Improve Doherty Amplifier in efficiency and output power

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What’s on offer?

- According to Darraji et al., the difference between two solutions
  - Analog Doherty
  - Digital Doherty
  is as much as:
  
  - 60% output power
  - 20% efficiency
  - 50% bandwidth
  - no degradation in DPD efficacy.

- But, how can the difference be identified on a case-by-case basis?
Background on Doherty architecture

**Facts**
- Invented almost 100 years ago
- Efficiency enhancement method
- Linearity-preserving
- Two (or more) amplifiers that interact through a special combining network

**Applications**
- Mostly for below 3 GHz until now
- Dominates on base station infrastructure

**New Frontier**
- Higher carrier frequencies, wider BW
- 5G in mmW, SatCom (Ku-, Ka-bands)
Background

- Various possibilities of efficiency-enhancement architectures
- Doherty amplifier is just one
Challenge 1: Combining the 2 paths

- Misalignment of signals
  - loss of power
  - loss of energy efficiency
  - destructive voltages/currents

- Input signals need to be matched for amplitude and phase
  - Time domain
  - Frequency domain
  - Amplitude domain
Challenge 2: 2 different paths

- Ideal performance by auxiliary characteristic is “dog leg”
  - Often approximated by “Class C” amplifier

- Performance driven by difference between the main and auxiliary curves

- The two extremes
  - Main, the Doherty ‘effect’ tends to 0 (or like ‘Balanced’)
  - Ideal, the Doherty ‘effect’ is maximized
Challenge 3: Find right amplifier setup for 2 paths

- Different classes of amplifier to drive the Doherty difference engine can be disadvantageous.

- The Fourier Analysis of conduction angle shows how, power and efficiency might be compromised.
  - Power is lost from the auxiliary
  - Efficiency is lost from the main

- The quiescent bias power demands of the main can prove costly, especially in TDMA operation.

![Efficiency and Output Power vs Conduction Angle](image)

**Power and Efficiency impacts of conduction angle [Cripps].**
Challenge 4: Signal splitter

- How to design the input splitter?

- After design and alignment of the output section, designers often use cut-and-try techniques on the input side.

- Salient features of this method:
  - Labour intensive
  - Non-exhaustive, sparse characterization
  - Global maxima unconfirmed
  - Cannot easily adjust amplitude balance
  - Poorly defined structures
  - Lossy components
  - Matching variations
Extremes of Doherty implementations:

- The default setup
  - Single gain stage inside a Split-Doherty Combine.
  - Differentially biased devices

- Digital Doherty
  - Independent paths all the way from digital domain
  - Common biased devices

In between lies a whole range of implementation solutions, with differing features and trade-offs.
Measurement aided development

**Idea**
- Additional measurement-based step in the traditional Doherty development process
- Remove the input split and phase shift networks
- Drive two Doherty input ports directly from a signal generator

**Benefits**
- Better view of performance tradeoffs
- In-depth understanding of sensitivities
- Benchmark maximum performance
- Select best input split and specify performance with confidence
- Applicable to all input split architectures

The test and measurement concept
Dual-Path Measurement (Linear)

- Same signal to both RF paths
- Sweep input power, amplitude and phase difference (optionally bias, etc.)
- Measure what is of interest like saturated power, RMS, PEP, Efficiency, ACLR or PAPRo

Result:
- Dispersion of amplitude/phase between parameter optima and frequency
- This is already far ahead of the usual characterization dataset.
Apply mean variance

- Simulation of production variation vs gain and phase
- In this case, die-die variation superimposed on wafer-wafer variation
- Then spread it over frequency range using measurement data as a LUT
Slight variation: equalized input

- Different input split, optimized for efficiency at the two design frequencies
- Apply the same randomized population of gain-phase spread across wafer and die – and the same post-processing…
Increased mean, reduced deviation

- Goal: optimized efficiency, we get on top
  - Increased mean value
  - Reduced standard deviation
  → improved specification

- Even a simple modification to the design flow and analysis can have significant improvements and consequences
Dual-Path Measurement (Non-Linear)

- Apply different, but related signals to the two RF paths and common-mode biasing. Simple case:
  - Auxiliary signal derived from square of the Main signal
  - Biased at threshold

- Driven by the increased saturated power (representing the limit of linearization)
  - 47% higher output power (43.8dBm -> 45.5dBm)
  - 11% higher efficiency (44% -> 49%)
  - 94% reduction in “stand-by” power consumption (100mA -> 6mA)

- Compare with the reported 60% output power, 20% efficiency, 50% bandwidth and no degradation in linearizability.
Results

Conventional Mode Operation

- Improve Doherty Amplifier in efficiency and output power

Dual-Input Mode Operation
Hardware

R&S®SMW200A Vector Signal Generator
- Dual-path with precise signal alignment
- Relative phase, amplitude, timing adjustment
- Power split and input-power dependent phase delta in real time
- Shaping

R&S®FSW Signal and Spectrum Analyzer
- Wide analysis bandwidth
- Dedicated amplifier test capabilities with all interesting parameters from EVM to Gain compression
- Vectors like AM-AM and AM-PM
R&S®SMW-K546 Digital Doherty Software Option

- Couple RF paths with precise phase and power alignment
- Power split and input-dependent phase delta
- Arbitrary delta-power, delta-phase
Conclusions

- Perfect Doherty operation cannot be achieved. But, performance can be strongly differentiated by the input side architecture.

- Various input side designs for the Doherty amplifier, including:
  - Fixed constant, or fixed dispersive, RF split
  - Programmable RF split
  - Dispersive RF split
  - Digital domain split
  … and so on, each correcting frequency, time or amplitude domain effects.

- The proposed measurement set-up enables a comprehensive, rapid and accurate characterization of the Doherty Prototype.

- Measuring as a Dual-Input:
  - Provides unprecedented insight.
  - Enables the best engineering decision to be made, supported by the most information, in the shortest time.
References, Acknowledgements & Further Reading.

