A Simplified, Empirical Large Signal Model for SiC MESFETs

Kelvin Yuk and G. R. Branner
Dept of Electrical and Computer Engineering
UC Davis

Outline

- Background
- Objectives
- Model Description
  - Drain current
  - Parasitics
- Experimental Verification
  - S-parameters measurements
  - Harmonic power measurements
- Conclusions

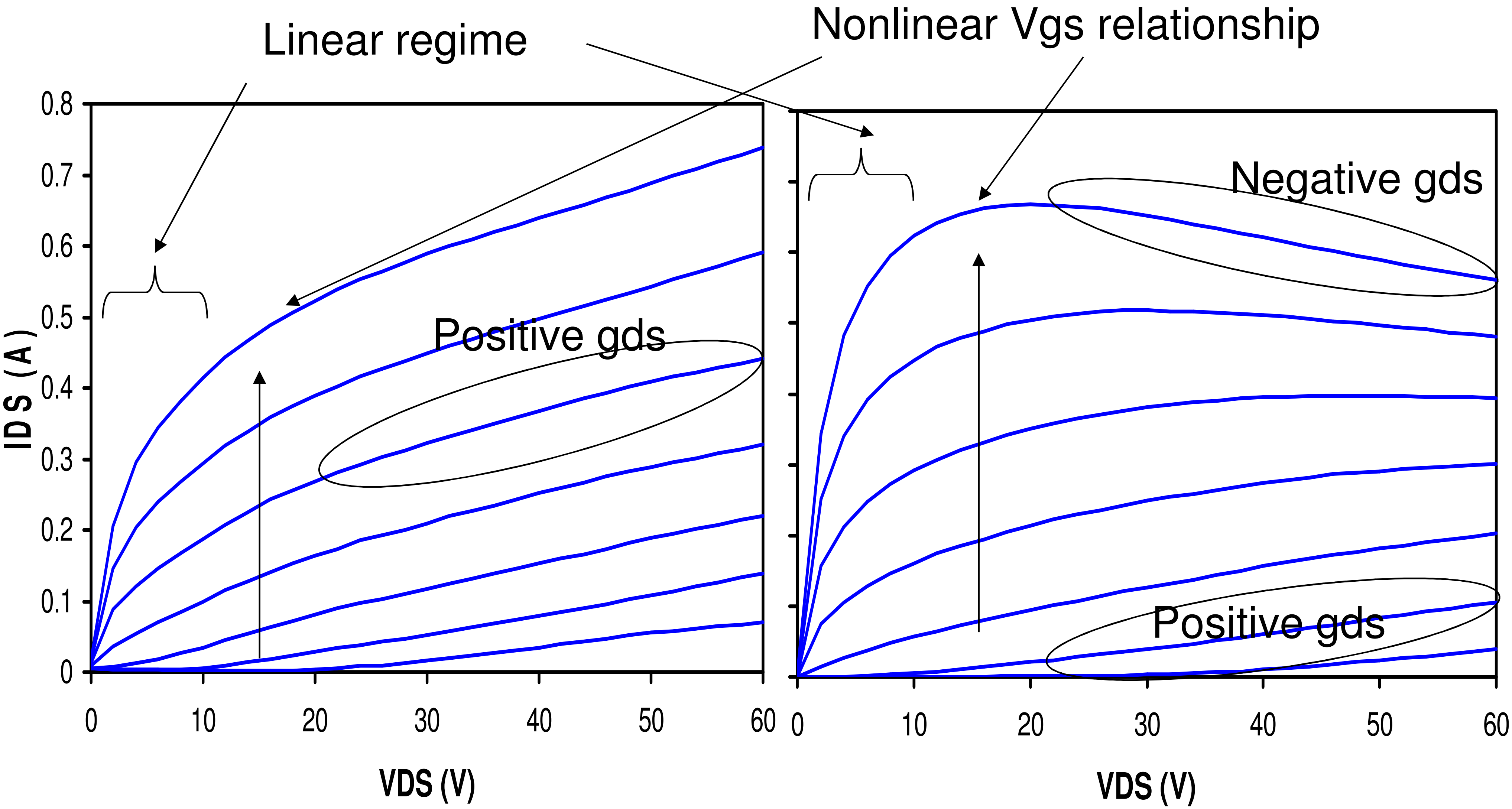
Background

- Growing interest in wide bandgap semiconductor technologies (SiC and GaN)
- SiC technology features
  - High breakdown voltage → high RF power output
  - High power density → Self-heating effects
- Applications: PAs , mixers, oscillators …
- Large-signal CAD model is important
- This Work
  - Cree CRF-24010 10W SiC MESFET

Objectives

- Develop an accurate empirical large-signal model capable of predicting
  - IV characteristics
  - Small signal S-parameters
  - Harmonic power for the first three harmonics
- Challenges
  - Obtaining accurate characterization of the device
  - Handling IV current dispersion “drooping” effects
  - Extracting intrinsic and extrinsic parasitics
  - Modeling output and input reflected harmonics
  - Minimizing model complexity

Elements of Pulsed and Static IV



Pulsed IV Characteristics

Static IV Characteristics

Drain Current Model

- How do we handle high power current dispersion?
- Use pulsed IV characteristics (PIV)
  - Resemble static IV curves of low power devices
  - Use known models with success
  - Only good for one bias → not for general purpose model
  - Static characteristics may be important (class A bias)
- Modify existing drain current models
  - Add dedicated parameters to account for dispersive behavior
  - Increased complexity. Parameters may not be fully exploited.
- In this work
  - Reformulate drain current equation using known mathematical modeling techniques
  - Develop mathematical model with variable order → model IV characteristics of variable complexity

Original Chalmer's Model

- Chalmer's model

$$\psi = P_1(Vgs - Vpk) + P_2(Vgs - Vpk)^2 + P_3(Vgs - Vpk)^3 \ldots$$

$$Ids = \underbrace{\underbrace{Ipk(1+\tanh(\psi))}_{\text{Nonlinear Vgs relationship}}}_{\text{Total Vgs dependence}} \underbrace{\underbrace{(1+\lambda Vds)}_{\text{Linear Vds relationship (saturation)}} \underbrace{\tanh(\alpha Vds)}_{\text{Nonlinear Vds relationship (linear regime)}}}_{\text{Total Vds dependence}}$$

Nonlinear Vgs relationship

Linear Vds relationship (saturation)

Nonlinear Vds relationship (linear regime)

Total Vgs dependence

Total Vds dependence

- Assumes influence of Vgs and Vds on Ids are separable
- Assumes gmpk occurs at the same Vgs independent of Vds

Drain Current Equation

- Drain current equation for this model

$$Ids = Ipk\left(1+\tanh\left(\psi\right)\right)$$

$$\psi = P_1\left(Vgs-Vpk\right)+P_2\left(Vgs-Vpk\right)^2+P_3\left(Vgs-Vpk\right)^3\ldots$$

$$P1 = Q_{01}+Q_{11}\left(Vds\right)+Q_{21}\left(Vds\right)^2+Q_{31}\left(Vds\right)^3\ldots$$

$$P2 = Q_{02}+Q_{12}\left(Vds\right)+Q_{22}\left(Vds\right)^2+Q_{32}\left(Vds\right)^3\ldots$$

$$P3 = Q_{03}+Q_{13}\left(Vds\right)+Q_{23}\left(Vds\right)^2+Q_{33}\left(Vds\right)^3\ldots$$

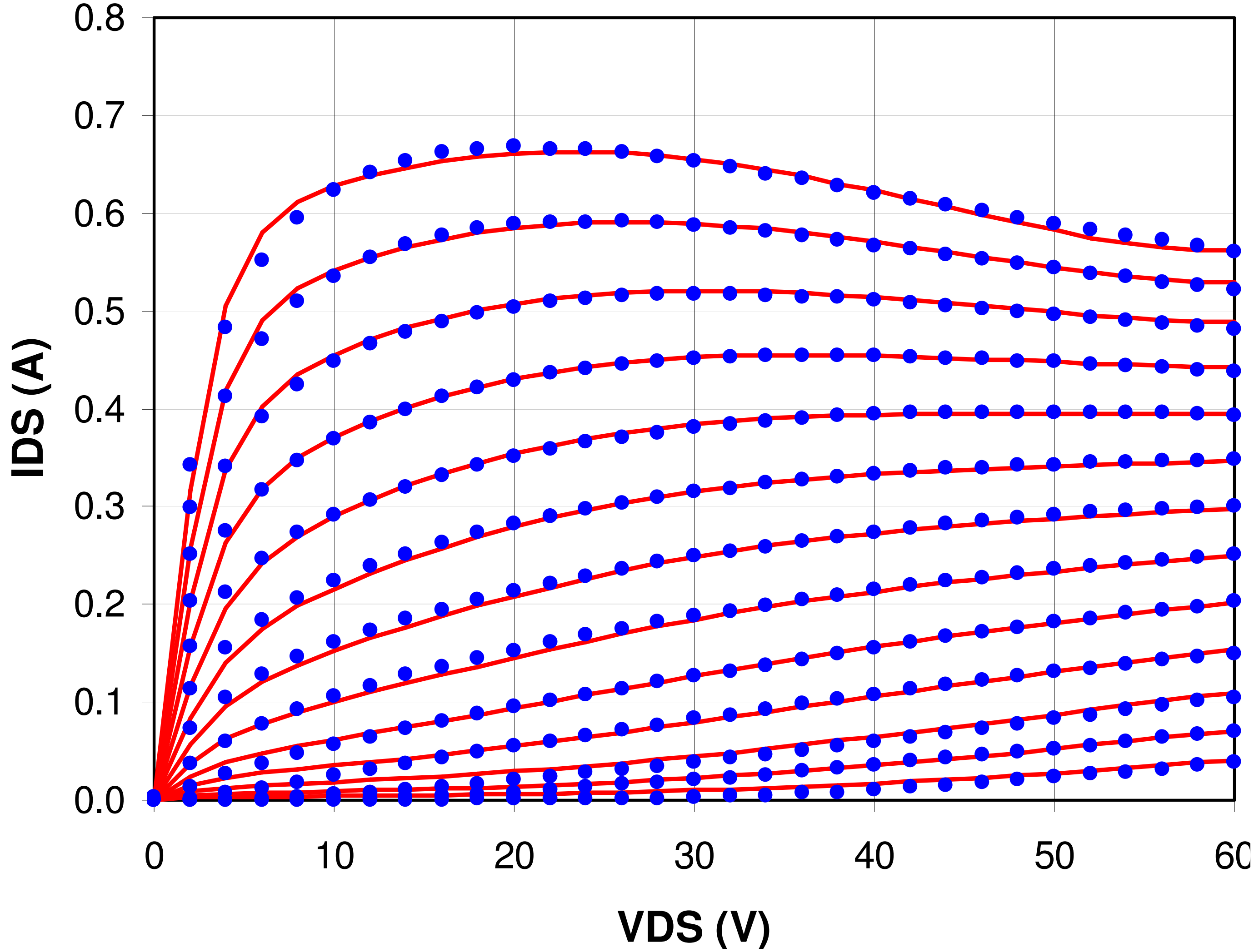
$$\vdots$$

- Use Chalmer’s method to describe Vgs nonlinearity
- Coefficients Pn are each a power series of Vds
- Since gmpk, Ipk, Vpk not constant across Vds, use power series to track Pn across Vds
- Effects of Vgs and Vds are not treated as separable

Drain Current Equation Advantages

- Polynomials
  - Easy to implement, coefficients easy to determine
  - Differentiable
  - Mathematical order can be configured
    - Linear channel length effects (low order)
    - Nonlinear channel length effects (high order)
- Chalmer's method for Vgs relationship → P2 is eliminated
- Possible elimination of tanh(αVds) term
  - linear region no different from saturation region if gmpk, Vpk and Ipk modeled correctly
  - gmpk, Vpk and Ipk difficult to model at low Vds
- Purely electrical characterization of Ids
  - No physical or temperature varying parameters

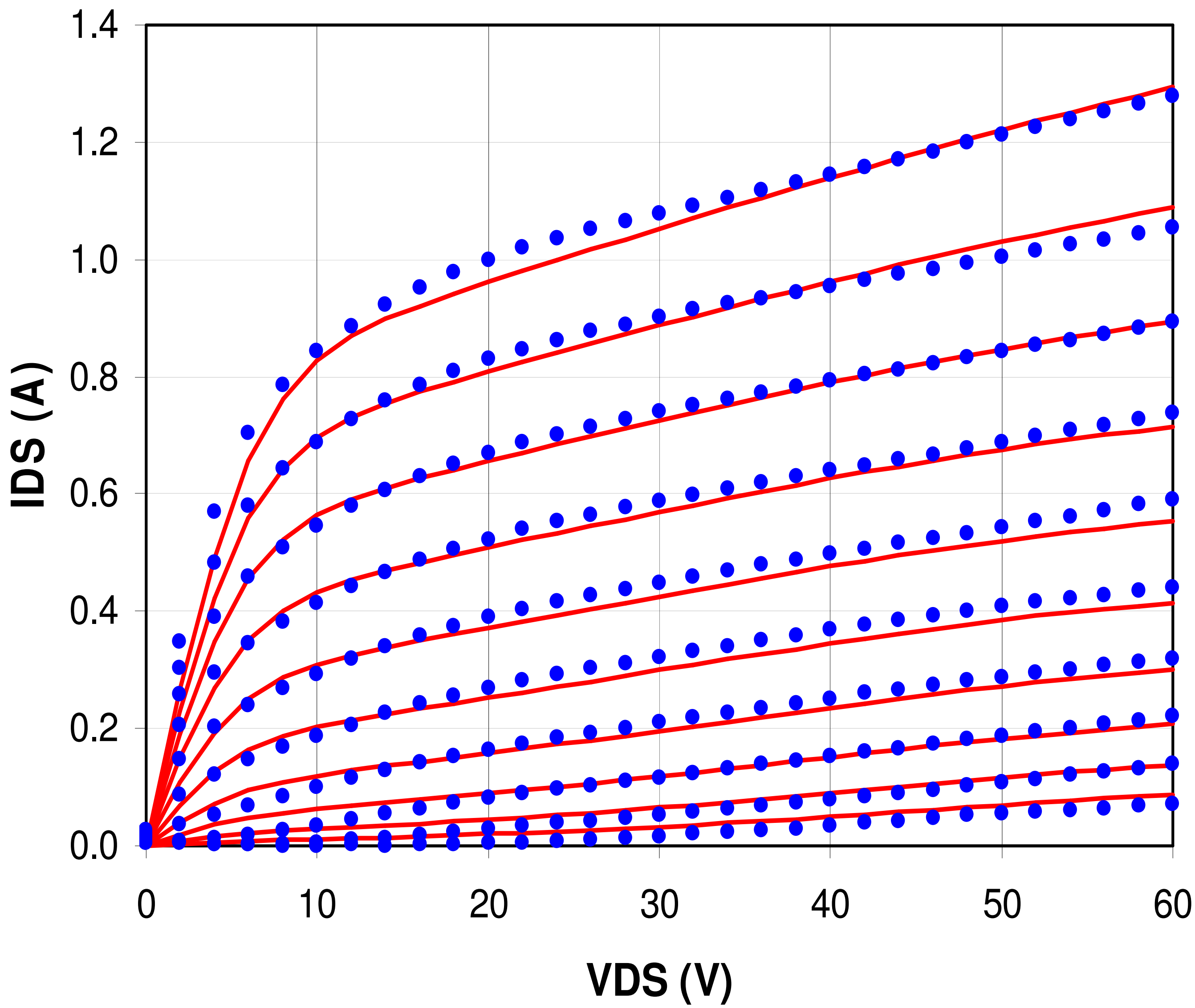
Drain Current Model – Static IV



- Vgs=-10.0V to -4.0V, 0.5V steps, Vds=0V to 60V, 2V steps
- Accurate modeling of complex static characteristics

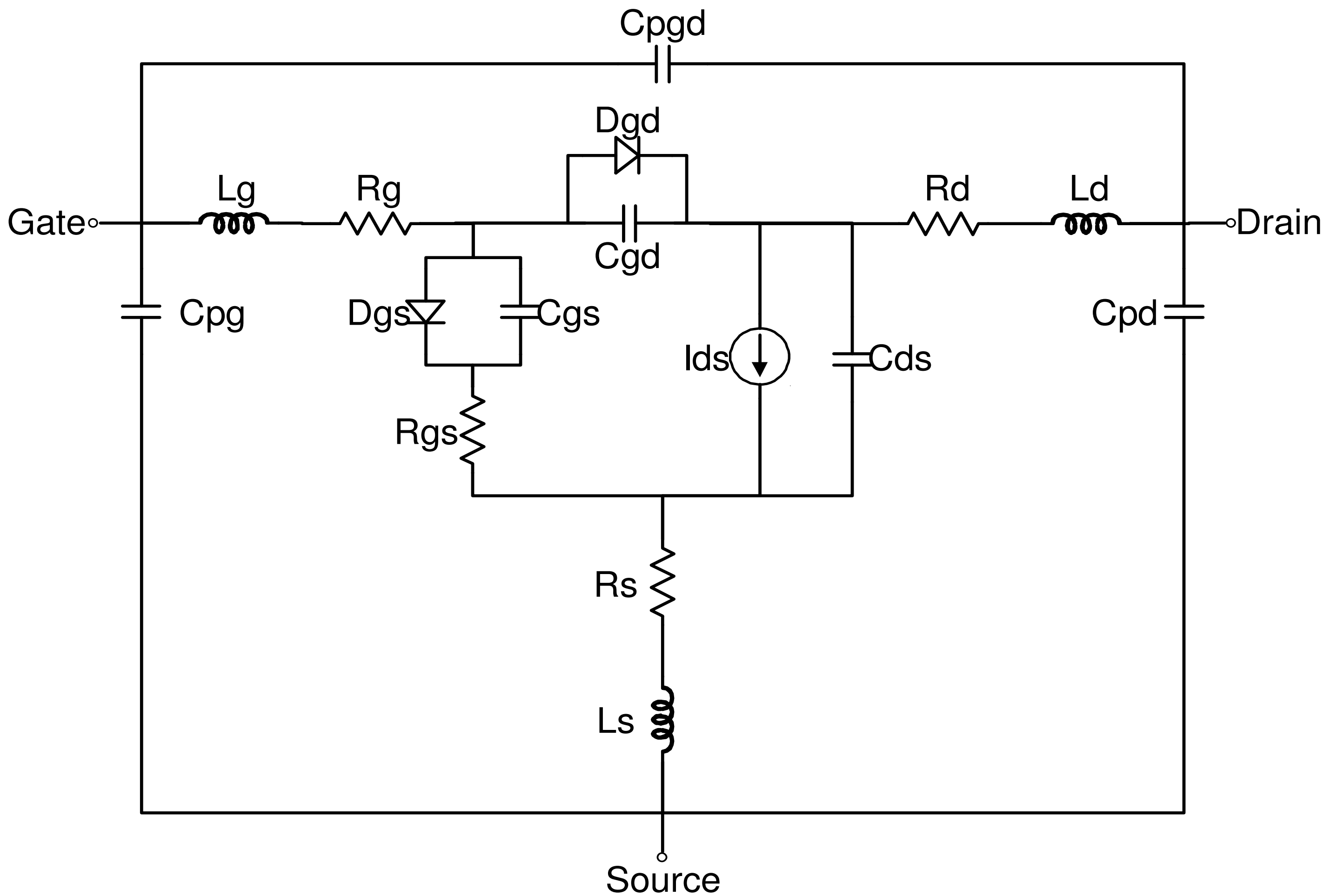
Drain Current Model – Pulsed IV

- Pulsed IV data using Auriga DIVA (Nanometrics)
- Same math form, variable order allows modeling of PIV
- tanh(αVds) improves linear regime fit
- PIV drain current model used in large-signal model



VGS=-10V to 1V, 1V steps, VDS=0V to 60V, 2V steps

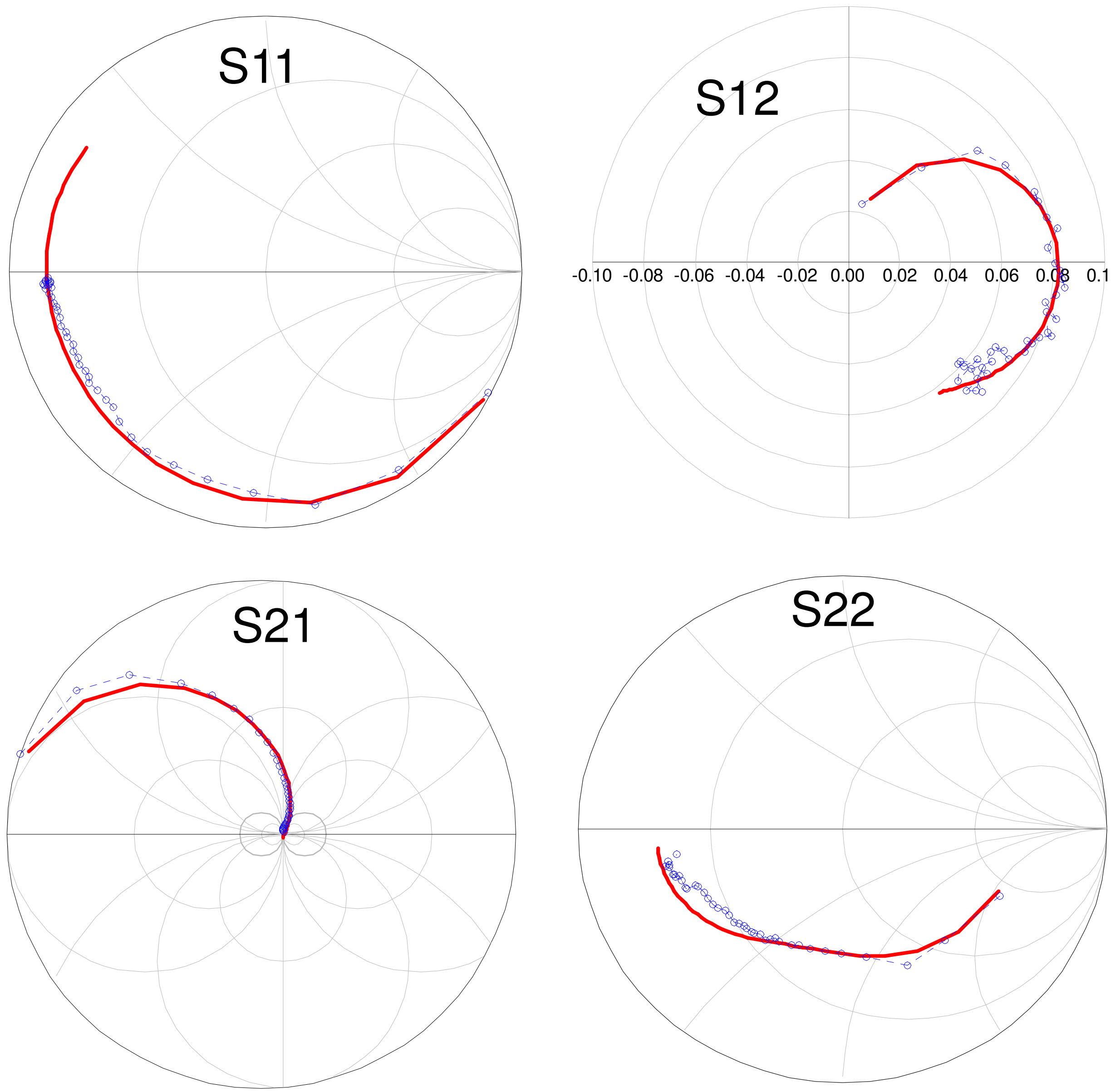
Complete Model with Parasitics



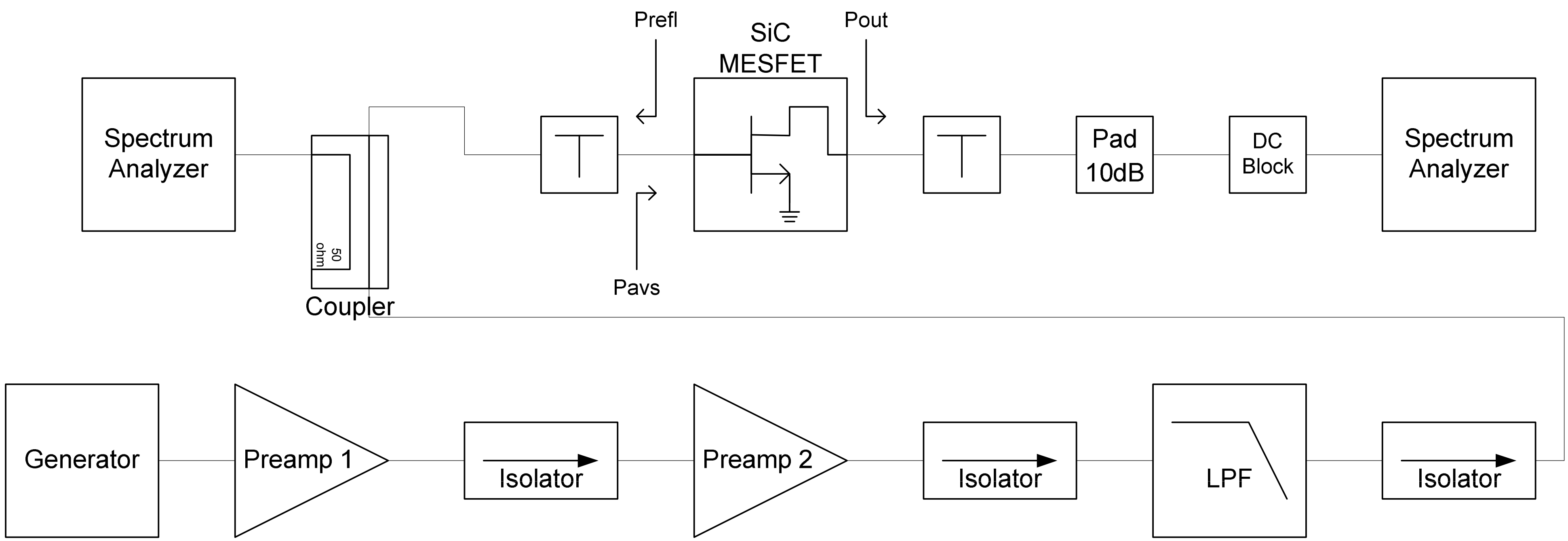
- Uses standard large-signal model topology → Simple
- Parasitics extracted from S-parameter measurements
- Ids parameters optimized with parasitic resistances
- Nonlinear caps modeled with Chalmer's charge eqs

S-parameter Verification

- Cree CRF-24010 biased at VDS=48.0V IDS=500mA
- Frequency range 0.1GHz to 4.0GHz at -5dBm source
- Good agreement with measured data
- Supplemental RF current generator not needed

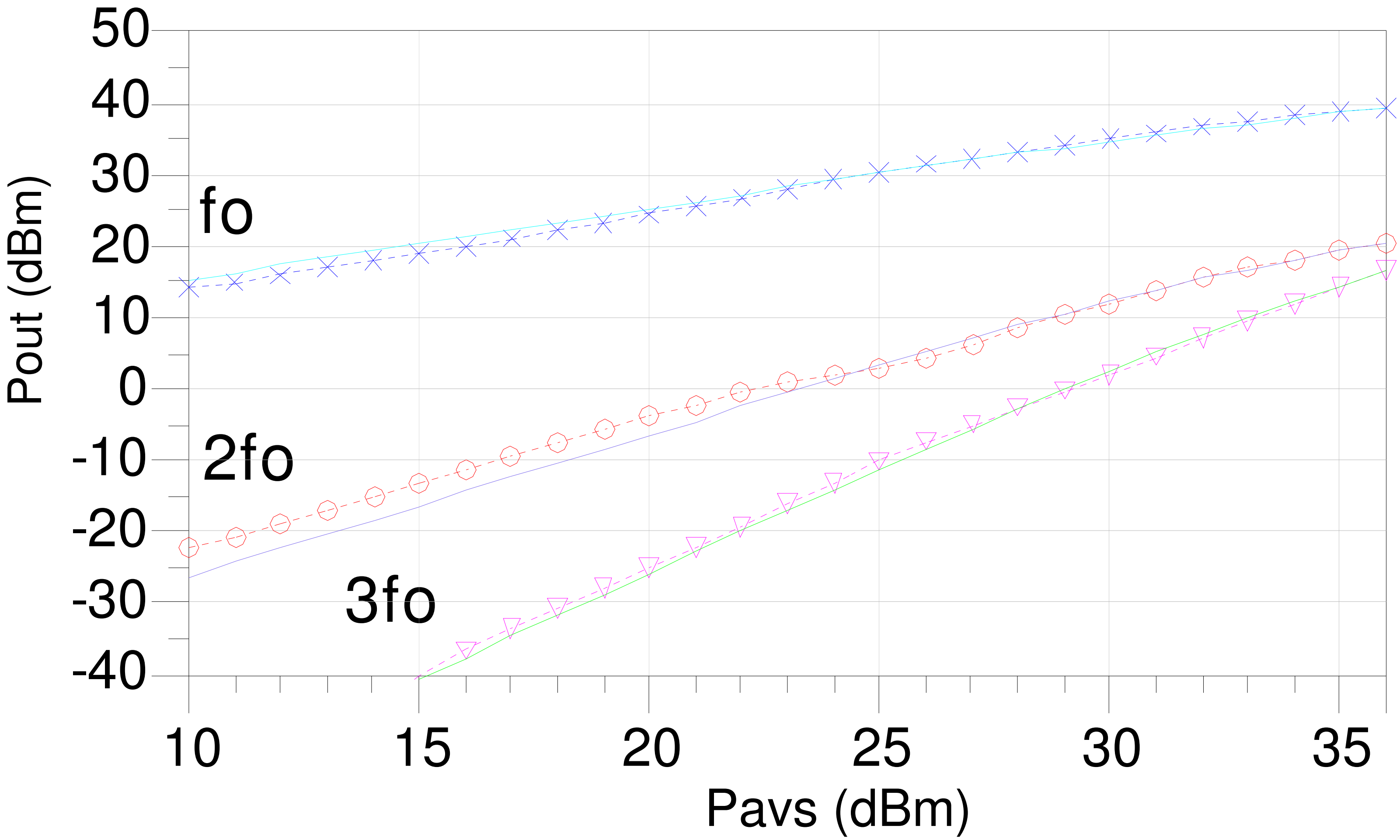


Harmonic Power Verification



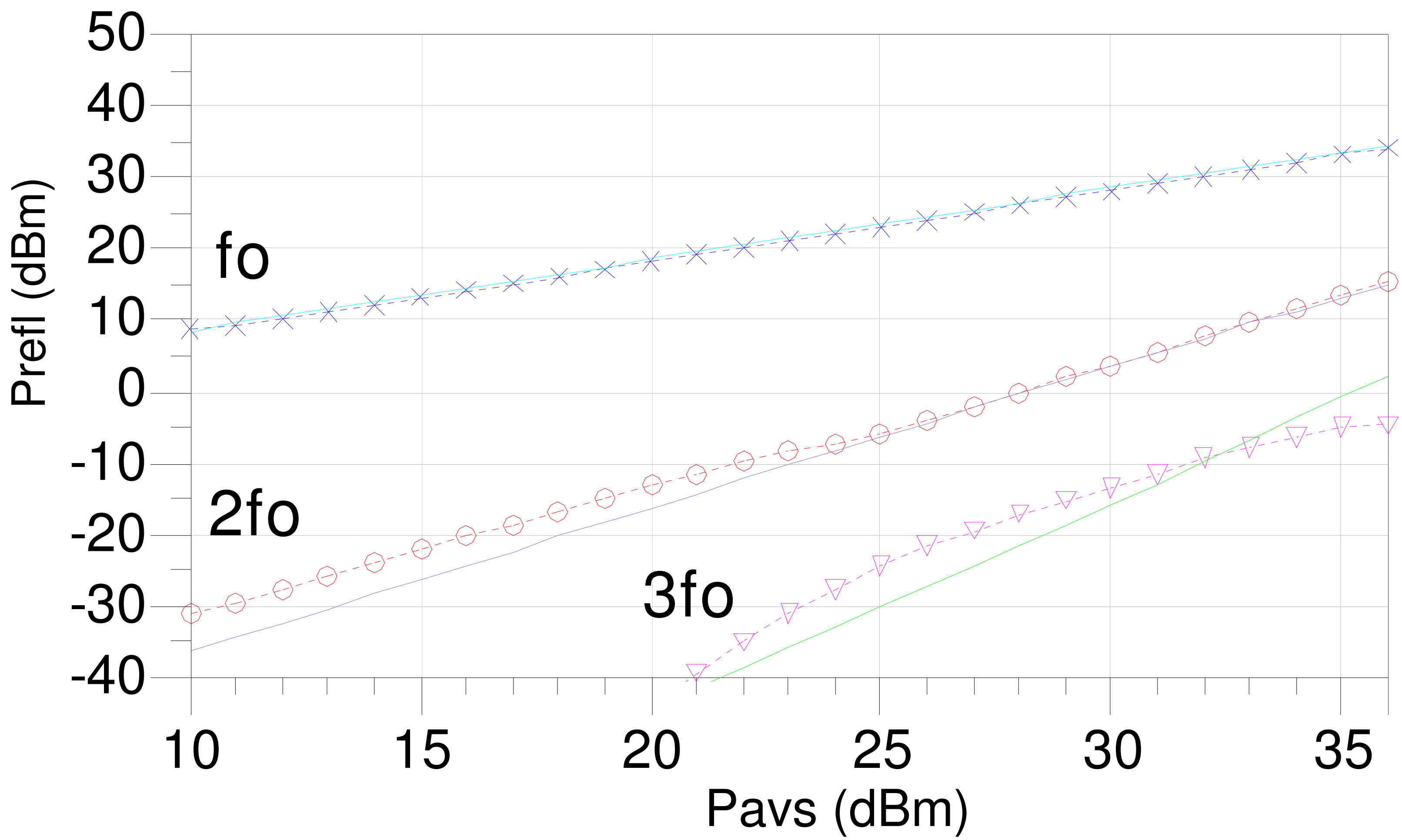
- Large signal measurement system
  - DUT driven at 2GHz from 10dBm to 36dBm
  - Output and input reflected power for three harmonics
- No impedance matching on DUT
  - Harmonic generation and power reflection
  - Generalized characterization using 50 Ohms terms

Output harmonic power



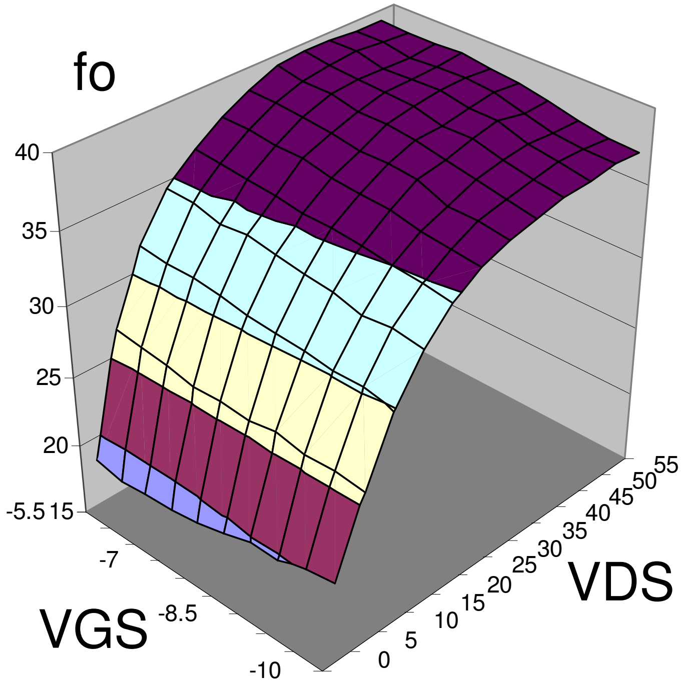
- Good agreement for three harmonics from 10dBm to 36dBm source power at 2.0GHz for DUT biased at VDS=48.0V, IDS=500mA
- Up to fundamental output power of 40dBm

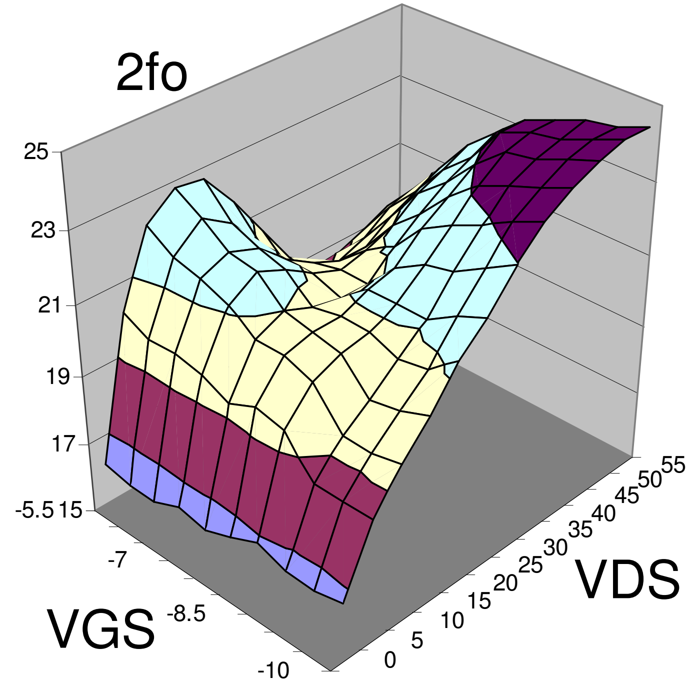
Input reflected harmonic power

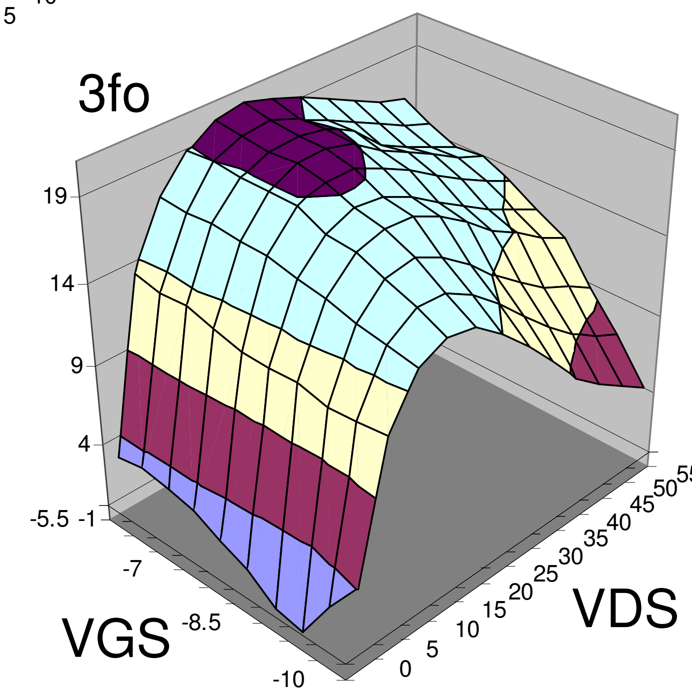


- Good agreement for three harmonics from 10dBm to 36dBm source power at 2.0GHz for DUT biased at VDS=48.0V, IDS=500mA
- Up to fundamental reflected power of 34dBm

Further Work - Harmonic Power







36dBm incident available source power

VGS=-10V to -5.5V in 0.5V steps

VDS=0V to 55V in 5V steps

- Large signal power measurement over swept biases

Conclusions

- A new, simple empirical large-signal model for SiC MESFETs presented
- Mathematically versatile drain equation combining power series with Chalmer's model
  - Static IV
  - Pulsed IV
- Large-signal SiC MESFET model can predict
  - Pulsed IV characteristics
  - S-parameters without RF current generator
  - Large signal output and input reflected power for three harmonics

Acknowledgements

- Authors would like to thank the following people for their support and contributions to this work
  - Dr. Giovonnae Anderson
  - Dr. David McQuate
  - Dr. Wayne Martin

Development of our IV model

- Step 1: Take data
- Step 2: (Optional) Interpolate and extrapolate data if necessary
- Step 3: Take the derivative of Ids wrt Vgs at every Vds value. From this, find gmpk, Ipk, Vpk at every Vds.
- Step 4: Fit gmpk, Ipk, Vpk wrt Vds to a polynomial
- Step 5: Guess a set of P parameters at each Vds
- Step 6: Optimize the P for every Vds. In other words, fit Ids vs Vgs curve for each value of Vds.
- Step 7: Fit the optimized P parameters as polynomial functions wrt to Vds.
- Step 8: Using the fitted parameters, compute the Ids based on the polynomial fitted Angelov model