



A Study and Comparison of Efficiency Enhancement Techniques for RF Power Amplifiers

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A Study and Comparison of Efficiency Enhancement Techniques for RF Power Amplifiers

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TOPICS TO BE COVERED

- Need to improve transmitter efficiency
- Investigation and comparison of technologies to improve DC to RF efficiency of solid state, linear, RF power amplifiers
- VHF, UHF, and L-Band frequency ranges
- Results of advanced technology assessments focused on RF amplifier efficiency enhancement



NEED FOR HIGHER EFFICIENCY

- High interest among broadcasters and RF network operators in new power amplifier technology that offers improved efficiency
- Benefits of higher power amplifier efficiency include:
 - AC power consumption savings
 - Reduction in physical size
 - Reduction in cooling requirements
 - Reduction of carbon footprint in support of green technology

RF AMPLIFICATION REQUIREMENTS

- Digital TV signals have high Crest Factor / Peak to Average power Ratio (PAR) compared to a constant envelope signal
- Digital modulation waveforms (OFDM / 8VSB) contain complex, simultaneous, AM & PM modulation requiring linear amplification
- Linear amplification needed to meet RF emission mask and minimize in-band RF IMD that degrade the digital signal to noise ratio (EVM / MER)

LINEAR AMPLIFICATION EFFICIENCY PENALTY

- Efficiency lost when PA operates between saturation and cutoff
- Loading on PA not optimum for RF waveform at point where static bias current through amplifying device is significant portion of total current
- RF Power amplifiers operate at highest efficiency when saturated for maximum power output

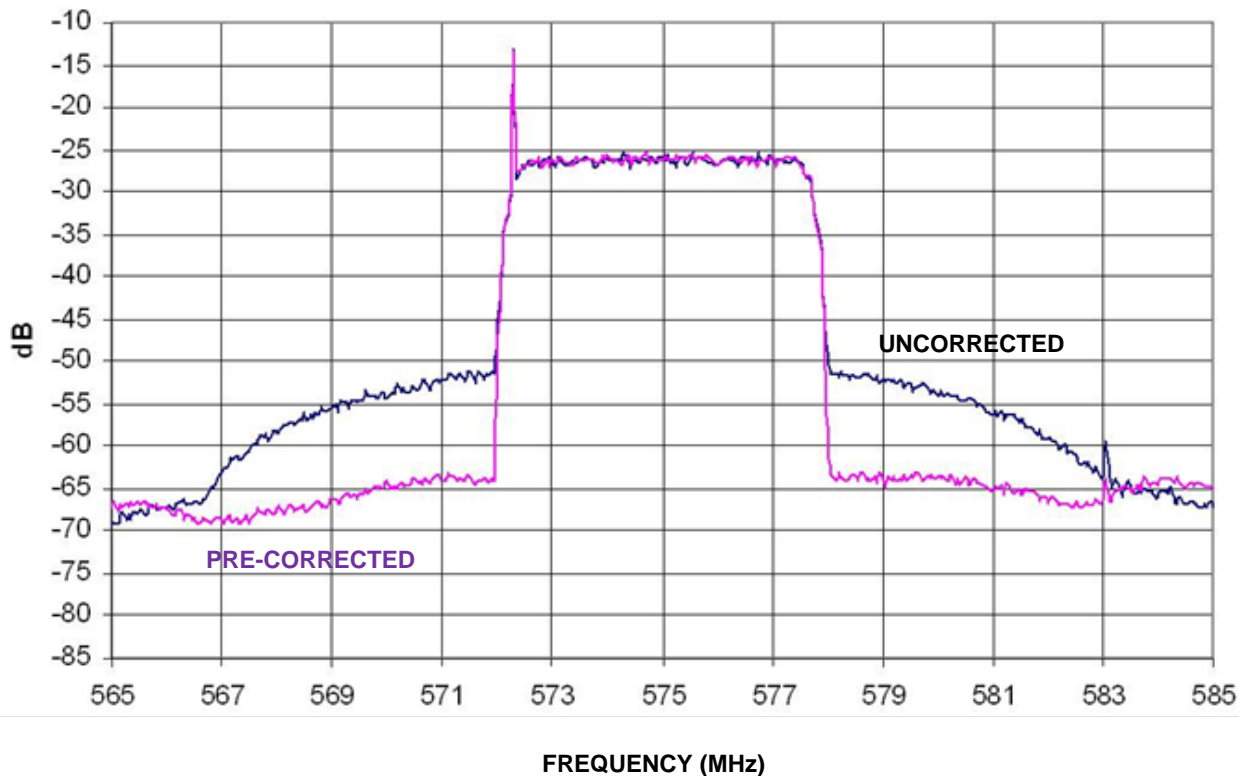
LINEAR AMPLIFICATION EFFICIENCY PENALTY

- To accommodate a digital signal with 8dB peak to average ratio, the amplifier needs to be biased into linear, Class-AB, mode
- Average power reduced by ~ 8dB to achieve good linearity
- Current UHF solid state devices can achieve saturated DC to RF efficiencies of up to 70%
- Backed off by 8dB into Class-AB operation, DC to RF efficiency drops to less than 30%

DIGITAL PRE-CORRECTION

- Real Time Adaptive Correction (RTAC) used by Harris
- Pre-corrects PA for AM/AM and AM/PM non-linearities
- Trade-off between in-band RF IMD products and how far into saturation the amplifier can go on envelope peaks
- RTAC raises efficiency of PA running it closer to saturation
- Still meet required digital signal to noise ratio (EVM / MER) and RF spectrum emission mask

REAL TIME ADAPTIVE PRE-CORRECTION

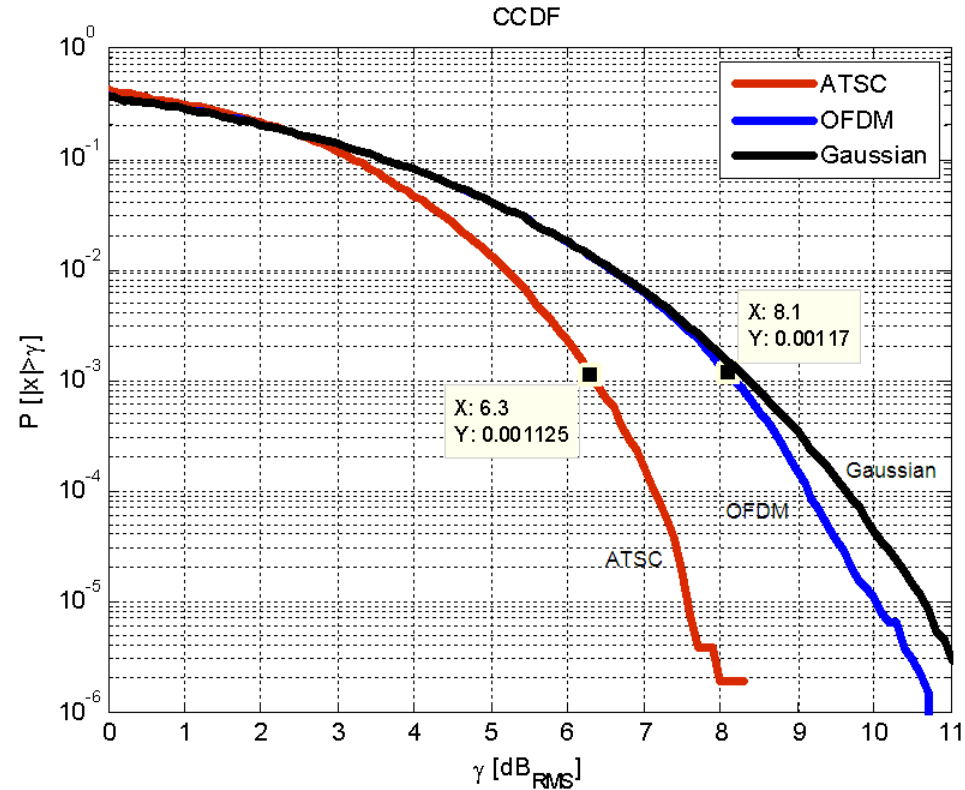


CREST FACTOR REDUCTION

- Peak to Average Ratio (PAR) of digital signal must be reduced to get reasonable RF power amplifier utilization
- (CFR) process introduces some distortion, but intelligent techniques can minimize distortion
- Amplitude of digital signal has statistical distribution estimated by Complementary Cumulative Distribution Function (CCDF)
- Instantaneous peaks at all levels are averaged over a large number of samples

PAR OF DTV WAVEFORMS

- Comparison of CCDF distributions over 1 million samples
- (PAR ~6.3dB) for ATSC (8-VSB)
- (PAR ~8.2dB) for DVB (OFDM)
- (PAR ~8.5dB) for Gaussian power
- PAR values shown in dB on the horizontal axis are taken at a probability of 10^{-3} or 0.01% as shown on the vertical axis



CREST FACTOR REDUCTION

- Reduction of the PAR within the limits imposed to meet a minimum Modulation Error Ratio or Error Vector Magnitude (MER/EVM) digital signal to noise ratio is the first step to improving RF linear amplifier utilization and efficiency

NEW SOLID-STATE RF POWER DEVICES

- Harris is constantly researching and evaluating new RF device technologies
- New solid state RF power device technologies have recently replaced V-MOS and T-MOS devices
- Most popular new solid state power devices for VHF, UHF, and L-Band applications based on Laterally Diffused Metal Oxide Semiconductor (LD-MOS) technology

LD-MOS DEVICE TECHNOLOGY

- LD-MOS places source terminal of FET at ground potential
- Geometry layout improves thermal performance
- Lower capacitances and source inductance
- Combination yields higher gain, higher power density, and higher device efficiency
- 50V LD-MOS = 3-4 x power density of 32V technology with 8dB higher gain and 4% higher efficiency

GALLIUM NITRIDE (GaN) TECHNOLOGY

- GaN popular at frequencies above 1GHz
- GaN devices are now available for the UHF and L-Band
- Much wider bandwidth (lower parasitics) than LD-MOS
- Slightly higher efficiency than LD-MOS
- More costly than LD-MOS at this time

POWER SUPPLY EFFICIENCY

- AC to DC conversion efficiency of power supply is second most important subsystem to achieve high overall AC to RF efficiency of transmitter
- Switching power supply technology offers up to 95% efficiency converting AC line to DC voltage for RF devices
- 48V power supplies are highly evolved and reliable
- Large volumes produced are the most cost effective
- Multiple, single phase, supplies provide redundancy and easily configurable for three phase or single phase AC

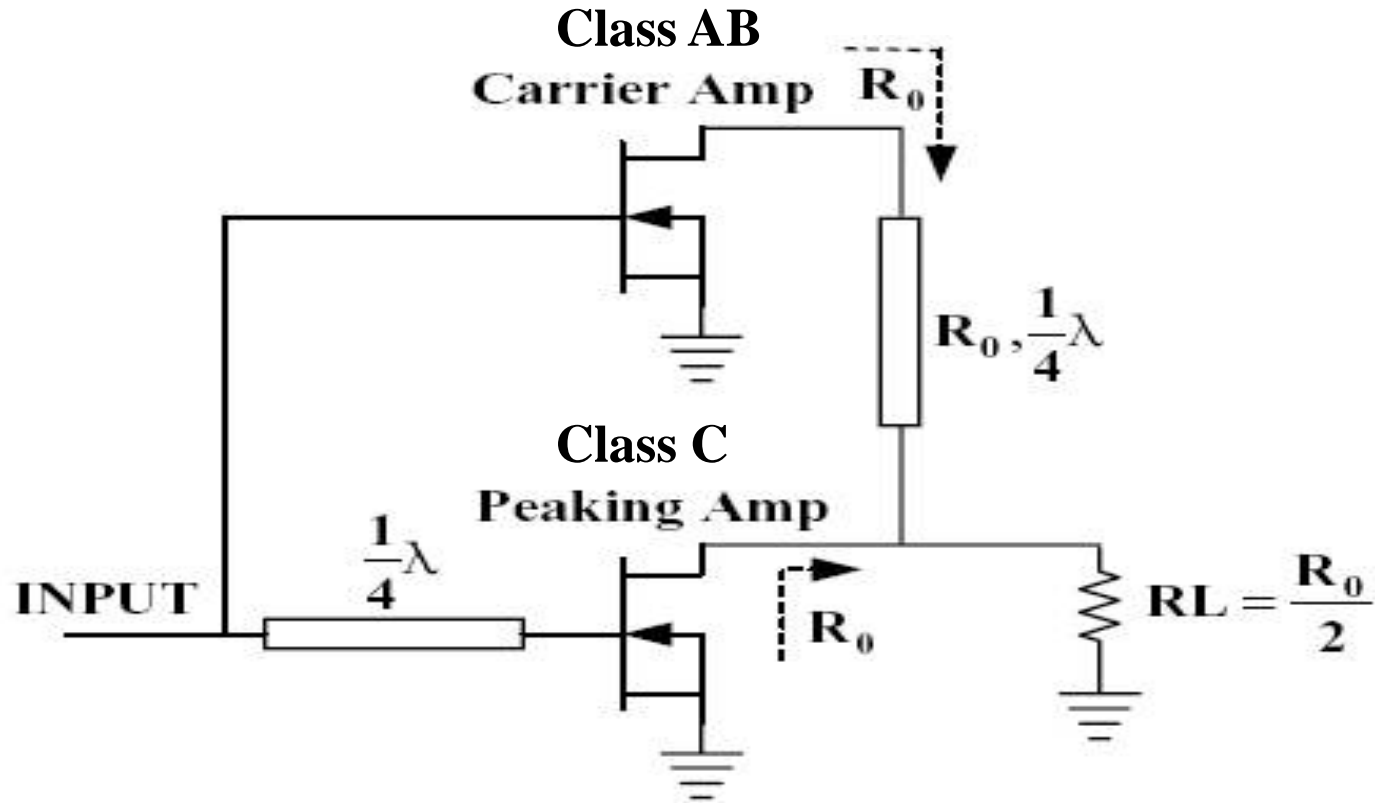
ENVELOPE ELIMINATION AND RESTORATION

- (EER) enables highly efficient, non-linear, amplifier to amplify an RF waveform with envelope component
- RF waveform de-composed into separate envelope and phase components
- PA simultaneously AM modulated with envelope component and phase modulated with phase component
- Original waveform reconstructed at the output of PA
- Not yet practical for wide modulation bandwidths required for DTV waveforms

DOHERTY LINEAR AMPLIFICATION

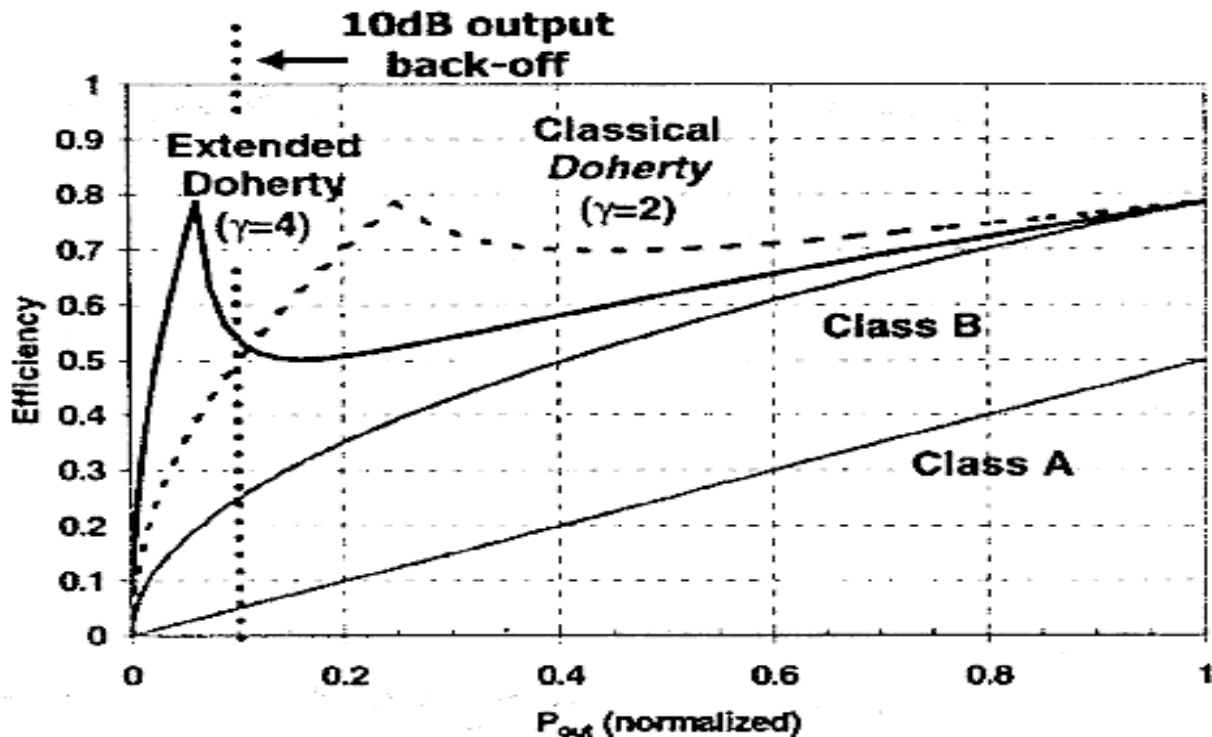
- Two or more amplifiers combined in a way that keeps one of the devices near saturation during all parts of the conduction cycle while the other device(s) operate in a linear mode for the bottom half of the envelope
- Two-way, three-way, and N-way Doherty have been investigated for OFDM and 8-VSB applications

2 - WAY DOHERTY AMPLIFICATION



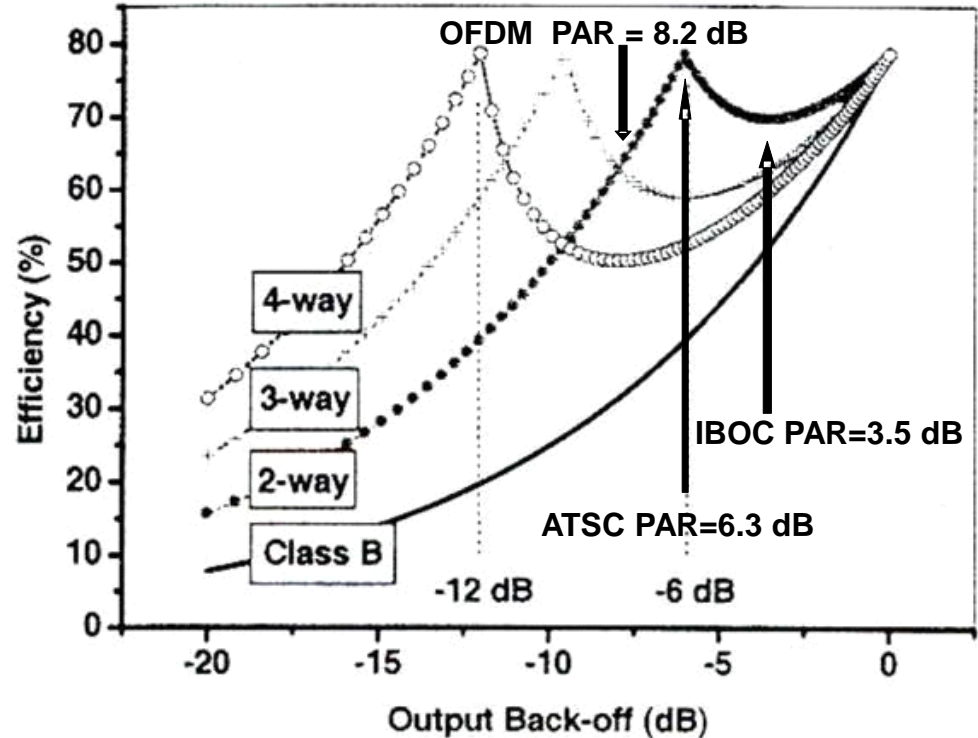
OPERATING CLASS VERSUS EFFICIENCY

PA Efficiency Comparison by Class of Operation



DOHERTY EFFICIENCY VERSUS PAR

- Two-way Doherty best compromise between minimizing the amplifier complexity and efficiency gain at PAR's between 6.3 dB and 8.5dB which covers the popular DVB and ATSC waveforms
- Some benefit to HD Radio (digital only) waveform



DOHERTY EFFICIENCY BENEFIT

- Efficiency improvement for LD-MOS devices operating in 2-way Doherty mode at UHF frequencies is ~10% with 8.5dB PAR waveform
- Efficiency improvement for LD-MOS devices operating in 2-way Doherty mode at L-Band frequencies is ~8% with 8.5dB PAR waveform
- These efficiency improvements at the RF device level can result in >32% reduction in overall dissipated power at the transmission system level.

ADVANTAGES OF DOHERTY AMPLIFICATION

- Simpler to implement
- Small impact on parts count or reliability
- Well understood, mature, technology
- Easy to digitally pre-correct
- Shortest development time to market
- Adds little additional cost
- Operating bandwidth is sufficient for 6% BW applications
 - L-Band
 - UHF (~ 6 x 6MHz. channels per band segment)

DISADVANTAGES OF DOHERTY AMPLIFICATION

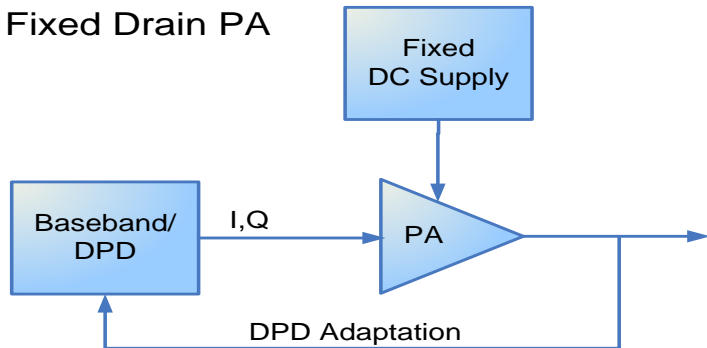
- The key disadvantage of Doherty is the limited operating bandwidth (~6 %) limitation that requires the VHF or UHF bands to be segmented

PA VOLTAGE MODULATION

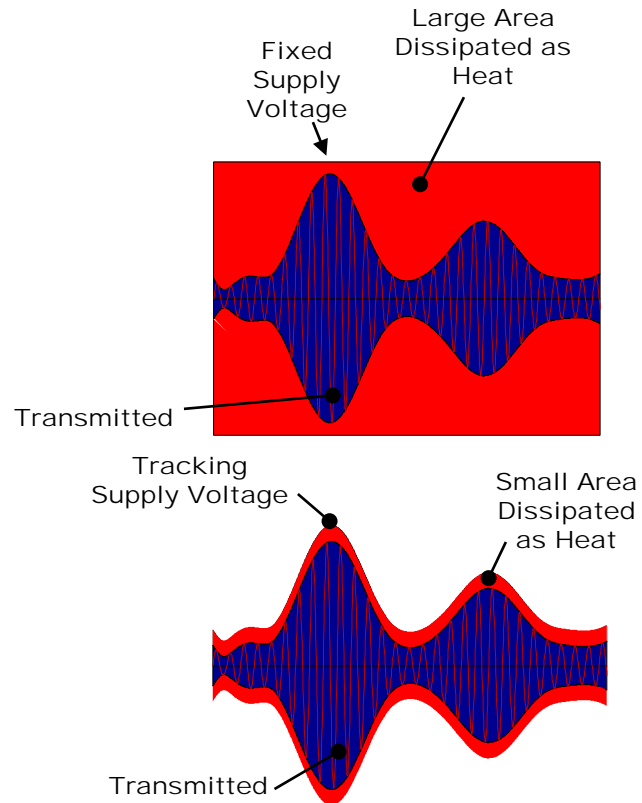
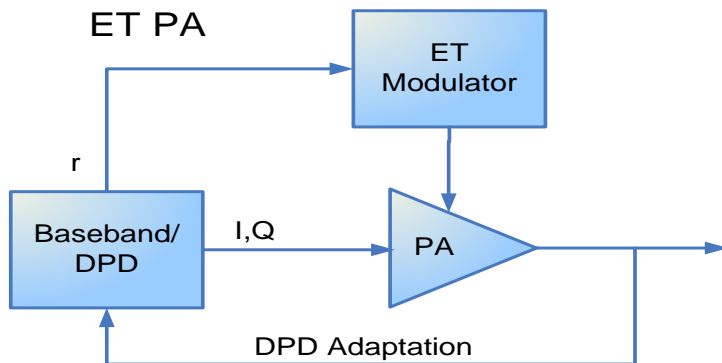
- Adjusting the supply voltage to the RF amplifying device to track the RF waveform envelope can keep the amplifier running closer to saturation throughout more of the waveform
- Earlier implementations of this technology on vacuum tube amplifiers include:
 - Anode Voltage Pulsing
 - MSDC Klystron and MSDC IOT

ENVELOPE TRACKING PA VOLTAGE

Fixed Drain PA

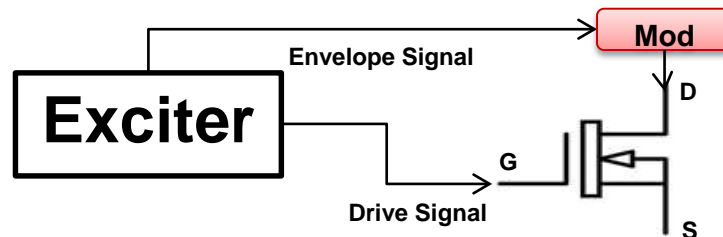


ET PA



DRAIN VOLTAGE MODULATION

- LD-MOS FET drain voltages modulated in step with the peak envelope power

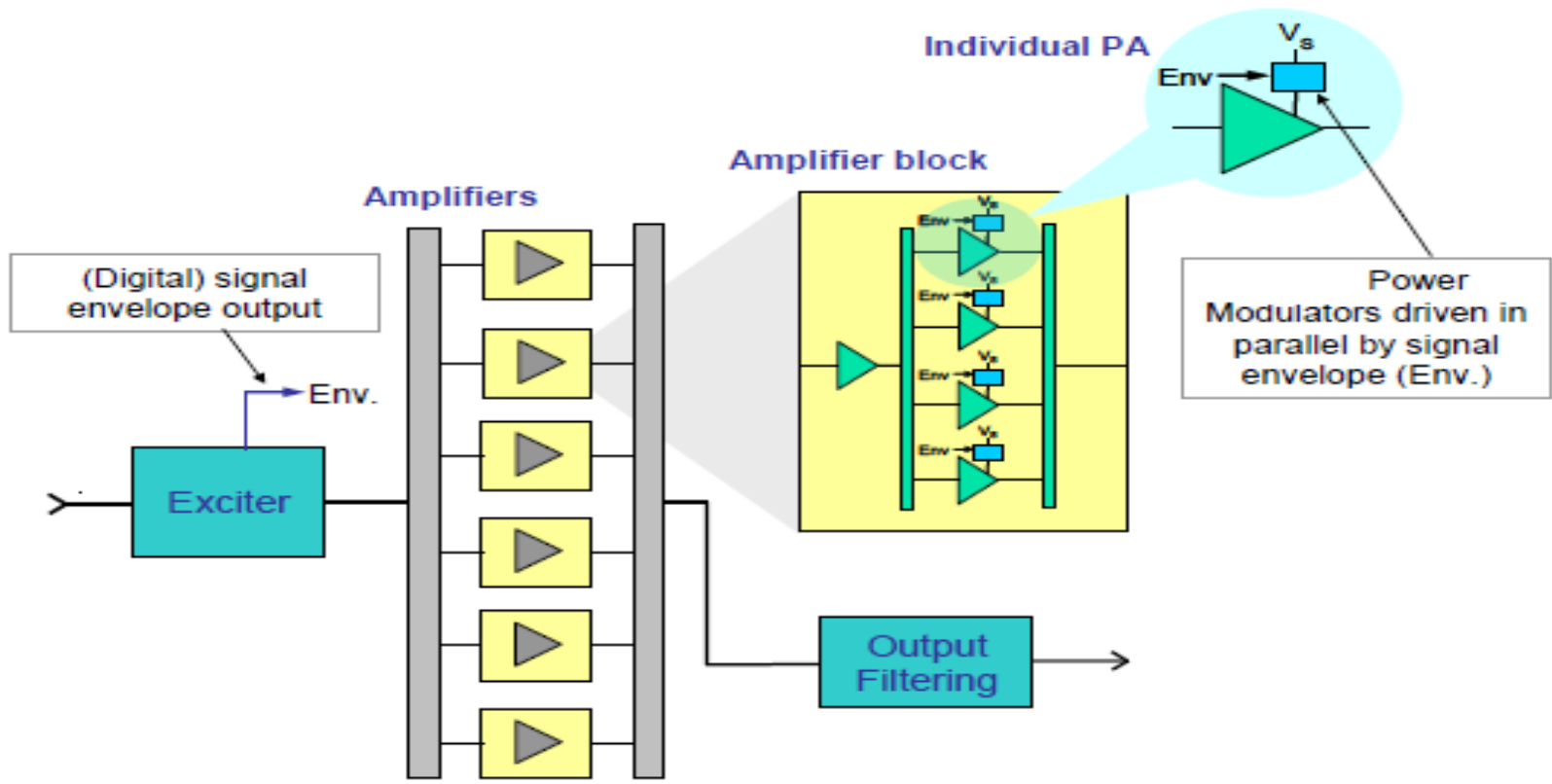


- Keeps amplifier operating near high efficiency saturation over a significant portion of the envelope depth
- Example = Nujira HAT (High Accuracy Tracking) technology

DRAIN VOLTAGE MODULATION

- Exciter calculates envelope peaks and sends time aligned digital command to each modulator
- Additional layer of digital pre-correction to correct for drain modulation non-linearities
- Wide bandwidth buss conveys instantaneous drain voltage commands to modulator at each transistor
- Drain modulator located LD-MOS FET
- Part of efficiency gain is lost to inefficiency of modulator

DRAIN VOLTAGE MODULATION SYSTEM



DRAIN VOLTAGE MODULATION BENEFIT

- Drain Voltage Modulation Efficiency Improvement
- Depending on voltage modulation depth, up to 45% DC to RF efficiency improvement, before subtracting the inefficiency of the modulator (~20-25%) leaving net DC to RF drain efficiency improvement of ~ 15 to 20% with 7.5dB PAR waveform

ADVANTAGES OF DRAIN VOLTAGE MODULATION

- The significant advantage of drain voltage modulation – Not RF bandwidth limited like Doherty
- Possible to build wideband RF linear amplifier with high efficiency
- Drain voltage modulation also can be a few percent more efficient than 2-way Doherty at PARs above 7.5dB.

DISADVANTAGES OF DRAIN VOLTAGE MODULATION

- Complexity of additional hardware and pre-correction
- Increased cost of extra hardware - partially offset by power supply and cooling savings
- Decreased reliability due to increased parts count
- Longer development time to market

EFFICIENCY BENEFIT VS. WAVEFORM PAR

- Efficiency benefits when the PAR is greater than 6 dB
- Benefit increases as the PAR increases
- Application to DTV, DAB, DRM+, and HD Radio (digital only) waveforms with high peak to average ratios
- Little benefit to applying these techniques to HD Radio common amplification with lower PAR

SYSTEM THERMAL EFFICIENCY IMPROVEMENT

- Reduced heat dissipation at RF power devices benefits cooling system
- Heat sink dissipation & temperature drop – Air / liquid flow reduced
- Size and power consumption cooling system proportionately reduced
- Efficiency improvement in PA has significant impact on overall AC power consumption of the transmitter system
- 15% improvement in DC to RF efficiency results in greater than 30% reduction in overall system power consumption
- Cost reduction in cooling components help offset cost of efficiency enhancement

MARKET NEEDS AND COST TRADEOFFS

- Introduction of new efficiency enhancing technologies depends on customer requirements
- Need to reduce power consumption
- Willingness to pay for this technology at time of equipment purchase
- Importance of lower overall cost of ownership over time
- Cost of higher efficiency products can be reclaimed < (2) years depending on electrical power rates and technology

MARKET NEEDS AND COST TRADEOFFS

- Narrowband technologies like Doherty are attractive from a simplicity, speed to market, and cost standpoint
- Wideband efficiency enhancement technologies like Drain Voltage Modulation are more complex and costly to implement, but offer full frequency agility across the frequency band of interest
- Users needing module interchangeability, prefer a wideband power amplifier technology that allows the transmitter system to be frequency agile across the entire VHF or UHF band

SUMMARY

- LD-MOS devices, crest factor reduction, and advanced digital pre-correction have enabled up to 5% efficiency improvement
- Two specific technologies have been reviewed that further improve solid state power amplifier efficiency by 10 to 15%
- Doherty linear RF amplification is simplest and least costly efficiency improvement if broadband frequency coverage is not mandatory
- 2-way Doherty amplification nearly equals drain voltage modulation efficiency enhancement at lower cost and simplicity

SUMMARY

- L-Band applications fall within the bandwidth capabilities of Doherty amplification
- Drain voltage modulation has the key benefit of offering broadband frequency coverage when frequency agility is required
- Drain modulation is preferred for covering the entire VHF or UHF band because it has no RF bandwidth limitation
- Both Doherty and drain voltage modulation offer a significant reduction in transmitter system cooling requirements

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Questions ?

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