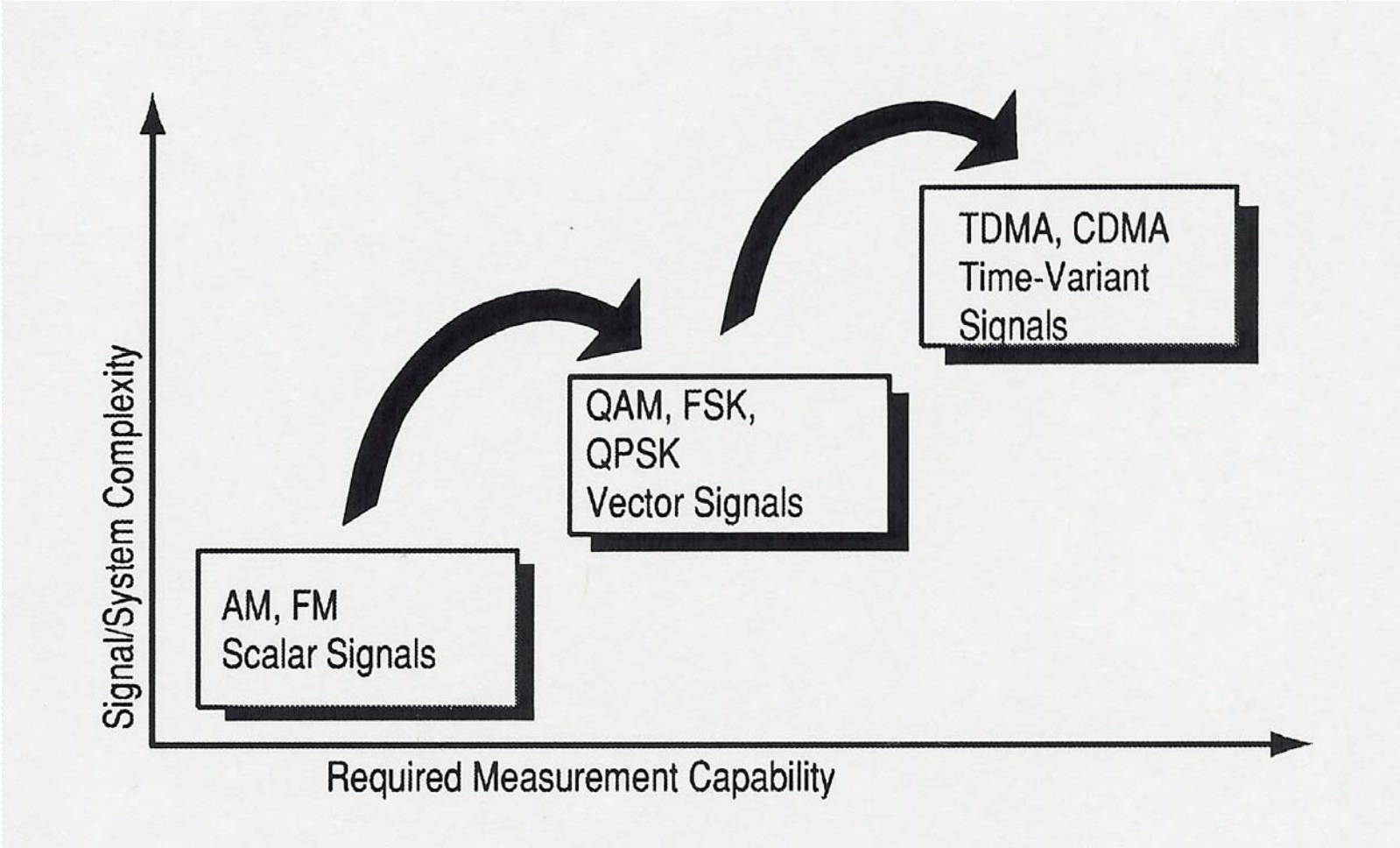
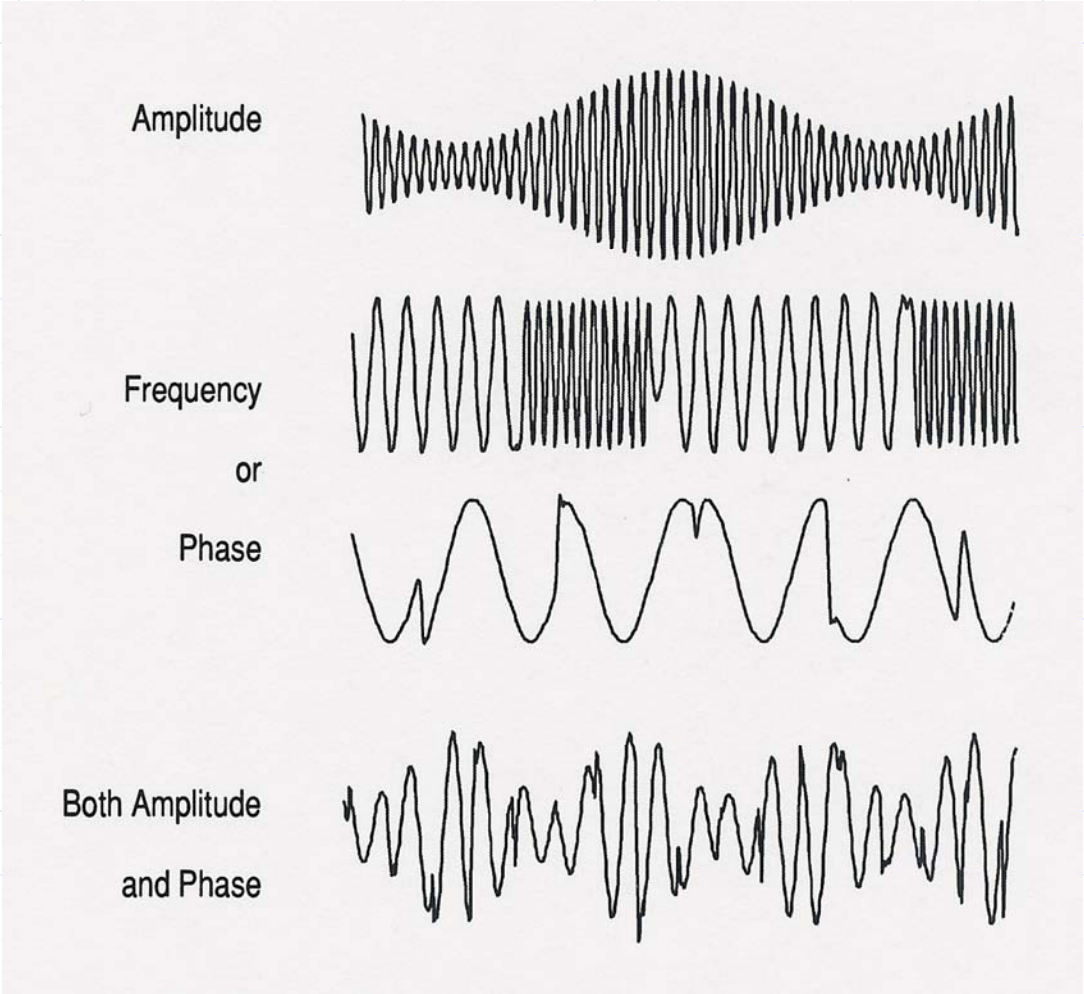
Communications Systems Analysis Using Hardware and Software-Based Vector Signal Analyzers

by Dr. Thad B. Welch, PE

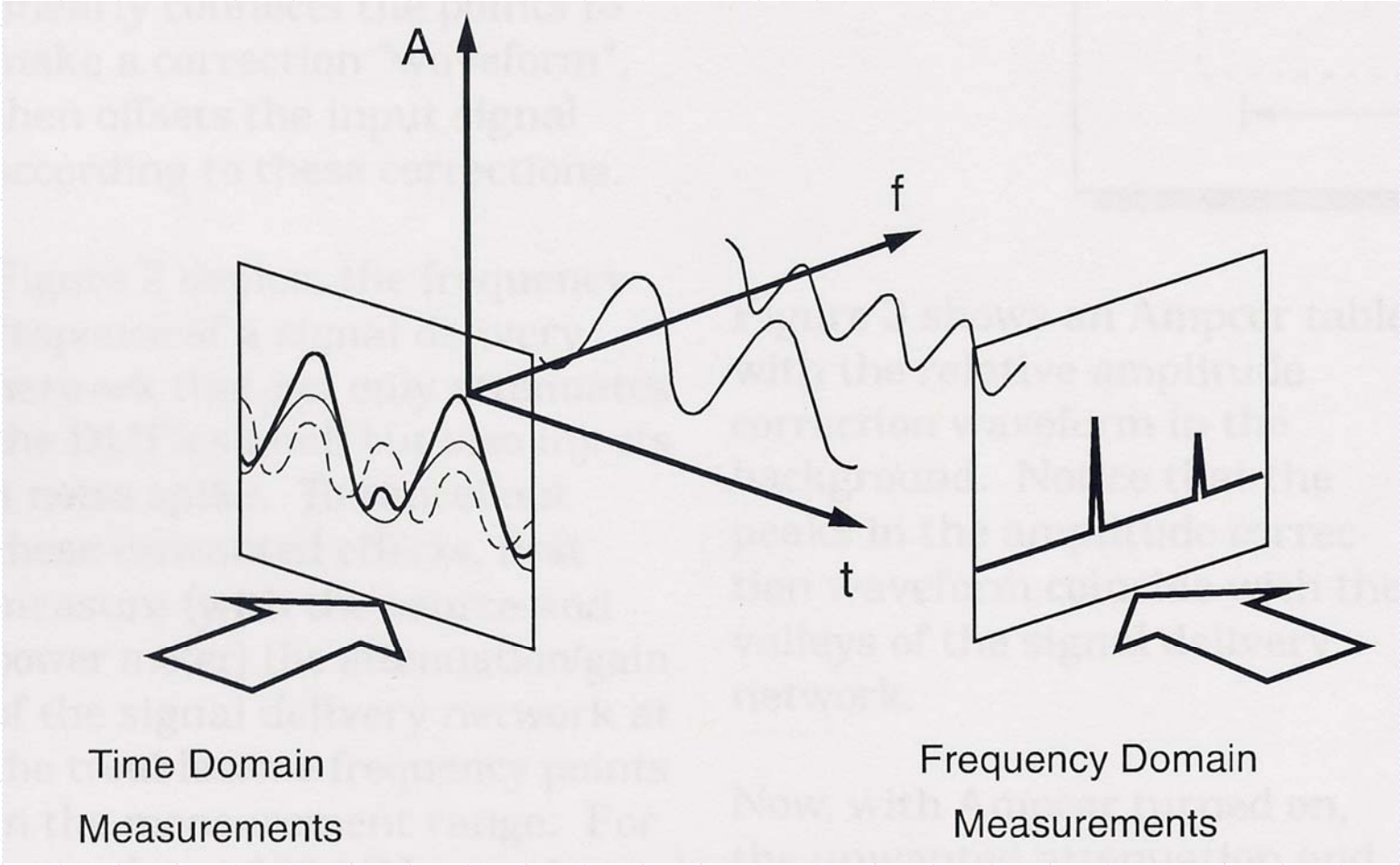
Trend in Complexity



Modulation Schemes



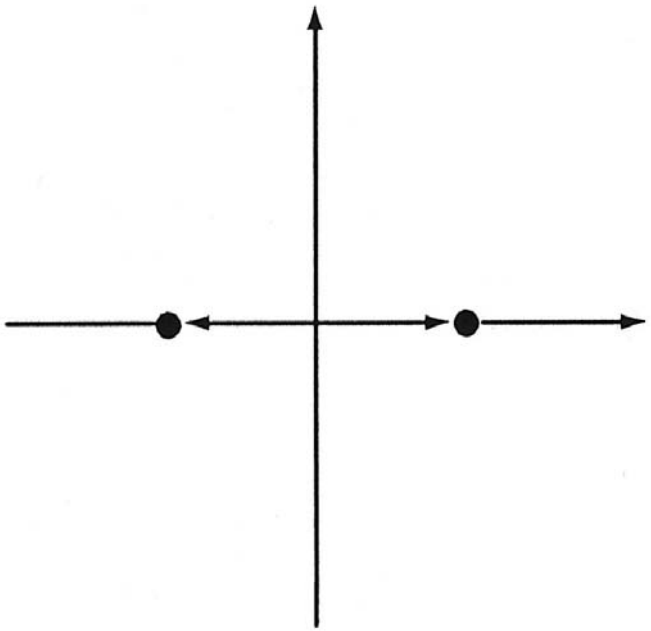
Time and Frequency Domains



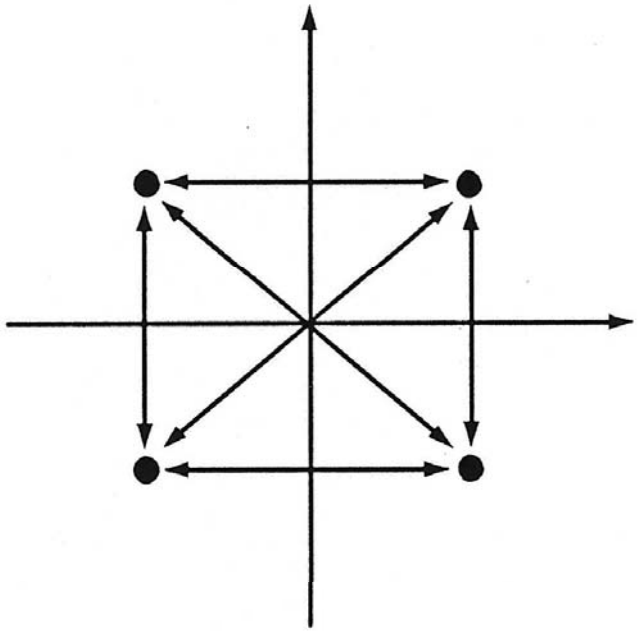
A Few Modulation Schemes

Modulation format	Application
MSK, GMSK	GSM, CDPD
BPSK	Deep space telemetry, cable modems
QPSK, $\pi/4$ DQPSK	Satellite, CDMA, NADC, TETRA, PHS, PDC, LMDS, DVB-S, cable (return path), cable modems, TFTS
OQPSK	CDMA, satellite
FSK, GFSK	DECT, paging, RAM mobile data, AMPS, CT2, ERMES, land mobile, public safety
8, 16 VSB	North American digital TV (ATV), broadcast, cable
8PSK	Satellite, aircraft, telemetry pilots for monitoring broadband video systems
16 QAM	Microwave digital radio, modems, DVB-C, DVB-T
32 QAM	Terrestrial microwave, DVB-T
64 QAM	DVB-C, modems, broadband set top boxes, MMDS
256 QAM	Modems, DVB-C (Europe), Digital Video (US)

Constellation Diagrams

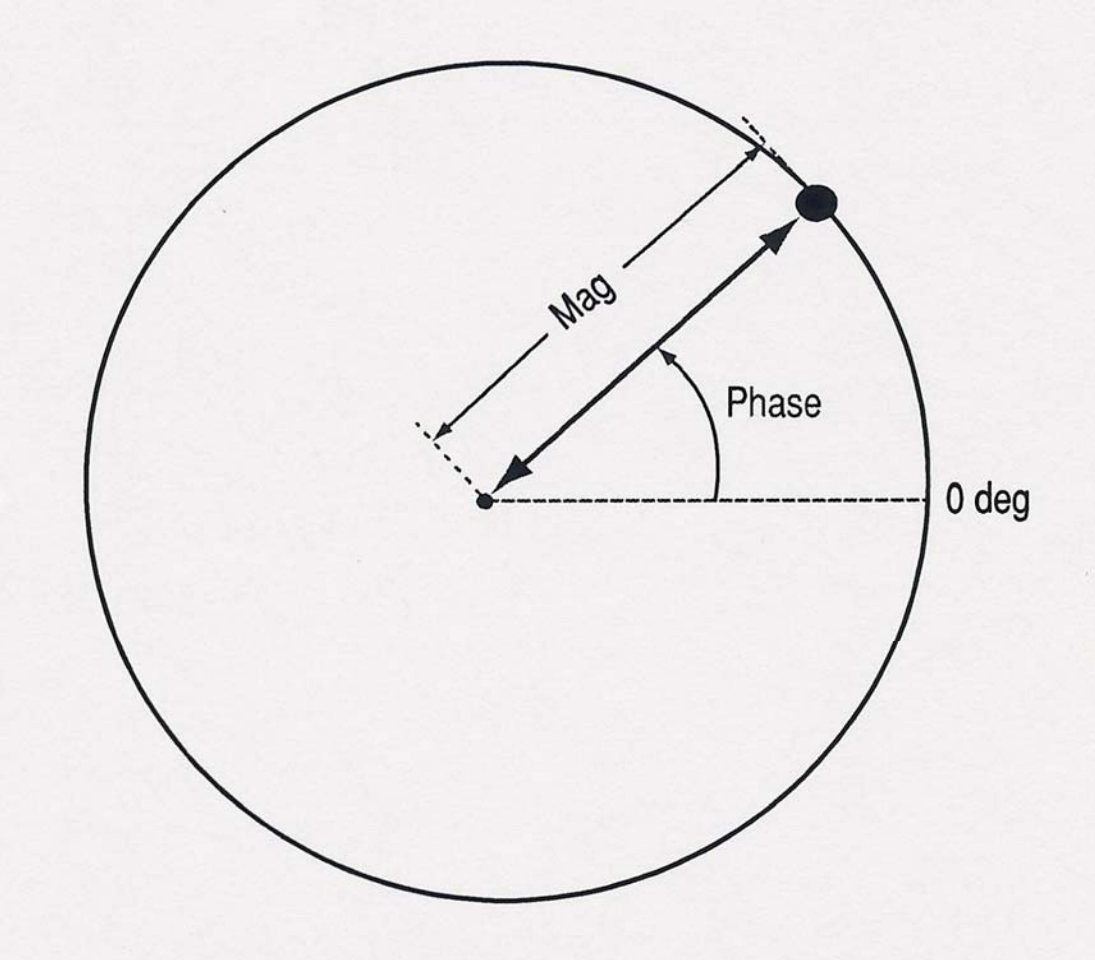


BPSK
One Bit Per Symbol

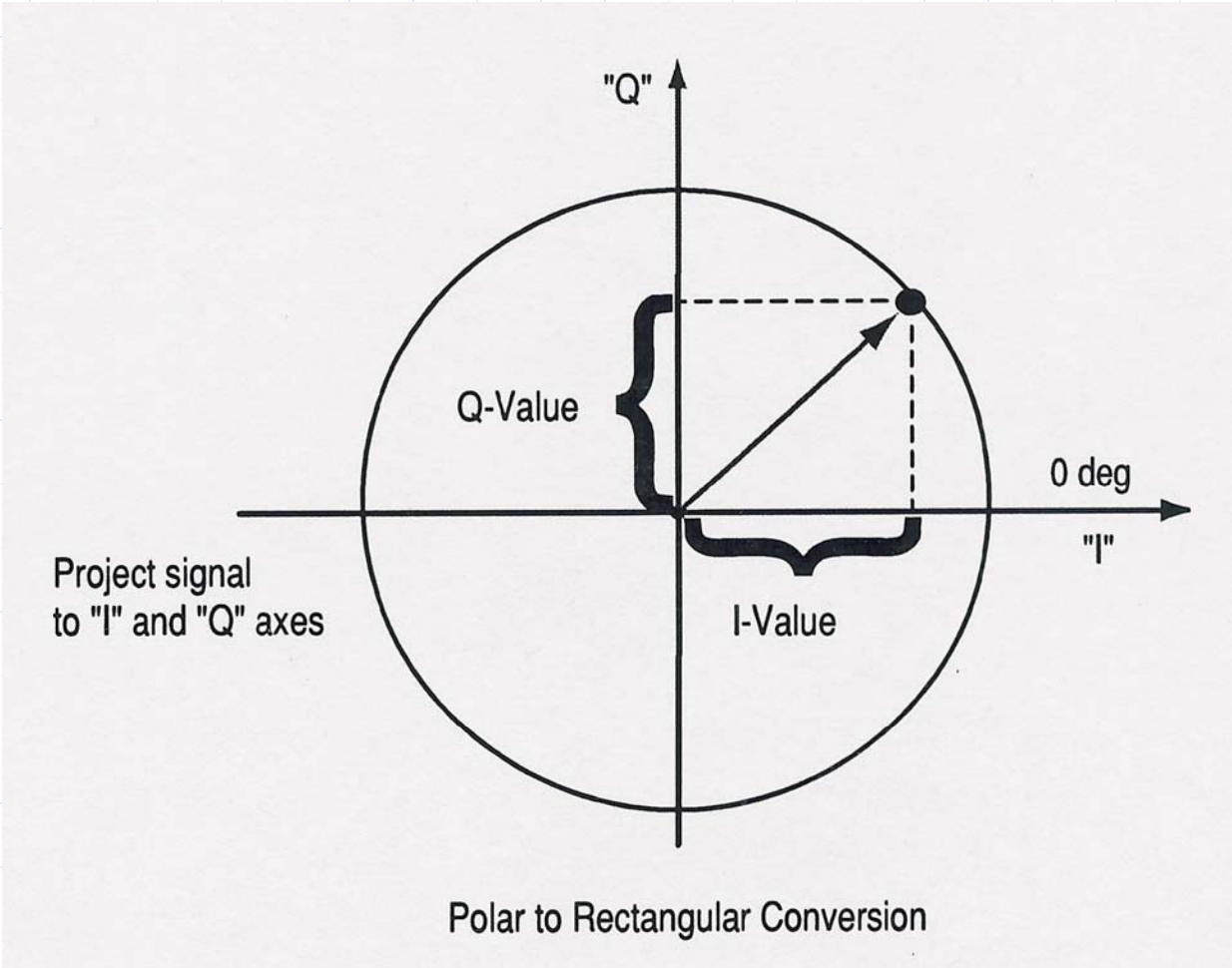


QPSK
Two Bits Per Symbol

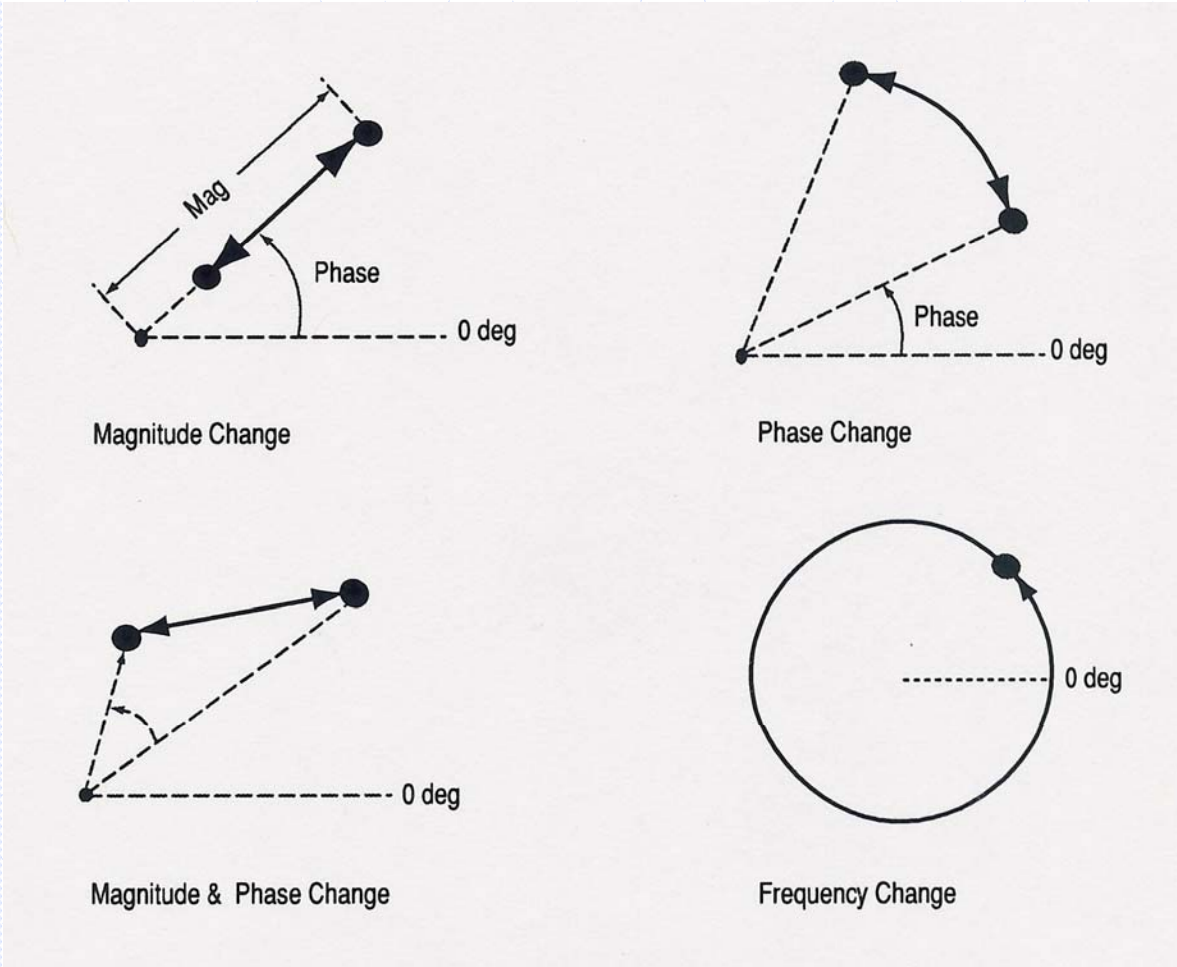
Polar or Rectangular?



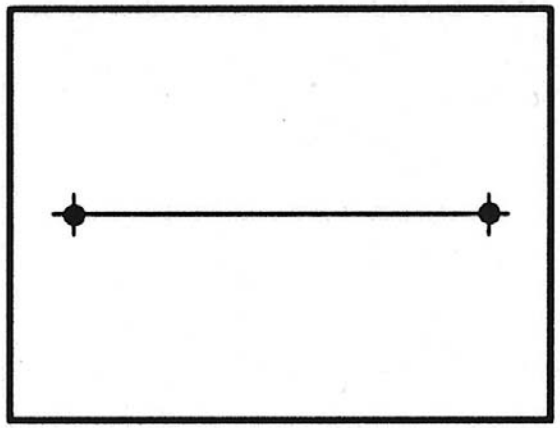
Conversion


"Q"
Q-Value
0 deg
"I"
Project signal
to "I" and "Q" axes
I-Value
Polar to Rectangular Conversion

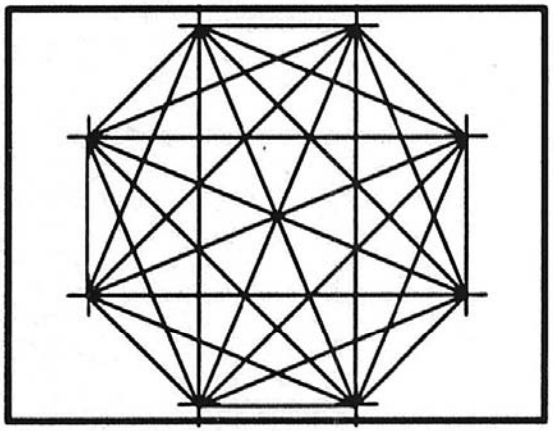
The Effect of Modulation



BPSK and 8-PSK

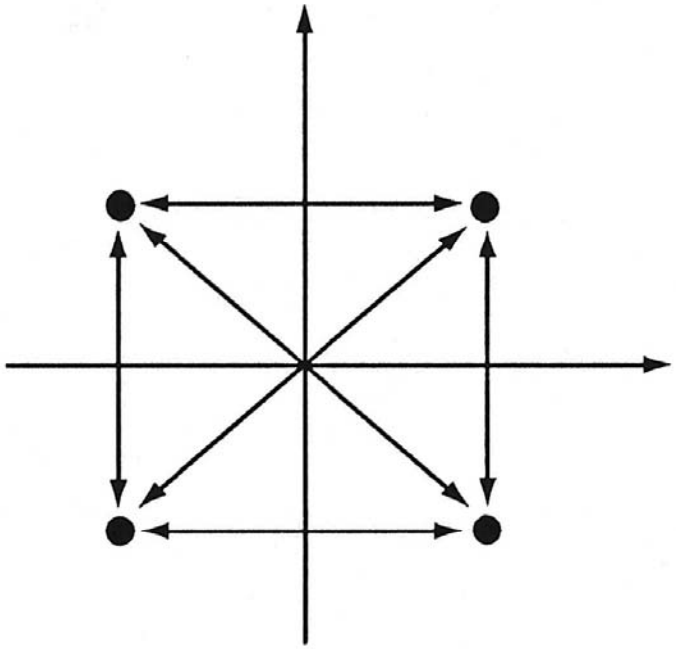


BPSK
One Bit Per Symbol
Symbol Rate = Bit Rate

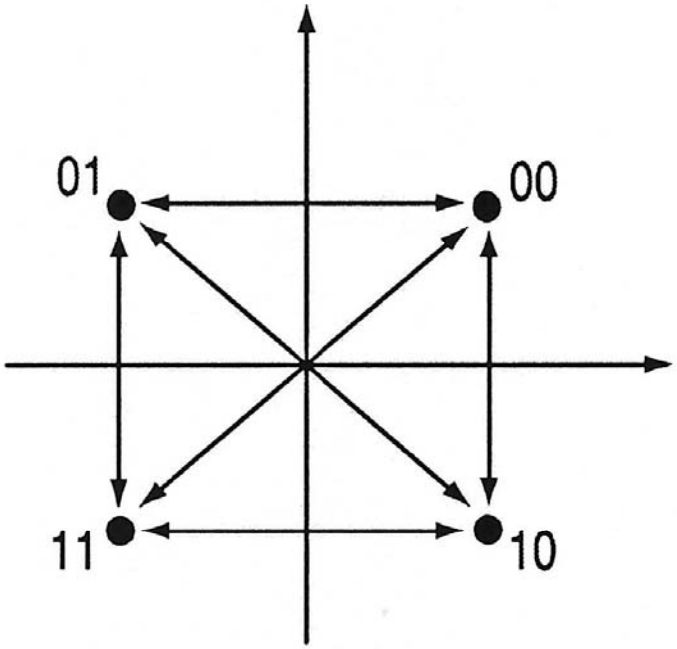


8PSK
Three Bits Per Symbol
Symbol Rate = 1/3 Bit Rate

Increasing Spectral Efficiency

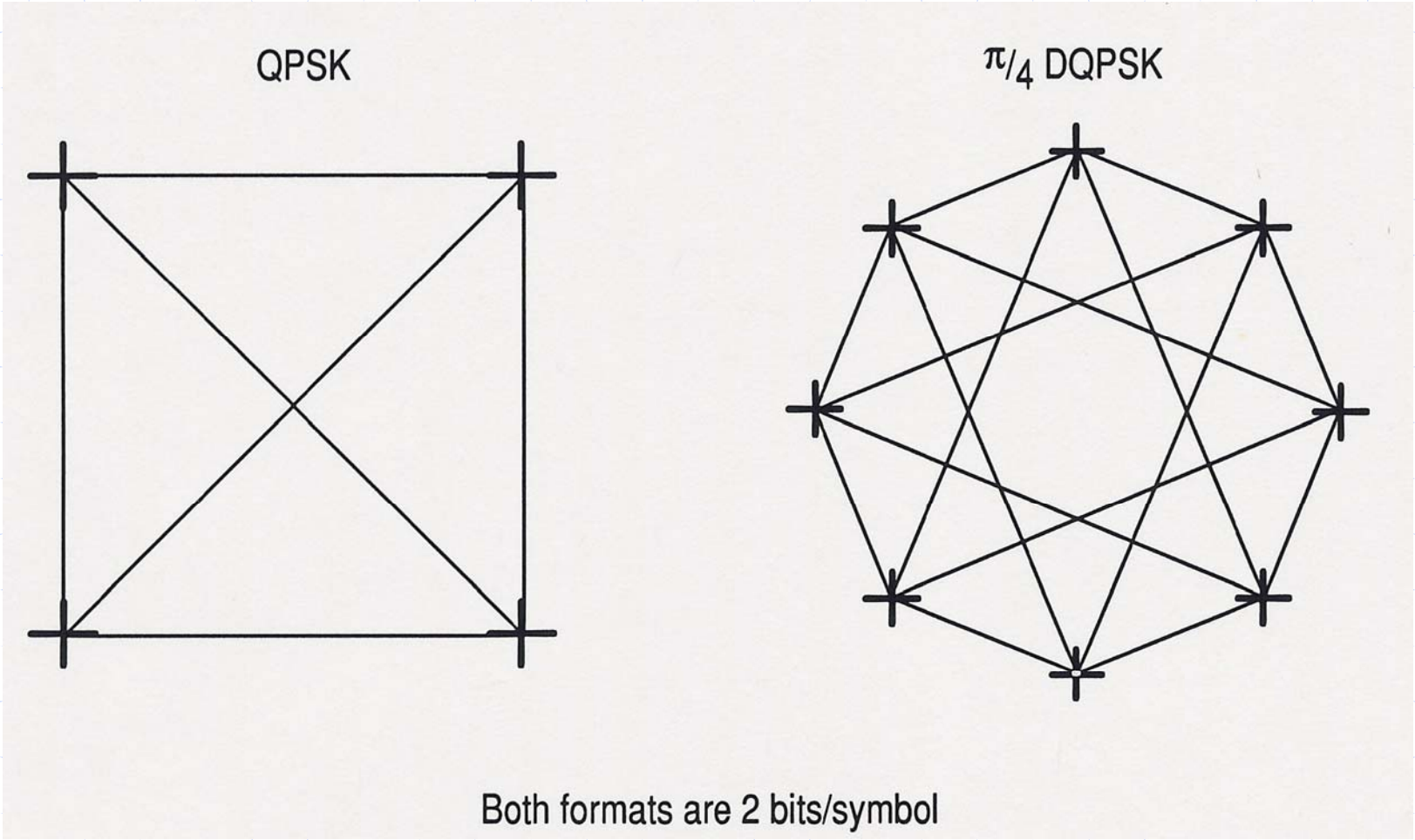


QPSK
Two Bits Per Symbol



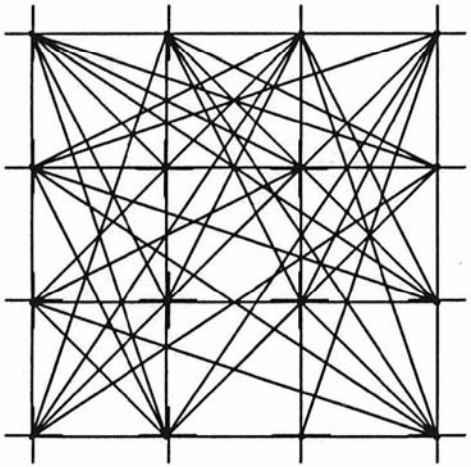
QPSK
State Diagram

Constellations Aren't Unique



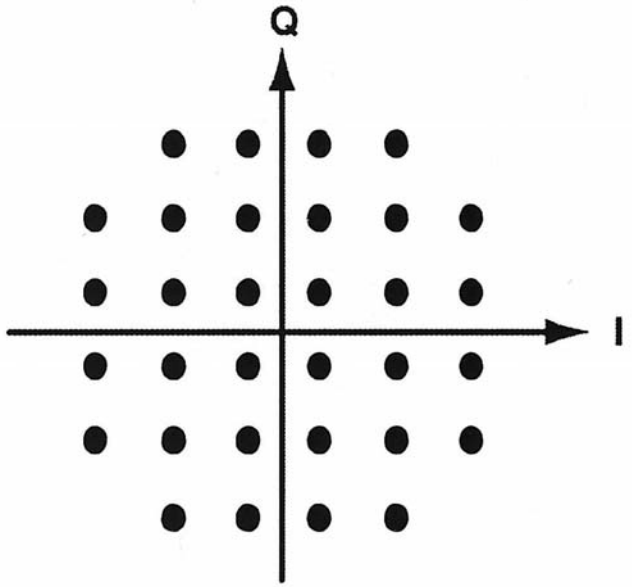
Some Higher Order Modulation Schemes

Vector Diagram



16QAM
Four Bits Per Symbol
Symbol Rate = 1/4 Bit Rate

Constellation Diagram

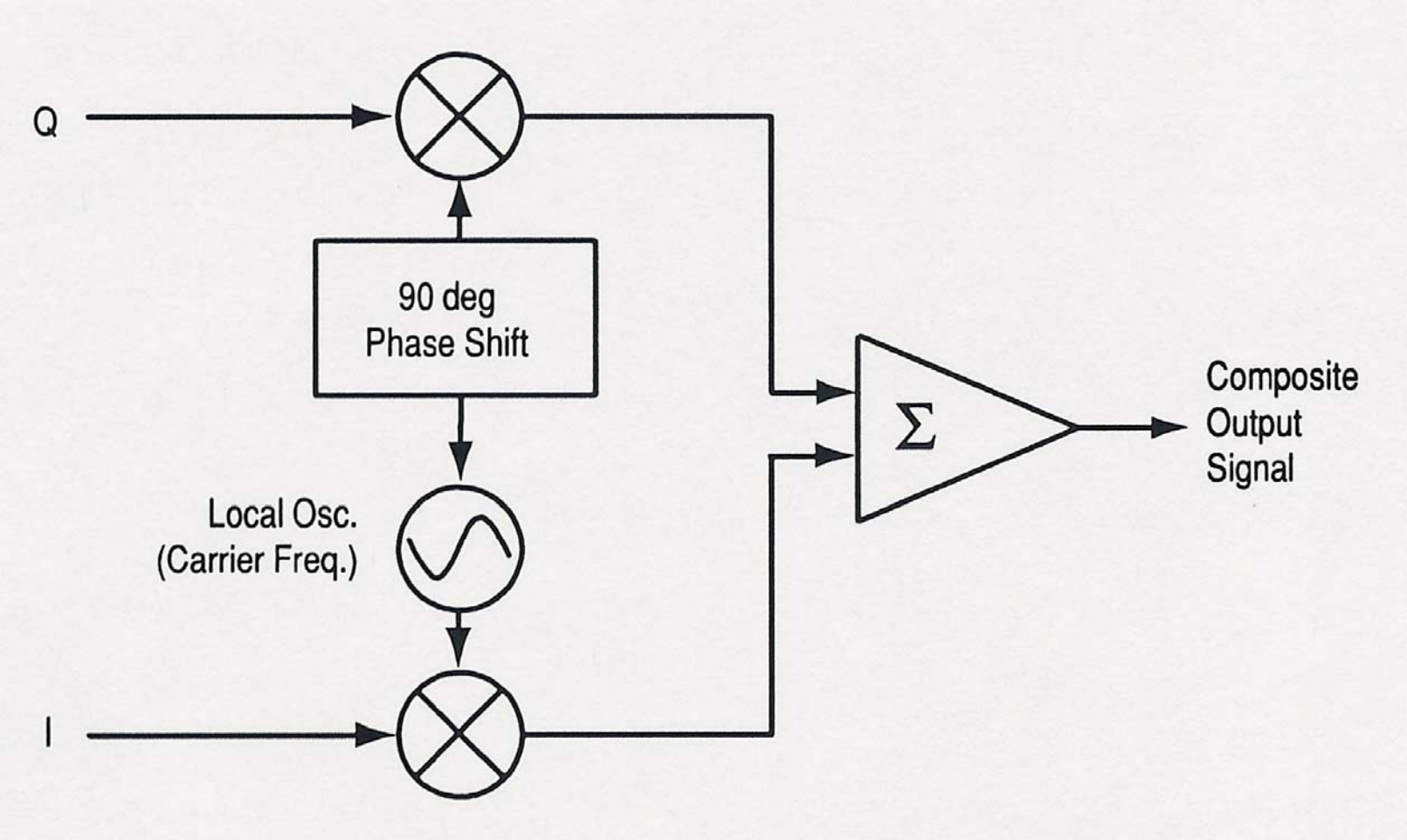


32QAM
Five Bits Per Symbol
Symbol Rate = 1/5 Bit Rate

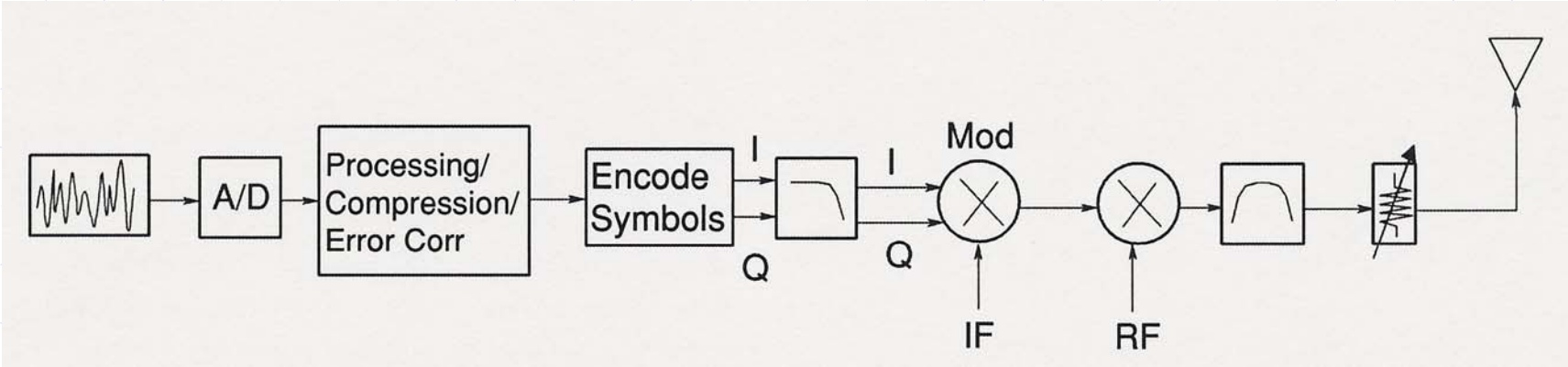
Spectral Efficiency Results

Modulation format	Theoretical bandwidth efficiency limits
MSK	1 bit/second/Hz
BPSK	1 bit/second/Hz
QPSK	2 bits/second/Hz
8PSK	3 bits/second/Hz
16 QAM	4 bits/second/Hz
32 QAM	5 bits/second/Hz
64 QAM	6 bits/second/Hz
256 QAM	8 bits/second/Hz

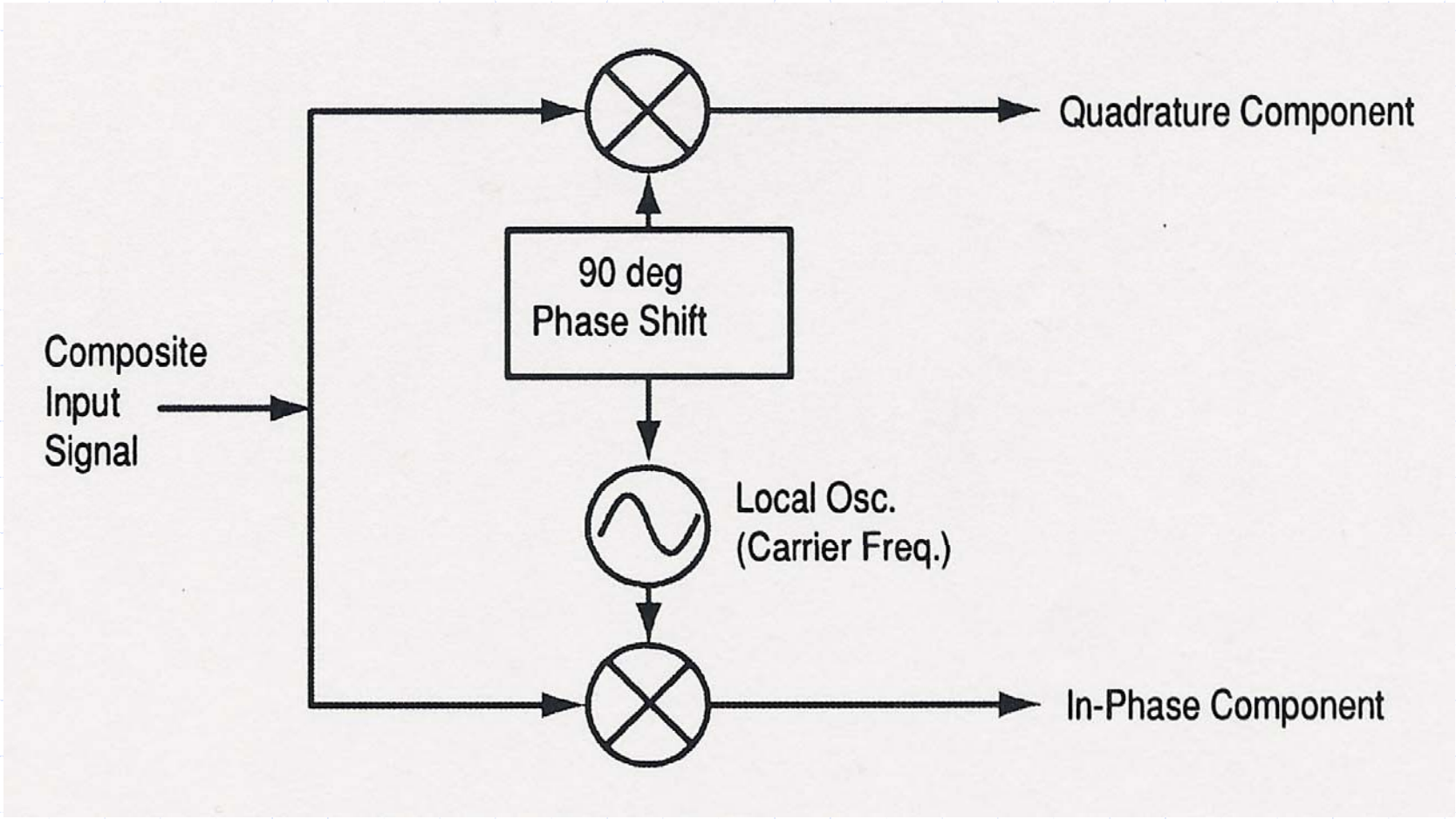
Basic Transmitter



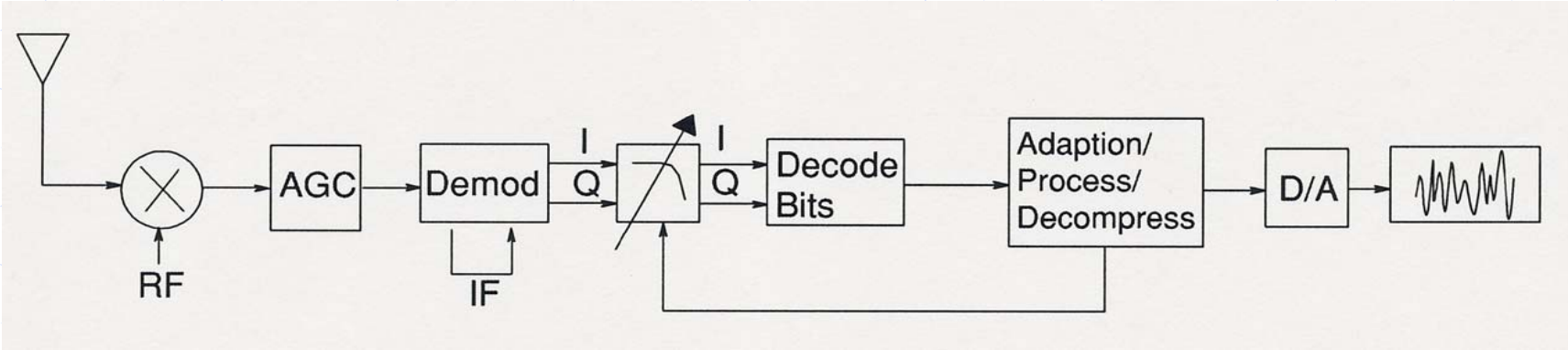
Detailed Transmitter



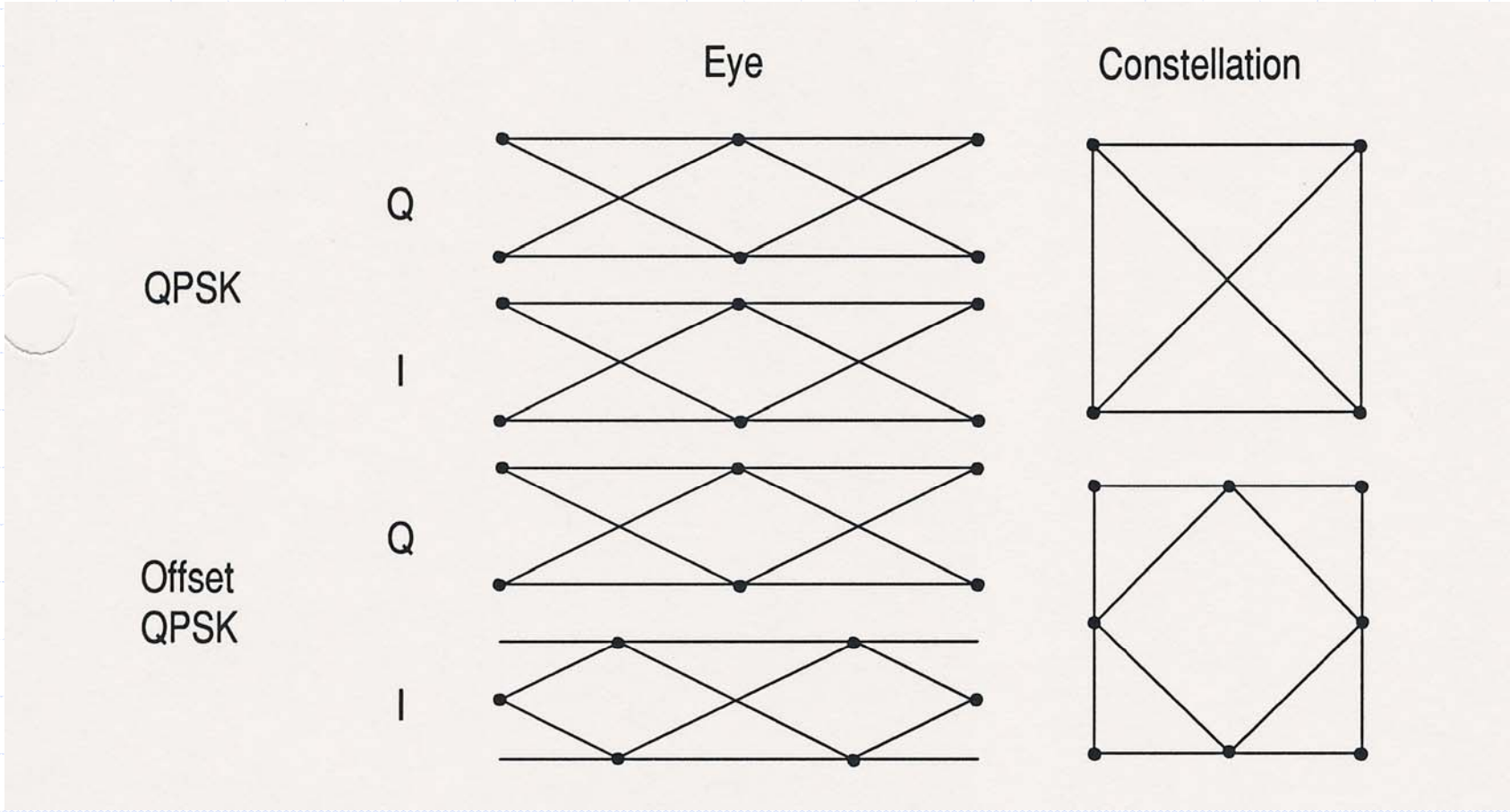
Basic Receiver



Detailed Receiver



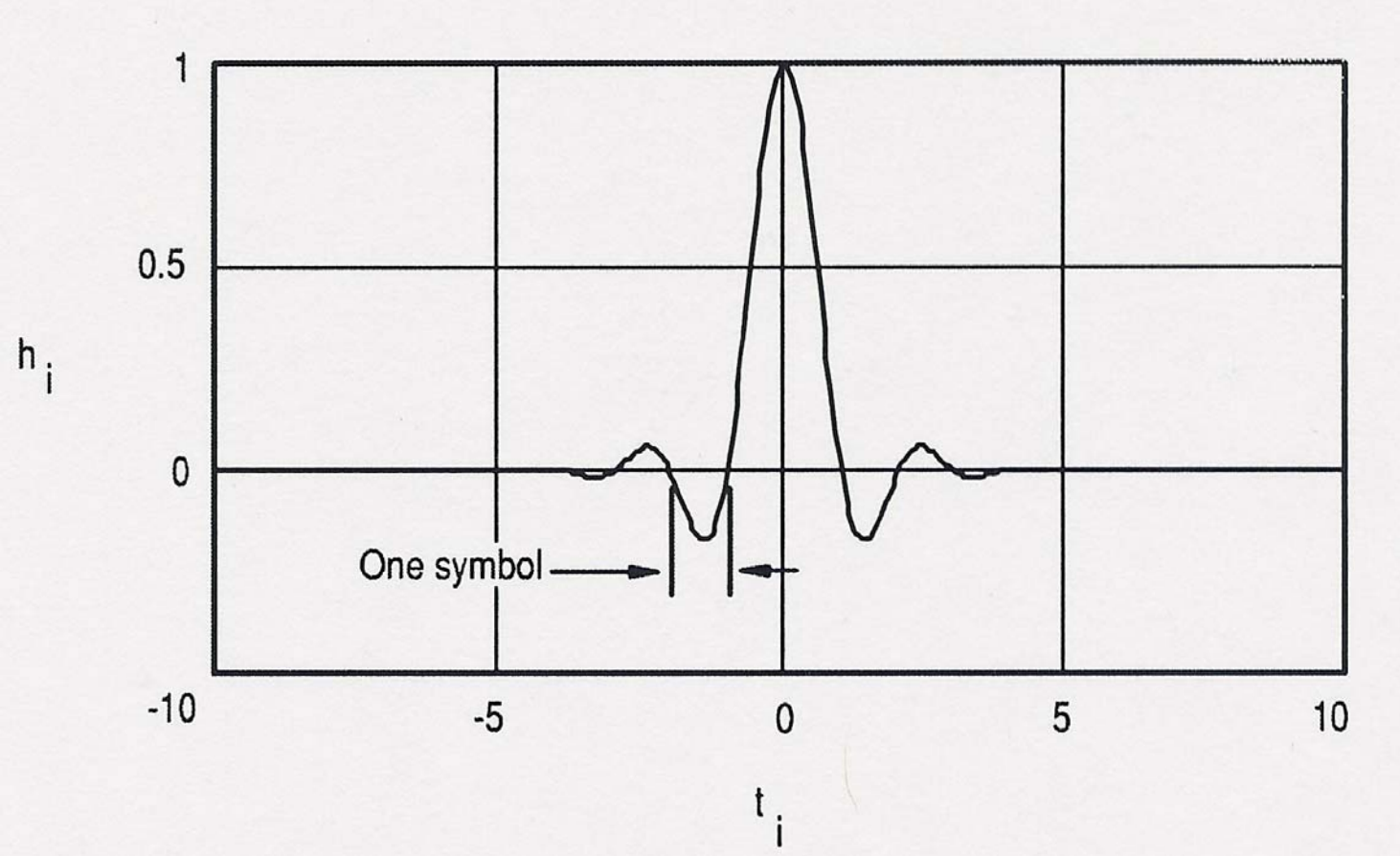
Eye-Pattern and the Constellation Diagram



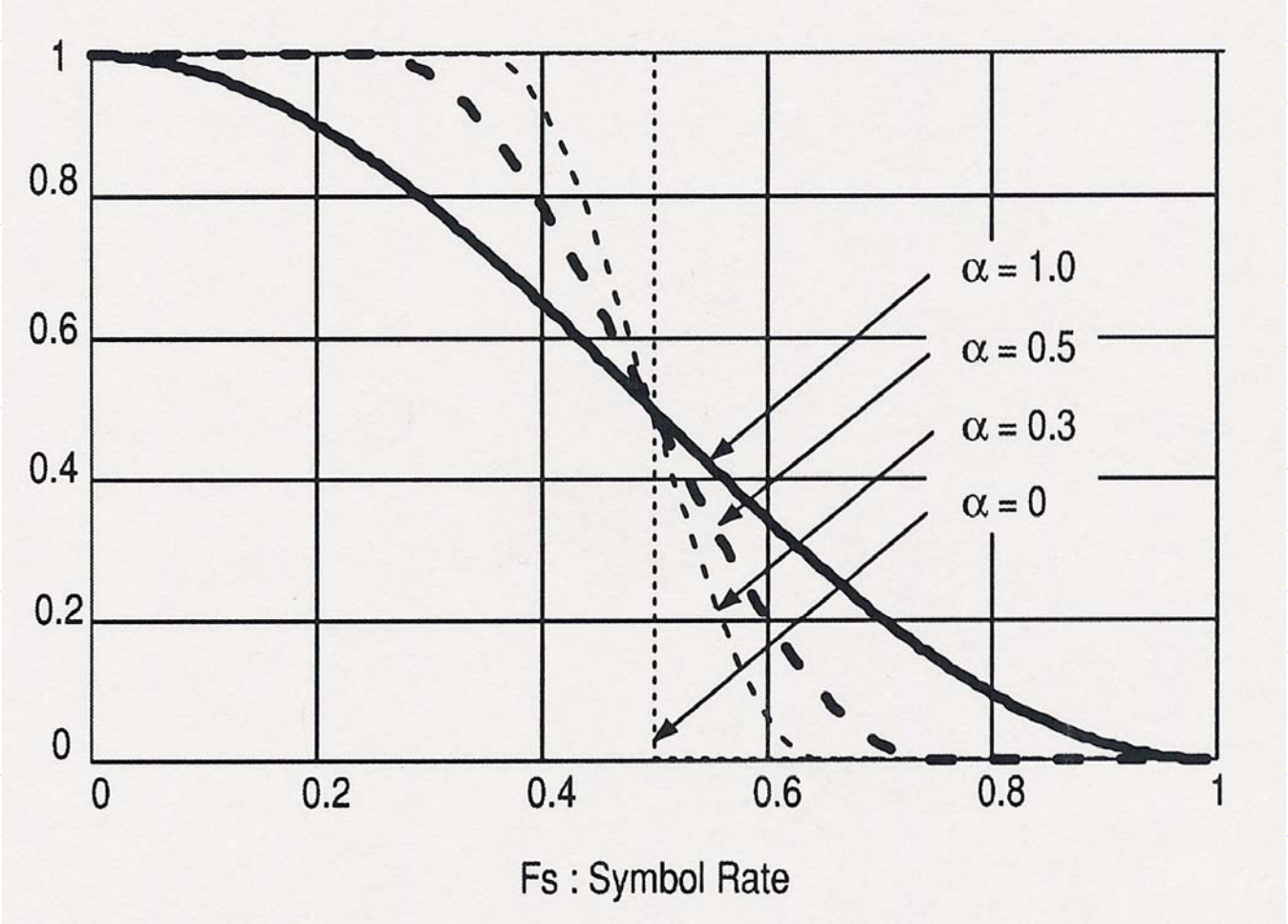
Demonstration 1

- Rectangular Pulsed 16-QAM
  - Oscilloscope
  - Trajectory diagram
  - Eye-pattern
    - Coupled markers
  - Spectrum

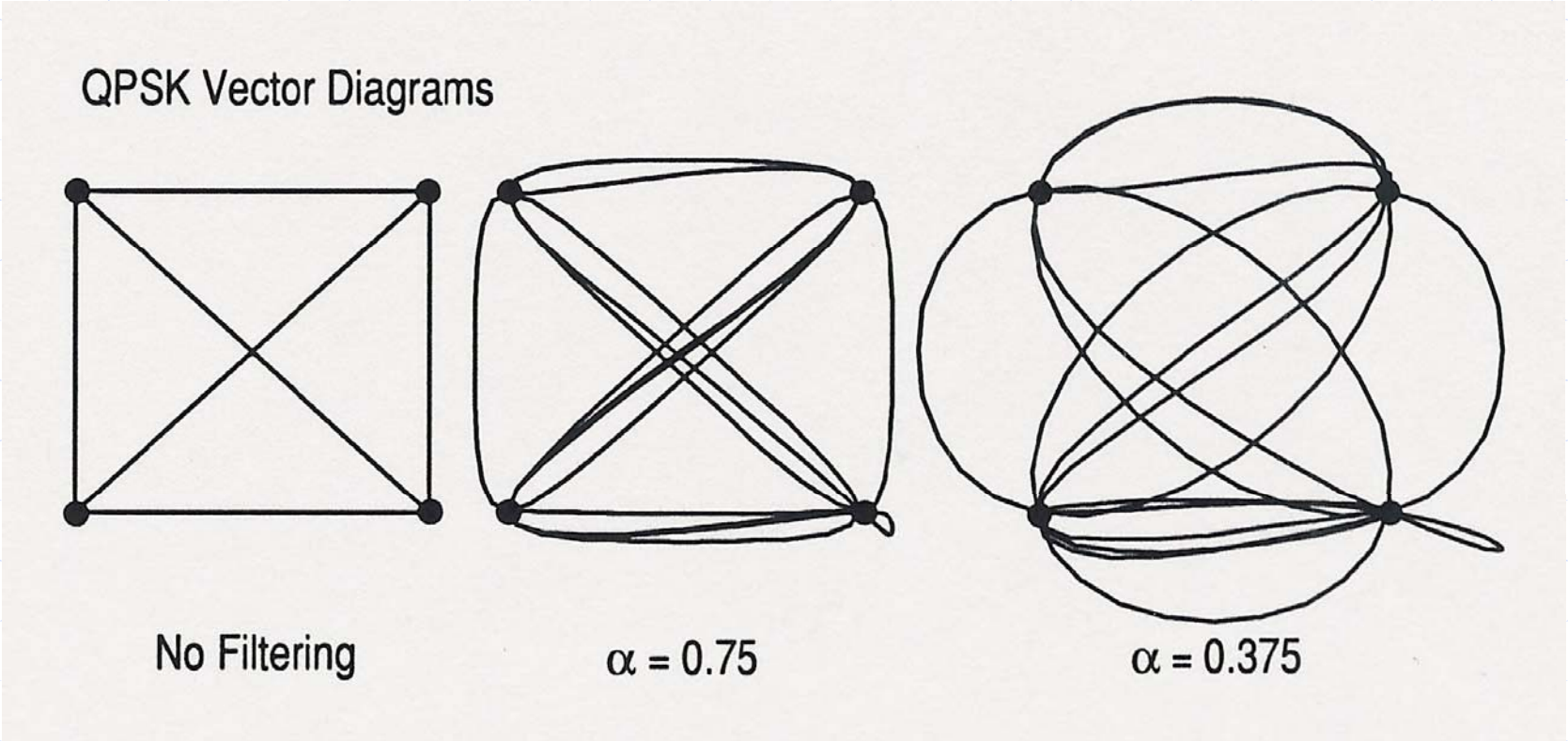
Pulse Shaping



Spectral Containment

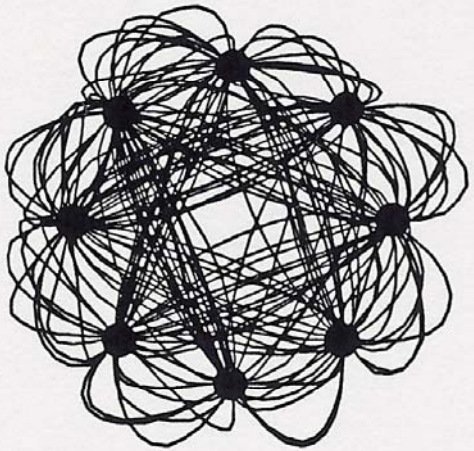


Effects of Pulse Shaping



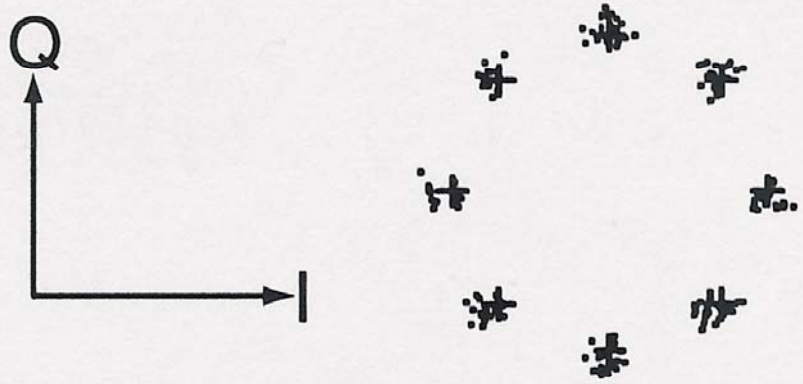
Symbol Sampling

Polar Diagram



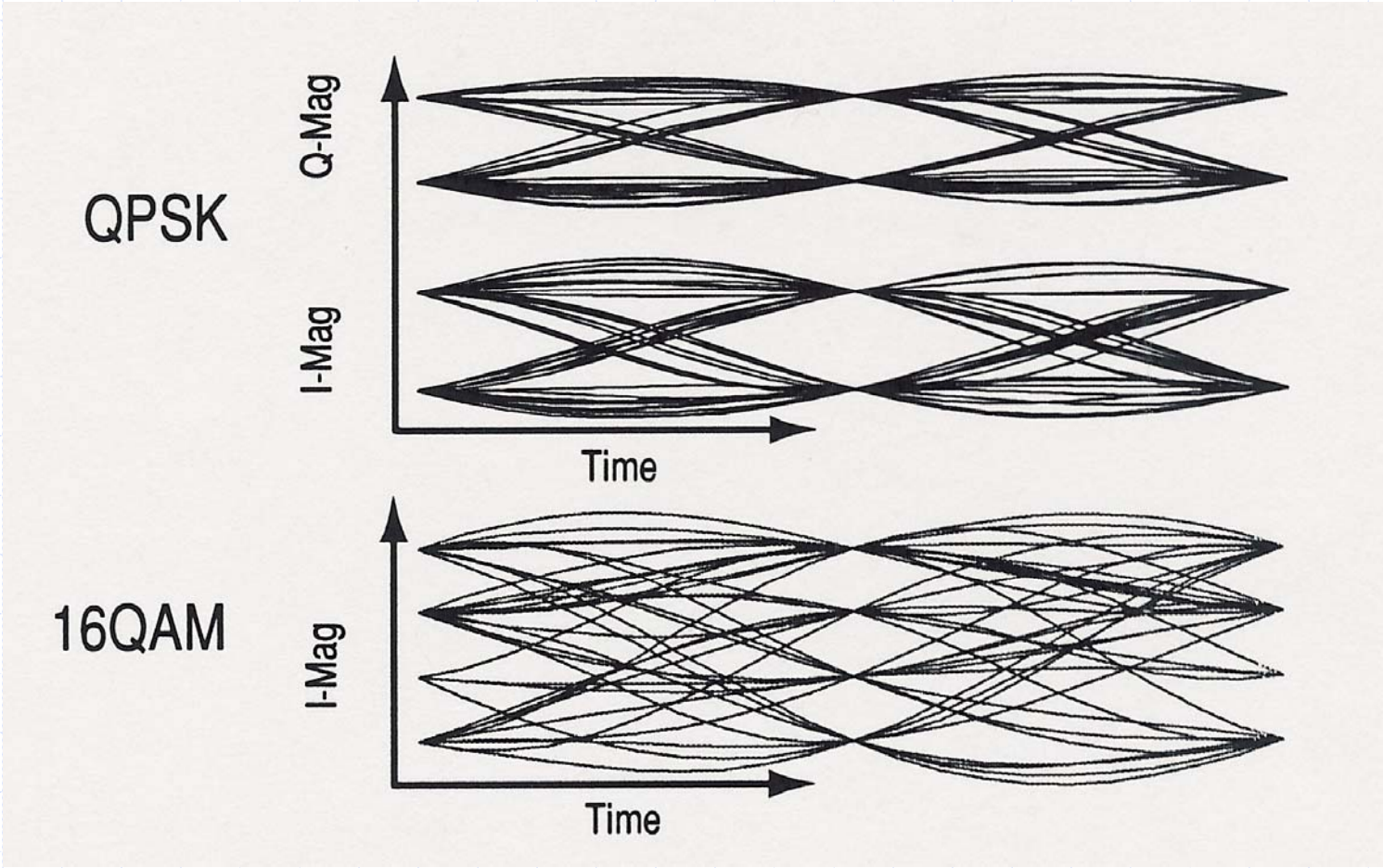
DQPSK, 157 Symbols
and "Trajectory"

Constellation Diagram



DQPSK, 157 Symbol
Constellation with Noise

Pulse Shaped Eye-Patterns



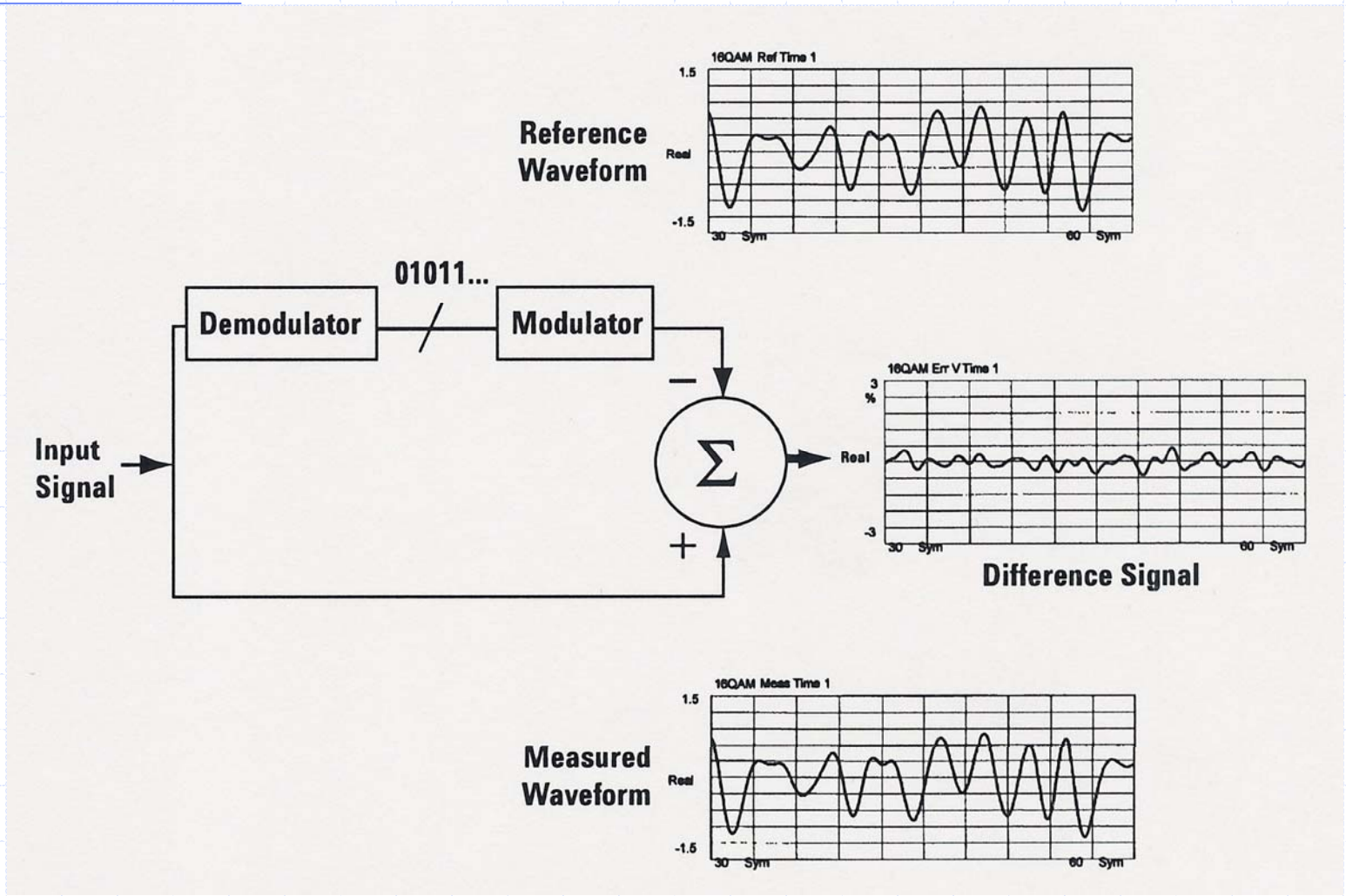
Demonstration 2

- Pulse shaped 16-QAM
  - Effect of changing the roll-off factor
    - Oscilloscope
    - Trajectory diagram
    - Eye-pattern
      - Coupled markers
    - Spectrum

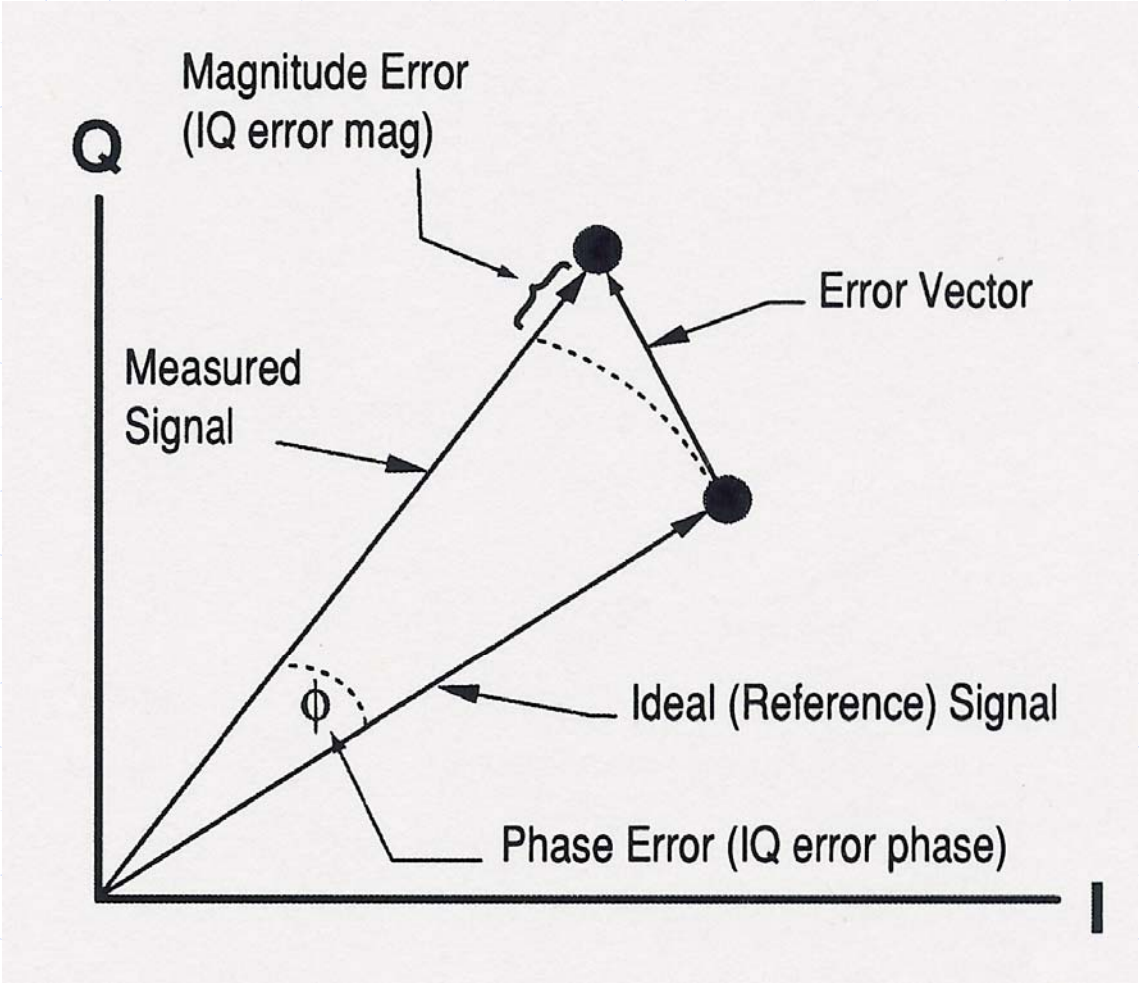
Let's Enter the 90's

- Eye patterns, constellation diagrams, and trajectory diagrams have been around for a ***long*** time
- Error vector magnitude (EVM) is a relatively new measurement that provides additional insight into channel and transmitter impairments
- EVM measurements require new, or at least different, hardware/software

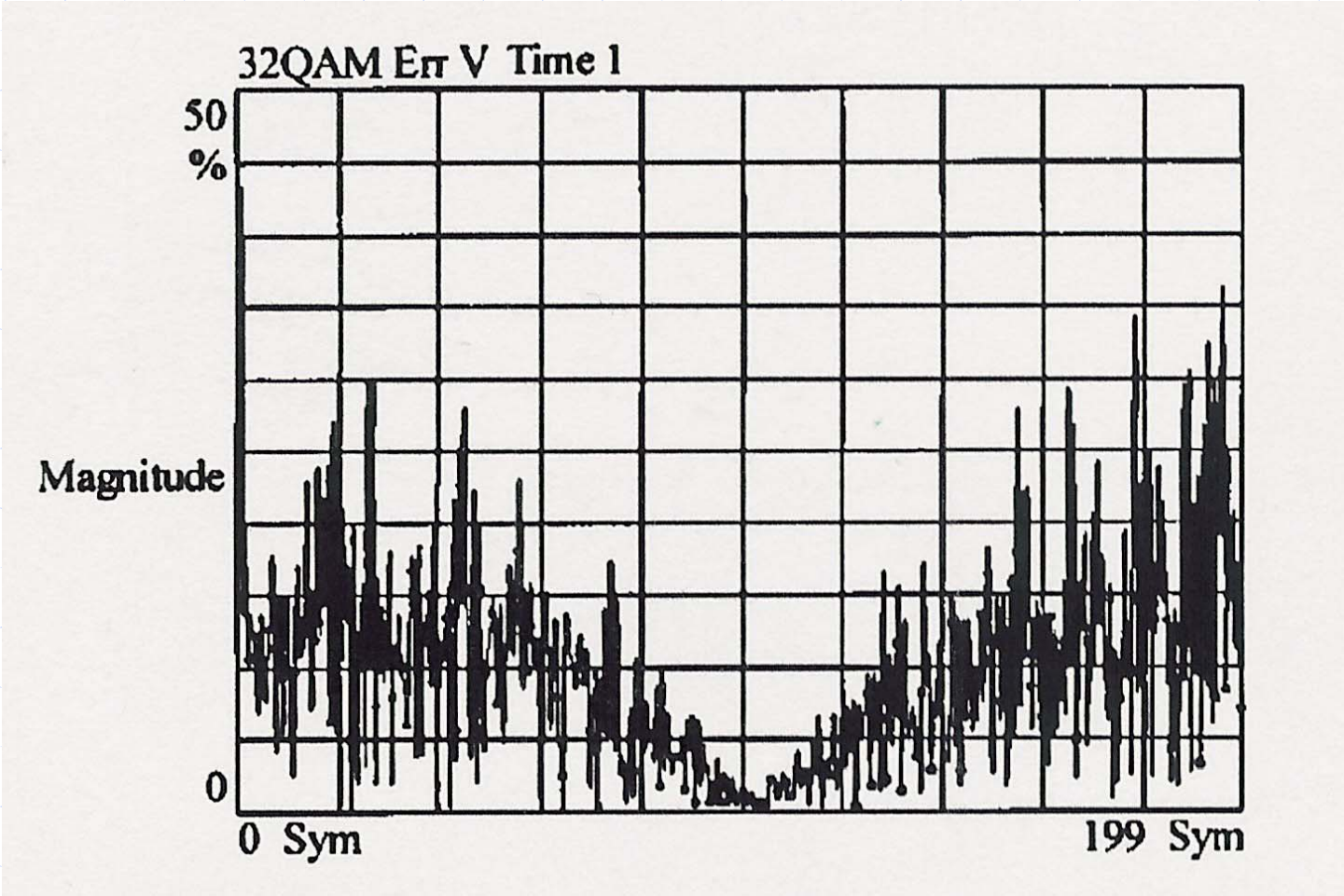
Error Vector Magnitude (EVM)



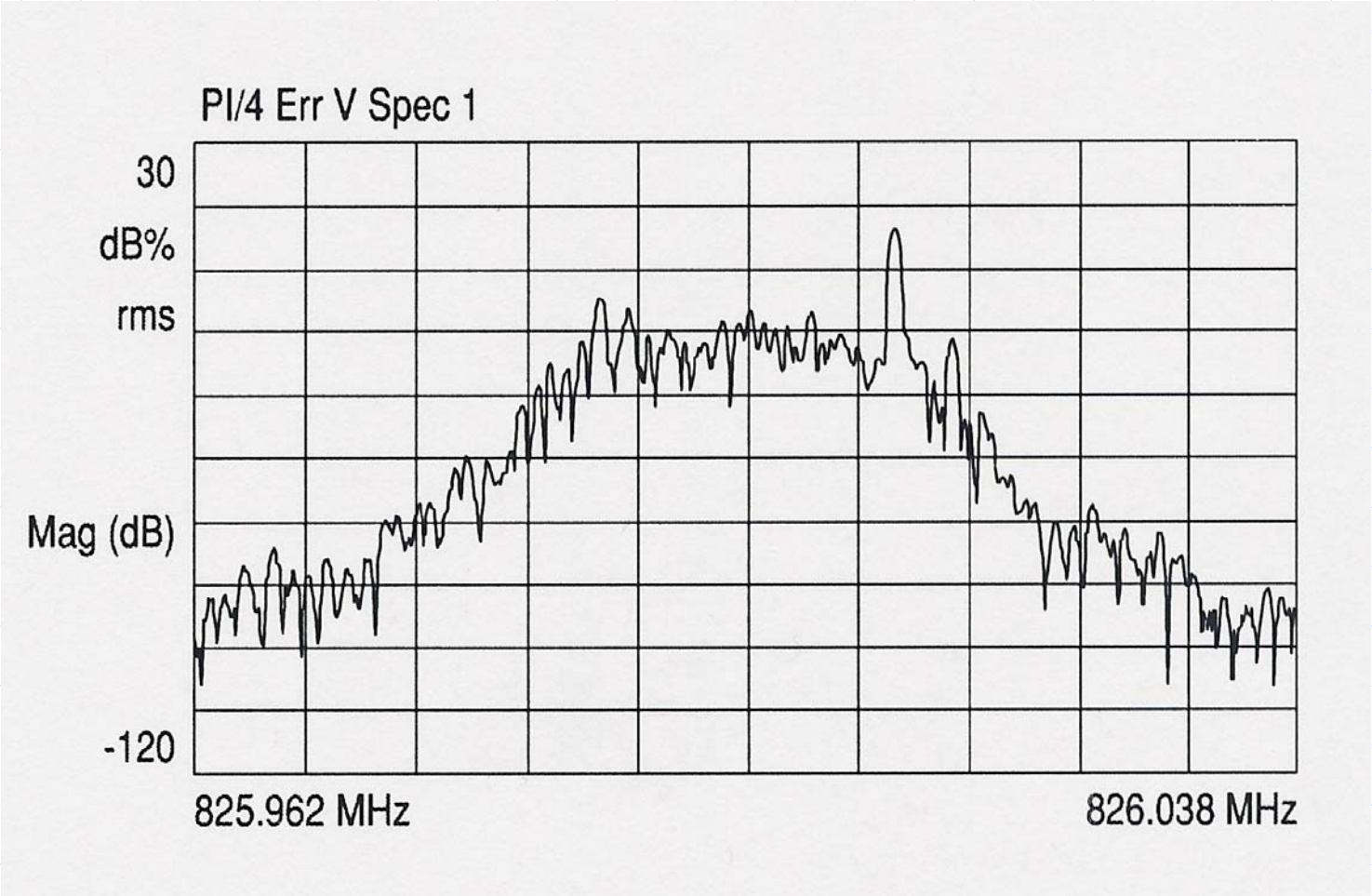
Interpretation of EVM



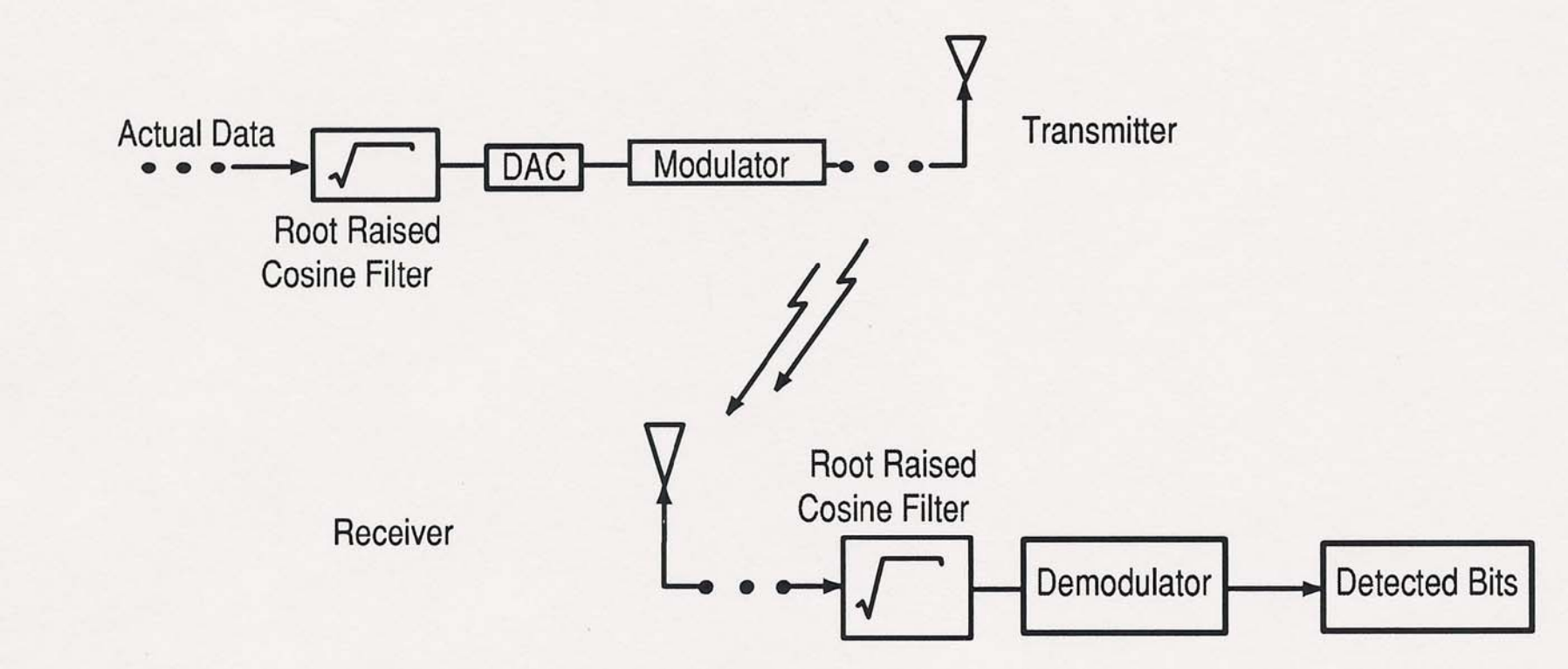
EVM w/ Symbol Rate Error



EVM Spectrum with an In-band Interferer



The Root Raise-Cosine System



Demonstration 3 (16-QAM)

- winDSK6 ... with the CommDSK feature
  - Noise
  - Quad skew
  - Gain imbalance
  - In-band interference
  - Frequency error
  - Symbol rate error