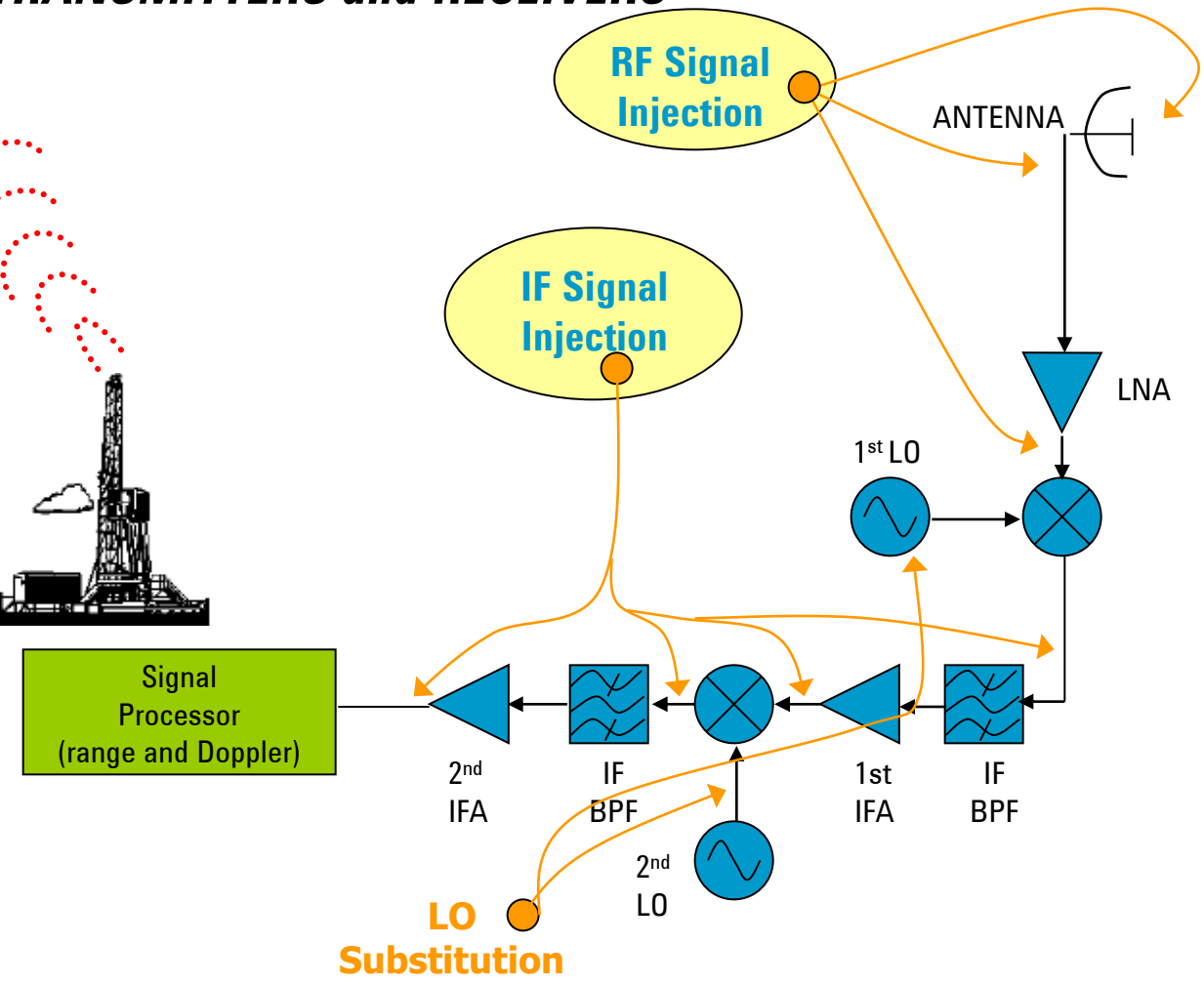


Aerospace Defense ….

TESTING RADAR TRANSMITTERS and RECEIVERS

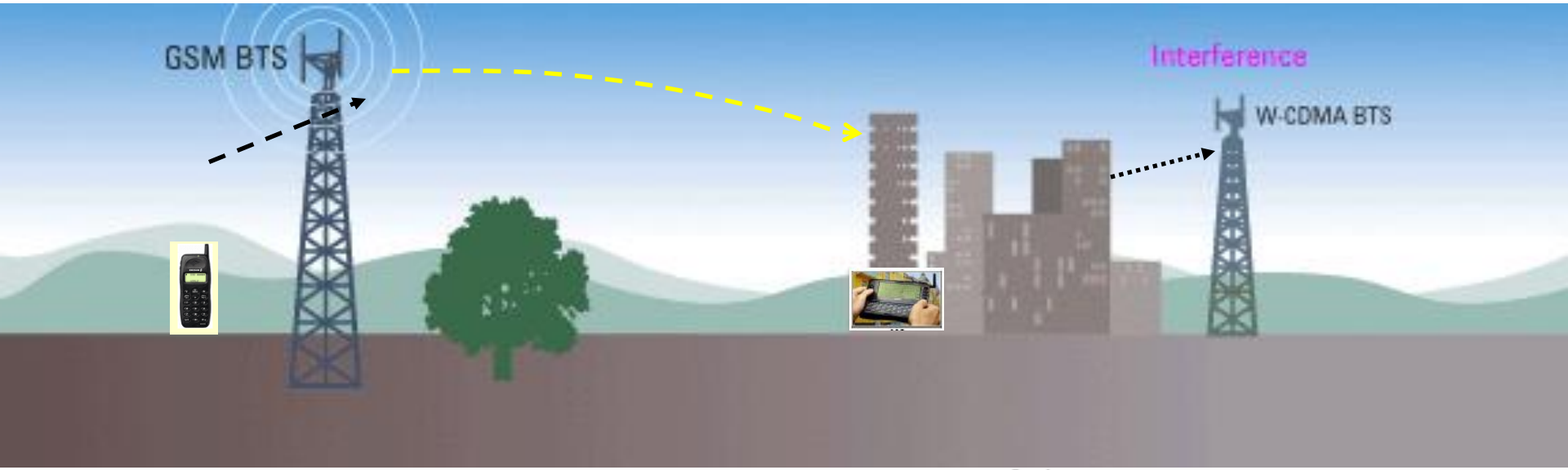


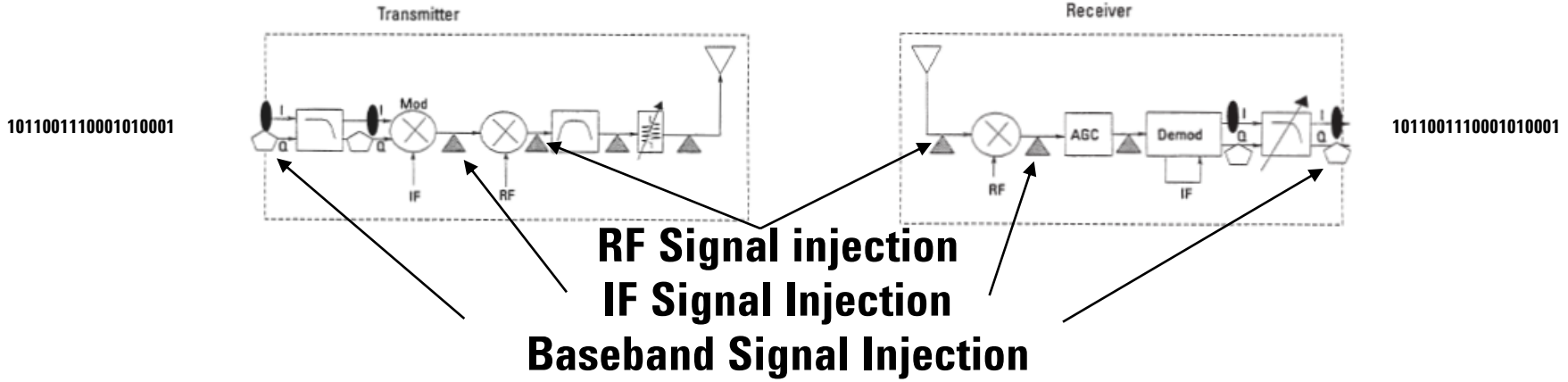




To Mobile Communications….

TESTING DIGITAL TRANSMITTERS and RECEIVERS





Agenda

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  - Aerospace Defense to Communications
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  - Analog Modulation
  - Composite Modulation
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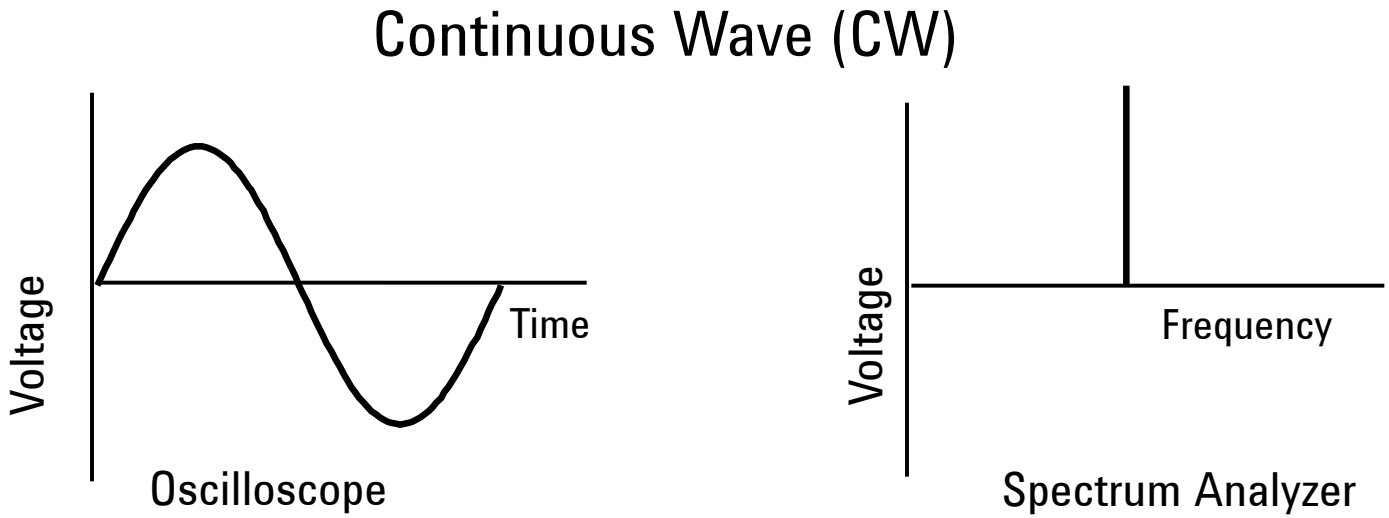
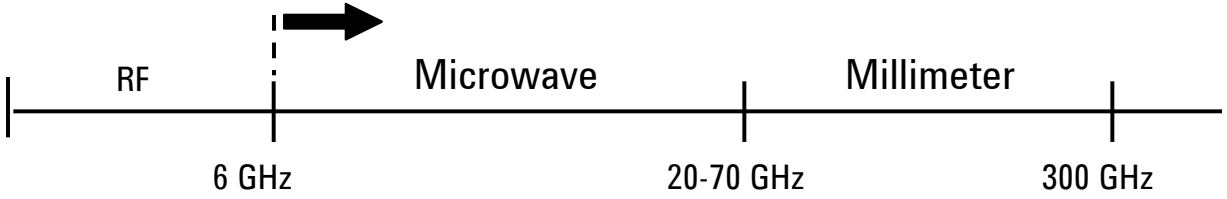
Generating Signals – No Modulation



The sine wave is the basic, non-modulated signal: It is useful for stimulus/response testing of linear components and for Local Oscillator substitution. Available frequencies range from low RF to Millimeter.



Generating Signals – Analog Modulation

Modulation: Where the Information Resides

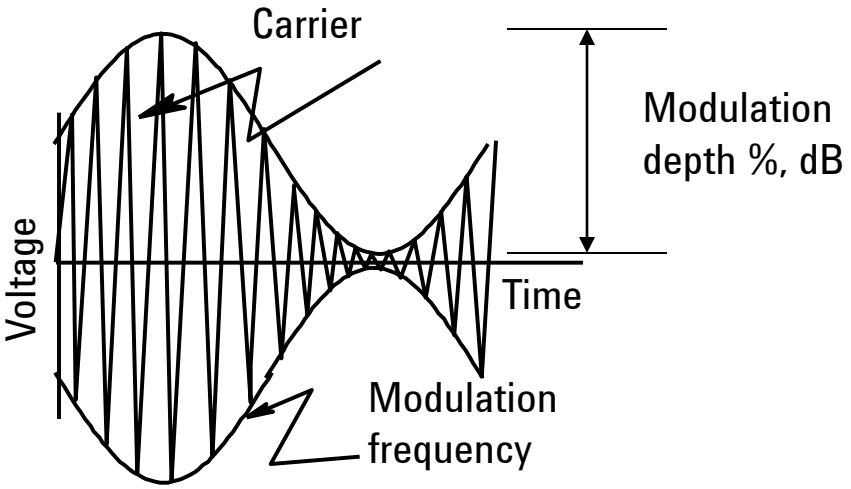
$$V(t) = \underbrace{A(t)}^{*}\cos[\underbrace{2\pi f_c t + \Phi(t)}]$$

AM, Pulse

FM, PM

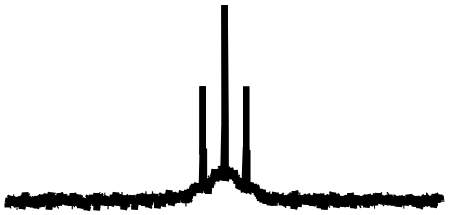
Generating Signals - Analog Modulation

Amplitude Modulation



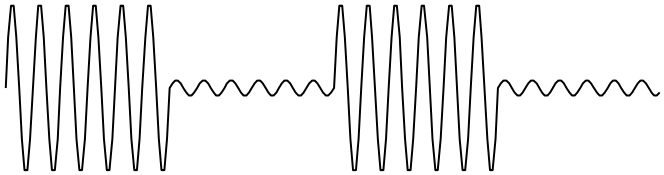
Important Characteristics for Amplitude Modulation

- Modulation frequency (rate)
- Depth of modulation (Mod Index)
- Linear AM (%)
- Log AM (dB)
- Sensitivity (depth/volt)
- Distortion %



Where are AM signals used?

- AM Radio
- Antenna scan
- ASK (early digital 100101)

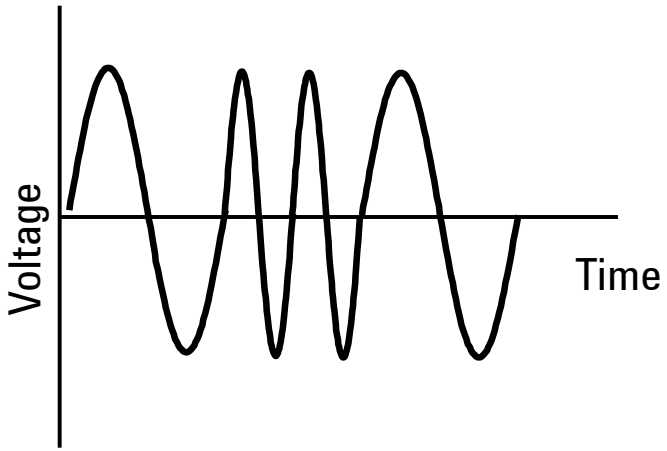


Generating Signals – Analog Modulation

Frequency Modulation

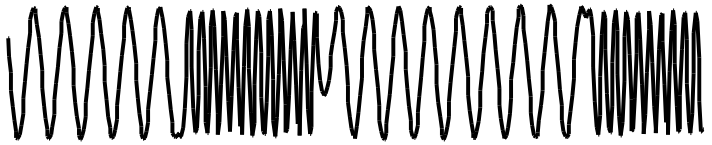
$$V(t) = A \cos[2\pi f_c t + \beta \sin 2\pi F_m t]$$

β is the modulation index,
where $\beta = \Delta F_{dev} / F_m$



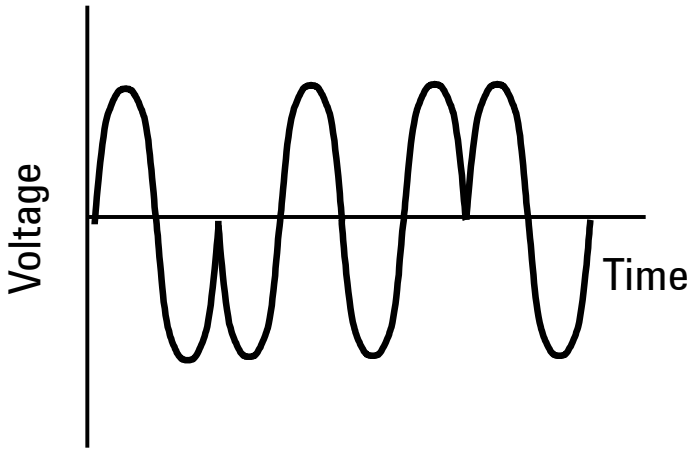
Important Characteristics for Frequency Modulation

- Frequency Deviation (ΔFdev)
- Modulation Frequency (Fm)
- Accuracy
- Resolution
- Distortion (%)
- Sensitivity (dev/volt)



Generating Signals – Analog Modulation

Phase Modulation



$$V(t) = A \cos[2\pi f_c t + \beta 2\pi F_m t]$$

Where $\beta = \Delta\theta$, the peak phase deviation

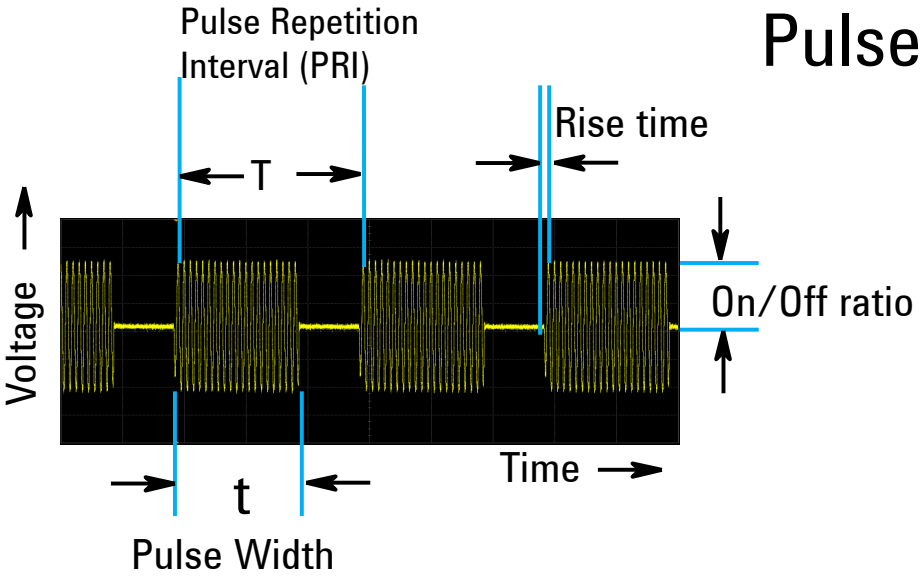
Important Characteristics for Phase Modulation

- Phase deviation (Δθ)
- Modulation Rate (Fm)
- Accuracy
- Resolution
- Distortion (%)
- Sensitivity (dev/volt)

Where are Phase Modulated signals used?

- PSK (early digital 1010)
- Radar (pulse coding)

Generating Signals – Analog Modulation



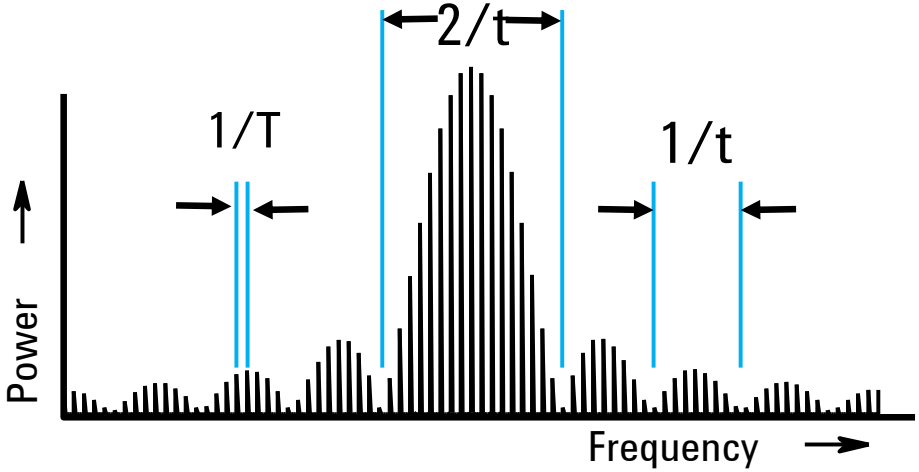
Pulse Modulation

Important Characteristics for Pulse Modulation

- Pulse width (t)
- PRF (1/T)
- Duty cycle (t/T)
- On/Off ratio (dB)
- Rise time (ns)

Where are Pulse Modulated signals used?

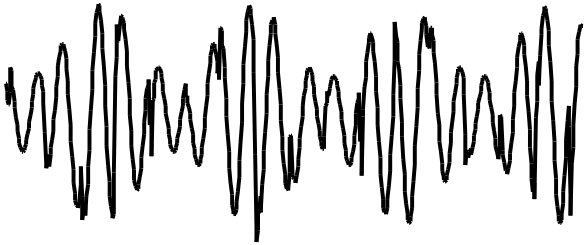
- Radar
- High Power Stimulus/Response
- Communications



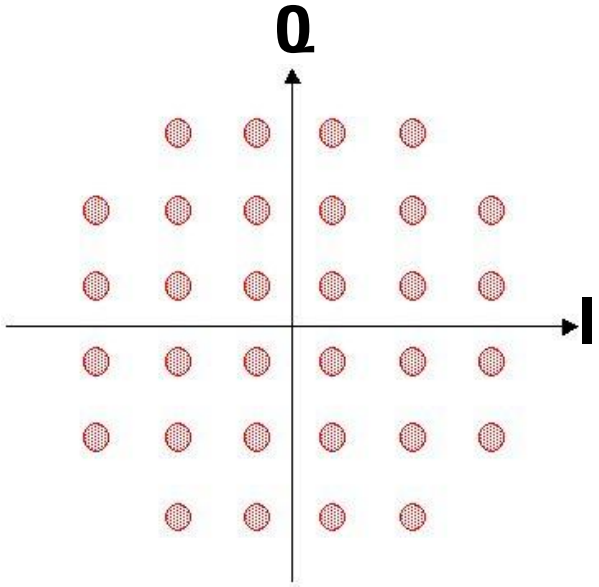
Generating Signals – Composite Modulation

Simultaneous modulation of two Mod Types

Independent Amplitude and Phase Modulation



Integrated IQ Modulator



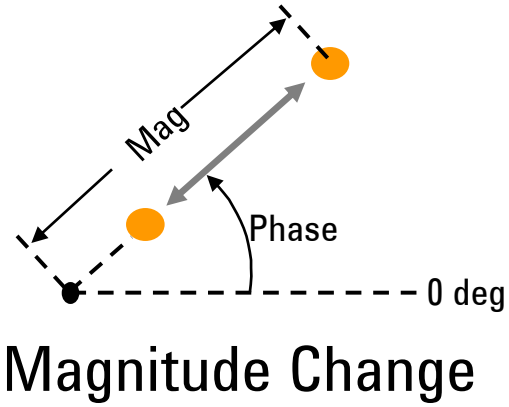
32 QAM Constellation Diagram

Independent FM and Pulse Modulation

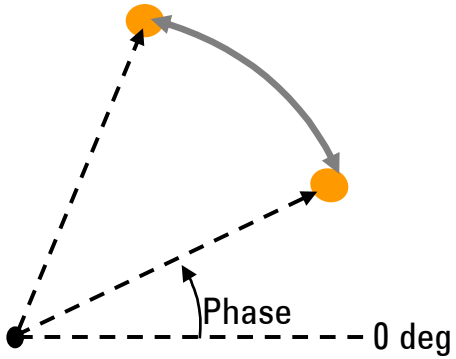
FM during the pulse = chirp

Generating Signals – Composite Modulation

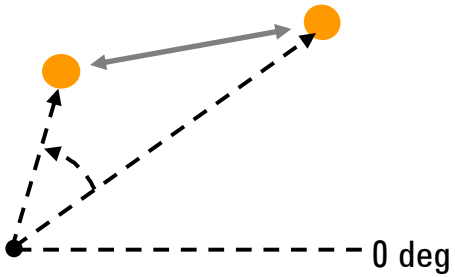
Vector Signal Changes or Modifications



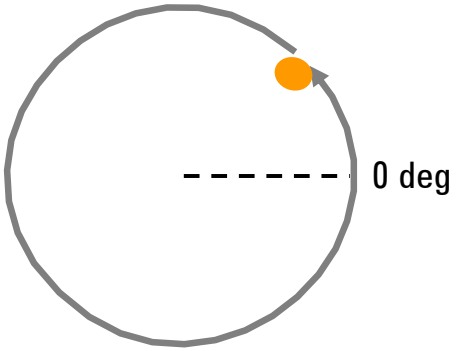
Magnitude Change



Phase Change



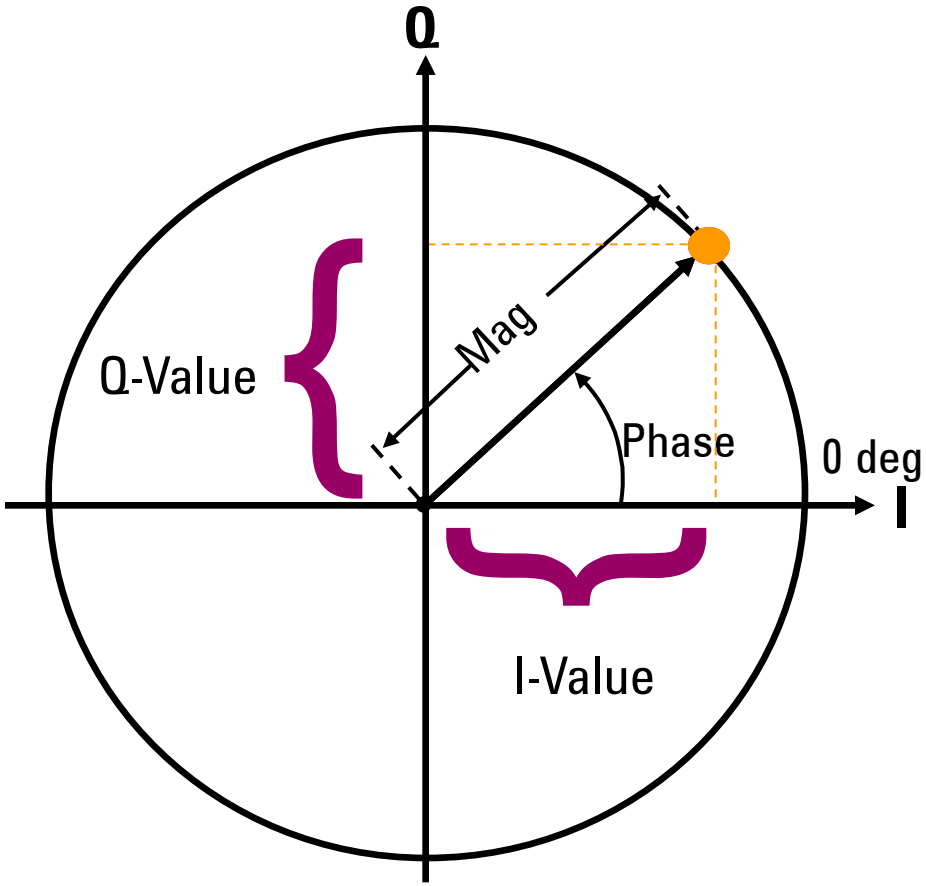
Both Change



Frequency Change

Generating Signals – Composite Modulation

Polar Versus I-Q Format



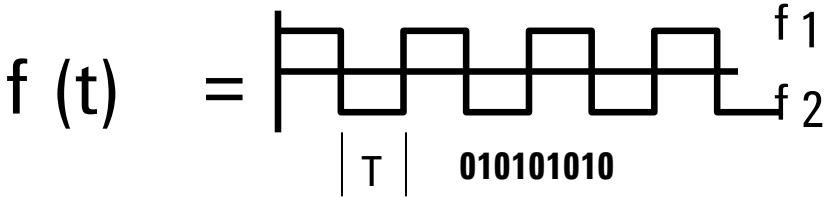
- Project Signals to "I" and "Q" Axes
- Polar to Rectangular Conversion
- IQ Plane Shows 2 Things:
  - What the modulated carrier is doing relative to the unmodulated carrier.
  - What baseband I and Q inputs are required to produce the modulated carrier

Generating Signals – Composite Modulation

Transmitting Digital Data -- Bits vs Symbols

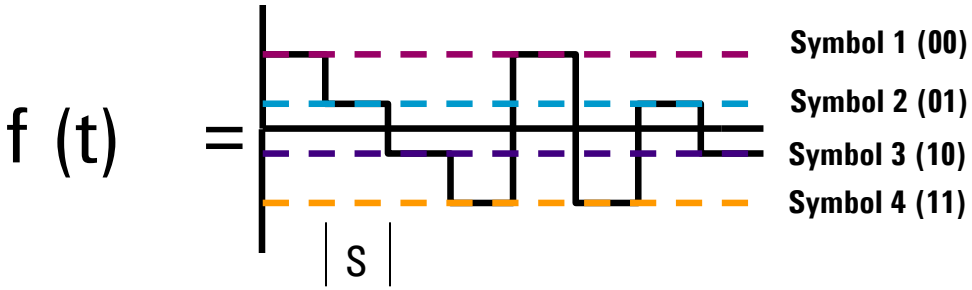
Binary Data bit = 0,1

Transmitting Digital Bits (f 1 = 0, f 2 = 1)

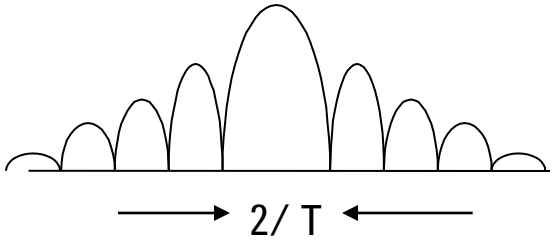


Symbol = Groups/blocks of Bits

2 bits/symbol (00 01 10 11)
3 bits/symbol (000 001 .....)
4 bits/symbol (0000 0001 ..)

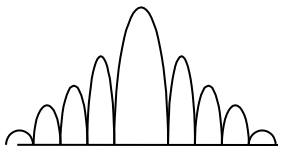


Transmission Bandwidth Required



Main lobe width is 2 Sample rate

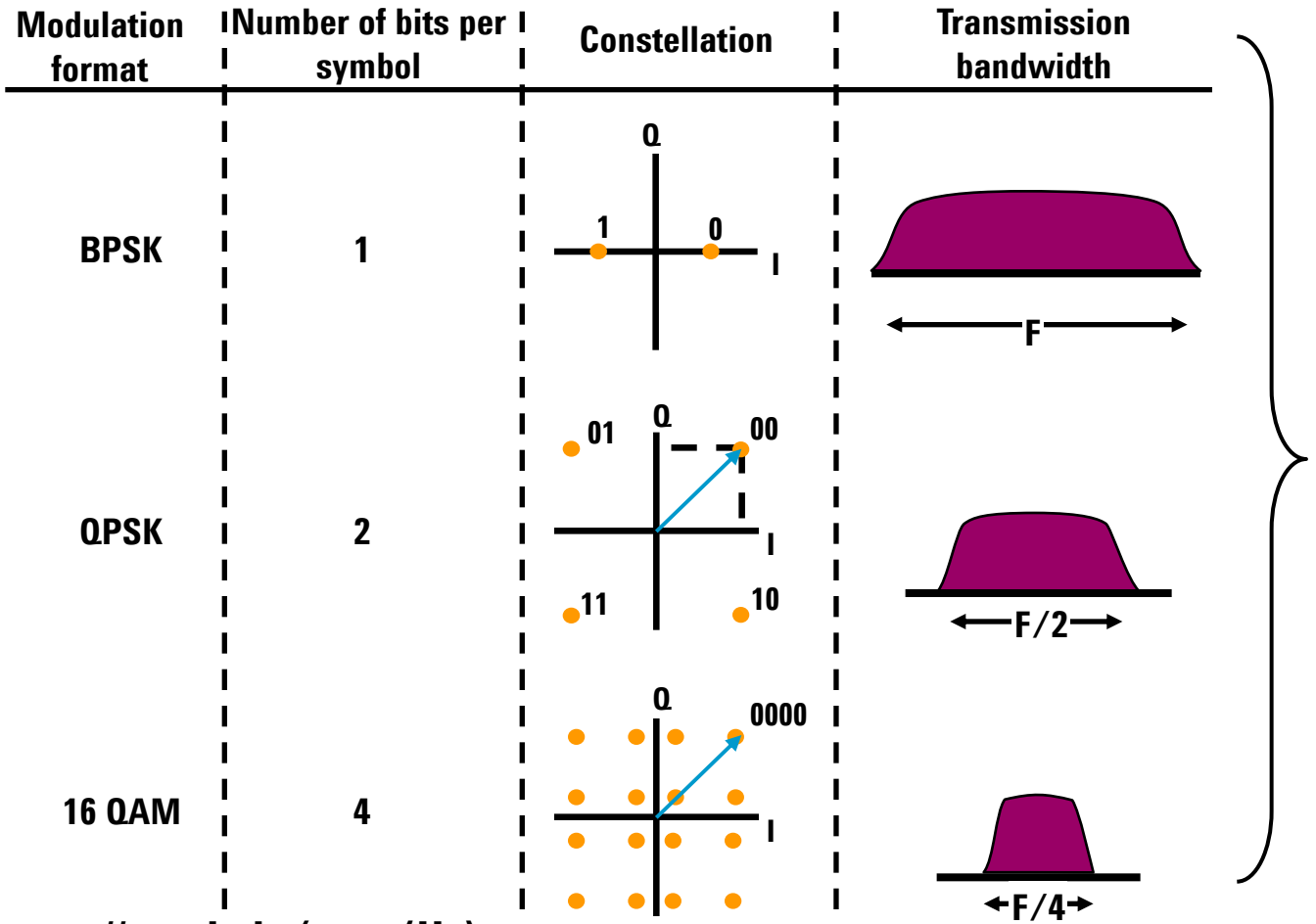
Symbol Rate = $\frac{\text{Bit rate}}{\text{\# bits per symbol}}$



Main lobe width is 2 Symbol rate

Generating Signals – Composite Modulation

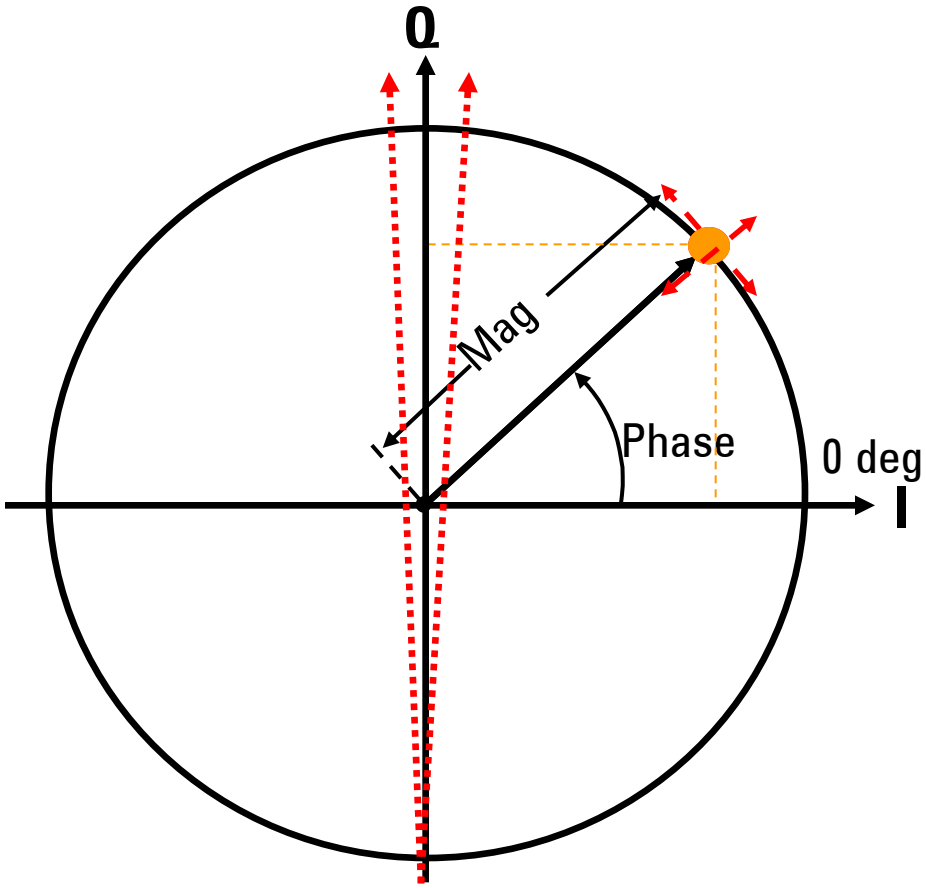
Digital Modulation Characteristics



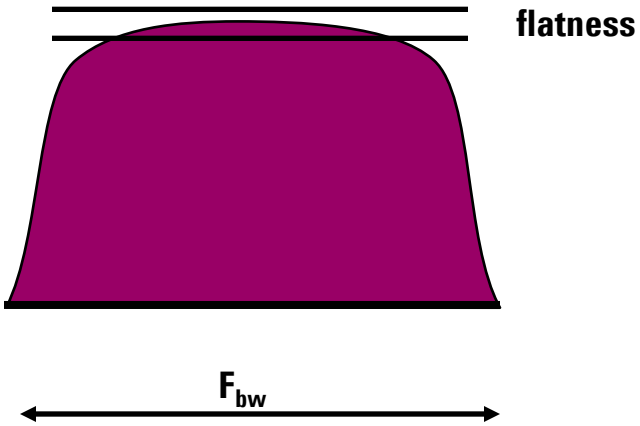
Symbol Rate = #symbols/sec. (Hz)

Generating Signals – Composite Modulation

Vector Modulation - Important Characteristics

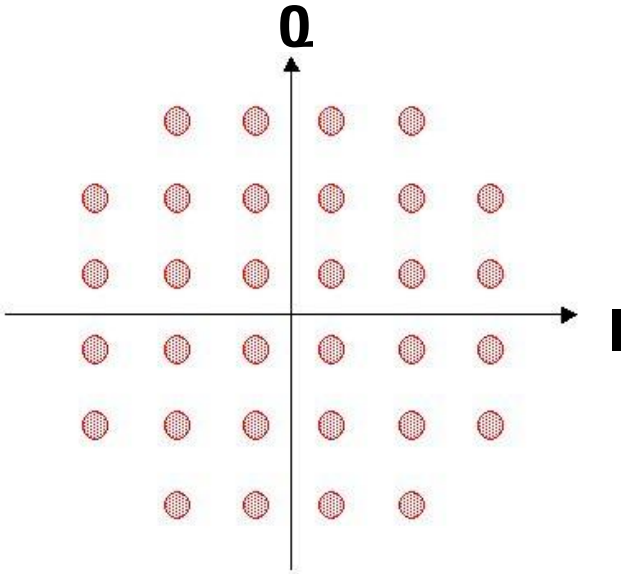


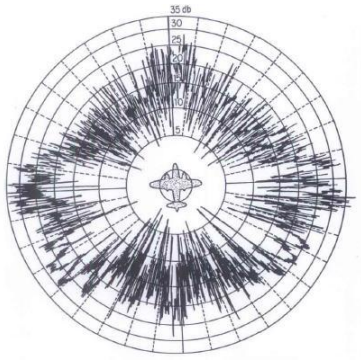
- IQ Modulation Bandwidth
- Frequency Response/flatness
- IQ quadrature skew
- IQ gain balance



Generating Signals – Composite Modulation

Vector Modulation - Where Used





- Mobile Digital Communications
- Modern Radars

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  - Aerospace Defense to Communications
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- Signal Generator Architecture
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Signal Generator Architecture

Basic CW Signals

- Block Diagram (RF and Microwave)
- Specifications
- Applications

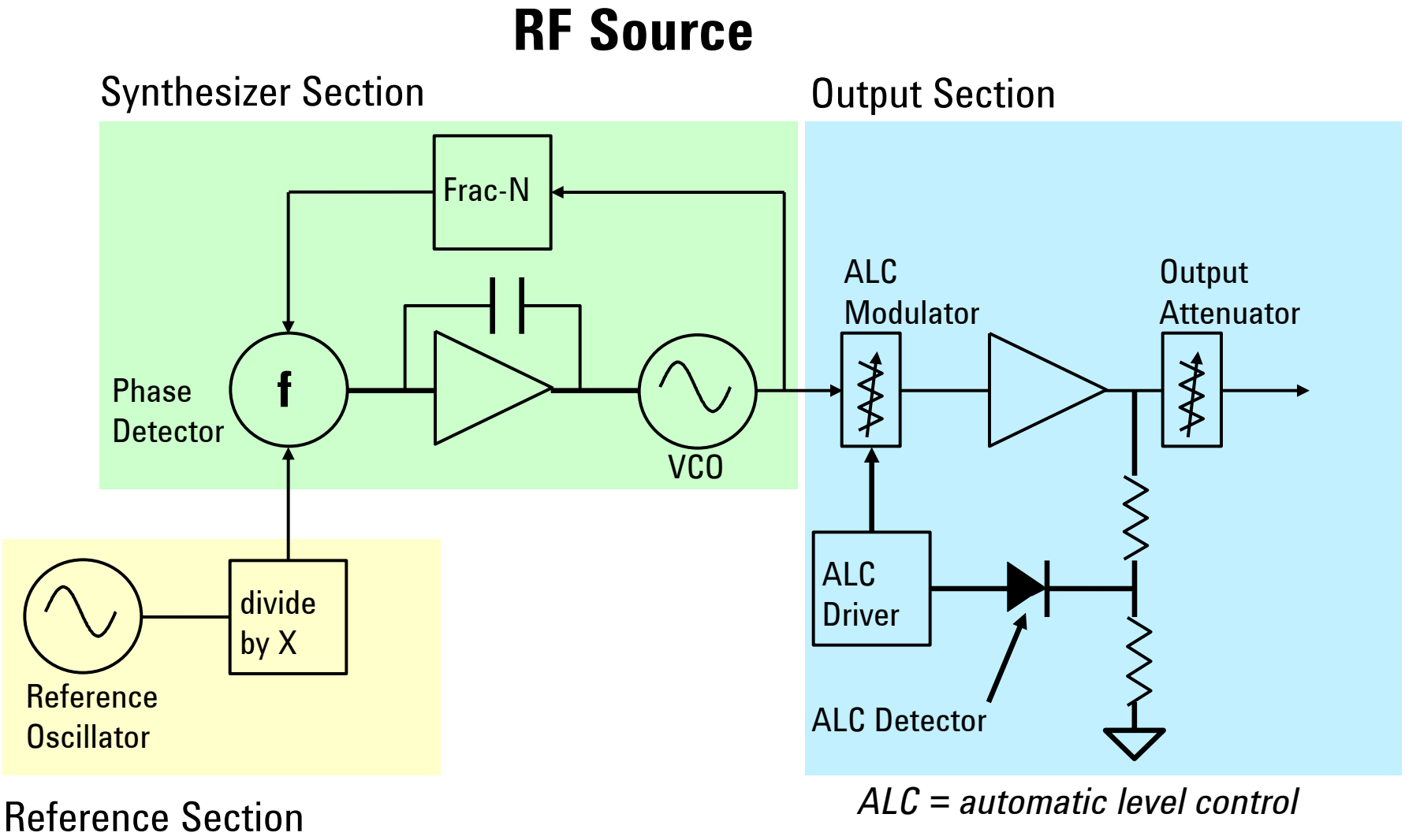
Analog Signals

- Block Diagram (AM, FM, PM, Pulse)
- Applications

Vector Signals

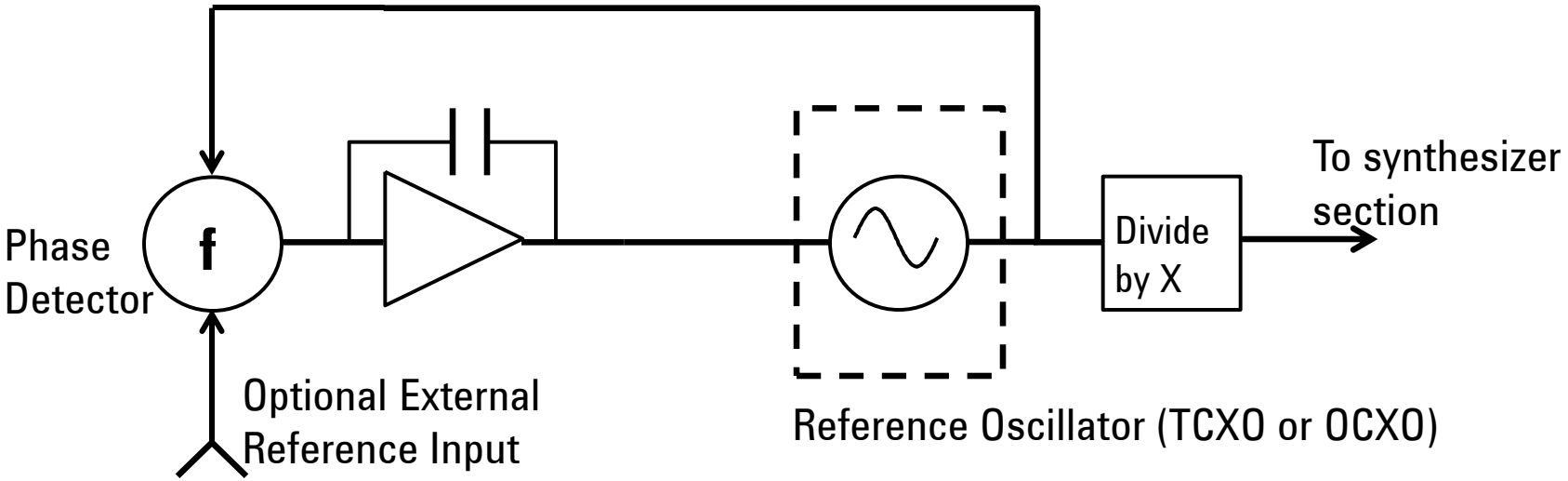
- Block Diagram (IQ)
- Applications

Basic CW Signals – Block Diagram



Basic CW Signals – Block Diagram

Reference Section

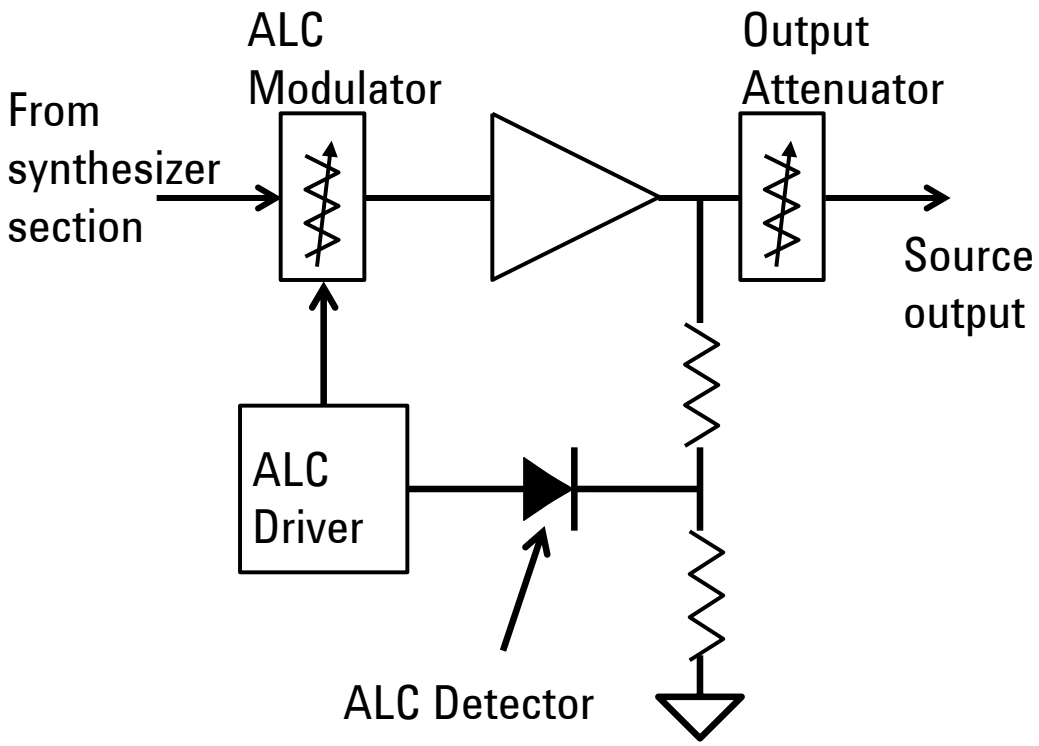


	TCXO	OCXO
Aging Rate	+/- 2ppm/year	+/- 0.1 ppm /year
Temp.	+/- 1ppm	+/- 0.01 ppm
Line Voltage	+/- 0.5ppm	+/- 0.001 ppm

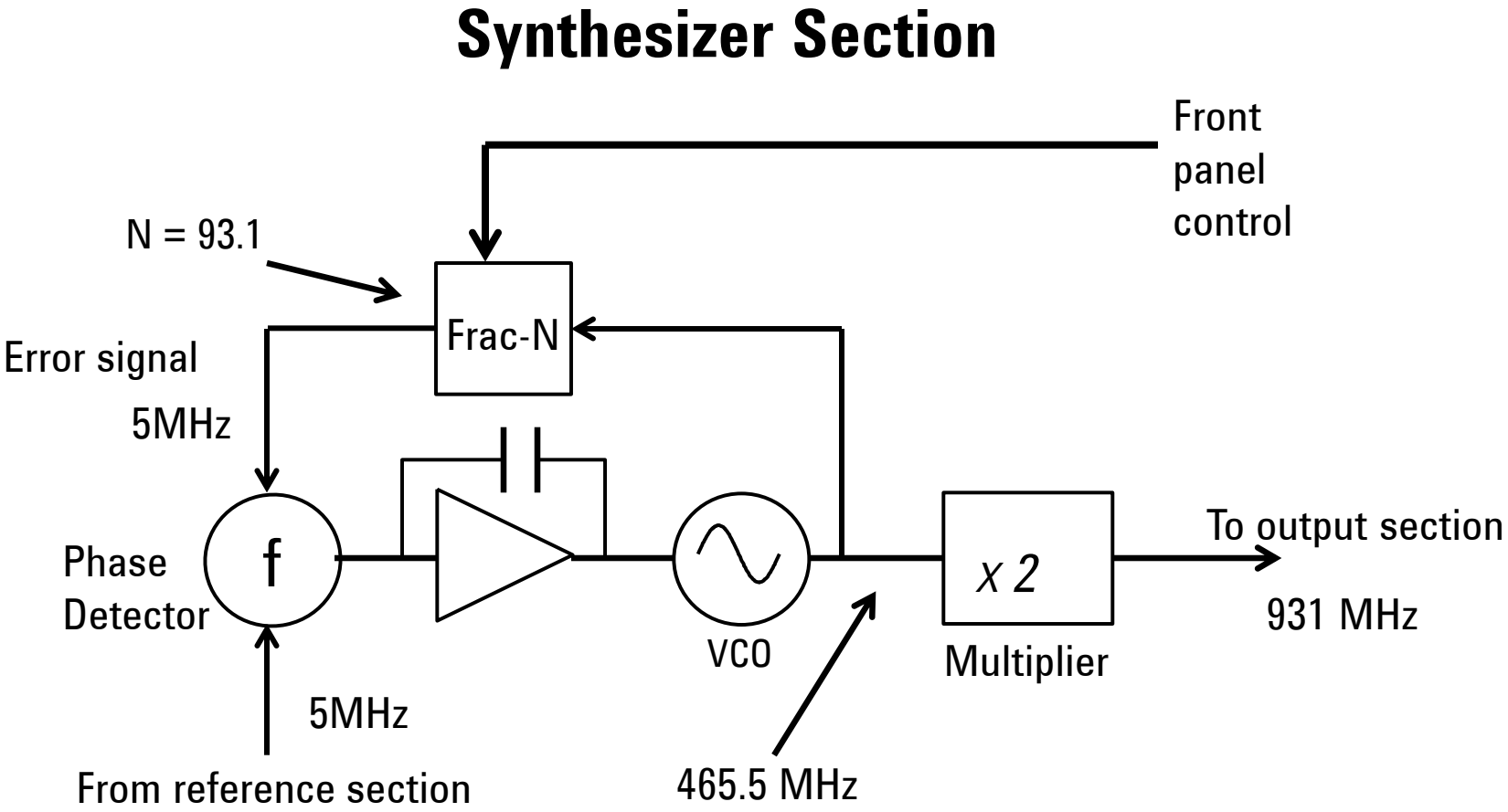
Basic CW Signals – Block Diagram

Output Section

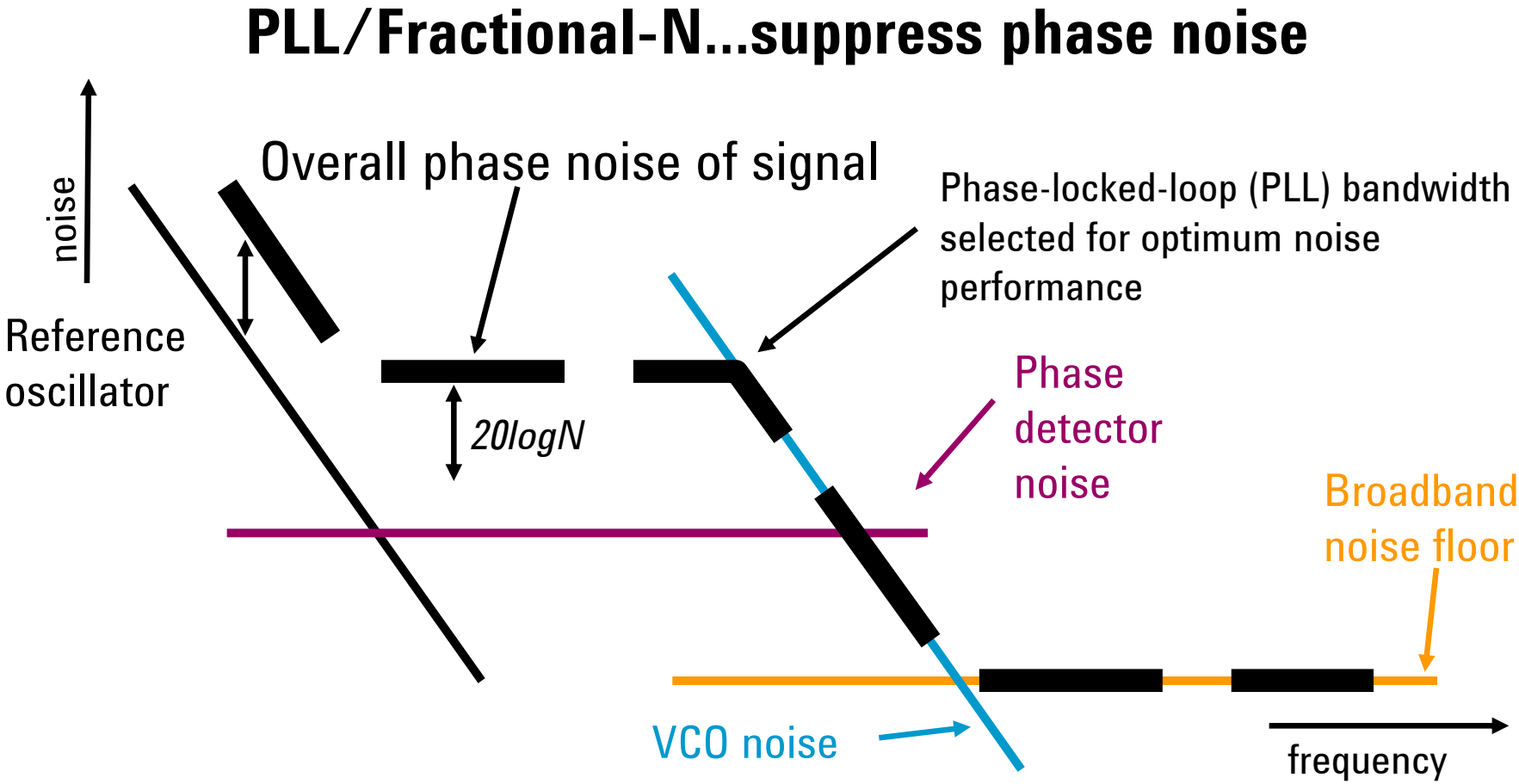
- ALC
  - maintains level output power by adding/subtracting power as needed
- Output Attenuator
  - mechanical or electronic
  - provides attenuation to achieve wide output range (e.g. -127 dBm to +23 dBm)



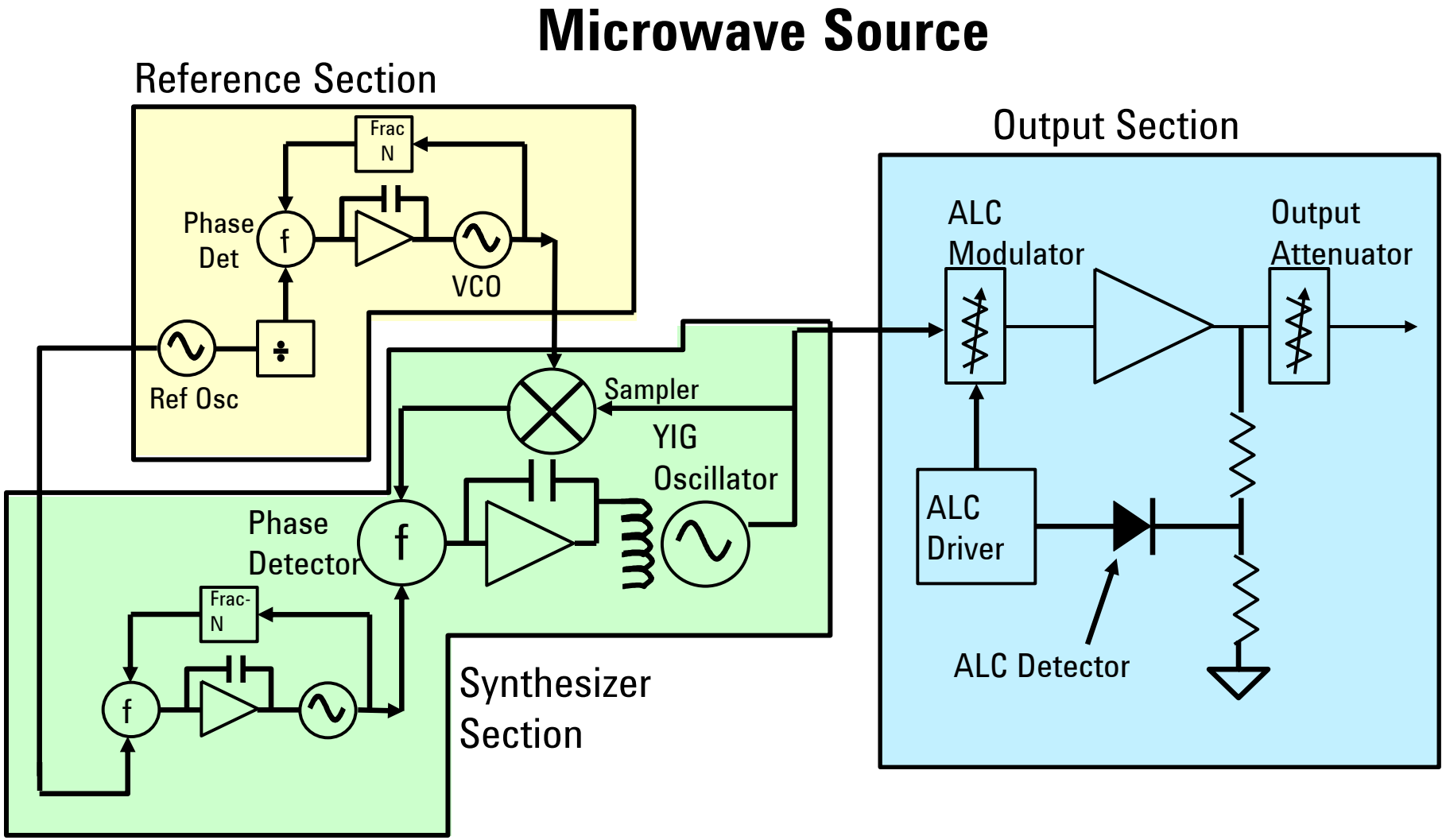
Basic CW Signals – Block Diagram



Basic CW Signals – Block Diagram



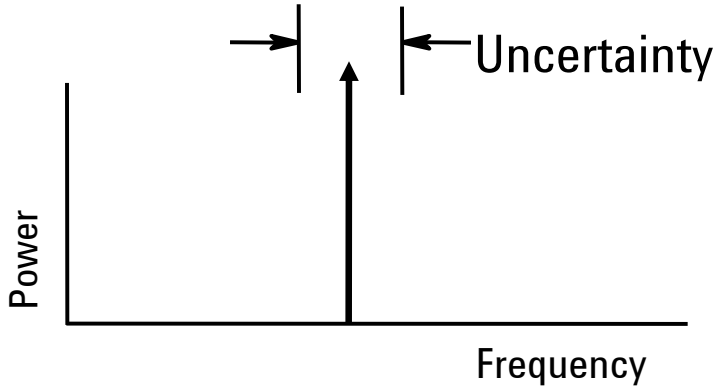
Basic CW Signals – Block Diagram



Basic CW Signals – Specifications

Frequency

- Range — F_{min} to F_{max}
- Resolution — Smallest frequency increment
- Accuracy — How close is the indicated frequency to the actual frequency?
- Switching Speed — How quickly can you change from one frequency to another?



Accuracy = $f_{CW} * t_{aging} * t_{cal}$

f_{CW} = CW frequency = 1 GHz

t_{aging} = aging rate = 0.152 ppm/year

t_{cal} = time since last calibrated = 1 year

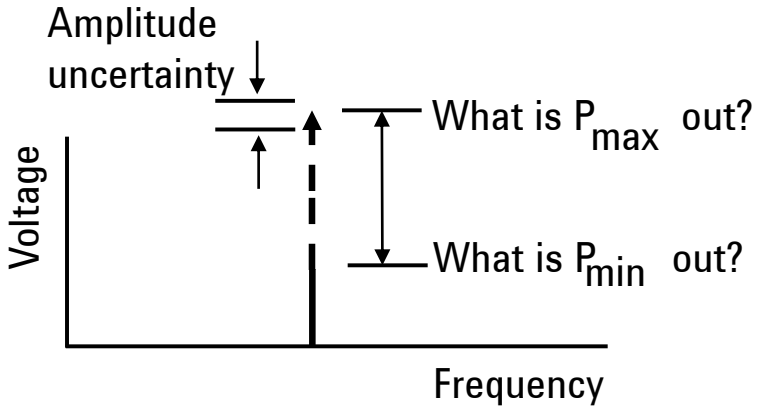
Accuracy = 152 Hz

Basic CW Signals – Specifications

Amplitude

• Range	P_{min} to P_{max}
• Resolution	Smallest amplitude increment
• Accuracy	How close is the indicated amplitude to the actual amplitude?
• Switching Speed	How quickly can you change from one amplitude to another?
• Reverse Power Protection	Maximum safe power that can be applied to the RF output

Source protected from accidental transmission from DUT

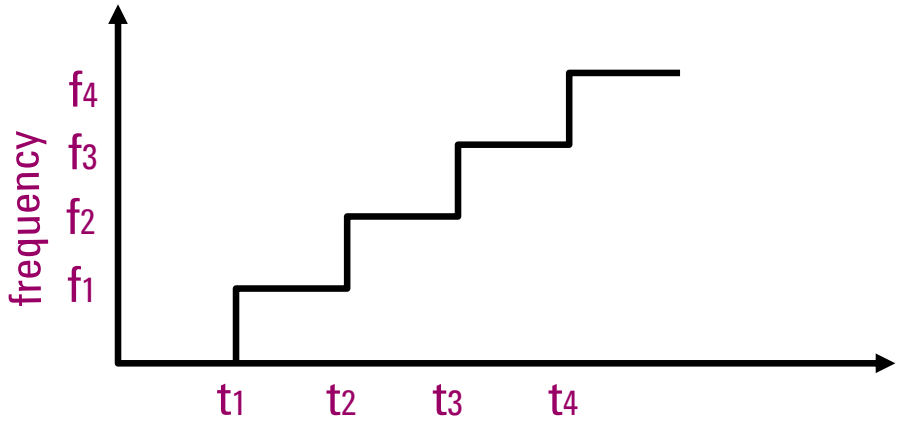


Basic CW Signals – Specifications

Frequency Sweep

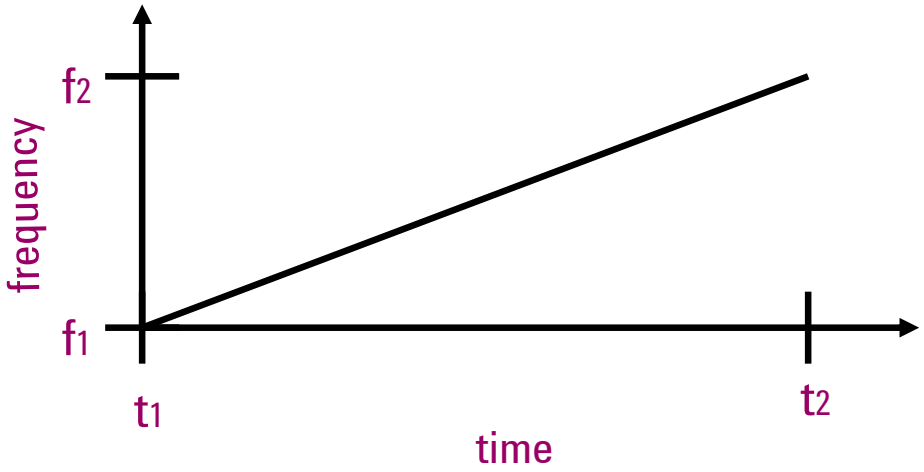
Step sweep

- accuracy
- number of points
- switching time



Ramp sweep

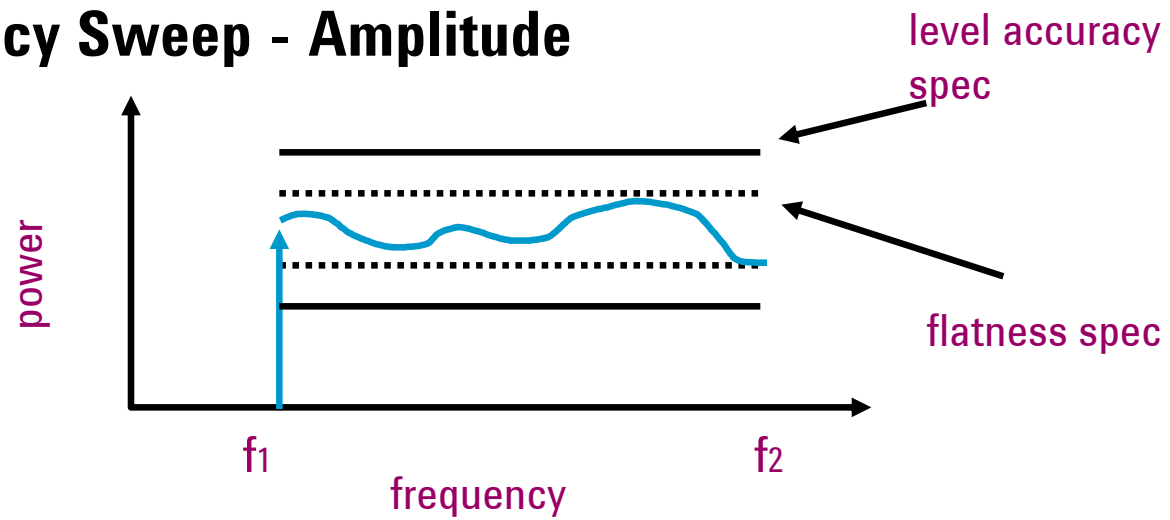
- accuracy
- sweep time
- resolution

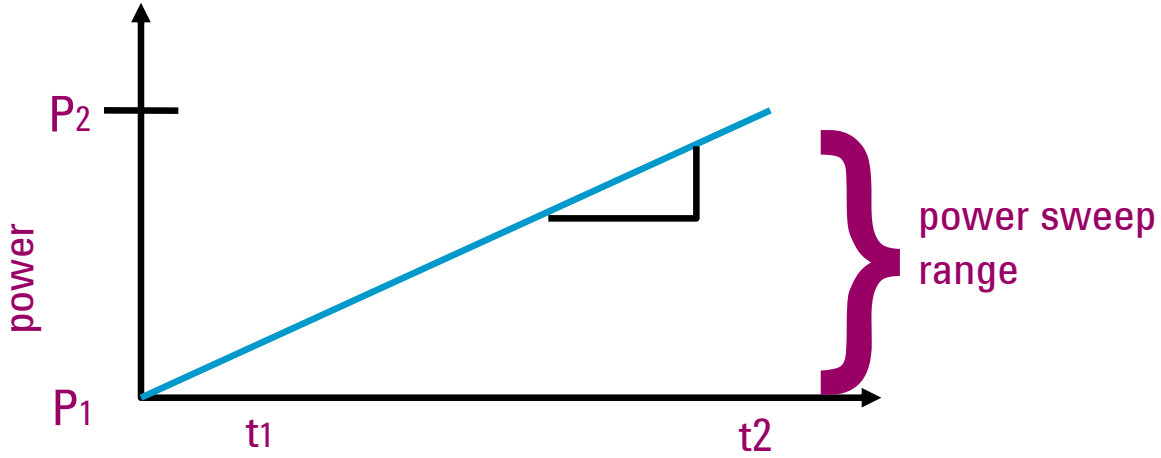


Basic CW Signals – Specifications

Frequency Sweep
- Level Accuracy
- Flatness
- Source Match (SWR)

Power Sweep
- Power Sweep Range
- Power Slope Range
- Source Match (SWR)

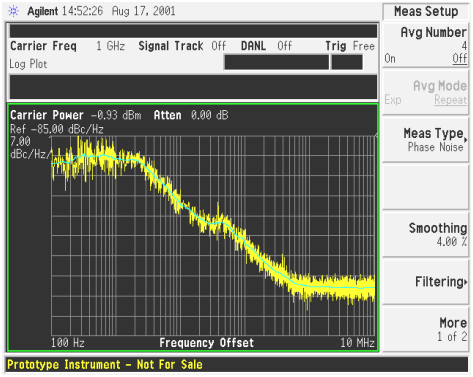


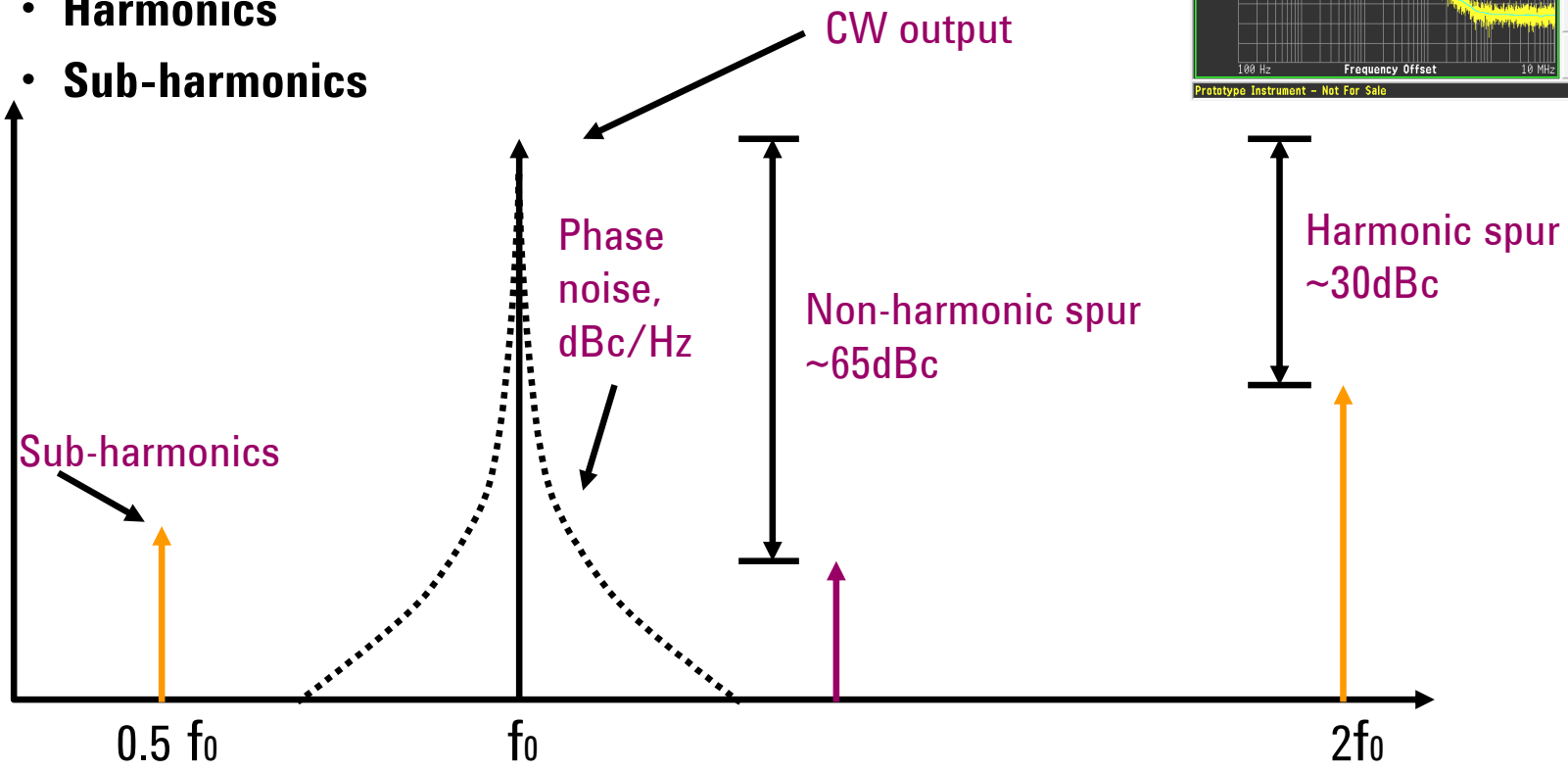


Basic CW Signals – Specifications

Spectral Purity

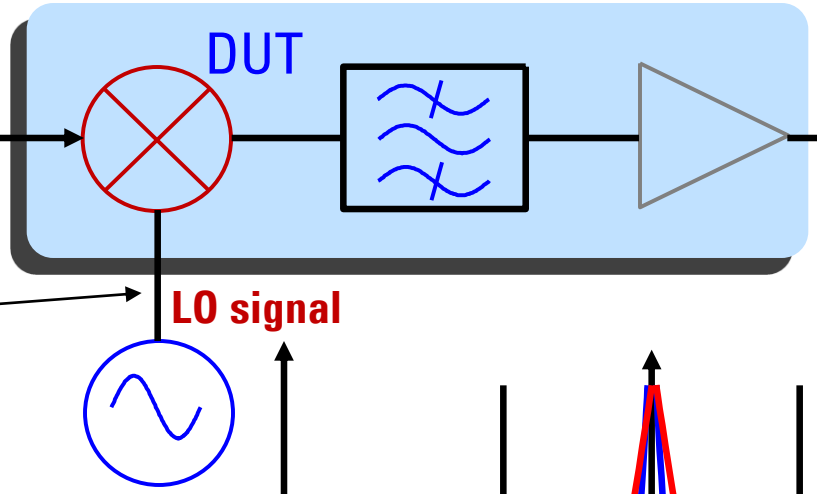
- Phase Noise
- Spurious
- Harmonics
- Sub-harmonics





Basic CW Signals – Applications

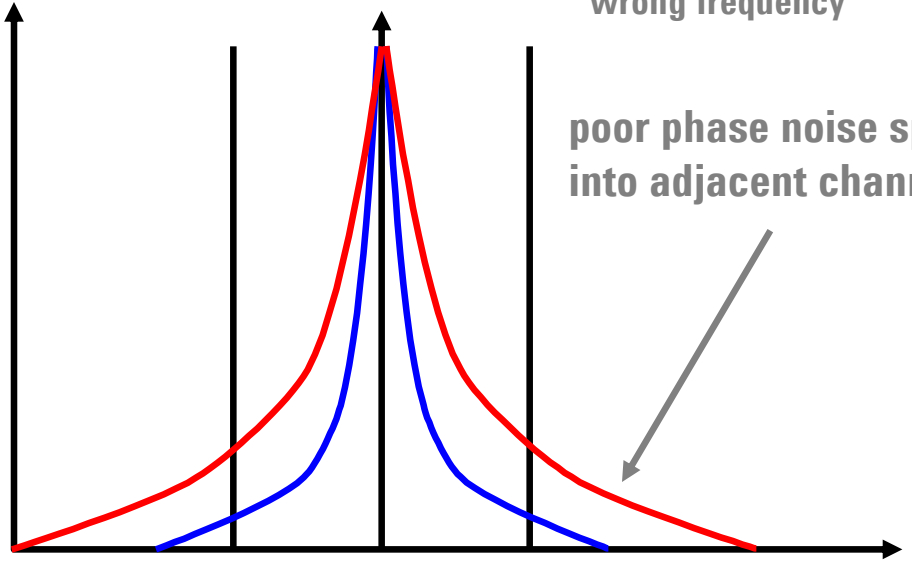
As a Local Oscillator



Poor frequency accuracy and/or resolution will cause the transmitter output to be at the wrong frequency

Key Specs:

- *Frequency Range*
- *Accuracy*
- *Resolution*
- *Output Power*
- *Phase Noise*

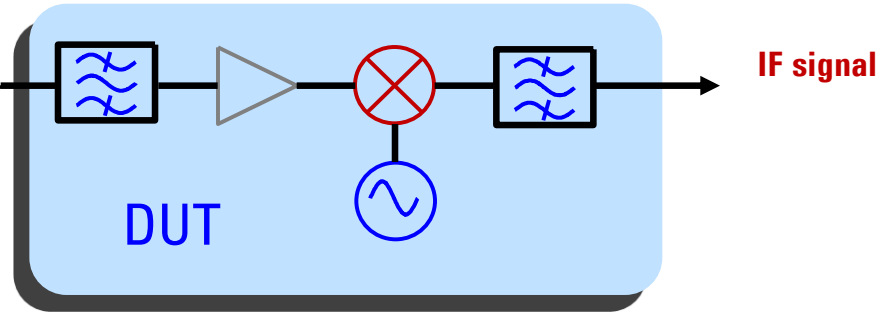


poor phase noise spreads energy into adjacent channels

Basic CW Signals – Applications

In-Channel Receiver Testing

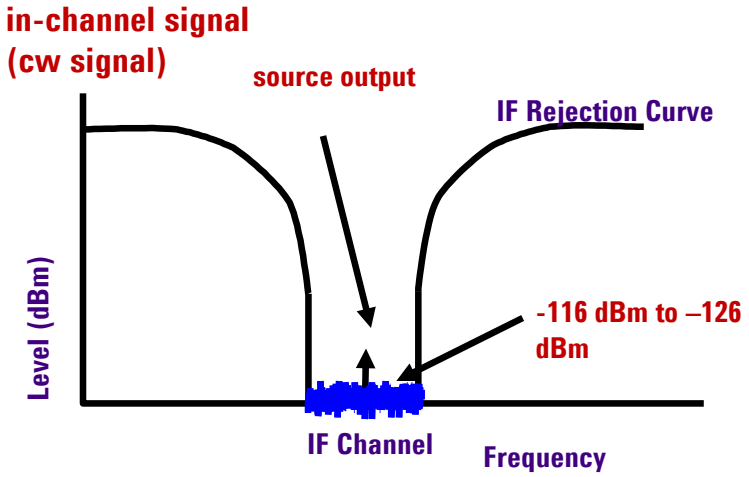
Receiver Sensitivity



The smallest RF signal that will produce a desired baseband output from the receiver

Key Specs:

- ***Amplitude Range***
- ***Amplitude Accuracy***
- ***Amplitude Resolution***

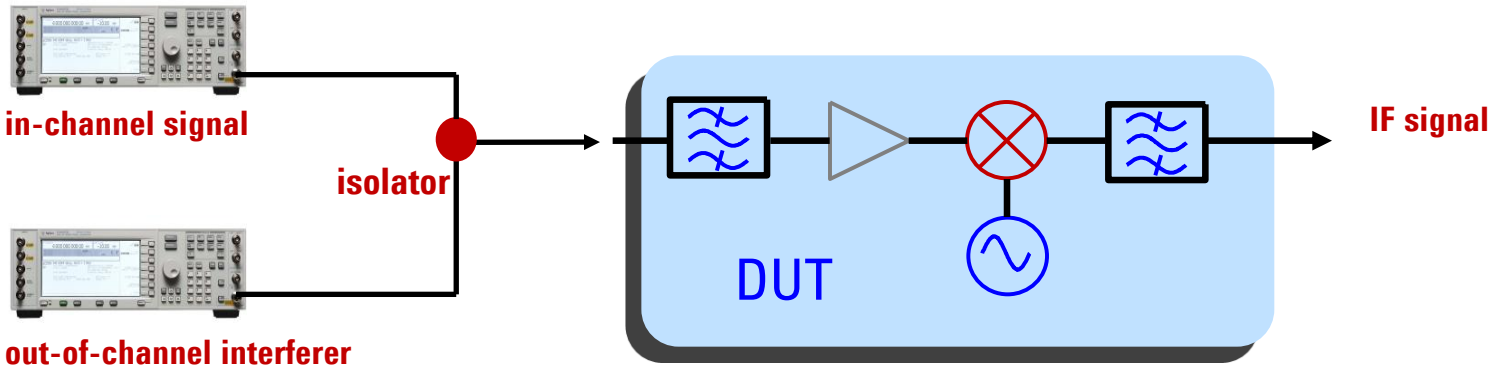


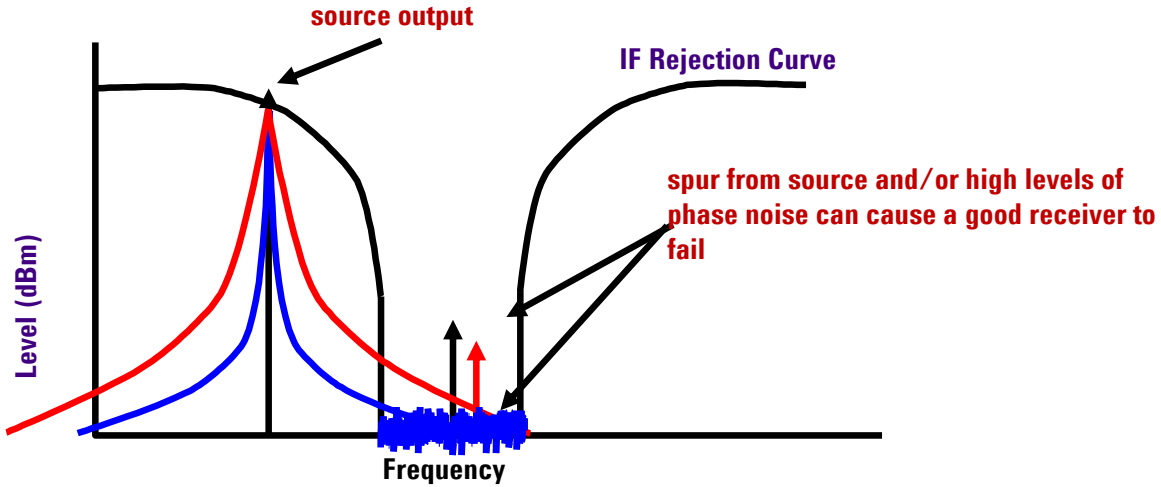
Basic CW Signals – Applications

Out-of-channel Receiver Testing

Receiver Selectivity

Spurious Response Immunity



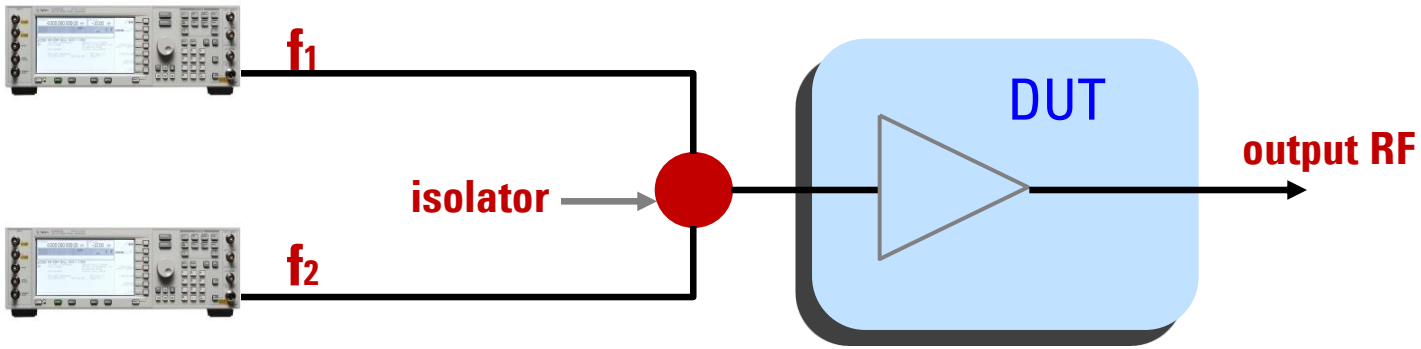


Key Specs:

- *Frequency Range*
- *Output Power*
- *Phase Noise*
- *Broadband noise*
- *Non-harmonic spurious*

Basic CW Signals – Applications

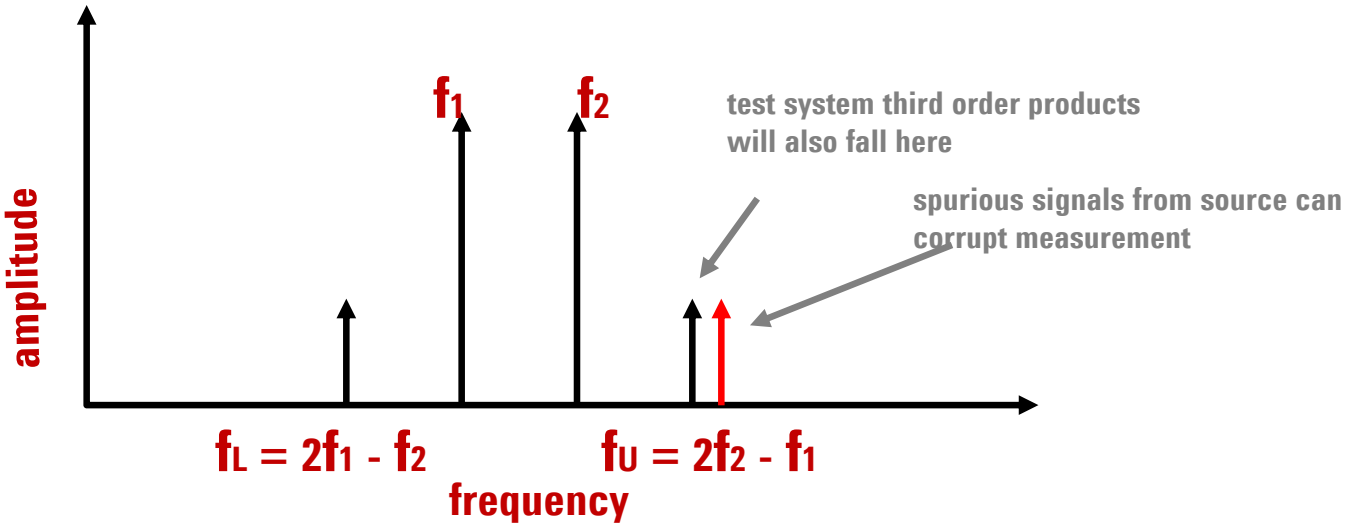
Non-linear Amplifier Testing - TOI



Key Specs:

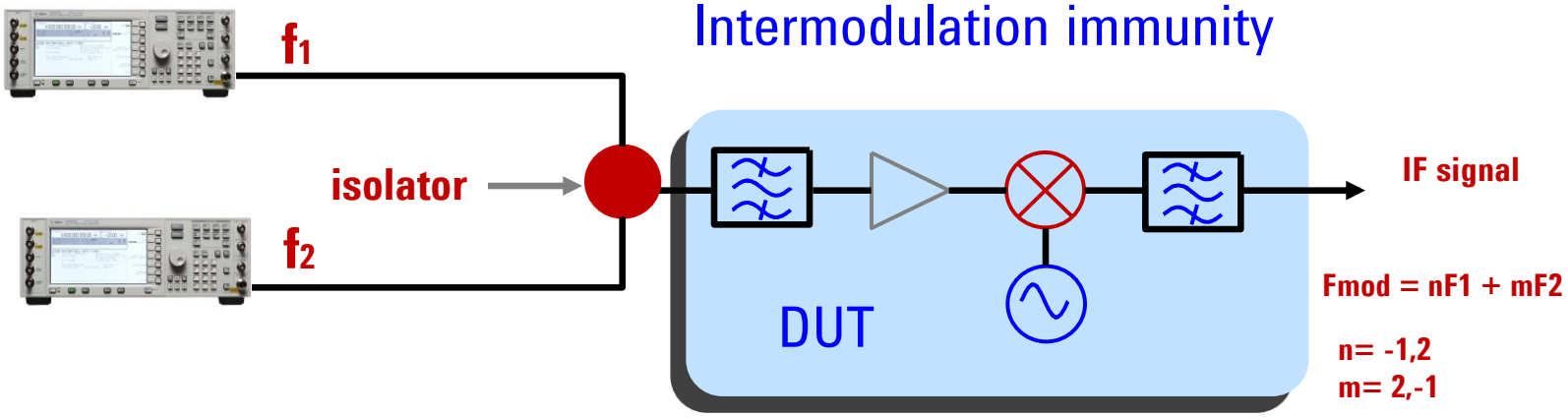
- *Frequency Range*
- *Frequency Accuracy*
- *Frequency Resolution*
- *Output Power*
- *Non-harmonic spurious*

Two-tone Intermodulation Distortion



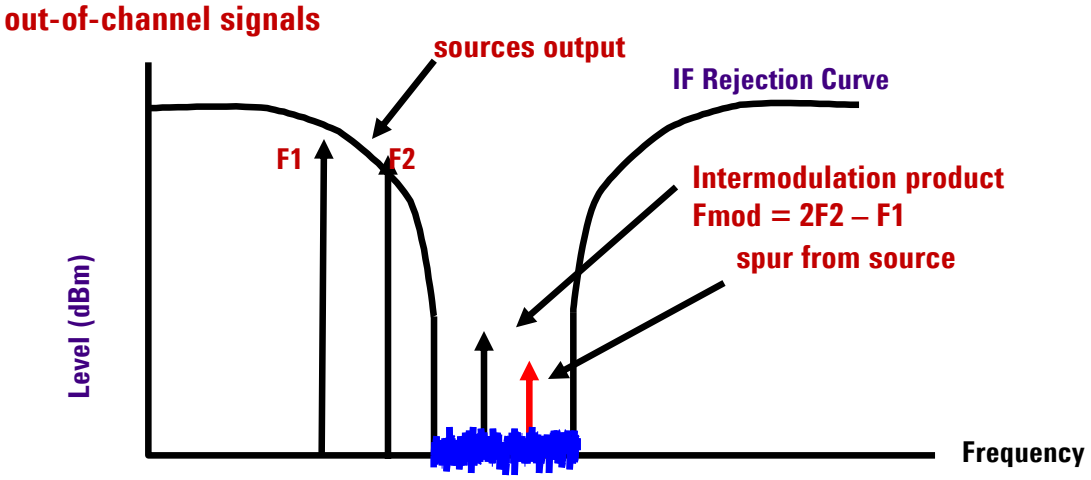
Basic CW Signals – Applications

Out-of-channel Receiver Testing - IMD



Key Specs:

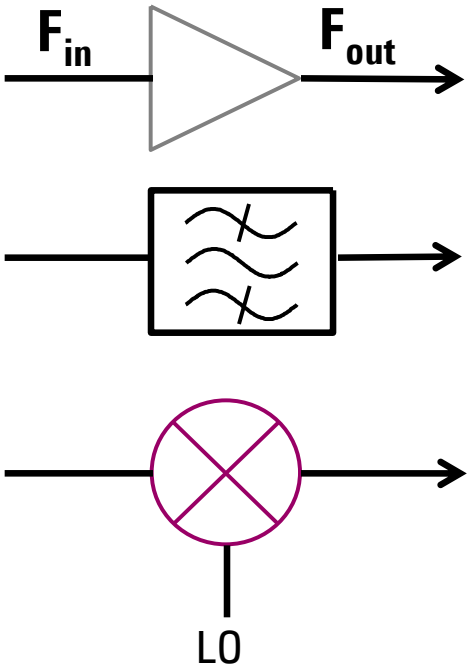
- *Frequency Range*
- *Frequency Accuracy*
- *Frequency Resolution*
- *Output Power*
- *Non-harmonic spurious*

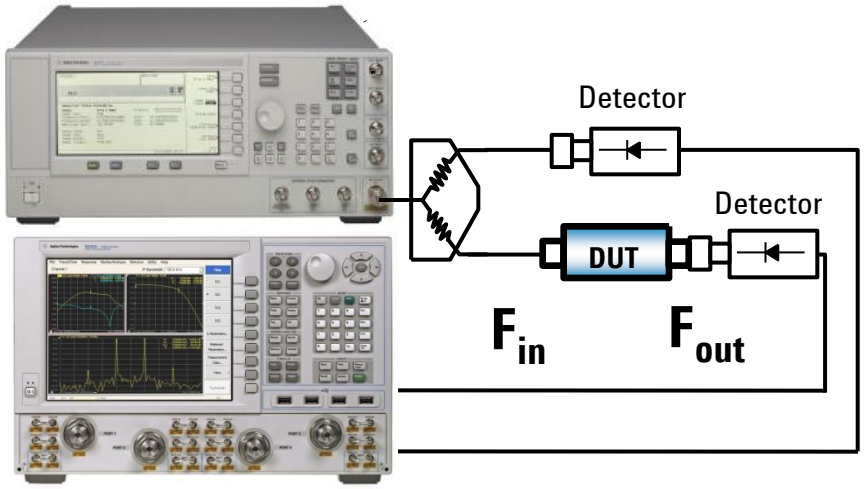


Basic CW Signals – Applications

Stimulus-Response Testing

Example DUT's





Key Specs:

- *Frequency Range*
- *Frequency Accuracy*
- *Frequency Ramp/step sweep*
- *Power sweep*
- *Sweep speed*
- *Output Power accuracy*
- *Residual FM*

Signal Generators

Basic CW Signals

- Block Diagram (RF and Microwave)
- Specifications
- Applications

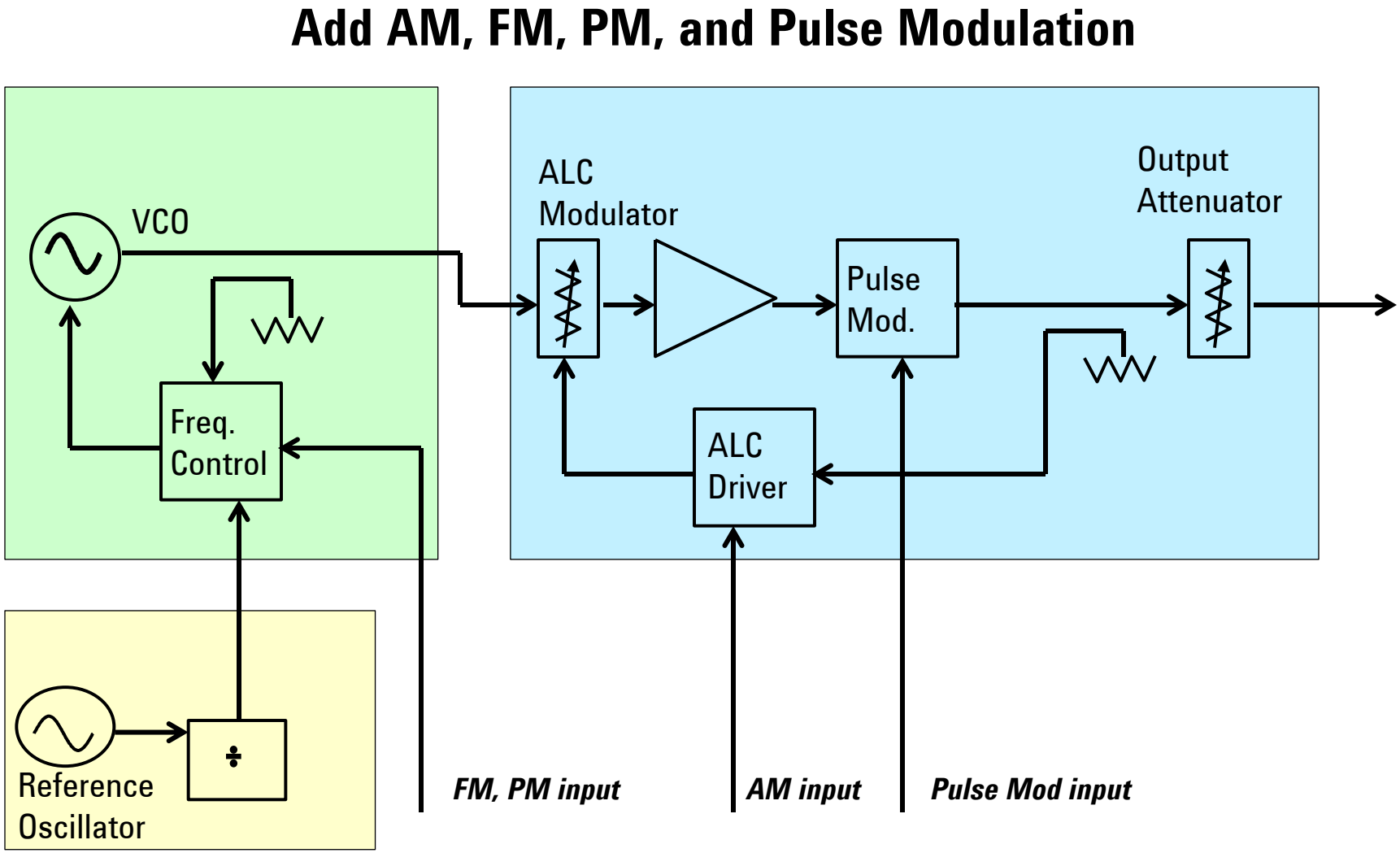
Analog Signals

- Block Diagram (AM, FM, PM, Pulse)
- Applications

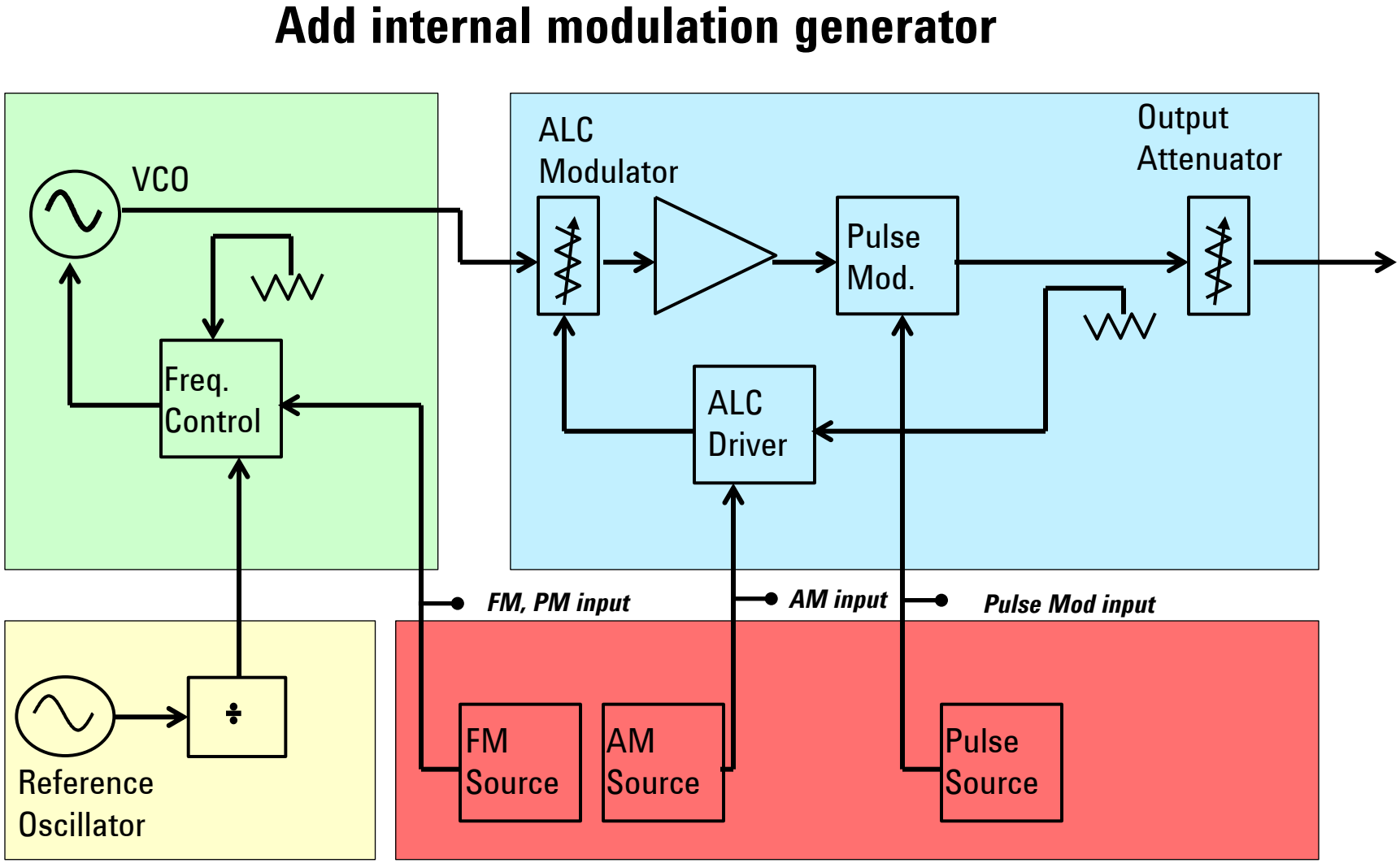
Vector Signals

- Block Diagram (IQ)
- Applications

Analog Signals – Block Diagram

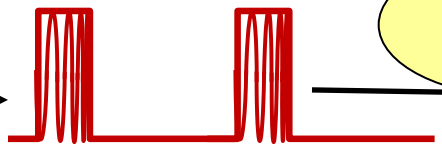


Analog Signals – Block Diagram



Analog Signals – Applications

Pulsed Radar Testing with Chirps



FM during the pulse = chirp

Key Specs:

- ***Frequency Range***
- ***FM Modulation rate/deviation***
- ***Pulse rate, width, rise time***

Signal Generators

Basic CW Signals

- Block Diagram (RF and Microwave)
- Specifications
- Applications

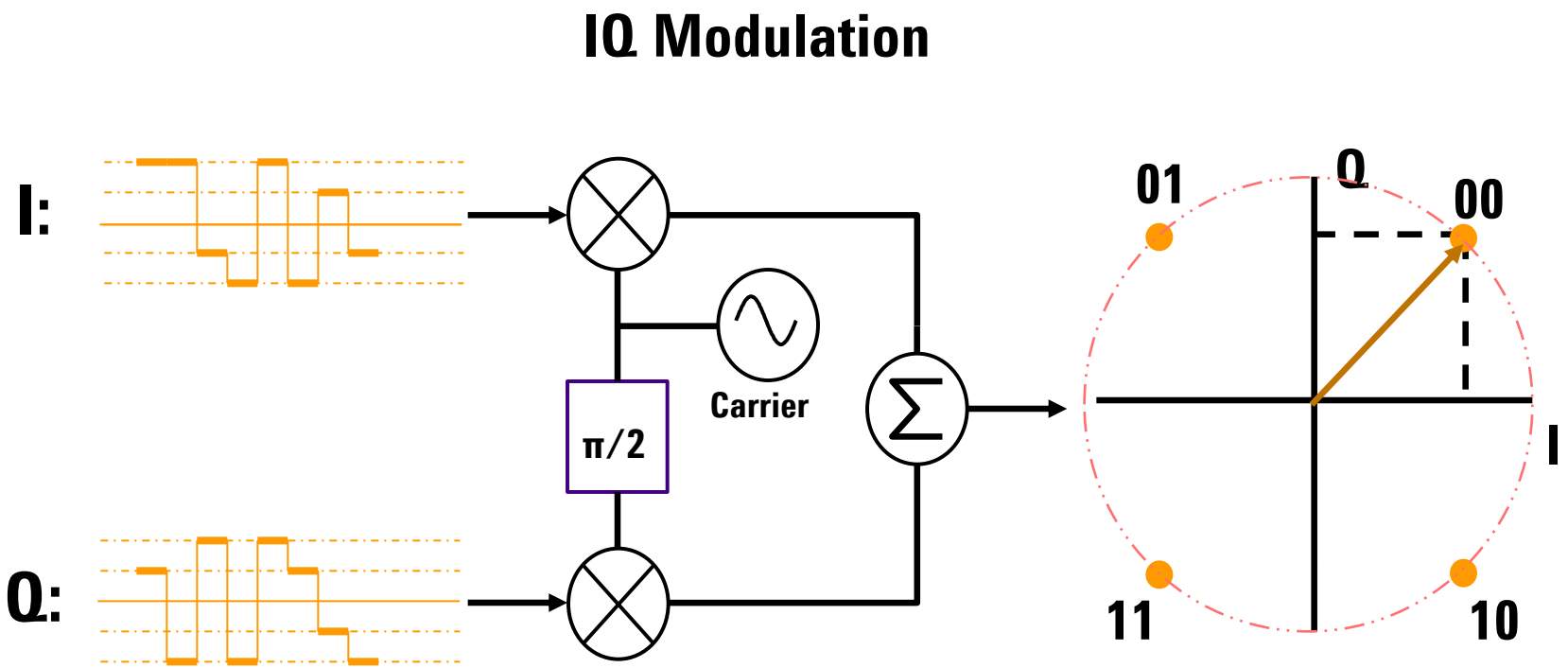
Analog Signals

- Block Diagram (AM, FM, PM, Pulse)
- Applications

Vector Signals

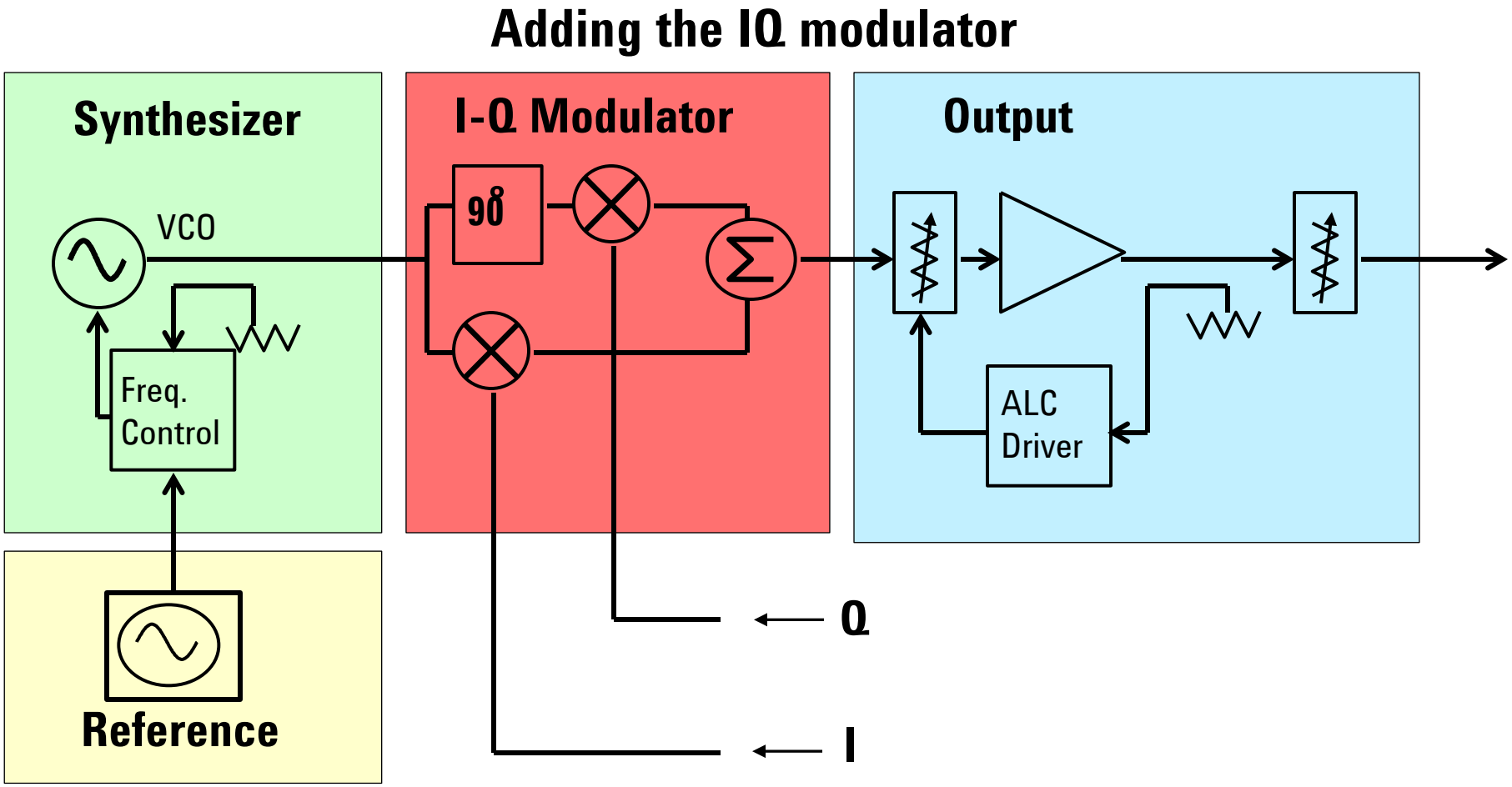
- Block Diagram (IQ)
- Applications

Vector Signals – Block Diagram

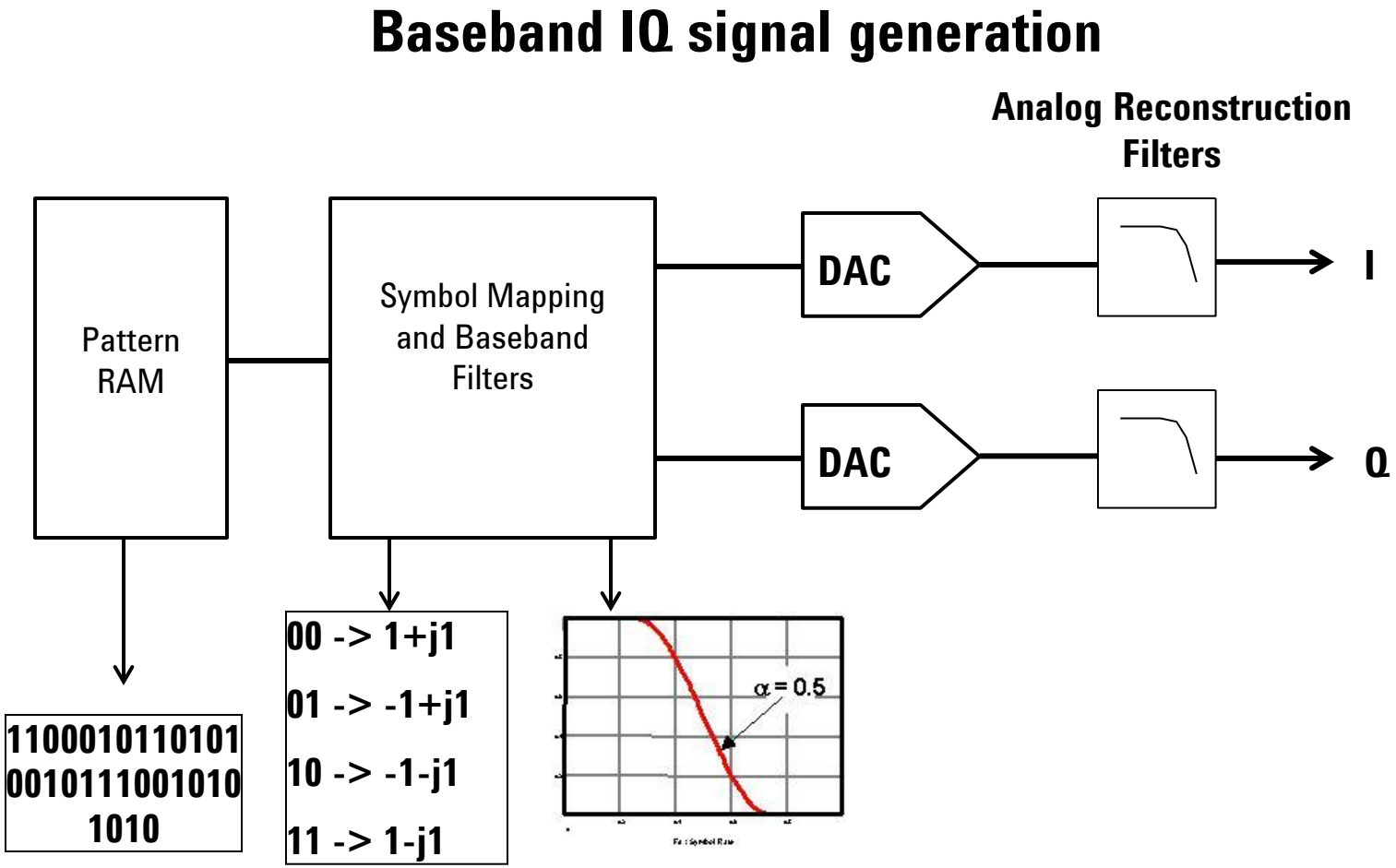


- Good Interface with Digital Signals and Circuits
- Can be Implemented with Simple Circuits
- Fast, accurate state change

Vector Signals – Block Diagram



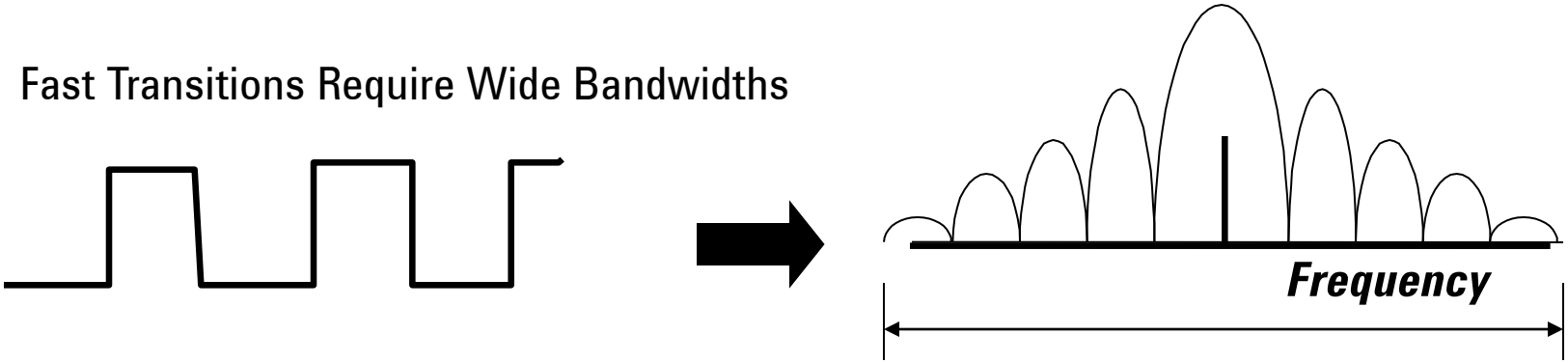
Vector Signals – Block Diagram

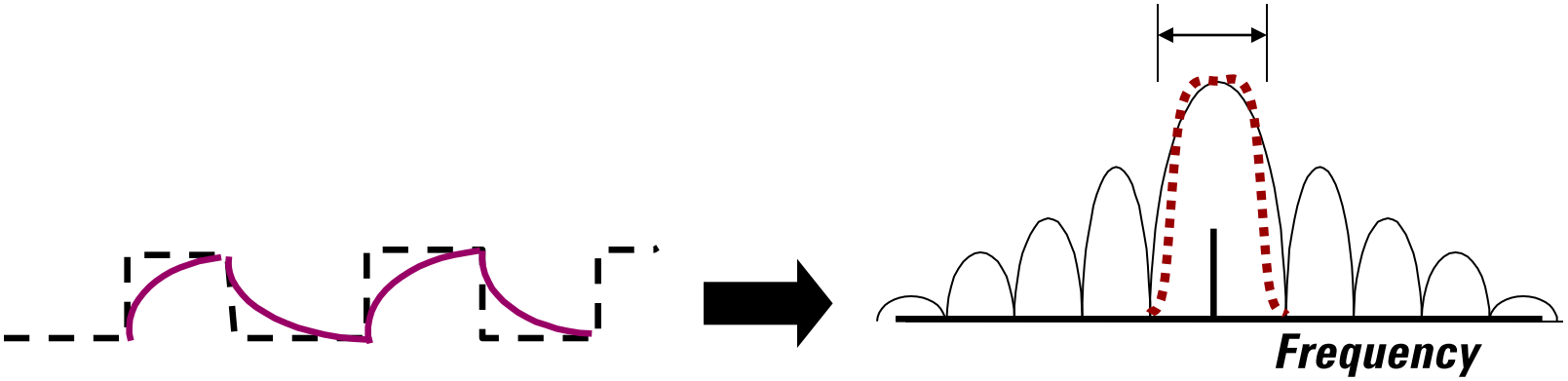


Vector Signals – Block Diagram

Baseband Generator: Baseband Filters

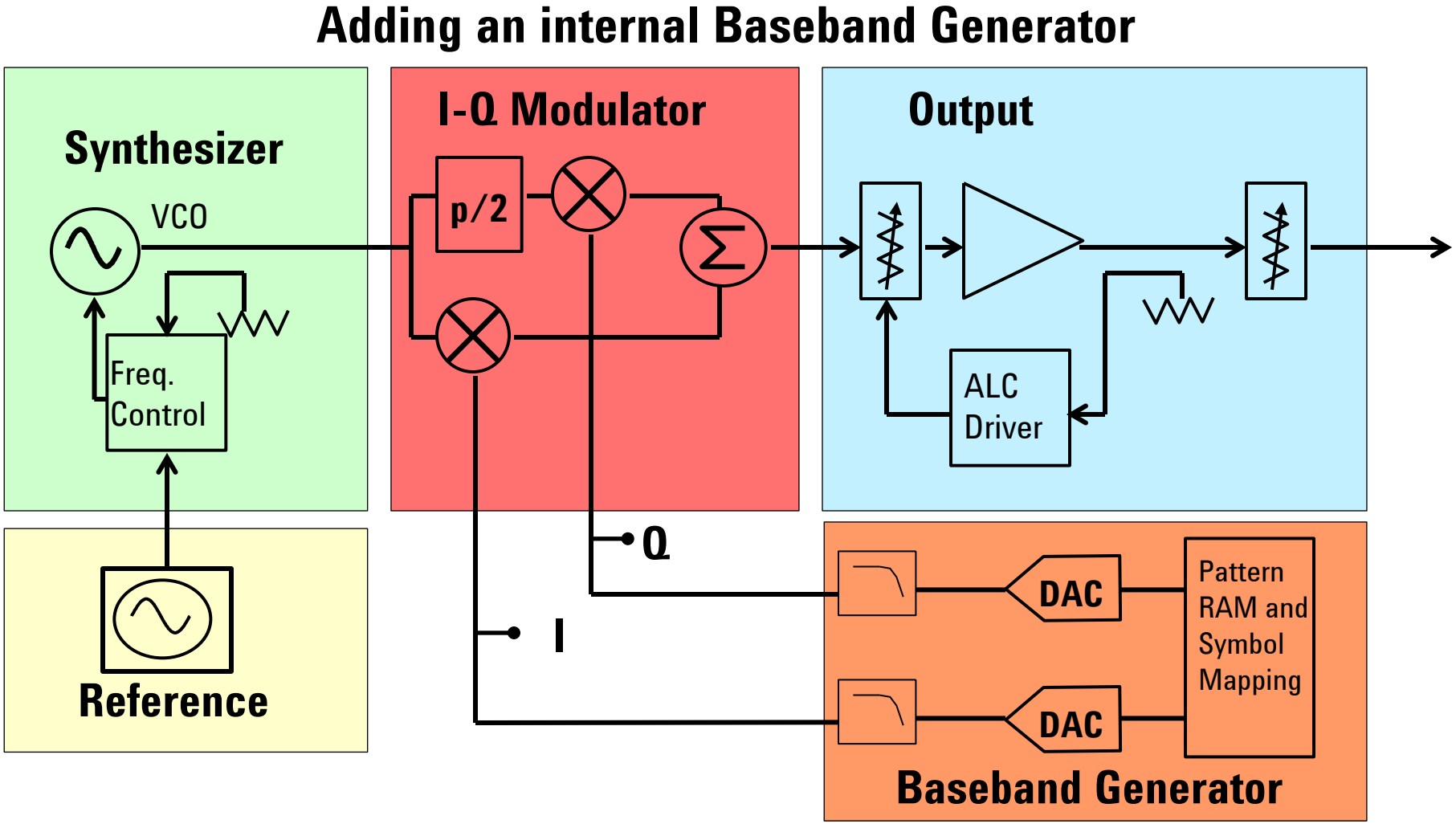
Fast Transitions Require Wide Bandwidths





Filtering Slows Down Transitions and Narrows the Bandwidth

Vector Signals – Block Diagram



Vector Signals – Applications

Format Specific Signal Generation

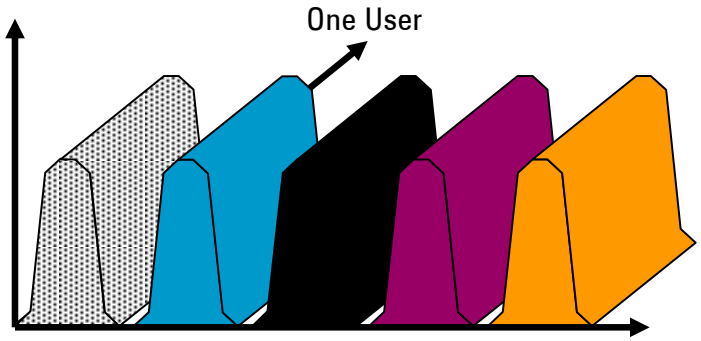
Receiver Sensitivity

Receiver Selectivity

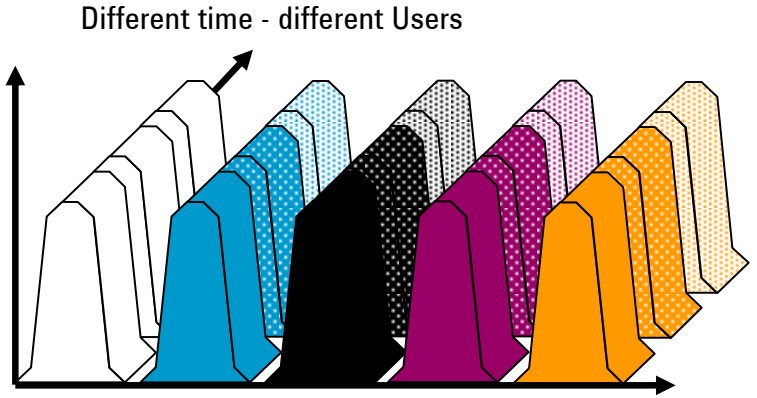
Component Distortion

Vector Signals – Applications

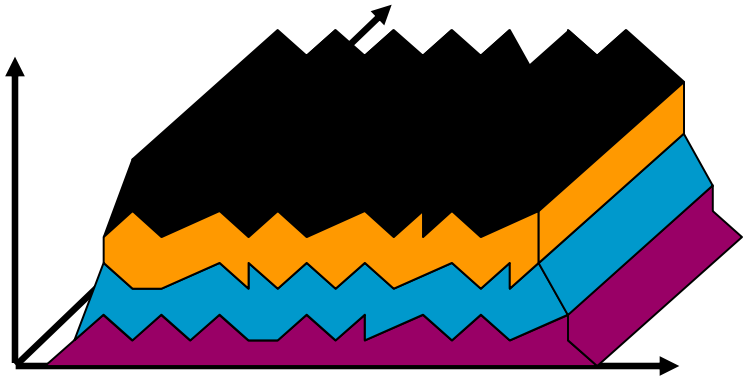
Digital Format Access Schemes



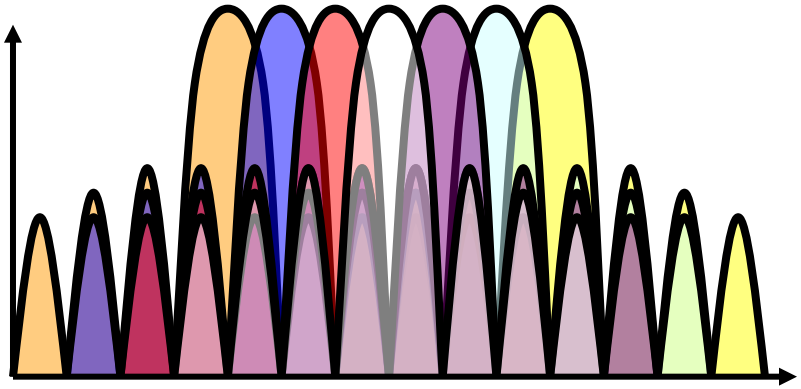
FDMA Differ channel - different Users



TDMA Different time - different Users



CDMA Same channel – many users

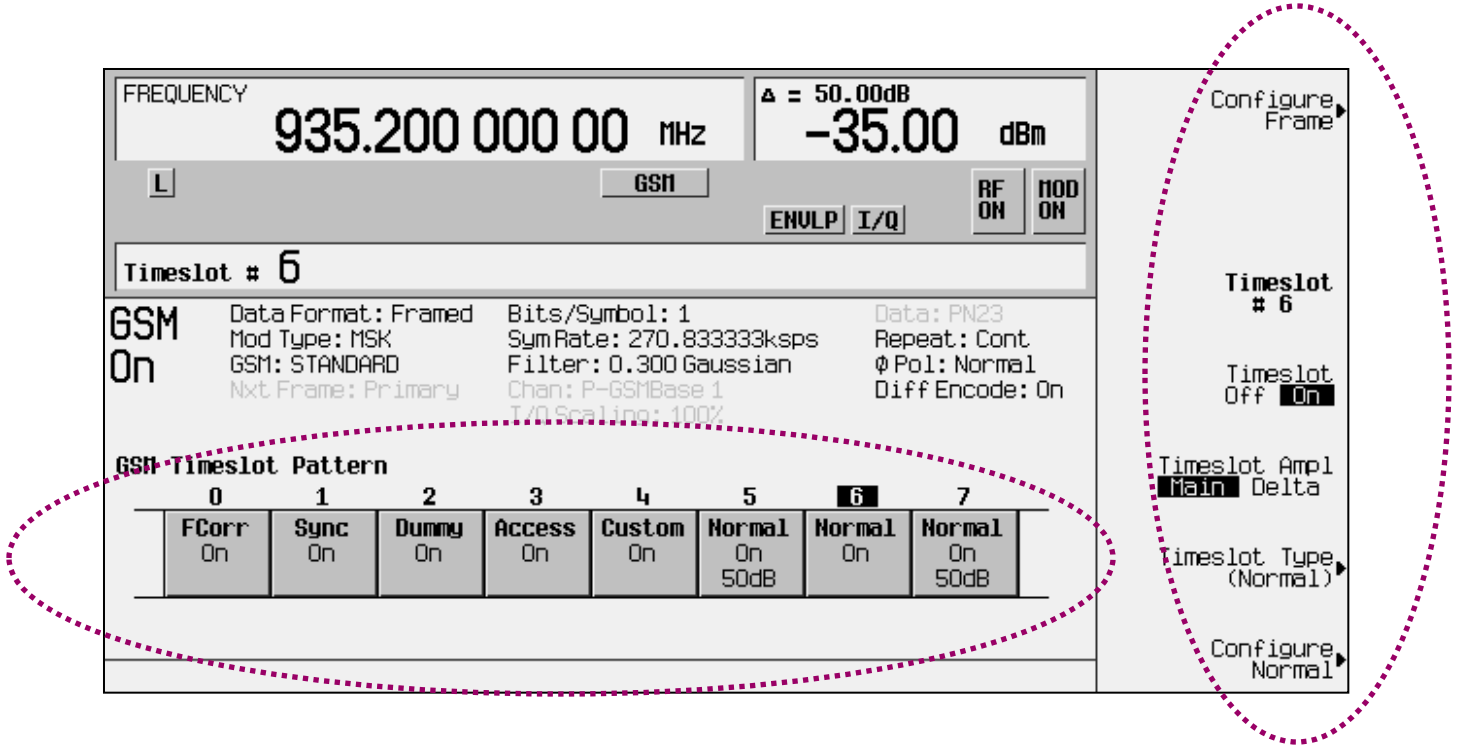


OFDM

Vector Signals – Applications

Format Specific Modulation

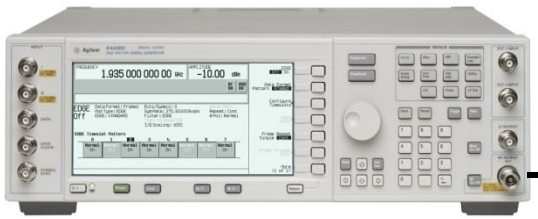
GSM: **A type of TDMA modulation**
Multiple users, same frequency, different time slots

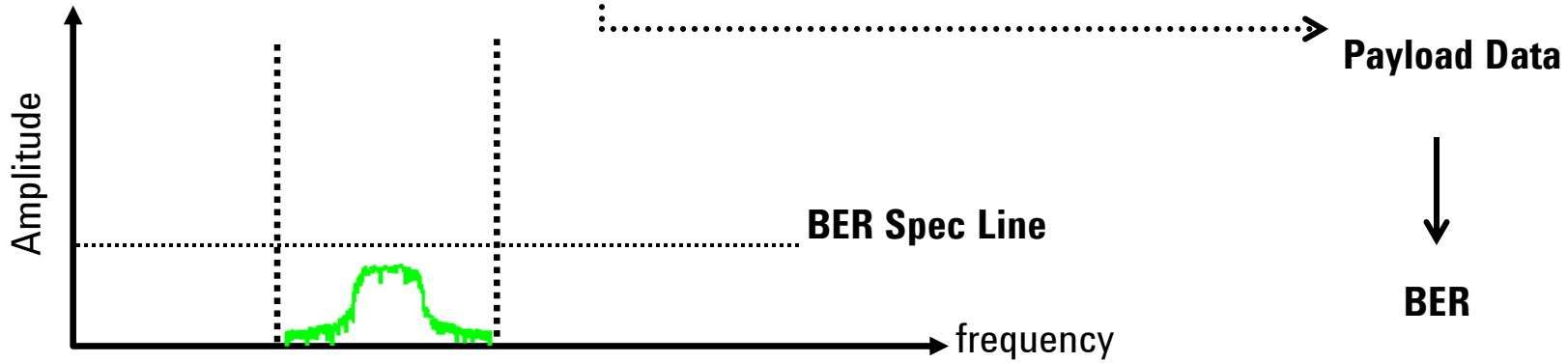


Vector Signals – Applications

Digital Receiver Sensitivity

The smallest modulated RF signal that will produce a specified BER from the receiver





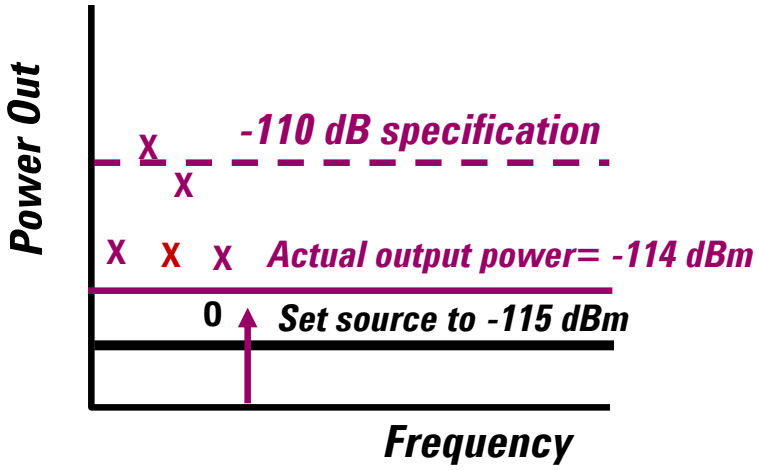
Vector Signals – Applications

Digital Receiver Sensitivity

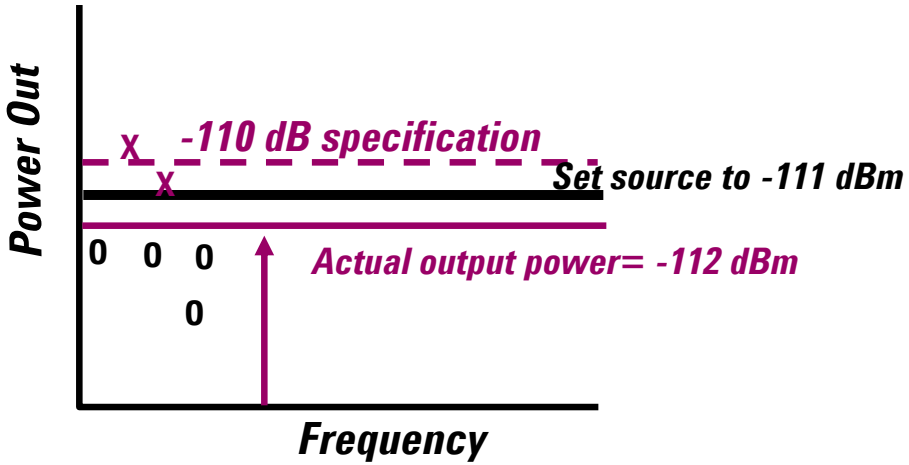
Testing a -110 dB sensitivity digital receiver:

X= Failed unit
0=Passed unit

Amplitude Accuracy Matters!



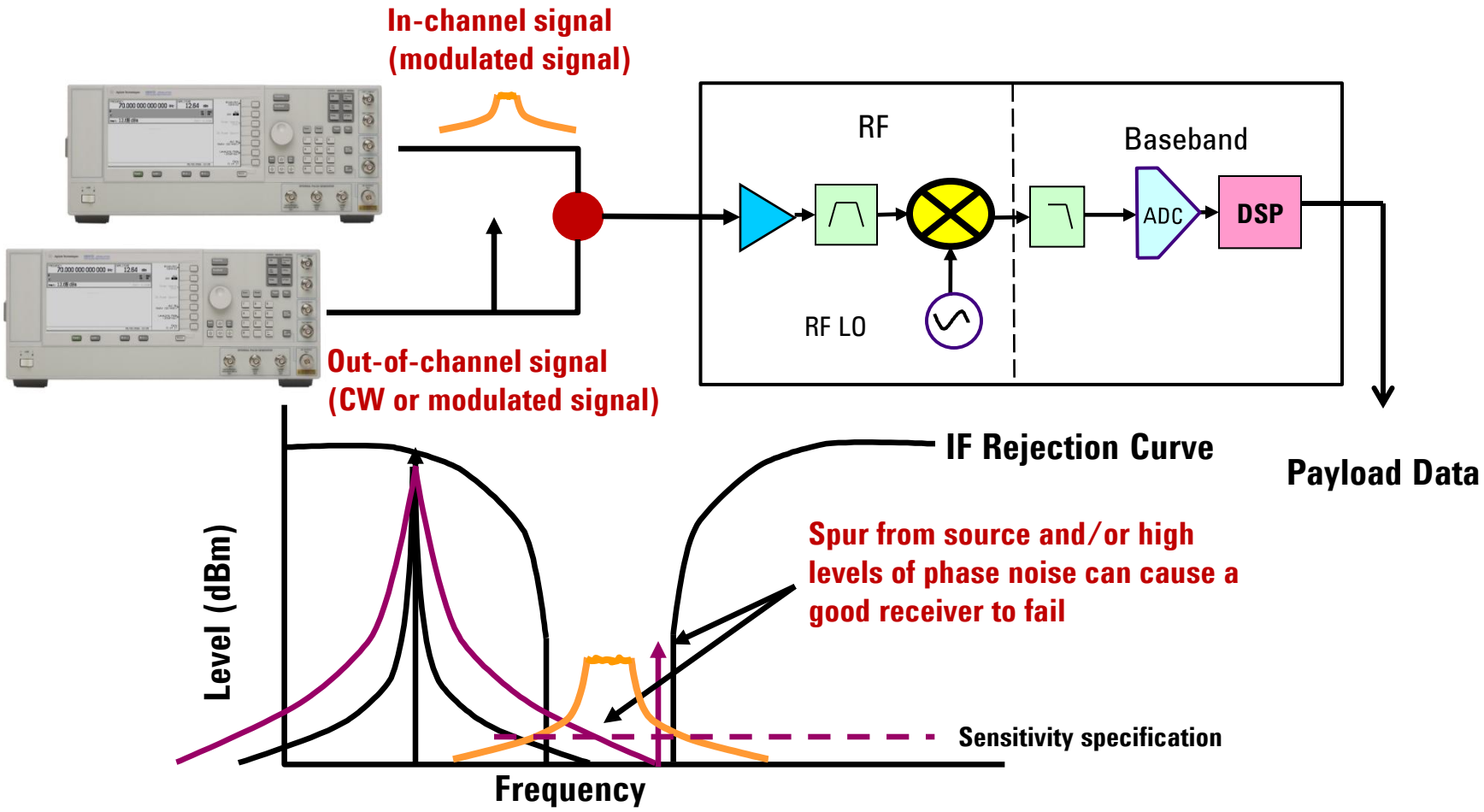
Case 1: Source has +/-5 dB of output power accuracy at -100 to -120 dBm output power.



Case 2: Source has +/-1 dB of output power accuracy at -100 to -120 dBm output power.

Vector Signals – Applications

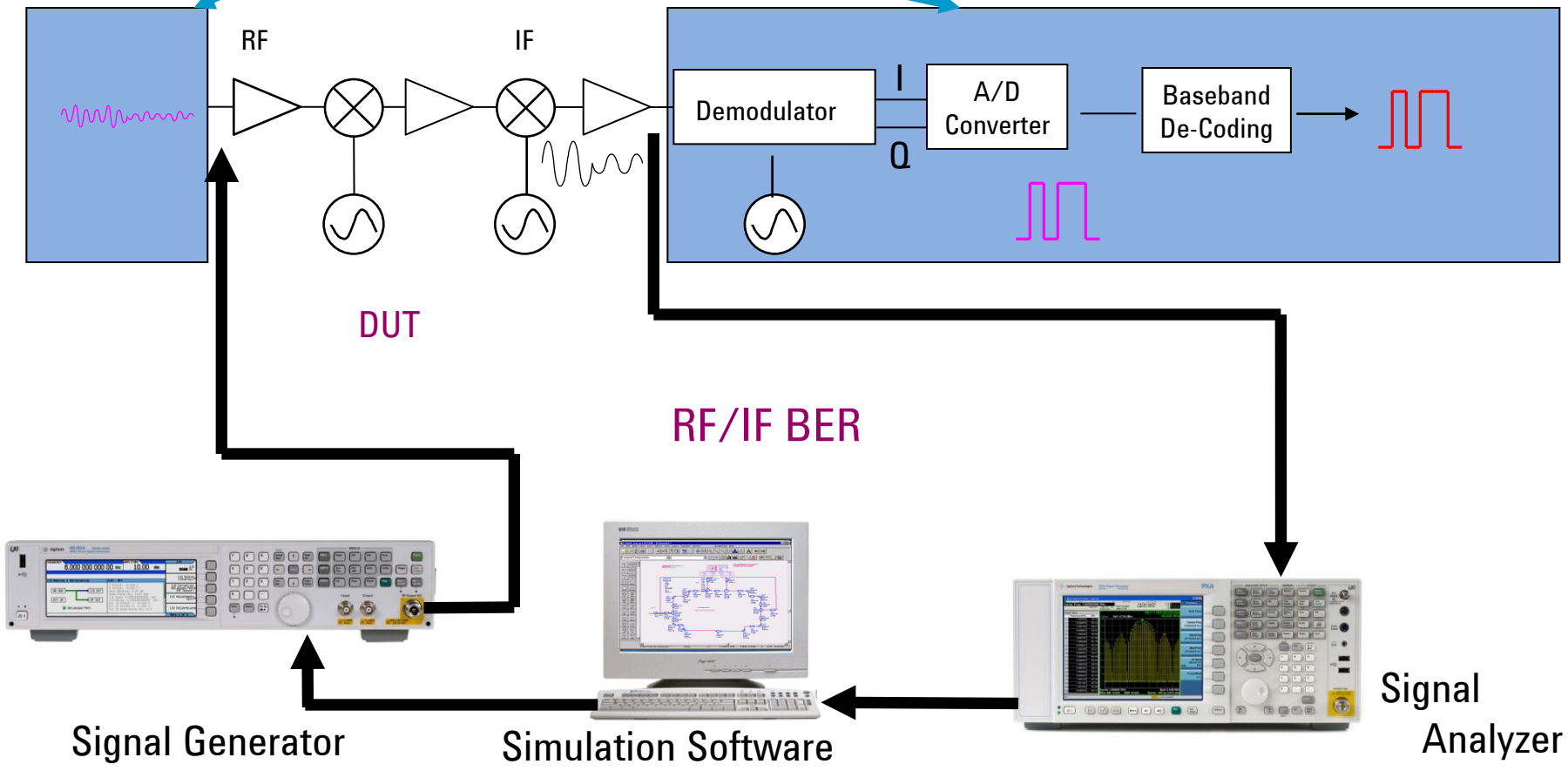
Receiver Selectivity (Blocking Tests)



Vector Signals – Applications

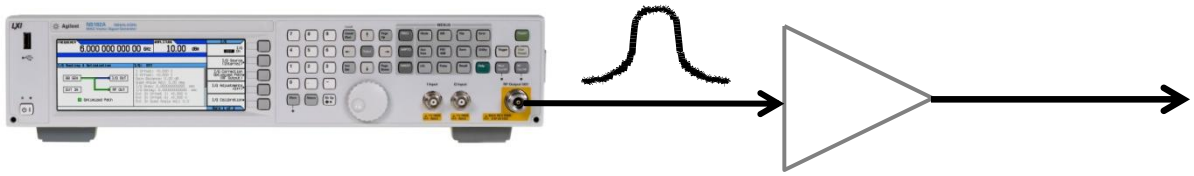
Receiver Sensitivity – Connected Solutions

- Simulated portion

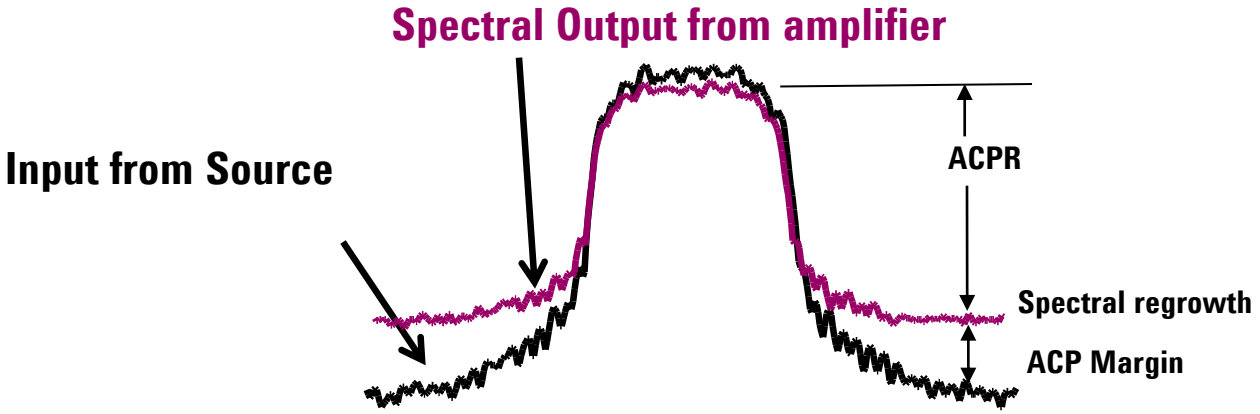


Vector Signals – Applications

Component Distortion – Adjacent Channel Power Ratio



DUT

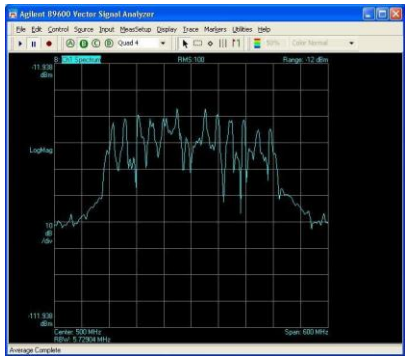


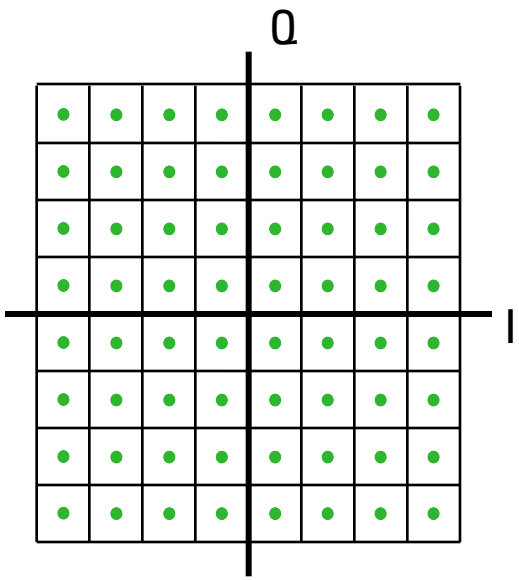
Margin (dB)	0	1	2	3	4	5	10	15
Error contribution (dB)	3.0	2.5	2.1	1.8	1.5	1.2	0.4	0.2

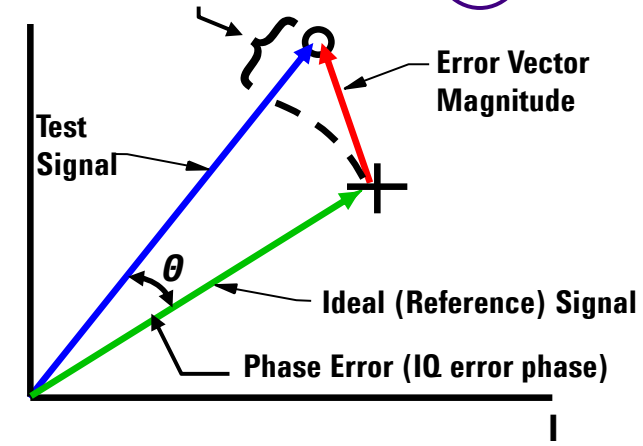
Vector Signals – Applications

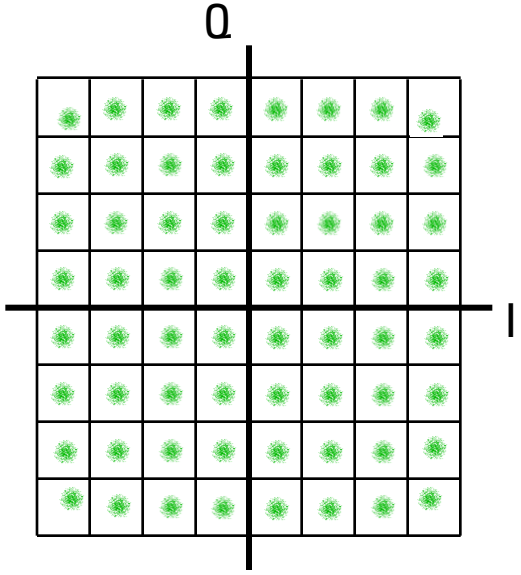
Component Distortion – Error Vector Magnitude

OFDM Signal - 400 MHz Bandwidth







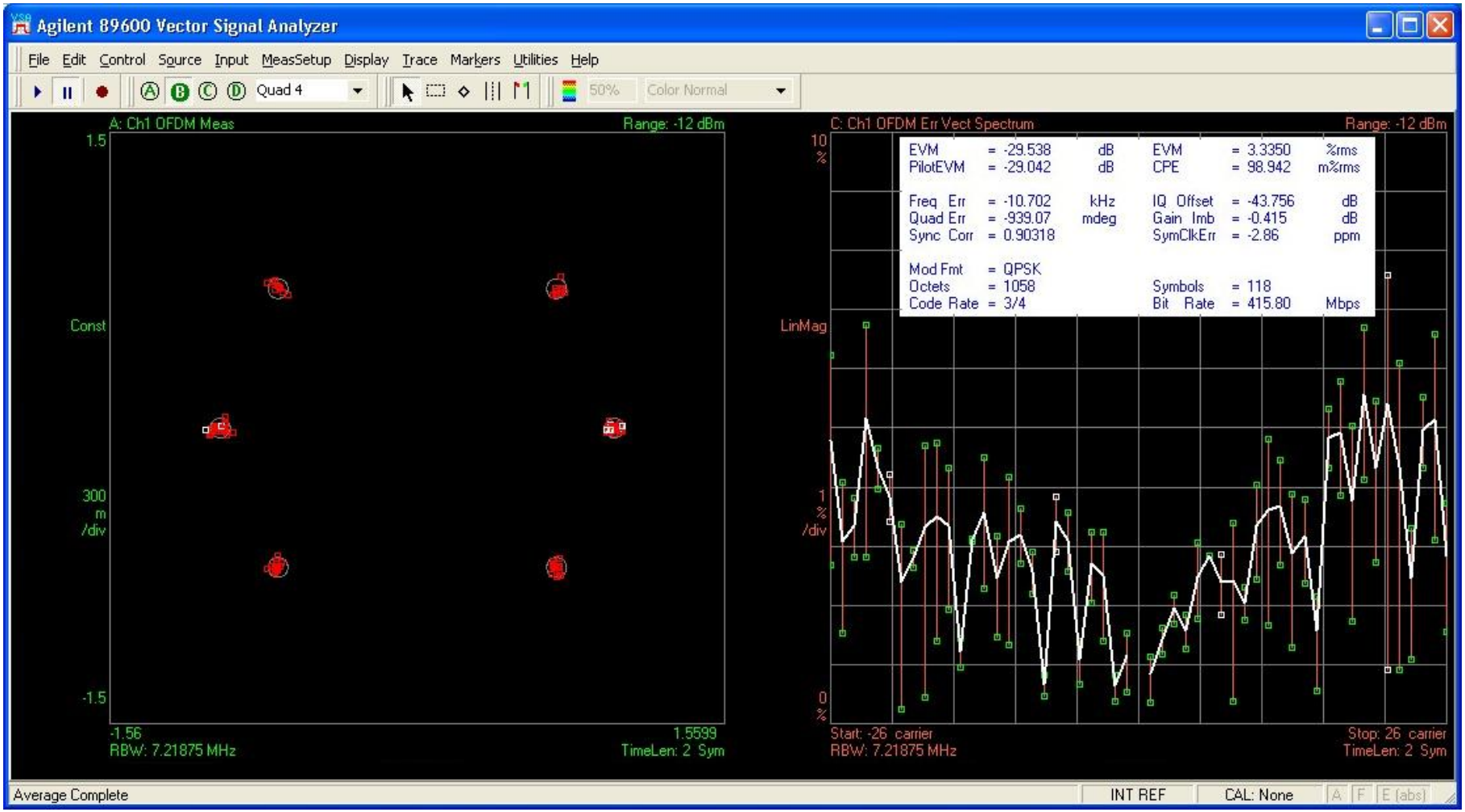


Vector Signals – Applications

OFDM Signal -
400 MHz Bandwidth

Component Distortion – EVM

Measured EVM = -30 dB, 3.3%

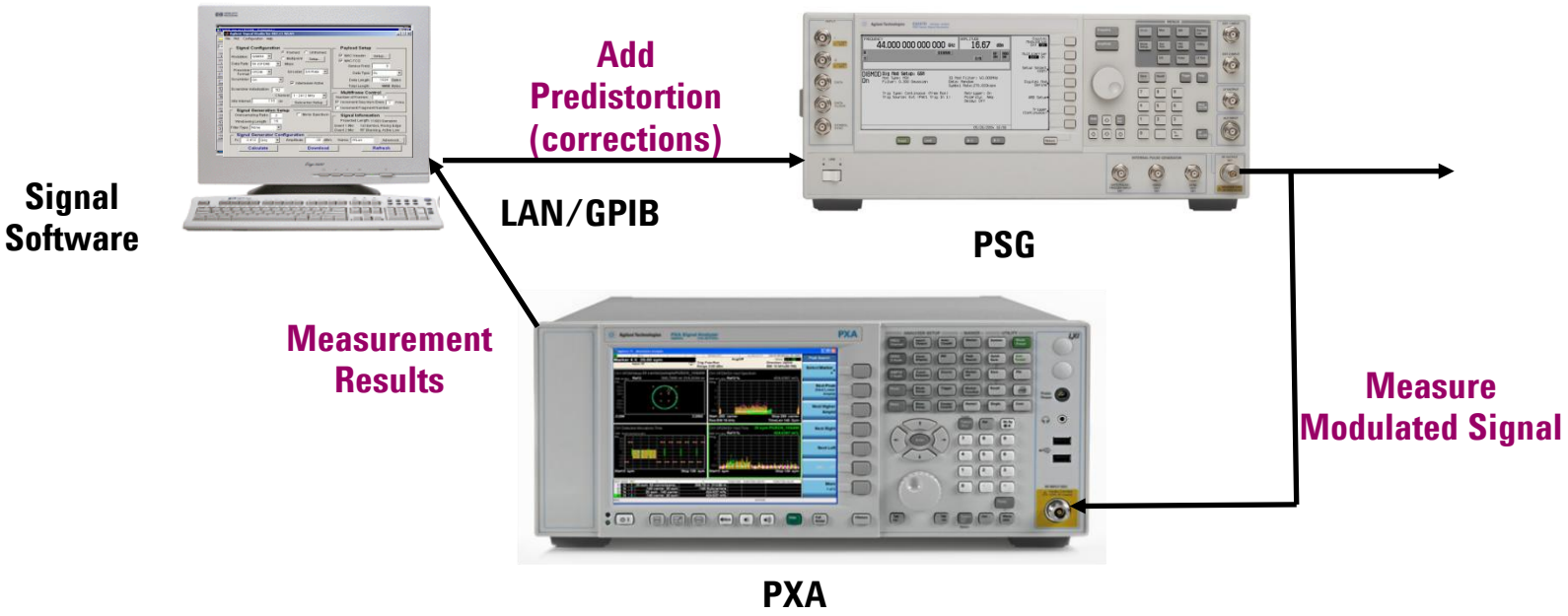


Agenda

- The need for creating test signals
  - Aerospace Defense to Communications
- Generating Signals
  - No modulation
  - Analog Modulation
  - Composite Modulation
- Signal Generator Architecture
- Signal Simulation Solutions
- Summary

Signal Simulation Solutions

Remove Test Signal Imperfections



Sources of error – I/Q modulator, RF chain, IQ path

Result – passband tilt, ripple, and roll off

Signal Simulation Solutions

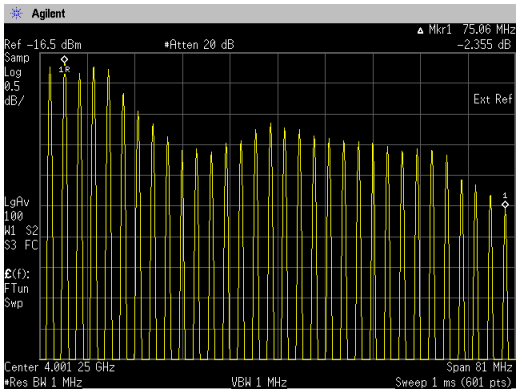
Remove Test Signal imperfections – IQ flatness

Solution – measure vector signal generator and apply predistortion

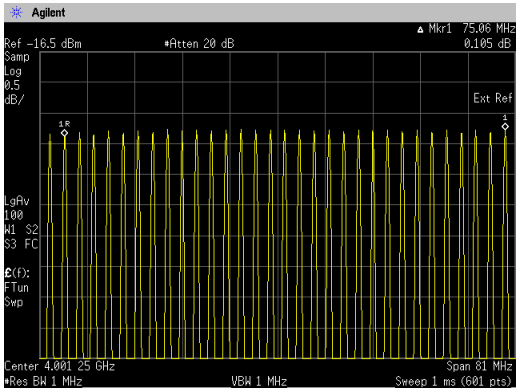
Tradeoff – calculation time, valid calibration time

Typical application – wideband, multitone, and multicarrier

32 tones - 80 MHz

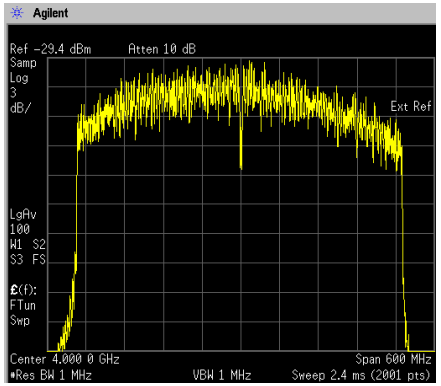


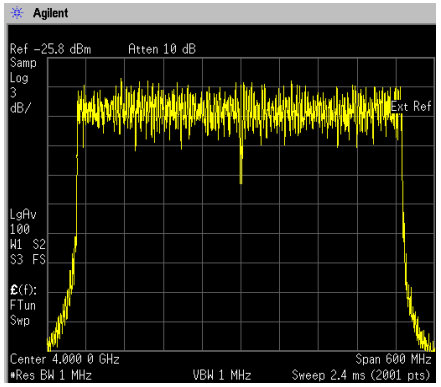
2.4 dB **Before** **6-8 dB**



0.1 dB **After** **< 3 dB**

500 MHz UWB



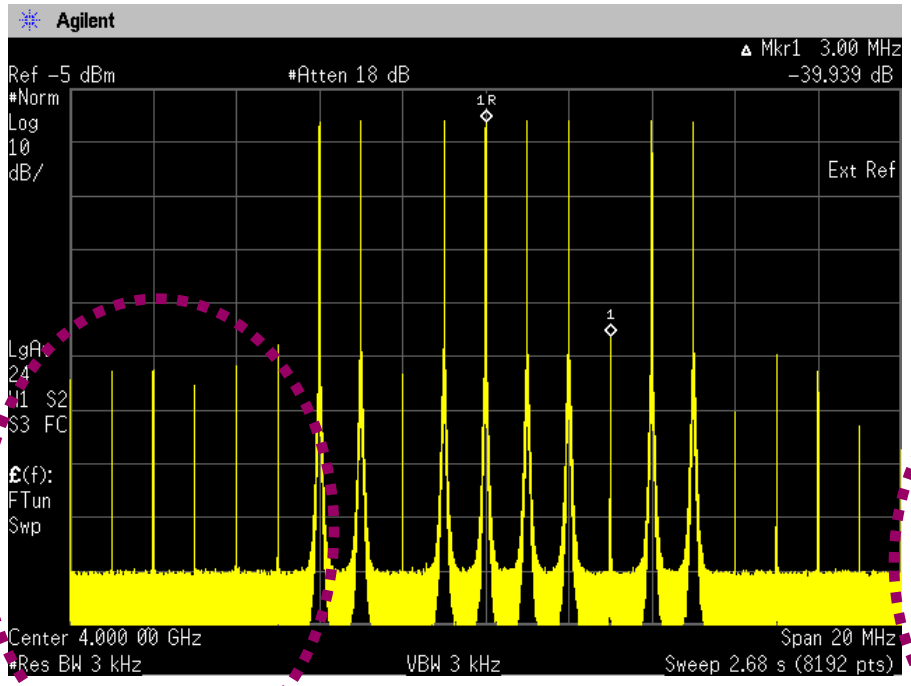


Signal Simulation Solutions

Removing Test Signal Imperfections - IMD

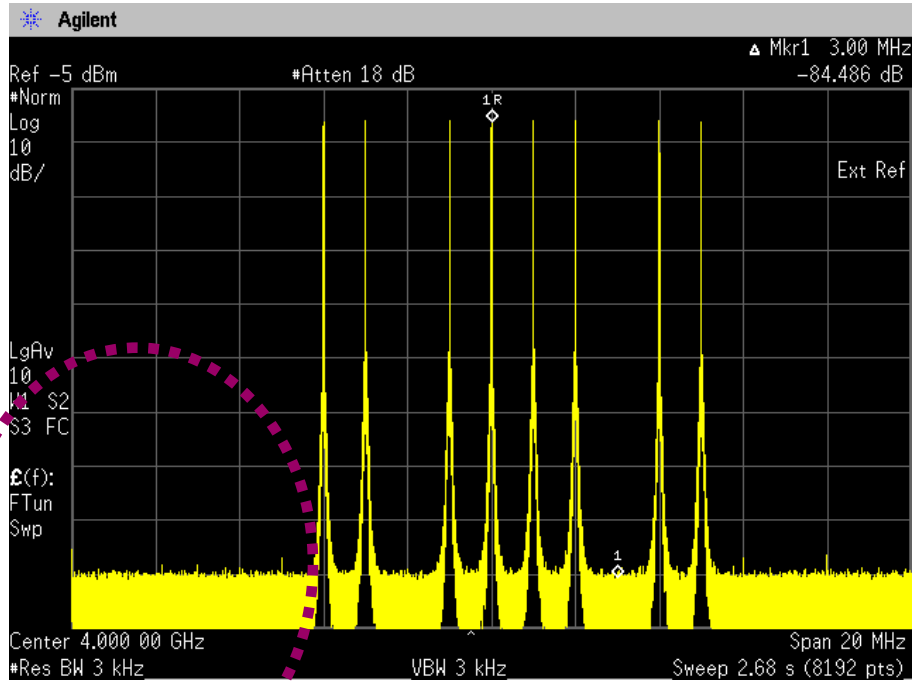
Before Predistortion

Measured in-band IMD = -40 dBc



After Predistortion

Measured in-band IMD = -84 dBc

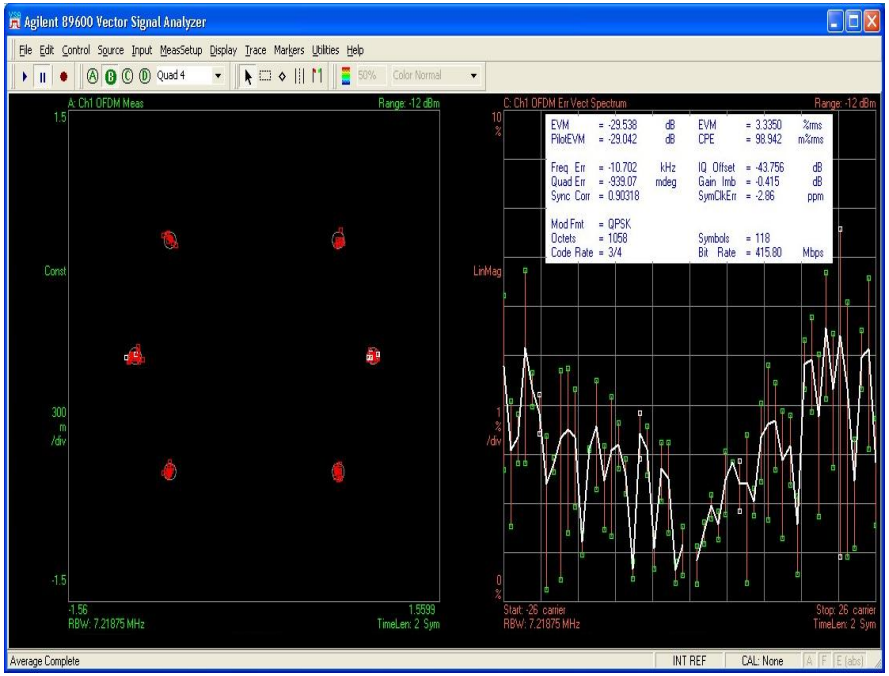


Signal Simulation Solutions

Removing Test Signal Imperfections – Group Delay

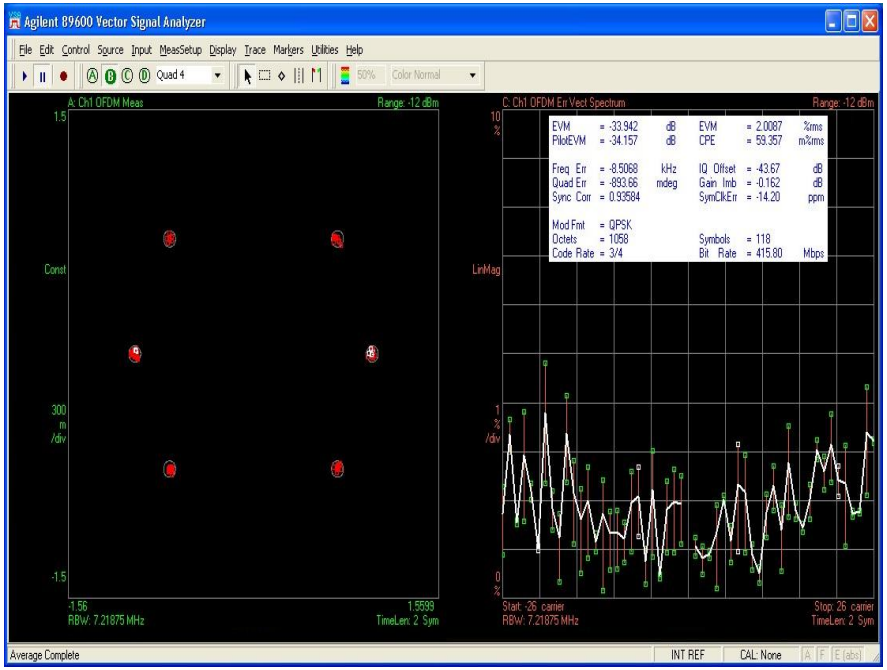
Before Predistortion

EVM -30 dB, 3.3%

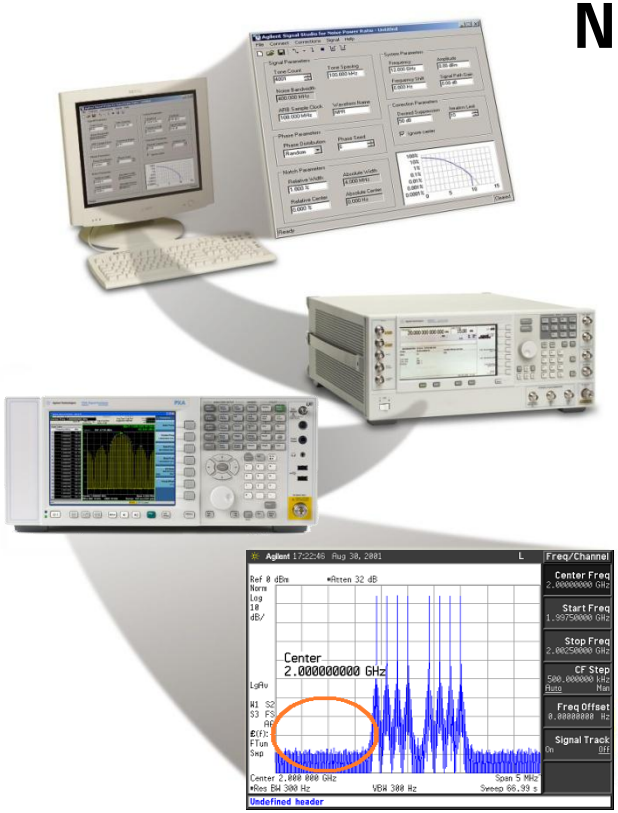


After Predistortion

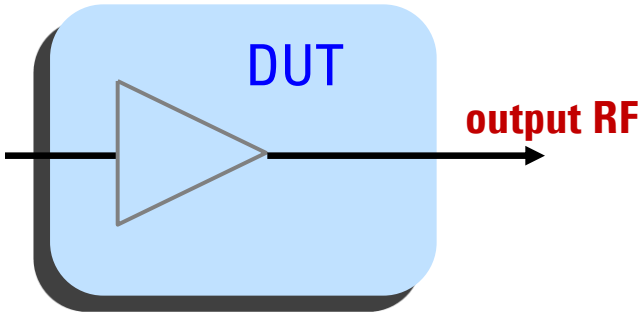
EVM –34 dB, 2%



Signal Simulation Solutions



Non-linear Amplifier Testing



Intermodulation Distortion

- Improved IMD suppression (typically > 80 dBc)
- Correct generator with additional devices in the loop
- Lower overall cost-of-test for large # tones
- Same hardware for ACPR/NPR distortion tests

Signal Studio – Enhanced Multitone

Up to 1024 tones

Set relative tone power

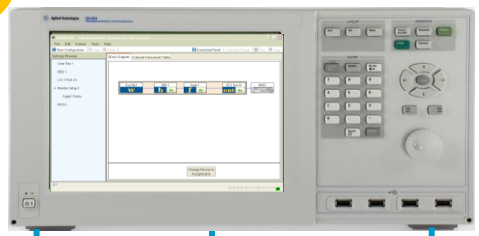
Set relative tone phase

80 MHz correction BW

CCDF plot

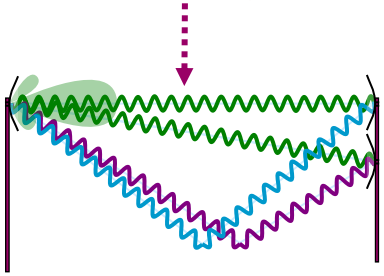
SISO BBG and Fading Test at RF/BB

1 PXB generates single channel signals with long playback



2 PXB applies SISO real-time fading

Faded signal & Interferers



Transmission channel

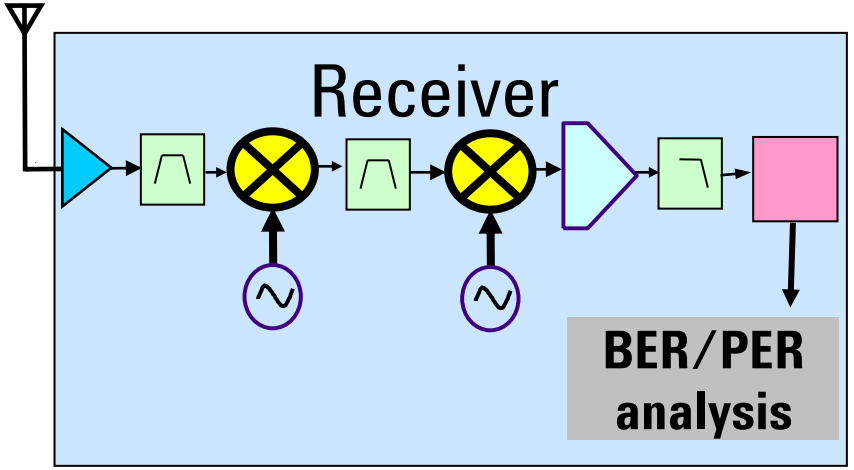
3 Output IQ or RF

Analog I/Q

N5102A
Digital I/Q

Vector MXG,EXG,ESG, or PSG used as an up converter

No BBG required for MXG or EXG



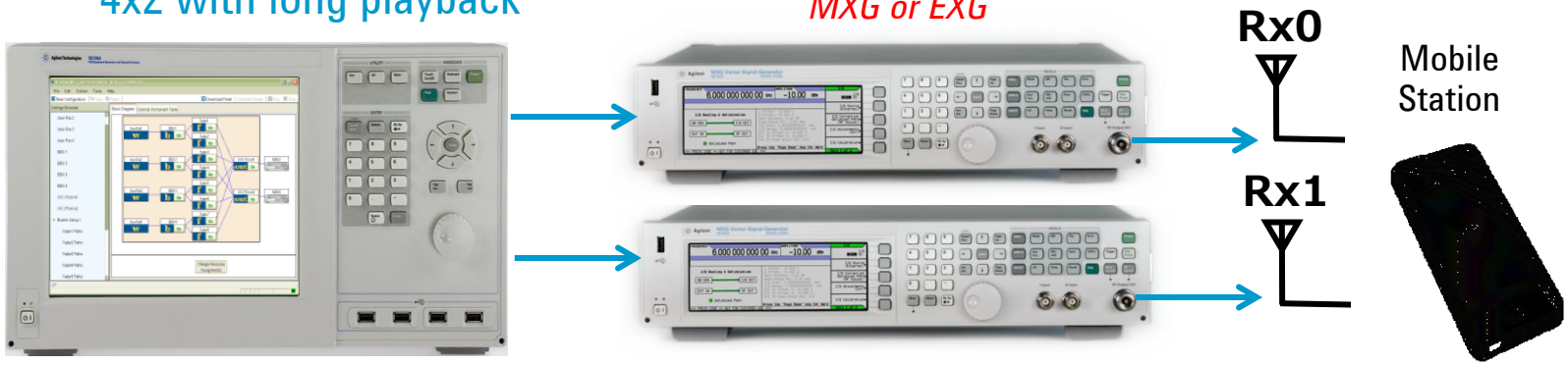
MIMO Receiver Test at RF/BB

Create MIMO signals with real-time fading for receiver test

1

PXB generates MIMO signals up to 4x2 with long playback

No BBG required for MXG or EXG



2

PXB applies flexible real-time fading to MIMO signals

3

Vector MXG, EXG or ESG used as RF up converters, one per receive antenna

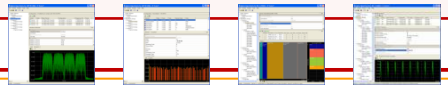
Agenda

- The need for creating test signals
  - Aerospace Defense to Communications
- Generating Signals
  - No modulation
  - Analog Modulation
  - Composite Modulation
- Signal Generator Architecture
- Signal Simulation Solutions
- Summary

Agilent Portfolio Summary

	Performance	Mid-Performance	High Performance		
Analog *AM, FM ØM, Pulse*	**RF**  **N9310A** • 3 GHz	**RF**  **N5171B EXG** • 1,3, or 6 GHz • High power & Fast switching **MW**  **N5183A MXG** • 20, 32, or 40 GHz • Fast switching	**RF**  **N5181B MXG** • 3 GHz or 6 GHz • Spectral purity	**RF**  **E8663D** • 3.2 or 9 GHz • World class SSB phase noise	**MW**  **E8257D PSG** • 20,32,40,50 or 67 GHz • Extensions up to 325 GHz • Highest power (over 1 watt) • World class SSB phase noise  **Oleson Microwave Labs (OML)** mm-wave source modules up to 325 GHz
Vector *AM, FM ØM, Pulse, I/Q*	**RF**  **N9310A** • 3 GHz • External I/Q only • 80 MHz ext I/Q BW	**RF**  **N5172B EXG** • 3 or 6 GHz • High power and ACPR • Fast switching • Real-time & ARB BBG • 3G, LTE, GNSS, WLAN, Digital Video, and more	**BB**  **N5106A PXB** • Analog & Digital I/Q outputs • Multi-channel BBG • Up to 8 real-time faders • Up to 24 paths per fader • Up to 4x2 MIMO • LTE, WiMAX, WLAN, Digital Video, and more	**RF**  **N5182B MXG** • 3 or 6 GHz • Best power, ACP & EVM • World class SSB phase noise • Real-time & ARB BBG • 160 MHz BW • 3G, LTE, GNSS WLAN, Digital Video, and more	**MW**  **E8267D PSG** • 20,32, or 44 GHz • High power • World class SSB phase noise • 2 GHz ext I/Q BW • Real-time & ARB BBG • Digital I/Q I/O • Pulse building, NPR/multitone, 3G, WiMAX, WLAN, and more

Signal Studio Software

Agilent Technologies RF Signal Generation

The New X-Series Signal Generators

MXG N5182B
Vector
9 kHz to 6 GHz

ESG E4438C
250 kHz to 6 GHz

MXG N5181B
Analog
9 kHz to 6 GHz

ESG E4428C
250 kHz to 6 GHz

EXG N5172B
Vector
9 kHz to 6 GHz

MXG N5182A
100 kHz to 6 GHz

EXG N5171B
Analog
9 kHz to 6 GHz

MXG N5181A
100 kHz to 6 GHz

The Worlds Best Performance

Most sophisticated Real-Time applications

Lowest Cost of Ownership

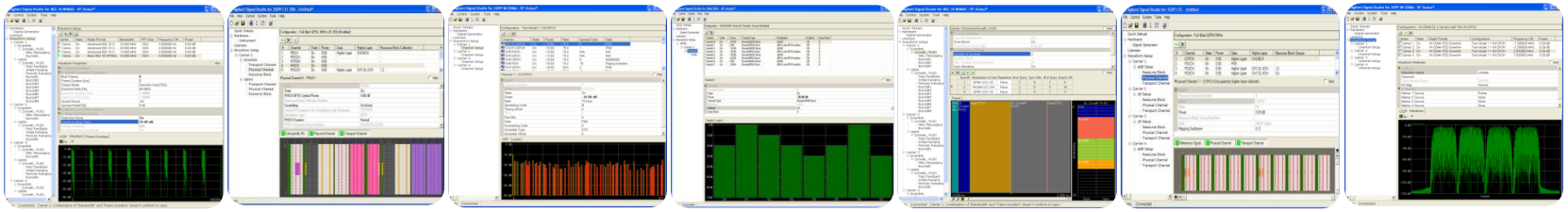
Code compatible

Millimeter Wave Signal Generation

- **E8257D has the widest specified frequency range of any signal generator on the market: 250 kHz to 67 GHz**
- **E8257D offers 8 different models of mm source modules covering 50 to 500 GHz**
  - 50 to 75 GHz
  - 60 to 90 GHz
  - 75 to 110 GHz
  - 90 to 140 GHz
  - 110 to 170 GHz
  - 140 to 220 GHz
  - 220 to 325 GHz
  - 325 to 500 GHz

Agilent Signal Studio & Embedded Software

Simplify Signal Creation – Validated & Performance Optimized



Cellular Communications

LTE-Advanced FDD/TDD
LTE FDD/TDD
MSR (under LTE)
W-CDMA/HSPA/HSPA+
TD-SCDMA/HSPA
GSM/EDGE/EDGE Evo
cdma2000/1xEV-DO

Wireless Connectivity

802.11ac WLAN
802.11n WLAN
802.11a/b/g/p/j WLAN
802.16 WiMAX
Bluetooth
MB-OFDM UWB

Audio/Video Broadcasting

ATSC
CMMB / DTMB
DAB/DAB+
DOCSIS
DVB-T/T2/H/C/S/S2
FM Stereo/RDS
ISDB-T/T_{SB}/T_{mm}
J.83 Annex A/B/C
S/T-DMB

Detection, Positioning, Tracking & Navigation

GPS
Glonass
Galileo
Pulse Builder

General RF & MW

Toolkit
Multitone
Enhanced Multitone
Noise Power Ratio
Jitter Injection
Phase Noise Impairment
Noise (AWGN)
Channel Emulation
Analog & Digital Mod
MATLAB

Platforms: RF/MW Signal Generators, Multi-Ch. BB Generator/Channel Emulator, DigRF Testers, Wideband ARBs, ADS, SystemVue, OBTs…

For Additional Information

Sources: http://www.agilent.com/find/sources

Signal Analyzers: http://www.agilent.com/find/sa

Recorded webcast : Back to Basics: Signal Analysis

THANK YOU!