Simulation of Traveling-Wave Tube Multi-Tone Behavior

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2.3 Traveling Wave Tubes - September 9, 2016

TUHH THALES

Outline

Outline

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Helix Traveling-Wave Tube.

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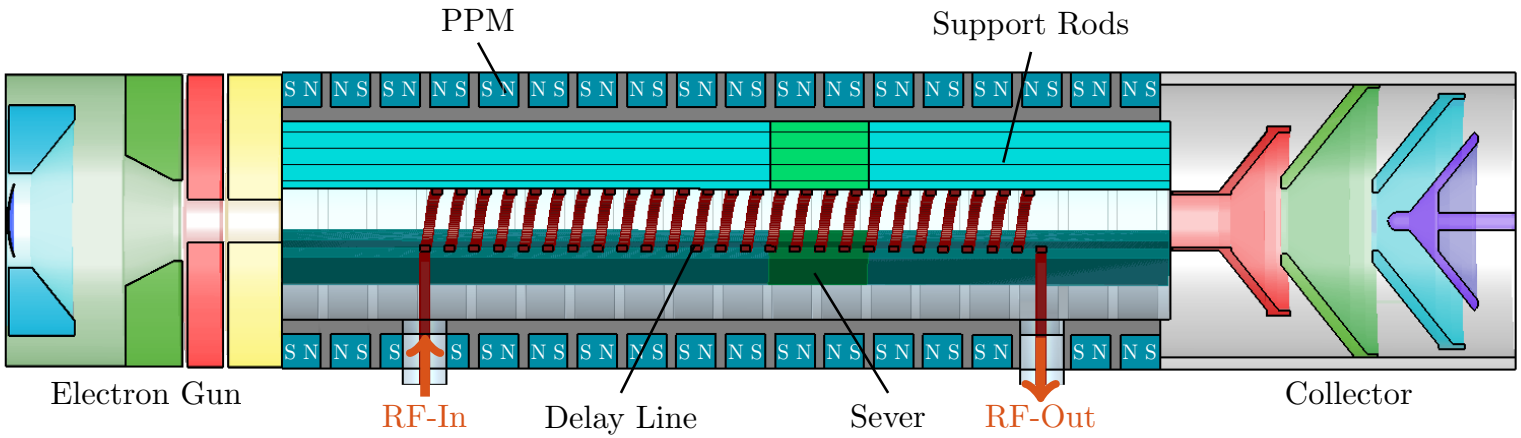

During design usually characterized by...

- ... cold properties
  (phase velocities, coupling impedance, ...)
- ... single carrier properties
  (AM-AM, AM-PM, saturation, efficiency, ...)
- ... bandwidth, harmonics, ...

→ Application: modulated signals, multiple carriers

Nonlinearities and Frequency-Dependencies - I.

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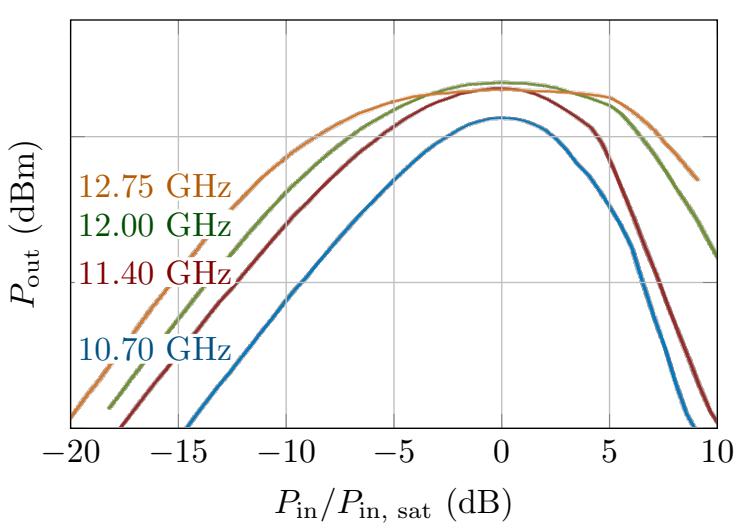
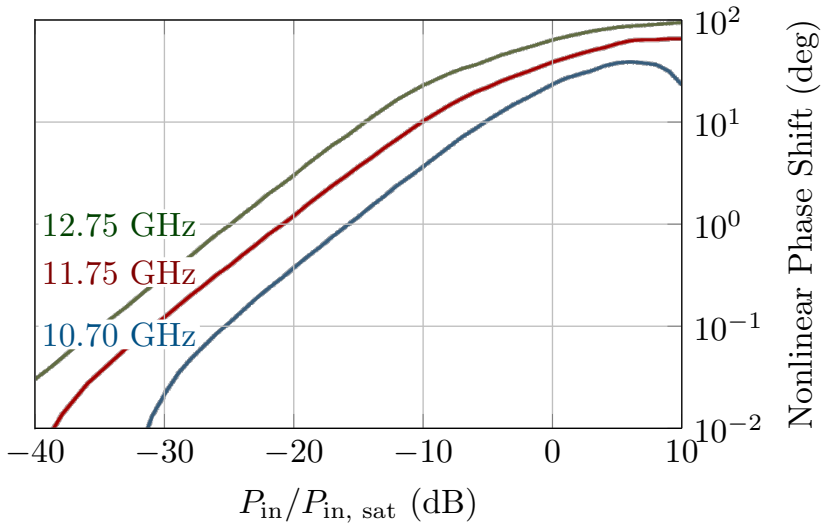
- ... single carrier properties
  (AM-AM, AM-PM, saturation, efficiency, ...)



→ AM-AM



→ AM-PM

Nonlinearities and Frequency-Dependencies - II.

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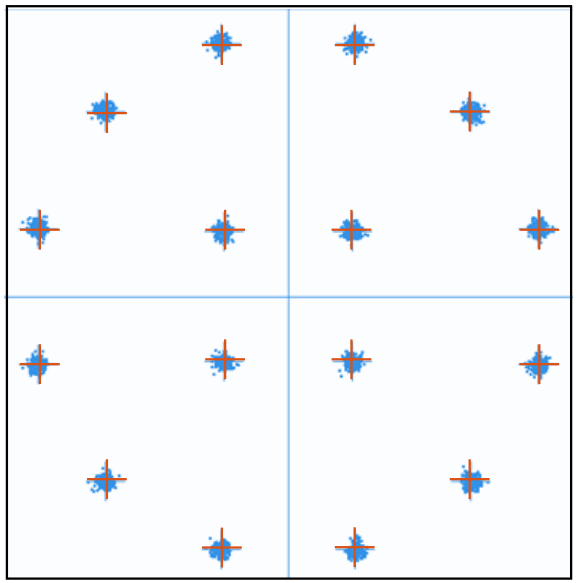
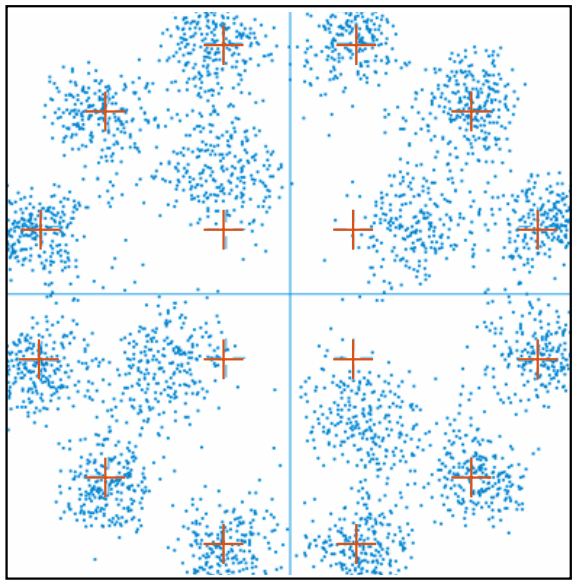
e.g., 16-APSK...



40 dB IBO

Saturation



Saturation

Project Overview: MuCa.

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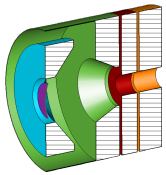
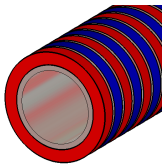
Goal: Prediction of the multicarrier behavior of traveling-wave tubes.

Electron gun

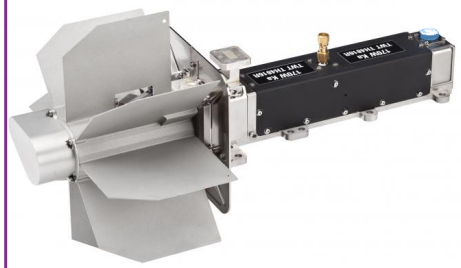


CST

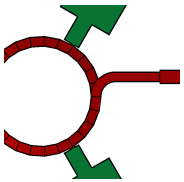
PPM stack



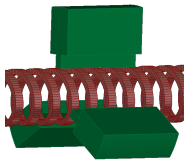
THALES



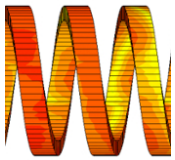
Couplers



Severs



Delay line



Singlecarrier results

Singlecarrier measurements

Multicarrier results

Envelope method

Multicarrier measurements

DiMo: THALES

Downlink chain model

Outline

Envelope Method - Starting Point: IMAL.

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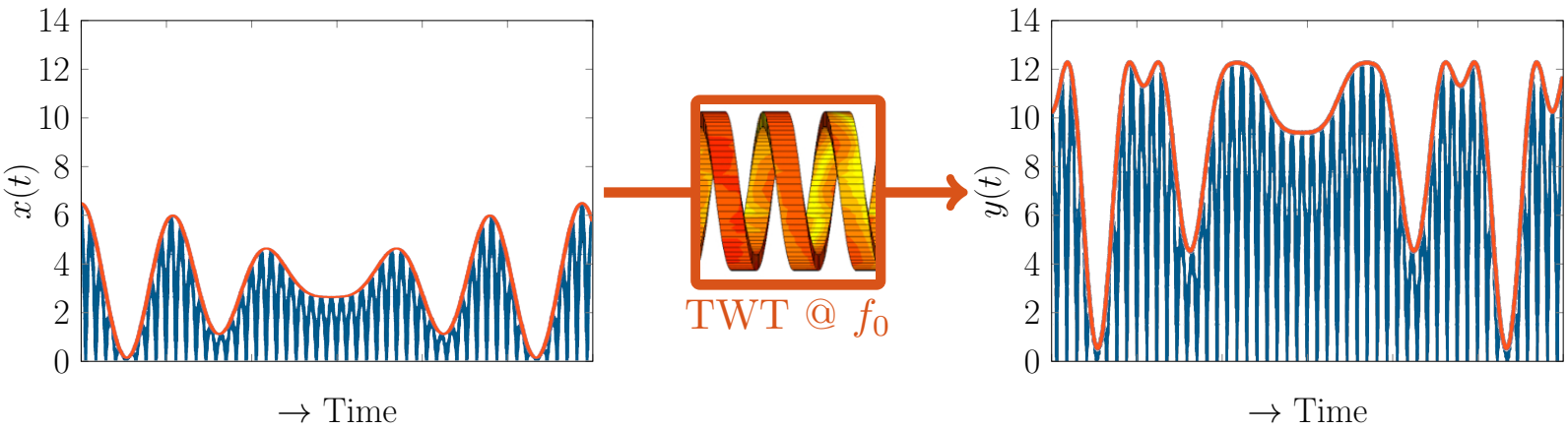
- Assumption 1: signal modulation time ($\approx 100\,\text{ns}$) significantly larger than TWT time constants ($\approx 1\,\text{ns}$)
- Assumption 2: Neglected delay line dispersion

$\rightarrow$ Break down TWT to complex transfer function

$\rightarrow$ Fast time-domain calculation



Poza-Sarkozy-Berger Model - I.

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- Assumes similarity of
  - AM/AM nonlinearity over frequency
  - AM/PM nonlinearity over frequency
- Fitting: Swept-tone AM/AM and AM/PM results
- Reference nonlinearity at f_{center}
- Separating frequency dependency and nonlinearity

[1] H. Poza, Z. Sarkozy, and H. Berger. "A wideband data link computer simulation model". In: *Proceedings of the National Aerospace and Electronics Conference*. Vol. 1. 1975, pp. 71–78.

[2] M. C. Jeruchim, P. Balaban, and K. S. Shanmugan. *Simulation of communication systems: modeling, methodology and techniques*. Springer Science & Business Media, 2006.

Poza-Sarkozy-Berger Model - II.

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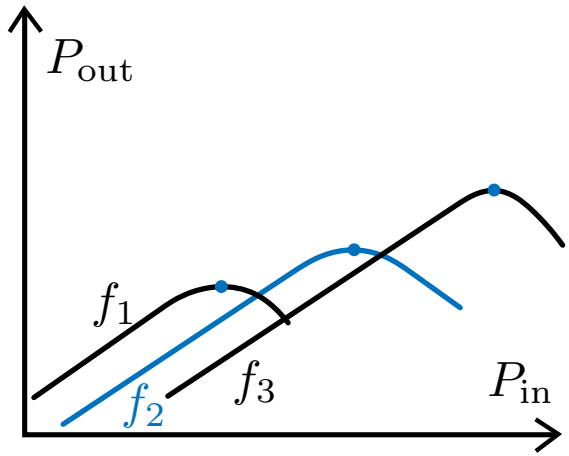

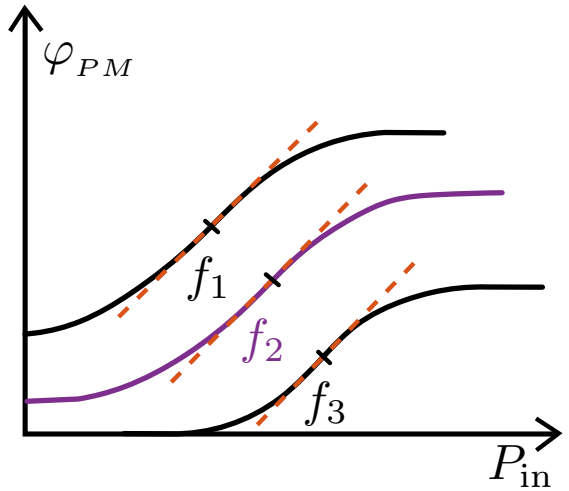

Poza-Sarkozy-Berger Model - II.

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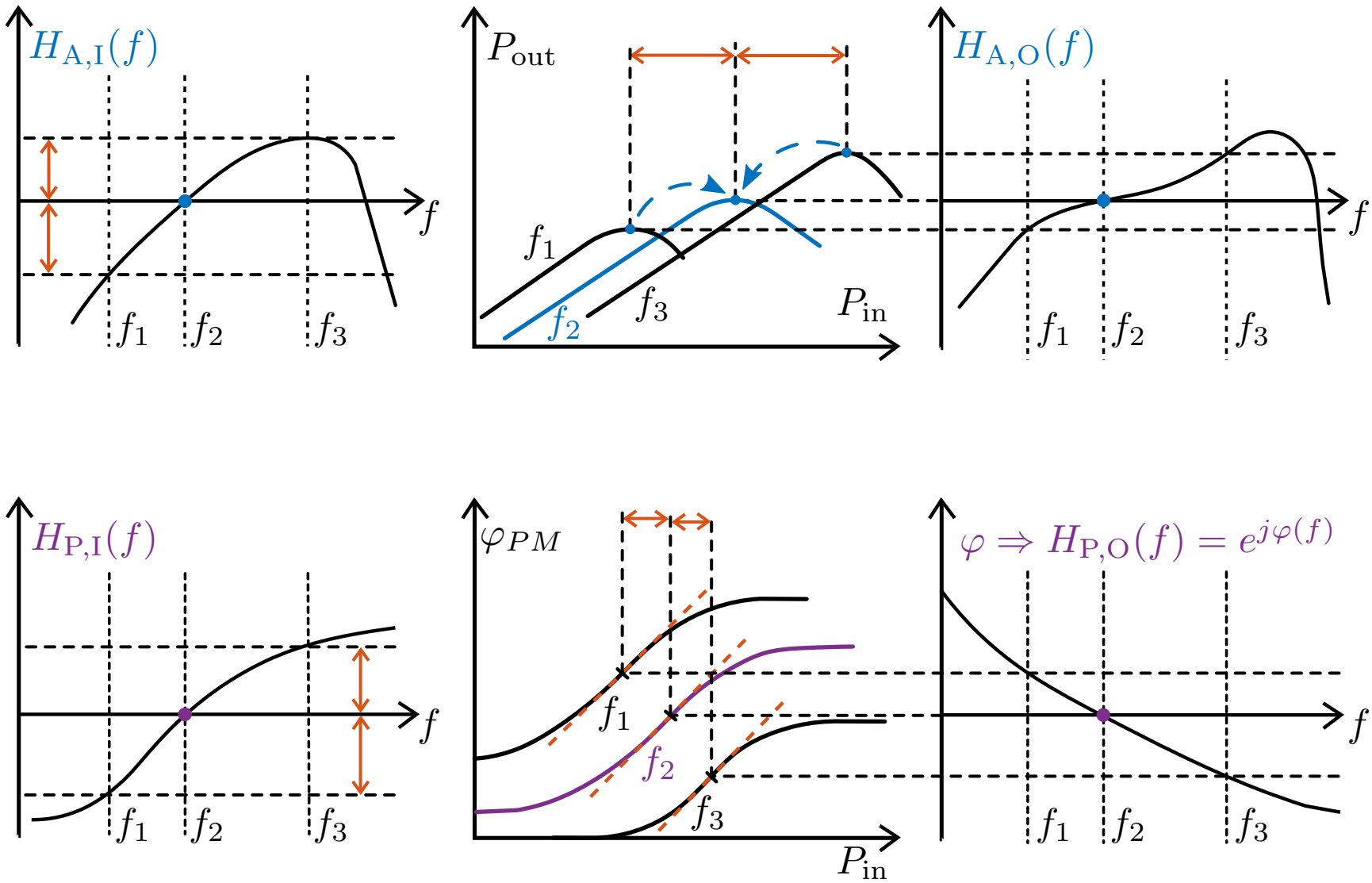

Poza-Sarkozy-Berger Model - II.

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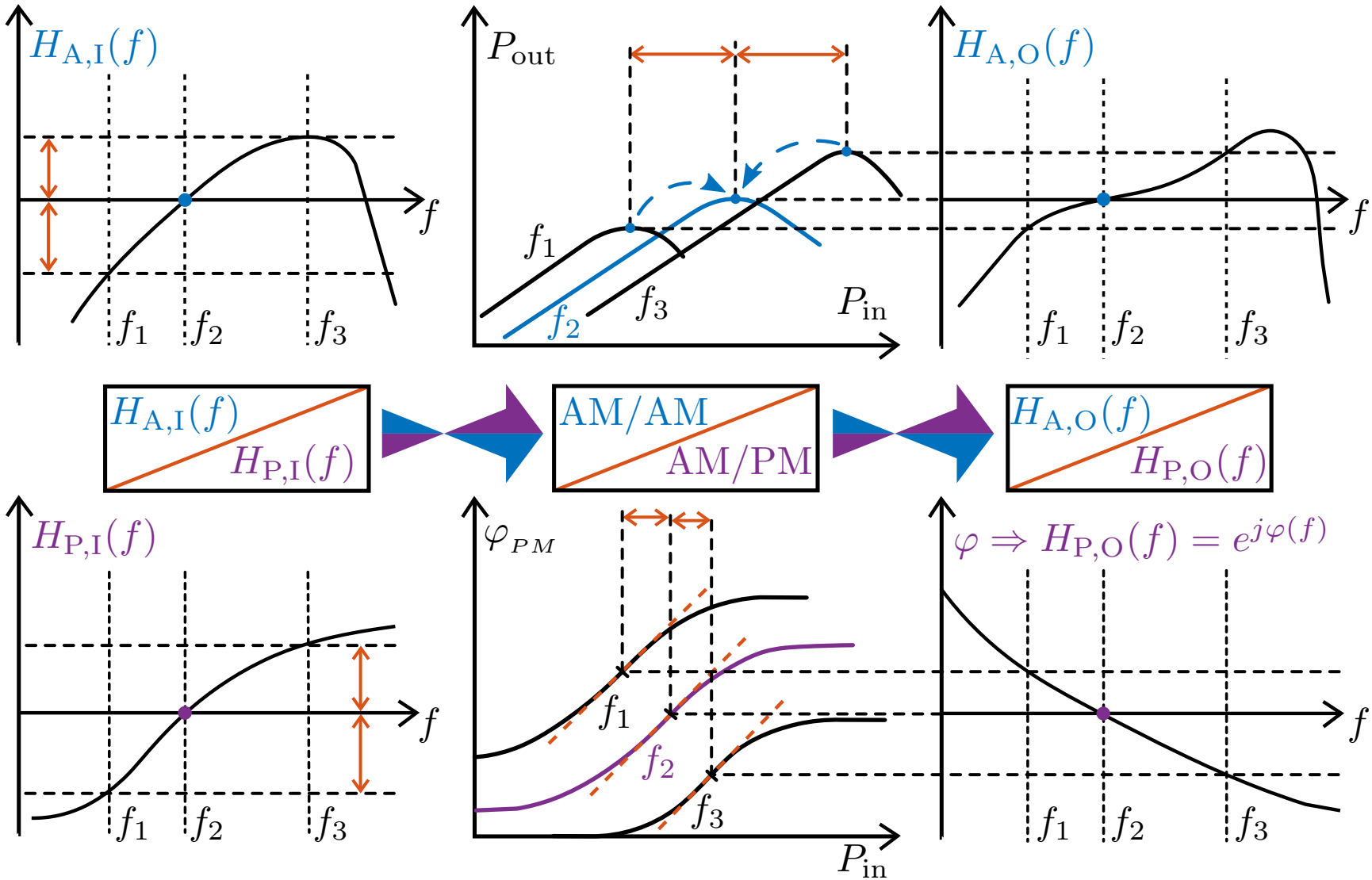

Poza-Sarkozy-Berger Model - II.

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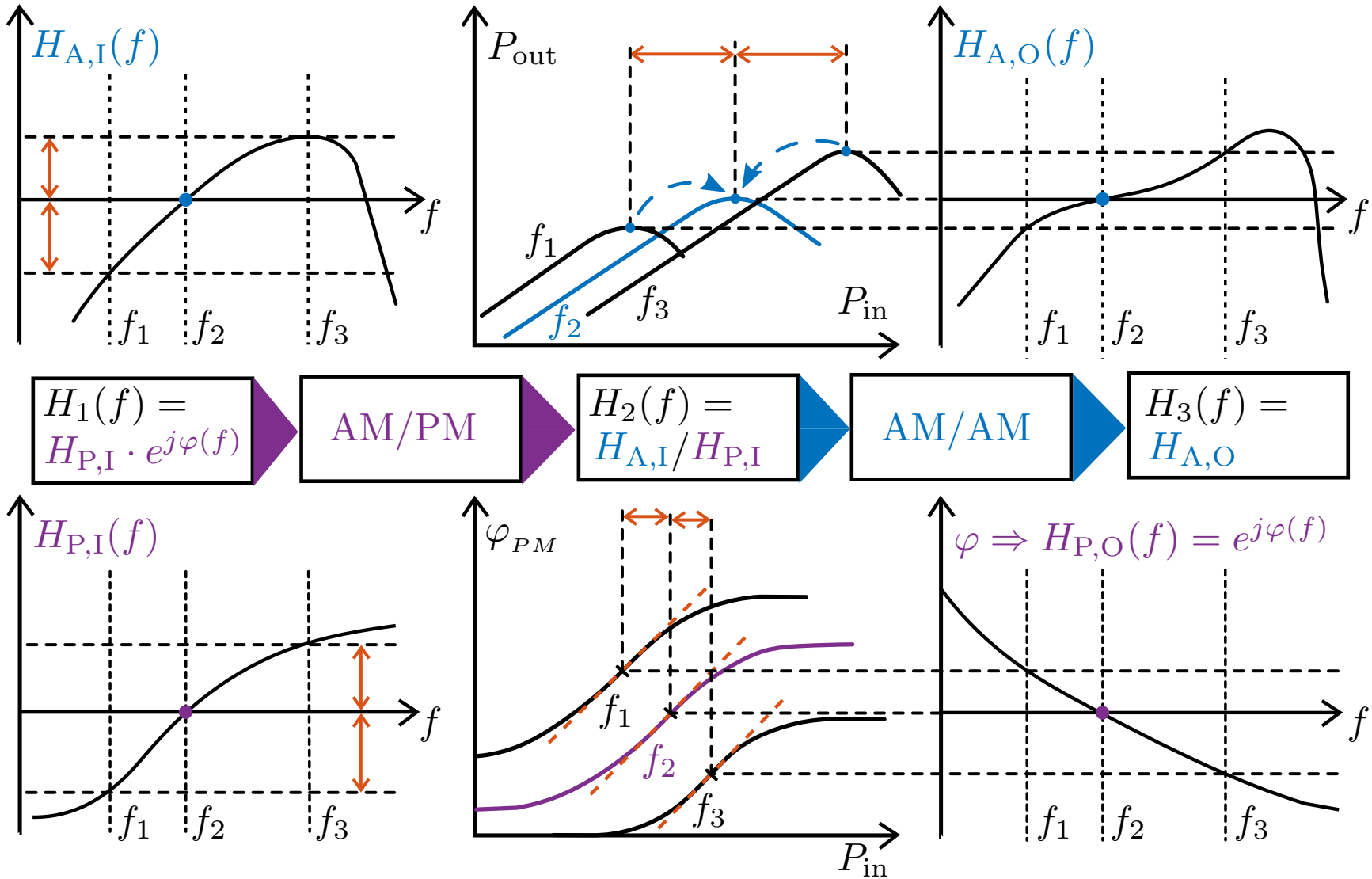

Poza-Sarkozy-Berger Model - III.

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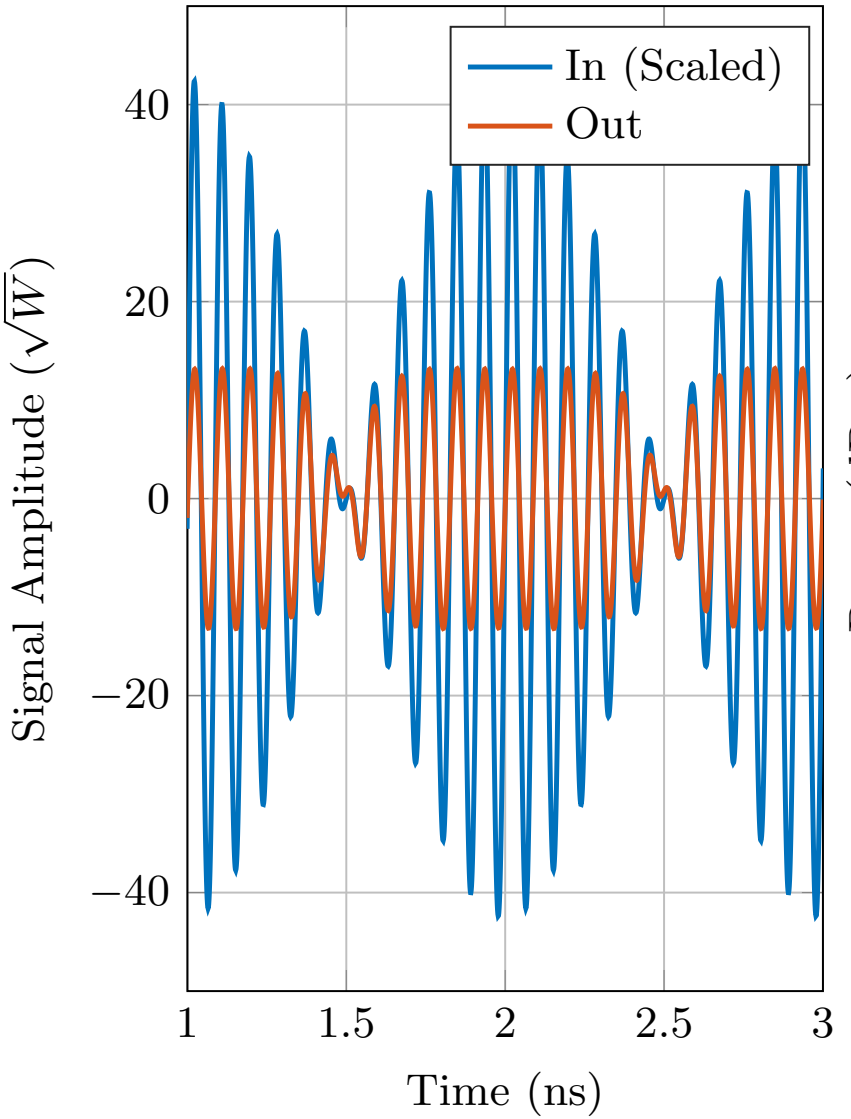

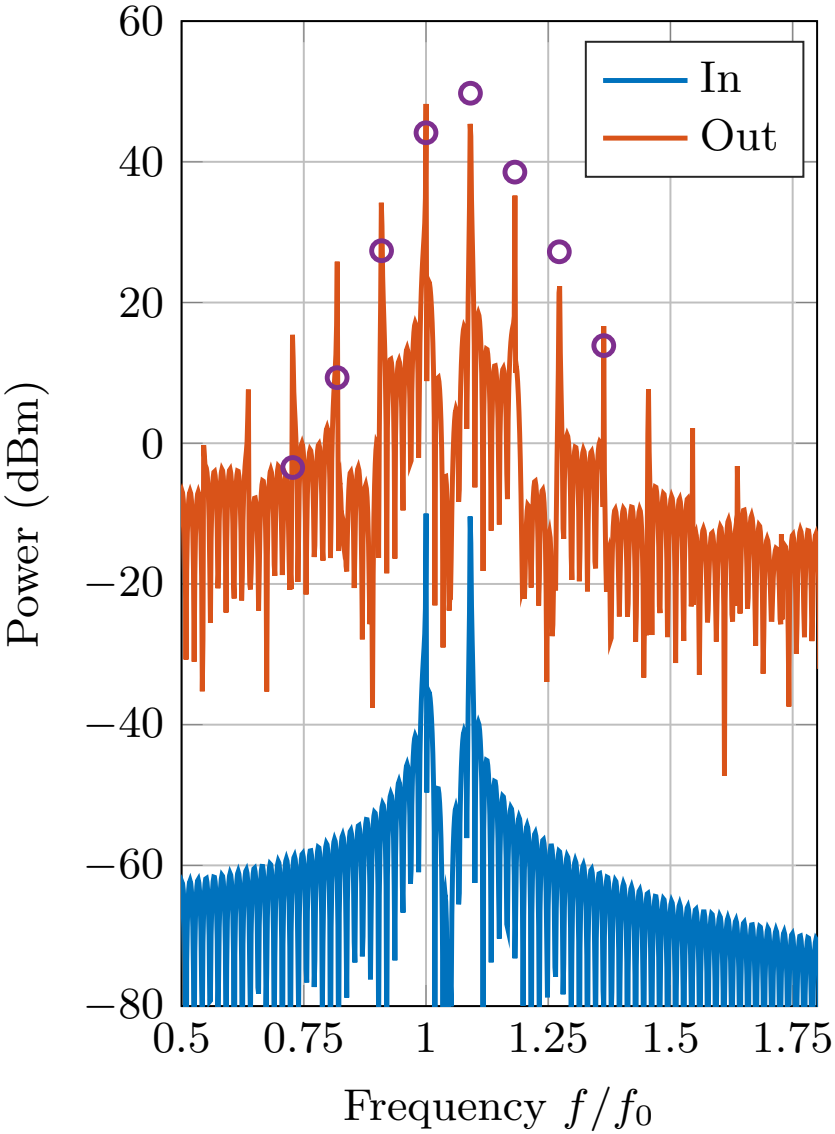

Poza-Sarkozy-Berger Model - IV.

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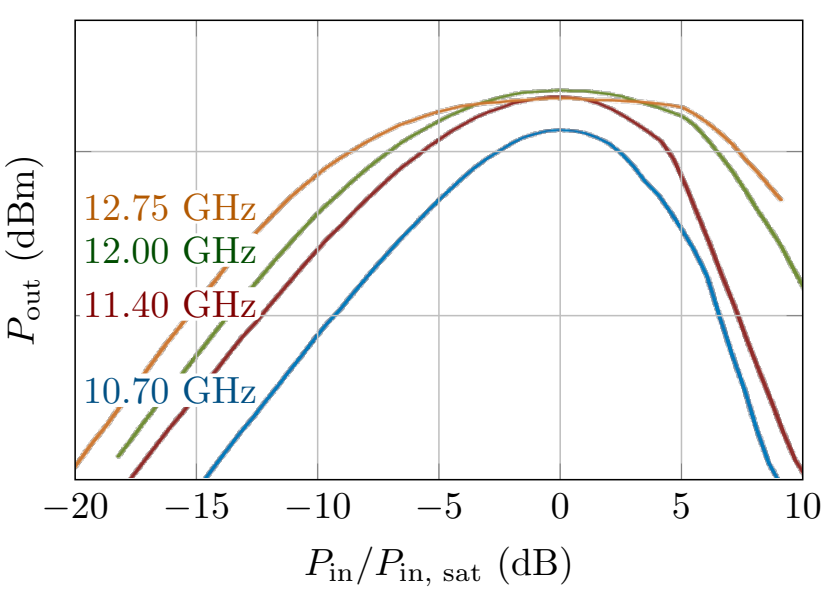
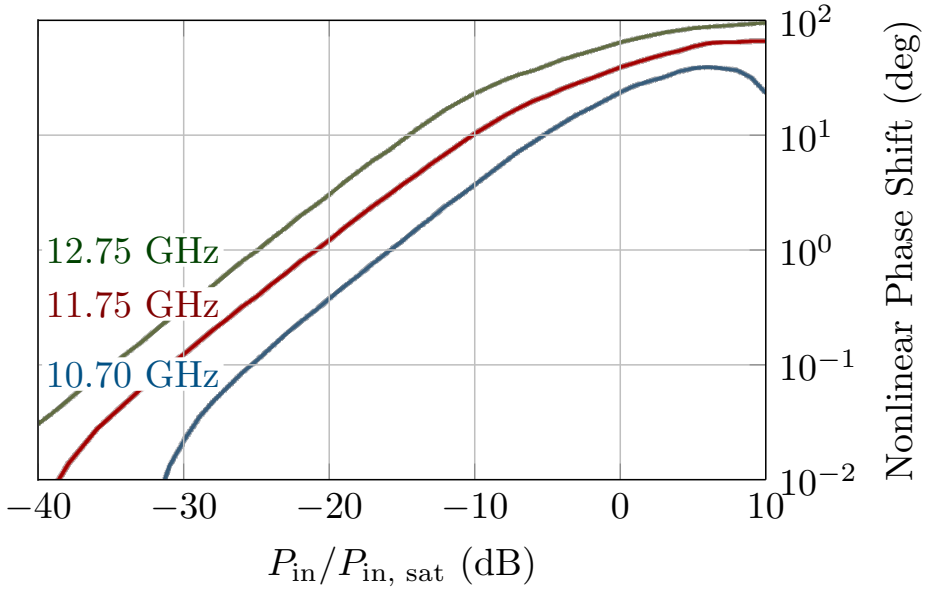


→ AM-AM



→ AM-PM

Distinction Serial and Quadrature Models.

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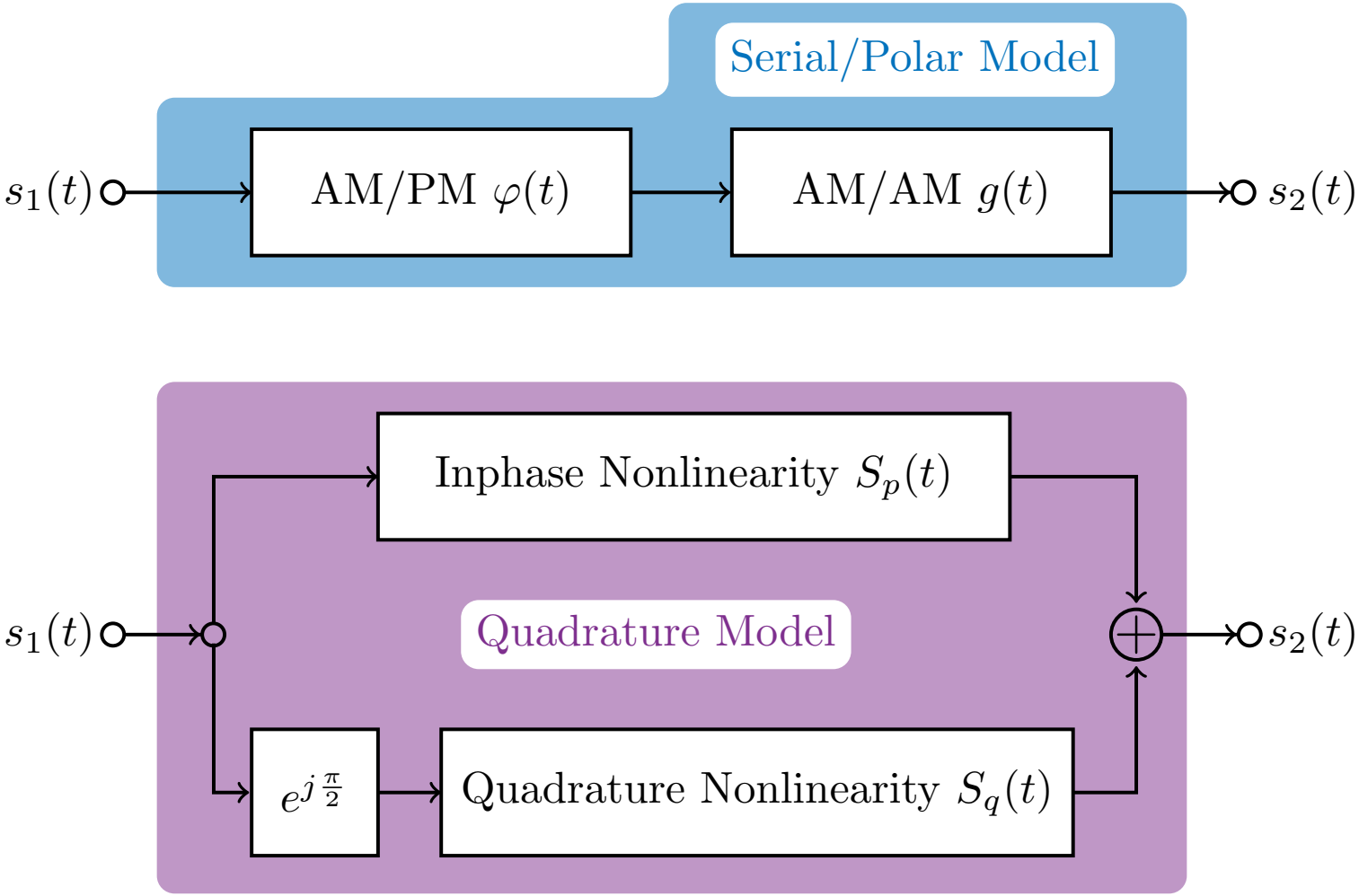


Saleh Model - I.

TUHH

- Extended model assumes similarity of
  - Inphase nonlinearity over freqeuency
  - Quadrature nonlinearity over frequency
- Fitting: Swept-tone AM/AM and AM/PM results
- Separating frequency dependency and nonlinearity

Inphase fitting

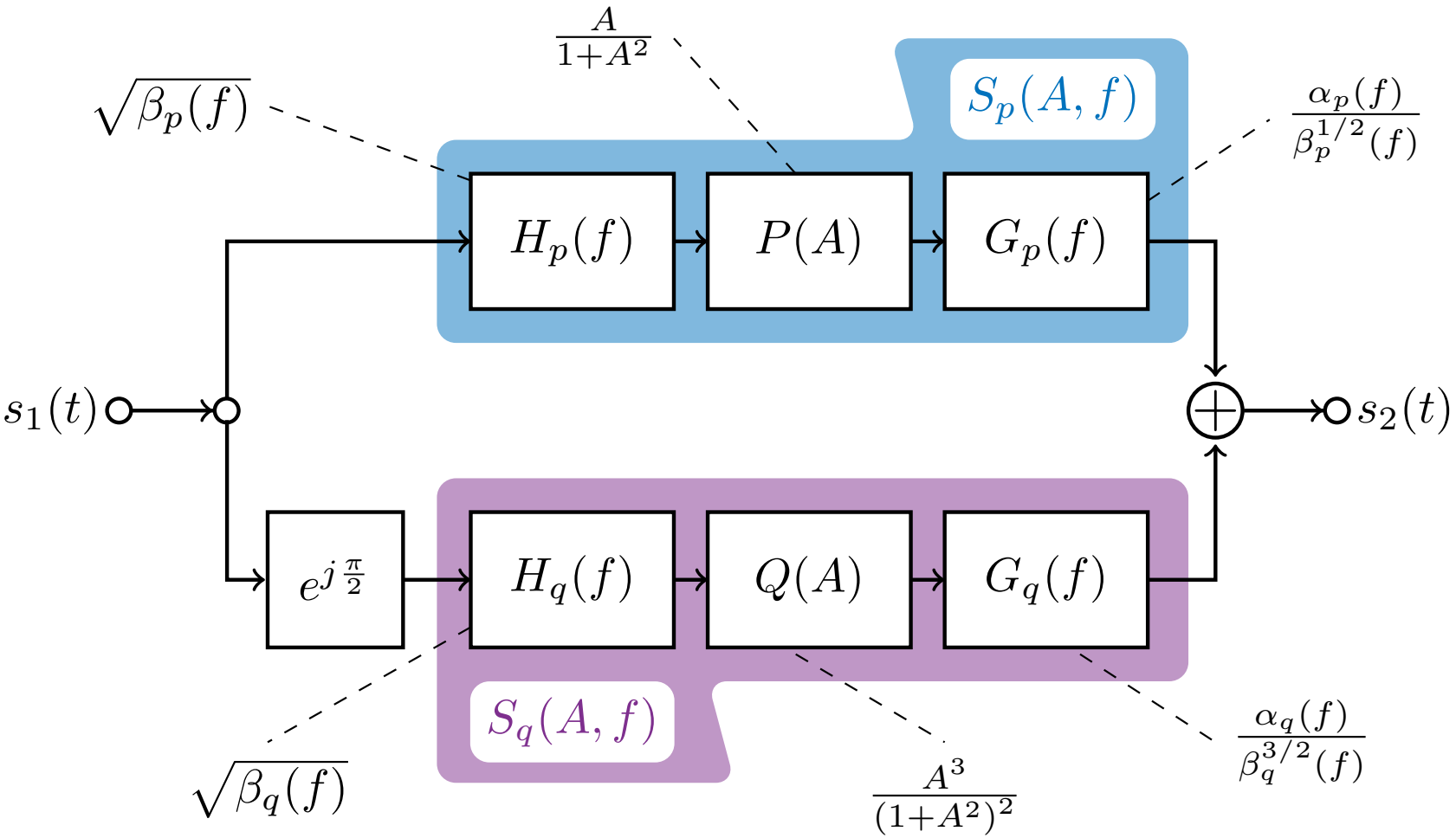
$$S_p(A,f) = \frac{A \cdot \alpha_p(f)}{1 + A^2 \cdot \beta_p(f)} \stackrel{!}{=} g(A,f)\cos(\phi(A,f))$$

Quadrature fitting

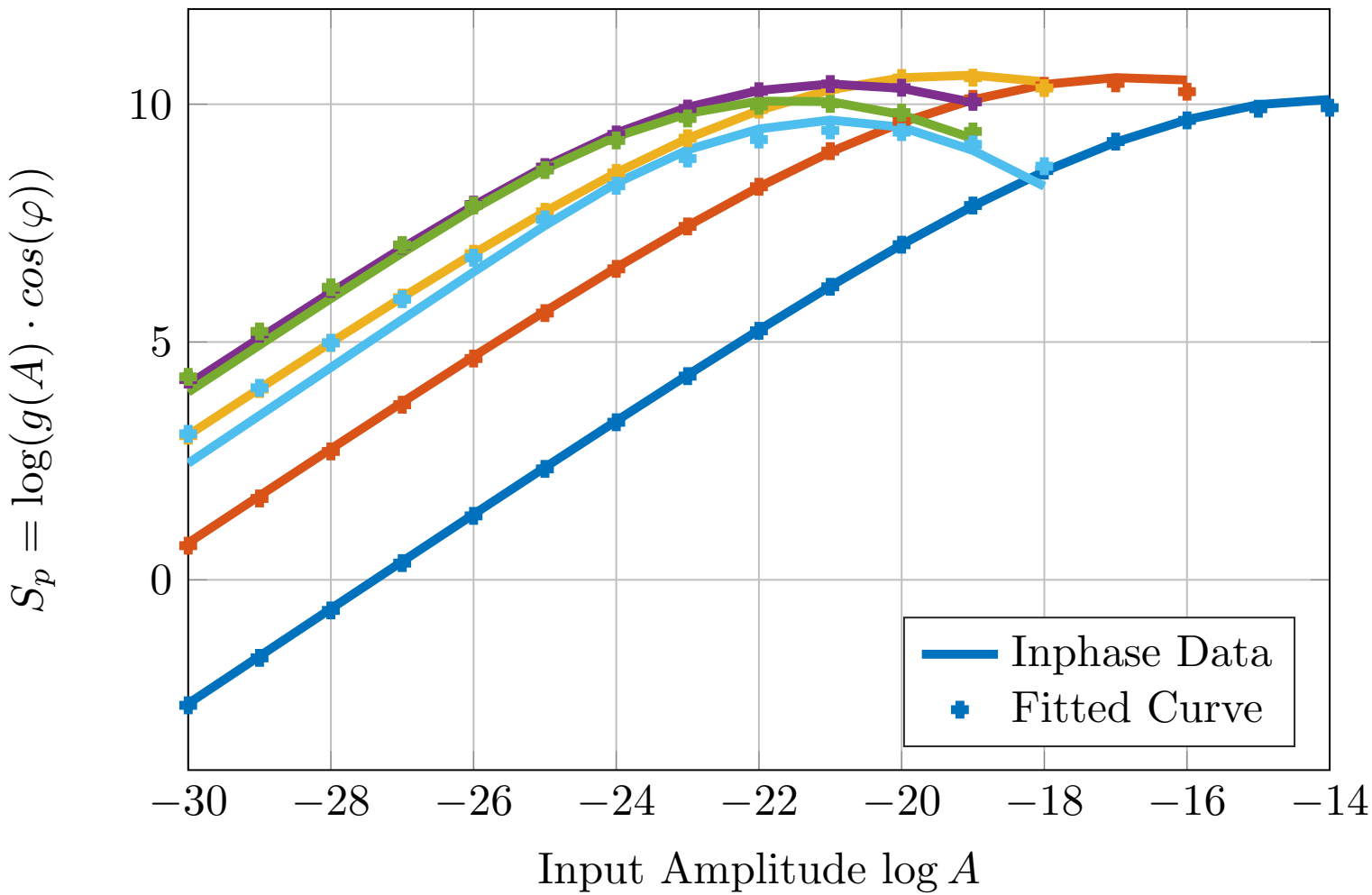
$$S_q(A,f) = \frac{A^3 \cdot \alpha_q(f)}{(1 + A^2 \cdot \beta_q(f))^2} \stackrel{!}{=} g(A,f)\sin(\phi(A,f))$$

[3] A. A. M. Saleh. "Frequency-Independent and Frequency-Dependent Nonlinear Models of TWT Amplifiers". In: *IEEE Transactions on Communications* 29.11 (1981), pp. 1715–1720.

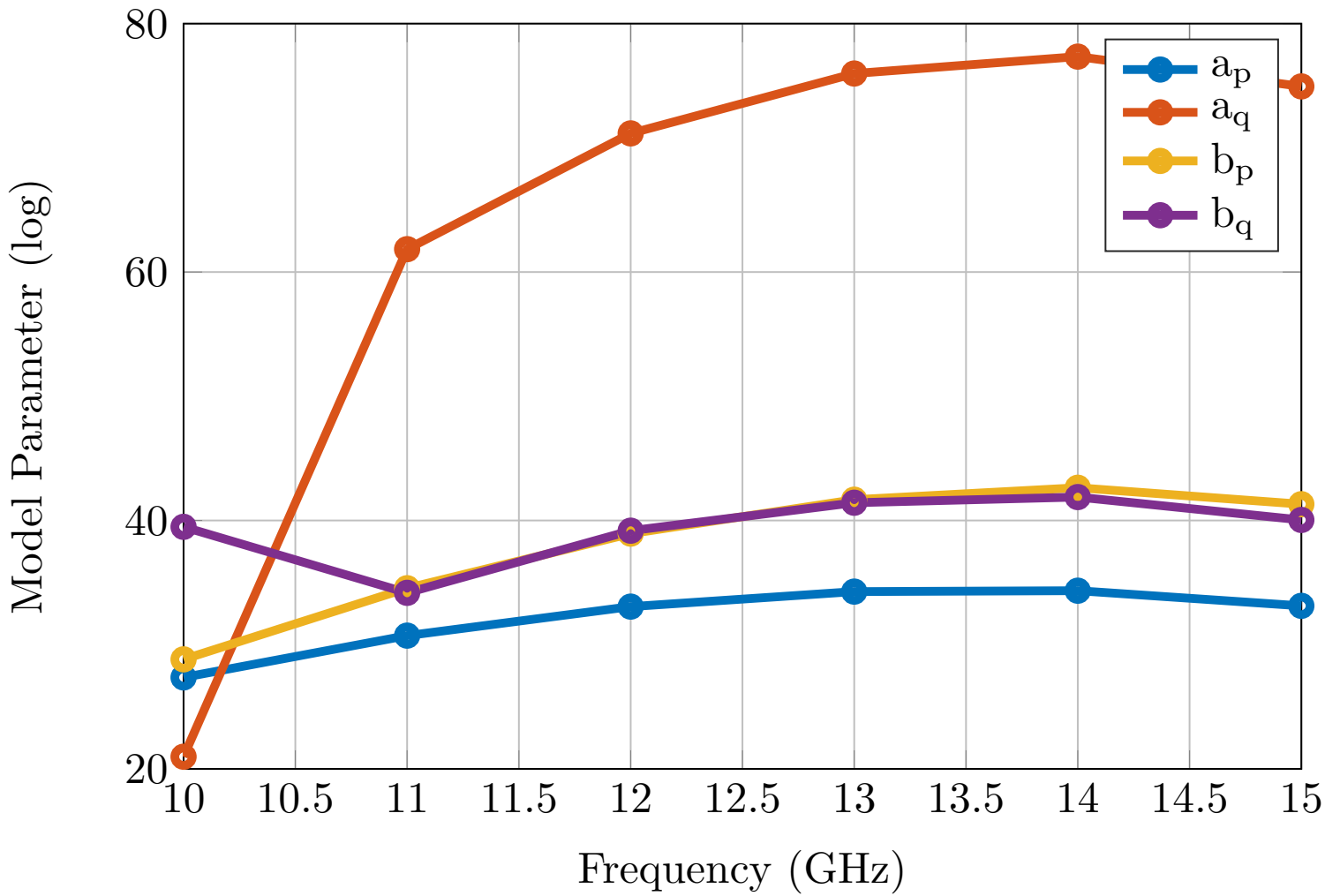
Saleh Model - II.



Saleh Model - III.

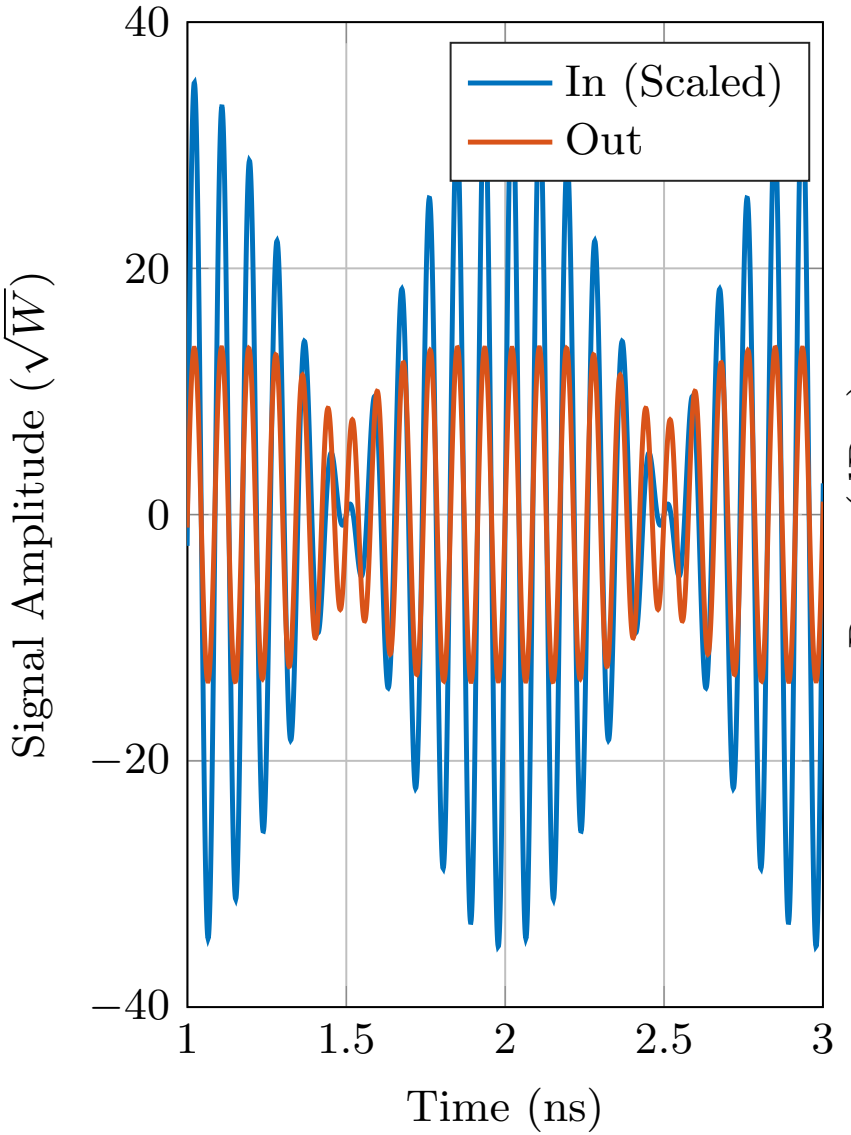


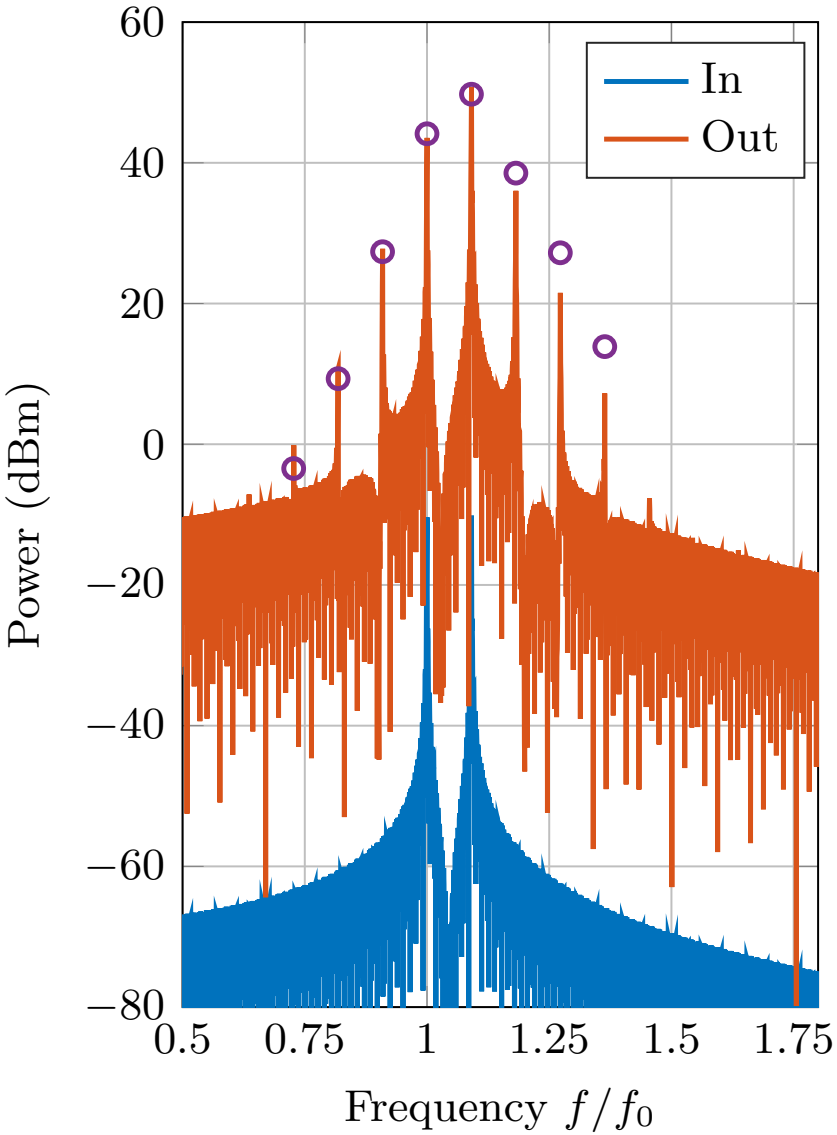
Saleh Model - IV.



Saleh Model - V.

TUHH





BF/ Abuelma'atti Model - I.

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- Same assumptions as Saleh model
- Fitting to Bessel functions (first order, first kind)[4]

Inphase fitting

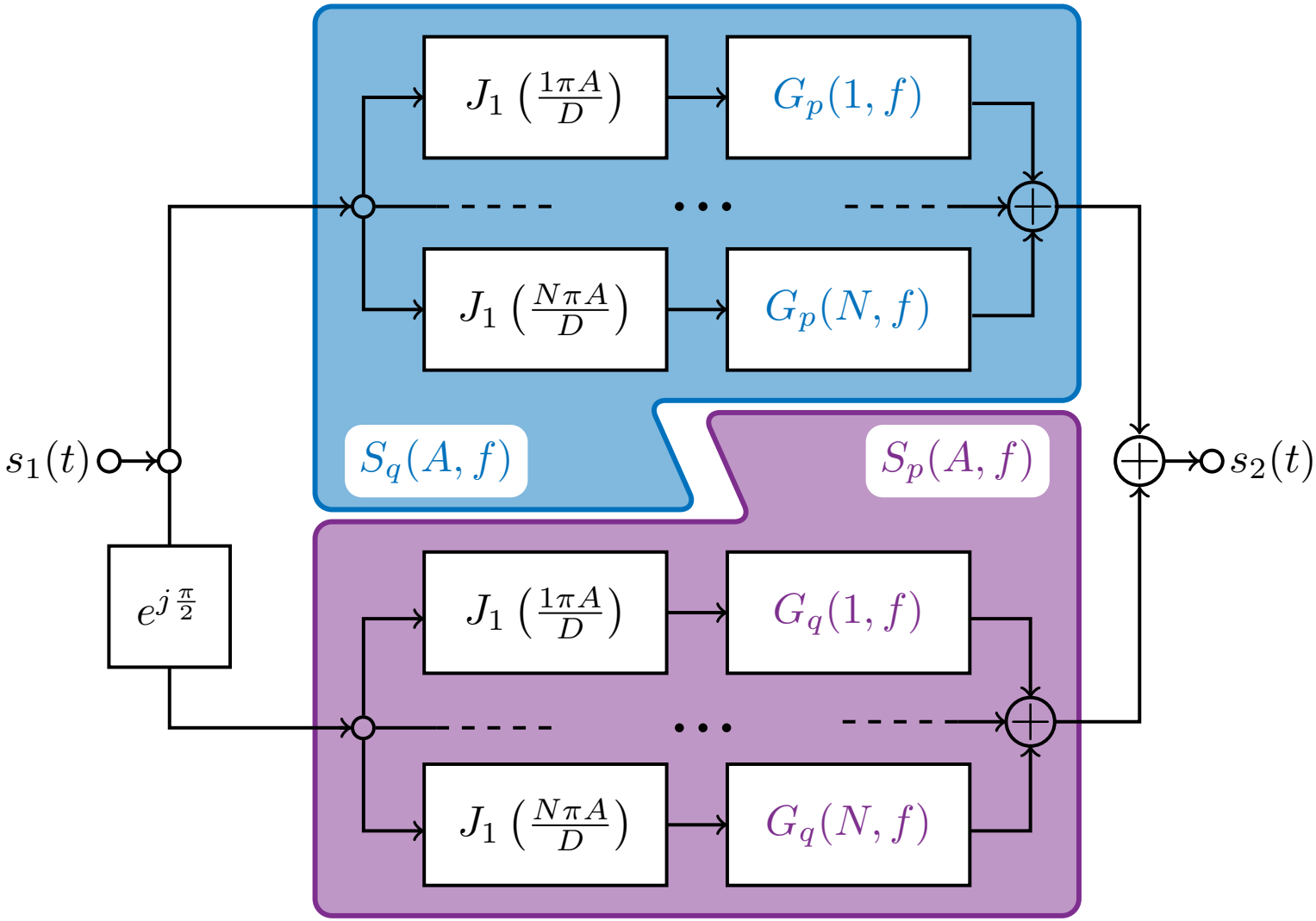
$$S_p(A,f) = \sum_{n=1}^{N} G_p(n,f) \cdot J_1\left(\frac{n\pi A}{D}\right) \stackrel{!}{=} g(A,f)\cos(\phi(A,f))$$

Quadrature fitting

$$S_q(A,f) = \sum_{n=1}^{N} G_q(n,f) \cdot J_1\left(\frac{n\pi A}{D}\right) \stackrel{!}{=} g(A,f)\sin(\phi(A,f))$$

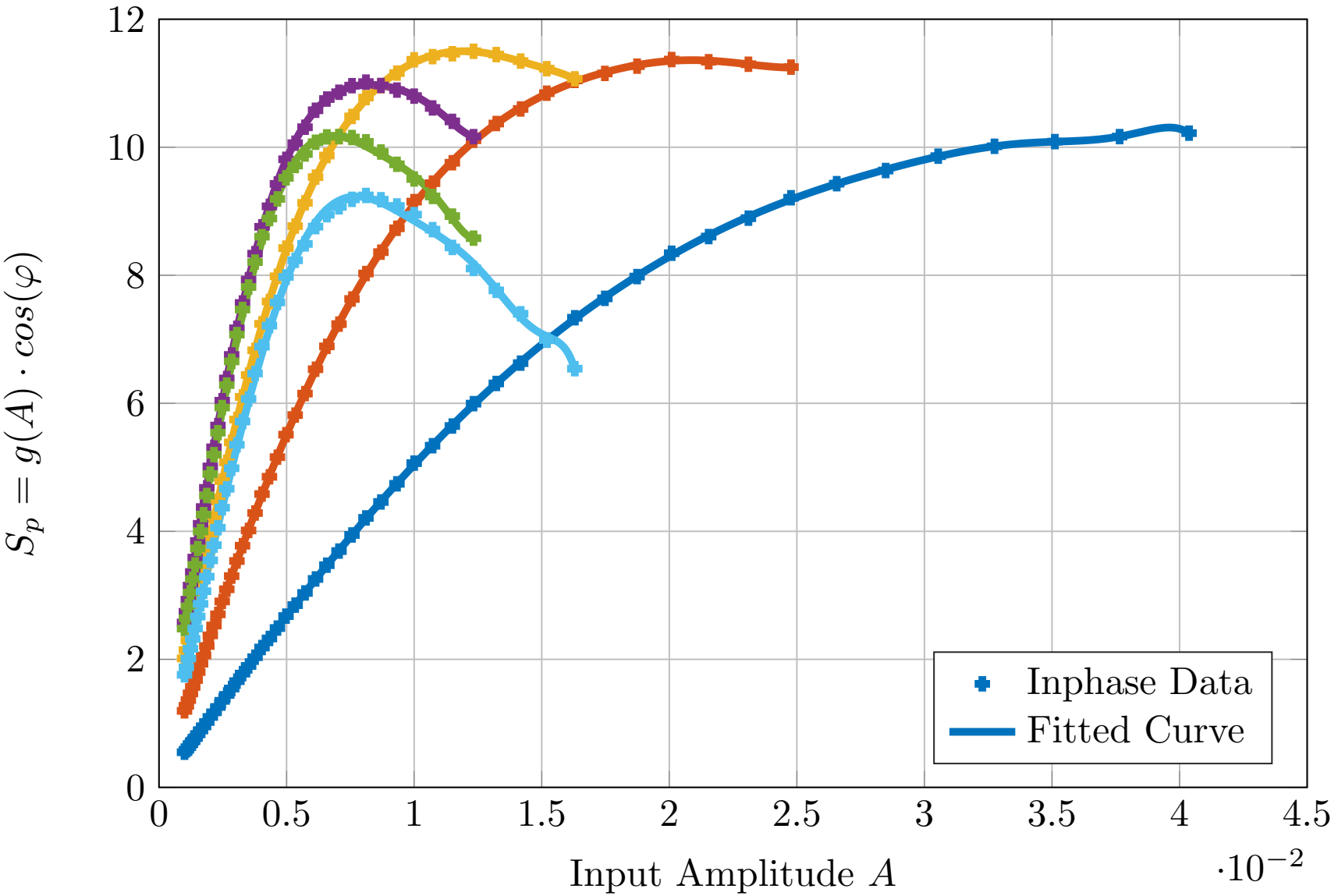
[4] A. Georgiadis et al. *Microwave and Millimeter Wave Circuits and Systems: Emerging Design, Technologies and Applications*. John Wiley & Sons, 2012.

BF Model - II.

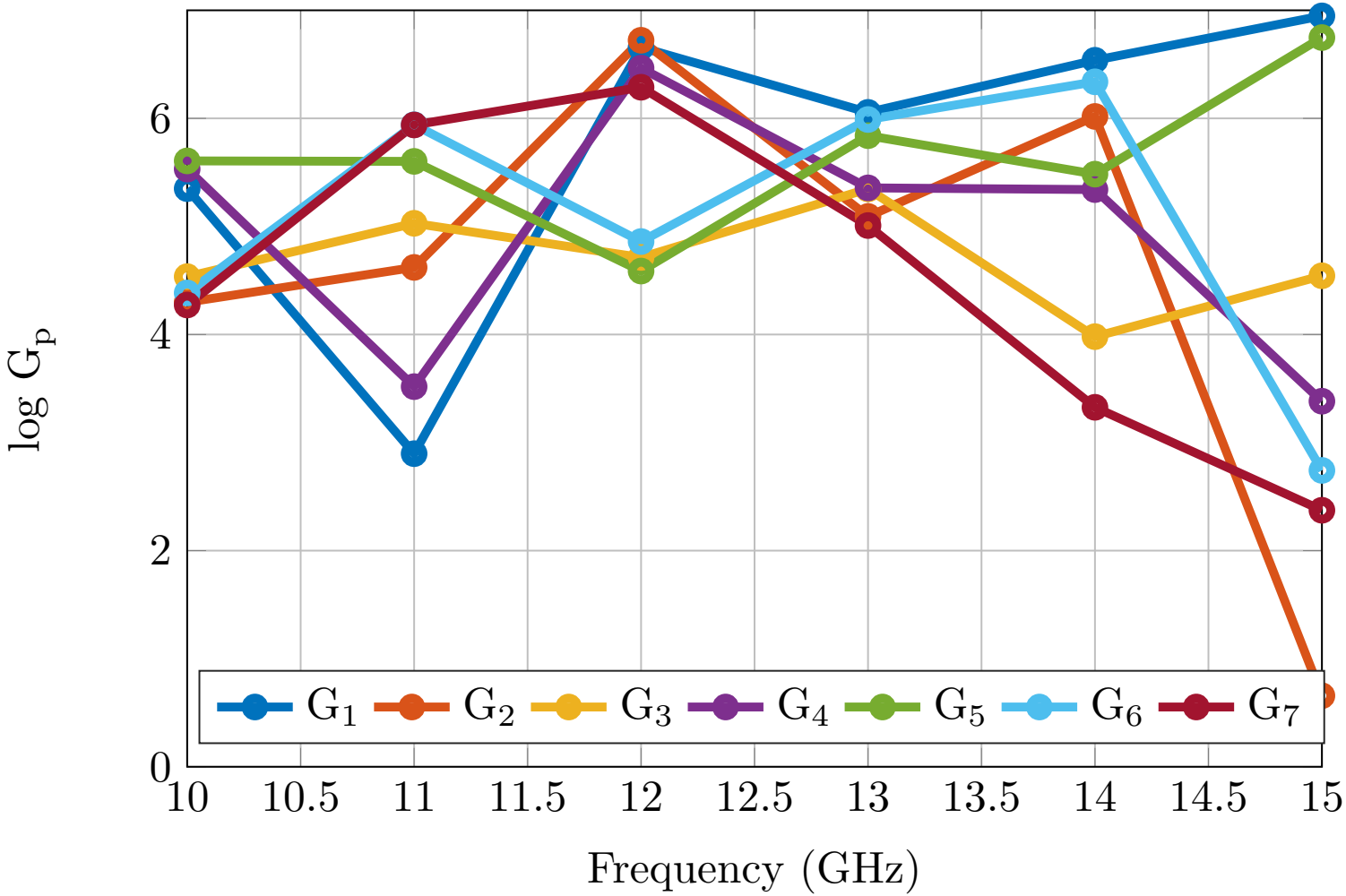

$J_1\left(\frac{1\pi A}{D}\right)$
$G_p(1,f)$
$J_1\left(\frac{N\pi A}{D}\right)$
$G_p(N,f)$
$S_q(A,f)$
$S_p(A,f)$
$s_1(t)$
$s_2(t)$
$e^{j\frac{\pi}{2}}$
$J_1\left(\frac{1\pi A}{D}\right)$
$G_q(1,f)$
$J_1\left(\frac{N\pi A}{D}\right)$
$G_q(N,f)$

BF Model - III.

TUHH

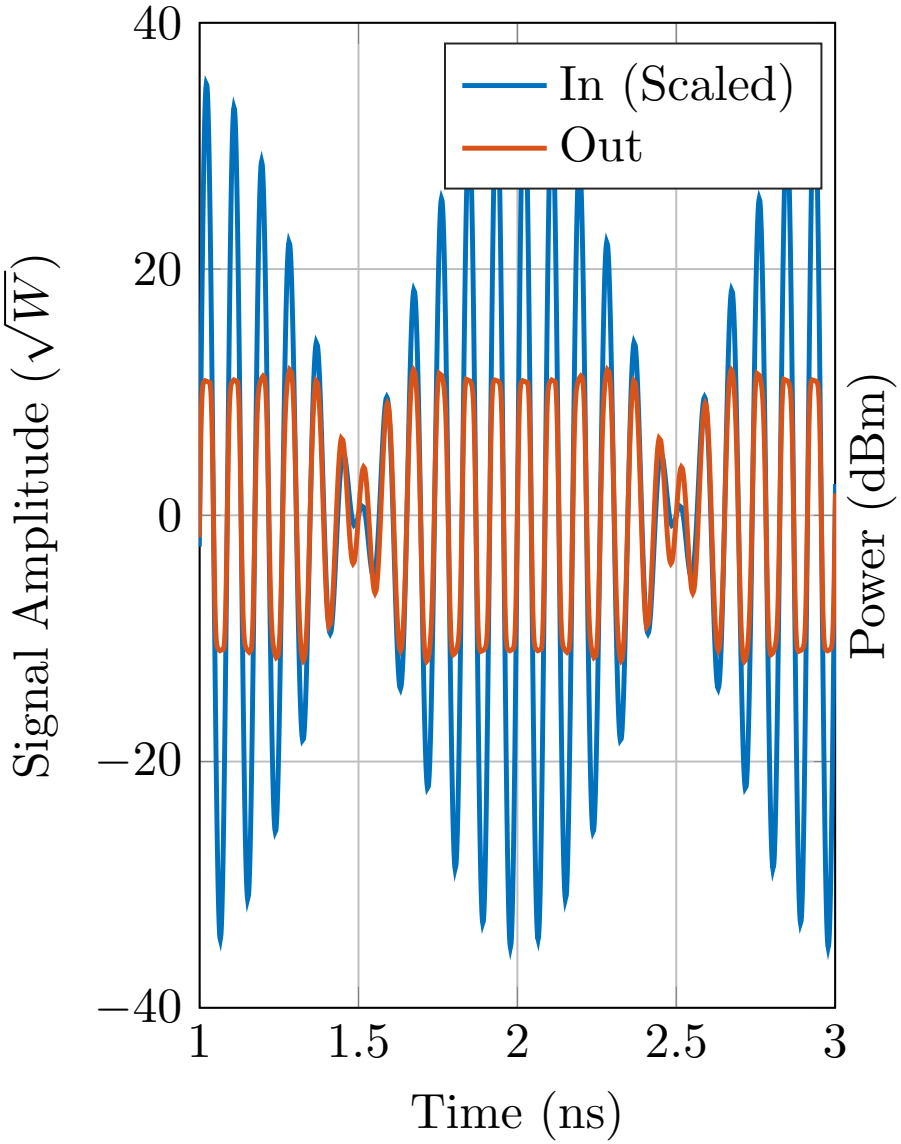


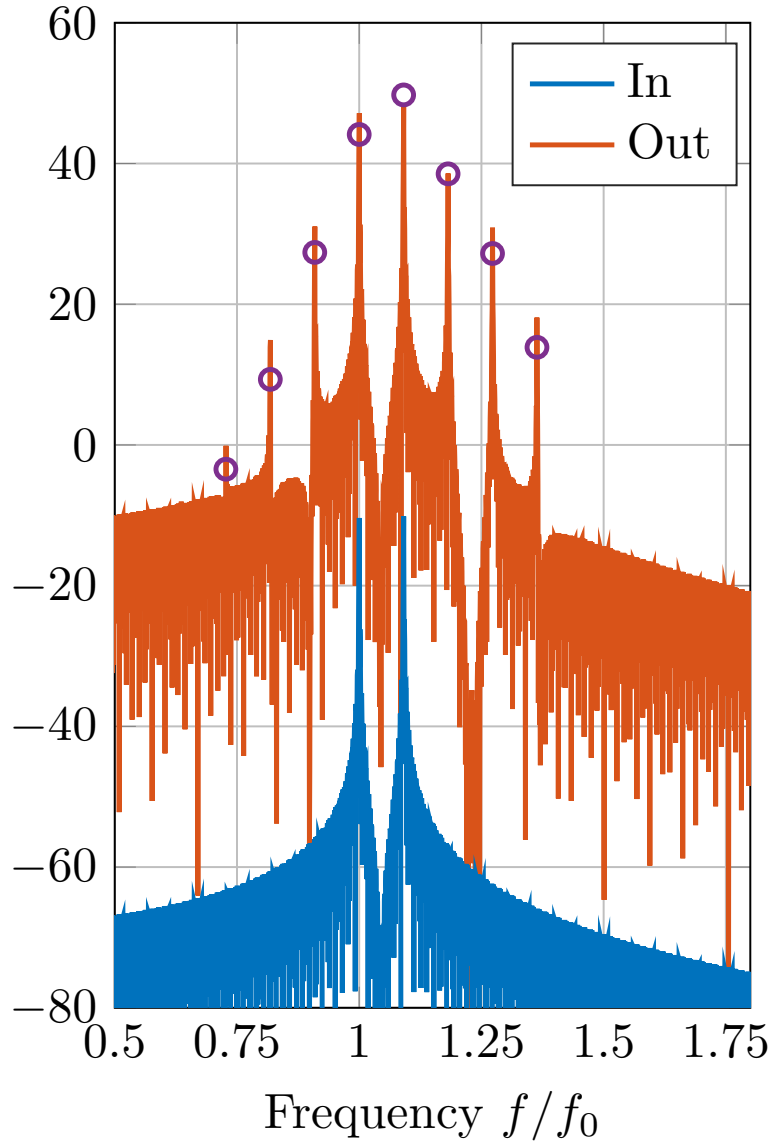
BF Model - IV.


log G_p
6
4
2
0
10
10.5
11
11.5
12
12.5
13
13.5
14
14.5
15
Frequency (GHz)
G1
G2
G3
G4
G5
G6
G7

BF Model - V.

TUHH





Outline

Conclusions and Outlook.

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Conclusions

- Variety of models available
- Quadrature models most suitable for multi-tone prediction
- Good prediction of intermodulation products

Outlook

- Improve BF model parameter dynamics
- Eye-diagrams, BER, ...
- Full downlink chain model

Conclusions and Outlook.

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Thank you for your attention!

Acknowledgments

Funded by the German Space Agency (DLR) on behalf of the Federal Ministry of Economics and Technology (BMWi).

Saleh Model - VI.