Simultaneously Reconfigurable RF Circuitry and Optimizable Waveforms to Meet Spectral Mask Requirements and Maximize Power Efficiency

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Joint Optimization: The Way Forward

- State-of-the-art approaches to improving spectral conformity have traditionally included separate examination of
  - Circuit design
  - Waveform design
- The technology and theory now exist to simultaneously optimize both!
- Stages
  - Test Bed Development
  - Implementation from FPGA cognitive radar platform.
Baylor Waveform and Load Optimization Lab Test Hierarchy

MATLAB

- Agilent Vector Signal Generator (Waveforms)
- Maury ATS Load-Pull Software and Tuners
- Spectrum Analyzer (ACPR and Distortion)
- Power Meter (Power/PAE Measurements)
Test Bed Configuration

Signal Generator (Agilent N5182A) ➔ Automated Impedance Tuner (Input) ➔ DC Bias (Agilent E3647A) ➔ DUT ➔ Automated Impedance Tuner (Output) ➔ 10 dB Attenuator ➔ 6 dB Power Splitter ➔ Power Meter (Agilent N1911A)

Legend
- RF Path
- Other

ATS Tuner Controller
Load Matching Circuit Optimization

• Empirical load-pull measurements can determine optimum $\Gamma_s$, $\Gamma_L$.

• Simulations of accurate nonlinear models are useful.

• A network parameter approach similar to S-parameters would be very helpful.
Fast Load-Impedance Optimization Algorithm*

- Traditional:
  - 400 Γ states
  - Maximum Power = 22.76 dBm
- Steepest Ascent:
  - 17 Γ states
  - Maximum Power = 22.72 dBm
- Accurate results for small number of simulations or measurements

Simulation: Different Search Starting Points

- All six endpoints within 0.02 dBm.
- Resistance
  - Mean: 17.537 Ω
  - St. Dev.: 0.422 Ω
- Capacitance:
  - Mean: -0.3421 pF
  - St. Dev.: 3.407 fF

Unbiased search yields low number of simulated points regardless of starting location.
Aiding the Optimization

- Searches are great, but a lot of variables!
  - Load reflection coefficient (2 real variables)
  - Source reflection coefficient (2 real variables)
  - Input waveform harmonics (perhaps 5)
- Data is needed to aid the optimization.
- Wirtinger Calculus for TIPP Systems characterizes the harmonic transfer characteristics of the system → information to optimize both waveform and circuit.
TIPP Systems

- Assume a time invariant periodicity preservation (TIPP) system.

LTI: All currents and voltages oscillate at the same frequency.

TIPP: All currents and voltages are periodic with the same period (harmonic levels can change).
Affine Approximation

- Consider a nonlinear function $f(x)$:

$$f(x_0 + \Delta x) \approx f(x_0) + \frac{df(x_0)}{dx} \Delta x$$

- Affine approximation around the operating point of a nonlinear function
Fourier Series Linearization: TIPP Parameters

\[ x(t) = X(t) + \Delta x(t) \quad \text{TIPP} \quad y(t) = Y(t) + \Delta y(t) \]

\[ \bar{y} = \bar{Y} + \Delta \bar{y} \approx \bar{Y}(\bar{X}) + [J(\bar{X})]\Delta \bar{x} + [J^*(\bar{X})]\Delta \bar{x}^* \]

\[ J_{mn} = \left. \frac{\partial y_m}{\partial x_n} \right|_{\Delta x \to 0} \approx \left. \frac{\Delta y_m}{\Delta x_n} \right|_{\Delta x \to 0} \]

Change in the mth harmonic at the output due to a small input perturbation at the nth harmonic.

The phasor at the \(-n\)th harmonic is the conjugate of the \(n\)th phasor.

\[ J_{mn}^* = \left. \frac{\partial y_m}{\partial x_n^*} \right|_{\Delta x \to 0} \approx \left. \frac{\Delta y_m}{\Delta x_n^*} \right|_{\Delta x \to 0} = \left. \frac{\Delta y_m}{\Delta x_{-n}} \right|_{\Delta x \to 0} \]

Examples: X-parameters, S-functions
Agilent X-Parameters

Each X parameter is a function of $|A_{11}|$.

$B_{ef} = X^{(F)}_{ef}(|A_{11}|)P^f + \sum_{g,h} X^{(S)}_{ef,gh}(|A_{11}|)P^{f-h}a_{gh} + \sum_{g,h} X^{(T)}_{ef,gh}(|A_{11}|)P^{f+h}a_{gh}^*$

* $D. \ Root, \ “A \ New \ Paradigm \ for \ Measurement, \ Modeling, \ and \ Simulation \ of \ Nonlinear \ Microwave \ and \ RF \ Components,” \ Presentation \ at \ Berkeley \ Wireless \ Research \ Center, \ April \ 2009.$

$P = e^{j\angle A_{11}}$ provides phase correction for harmonic conversion.

**C. \ Baylis \ et \ al., \ “Going \ Nonlinear,” \ IEEE \ Microwave \ Magazine, \ April \ 2011.”**
Conclusions

• Spectral spreading from radar systems must be mitigated, but not at the cost of system efficiency.
• Several useful design approaches exist for linearity and efficiency improvement.
• An apparent solution is in joint waveform and circuit optimization with the Wirtinger calculus.
• An approach and test platform for real-time load-pull and waveform optimization is under development at Baylor University.
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