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WIRELESS AND MICROWAVE CIRCUITS AND SYSTEMS

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

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ISART R&D Panel
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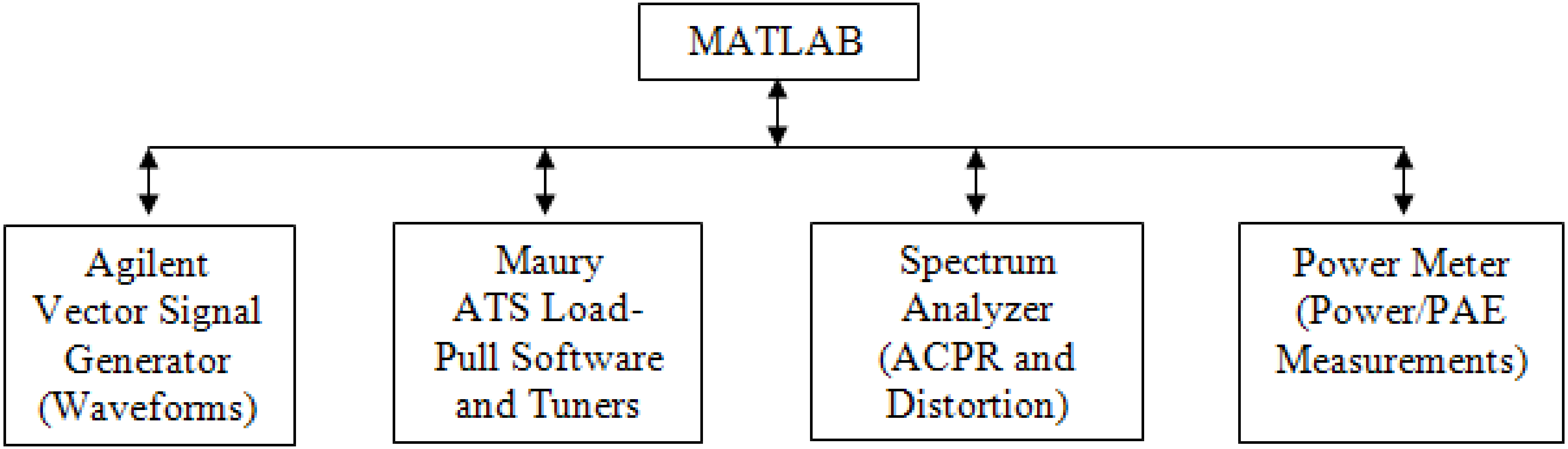
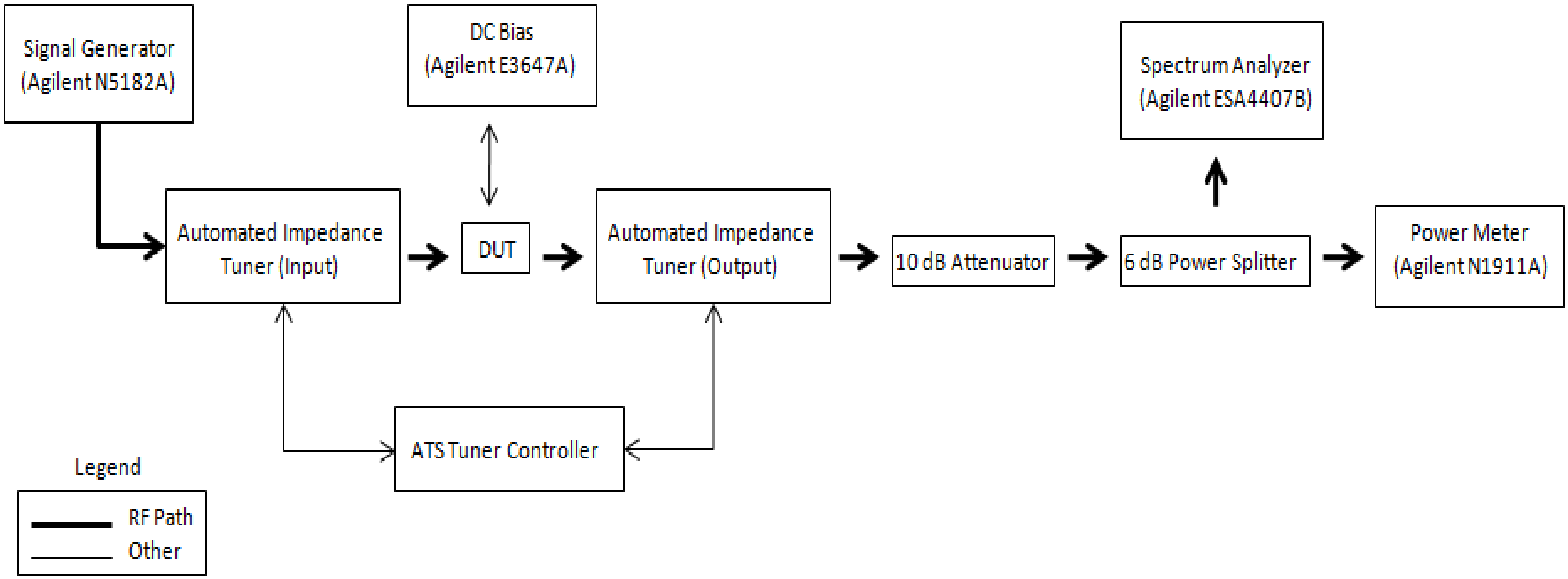
Joint Optimization: The Way Forward

- 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



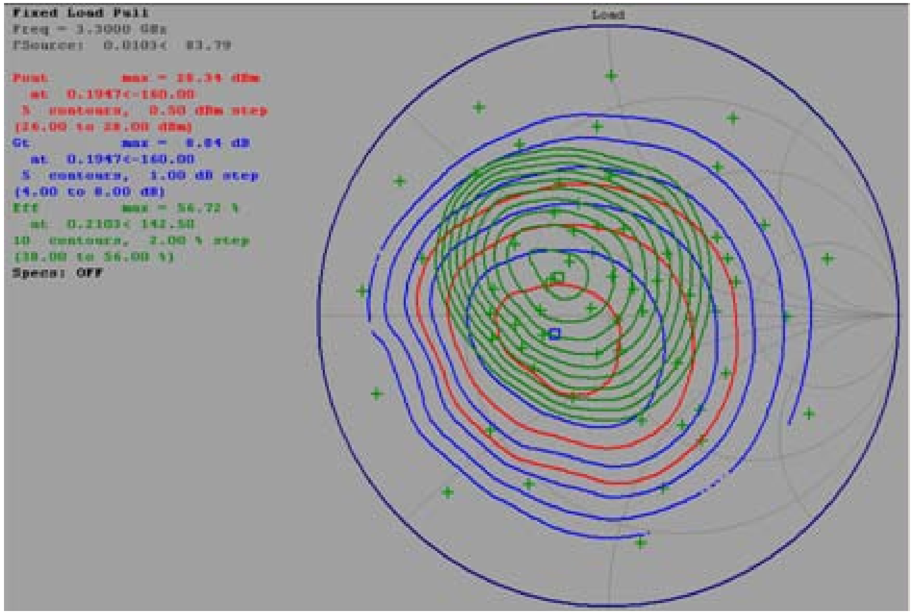
Test Bed Configuration



Load Matching Circuit Optimization

- Empirical load-pull measurements can determine optimum Γ_s, $\Gamma_{L.}$
- Simulations of accurate nonlinear models are useful.
- A network parameter approach similar to S-parameters would be very helpful.

GaN HEMT Load-Pull Measurement:



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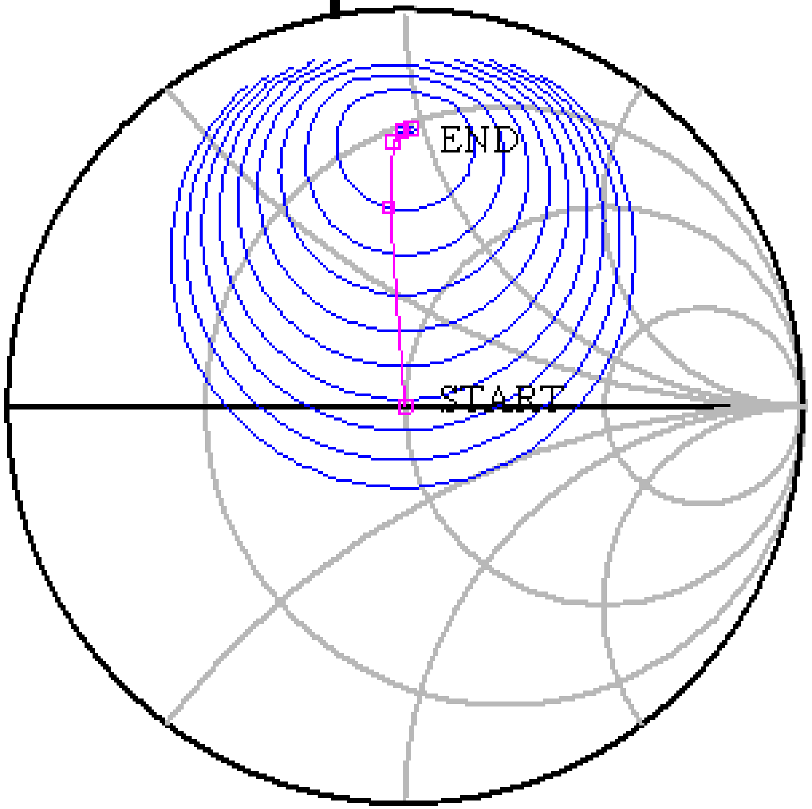
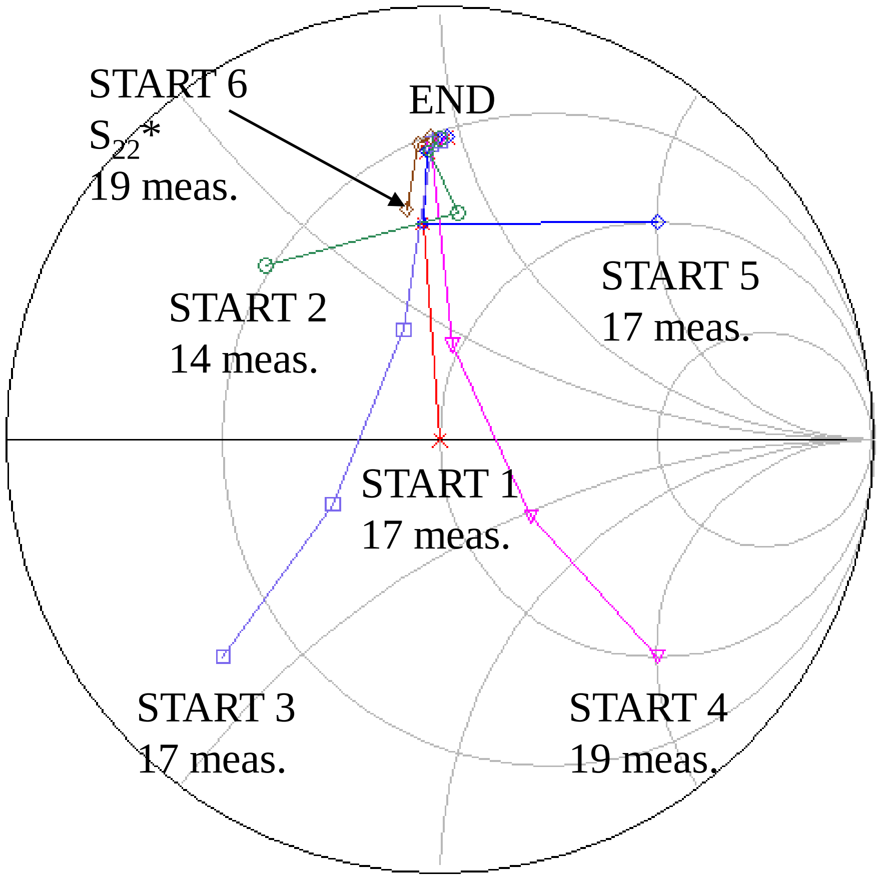
Fast Load-Impedance Optimization Algorithm*



- 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

*C. Baylis, L. Dunleavy, S. Lardizabal, R.J. Marks II, and A. Rodriguez, "Efficient Optimization Using Experimental Queries: A Peak-Search Algorithm for Efficient Load-Pull Measurements," *Journal of Advanced Computational Intelligence and Intelligent Informatics*, Vol. 15, No. 1, January 2011.

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

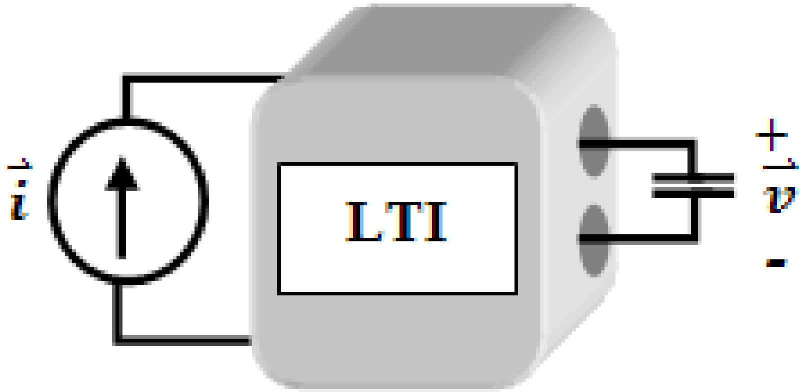
Unbiased search yields low number of simulated points regardless of starting location.

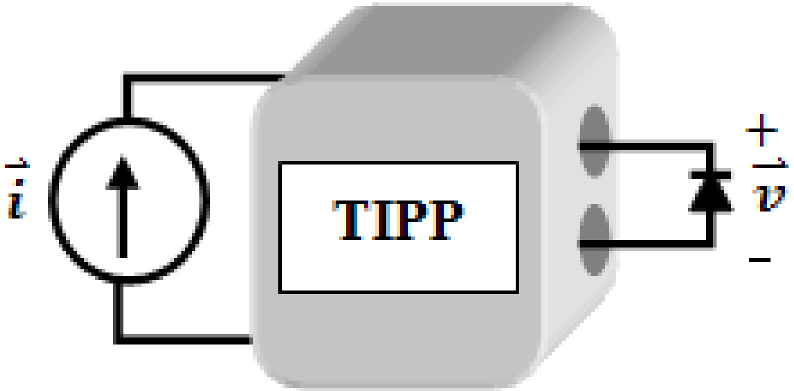
Aiding the Optimization

- 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.



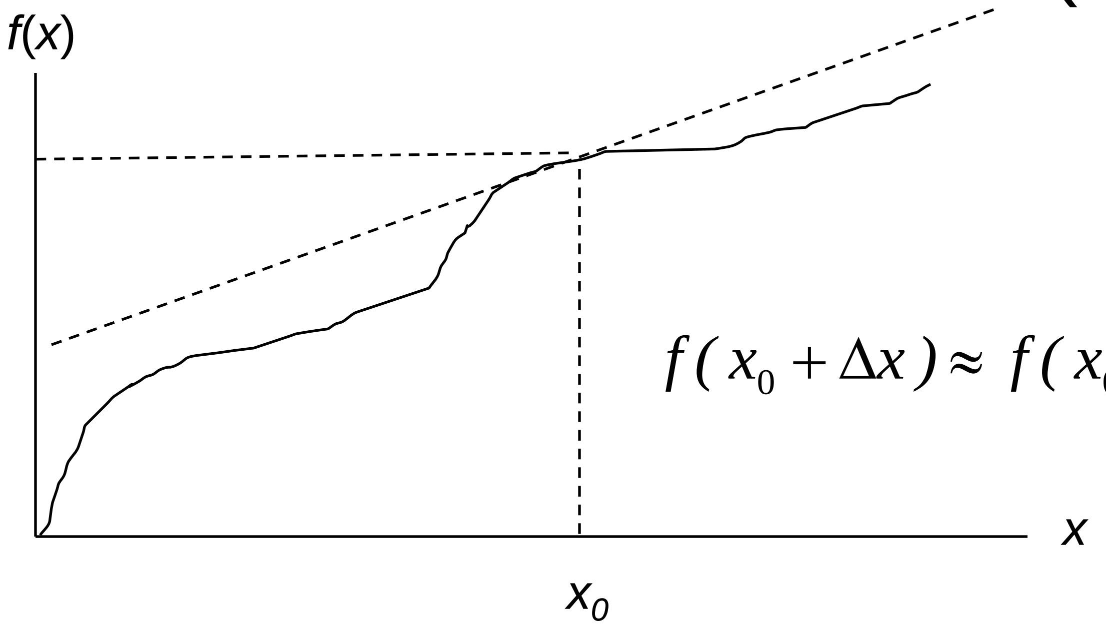


LTI: All currents and voltages oscillate at the same frequency.

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

Affine Approximation

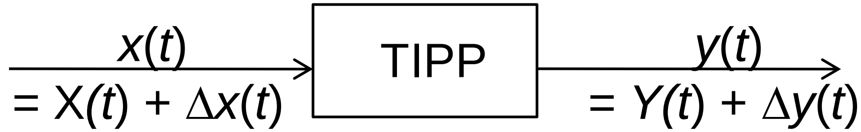
- Consider a nonlinear function *f* (*x*):



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

- Affine approximation around the operating point of a nonlinear function

Fourier Series Linearization: TIPP Parameters



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

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

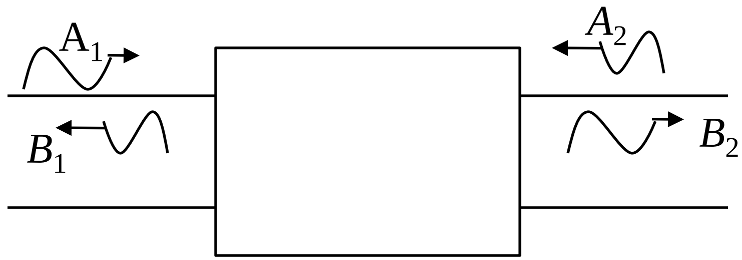
Change in the mth harmonic at the output due to a small
Input perturbation at the nth harmonic

$$J^*_{mn} = \frac{\partial y_m}{\partial x^*_n} \approx \left.\frac{\Delta y_m}{\Delta x^*_n}\right|_{\Delta x \to 0} = \left.\frac{\Delta y_m}{\Delta x_{-n}}\right|_{\Delta x \to 0}$$

The phasor at the –nth harmonic
Is the conjugate of the +nth phasor.

Examples: X-parameters, S-functions

Agilent X-Parameters[1]*



[1]X-parameters is a registered trademark of Agilent Technologies.

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

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

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

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

$$X_{ef,gh}^{(S)}$$

Arrival Port — Arrival Harmonic — Departure Port — Departure Harmonic

**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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