

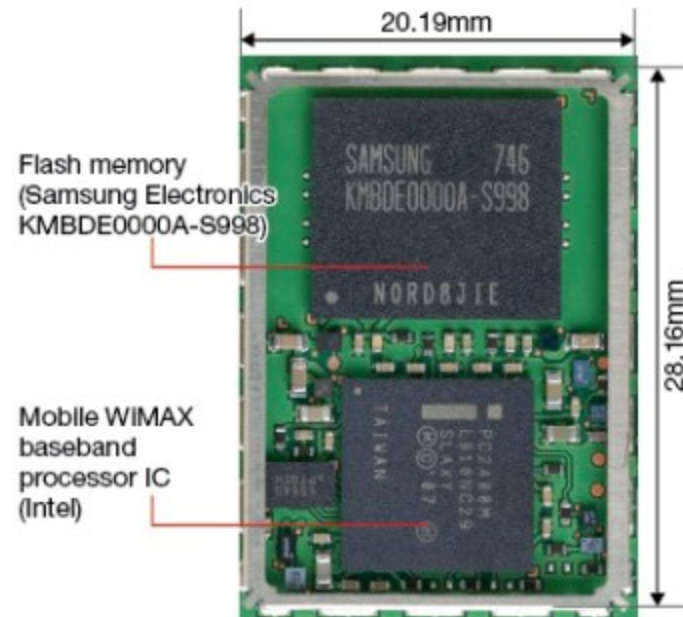
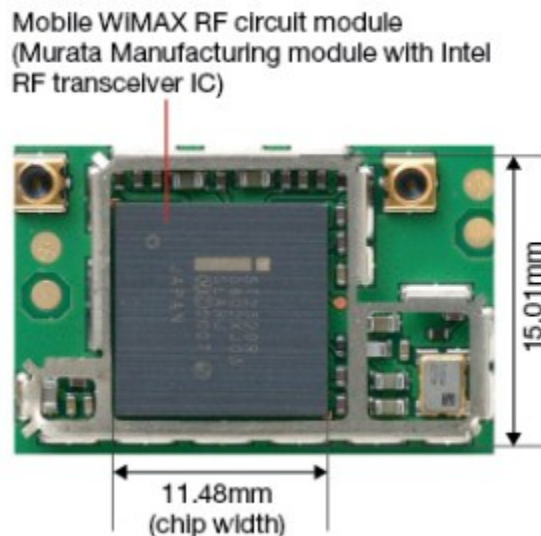
Use of Digital Signal Processing in Real Wireless Transmitter Systems

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Goals

- Demonstrate an application of digital signal processing to a practical problem with significant economic impact
- Discuss tradeoffs choices when implementing a design. Tradeoffs involve: DSP, circuit design, & communications



Motivation

- Learn yet another application of DSP
- Gain hands on simulation experience in working around impairments introduced by real amplifiers and efficiency concerns

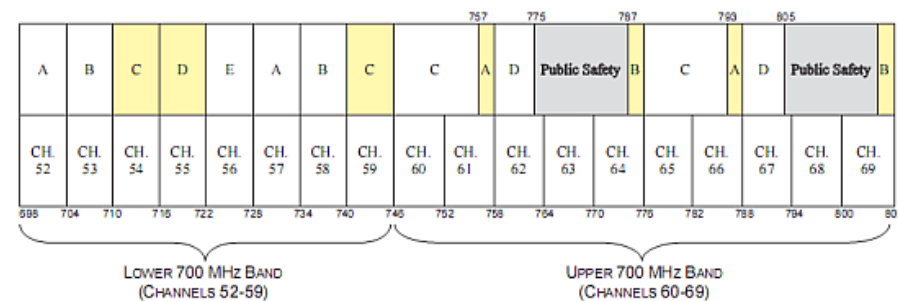


Limited Bandwidth

- Cellular providers must purchase spectrum in which to offer service
- Spectrum is very expensive.
 - Providers want highest data rate in available BW
- Means using advanced modulation schemes
 - Amplitude & Phase Modulation

- United States Wireless Auction 2008

United States 2008 wireless spectrum auction



One Auction, 110MHz, One Country.
\$20 billion

The licenses for Band C over the continental United States alone (22MHz) were bought by Verizon Wireless for \$4.7 billion

“Green Wireless”

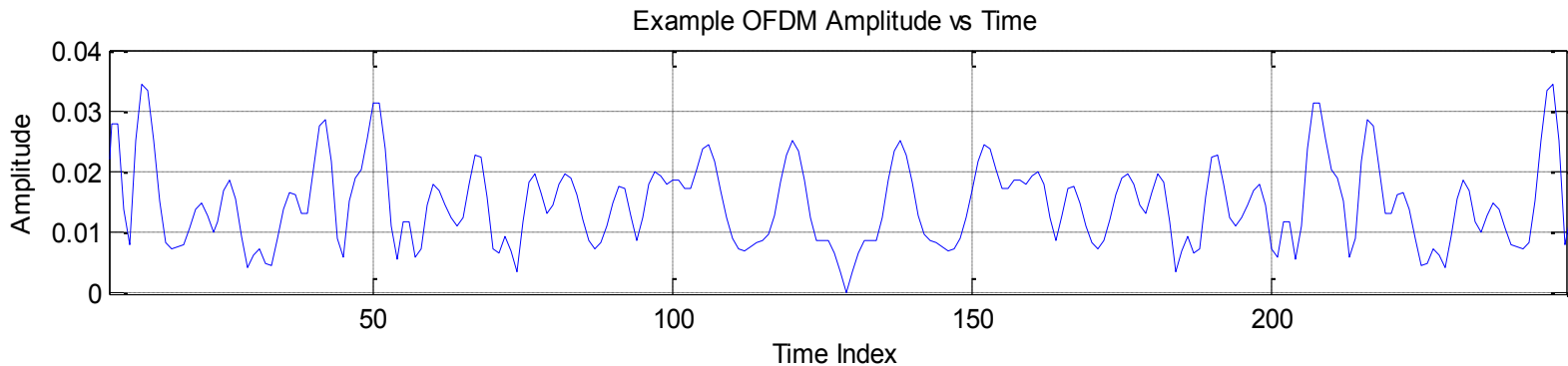
Limited Power Consumption

- Base Stations
 - Base Stations Consume Electricity
 - High Power Consumption means designing a fancy cooling system for base station electronics plus higher operating costs
- Handsets
 - Long battery life increases device usefulness
 - High-output power amplifiers are larger, generally more expensive than low power ones



Amplitude Modulation

- Most modern modulation schemes modulate both amplitude and phase to achieve a maximum data rate in a given bandwidth
- To avoid distortion:
 - Amplifier should have constant gain across all amplitudes to be transmitted.



On to amplifiers...

- Fundamentally, the amplifier in your car is similar to the amplifier in your cell phone's transmitter.
- Where does your car do the most efficient job of converting the DC power it draws from the battery into sound power?

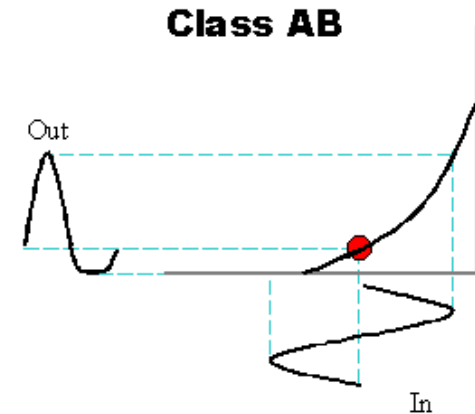


Sound quality?

- **High efficiency operation occurs near the amplifier the peak output amplitudes.**
- What happens to the sound quality when you have the volume cranked up to be in the “highly-efficient” region?
- Can we correct for it using digital signal processing?

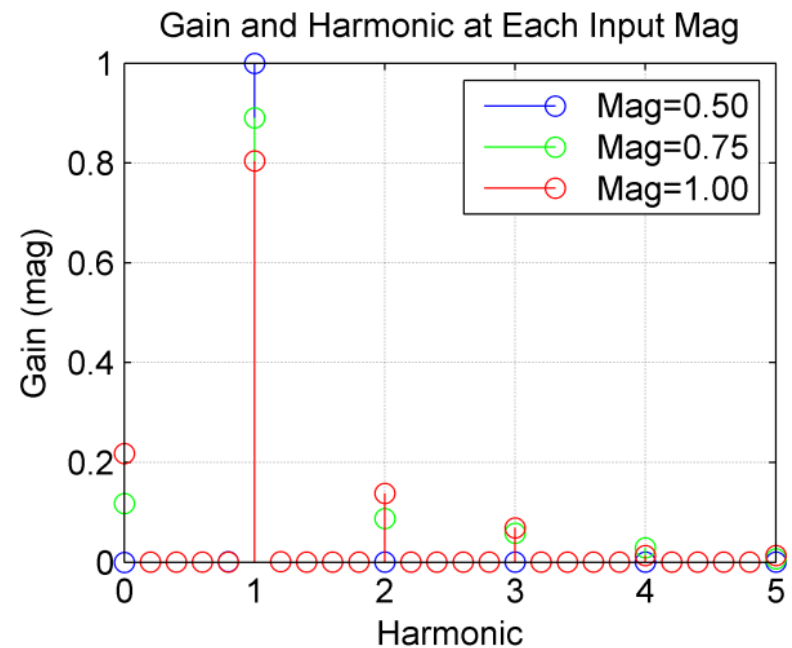
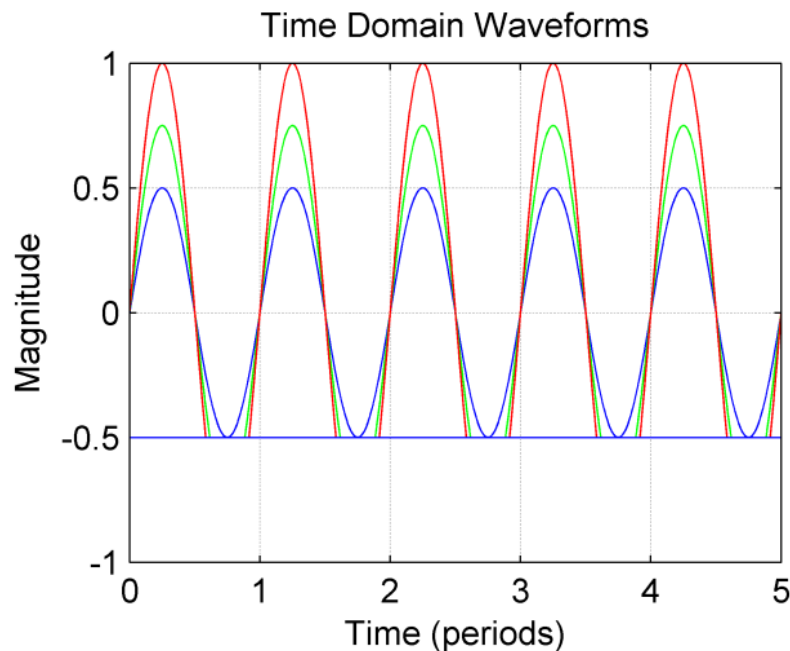
Power Amplifiers Classes

- Differ in the fraction of the time the waveform is “clipped”
- Power Amplifier Class A
 - Amplifies sinusoid during full cycle
 - Good linearity, low distortion without clipping
 - Inefficient due to large bias current to keep transistors “linear”
- Power Amplifier Class AB
 - Conducts between half and full of sinusoid period
 - Linearity Degradation, Produces Harmonics
 - Gains Efficiency by reducing required bias current
- Power Amplifier Class D
 - Square Wave Output. Switched very quickly.
 - Use an Low-Pass Filter to “Average” the value to what you want
- **Design Tradeoff: Linearity vs. Efficiency**
- Other topologies exist, but the tradeoff remains

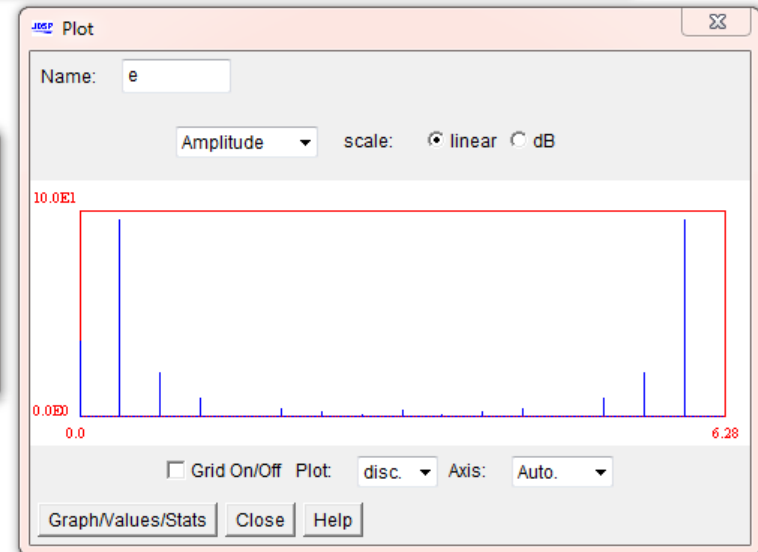
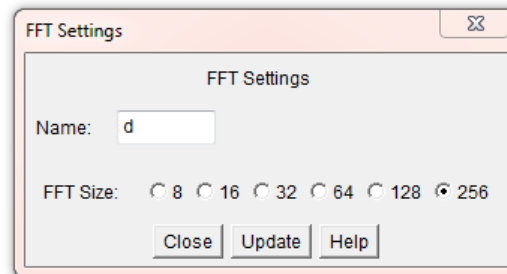
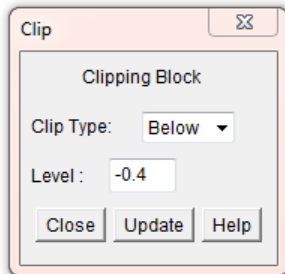
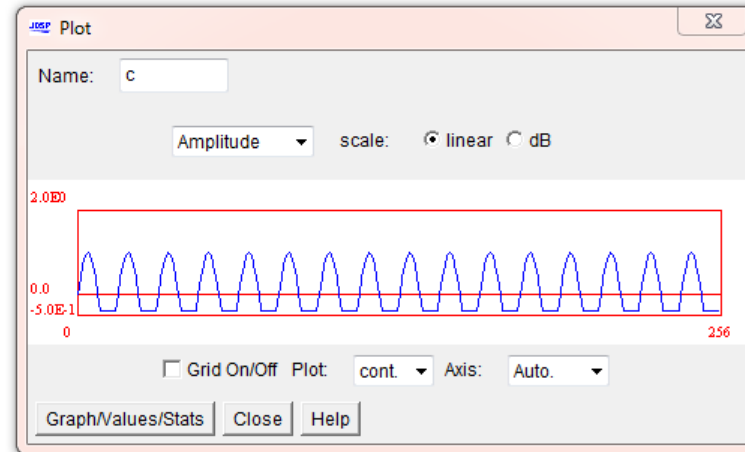
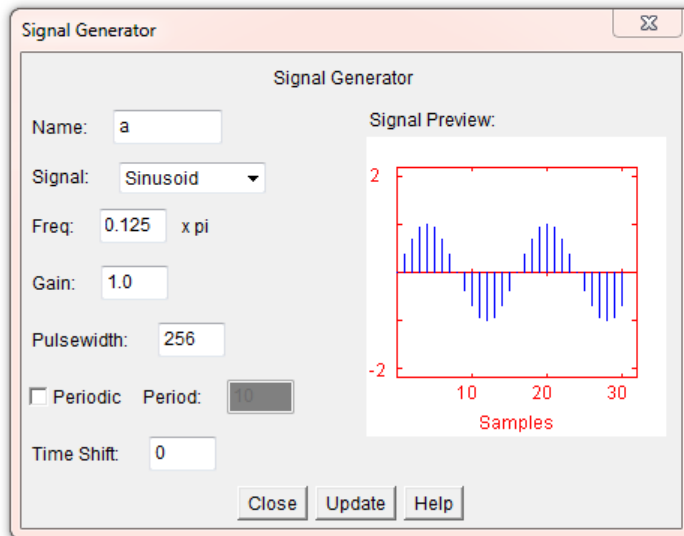
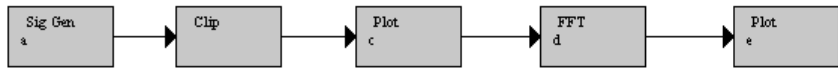


Class AB Amplifiers

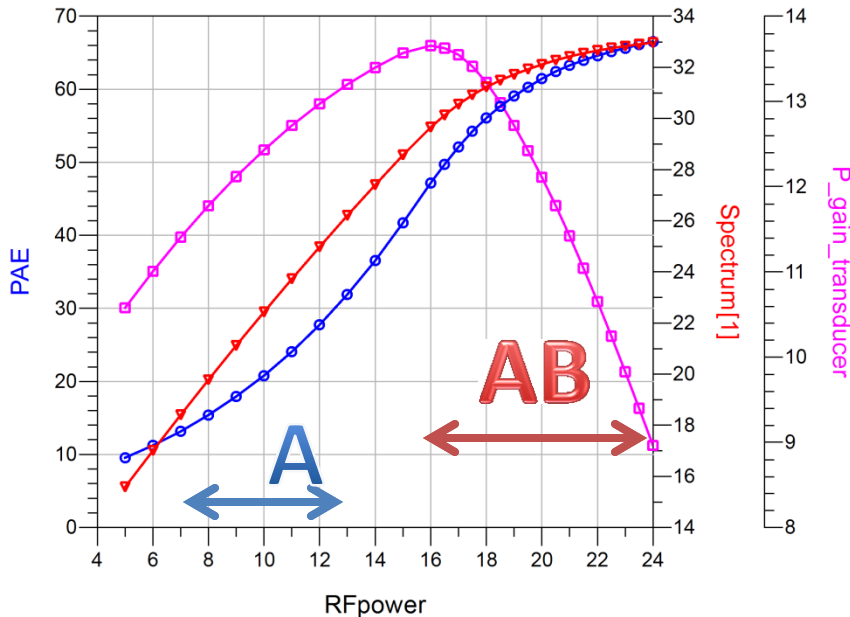
- Class AB Clipping magnitude is typically fixed
 - Conduction Angle depends on Input Magnitude
 - **Gain change based on magnitude (non-linearity)**



JDSP Demonstration



Why bother with class AB?



- Moving 5dB up relative to maximum power output can double efficiency (PAE)

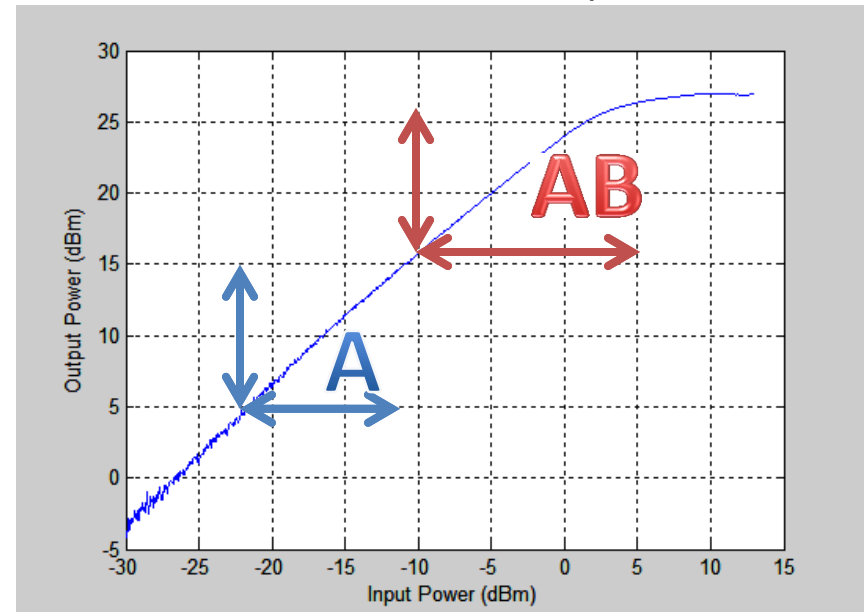
- 50+% more talk/data time in a real system.
- Big difference
- But gain changes

- **Use filters to correct for the changing gain.**

Fundamental Frequency Tone: Class AB Power Curve

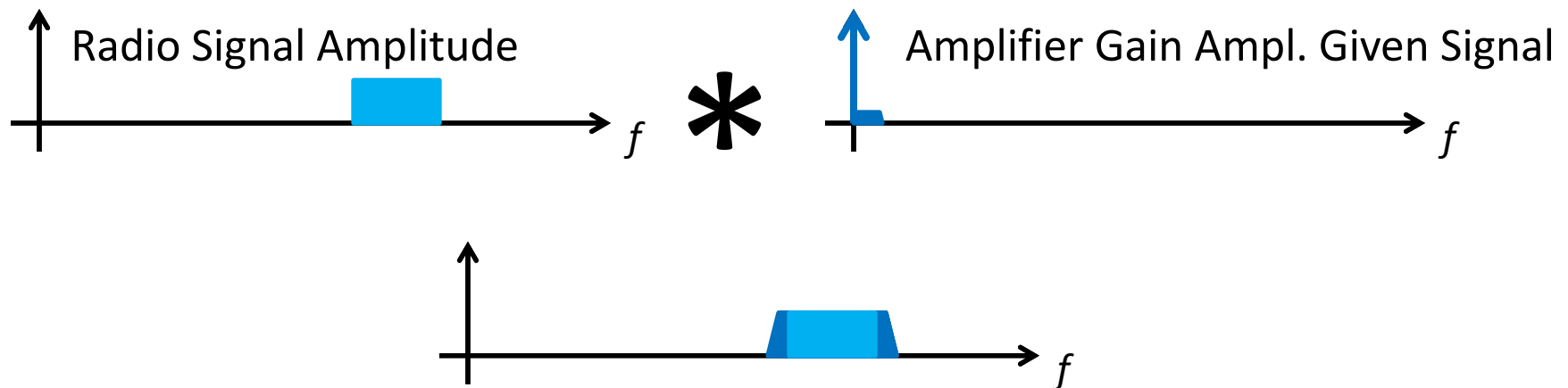
- Why not just back off input until input power range is in the linear region?
- Efficiency
 - Backing off power basically makes amplifier class A
 - Drive PA near saturation

Measured Power Out vs. Power In
For a WLAN Power Amplifier



Gain Changes w/ Amplitude

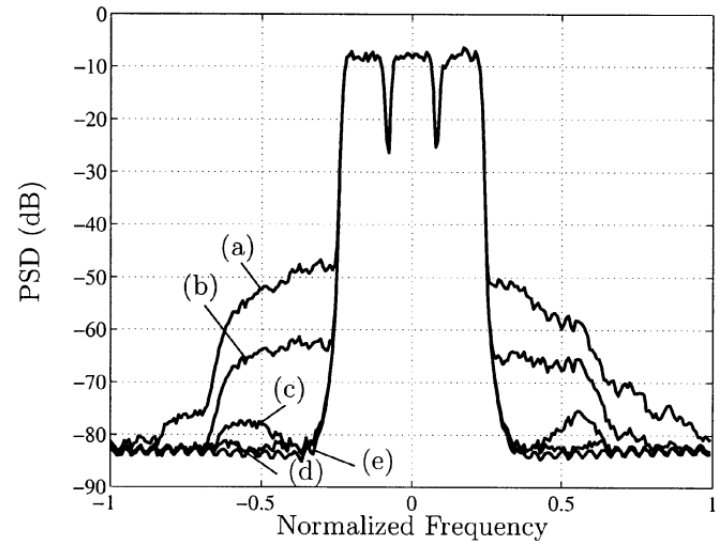
- PA gain is a now time-varying function
 - Thus it has some frequency spectrum
 - Convolve with original modulation spectrum
 - Resultant spectrum is wider (spectral leakage)



Spectrum is Broadened ... Some energy leaks into Adjacent Channels

Frequency Spreading

- The amount of amplifier non-linearity, and thus spectral spreading, determines how closely you can space adjacent channels in your (expensive) frequency space.
- **Determines the number of channels you can have within a band of frequencies**
- A person standing near your transmitter, operating on normalized frequency -0.5 can actually have their signal overwhelmed by the leakage from your nearby transmitter.



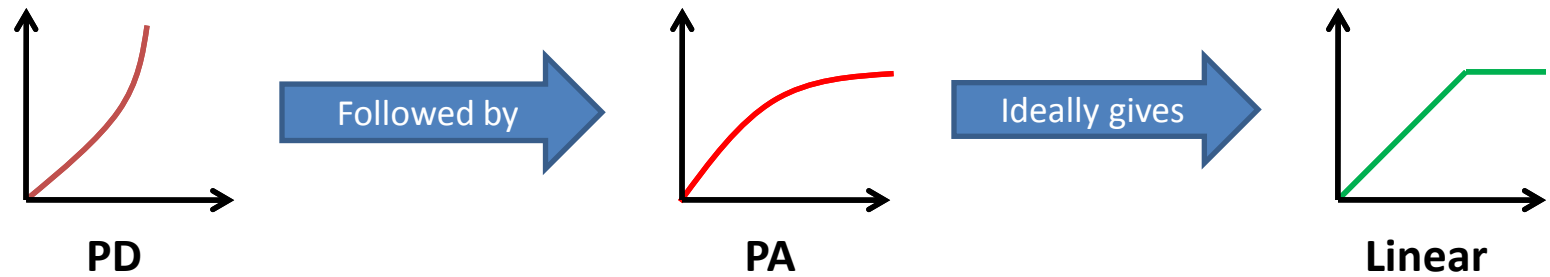
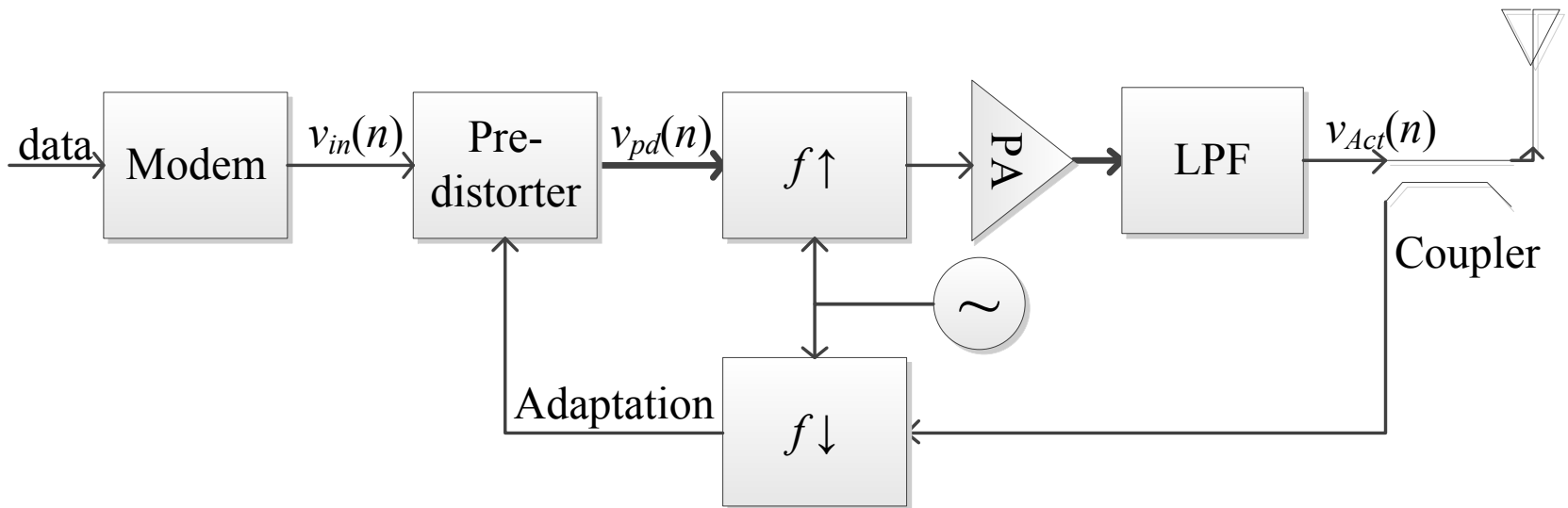
Introduce a new component.

- How do we correct for a time-varying gain?
- **With a nonlinear time-varying filter called the predistorter.**
- The gain also changes with your transmitter's power supply level and temperature, so you must do it *adaptively* in your transmitter. Cannot pre-determine the filter.

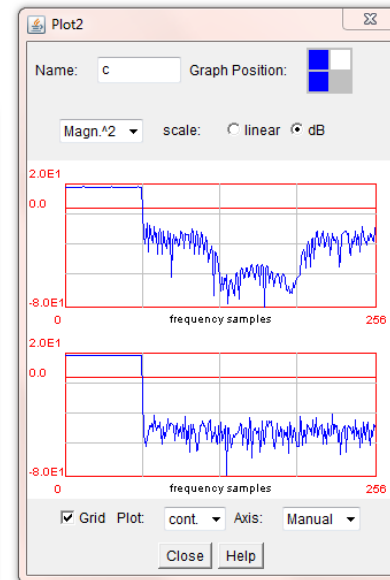
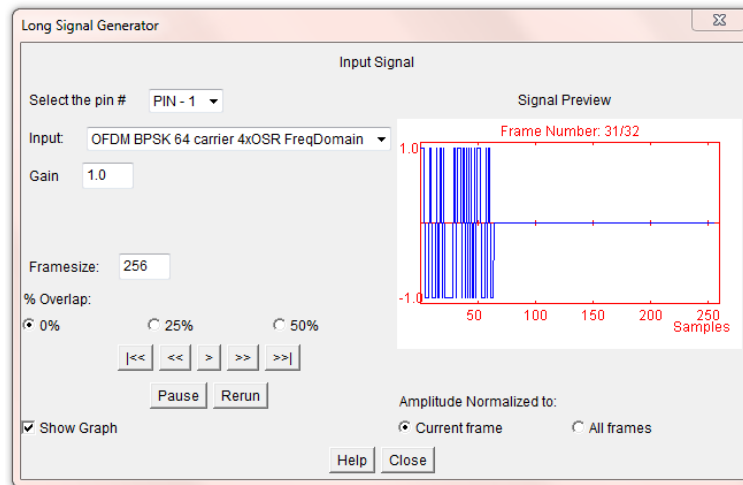
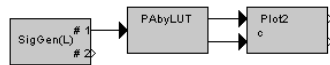
Design Target

- Introduce a new component in the transmitter that attempts to cancel the gain changes
- New component (predistorter) has:
 - “gain expansion” with increasing amplitudes
- To cancel amplifier’s
 - “gain compression” with increasing amplitudes
- Total system thus is:
 - “gain constant” with increasing amplitude

Predistorted Transmitter Topology



JDSP Demonstration



Conclusion

- Amplifier designers must face a tradeoff
 - Amplifiers operate most efficiently when in “compression”
 - “Compression” introduces non-linearity
 - Time-varying non-linear gain
- Non-linear gain causes spectral broadening, distortion
- Introduce a new filter in DSP to correct for RF
 - Time-varying non-linear filter
 - Gain Expansive characteristic to compensate for gain compressive amplifier
 - Called a Predistorter

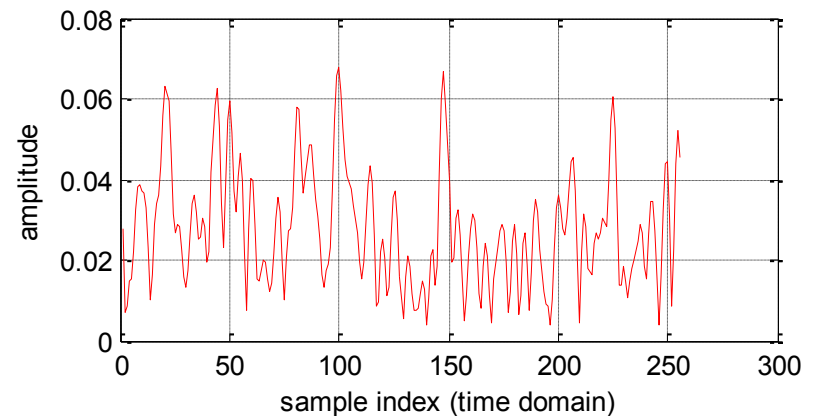
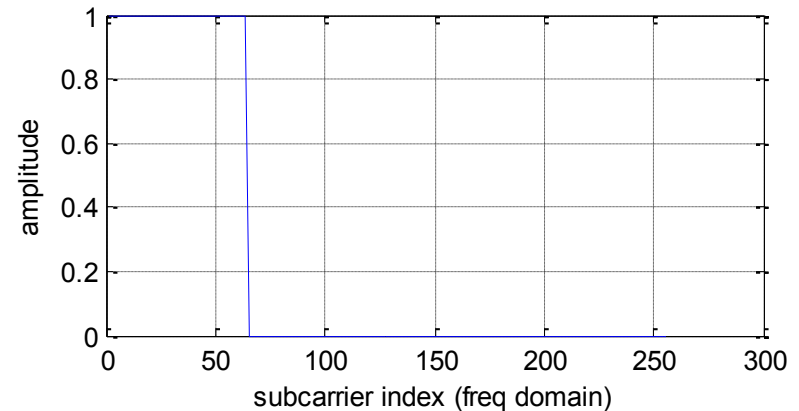
Backup

OFDM

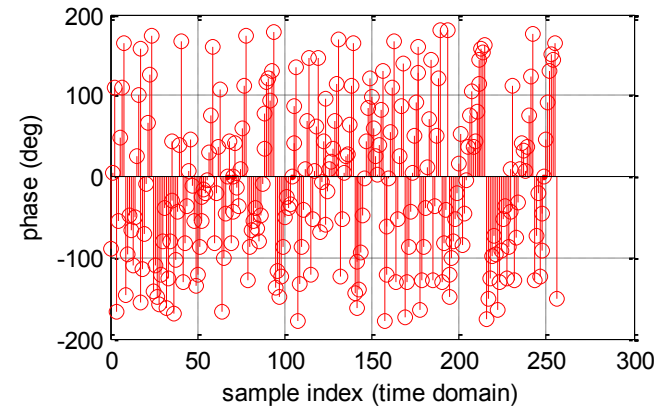
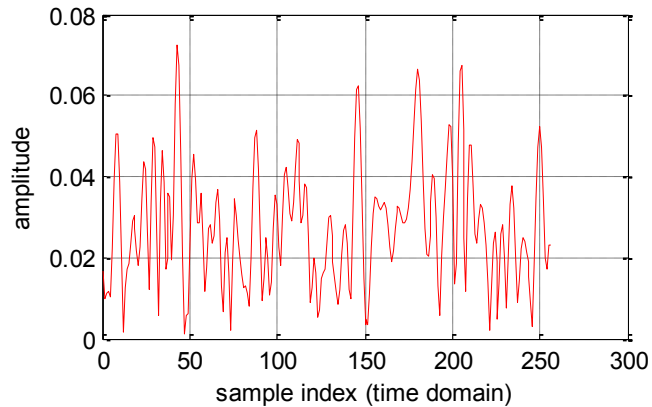
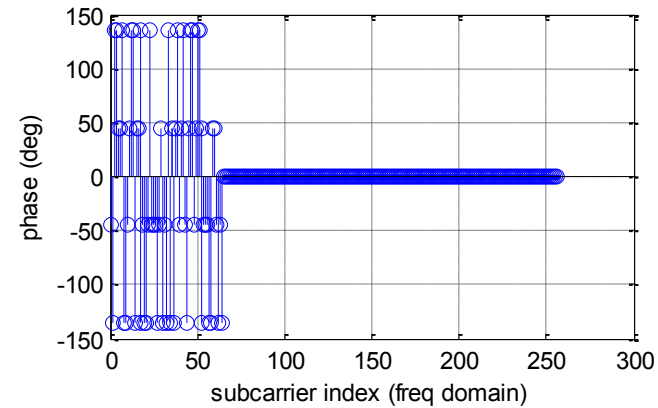
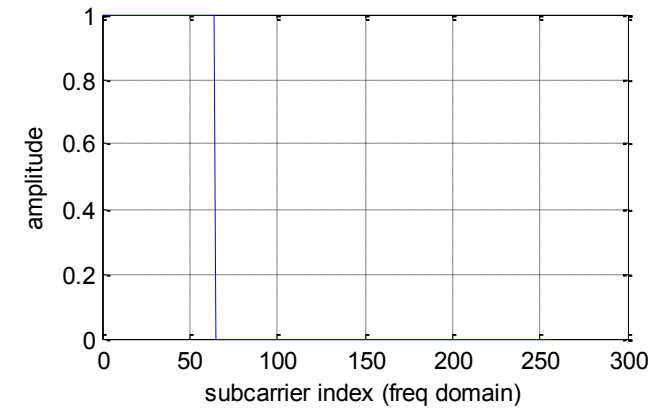
- A transmitted signal may take multiple paths to get to a receiver.
 - Line of sight, reflected off buildings, etc.
- If we transmitted a sequential series of symbols as fast as possible, the order at which they arrive at the receiver after travelling different paths can be jumbled.
- Instead, split your available frequency band into a series of subcarriers which each transmit a single slow symbol in parallel. Placing enough in parallel makes the symbol long enough in duration that arrival time is a non-issue.

What does an OFDM symbol look like?

- In the frequency domain, each subcarrier holds a given symbol. These can be independently modulated.
- Transmitters are still operate in the time-domain. They are fed by a DAC that generates a series of analog inputs to a mixer and amplifier.
- So you need to take IFFT.
- The independent sinusoids in frequency domain result in a random combine

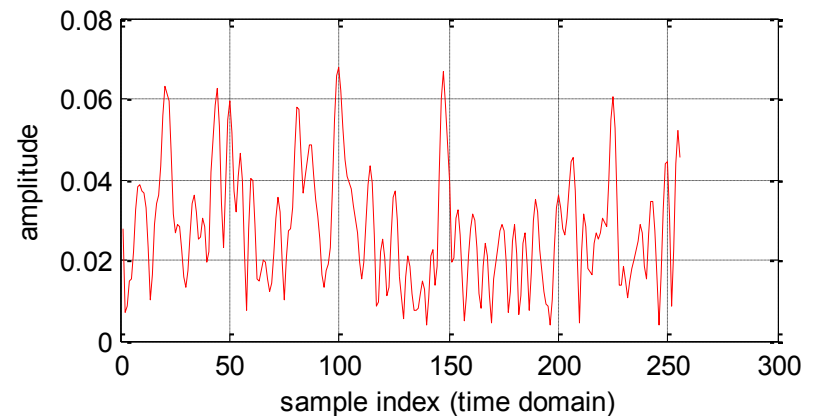
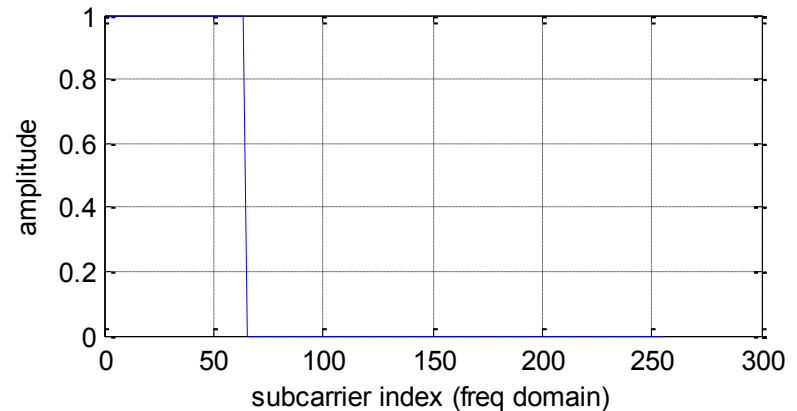


Simple case: Information carried by subcarrier phase only



An Additional Benefit

- OFDM allows you to have very steep attenuation outside of your desired operating frequency
- Allows use of adjacent band of frequencies bands or “channels” with very little gap
- Why is it important to place channels close together?

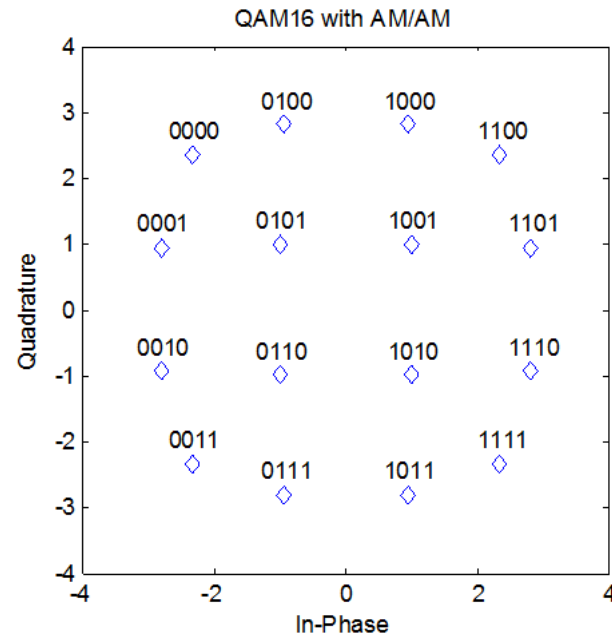
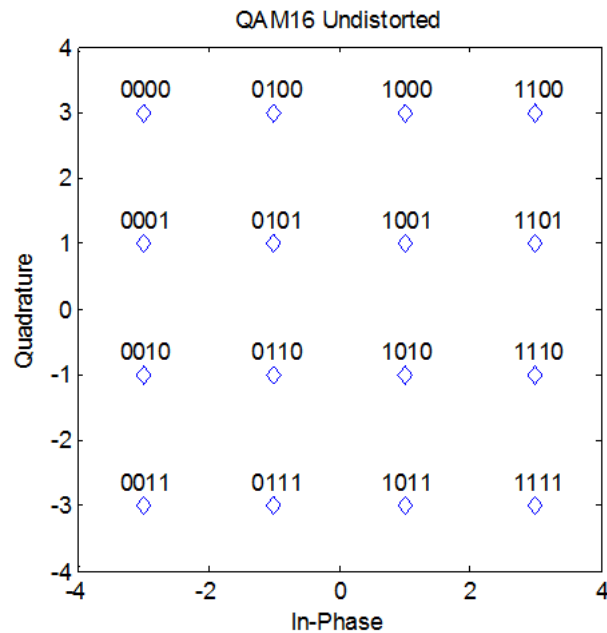


Review what we have:

- A modulation scheme that works well in a multiple path of propagation environment
- Signal that is transmitted has significant peaks and valleys in its amplitude

Non-linear Gain Causes In-band Distortion

- If amplifier has AM/AM distortion,
 - Constellation gets distorted
 - Error Vector Magnitude (EVM) increases



Another Pre-distortion Block Diagram

