Digital Signal Analysis
Objectives

- Provide a digital modulation overview
- Review common digital radio impairments
Digital Modulation Overview
Vector Signal Analysis on one page
Receiver Overview

[Diagram showing the receiver overview]
Signal Characteristics to Modify

Amplitude

Frequency

Phase

Amplitude & phase

Digital data

Digital baseband modulating signal
Polar Display / IQ Relationship

A discrete point on the I-Q diagram represents a digital state or symbol location.
Quadrature Amplitude Modulation

- **QPSK**
  - 2 bits / symbol
  - Symbol Rate = 1/2 bit rate

- **16 QAM**
  - 4 bits / symbol
  - Symbol Rate = 1/4 bit rate

- **32 QAM**
  - 5 bits / symbol
  - Symbol Rate = 1/5 bit rate

- **64 QAM**
  - 6 bits / symbol
  - Symbol Rate = 1/6 bit rate

- **128 QAM**
  - 7 bits / symbol
  - Symbol Rate = 1/7 bit rate
Comparing OFDM and SC-FDMA
QPSK example using N=4 subcarriers

The following graphs show how this sequence of QPSK symbols is represented in frequency and time:

1, 1, -1, -1, -1, 1, 1, -1

OFDMA
Data symbols occupy 15 kHz for one OFDMA symbol period

SC-FDMA
Data symbols occupy N*15 kHz for 1/N SC-FDMA symbol periods
IQ Modulator

Rectangular coordinates  $\rightarrow$ Polar coordinates

- **I baseband**
- **Q baseband**
- **Local oscillator (carrier frequency)**

90 deg. phase shift

(Quadrature component)

Summing circuits

Composite output signal (I-Q modulated carrier)

0,0
0,1
1,0
1,1

Symbol
IQ Demodulation

Composite input signal (I-Q modulated carrier) -> Power splitter

Polar coordinates -> Rectangular coordinates

I baseband (In-phase component)

Local oscillator (phase locked to the carrier frequency)

90 deg. phase shift

Q baseband (Quadrature component)
Error Vector Concept

\[ EVM[n] = \sqrt{I_{err}[n]^2 + Q_{err}[n]^2} \]

where \([n] = \) measurement at the symbol time

\[ I_{err} = I_{ref} - I_{meas} \]

\[ Q_{err} = Q_{ref} - Q_{meas} \]
How EVM is calculated

A flowchart illustrates the process of calculating EVM (Error Vector Magnitude) in a signal. The diagram shows the following steps:

1. Measurement filter
2. Root raised cosine filter
3. Demodulator
4. Detected bits
5. Reference generator
6. Ideal/reference signal generated
7. Raised cosine filter
8. Reference filter
9. Reference signal generation
10. I-Q error waveform
11. I-Q reference waveform
12. I-Q measured waveform

The flowchart indicates how each component contributes to the final EVM calculation.
Digital Radio Impairments and Measurements
Common Radio Impairments

Transmitter

- IQ Imbalance
- Compression
- DAC/DSP Error
- Phase Noise
- Spurious

Receiver

- Interferers
- Thermal Noise
- Ripple & Tilt
- Incorrect Coefficients
Wrong filter coefficients

For this example, the alphas for the Nyquist filter were 0.2 in the transmitter and 0.35 in the receiver.
Amplifier Nonlinearity

Transmitter

Symbol Encoder

BB Filter

DAC

I/Q Modulator

0 deg

90 deg

IF LO

IF Filter

PA

RF LO

Competition

Traditional Two-Tone Test

Testing a Digitally Modulated Signal

f₁

f₂

IMD

With compression

Without compression
Amplifier Nonlinearity - CCDF

What are the other observable effects of Compression?

CCDF Measurements

![CCDF graph]

- Compressed QPSK Signal
- Non-compressed QPSK Signal
- AWGN Signal as a reference

dB above the average

probability
Amplifier Nonlinearity - Demodulation

What are the other observable effects of Compression?

Vector (IQ) Diagram

Without compression

With compression

Increased EVM
I/Q Impairments

- Gain Imbalance
- Quadrature Error
- DC Offset
- Path Difference - Delay
I/Q Impairments – Gain Imbalance

IQ Constellation

QPSK Summary Table

Gain Imb. = 1.02 dB (Ideally 0 dB)
I/Q Impairments – Quadrature Error

IQ Constellation

QPSK Summary Table

Quad. Error = 5.9 deg. (Ideally 0 deg*)

Ideal (square) Measured (parallelogram)

* meaning that I and Q are ideally 90 deg. apart
What is causing this problem?

Interferers

![Diagram of a receiver system with components labeled such as RF Filter, LNA, IF Amp, IF Filter, I/Q Demodulator, I/O Demodulator, Receiver, RF LO, ADC, BB Filter, Symbol Decoder, and I and Q signals.]

- Spectrum A
  - Spur: 156.25 kHz
  - Tolerance: 3 dB
  - ACP Looks Good

- Spectrum B
  - Spur: 156.25 kHz
  - Tolerance: 3 dB
  - ACP Looks Good

No Spurious Signals

ACP Looks Good

Interferers
Signal A: Demodulation is Good

Spectrum A

Demod

EVM Low (0.4%)
Signal B: Demodulation

EVM High (3.6%)
Mag & Phase Errors High and comparable

Points are not randomly distributed

Spectrum B
Demod

EVM Hi (3.6%)
Signal B: EVM Spectrum Shows Spur

EVM Spectrum

Spurious Signal

-36dBc spur was buried under the modulated carrier

Spectrum B
Infamous V-shape

Symbol Rate
Digital Modulation Measurements
Constellation Errors

64 QAM Constellation

- Ideal Symbol Point
- Random Noise
- Phase Noise
- AM Distortion
- PM Distortion
- Delay Distortion/ISI
- Interference
Demonstration
THANK YOU!