Signal Generation Back to Basics

Presented by:

Michel Joussemet

Agilent Technologies

Agenda

- The need for creating test signals
  - Aerospace Defense to Communications
- From Generating Signals…
  - No modulation
  - Analog Modulation
  - Composite Modulation
- …To Simulating Signals
  - Simulating real-life signals
- Signal Generators
- Signal Simulation Solutions
- Summary

From Movies ….

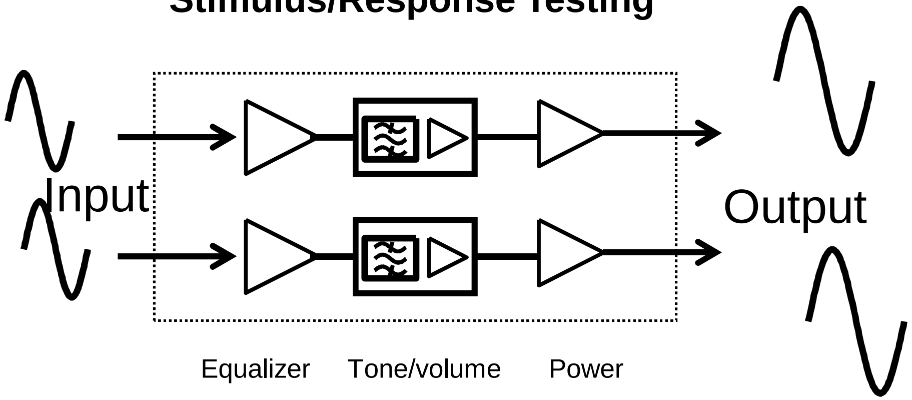
Nov. 1940 - News Flash

*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.

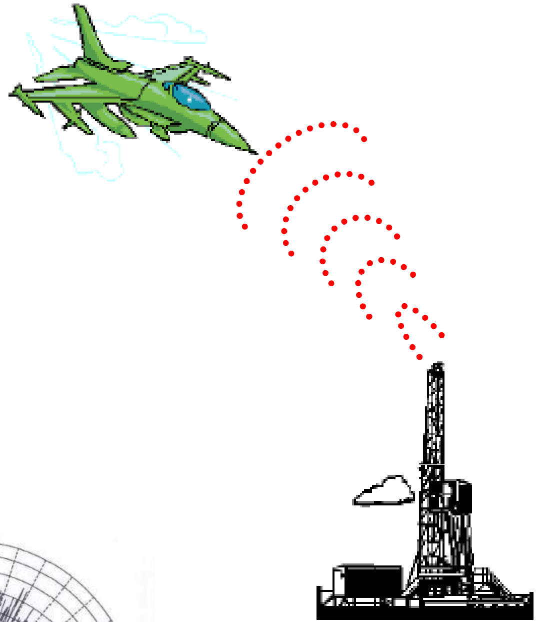
The 200B was used to calibrate the breakthrough sound system of Walt Disney's celebrated animated film, Fantasia

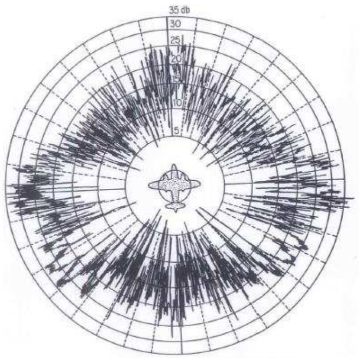
Stimulus/Response Testing

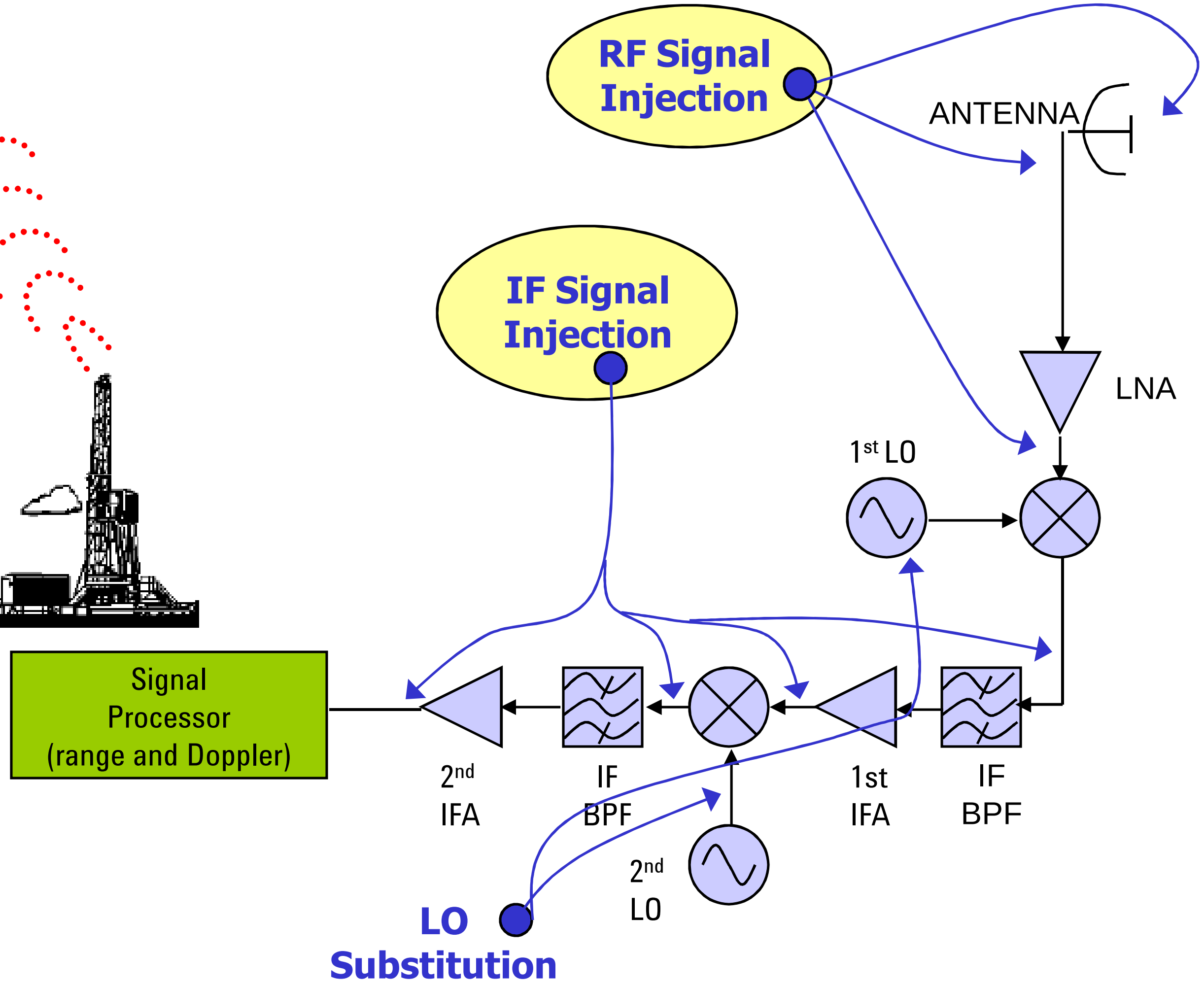


Aerospace Defense ….

TESTING RADAR TRANSMITTERS and RECEIVERs

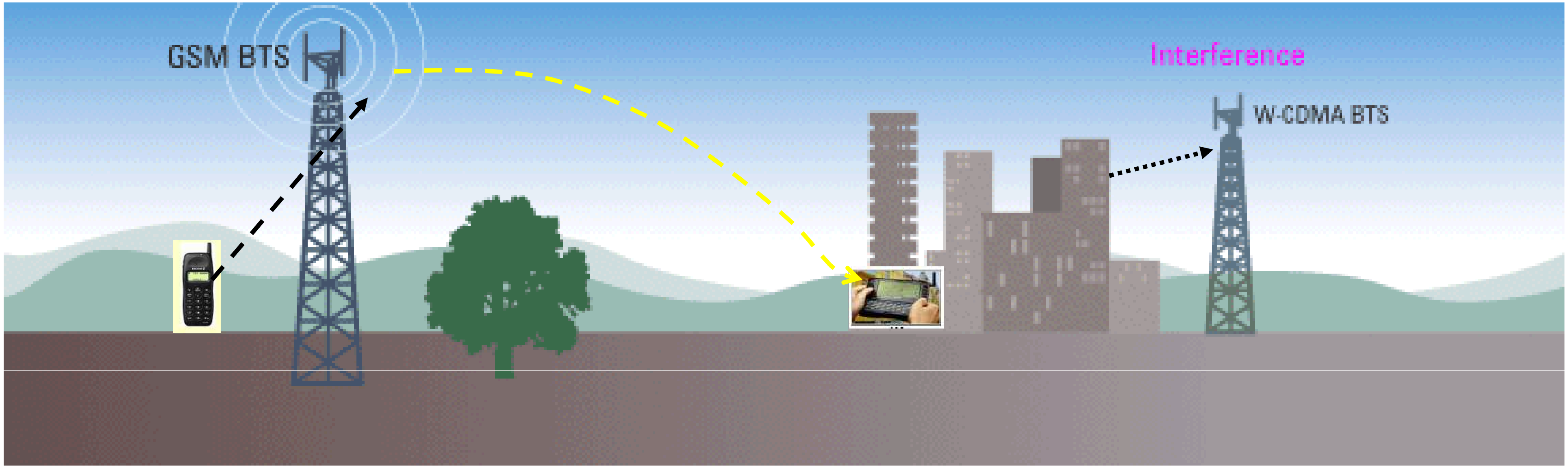


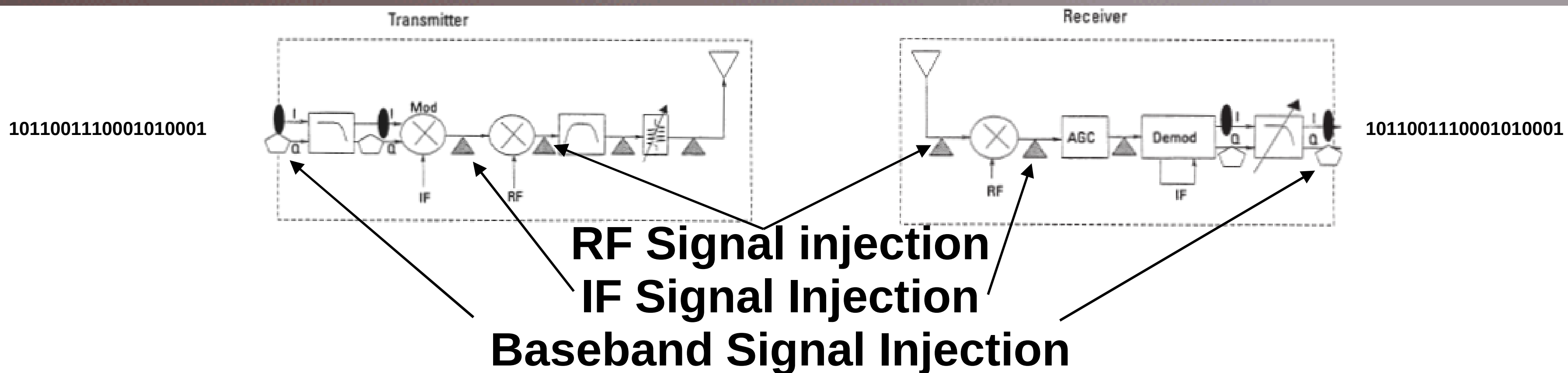




To Mobile Communications….

TESTING DIGITAL TRANSMITTERS and RECEIVERs





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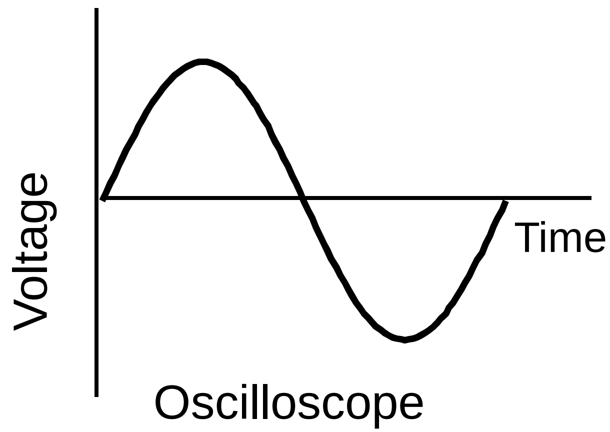
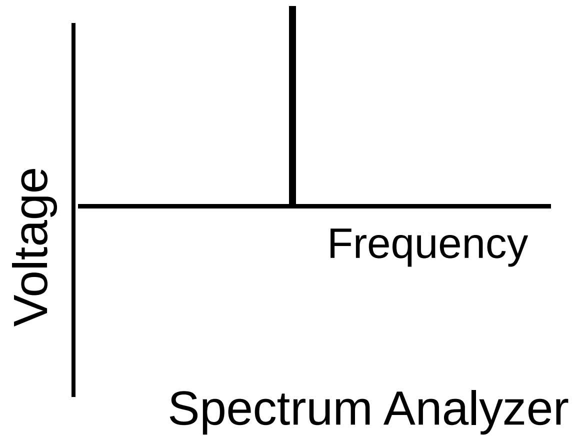
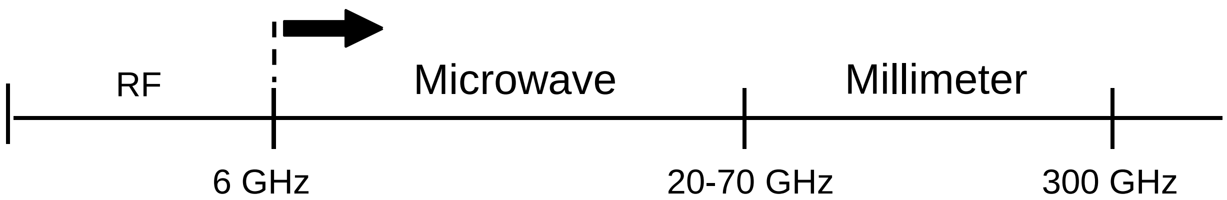
Generating Signals – No Modulation

Continuous Wave (CW)





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

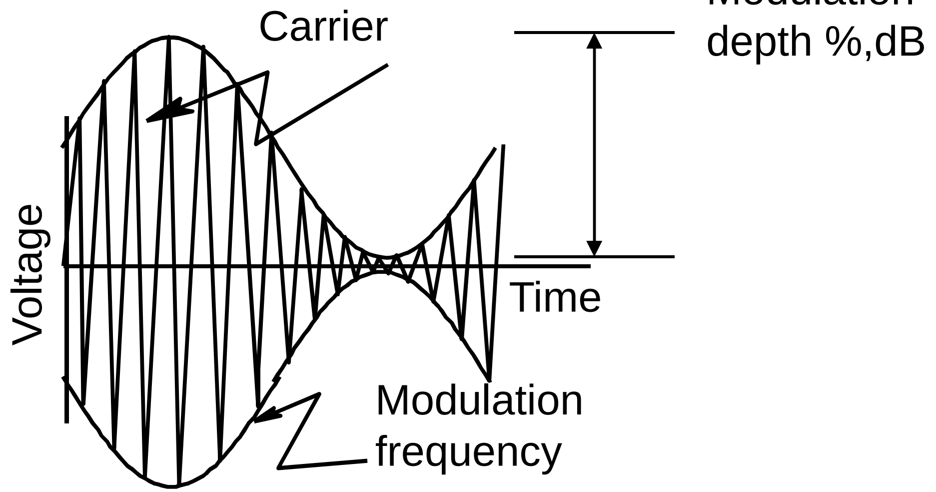
Modulation: Where the Information Resides

$$V = V(t)\ \sin[2p\ f_c(t) + f(t)]$$

AM, Pulse   FM   PM

$$V = V(t)\ \sin[q(t)]$$

Amplitude Modulation

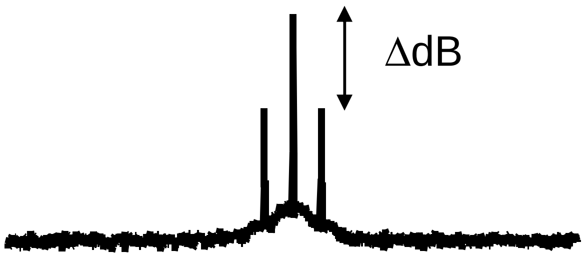


Important Characteristics for Amplitude Modulation

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

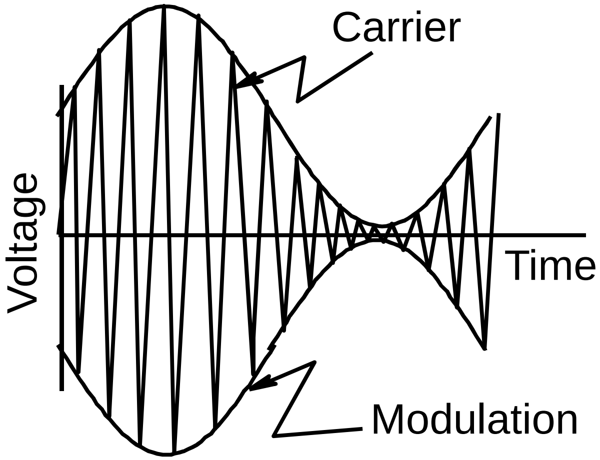
- $v(t) = [1 + m \times cos(w_m \times t) \times cos(w_c \times t)$
- Modulation index
  - $m = 2 \times V_{sideband} \div V_{carrier}$

%AM	ΔdB
10%	-26dBc



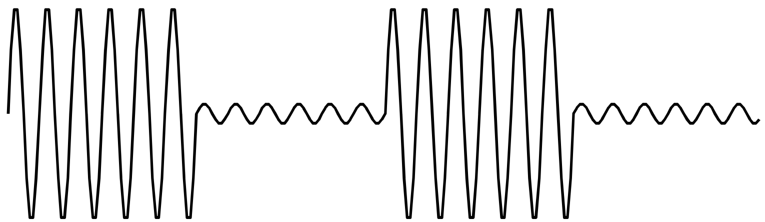
Generating Signals – Analog Modulation

Amplitude Modulation



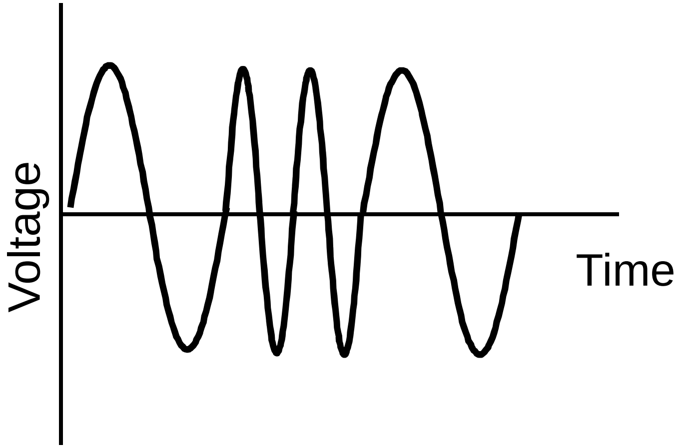
Where are AM signals used?

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



Generating Signals – Analog Modulation

Frequency Modulation

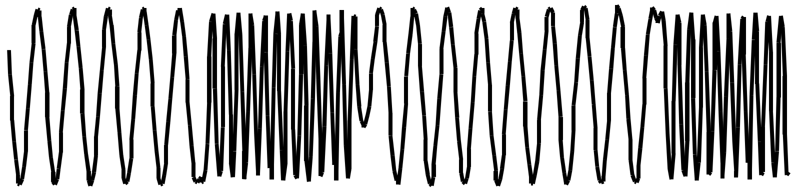


Important Characteristics for Frequency Modulation

- Frequency Deviation
- Modulation Frequency
- dcFM
- Accuracy
- Resolution
- Distortion
- Sensitivity (dev/volt)

Where are FM signals used?

- FM Radio
- Aviation Flight systems
- Radar
- FSK (early digital 1011)

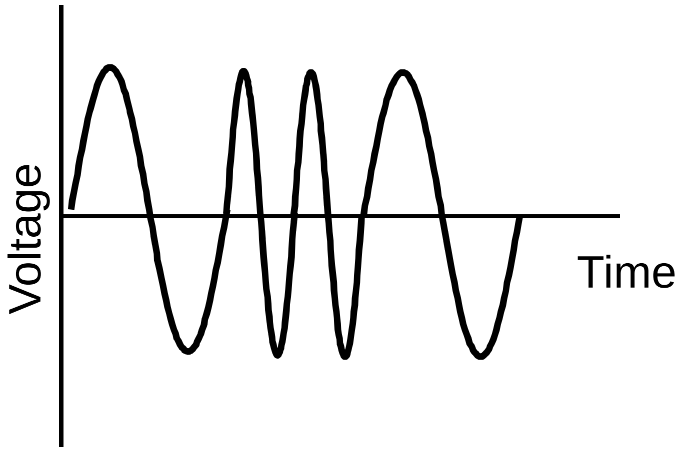


Generating Signals – Analog Modulation

Frequency Modulation

$$V = A \sin[2pf_c t + \beta m(t)]$$

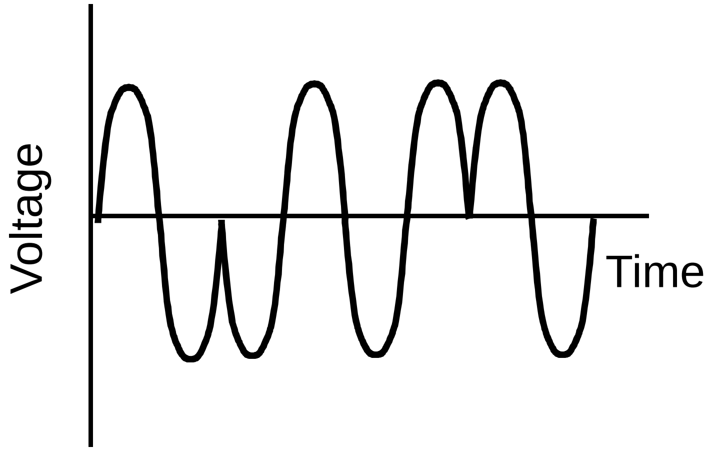
$$\beta = \Delta F_{dev} / F_{mod}$$



Important Characteristics for Frequency Modulation

- Frequency Deviation
- Modulation Frequency
- dcFM
- Accuracy
- Resolution
- Distortion
- Sensitivity (dev/volt)

Phase Modulation



Important Characteristics for Phase Modulation

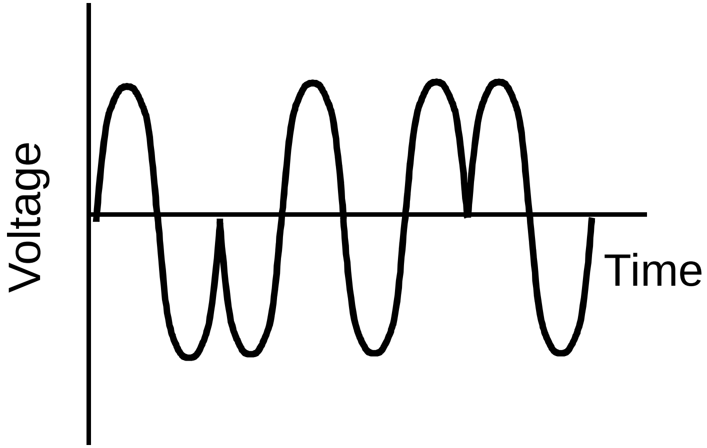
- Phase deviation
- Modulation Rate
- Accuracy
- Resolution
- Distortion
- Sensitivity

Where are Phase Modulated signals used?

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

Generating Signals – Analog Modulation

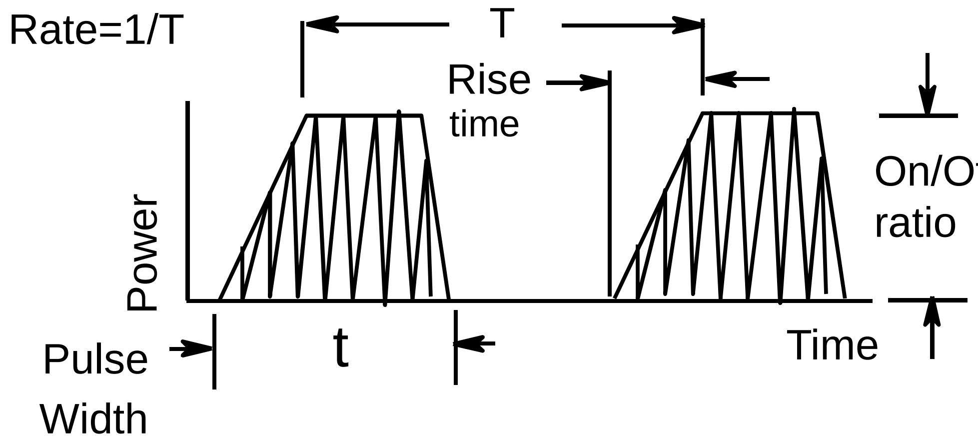
Phase Modulation



Where are Phase Modulated signals used?

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

Pulse Modulation

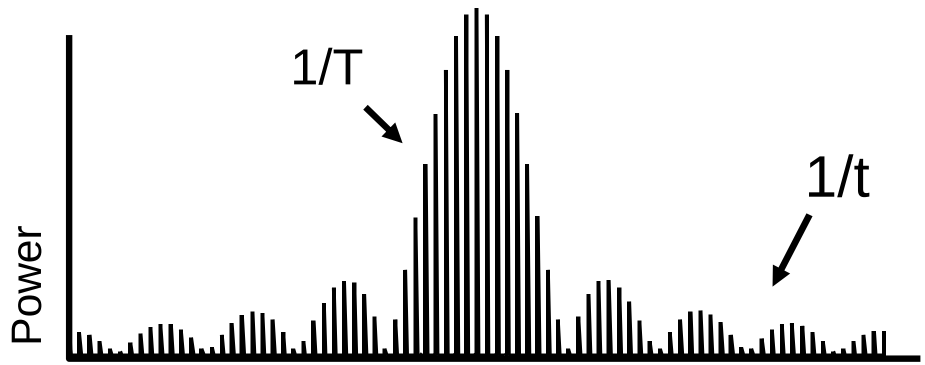


Important Characteristics for Pulse Modulation

- Pulse width
- Pulse period
- On/Off ratio
- Rise time

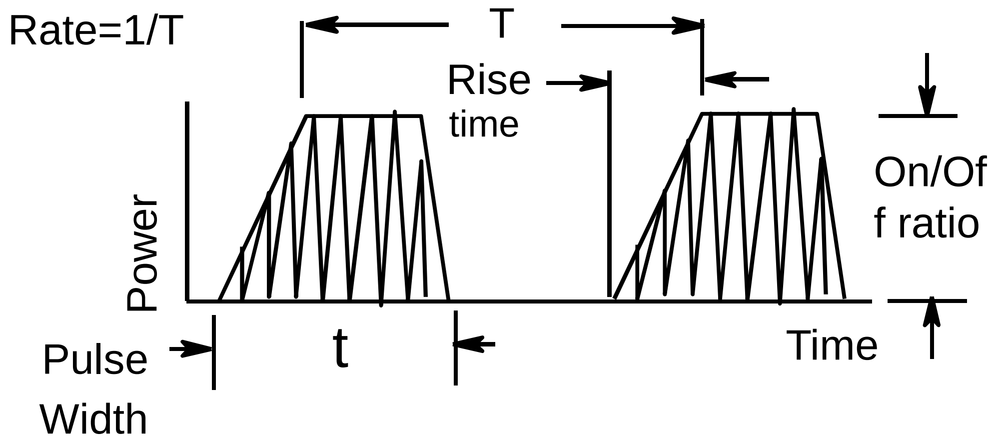
Where are Pulse Modulated signals used?

- Radar
- High Power Stimulus/Response
- Communications



Generating Signals – Analog Modulation

Pulse Modulation



Where are Pulse Modulated signals used?

- Radar
- High Power Stimulus/Response
- Communications

Generating Signals – Composite Modulation

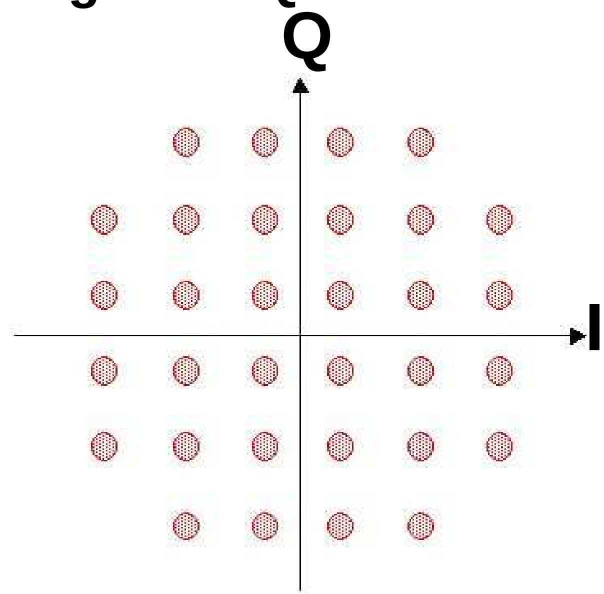
Simultaneous modulation of two Mod Types

Independent Amplitude and Phase Modulation

Independent FM and Pulse Modulation

FM during the pulse = chirp

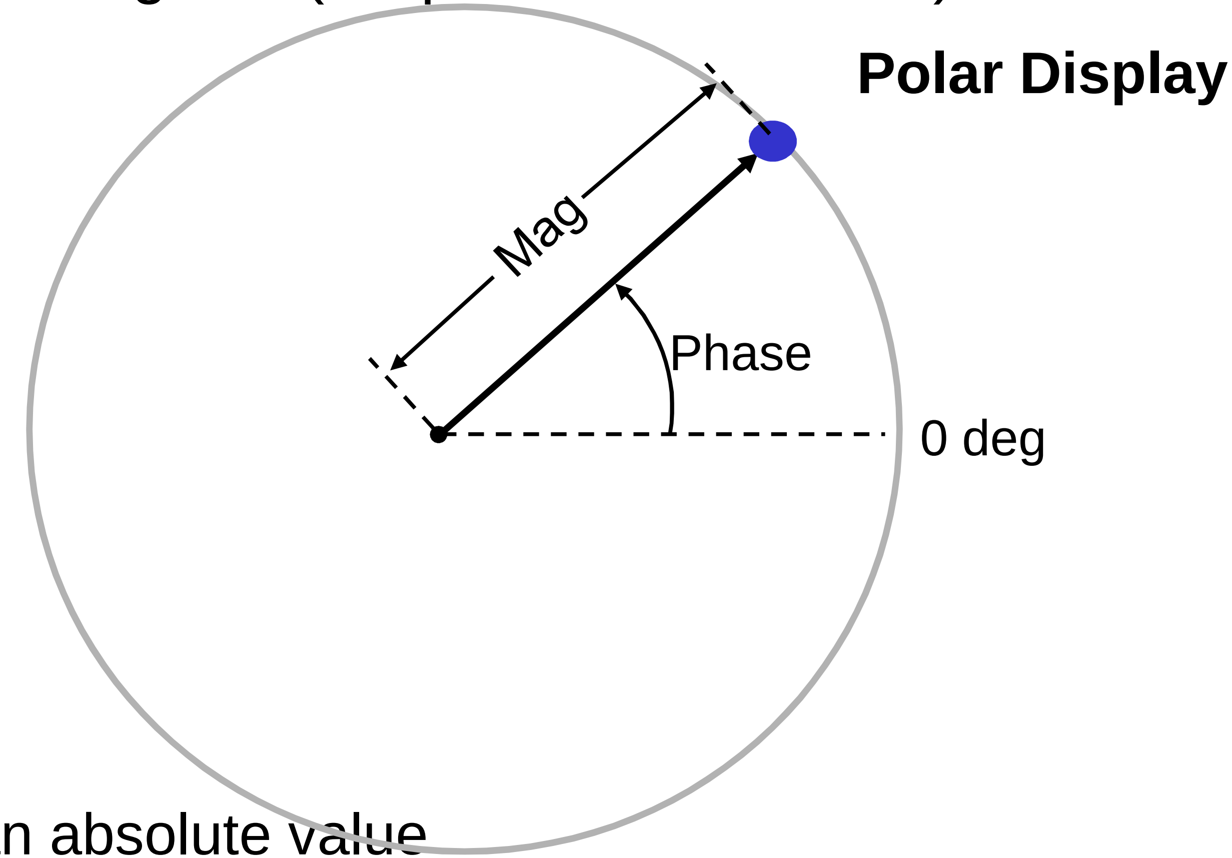
Integrated IQ Modulator



32 QAM Constellation Diagram

Generating Signals – Composite Modulation

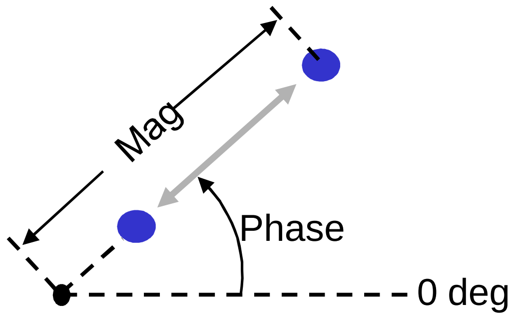
Vector Signals (Amplitude and Phase)



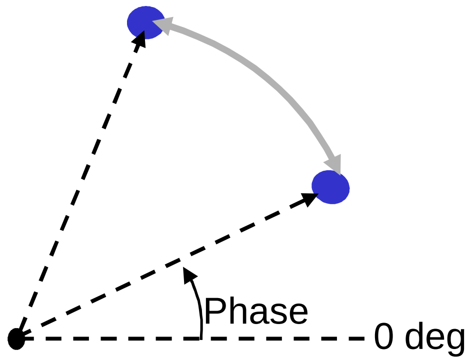
- Magnitude is an absolute value
- Phase is relative to a reference signal (0 degrees)

Generating Signals – Composite Modulation

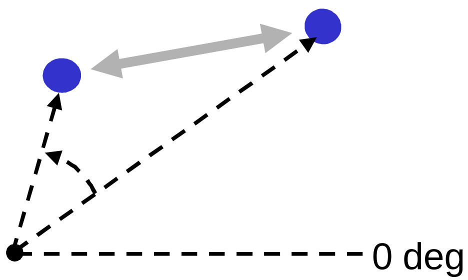
Vector Signal Changes or Modifications



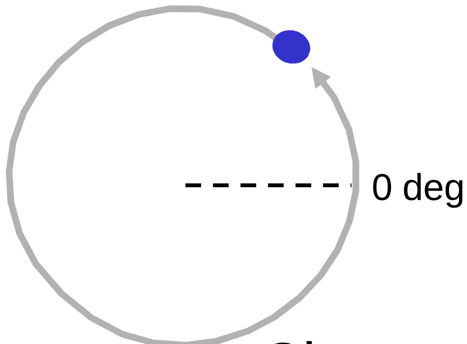
Magnitude Change



Phase Change



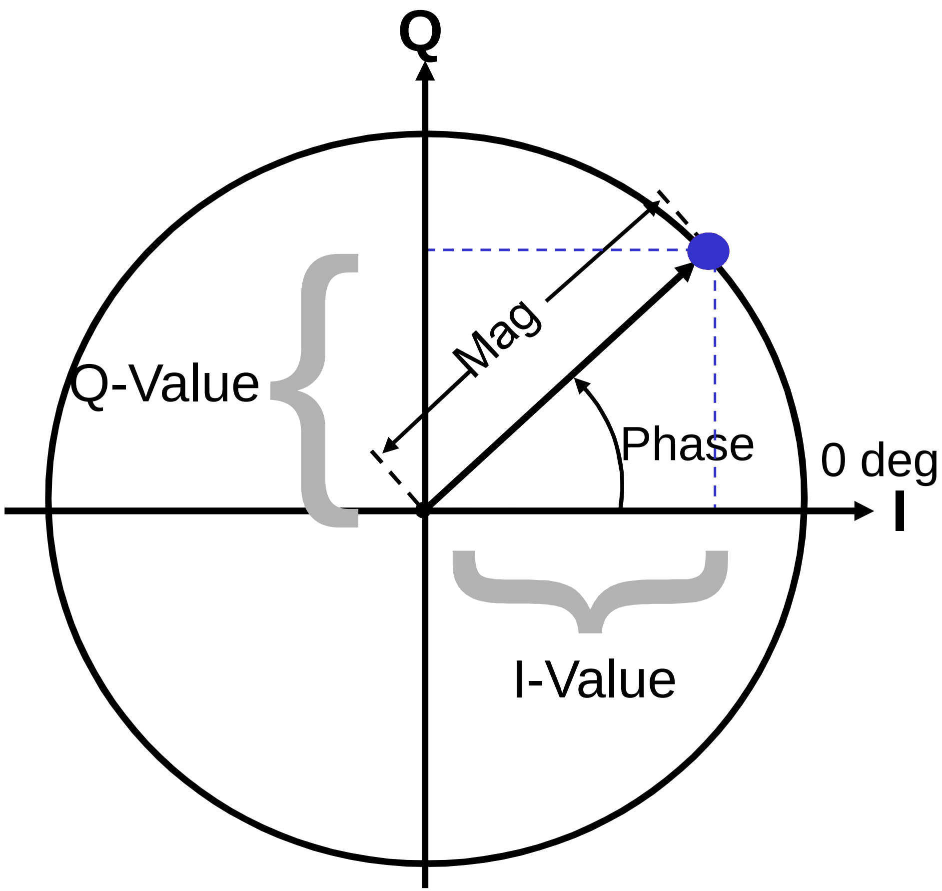
Both Change



Frequency Change

Generating Signals – Composite Modulation

Polar Versus I-Q Format



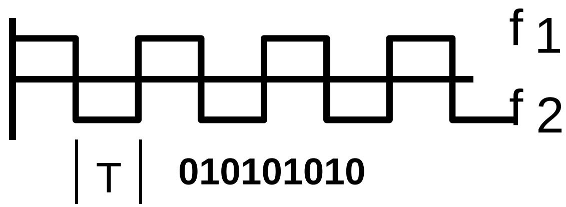
- Project Signals to “I” and “Q” Axes
- Polar to Rectangular Conversion
- IQ Plane Shows 2 Things
  - What the modulated carrier is doing relative to the unmodulated carrier.
  - What baseband I and Q inputs are required to produce the modulated carrier

Transmitting Digital Data -- Bits vs Symbols

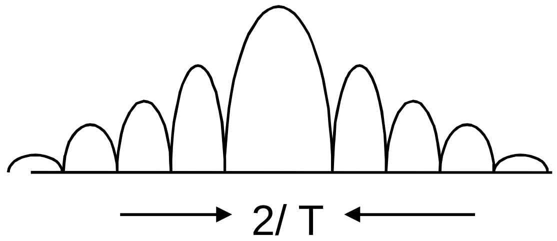
Binary Data bit = 0,1

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

f (t) =



Transmission Bandwidth Required



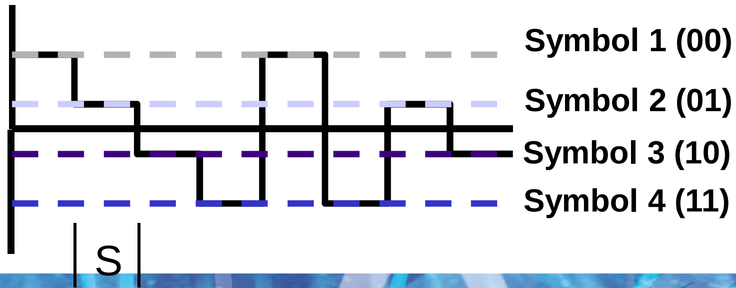
Main lobe width is 2 × Sample rate

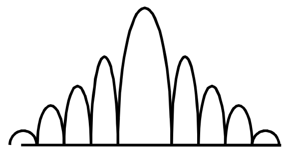
Symbol = Groups/blocks of Bits

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

Symbol Rate = Bit rate / # bits per symbol

f (t) =



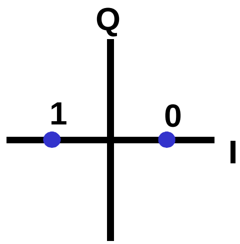
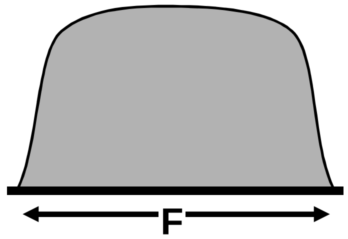
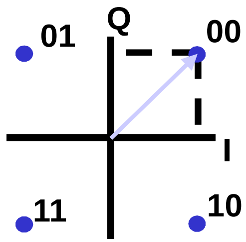
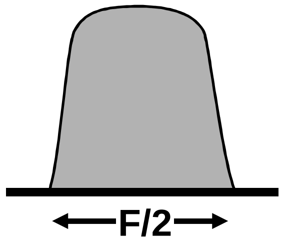
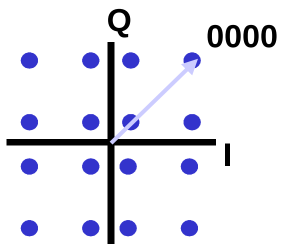
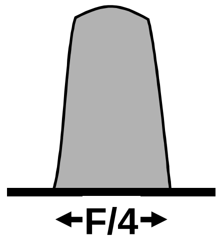


2/ S

Main lobe width is 2 × Symbol rate

Generating Signals – Composite Modulation

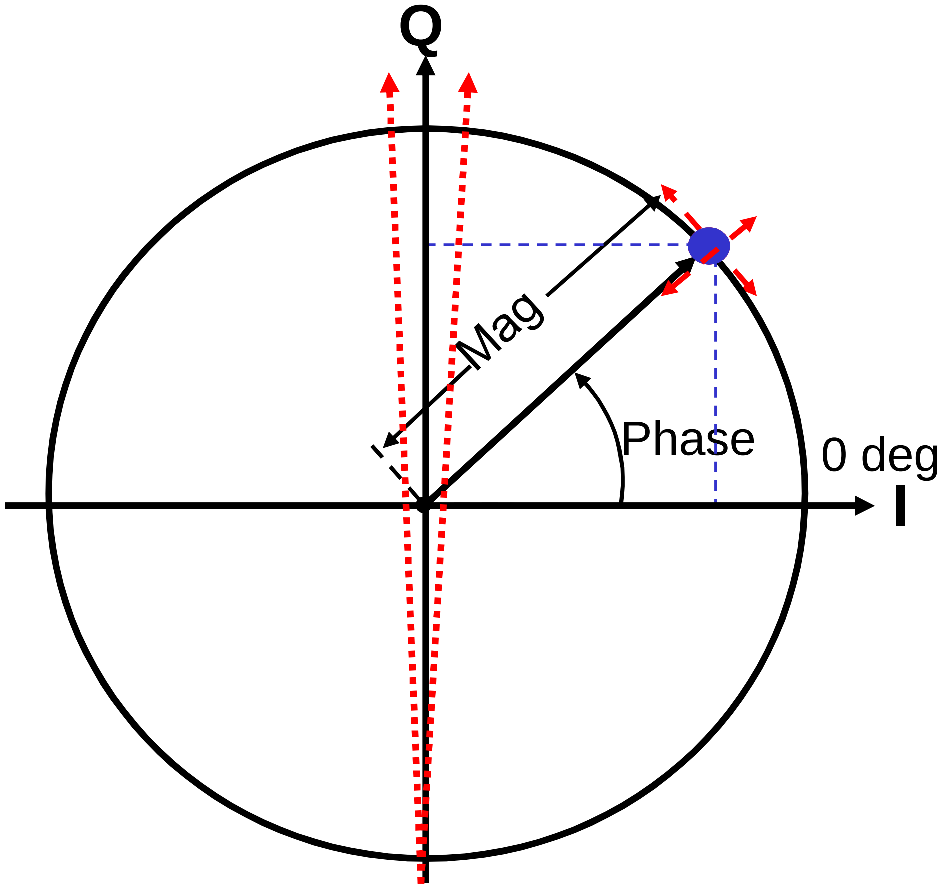
Digital Modulation Characteristics

Modulation format	Number of bits per symbol	Constellation	Transmission bandwidth
BPSK	1		
QPSK	2		
16 QAM	4		

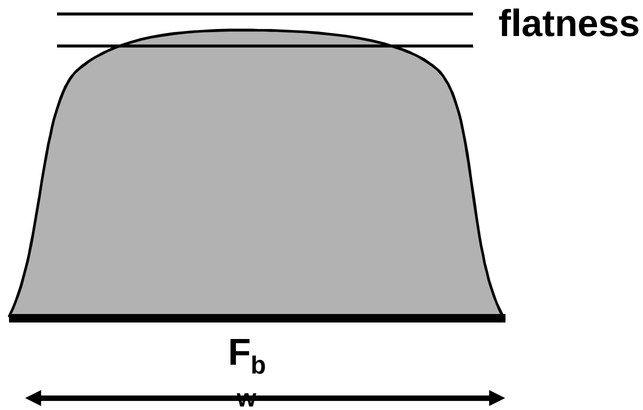
Symbol Rate = #symbols/sec. (Hz)

Generating Signals – Composite Modulation

Vector Modulation - Important Characteristics

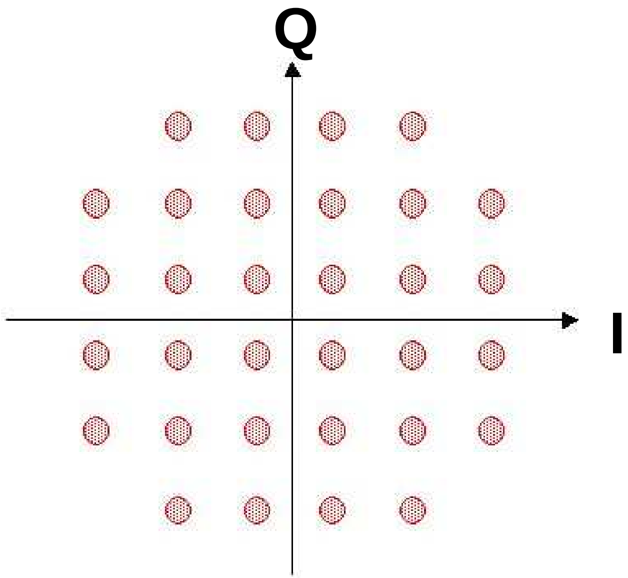


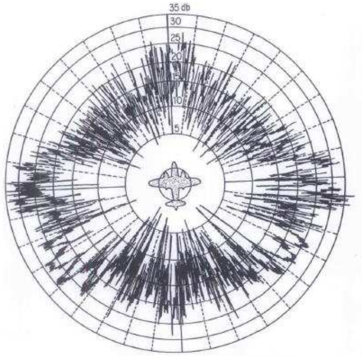
- IQ Modulation Bandwidth
- Frequency Response/flatness
- IQ quadrature skew
- IQ gain balance



Generating Signals – Composite Modulation

Vector Modulation - Where Used





- Mobile Digital Communications
- Modern Radars

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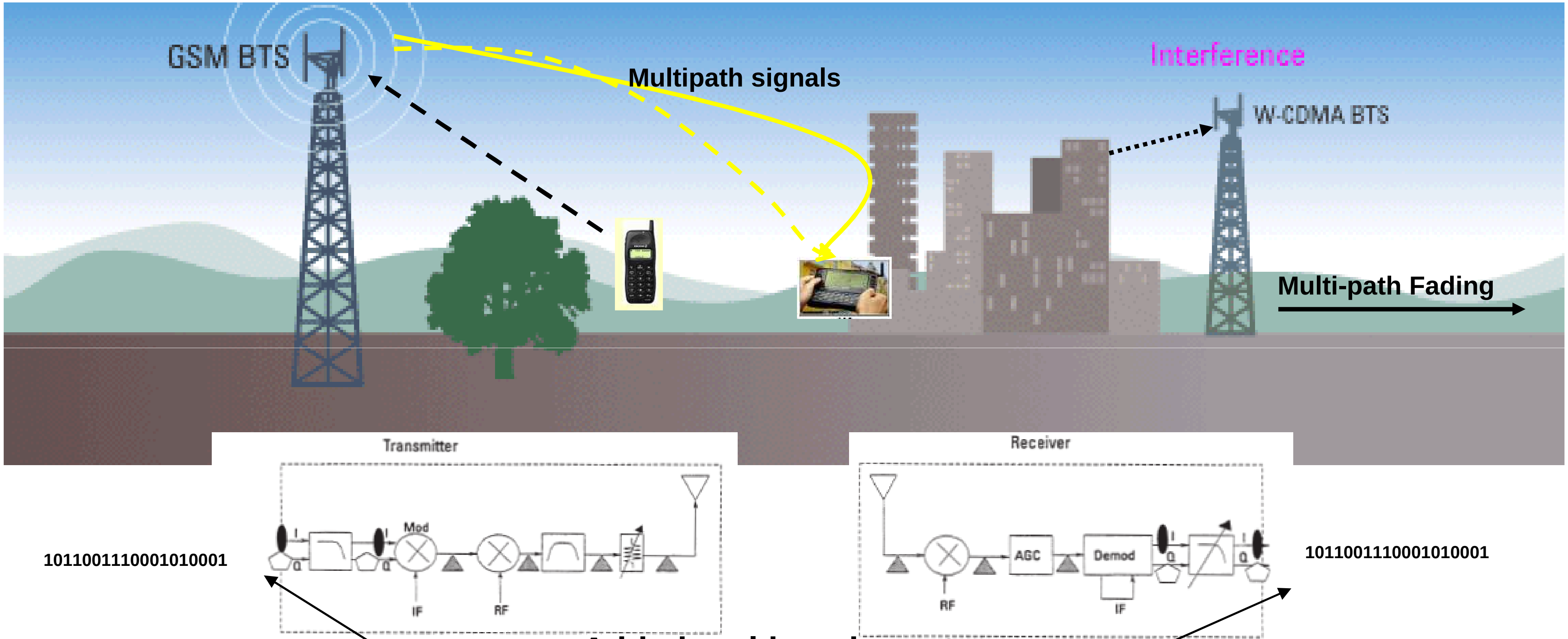
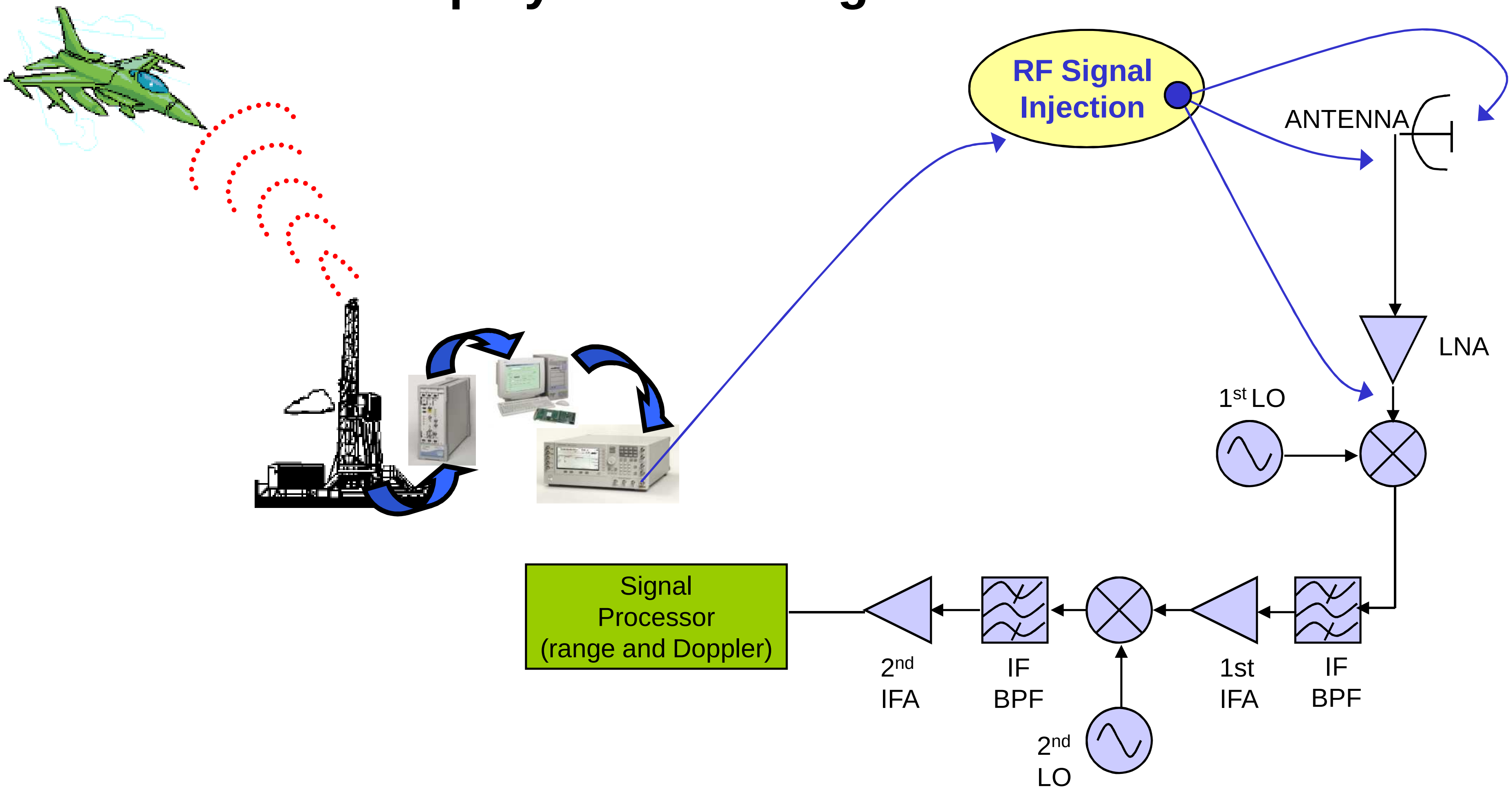
Simulating Signals

Add interference/impairments to user data



Add signal impairments
Streaming data
Recovering User Data
Removing test signal imperfections

Record/playback real signals scenarios



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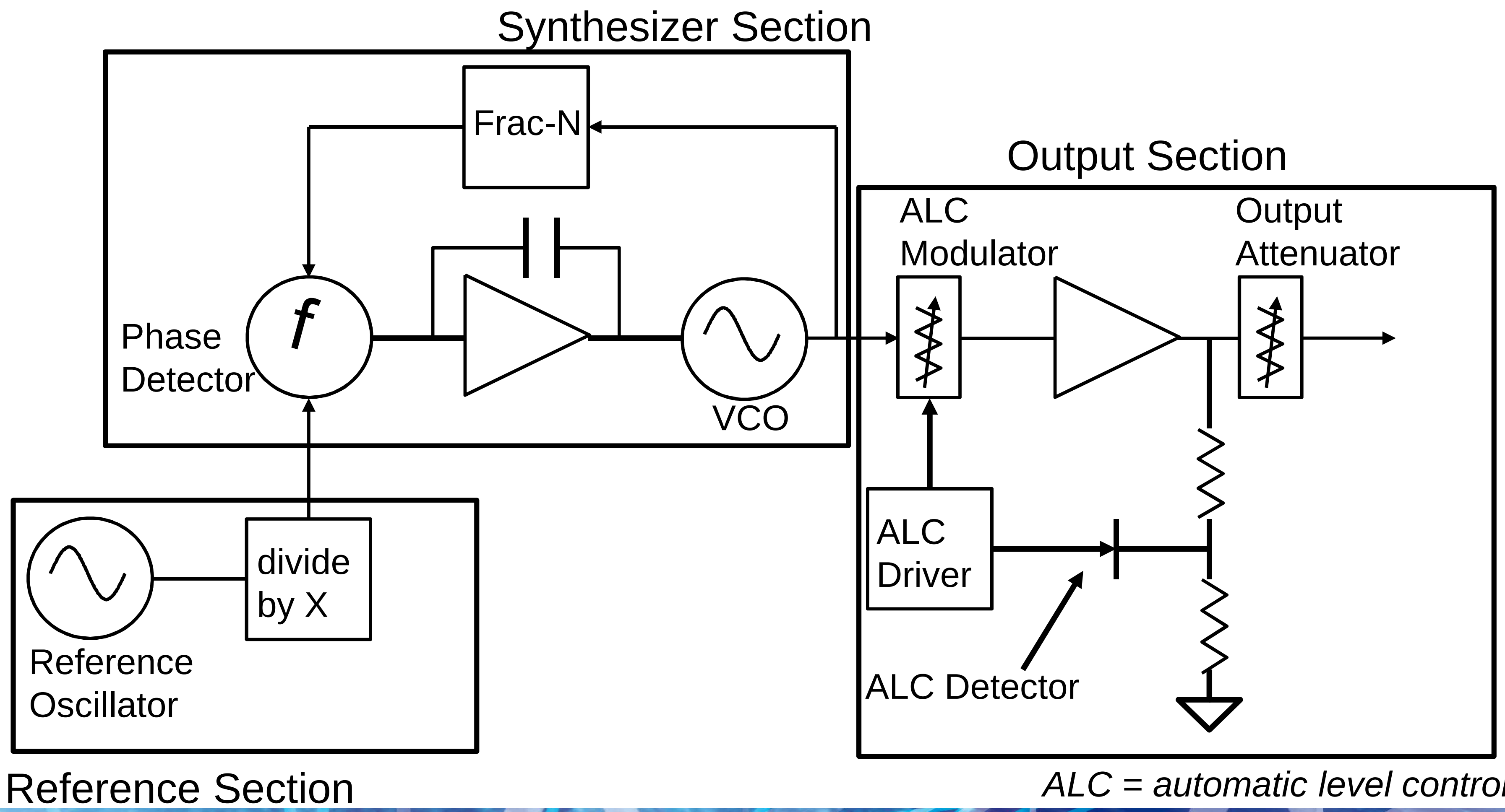
Signal Generators

- **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**

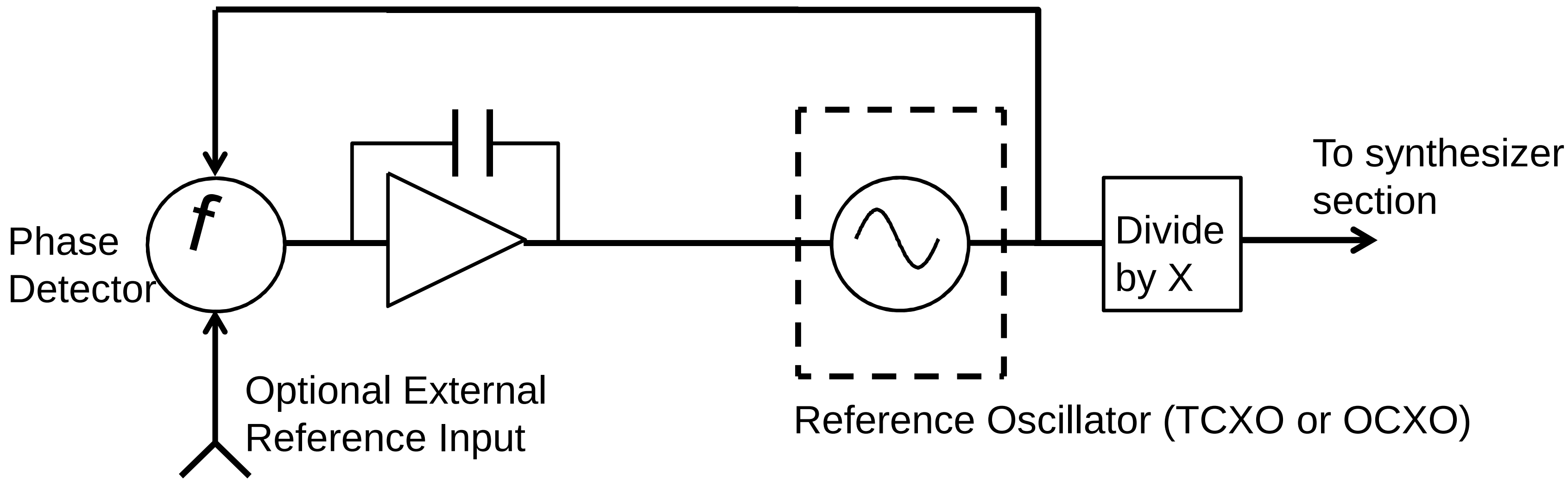
Basic CW Signals – Block Diagram

RF Source



ALC = automatic level control

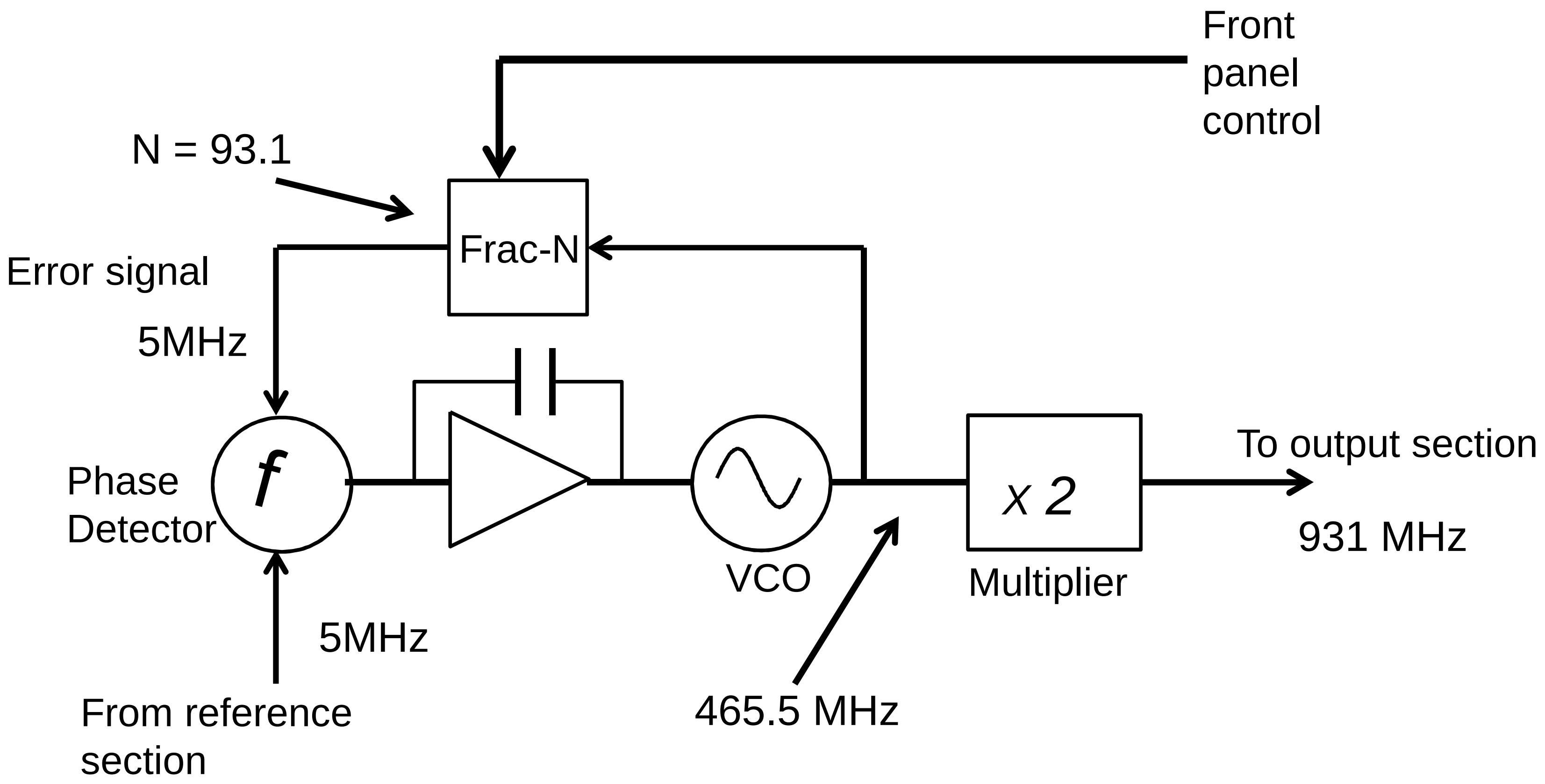
Reference Section



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

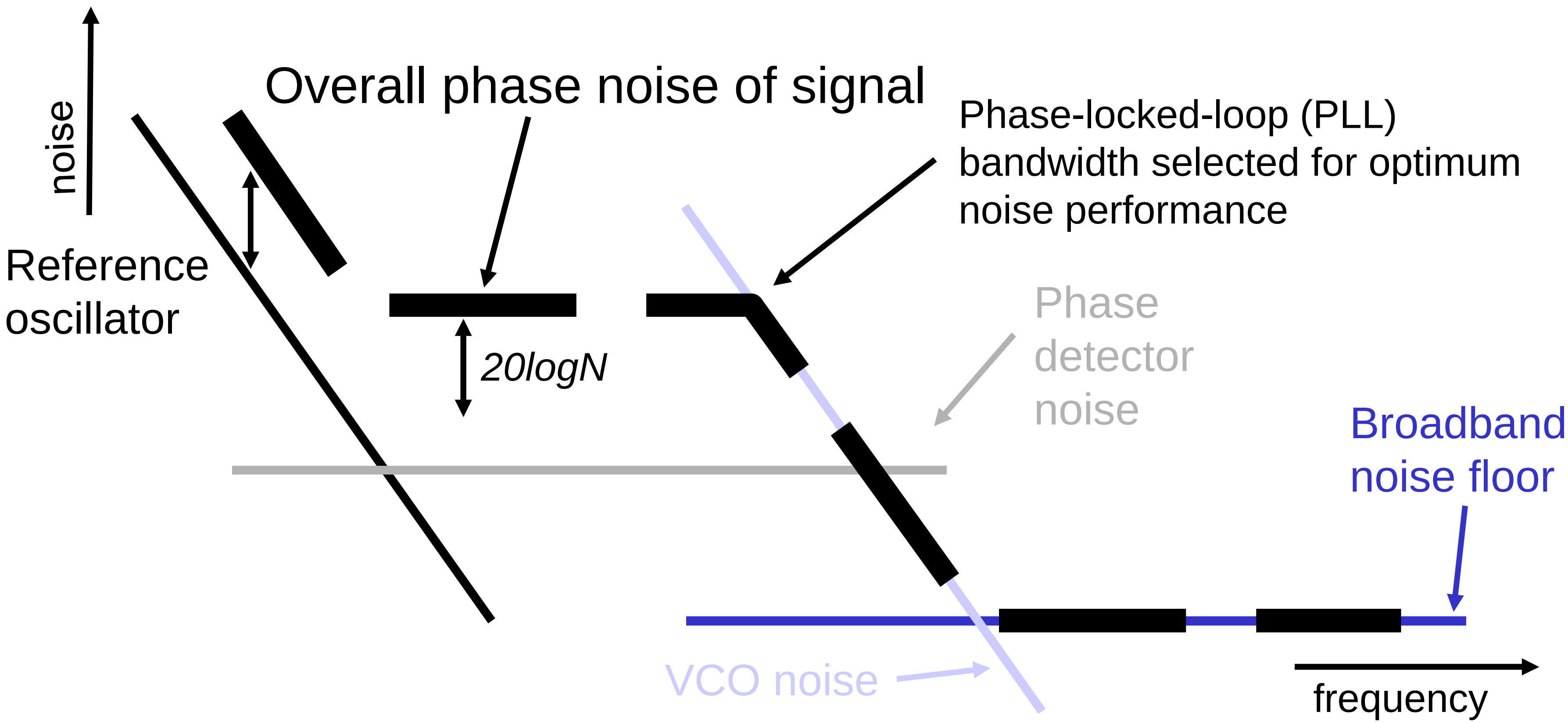
Basic CW Signals – Block Diagram

Synthesizer Section



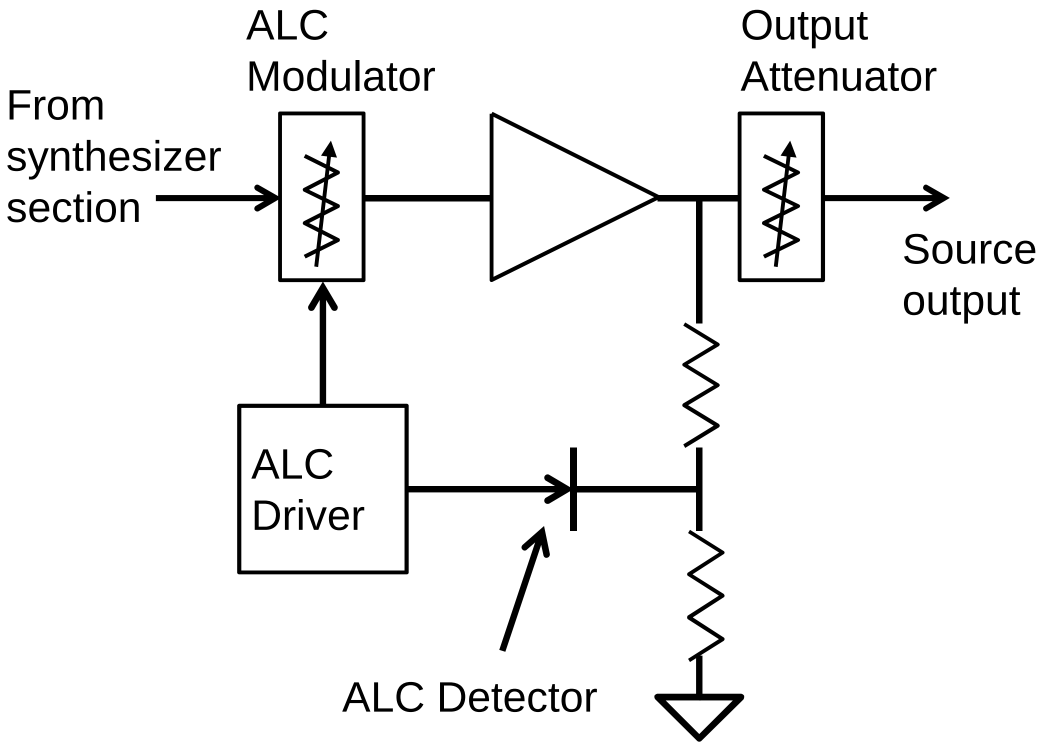
Basic CW Signals – Block Diagram

PLL/Fractional-N…suppress phase noise

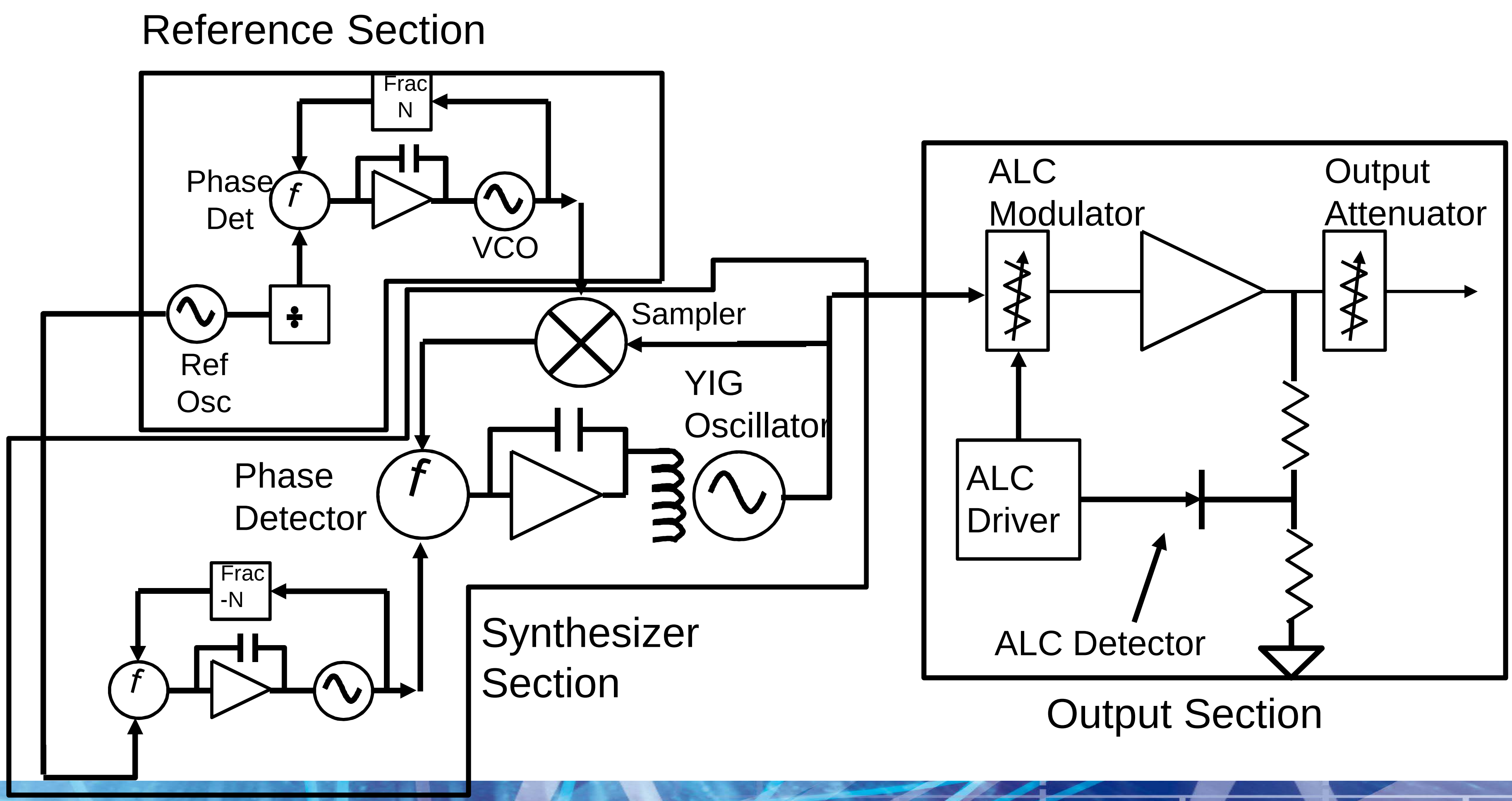


Output Section

- 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. -136dBm to +17dBm)



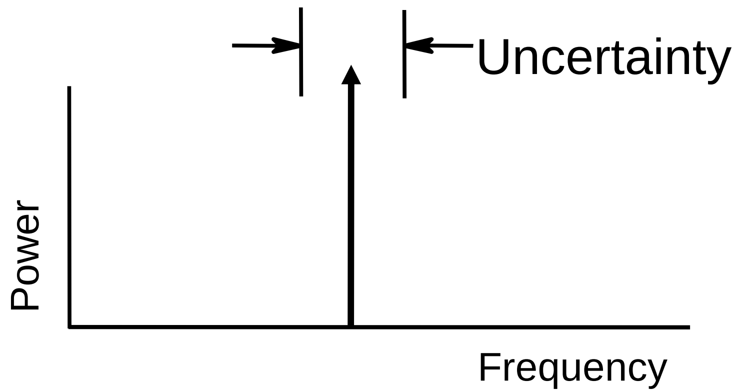
Microwave Source



Basic CW Signals – Specifications

Frequency

- Range -- F_{min} to F_{max}
- Resolution – smallest frequency increment
- Accuracy – is it where it says it is



$$\text{Accuracy} = \pm f_{CW} * t_{aging} * t_{cal}$$

f_{CW} = CW frequency = 1 GHz

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

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

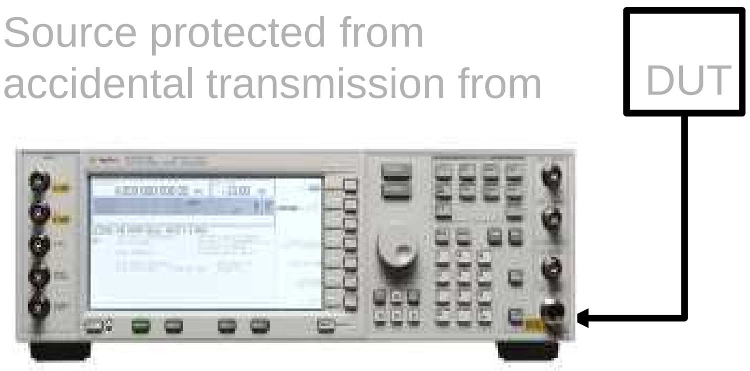
Accuracy = $\pm$152 Hz

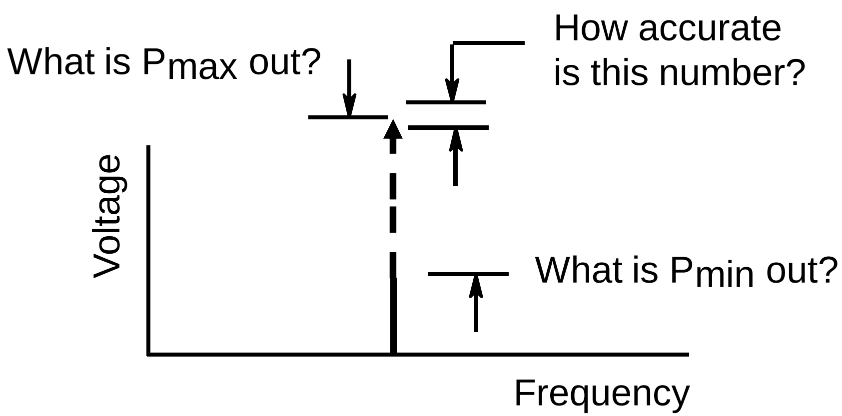
Basic CW Signals – Specifications

Amplitude

- Range (-136dBm to +17dBm)
- Accuracy (+/- 0.5dB)
- Resolution (0.02dB)
- Switching Speed (19ms)
- Reverse Power Protection

Source protected from accidental transmission from

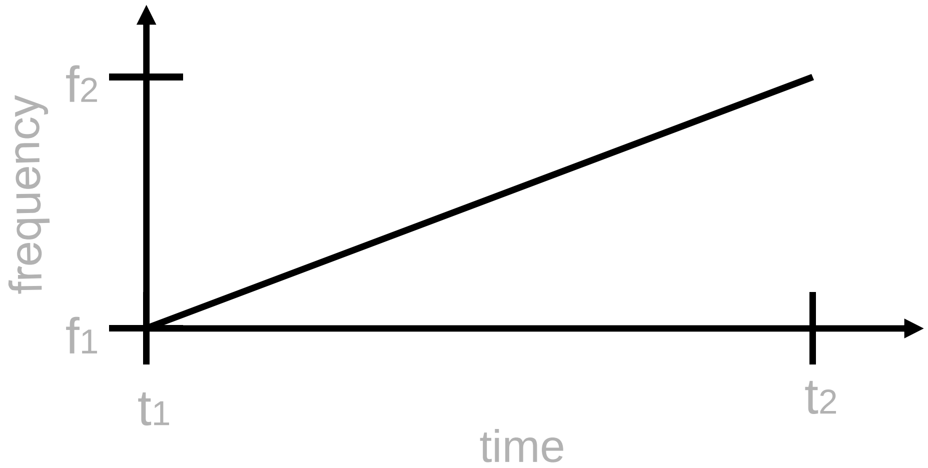




Frequency Sweep

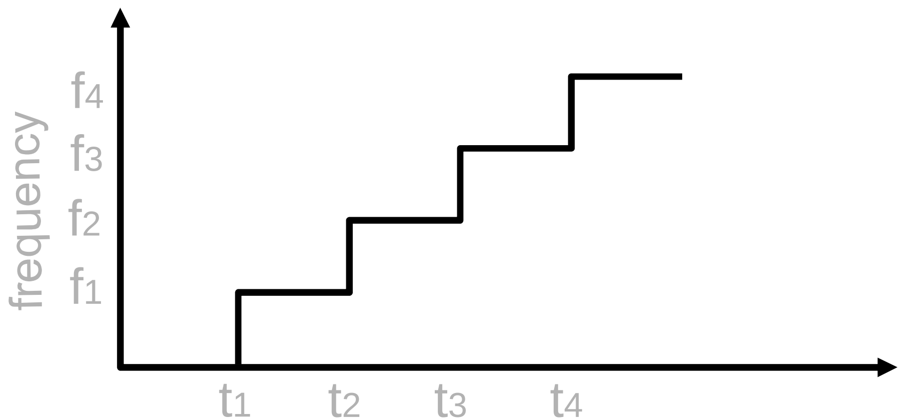
Ramp sweep

- accuracy
- sweep time
- resolution



Step sweep

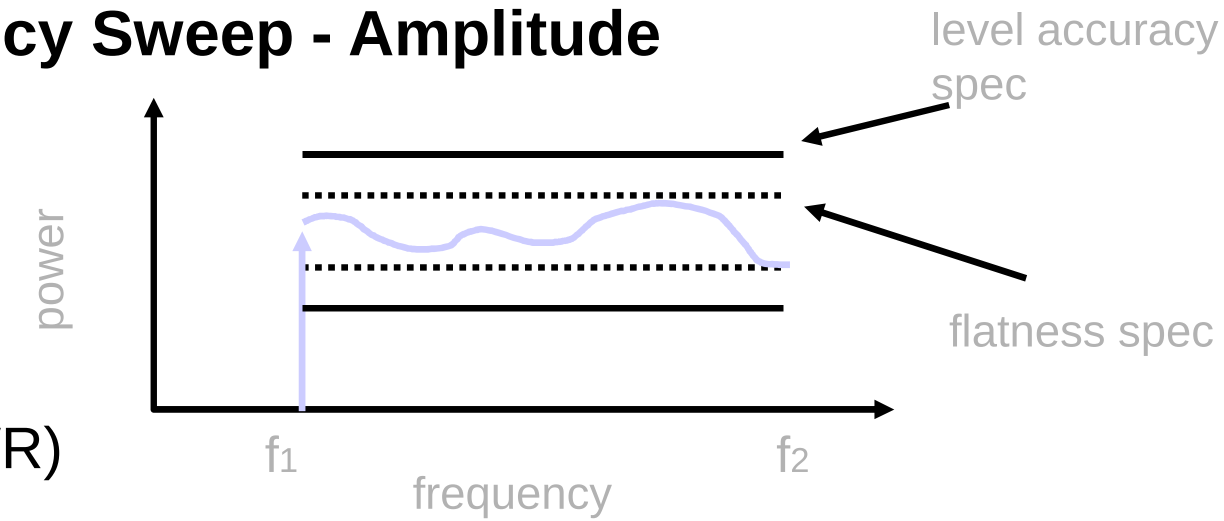
- accuracy
- number of points
- switching time



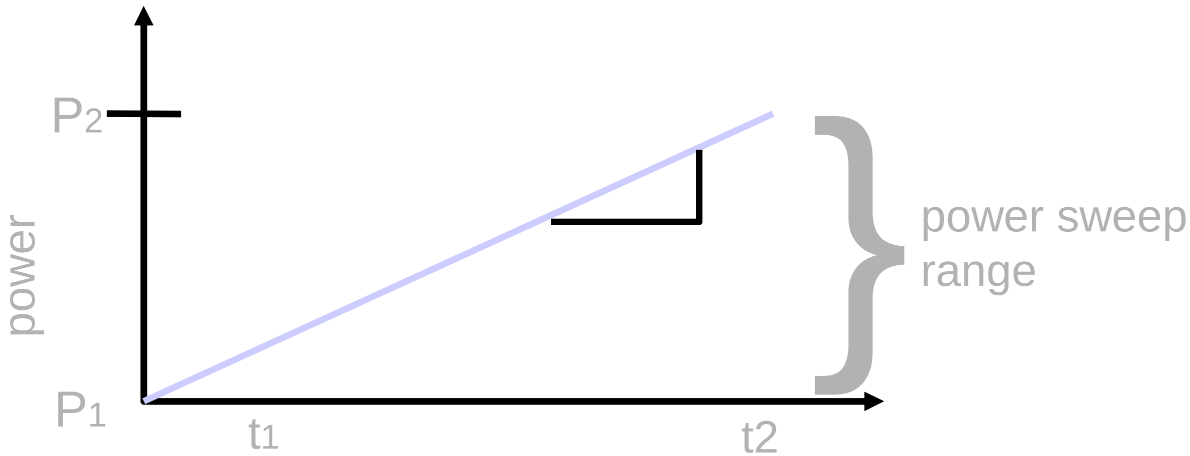
Basic CW Signals – Specifications

Frequency Sweep - Amplitude

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

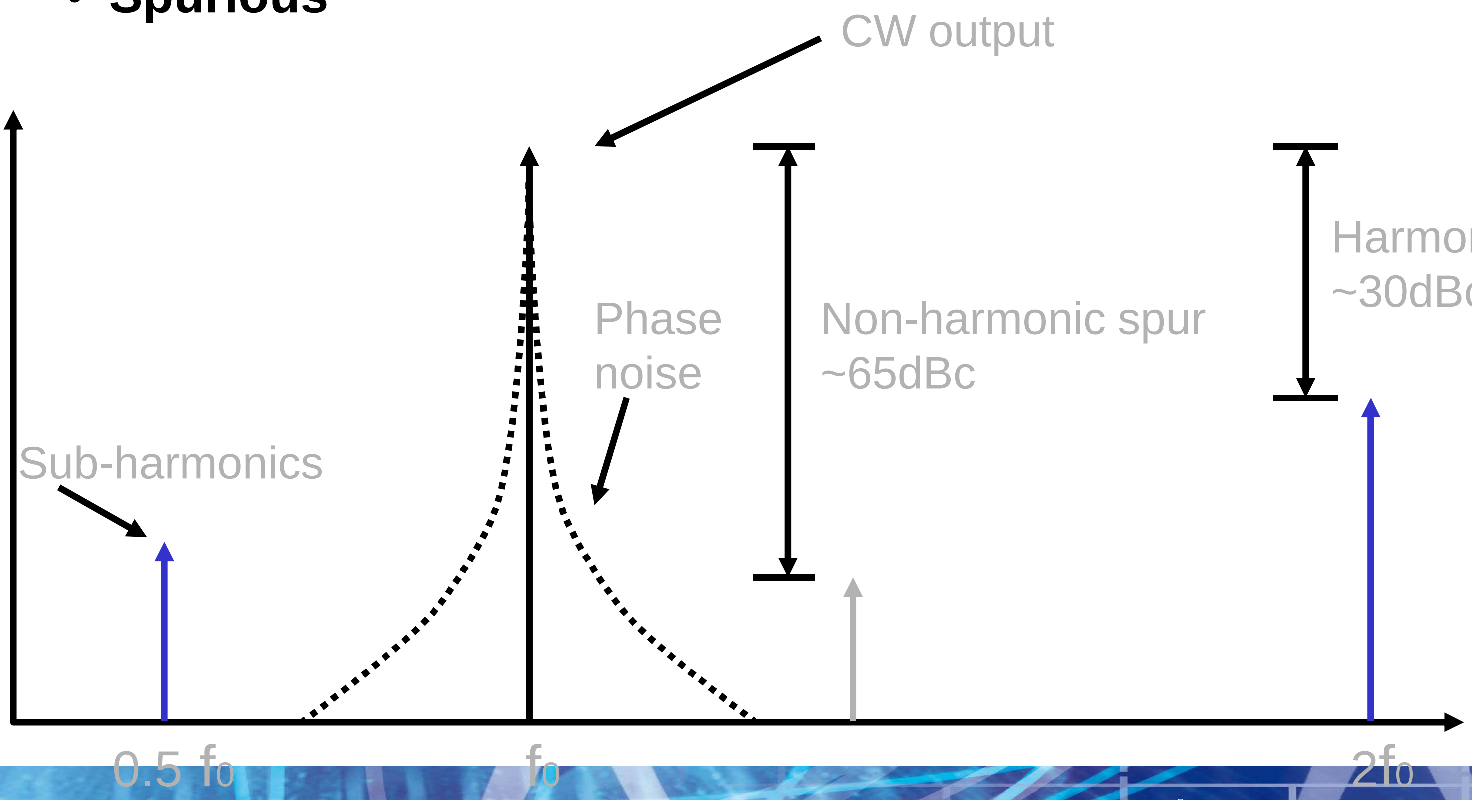


Power Sweep
- Power Sweep Range
- Power Slope Range
- Source Match (SWR)

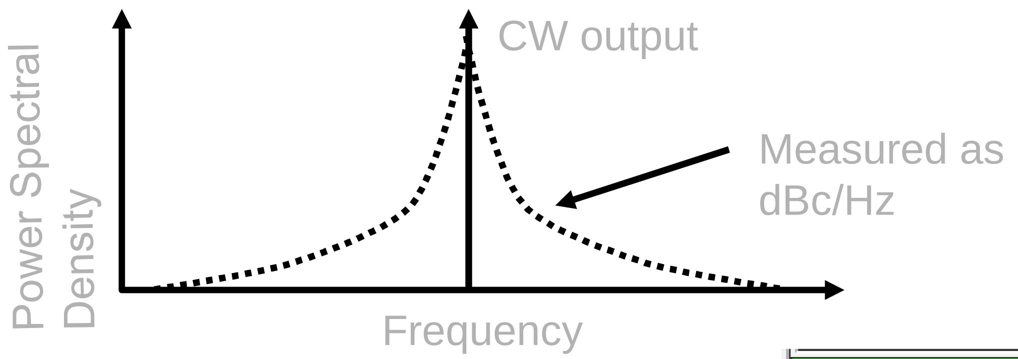


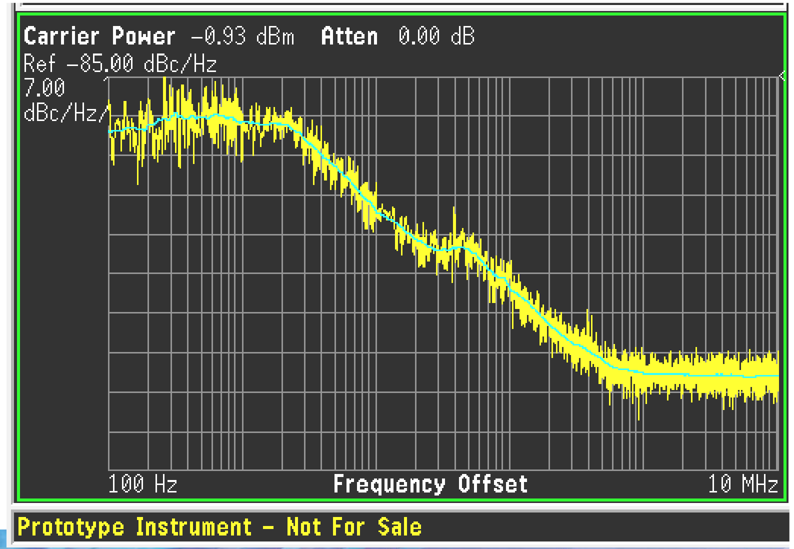
Spectral Purity

- **Phase Noise**
- **Spurious**



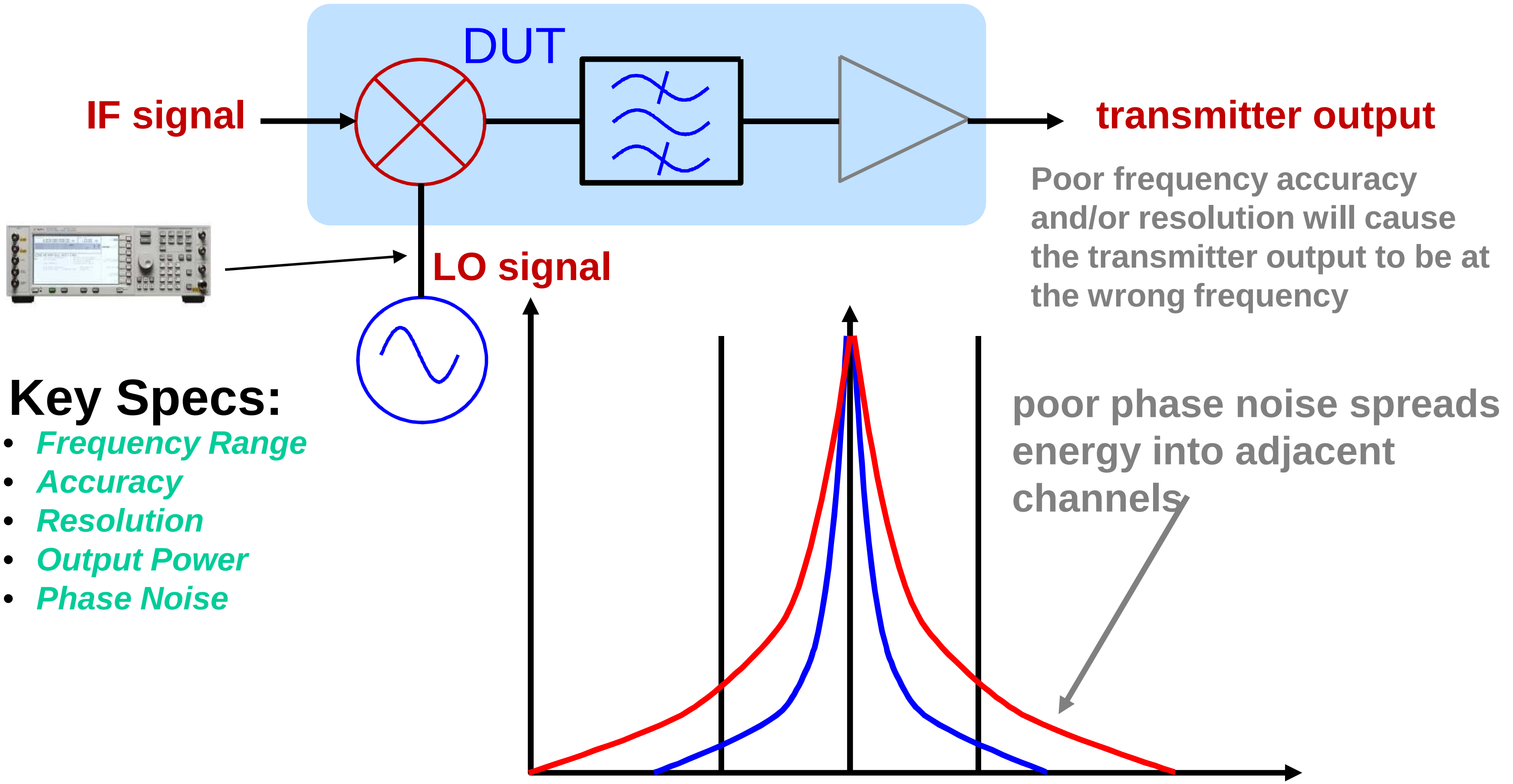
Spectral Purity – Phase Noise





Basic CW Signals – Applications

As a Local Oscillator



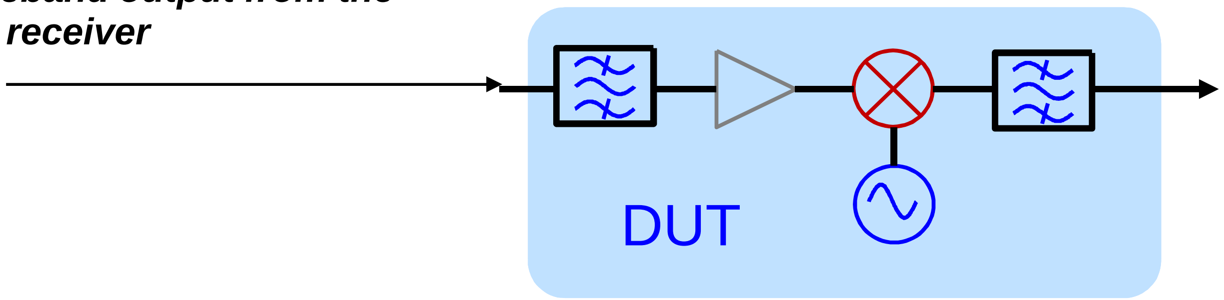
Key Specs:

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

In-Channel Receiver Testing

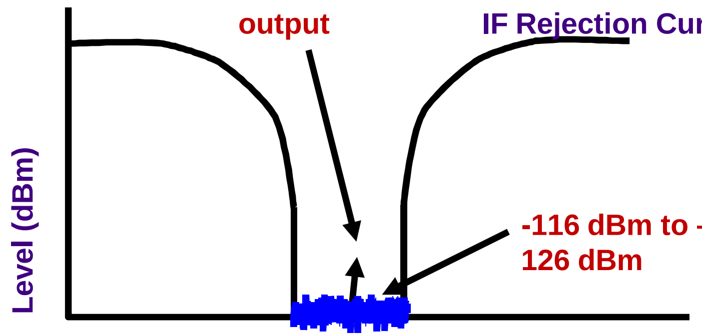
The smallest RF signal that will produce a desired baseband output from the receiver

Receiver Sensitivity



Key Specs:

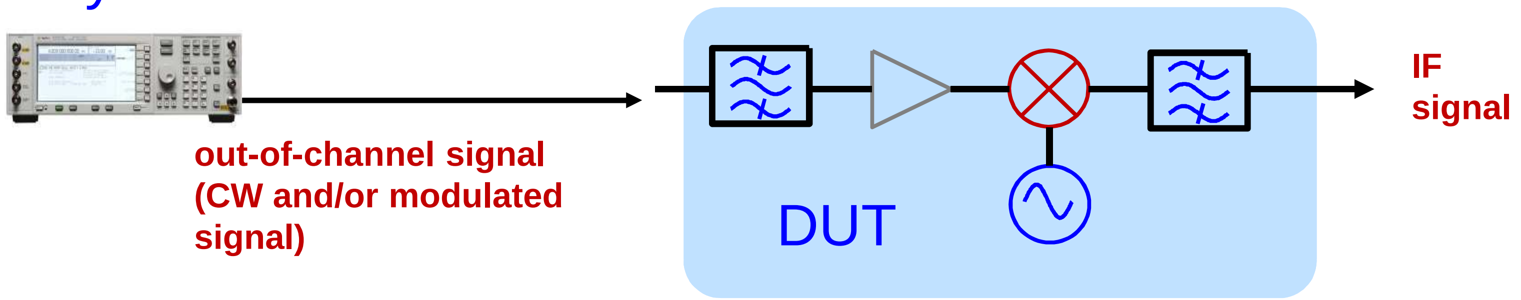
- *Range (-136dBm to +17dBm)*
- *Accuracy (+/- 0.5dB)*
- *Resolution (0.02dB)*



Basic CW Signals – Applications

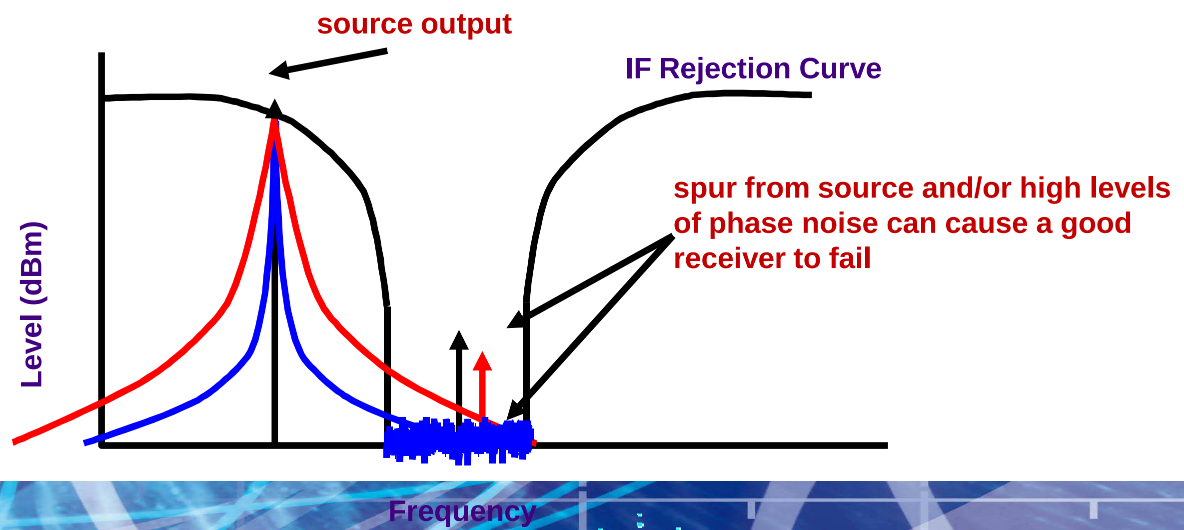
Out-of-channel Receiver Testing

Receiver Selectivity
Spurious Response
Immunity

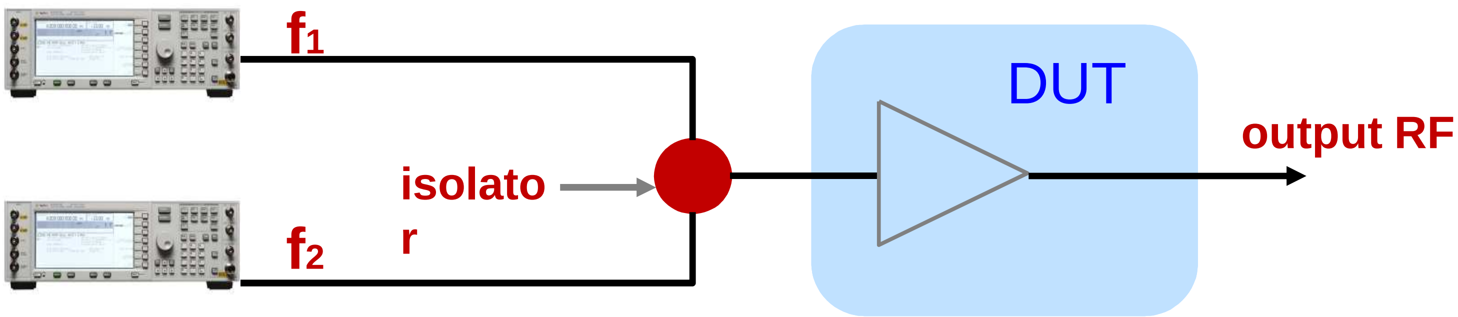


Key Specs:

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

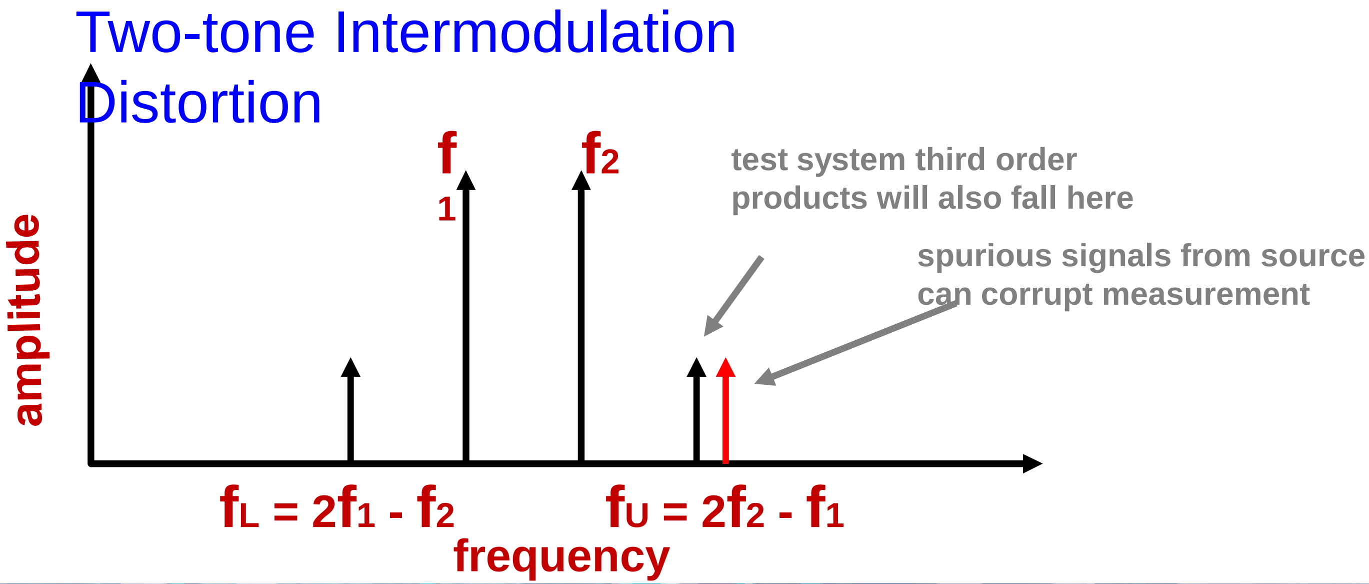


Non-linear Amplifier Testing - TOI

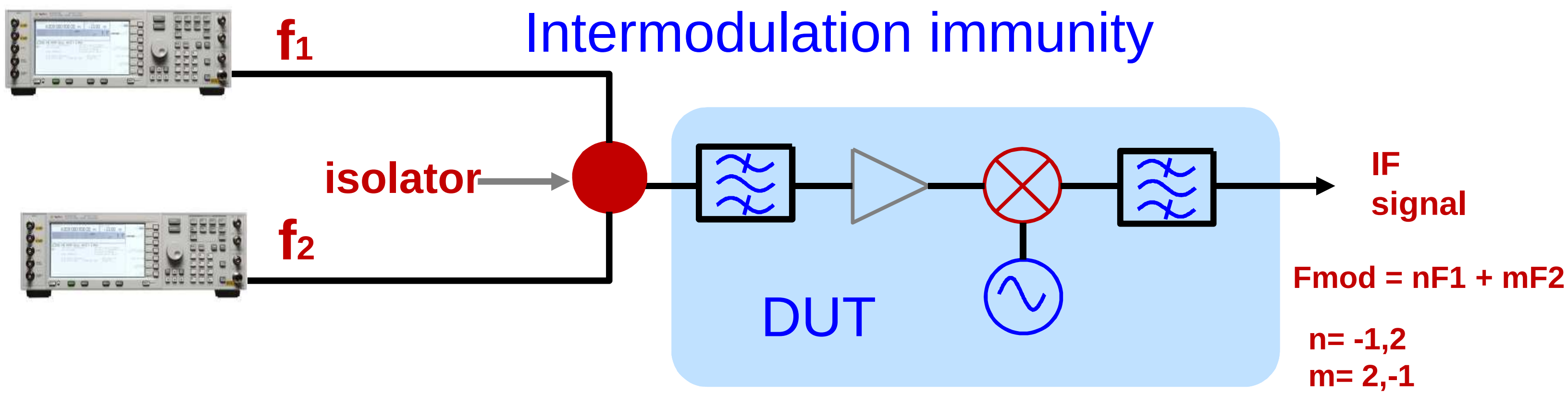


Key Specs:

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

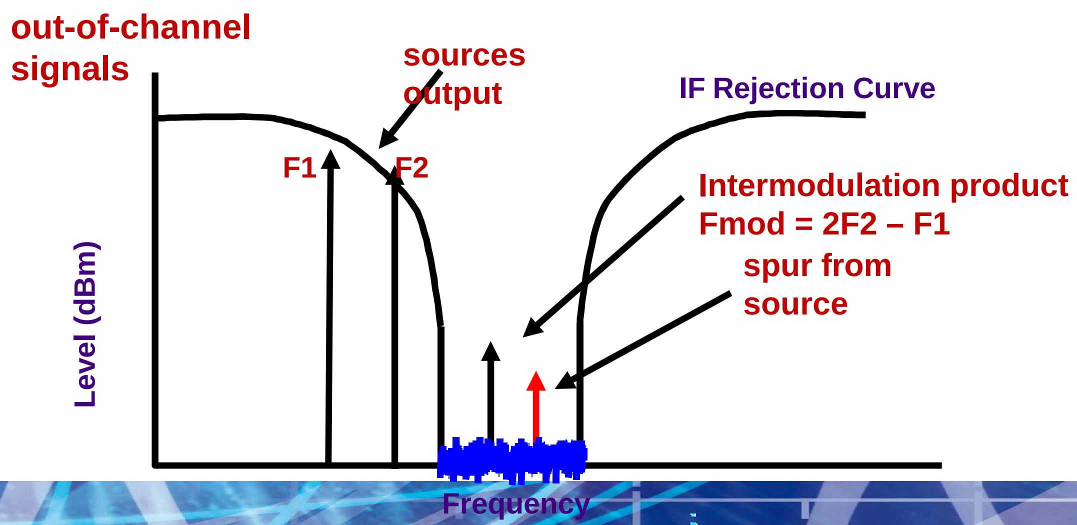


Out-of-channel Receiver Testing - IMD



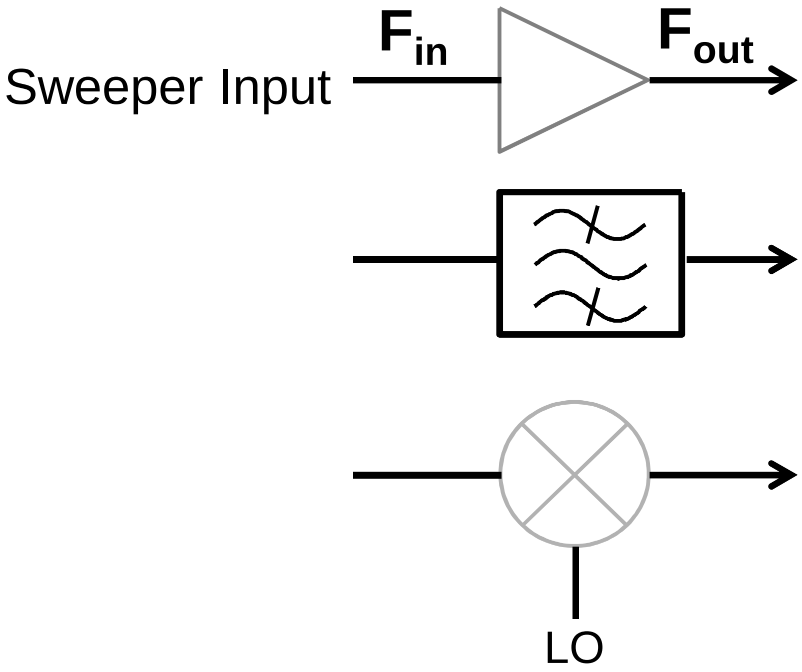
Key Specs:

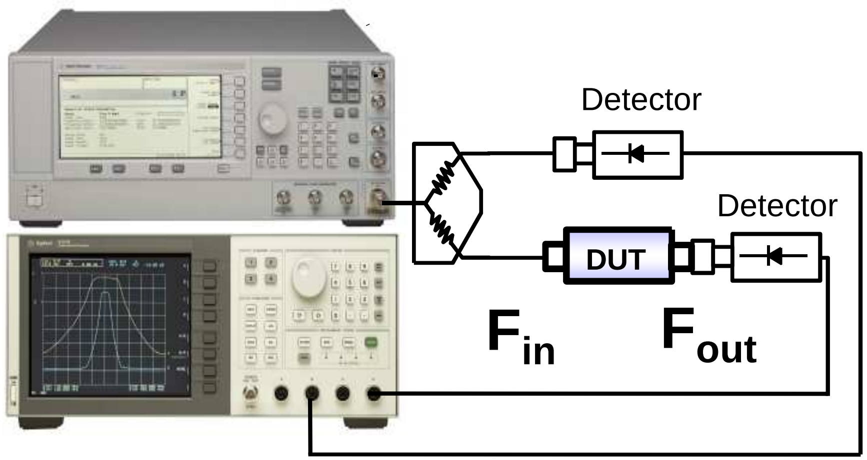
- *Frequency Range*
- *Frequency Accuracy*
- *Frequency Resolution*
- *Output Power*
- *Non-harmonic spurious*



Basic CW Signals – Applications

Stimulus-Response Testing





Key Specs:

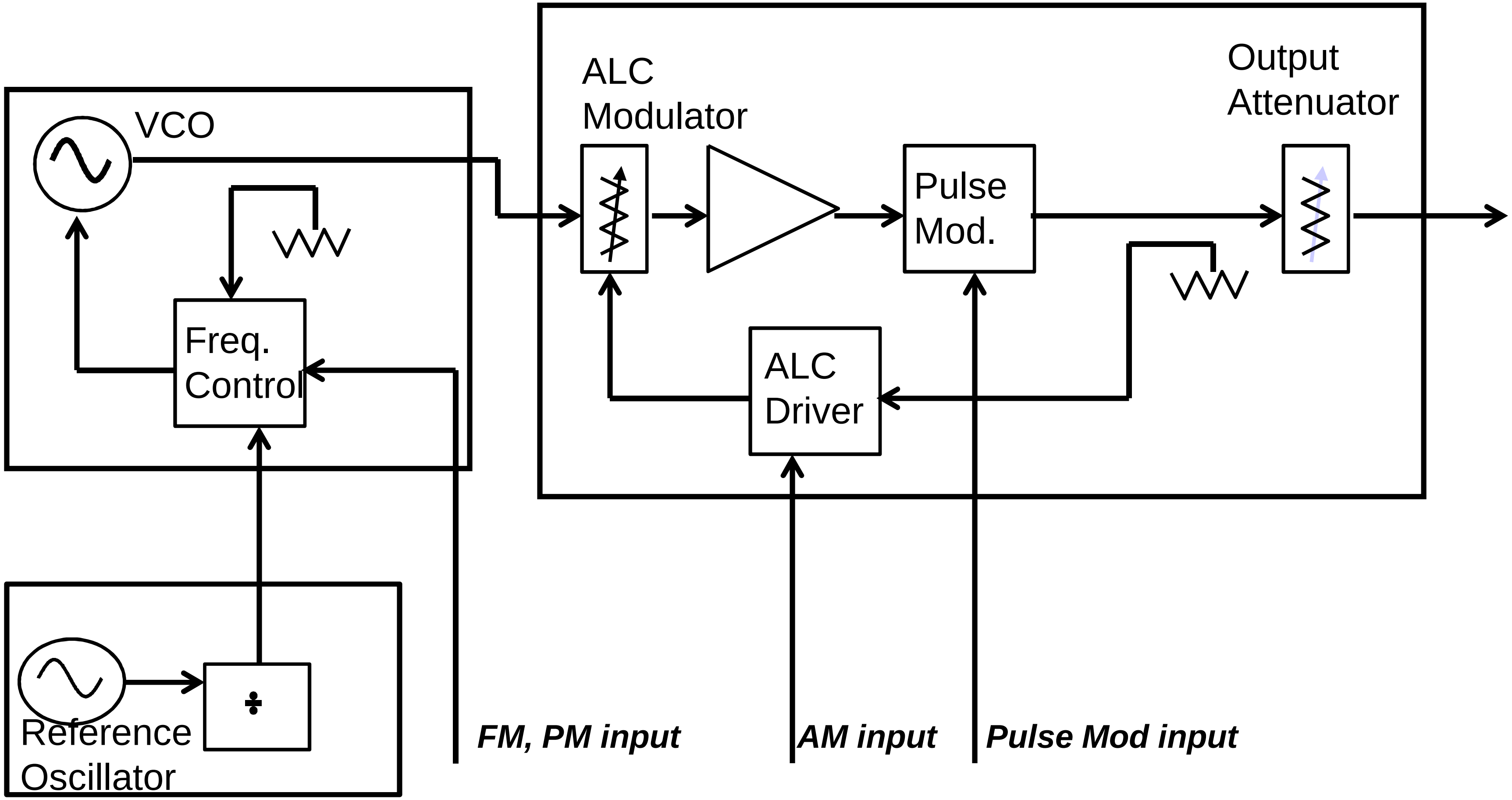
- ***Frequency Range***
- ***Frequency Accuracy***
- ***Frequency Ramp/step sweep***
- ***Power sweep***
- ***Sweep speed***
- ***Output Power accuracy***
- ***Residual FM***

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**

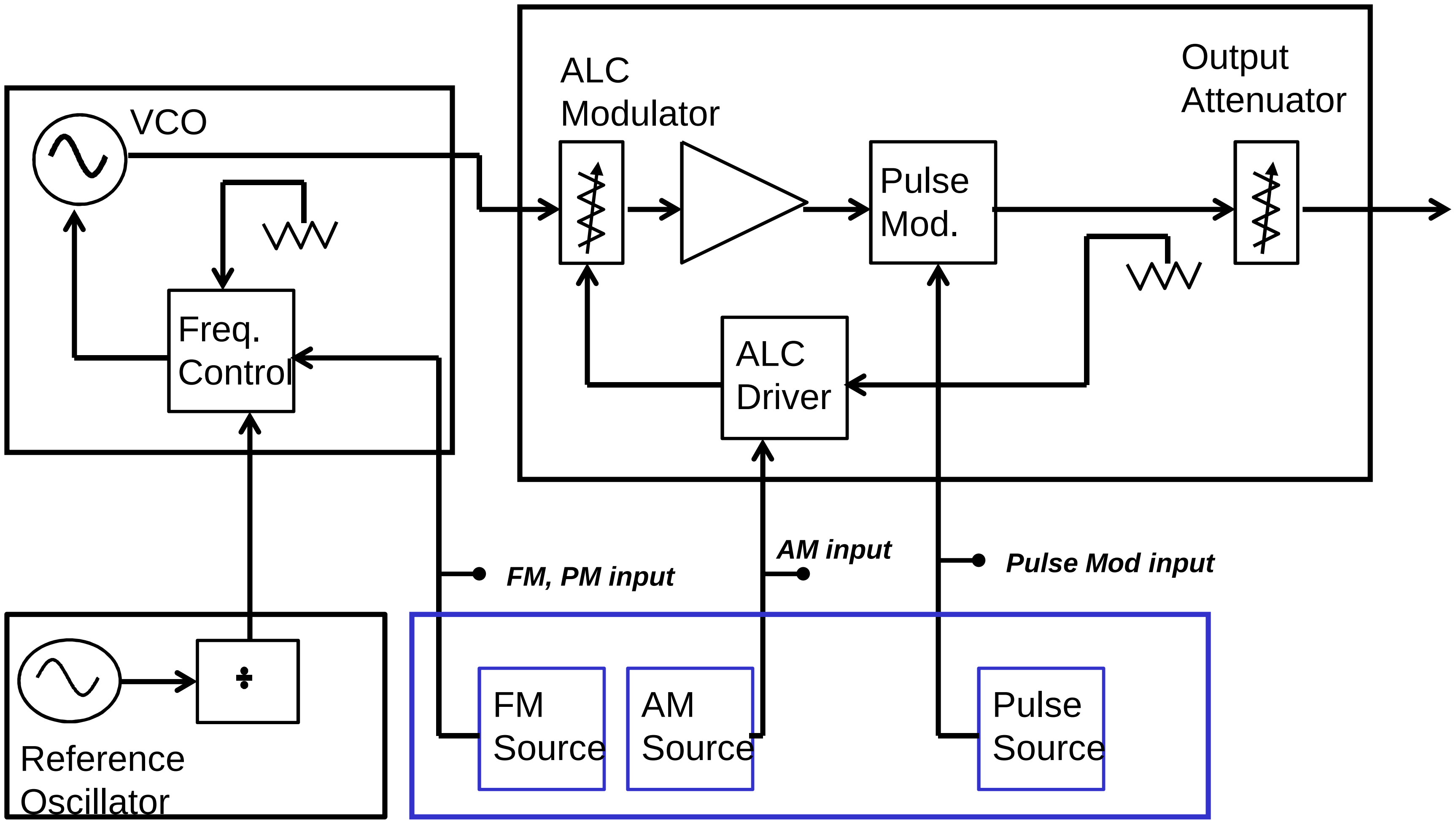
Analog Signals – Block Diagram

Add AM, FM, PM, and Pulse Modulation



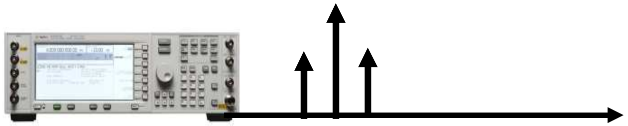
Analog Signals – Block Diagram

Add internal modulation generator

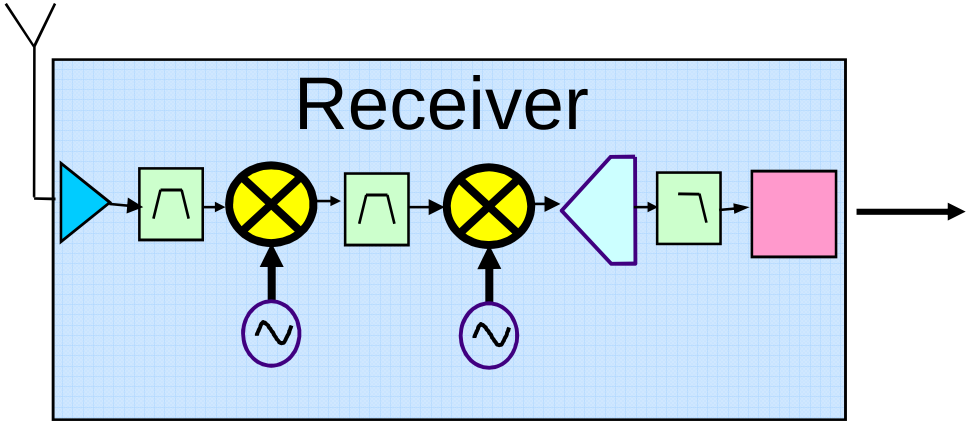


Analog Signals – Applications

Receiver Baseband Distortion



In-channel signal
(modulated signal)



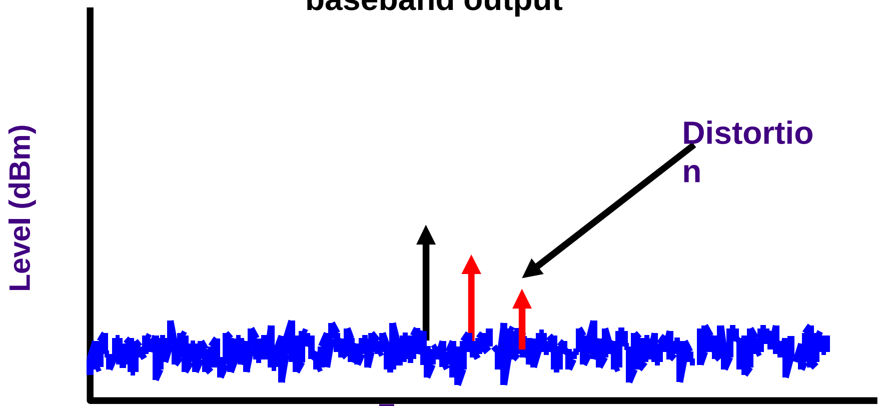
Key Specs:

- *Frequency Range*
- *Modulation rate/deviation*
- *Modulation Distortion*

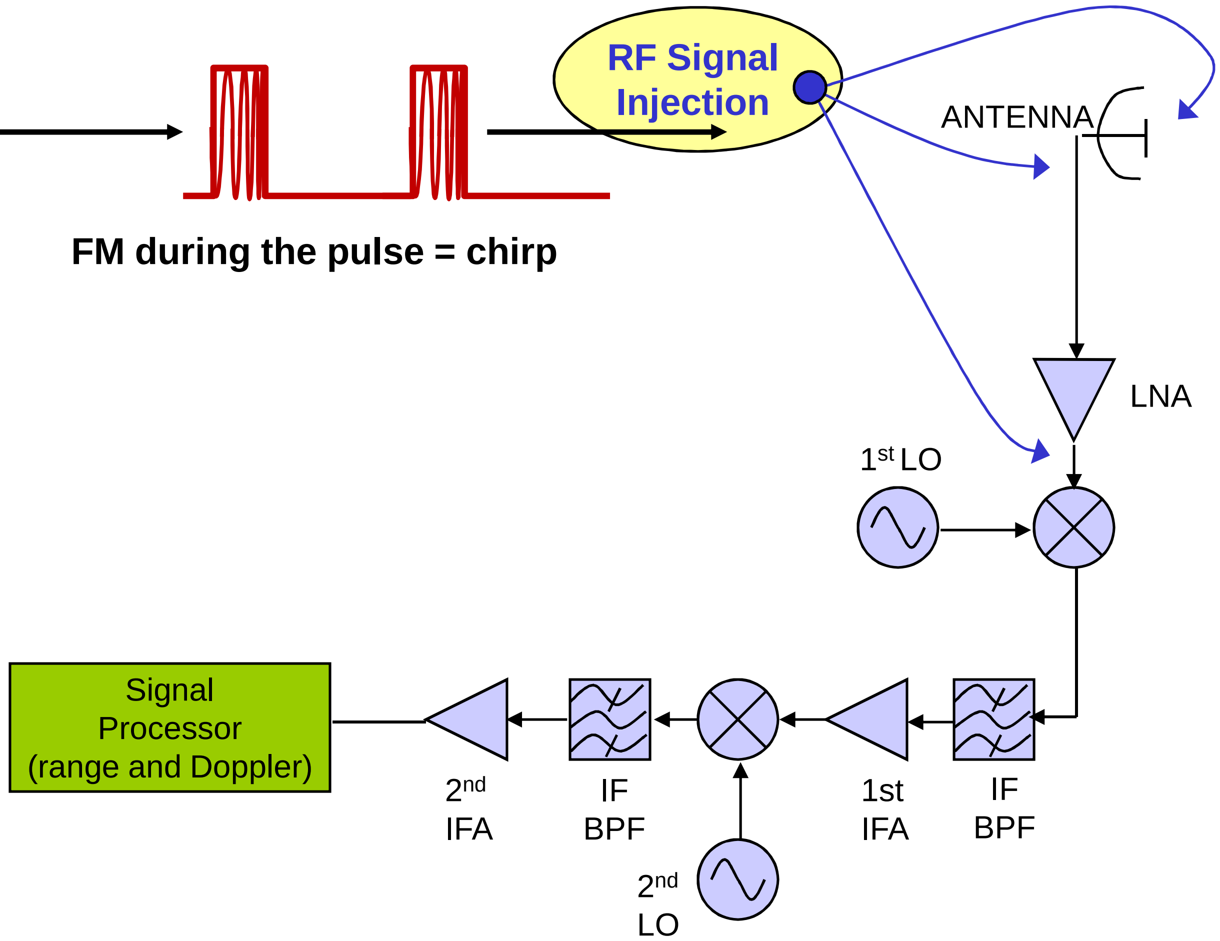
$$\text{Required SG Modulation distortion} = \text{Receiver Distortion \%} \times 10^{-(margin(dB)/20)}$$

Example:
For a receiver distortion of 5% and a 10 dB test margin, the SG must have < 1.58% mod distortion

Non-linear distortion is characterized by the appearance of harmonics other than the fundamental component in the baseband output



Pulsed Radar Testing with Chirps



Key Specs:

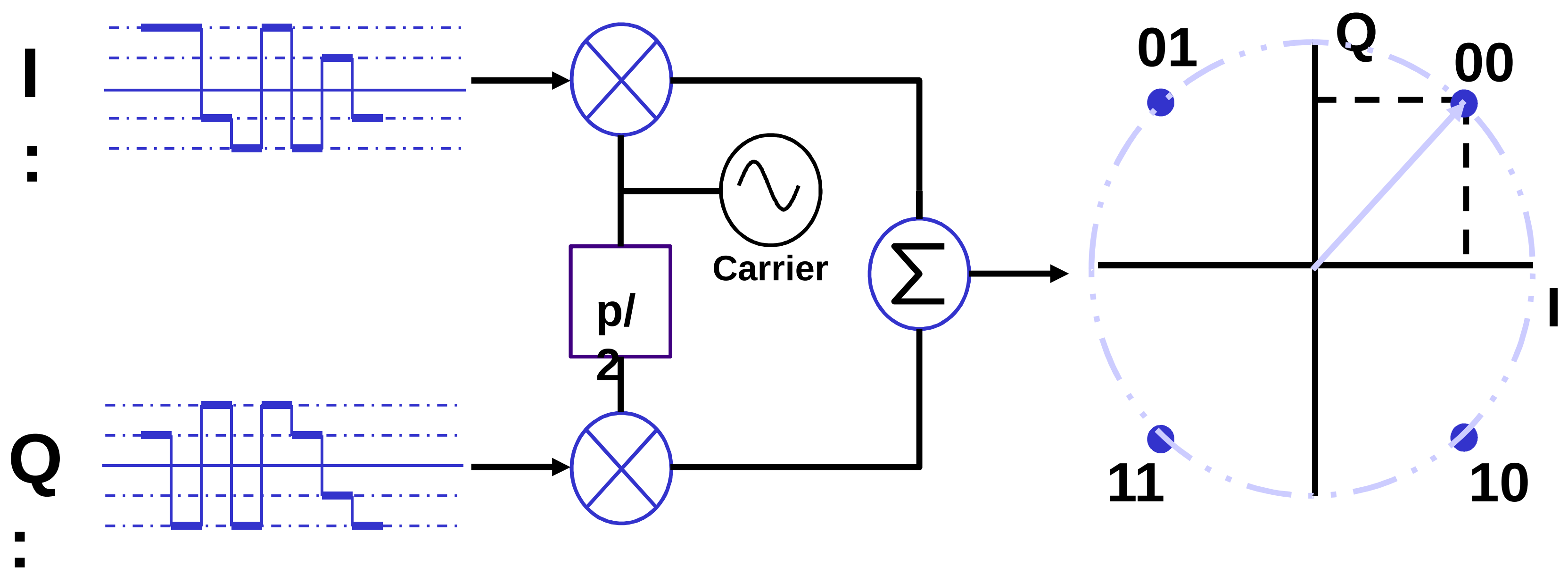
- *Frequency Range*
- *FM Modulation rate/deviation*
- *Pulse rate, width, rise time*

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

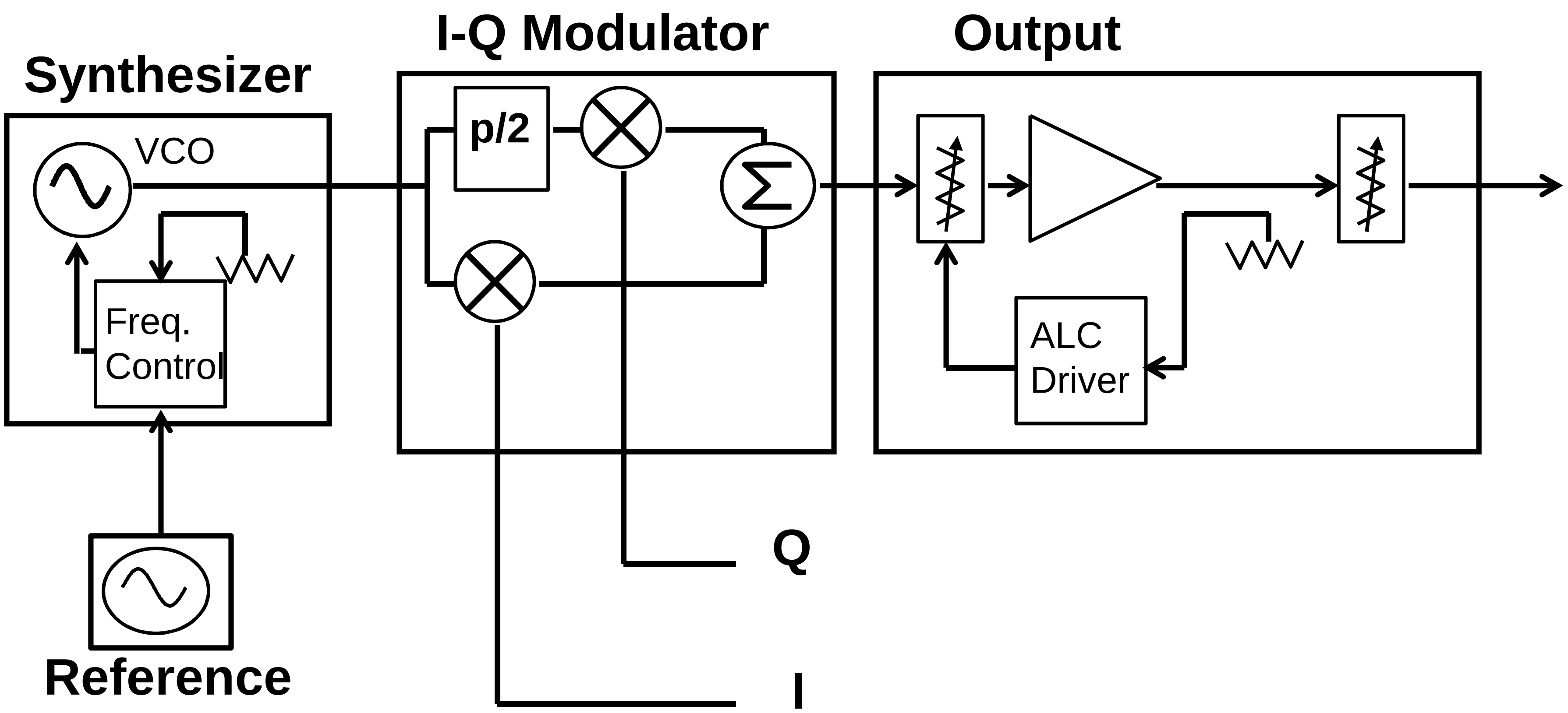
IQ Modulation



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

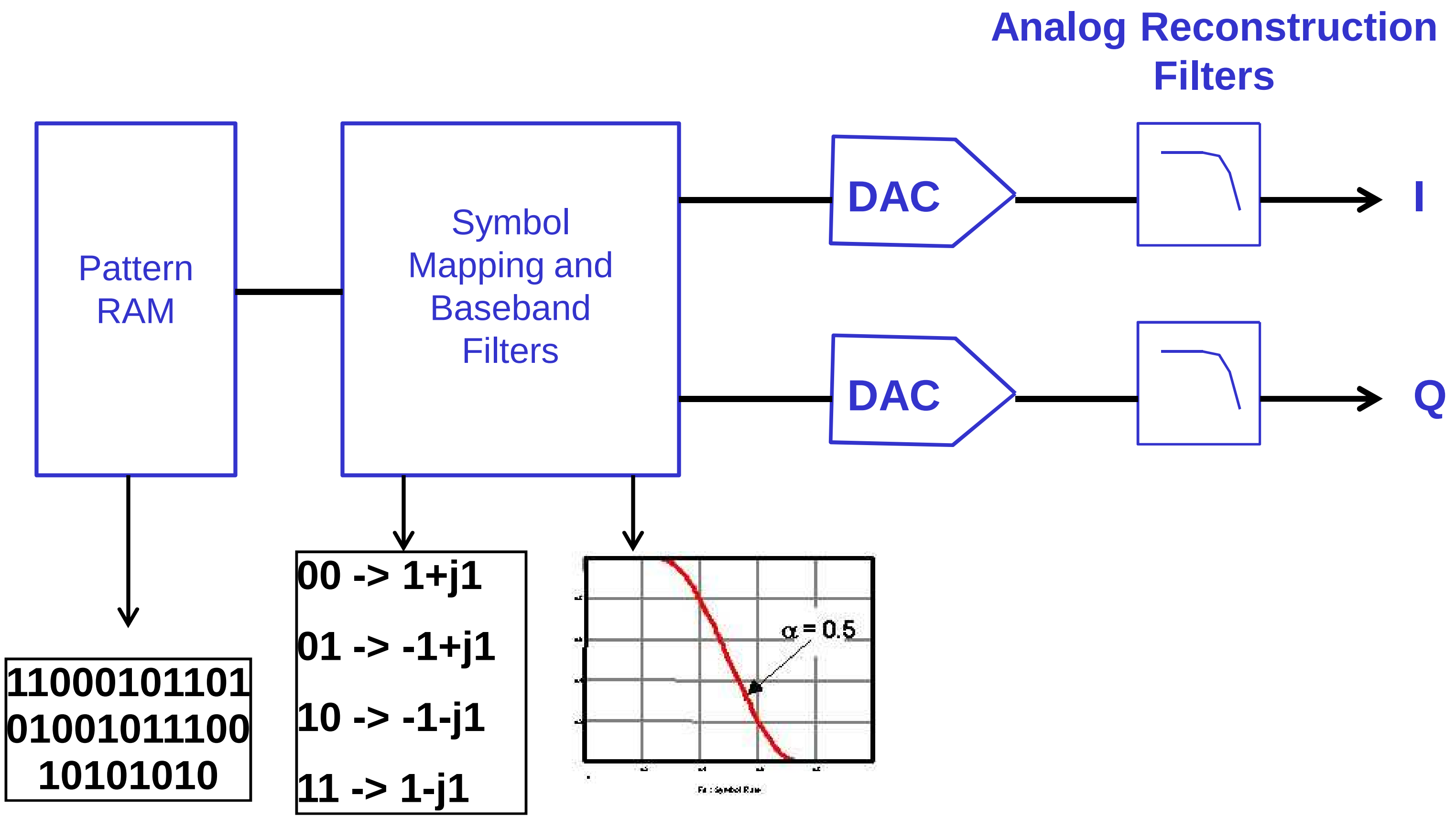
Vector Signals – Block Diagram

Adding the IQ modulator



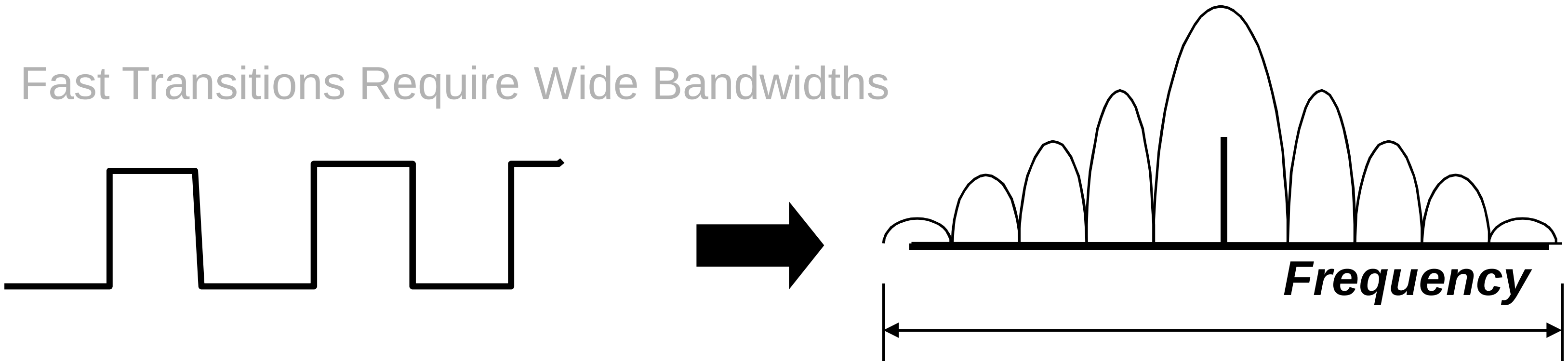
Vector Signals – Block Diagram

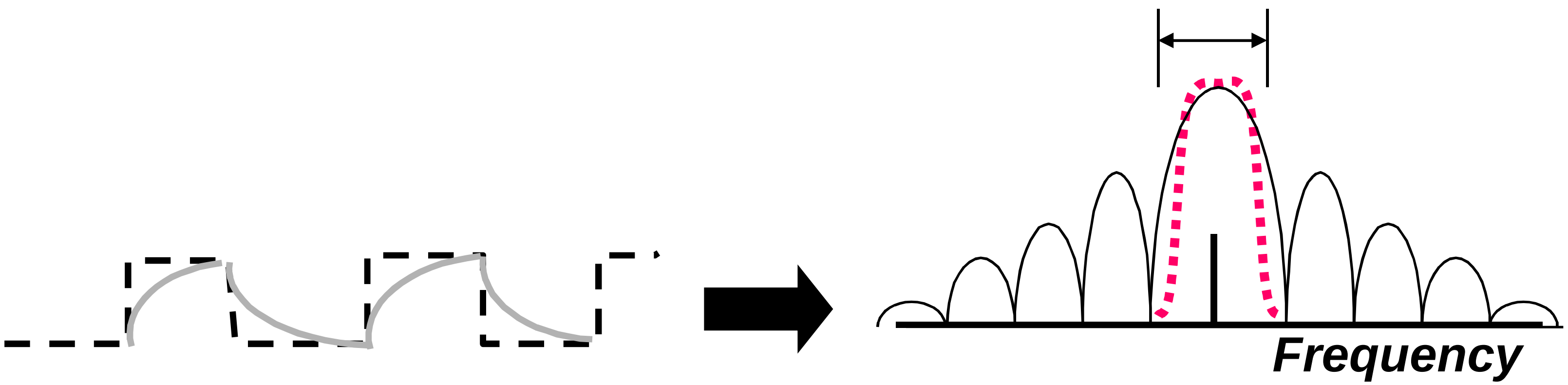
Baseband IQ signal generation



Baseband Generator: Baseband Filters

Fast Transitions Require Wide Bandwidths

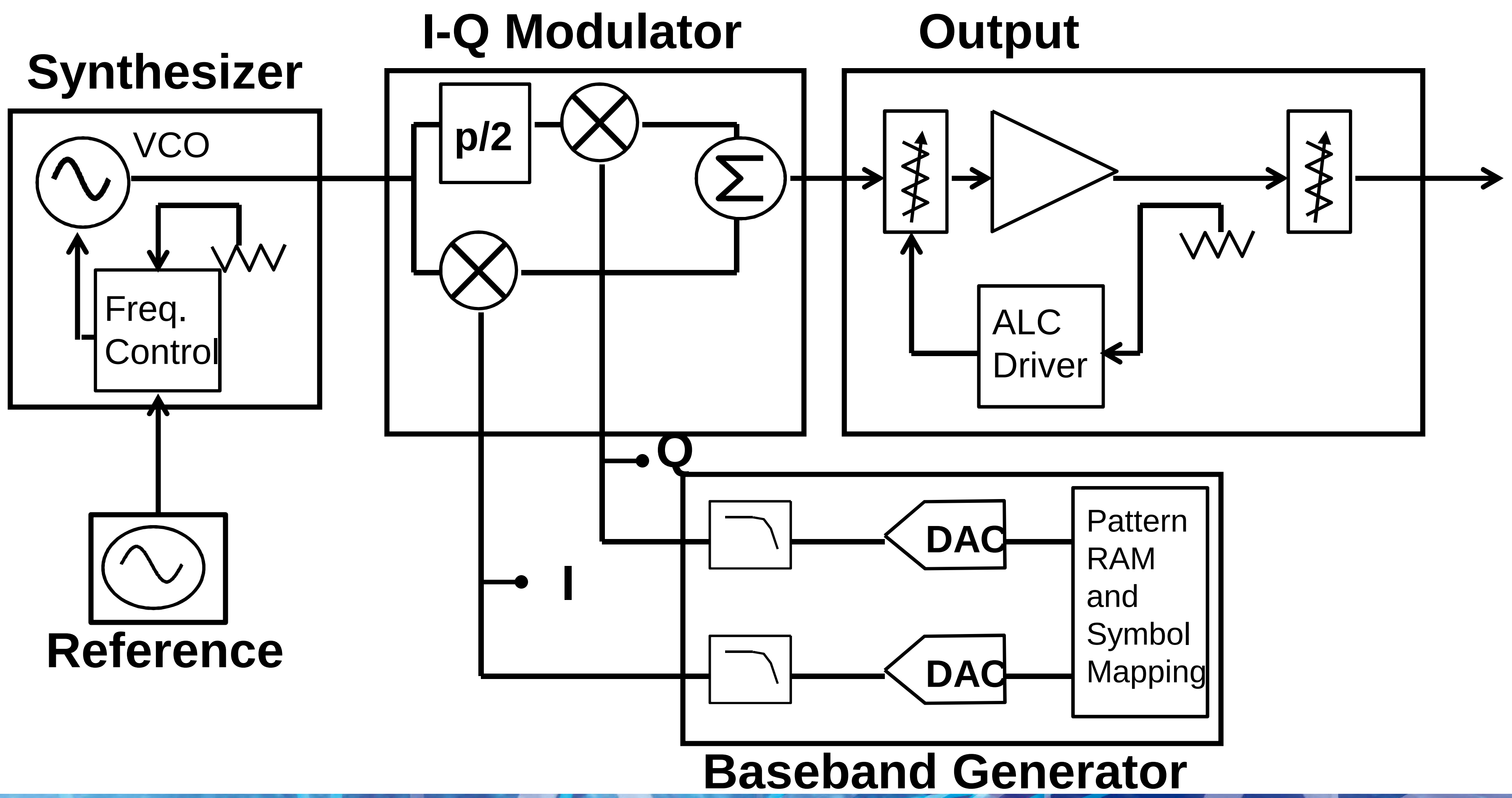




Filtering Slows Down Transitions and Narrows the Bandwidth

Vector Signals – Block Diagram

Adding an internal Baseband Generator

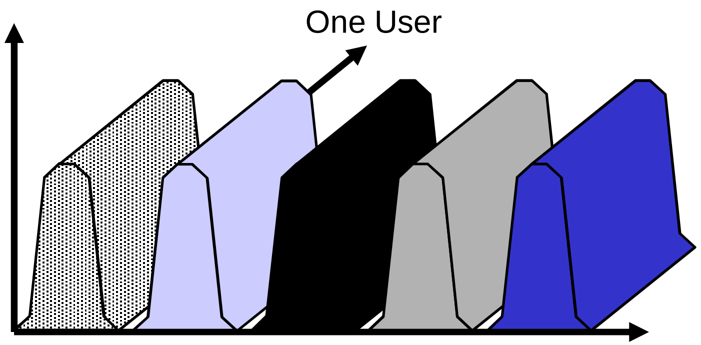


Vector Signals – Applications

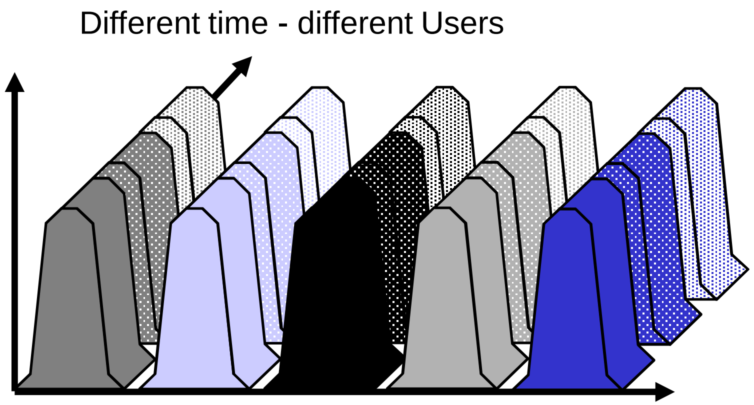
- Format Specific Signal Generation
- Receiver Sensitivity
- Receiver Selectivity
- Component Distortion

Vector Signals – Applications

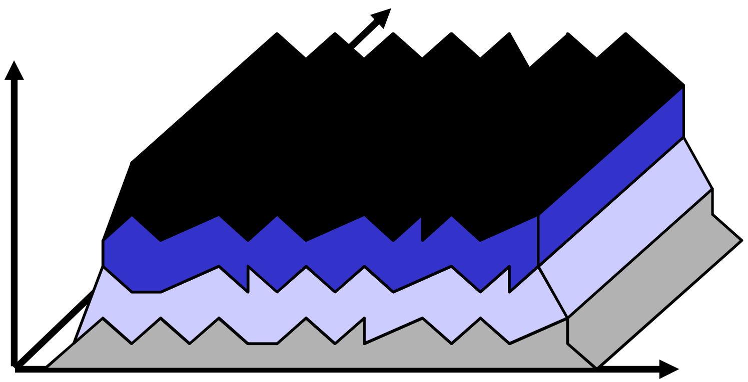
Digital Format Access Schemes



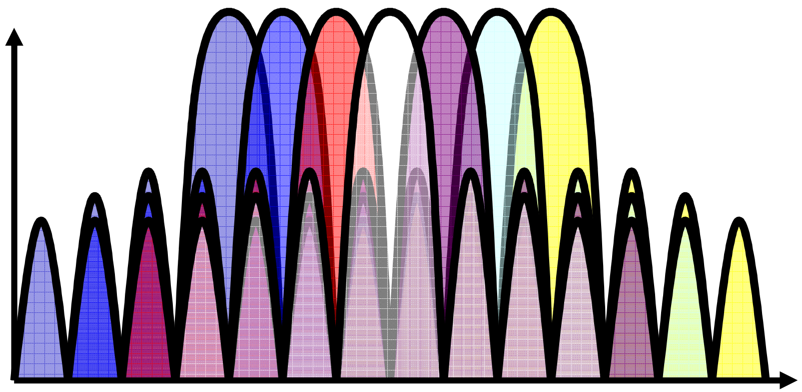
FDMA Differ channel - different Users



TDMA Different time - different Users



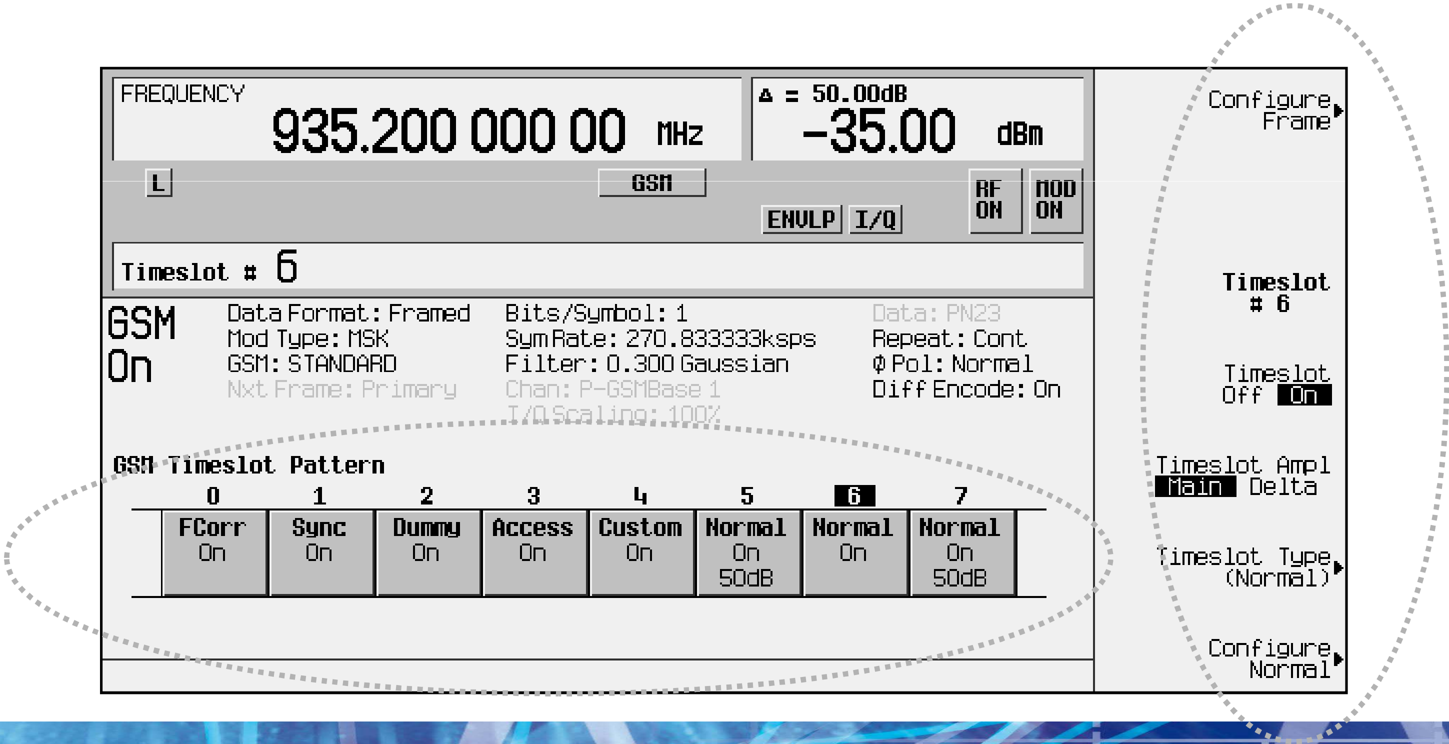
CDMA Same channel – many users



OFDM

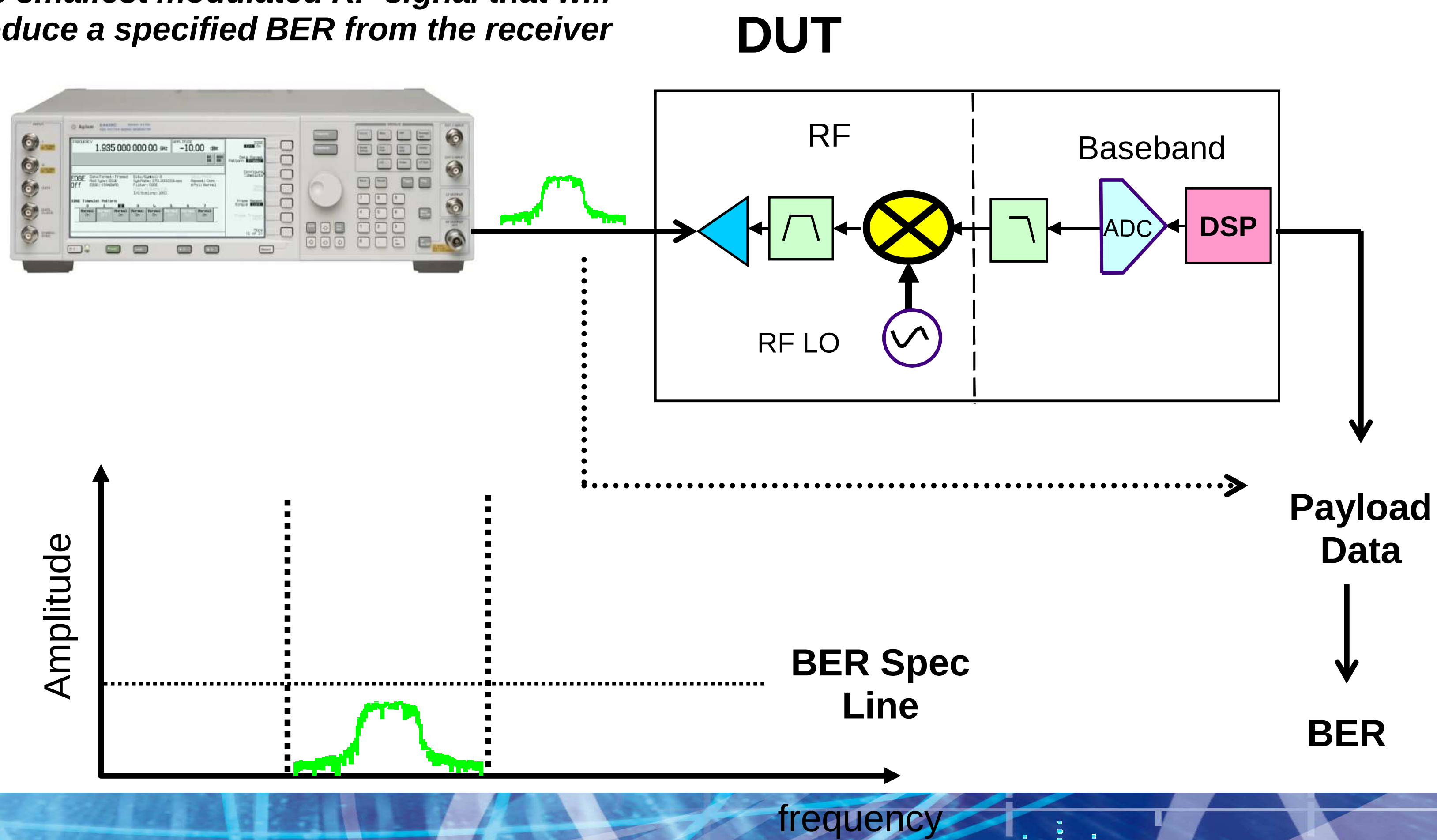
Format Specific Modulation

GSM: multiple users, same frequency, different time slots



Digital Receiver Sensitivity

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

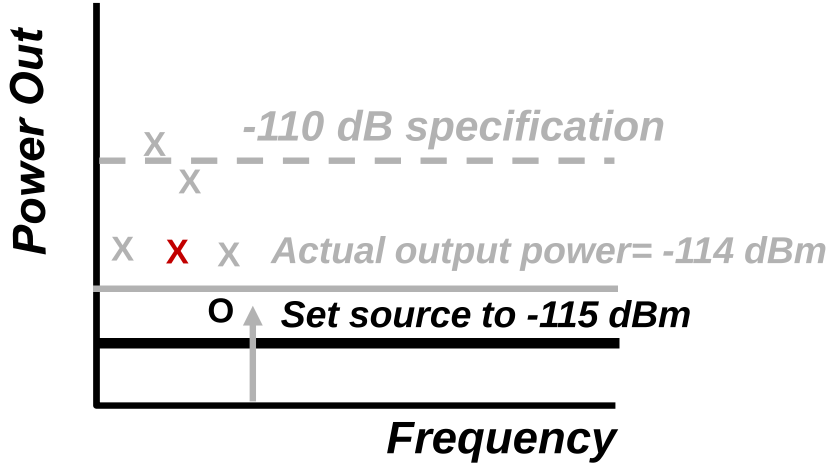


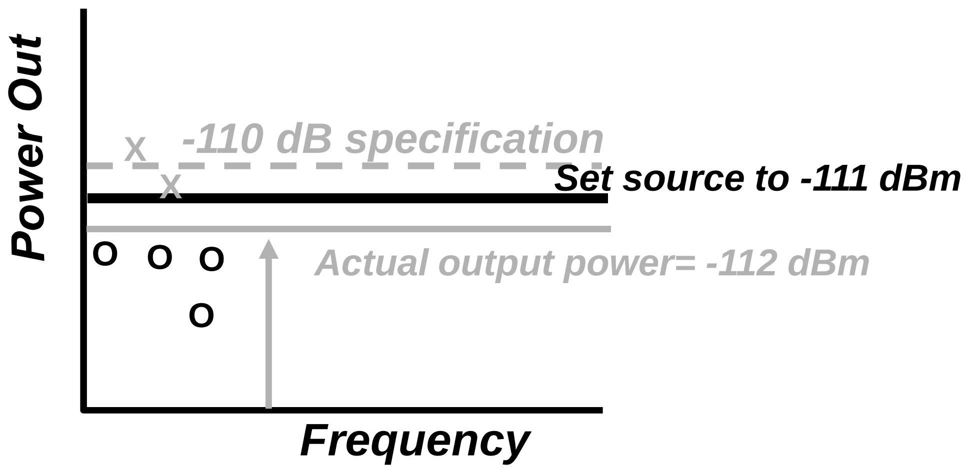
Digital Receiver Sensitivity

Testing a -110 dB sensitivity digital receiver:

X= Failed unit

O=Passed unit





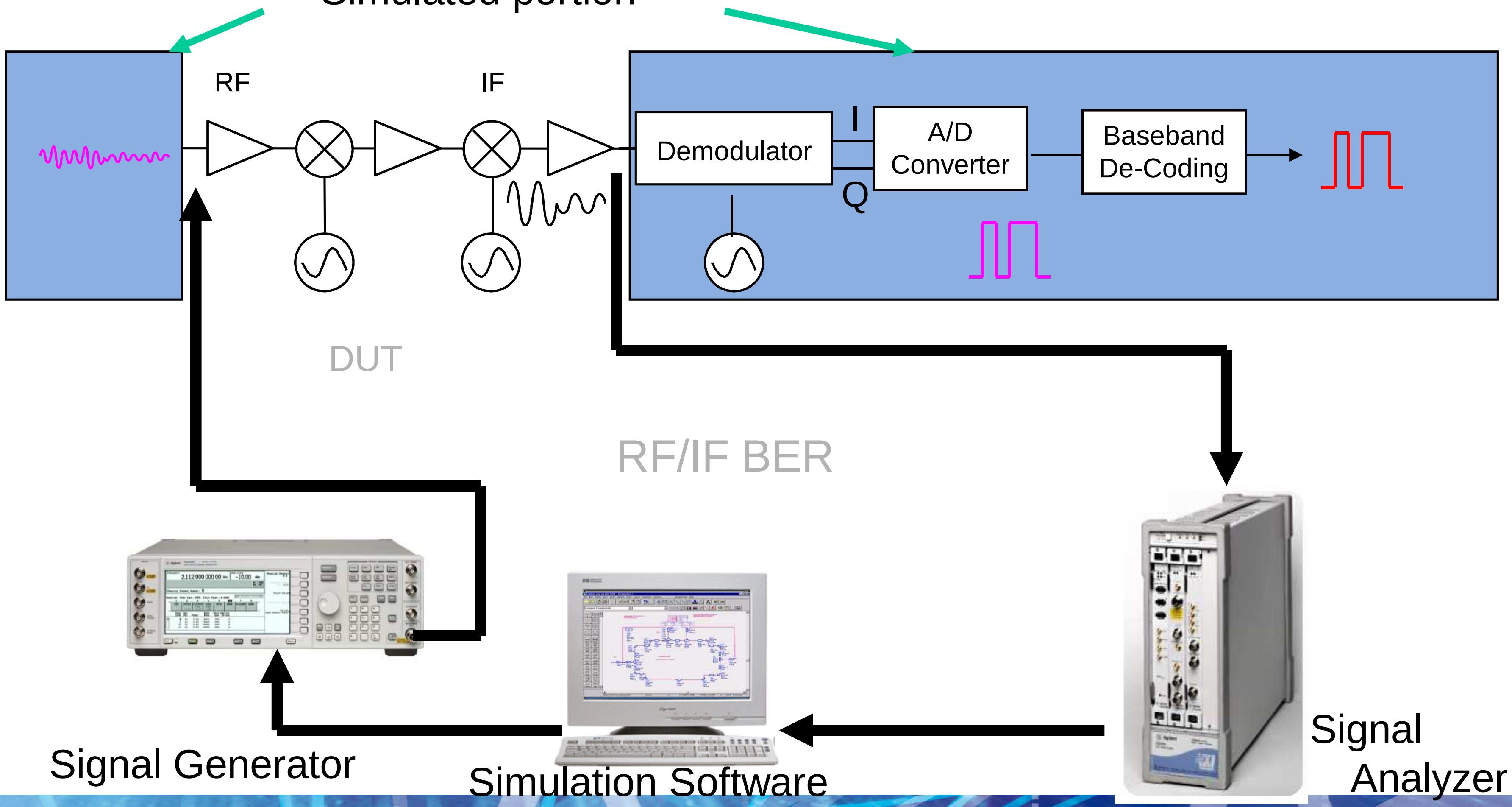
Case 1: Source has +/-5 dB of output power accuracy at -100 to -120 dBm output power.

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

Vector Signals – Applications

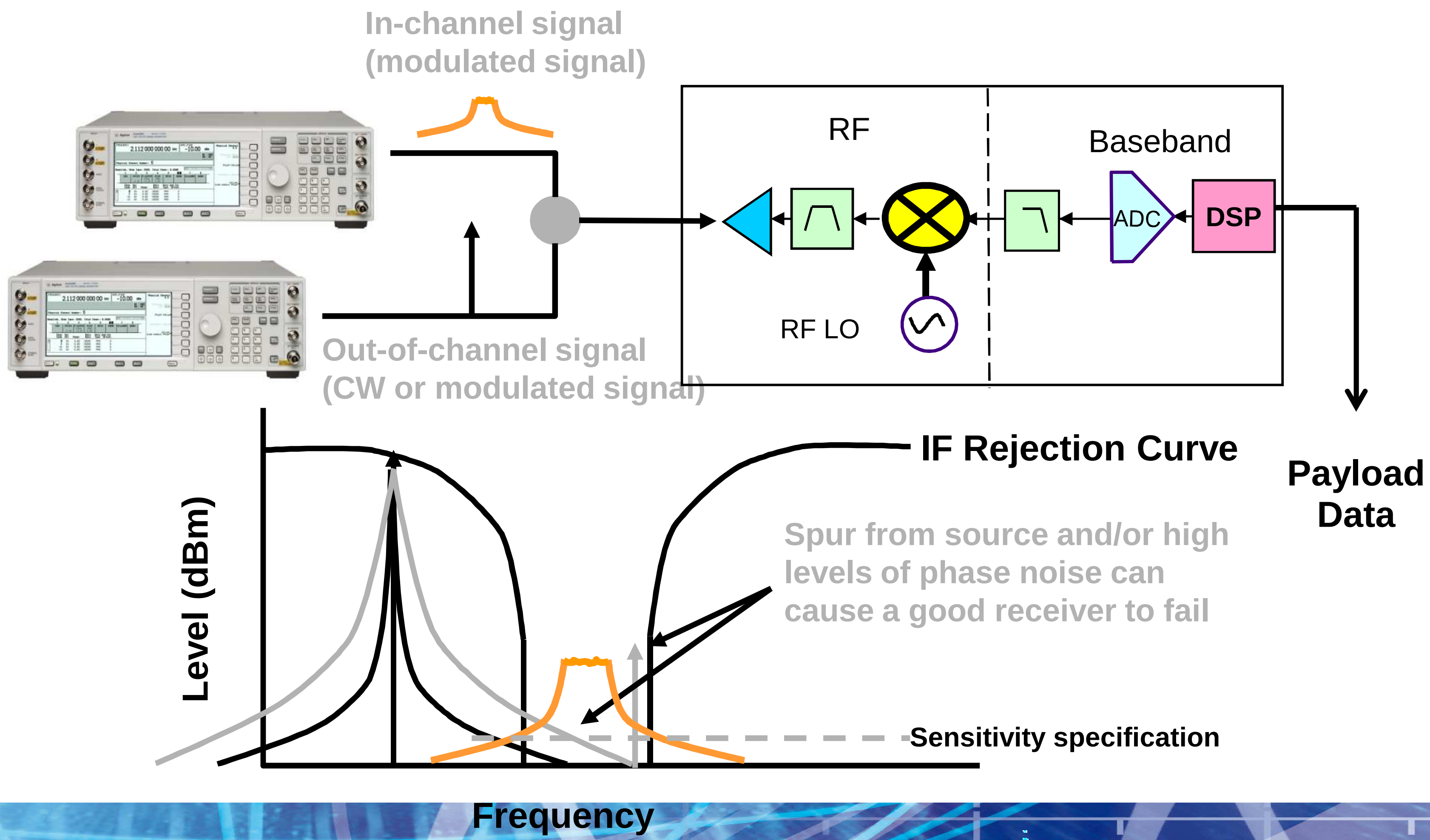
Receiver Sensitivity – Connected Solutions

- Simulated portion

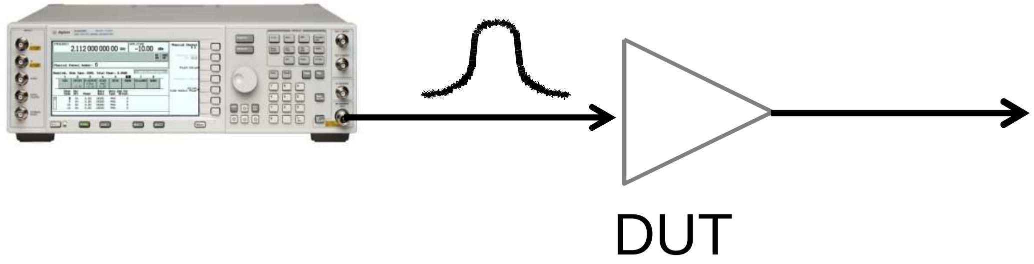


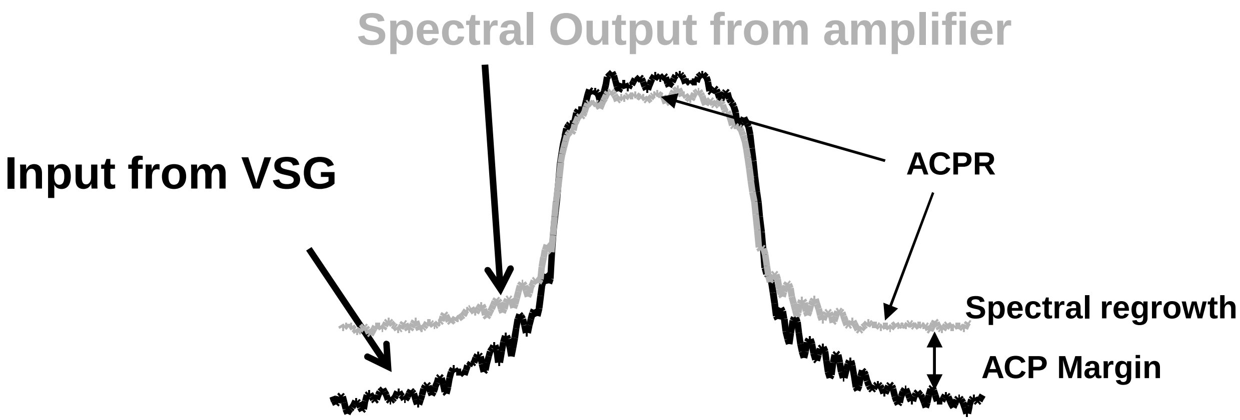
Vector Signals – Applications

Receiver Selectivity (Blocking Tests)



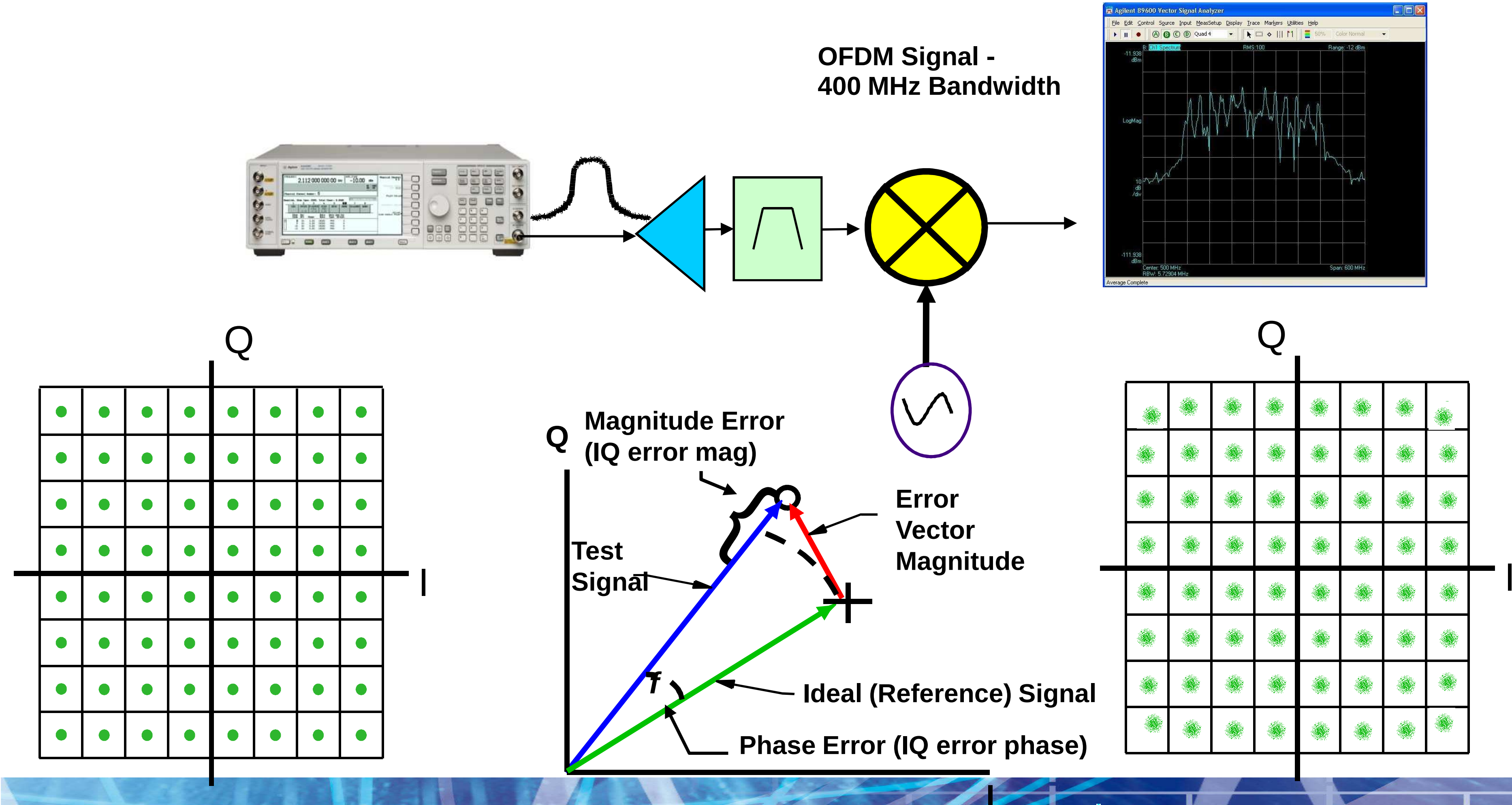
Component Distortion – Adjacent Channel Power Ratio





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

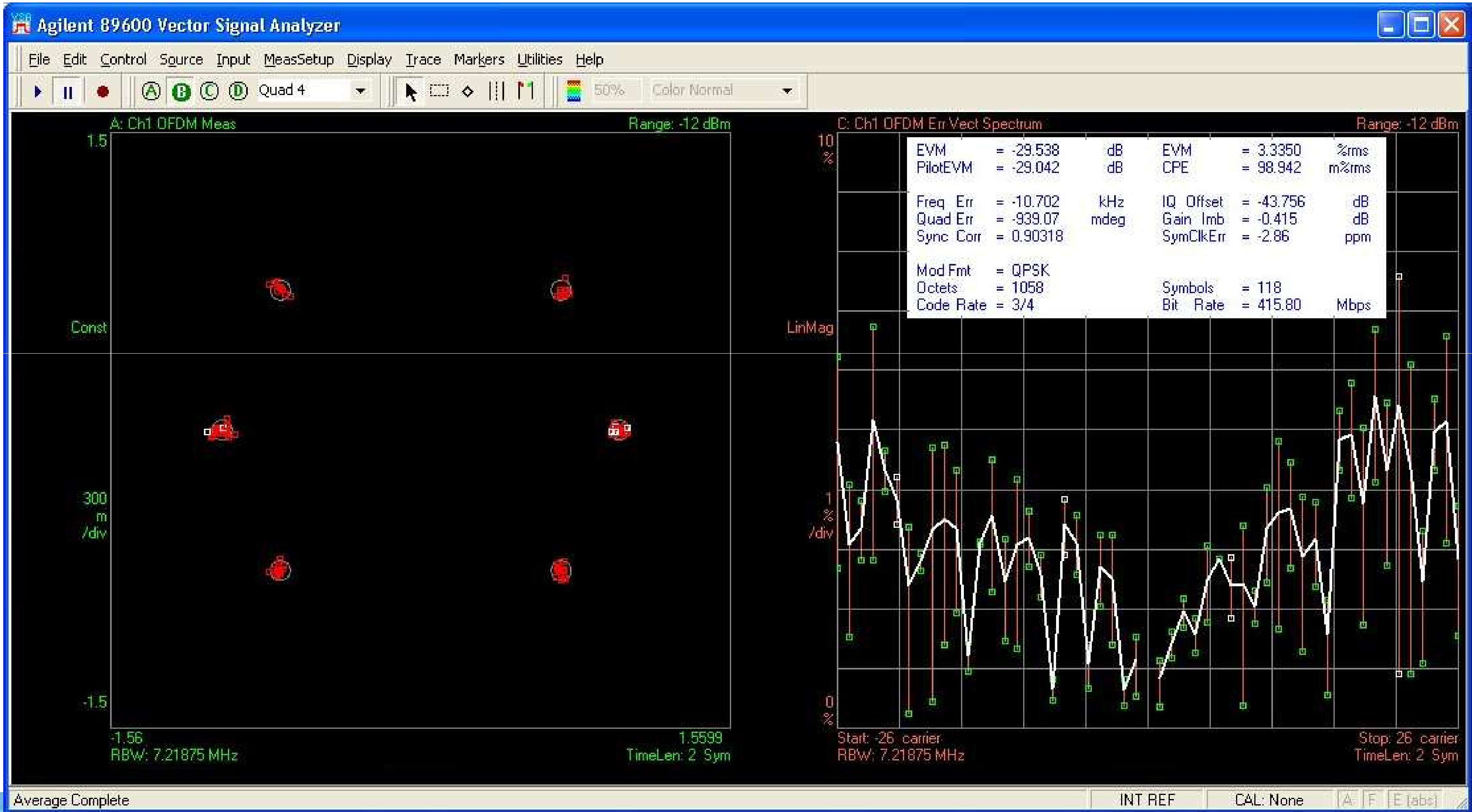
Component Distortion – Error Vector Magnitude



Vector Signals – Applications

Component Distortion – EVM

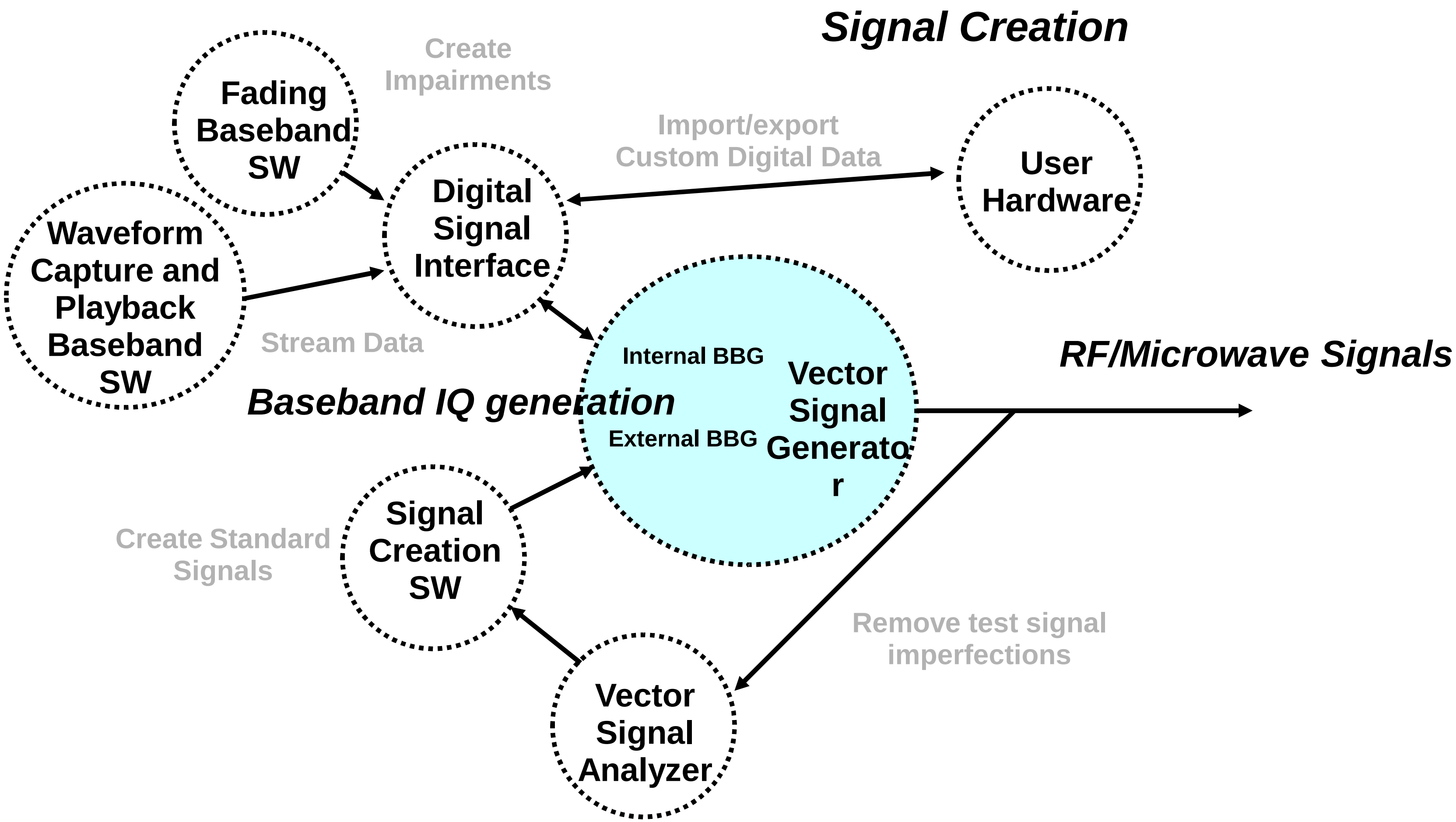
Measured EVM = -30 dB, 3.3%



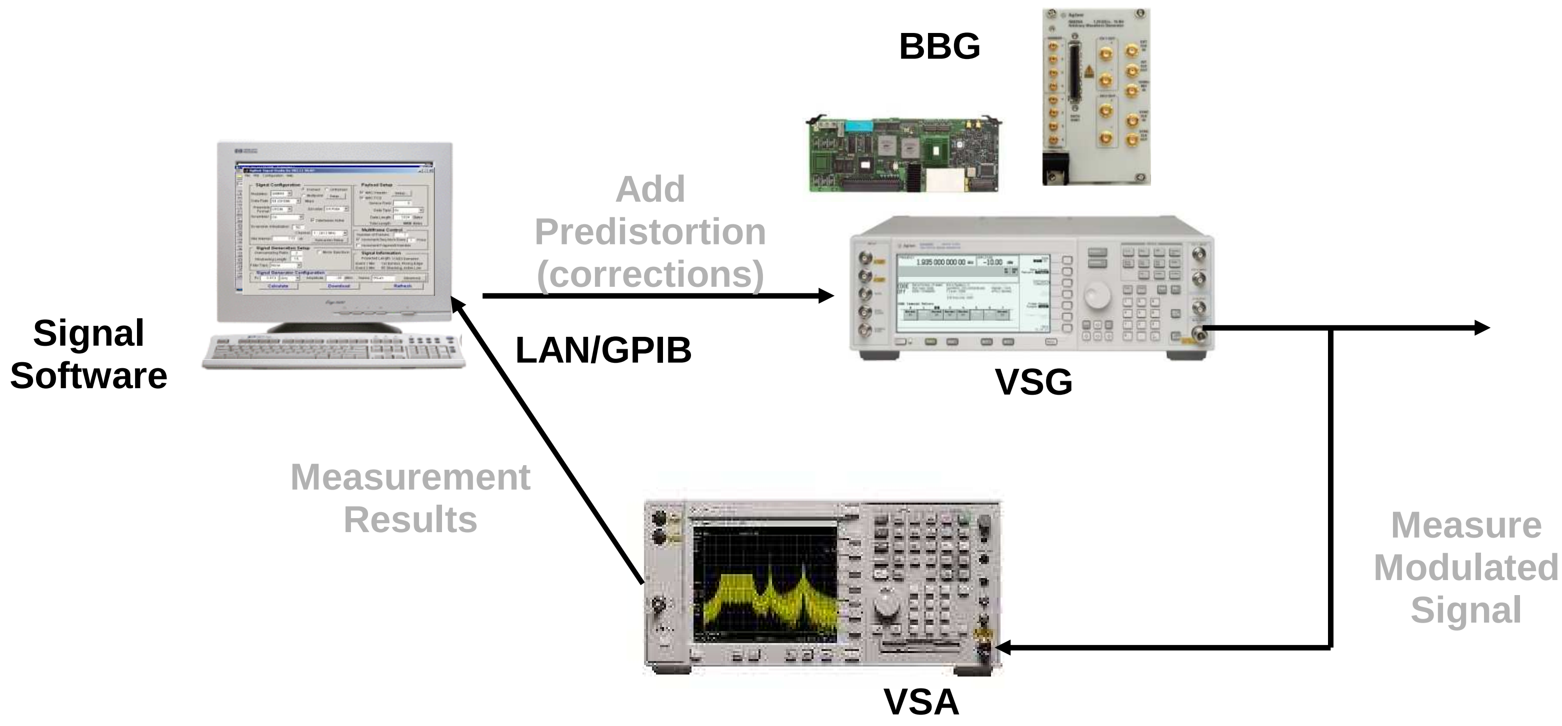
Agenda

- The need for creating test signals
  - Aerospace Defense to Communications
- From Generating Signals…
  - No modulation
  - Analog Modulation
  - Composite Modulation
- …To Simulating Signals
  - Simulating real-life signals
- Signal Generators
- Signal Simulation Solutions
- Summary

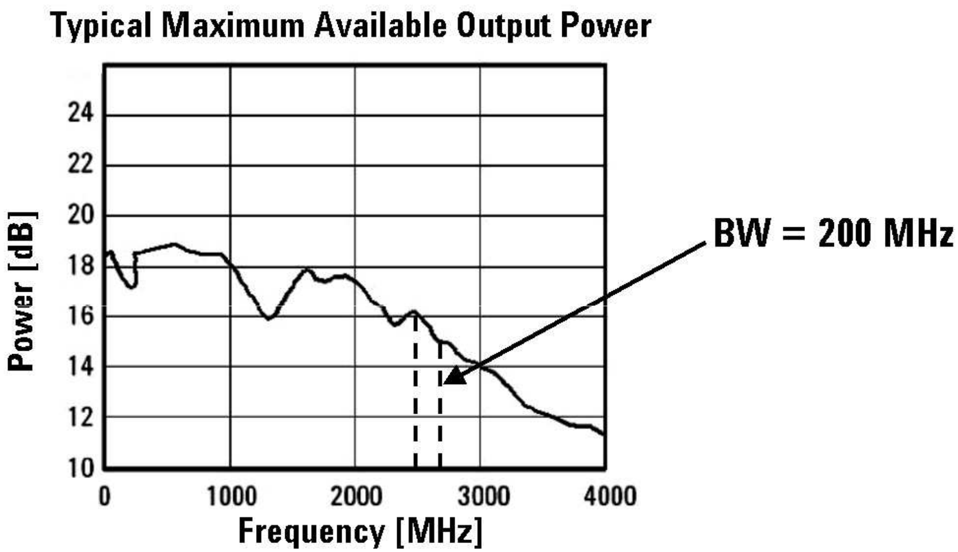
Simulating real signal environments

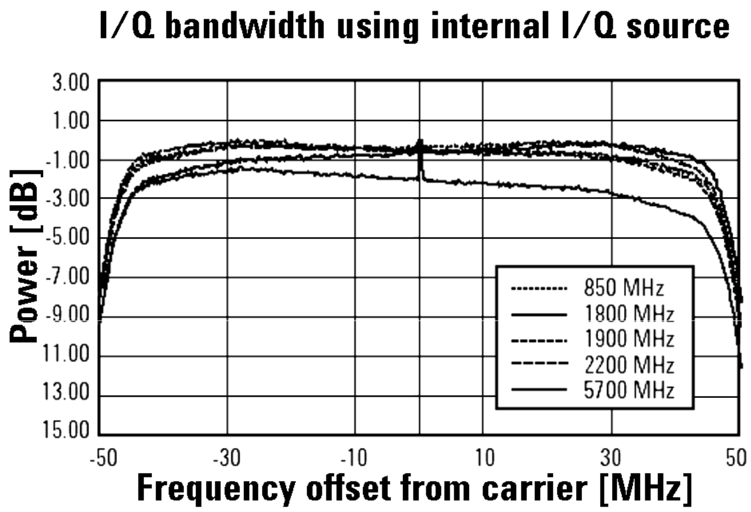


Remove Test Signal Imperfections



Remove Test Signal Imperfections – IQ Flatness





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

Result – passband tilt, ripple, and roll off

Remove Test Signal imperfections – IQ flatness

Solution – measure vector signal generator and apply predistortion

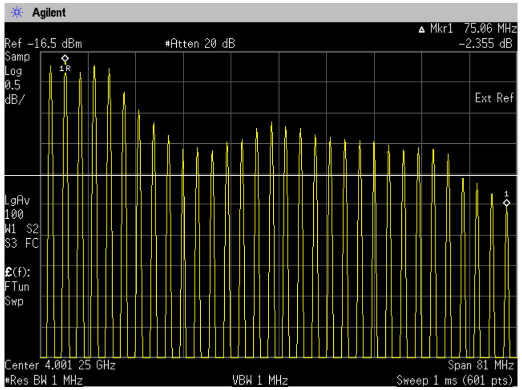
Tradeoff – calculation time, valid cal time

Typical application – wideband, multitone, and multicarrier

32 tones - 80 MHz

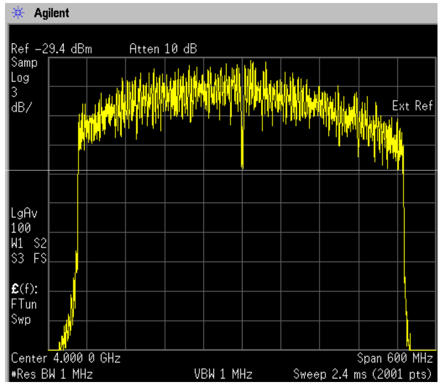
500 MHz UWB

Before

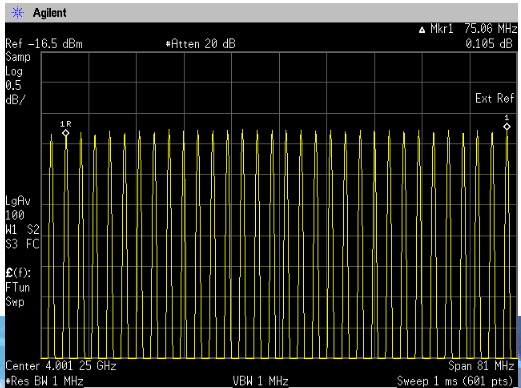


2.4 dB

6-8 dB

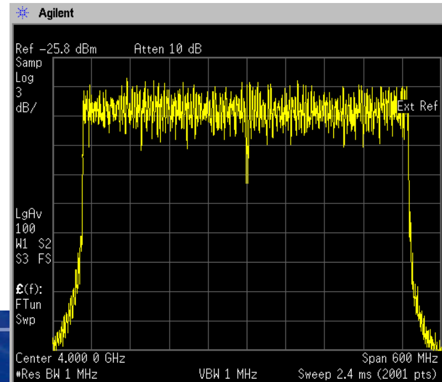


After



0.1 dB

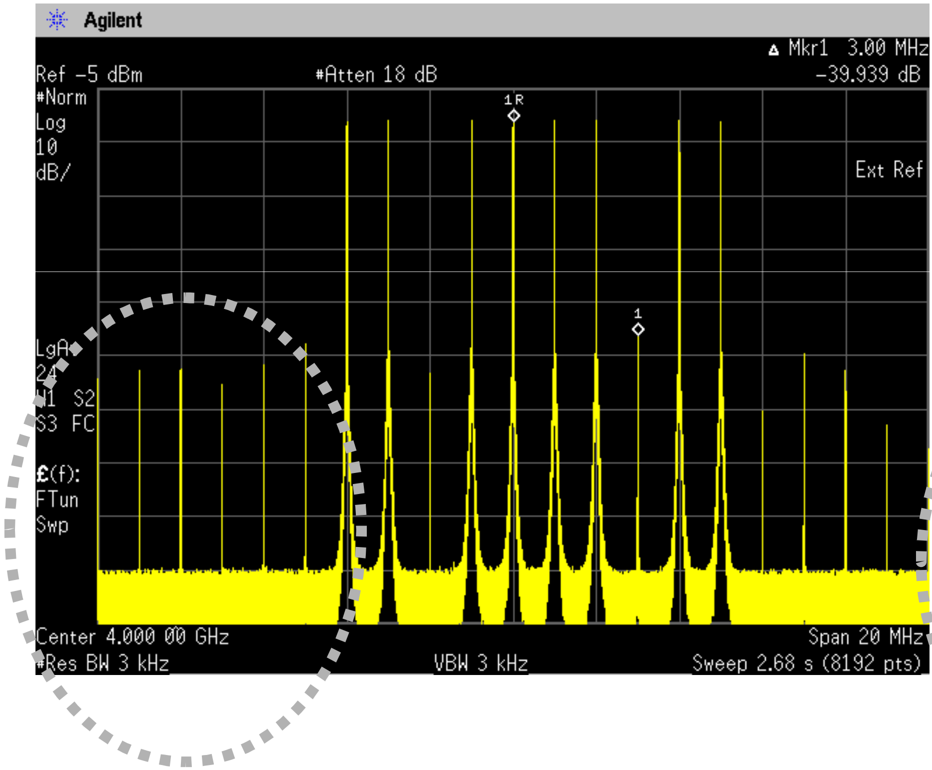
< 3 dB



Removing Test Signal Imperfections - IMD

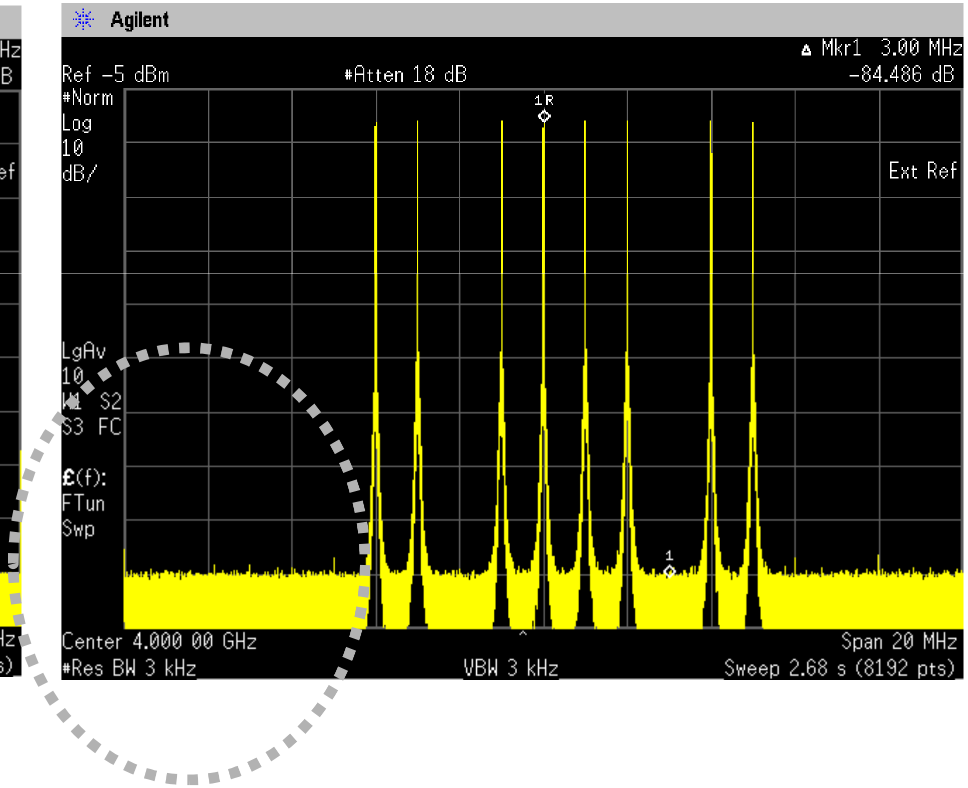
Before Predistortion

Measured in-band IMD = -40 dBc



After Predistortion

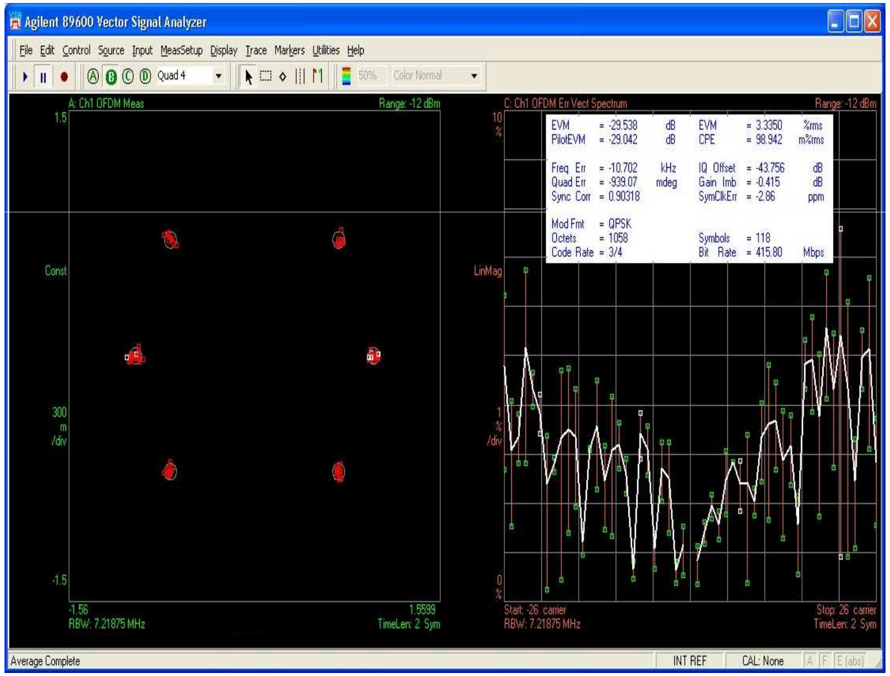
Measured in-band IMD = -84 dBc



Removing Test Signal Imperfections – Group Delay

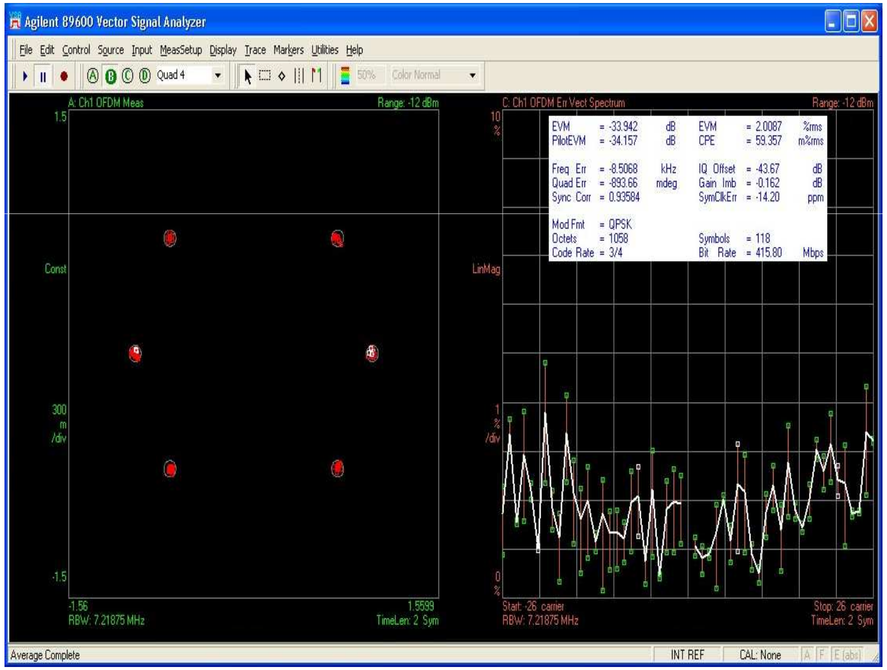
Before Predistortion

EVM -30 dB, 3.3%

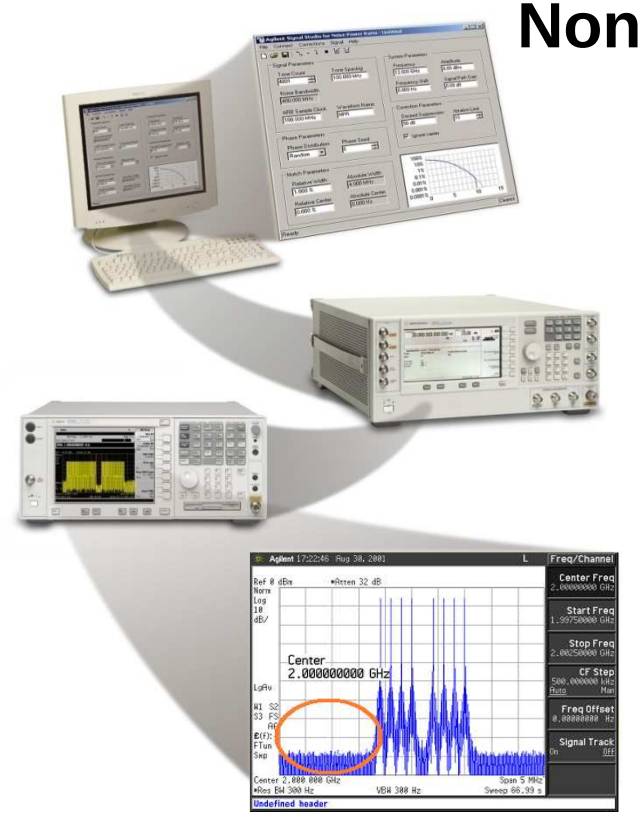


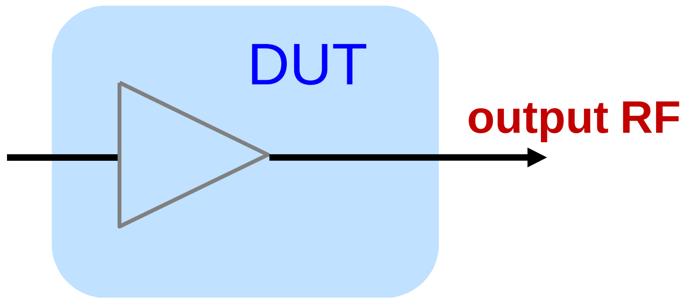
After Predistortion

EVM –34 dB, 2%



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

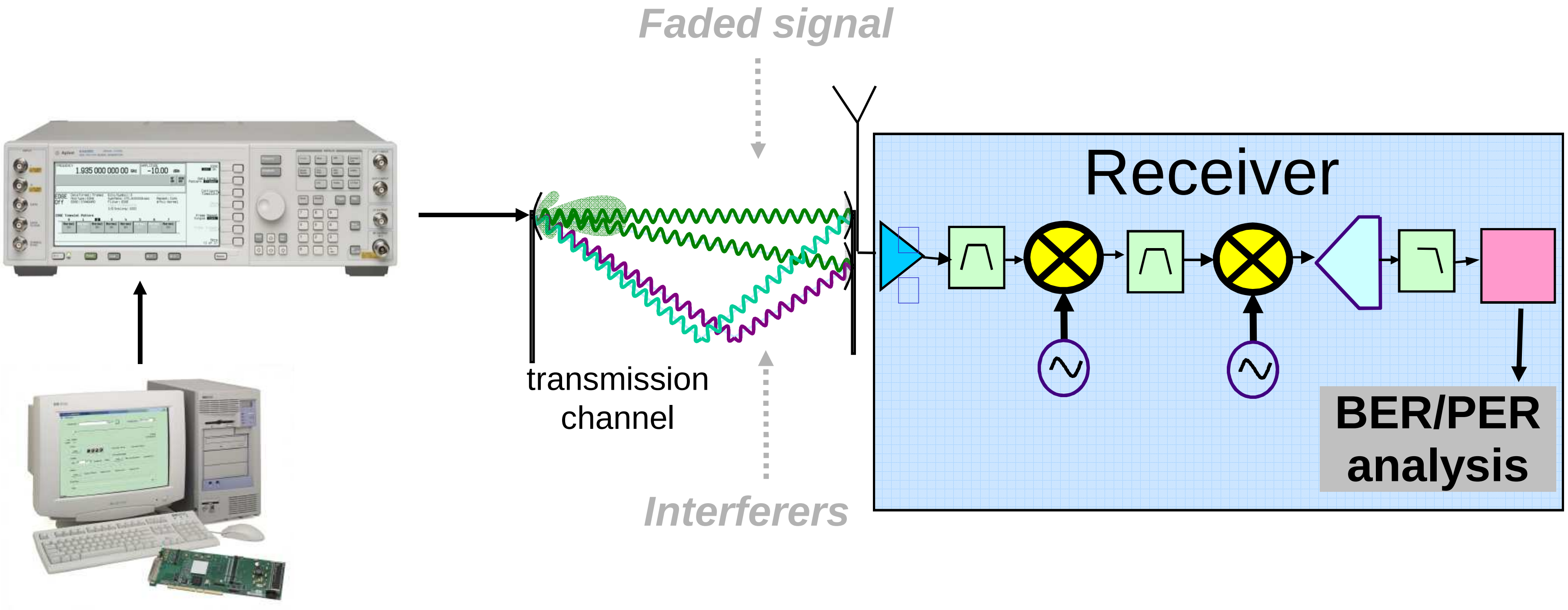
Set relative tone power

Set relative tone phase

80 MHz correction BW

CCDF plot

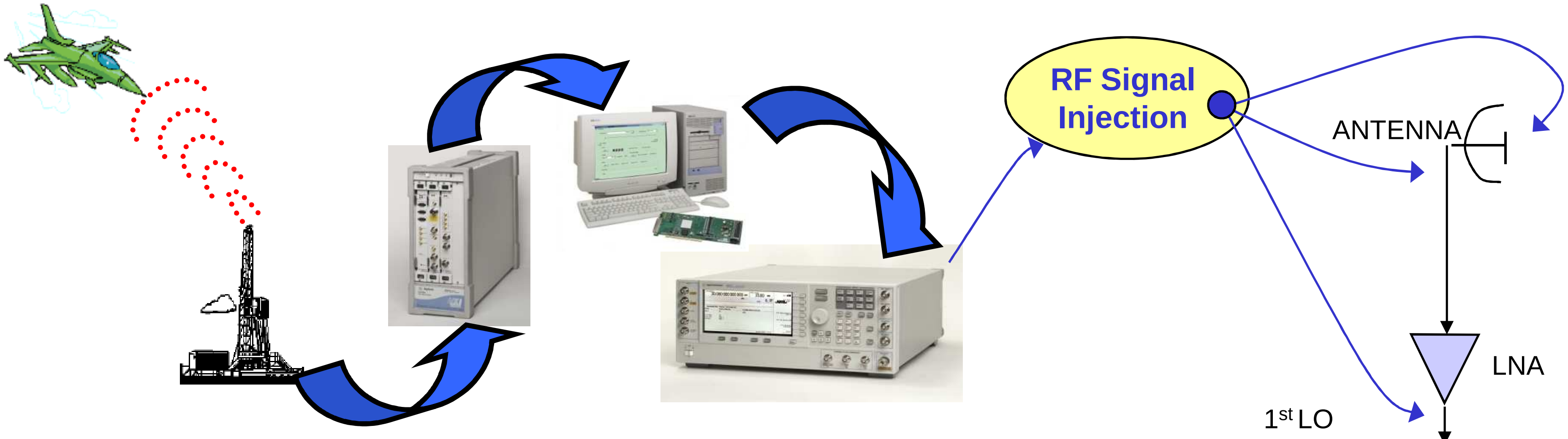
Adding Impairments to Signals – Fading



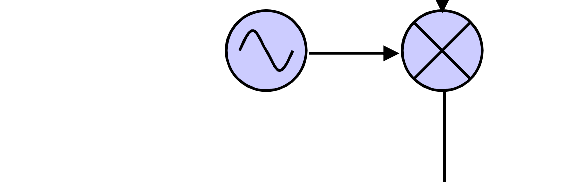
SW and interface hw

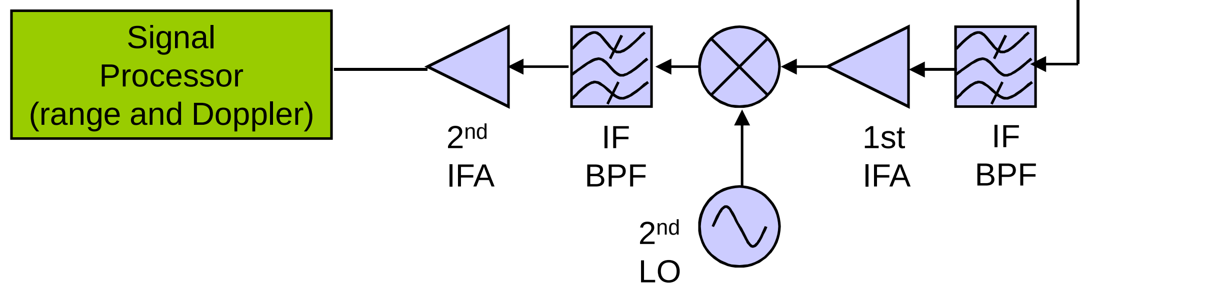
- Faded analog RF, IF, or IQ for receiver test
- Faded digital IQ baseband for digital subsystem test

RF Capture & Playback



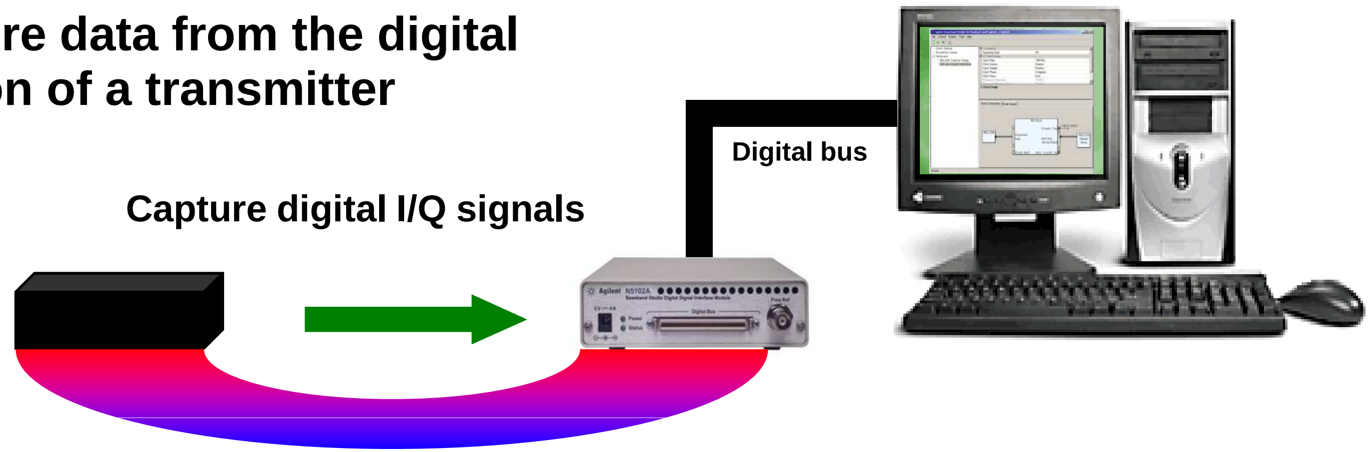
- Record signals off the air
- Transfer files to a PC equipped with Baseband Studio and re-format
- Stream them into the Vector PSG signal generator for playback



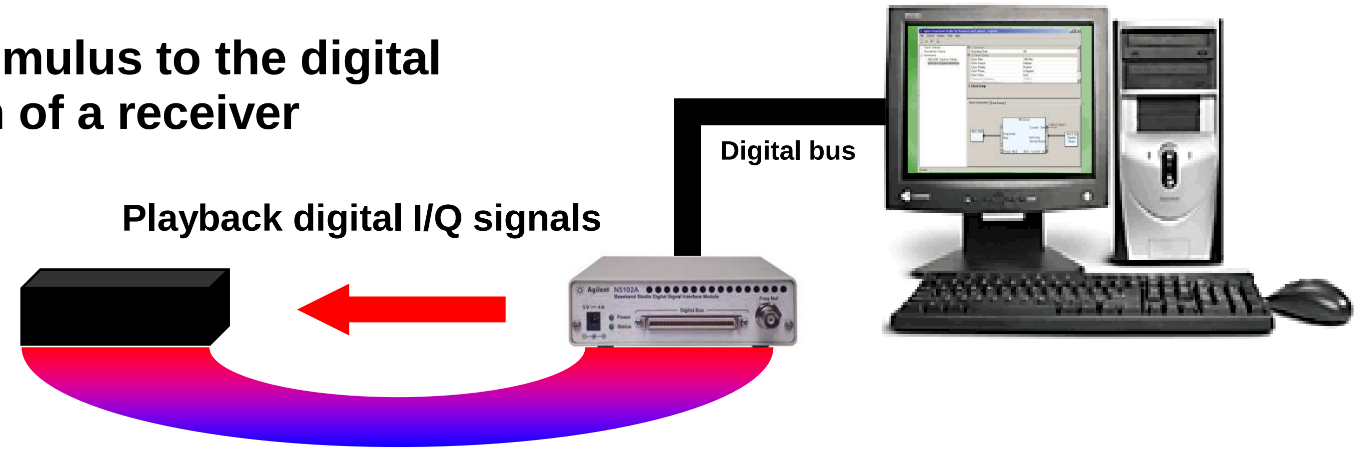


Digital Capture & Playback

Capture data from the digital section of a transmitter



Test stimulus to the digital section of a receiver



Agenda

- The need for creating test signals
  - Aerospace Defense to Communications
- From Generating Signals…
  - No modulation
  - Analog Modulation
  - Composite Modulation
- …To Simulating Signals
  - Simulating real-life signals
- Signal Generators
- Signal Simulation Solutions
- Summary

A Portfolio of Signal Generators

Analog	Vector

Basic & Mid-performance

RF mid-performance (Analog)

N5181A MXG
New price/performance point,
fast switching

RF mid-performance (Vector)

N5182A MXG
New price/performance point,
fast switching, best ACPR

High performance

Analog

RF

E4428C ESG
High spectral purity

RF

E8663B
Best close-in phase noise

MW

E8257D PSG
High power, low phase noise

Vector

RF

E4438C ESG
Real-time BBG, BERT, digital I/Q

MW

E8267D PSG
Agilent INNOVATION first vector modulation at MW

Agilent Signal Studio & Embedded Software

product portfolio

- 3GPP W-CDMA
- 3GPP W-CDMA
- 3GPP W-CDMA w/ HSPA
- LTE
- CPRI BTS
- TD-SCDMA
- CDMA2000 & IS-95-A
- CDMA2000 & 1xEV-DV
- cdma2k & 1xEV-DO
- GSM/EDGE
- Real-Time TDMA: GSM/EDGE, GPRS/EGPRS, NADC, PDC/PHS, DECT/TETRA
- ARB TDMA: GSM/EDGE, NADC, PDC/PHS, DECT/TETRA, APCO, PWT, CDPD

- 802.16e Mobile WiMAX
- 802.16d Fixed WiMAX
- 802.15 MB-OFDM UWB
- Bluetooth
- 802.11a/b/g/p/j/n WLAN & MIMO

- DVB-T/H/C
- T-DMB
- S-DMB

- Pulse Building
- GPS

- Digital, RF, & MW Fading
- Toolkit
- Jitter Injection
- Distortion Test (Enhanced Multitone and NPR)
- Multitone
- Calibrated AWGN
- Custom Modulation

= new

= Signal Studio

= Embedded SW

Agilent Baseband Studio

- N5110A Baseband Studio for waveform streaming
  - **Virtually unlimited playback memory**
- N5115A Baseband Studio for fading
  - **Optimize number of paths versus bandwidth**
  - **Up to 48 paths or 30 MHz bandwidth**
- N5102A Baseband Studio digital signal interface module
  - **Digital I/Q & digital IF output**
  - **Extremely flexible**
- For Further Information:

www.agilent.com/find/baseband studio

The End

THANK YOU!