Agenda

- Generating Signals
  - Basic CW signal
  - Block diagram
  - Applications

- Analog Modulation
  - Types of analog modulation
  - Block diagram
  - Applications

- Digital Modulation
  - Overview of IQ modulation
  - Block diagram
  - Applications
What is a signal generator?
Generating Continuous Wave (CW) Signals
Basic CW Signal Generator Block Diagram

Synthesizer Section

- Reference Oscillator
  - Reference Section

- Phase Detector
  - Frac-N
  - VCO

- f

Output Section

- ALC Modulator
- Output Attenuator
- ALC Driver
- ALC Detector

ALC = automatic level control
Synthesizer Components: VCO

Input Tune Voltage

Voltage-Controlled Oscillator (VCO)

Tuning Range: Output Frequency Range

Tuning Gain: V / Hz

VCO Slope: ↑ F for ↑ V

Phase-Noise: dBc/Hz
Synthesizer Components: Phase-Locked Loop

Reference Signal → Phase Detector → Loop Amp/Filter → VCO

Error Voltage → Tune Voltage
Key CW Signal Generator Specifications

FREQUENCY, AMPLITUDE, AND SPECTRAL PURITY

- Frequency: range, resolution, accuracy, switching speed
- Amplitude: range, resolution, accuracy, switching speed, reverse power protection
- Spectral purity: phase noise, spurious, harmonics, subharmonics
Spectral Purity

Sub-harmonics from multipliers used to extend the frequency output

Phase noise (dBc/Hz) from LO’s

Non-harmonic spur from power supplies and other contributors

Harmonic spur ~30dBc from non-linear components

Broad Band Noise Floor
Thermal noise of source

CW output

0.5 \( f_0 \)

\( f_0 \)

2\( f_0 \)
Why Spurs and Harmonics Matter

**RADAR/ELECTRONIC WARFARE EXAMPLE**

**Radar/Electronic Warfare Example**
False target/threat detection & interference

**Satellite Example**
In channel receiver interference degrades sensitivity and range

**Cellular Example**
Out of channel interference pollutes neighbors receiver sensitivity & degrades range and data rates
Why Phase Noise Matters

Phase noise can prevent resolution of unequal signals.
Main Contributors to Phase Noise

Absolute SSB Phase Noise at 10 GHz in dBC/Hz

- Reference Oscillator Noise
- PLL BW
- Phase detector noise
- Broadband noise floor, thermal noise of source
- VCO noise
Oscillator / Clock Substitution

Simplified Receiver Block Diagram

Antenna

Local Oscillator In

MXG

DDS

Ref In

Ref out

Clock In

ADC

FPGA
Amplifier Gain Testing

**Using a Power Sensor**

Gain (dB) = \(10 \log \frac{P_{out}}{P_{in}}\)

\[\text{Gain (dB)} = P_{out} \text{ (dBm)} - P_{in} \text{ (dBm)}\]

\(P_{in} = \text{input power to amplifier (Watts)}\)

\(P_{out} = \text{output power from amplifier (Watts)}\)
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$A(t)\sin[2\pi f(t) + \Phi]$
Analog Modulation

Baseband Signal

Amplitude (AM)

Frequency (FM)

Phase (PM)
Amplitude Modulation

Important Characteristics for Amplitude Modulation

- Modulation frequency (rate)
- Depth of modulation (Mod Index)
- Distortion (%)

Where are AM signals used?

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

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

\( \beta \) is the modulation index, where
\( \beta = \frac{\Delta F_{\text{dev}}}{F_m} \)

**Important Characteristics for Frequency Modulation**

- Frequency Deviation (\( \Delta F_{\text{dev}} \))
- Modulation Frequency (\( F_m \))
- Accuracy
- Resolution
- Distortion (%)
- Sensitivity (dev/volt)
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 (\( \Delta \theta \))
- Modulation Rate (\( F_m \))
- Accuracy

**Where are PM signals used?**
- PSK (early digital 1010)
- Radar (pulse coding)
Pulse Modulation

Important Characteristics for Pulse Modulation

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

Where are Pulse Modulated signals used?

- Radar
- High Power Stimulus/Response
- Communications
Analog Signal Generator Block Diagram

**ADD INTERNAL MODULATION GENERATOR**

- **VCO**
  - Freq. Control
- **Reference Oscillator**
- **ALC Modulator**
- **Pulse Mod.**
- **Output Attenuator**
- **LF Generator**
  - FM Source
  - AM Source
  - Pulse Source

Connections:
- FM, PM input
- AM input
- Pulse Mod input
Receiver Baseband Distortion

\[
\text{Required SG Modulation distortion} = \text{Receiver Distortion} \% \times 10^{\left(\frac{\text{margin(dB)}}{20}\right)}
\]
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Digital Modulation

Signal Characteristics Are Modified Discretely

- Amplitude (ASK)
- Frequency (FSK)
- Phase (PSK)
- Both Amplitude and Phase (QAM)
Composite Modulation

SIMULTANEOUS MODULATION OF TWO MODULATION TYPES

Independent Amplitude and Phase Modulation

Independent FM and Pulse Modulation

Integrated IQ Modulator

32 QAM Constellation Diagram

FM during the pulse = chirp
Vector Signal Changes or Modifications

- **Magnitude Change**: 0 deg
- **Phase Change**: 0 deg
- **Both Change**: 0 deg
- **Frequency Change**: 0 deg
Polar Versus IQ Format

Q-Value

I-Value

Mag

Phase

0 deg
Transmitting Digital Data: Bits vs Symbols

Binary Data bit = 0, 1
Transmitting Digital Bits ($f_1 = 0, f_2 = 1$)

F(t) = \[ \begin{array}{c|c|c}
T & 010101010 & f_1 \\
S & S & f_2
\end{array} \]

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 $2 \times$ Sample rate

Symbol Rate = Bit rate
\# bits per symbol

Main lobe width is $2 \times$ Symbol rate
## Digital Modulation Characteristics

<table>
<thead>
<tr>
<th>Modulation Format</th>
<th>Number of Bits per Symbol</th>
<th>Constellation</th>
<th>Transmission Bandwidth</th>
</tr>
</thead>
</table>
| BPSK              | 1                         | \[
| QPSK              | 2                         | \[
| 16 QAM            | 4                         | \[

Symbol Rate = \#symbols/sec. (Hz)
Important Vector Modulation Characteristics

- IQ Modulation Bandwidth
- Frequency Response/Flatness
- IQ Quadrature Skew
- IQ Gain Balance
Good interface with digital signals and circuits
Can be implemented with simple circuits
Fast, accurate state change
Vector Signal Generator Block Diagram

Adding an IQ Modulator and Baseband Generator

Synthesizer
- VCO
- Frequency Control
- Reference

I-Q Modulator
- 90°
- Summation
- I, Q

Output
- ALC Driver

Baseband Generator
- DAC
- Pattern RAM and Symbol Mapping
Baseband IQ Signal Generator

Pattern RAM
Binary Info to be transmitted

Symbol Mapping and Baseband Filters
Map to digital symbols then to Digital I Q signals

DAC’s convert digital IQ signals to analog IQ signals

Send to IQ Modulator

DAC
DAC

I
Q

<table>
<thead>
<tr>
<th>Binary</th>
<th>Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>1+j1</td>
</tr>
<tr>
<td>01</td>
<td>-1+j1</td>
</tr>
<tr>
<td>10</td>
<td>-1-j1</td>
</tr>
<tr>
<td>11</td>
<td>1-j1</td>
</tr>
</tbody>
</table>
M9383A: A Closer Look

• Combination of high performance modules create uncompromising vector signal generator performance in PXIe form factor
  • M9316A Vector Modulator
  • M9312A Source Output
  • M9303A Synthesizer
  • M9300 Reference
Digital Receiver Sensitivity

DUT

RF

Baseband

RF LO

DAC

DUT

Payload Data

BER Spec Line

BER

Frequency

Amplitude
Receiver Selectivity

In-channel signal

Out-of-channel interferer

IF Rejection Curve

Payload Data

DUT

RF

Baseband

RF LO

ADC

DSP

Payload Data
# Measuring Component Distortion

## ACPR

![ACPR Graph]

<table>
<thead>
<tr>
<th>Margin (dB)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error contribution (dB)</td>
<td>3.0</td>
<td>2.5</td>
<td>2.1</td>
<td>1.8</td>
<td>1.5</td>
<td>1.2</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Measuring Component Distortion

EVM

![Diagram showing EVM measurement process](image)

- **Magnitude Error (IQ error mag)**
- **Error Vector Magnitude**
- **Test Signal**
- **Ideal (Reference) Signal**
- **Phase Error (IQ error phase)**
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Keysight’s Signal Generation Solutions

- N9310A
- EXG
- MXG
- M9380A
- M9381A
- M9383A
- PSG
- UXG
- Signal Studio Software
Thank You!

ADDITIONAL INFORMATION

- More Webcasts: www.keysight.com/find/WebcastSeries
- Signal Sources: www.keysight.com/find/sources
- Signal Analyzers: www.keysight.com/find/sa