Trends in Linear Power Amplifiers for Communications Systems

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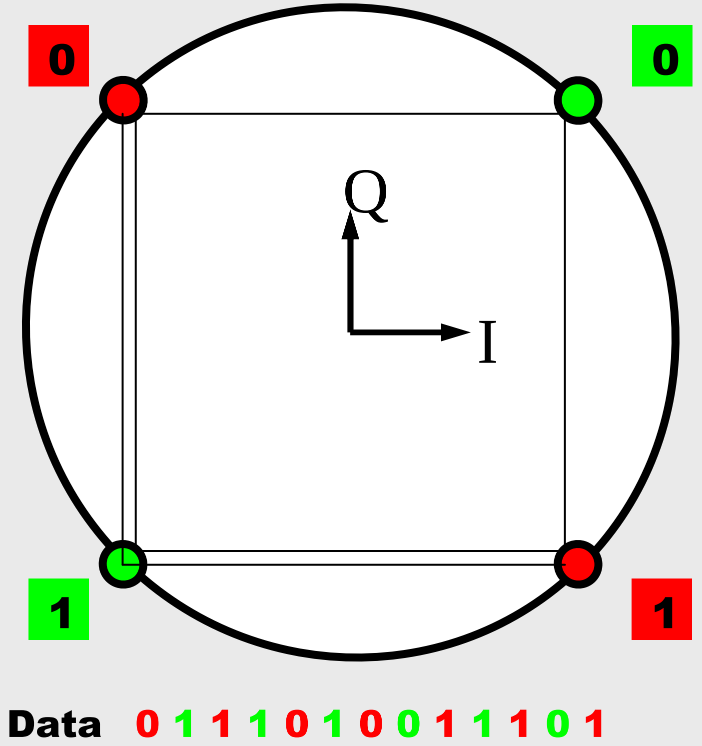
Outline

- Perspective - Key aspects of 2, 2½ and 3G systems
  - Modulation formats
    - *GSM, EDGE to 3G*
  - Network evolution
    - *Circuit switched, packet switched to IP*
- Trends
  - More power, higher efficiency and lower cost
  - Pick any 3
  - Software defined systems
  - Ubiquitous communications produces rich variety of services
- Linearity – More to it than meets the eye
  - Spectral spreading is just the start
  - All the trends have linearity at the core
- Summary

GSM Modulation

- BPSK modulation
- 1 bit per symbol
- Interleaved symbol sets
- Gaussian filtered

- Constant envelope
- 0 dB pk / average

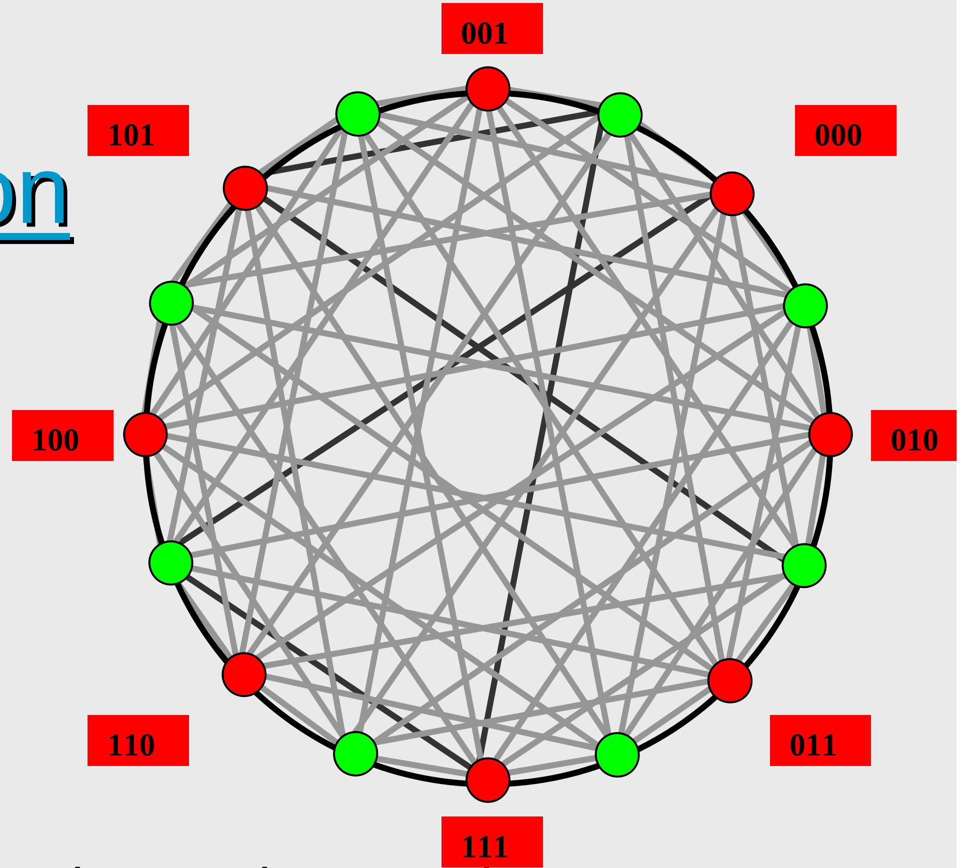


- 8 voice channels, time multiplexed on each RF carrier
- 200 kHz per RF channel
- 7:1 channel re-use

EDGE Modulation

- 8 PSK modulation
- 3 bits per symbol
- Interleaved symbol sets
- Gaussian filtered

- 6 dB pk / Average

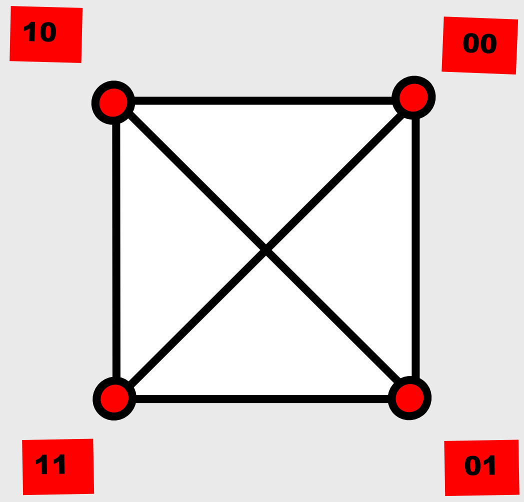


- 8 signal channels time multiplexed on each RF carrier
- 200 kHz RF channels
- 7:1 channel re-use

Data 000 111 111 101 101 000

W-CDMA Modulation

- QPSK Modulation
- 2 bits per symbol
- Symbols are “coded”
  - multiplied by orthogonal codes
  - Added together
- Root raise cosine filtered



- >10dB pk/Average

Data **00 10 01 11 01 00 10 11**

- Many signal channels per 3.84 MHz carrier
  - e.g. 64 voice signals typical
- 1:1 frequency re-use

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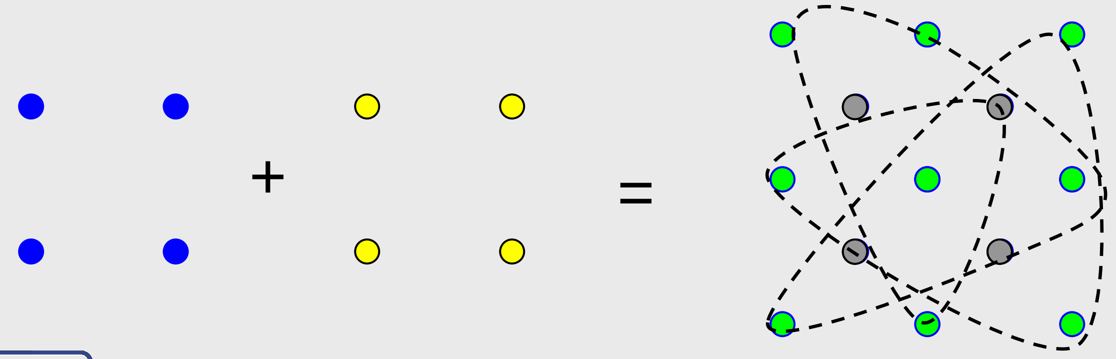
W-CDMA Coding

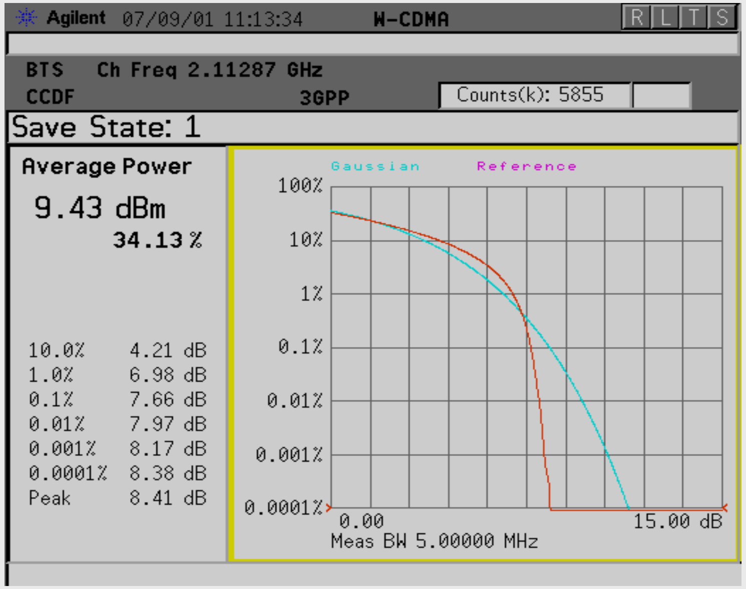
- Each QPSK signal is spread using a scrambling code
  - Producing another, different QPSK signal
- Then many spread signals are added together
- The resulting signal has high peak to average ratio
  - Peaks are rare because they only occur when all the scrambled signals coincide with the same symbol

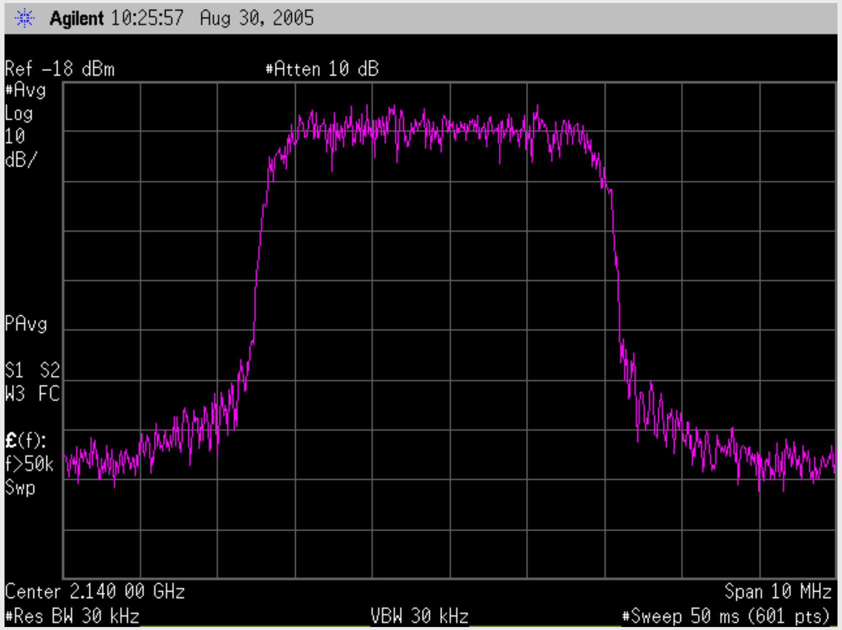
Data1 00 10 01 11 * scrambling code1 = 10 11 00 00

Data2 01 00 11 01 * scrambling code2 = 11 10 10 10



W-CDMA Signal





- Signal spread to 3.84 MHz BW
- Noise like spectrum
- Peaks up to 10dB more than the average
- CCDF shows the statistical distribution

Key Aspects of 2, 2½ and 3G

- GSM – Transmitter friendly
  - Constant envelope signal 0dB pk.Av
  - Fixed, low data rate
- EDGE – A clever extension of GSM
  - 6dB pk/Av envelope
  - 3 times data rate in the same bandwidth
- W-CDMA – Transmitter unfriendly
  - 12dB pk/Av envelope, typically clipped to 8.5dB
  - Variable rate transmission via tree structured codes
  - Wide bandwidth with 1:1 frequency re-use
- Key change is a “data centric” view of signals

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W-CDMA Side Effects

- Rapid mobile power control
  - BTS to Mobile channel characterisation
- Soft and softer handover
  - Code sharing and BTS Collaboration
- Alamouti coding
  - Transmit diversity (2x2 MIMO via Tx upgrade)

- Dynamic allocation of resources to mobiles
  - Diversity enhancements
  - Exploitation of clear downlink channels
  - Rapid data rate adjustments

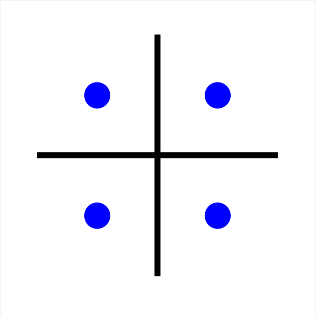
Beyond 3G

- HSDPA
  - Increase peak downlink data rates to 14Mbps
  - Reduce network delays
  - Increase capacity 2 to 3 times

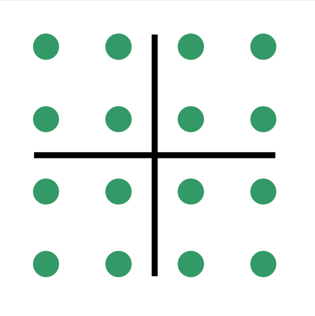
- WiFi, WiMAX and 4G
  - OFDM, MIMO, etc etc
  - Alphabet soup, more and more of the same

Planned 3G Extensions

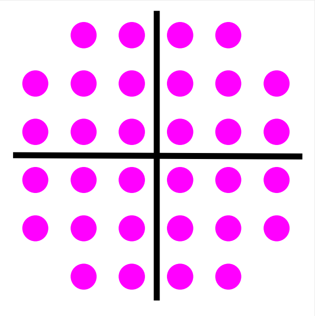
- Data is Data
  - Different modulation to suit the available power/channel characteristics
  - More and more bits per symbol



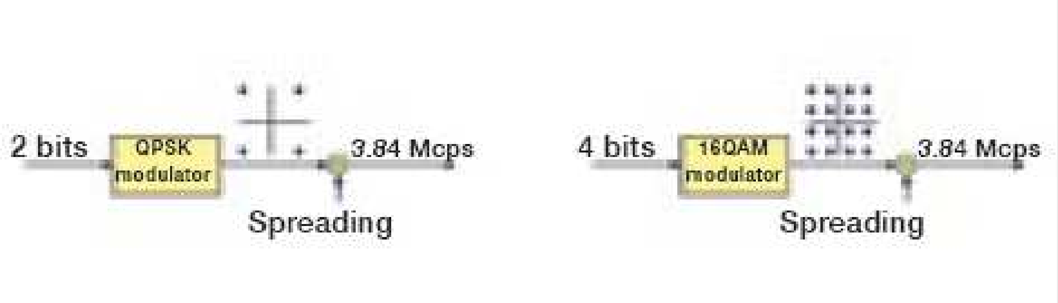
QPSK



16QAM



32QAM



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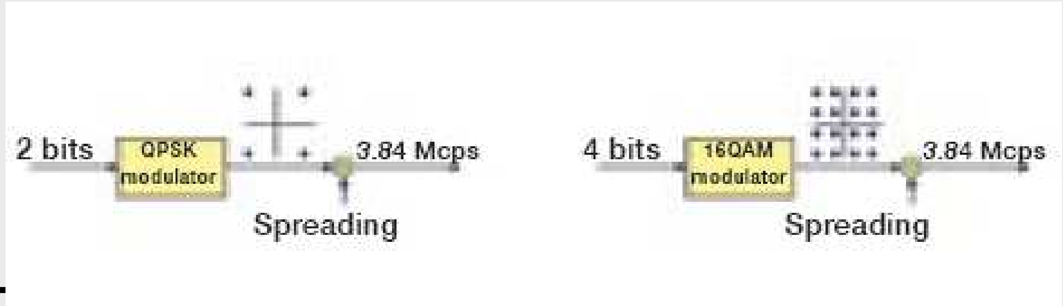
Extension What Extension?

- This might seem complicated
  - But these functions are in the digital baseband
  - These are just FPGA changes
    - *On a single dedicated physical channel DPCH*
  - And can be done in real time
- Better channels get faster data rates
- Spare Tx power used to increase Eb/No



HSDPA

- Unused Tx power is unused capacity
  - Tight power control of DPCHs gives available power to supply high speed data access via HSDPA

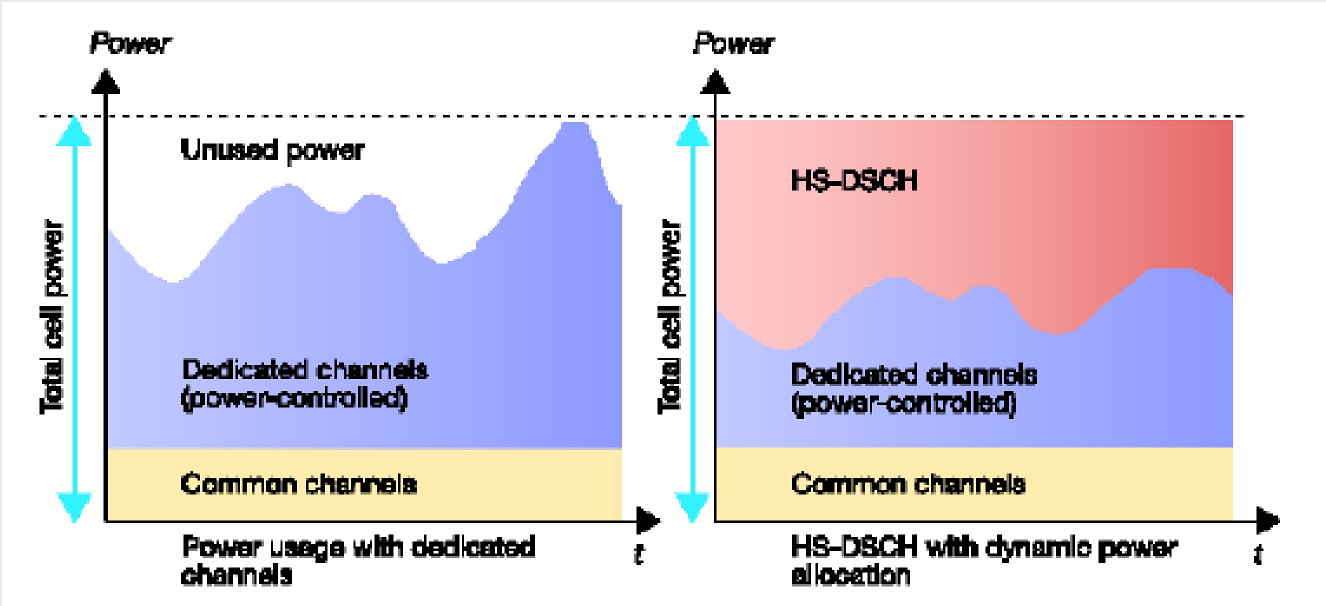


Figure from Ericsson Review Dec 2005

Evolution Summary

Generation		Data Rate	
2	Voice	BPSK	Fixed
2½	Voice+Data	8PSK	Fixed
3	Voice+Data	QPSK	Variable
Beyond	IP/Packet	N-QAM	Arbitrary

- 3G forms the basis for a fundamental shift in the Communications Channel utilisation
- All digital → IP/Packet Data
- Multiple simultaneous modulation schemes
  - All just handled by software defined radio standards
- Arbitrary data rates, maximising system capacity and maximising revenues

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Continuing Trends

- Increased Power
  - Initial roll-out often has just enough to provide the initial service
  - Power proportional to downlink capacity
  - Tx diversity as a capacity enhancement
- Increased Efficiency
  - BST power is most significant in whole network
  - PA power is most significant in the BTS
- Relentless pressure on Cost
  - Cost per av. Watt of RF <$20 and decreasing

Power

- There is always a regulatory limit
- But many systems are not yet at that limit
  - Substantial cable losses in “hut” configuration
  - Significant drive towards tower mounted PAs
    - *Efficiency and reliability concerns*
- Transmit diversity and Alamouti coding
  - Handset standard has already been upgraded
  - All new handsets can handle this signal
  - Additional Tx required on the existing diplexer antenna used for Rx diversity
  - A whole new set of power amplifiers

Efficiency

- Radio Unit efficiency typically 10%
  - This is PSU, TRX circuitry and the PA
    - *DC power in to RF power out*
- DPD can boost this to 15%
- Doherty amplifier with DPD up to 20%
  - Considerable energy saving
  - Savings on network running cost
  - Saving space; power upgrades in the same cabinet
  - CO_2 emissions reductions (600g / kWh)
    - *Estimated average drain efficiency 40%*

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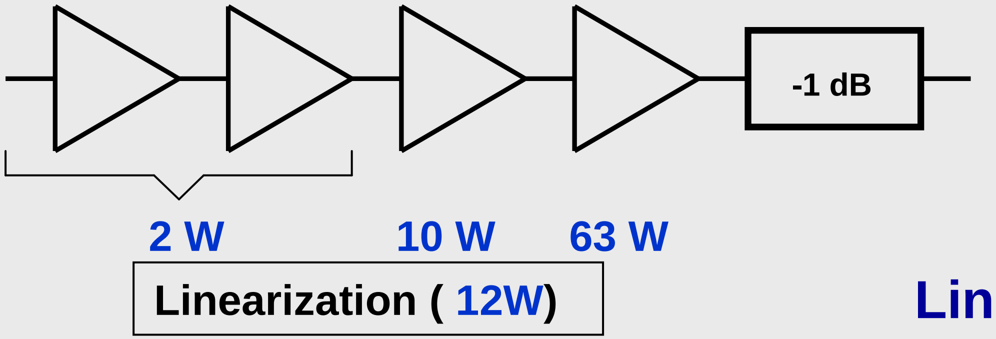
Where Does all the Power Go?



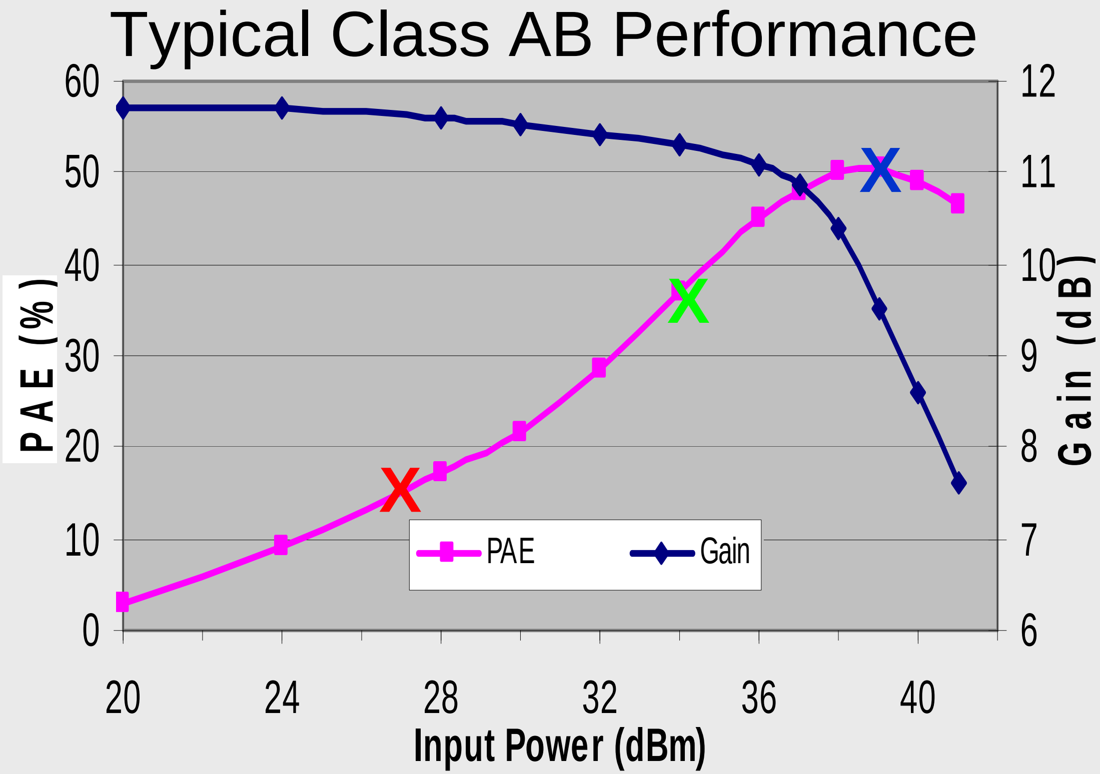
RF = 20W

Total for amps 26.7%

Linearization cuts that to 23%

- For a 20W PA with modest output losses
  - Actually need 25.2 W of RF from the amplifier
  - At 40% average drain efficiency, that’s 63W of DC
- And ~2.5 Watts drive
  - At good linearity (25%) another 10W
- Also need 2 more stages of gain
  - Another 2W or so
- Then some form of linearization (12W)

PA Performance for 2, 2 ½ and 3G



- GSM
  0dB pk/Average
- EDGE
  6dB pk/Average
- W-CDMA
  8.5dB pk/Av

Typical values, excluding further back-off required for IM compliance

W-CDMA ~15% ***EDGE ~35%*** ***GSM ~50%***

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Linearity and Time Invariance

If	$x(t) \Rightarrow X(t)$
and	$y(t) \Rightarrow Y(t)$
then	$a \cdot x(t) + b \cdot y(t) \Rightarrow a \cdot X(t) + b \cdot Y(t)$
And if	$x(t) \Rightarrow X(t-\tau)$
then	$a \cdot x(t-\tau) + b \cdot y(t) \Rightarrow a \cdot X(t-\tau) + b \cdot Y(t)$

- Linearisation has to encompass non-linearity and time variance of the system
- To do that it must encompass whole time scale

- Note how HSDPA involves average power and/or coding standard changes in the mS time frame.

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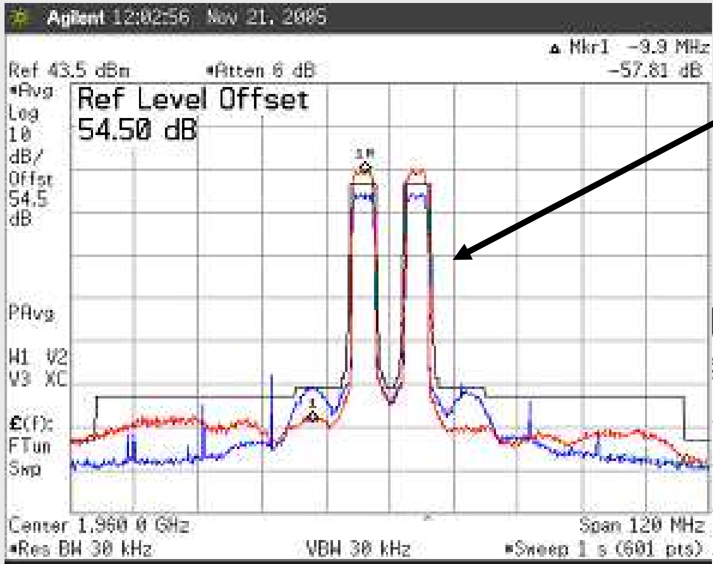
DPD Linearisation

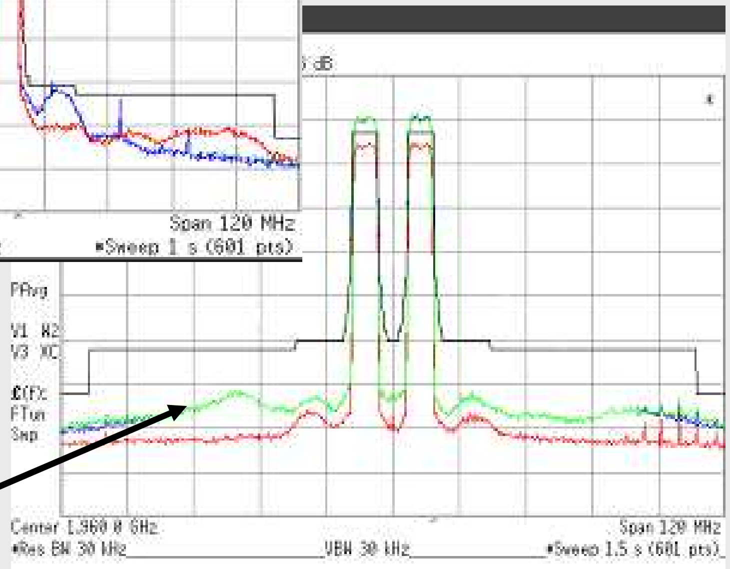
- Most DPD linearisation techniques include some memory effects
  - Device memory effects can usually be accommodated within the latency of the system
  - Longer effects cannot be linearised
  - Look-up tables can only compensate
- Static Linearity
  - Uniform average power with
  - Instantaneous changes at the modulation rate and
  - A static modulation standard
- Dynamic Linearity
  - Instantaneous changes at the modulation rate
  - Encompassing changes in average power and
  - Changes in modulation standard

Static and Dynamic Linearisation

- DPD Lineariser performance with power back-off
- Static
  - Most common
  - Same average power in the test signal
- Dynamic
  - Average power changes
  - Simple On/Off tests
  - Here a full and 6dB back-off test
  - Or pulsed power tests



Blue shows reduced power, increased IM



Red shows reduced power reduced IM

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Static and Dynamic Lineariastion

- Almost all published results show static linearisation
  - Classic before/after DPD results are for test signals with uniform average power
- Real signals have variable average power
  - Variability is more rapid than DPD computation rate
- A true lineariser would have to encompass the time of the average power variations
  - Far too long for proper system operation
- Dynamic tests quantify the practical DPD solutions

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Summary

- Two key factors in system architecture
  - Digital modulation enables alternative modulation schemes
  - IP, packet based protocols enable dynamic allocation of user data rates
- Driving factors
  - More bits/symbol increases capacity
  - Dynamic allocation increases resource utilisation
- Linearity – tighter and tighter
  - Higher QAM, less phase and amplitude margins
  - Dynamic power control exercises device over a wide variety of time frames