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Title:

Proposed System Impairment Models

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Purpose:
Aid in the PHY Task Group's preparation of a detailed evaluation table for performance of PHY layer air interface proposals.

System Impairment Model

Ad hoc modelling committee:

David Falconer, Carleton University

Tom Kolze, Broadcom

Yigal Leiba, Breezecom

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With thanks also to:

Naftali Chayat, (Breezecom) Bruce Cochran, (Sicom) Scott Enserink, (Sicom) Lucille Rouault, (ENST/NIST) Val Rhodes, (Intel) Benoit Verbaere, (ENST/NIST)

Process

- Identify primary performance degradation sources
- Model and parameterize these sources
- Establish performance metrics
- Establish baseline characterization techniques

Performance degradation sources

- Phase noise
- Power amplifier
- Multi-path
- Model parameters may be
  - Set by group and simulated by contributors
  - Stated and simulated by contributors

Power Amplifier Models

Saleh Model

- Uses simple two-parameter functions to model the AM-to-PM and AM-to-AM characteristics of nonlinear amplifiers.
- Originally developed to specify the behavior of TWTA's. Appropriate selections for the amplitude and phase coefficients (α's and β's) provide a suitable model for solid state amplifiers as well.
- It is a frequency-independent model. Can be made frequency-dependent by adding filters that mirror how the coefficients change with frequency.

Saleh Model

Input signal:

$x(t)=r(t)\cos[\omega_0 t+\psi(t)]$

- ω_0 is the carrier frequency,
- $r(t)$ is the modulated envelope
- $\psi(t)$ is the modulated phase

The output of the nonlinear amplifier is:

$y(t)=A[r(t)]\cos\{\omega_0 t+\psi(t)+\Phi(r(t))\}$

- $A(r)$ represents the AM-to-AM conversion
- $\Phi(r)$ represents the AM-to-PM conversion.

Saleh Model

- The specific forms of the two functions:

  $A(r)=\alpha_a r/(1+\beta_a r^2)$

  $\Phi(r)=\alpha_\phi r^2/(1+\beta_\phi r^2)$

- As an example, the set of parameters that closely matches TWTA data [1] is,

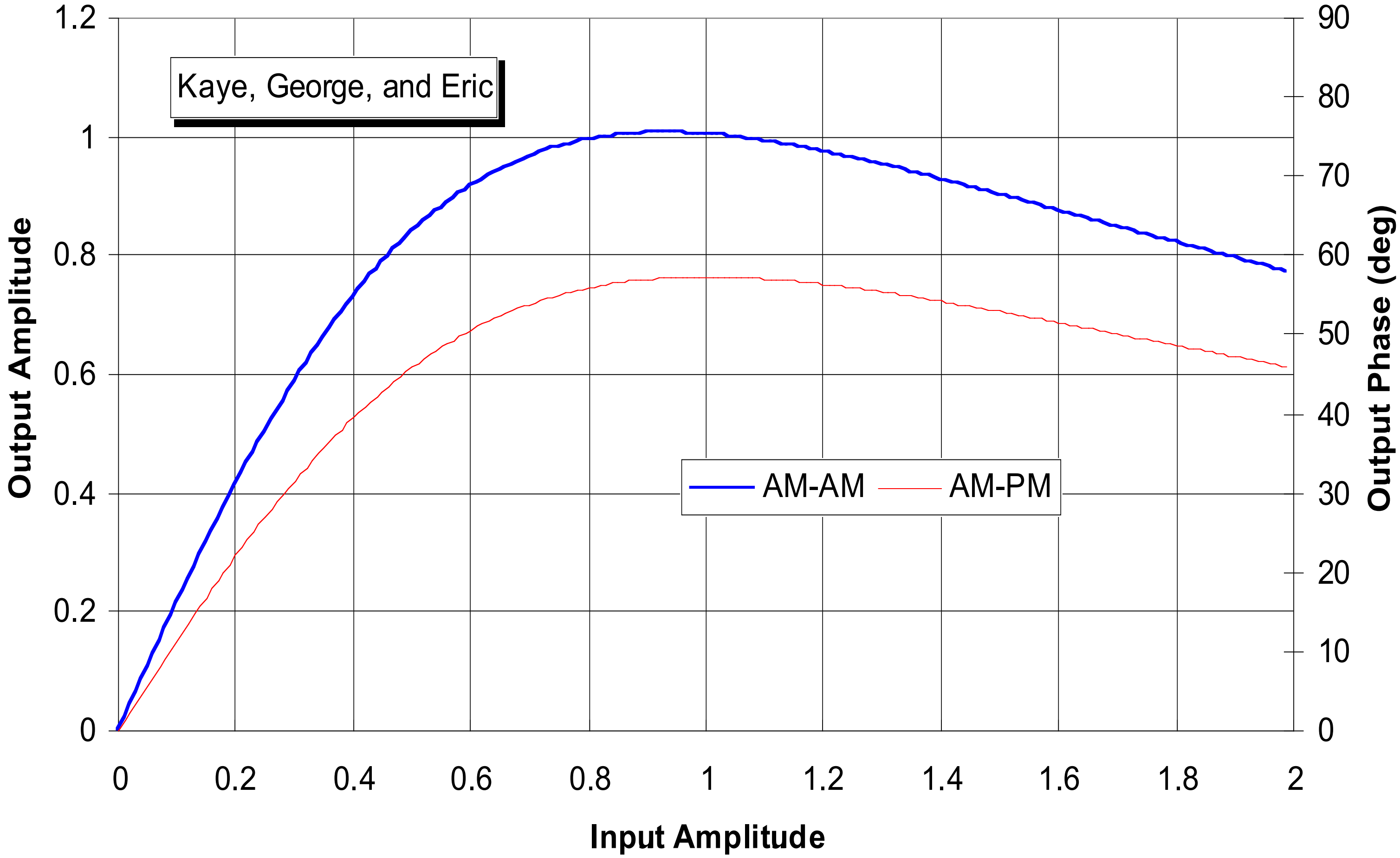
  $\alpha_a = 2.1587$ $\beta_a = 1.1517$

  $\alpha_\phi = 4.033$ $\beta_\phi = 9.1040$

Saleh Model

Saleh model with parameters:

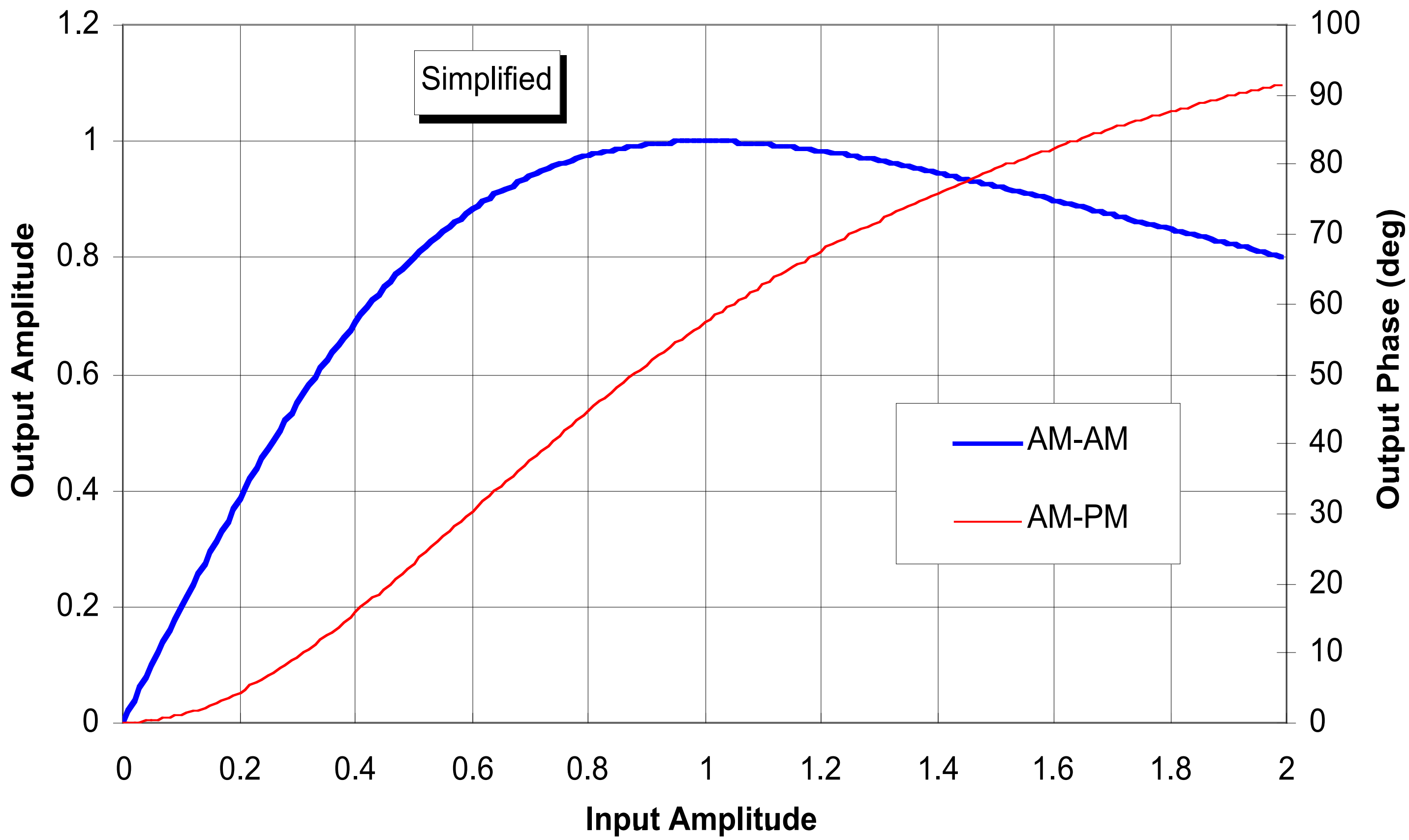
α_a= 2.1587, β_a= 1.1517, α_ϕ= 4.033, β_ϕ= 9.1040



Saleh Model

Saleh model with simplified parameters:

$\alpha_a = 2$, $\beta_a = 1$, $\alpha_\phi = 2$ and $\beta_\phi = 1$



Saleh Model Summary

- Uses simple two-parameter functions to model the AM-to-PM and AM-to-AM characteristics of nonlinear amplifiers.
- Appropriate selections for the amplitude and phase coefficients (α's and β's) can provide a suitable model for solid state amplifiers well.
- Saleh's models for TWTAs are shown to accurately match actual measured data .
- Can be altered to a frequency-dependent model.

Rapp Model

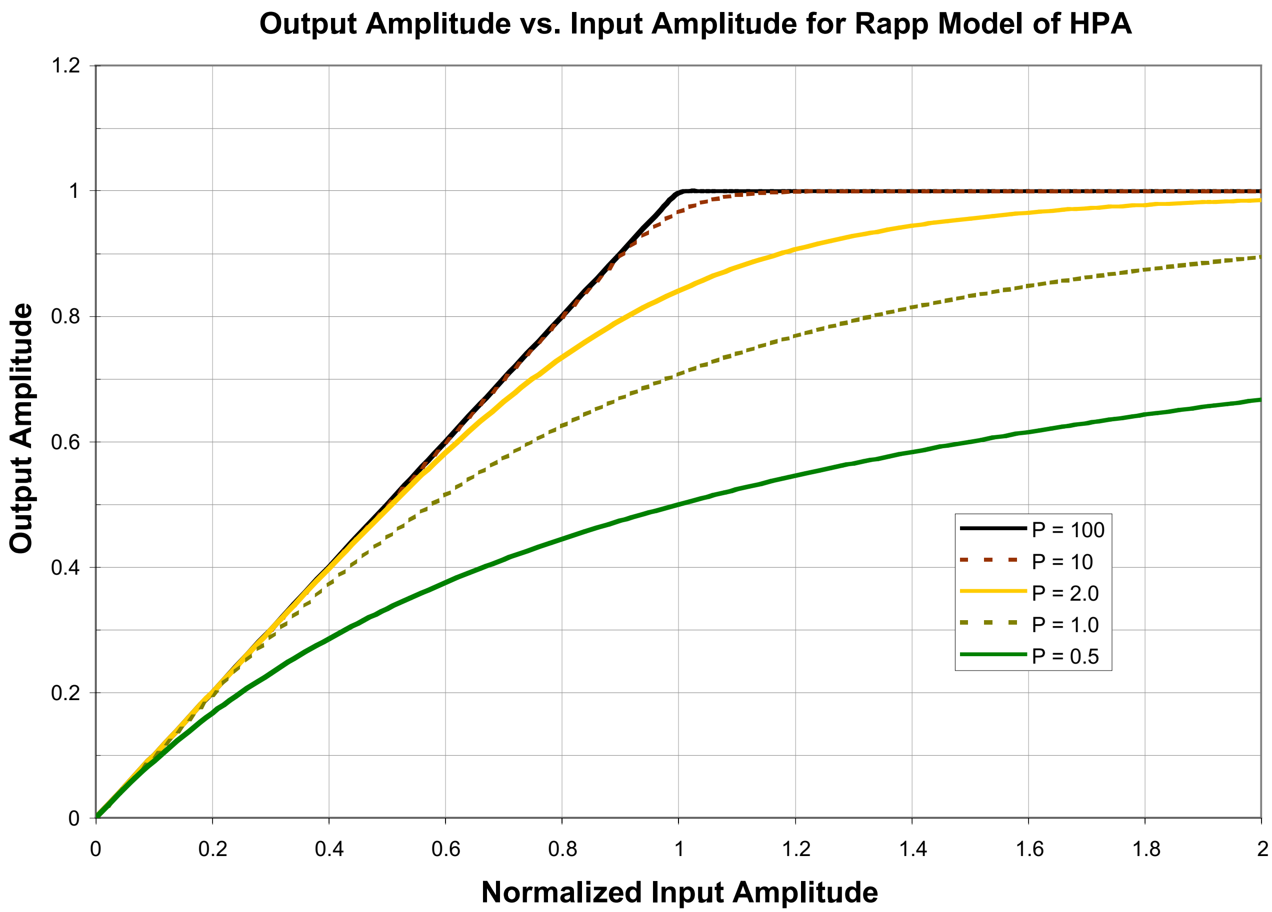
- Developed for solid-state power amplifiers.
- Produces a smooth transition for the envelope characteristic as the input amplitude approaches saturation.

  $$Vout = Vin/(1 + (|Vin|/Vsat)^{2P})^{1/(2P)}$$

  Where *Vsat* is the saturation voltage of the power amplifier and *P* is the smoothness factor.

Rapp Model

Curves for various smoothness factors “P”:



Rapp Model- Modified

- Honkanen and Haggman altered the low-level portion of the AM/AM characteristic in order to better mirror the exponential relationships of bipolar junction devices.
- Included AM/PM model as well.
- Their AM/AM and AM/PM models matched measurements of actual class AB mobile phone amplifier.
- Resulted in more accurate portrayal of intermodulation effects than the Rapp model when compared to a class AB mobile phone amplifier.
- They do not list their model’s parameters.

Ghorbani model

- Similar approach to Saleh.
- Claimed more suitable for SSPAs then Saleh.
- PA output :

  $y(t)=A(r(t))\cos\{\omega_0 t+\Psi(t)+\Phi(r(t))\}$

  where,

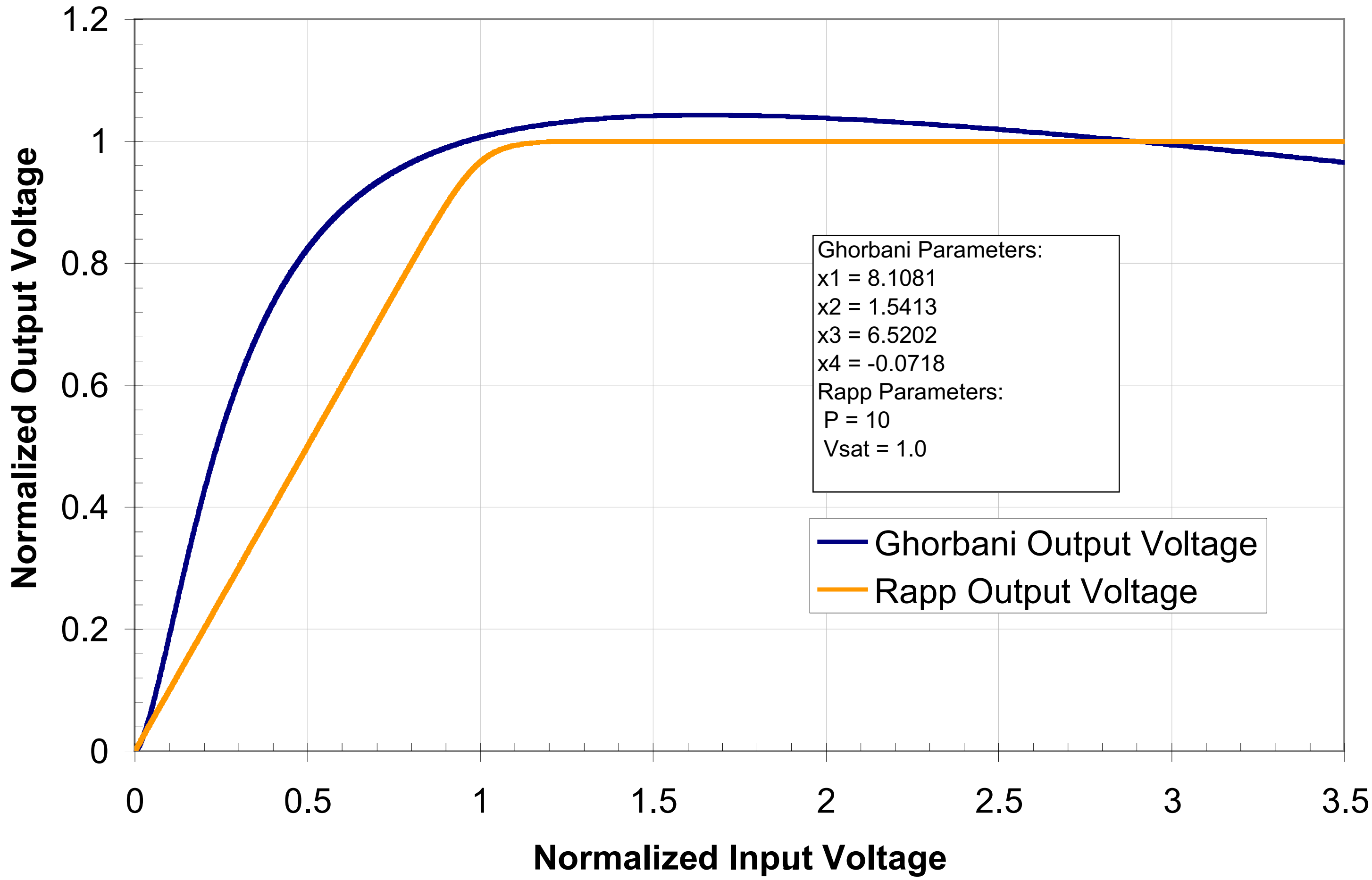
  $A(r) = x_1 r^{x_2}/(1+x_3 r^{x_2}) + x_4 r$

  $\Phi(r) = y_1 r^{y_2}/(1+y_3 r^{y_2}) + y_4 r$
- For the GaAs FET SSPA characterized by Ghorbani:

x1 = 8.1081	y1 = 4.6645
x2 = 1.5413	y2 = 2.0965
x3 = 6.5202	y3 = 10.88
x4 = -0.0718	y4 = -0.003

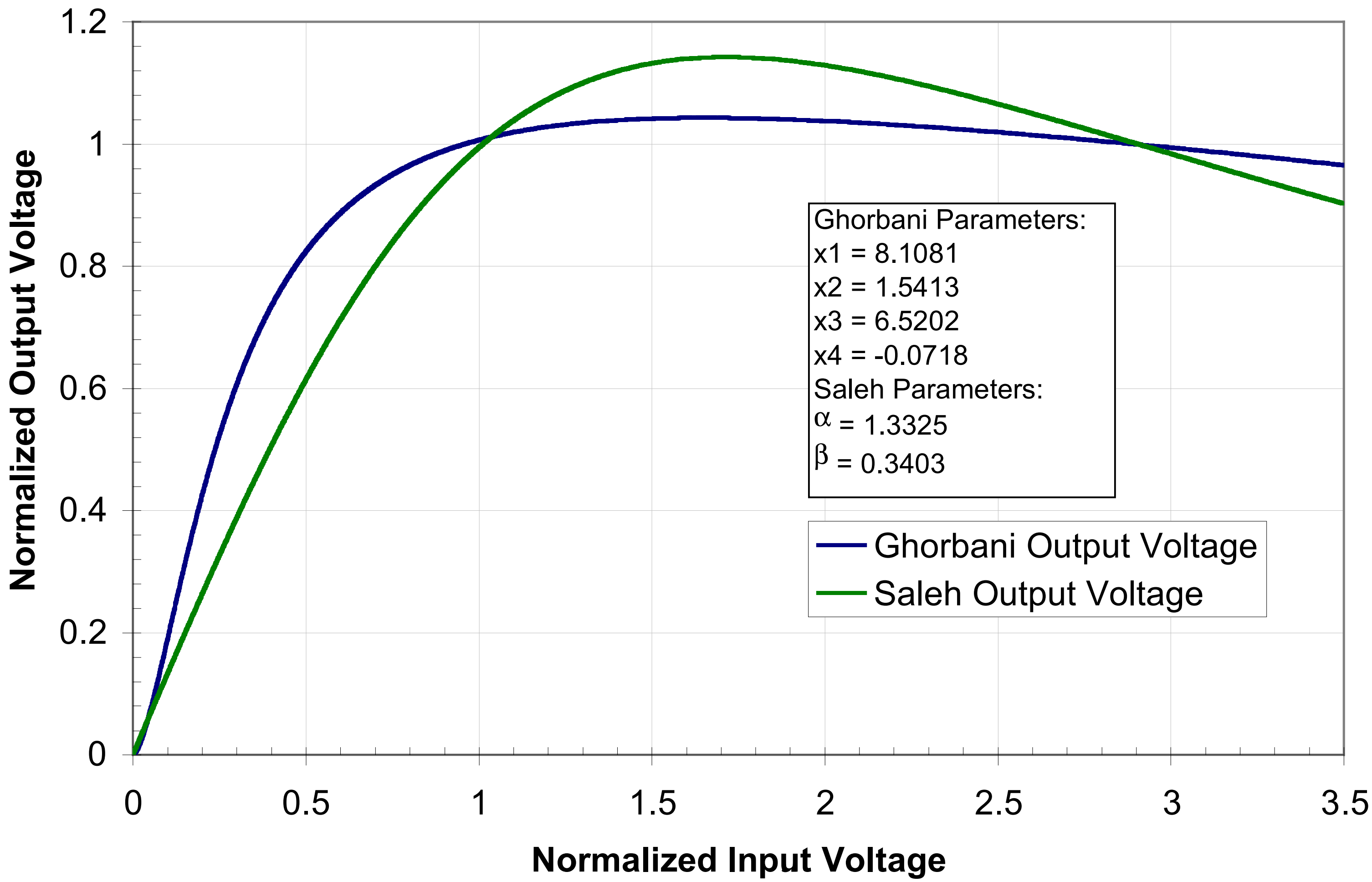
Ghorbani model compared to Rapp

Ghorbani model AM/AM curve, customized to a FET, and Rapp's AM/AM curve:



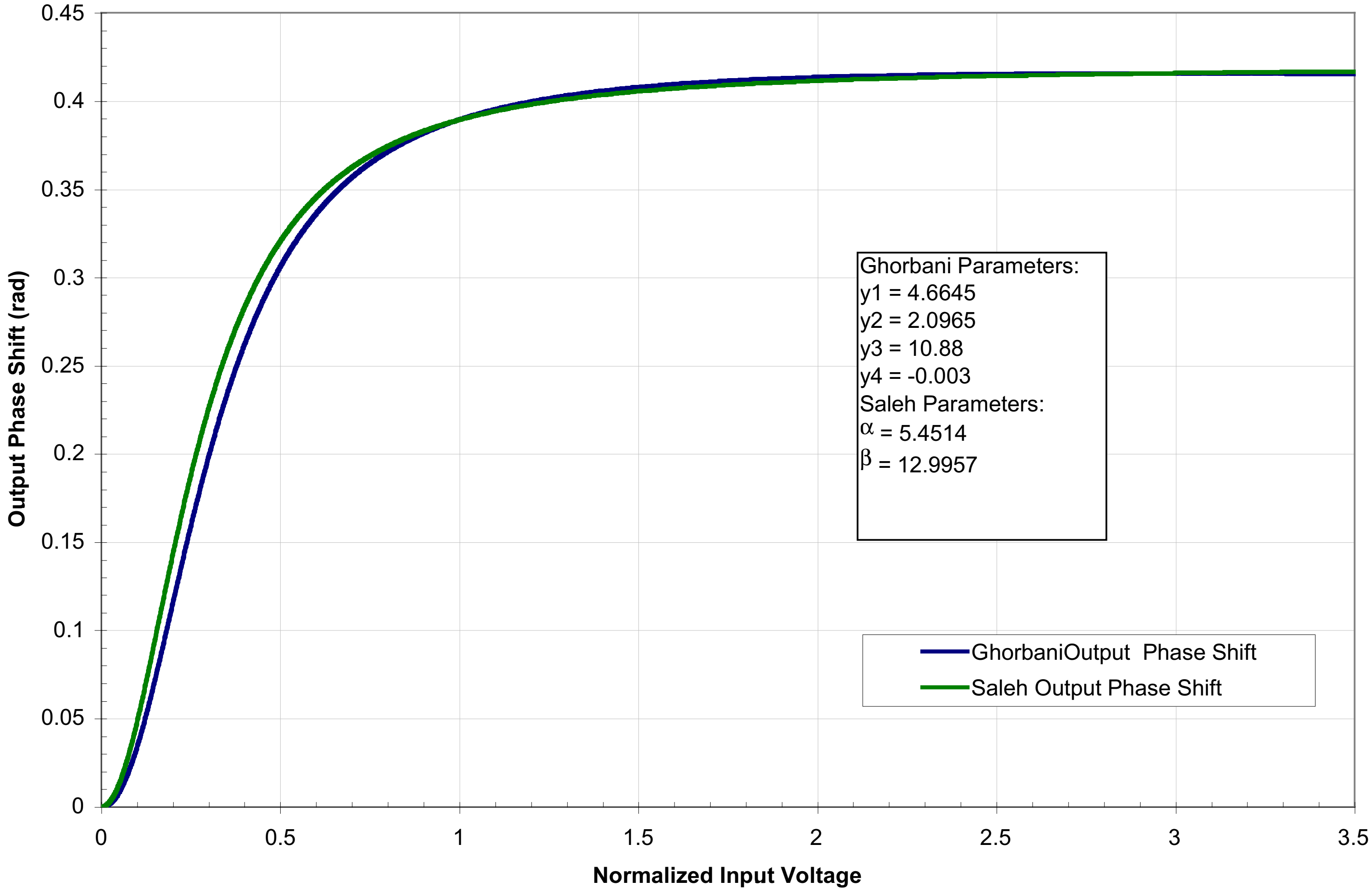
Ghorbani Compared to Saleh

Ghorbani model AM/AM curve, customized to a FET, and Saleh model's best fit to that curve:



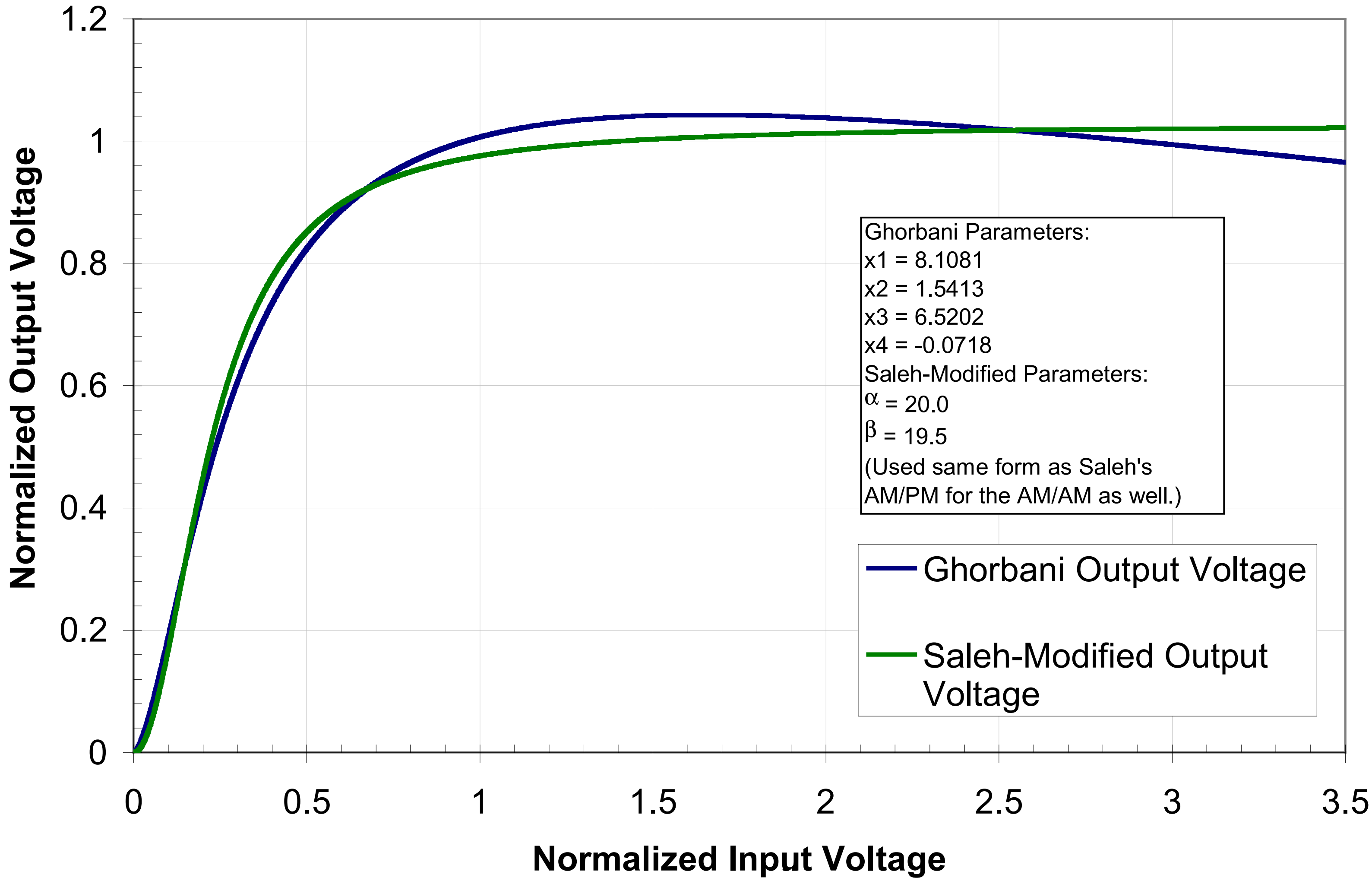
Ghorbani Compared to Saleh

Ghorbani model AM/PM curve, customized to a FET, and Saleh model's best fit to that curve:



Modified Saleh (Enserink)

Ghorbani model AM/AM curve, customized to a FET, and modified Saleh AM/AM fit to that curve:



Ghorbani Compared to Saleh

- Saleh model matches the GaAs FET amplifier's AM/PM characteristic well.
- Saleh model does not match the FET amplifier's AM/AM characteristic very well. Can improve the match by changing the Saleh AM/AM equation to have the same form as the Saleh AM/PM equation.
- Ghorbani model is better suited to the FET amplifier's characteristics and matches them closely.

Recommendation

- Adopt the well-known Saleh model as a comparison baseline.
- Baseline model serves as a reference point for comparison with other power amplifier models, (e.g., Ghorbani model).

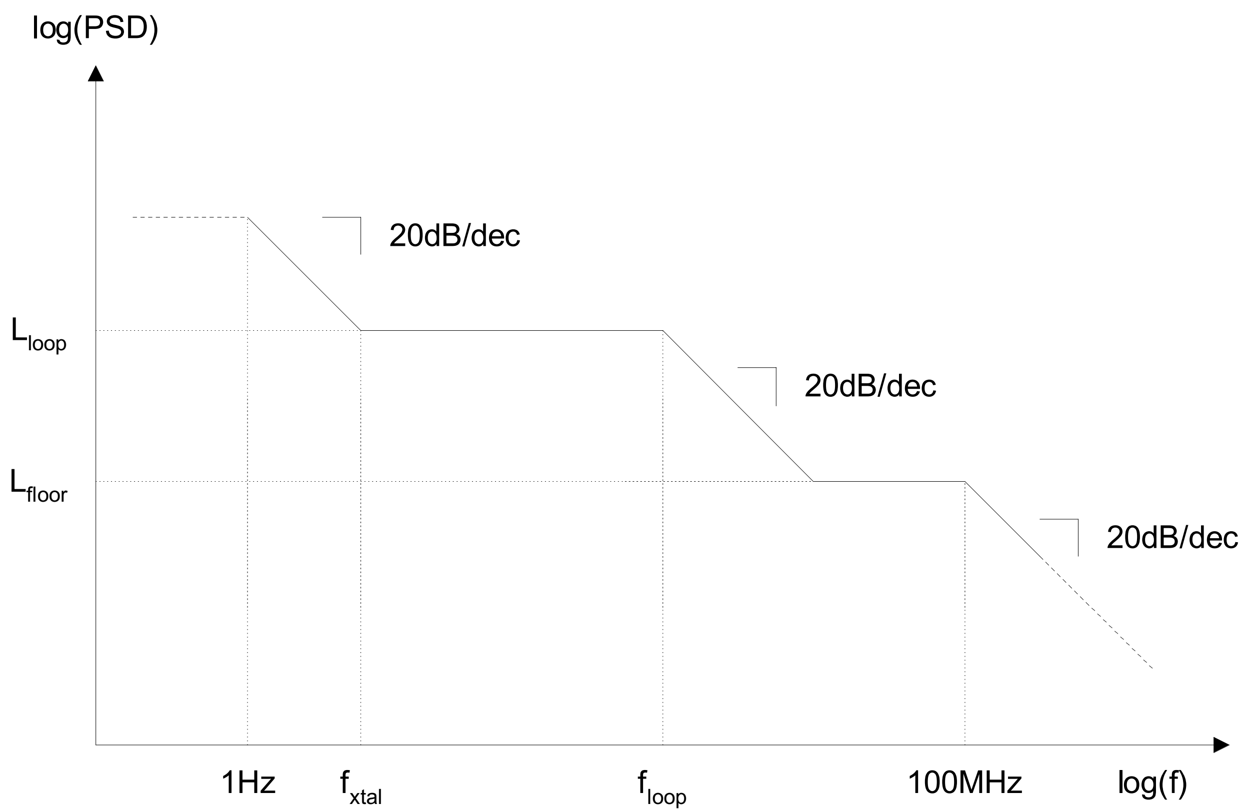
References

- A.A.M. Saleh, “Frequency-independent and frequency-dependent nonlinear models of TWT amplifiers,” *IEEE Trans. Communications*, vol. COM-29, pp.1715-1720, November 1981.
- A.R. Kaye, D.A. George, and M.J. Eric, “Analysis and compensation of bandpass nonlinearities for communications,” *IEEE Trans. Communications Technology*, vol. COM-20, pp.965-972, October 1972
- C. Rapp, “Effects of HPA-Nonlinearity on a 4-DPSK/OFDM-Signal for a Digitial Sound Broadcasting System”, in Proceedings of the Second European Conference on Satellite Communications, Liege, Belgium, Oct. 22-24, 1991, pp. 179-184.
- M. Honkanen and Sven-Gustav Haggman, “New Aspects on Nonlinear Power Amplifier Modeling in Radio Communication System Simulations”, Proc. IEEE Int. Symp. On Personal, Indoor, and Mobile Comm.,PIMRC ’97, Helsinki, Finland, Sep. 1-4, 1997, pp. 844-848.
- A. Ghorbani, and M. Sheikhan, “The effect of Solid State Power Amplifiers (SSPAs) Nonlinearities on MPSK and M-QAM Signal Transmission”, Sixth Int’l Conference on Digital Processing of Signals in Comm., 1991, pp. 193-197.

Phase noise assumptions

- Purpose: weighing sensitivity of different proposals to phase noise – **not an interface specification**
- Transmitter mmW up-converter and receiver mmW down-converter are expected to dominate phase noise
- Based on PLL-oscillator model

SSB phase noise PSD, L(f)



Phase noise model

- The model has four parameters
  - Corner frequency for crystal phase noise
  - Corner frequency for PLL loop
  - LO noise floor level
  - PLL phase noise level
- Two parameters for ease of simulation are a zero at 1Hz, and a pole at 100MHz
- To ease simulation, 1/f noise is not accounted for

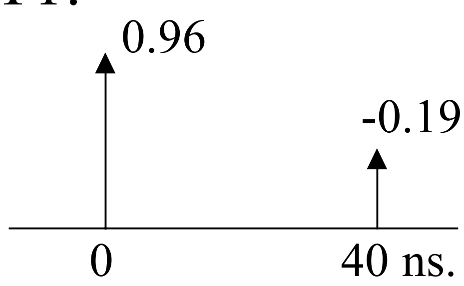
Phase noise notes

- Thermal noise, discrete spurs and demodulator induced phase noise are **NOT** included in this model.
- Model is to be used for comparison purposes, **NOT** for precise performance evaluation

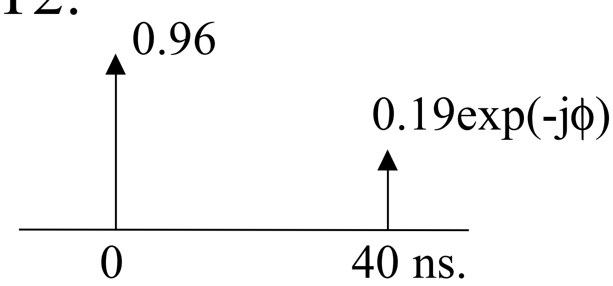
ETSI/BRAN Multipath Models

ETSI/BRAN document HAPHY151TL03**,** “Channel model suitable for bands over 20 GHz”, 21 Sept. 1999.

T1:



T2:

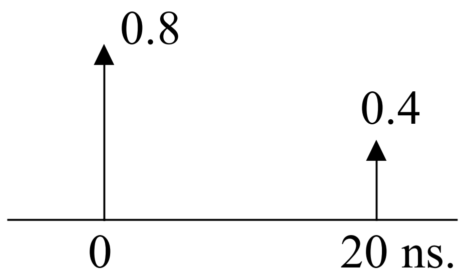


$$\varphi=\pi(1-0.8(40\text{ ns.})/T_{symbol}))$$

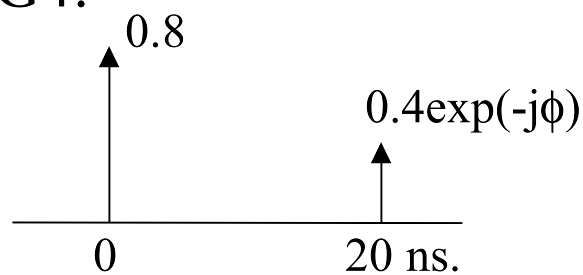
Based on measurements in Europe by Telia

ETSI/BRAN (cont.) and Papazian

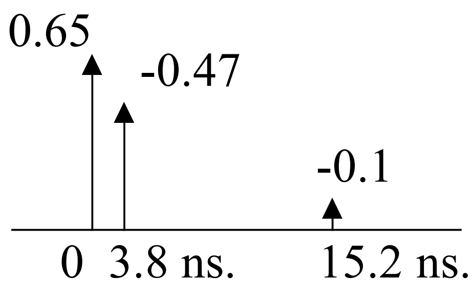
G3:



G4:

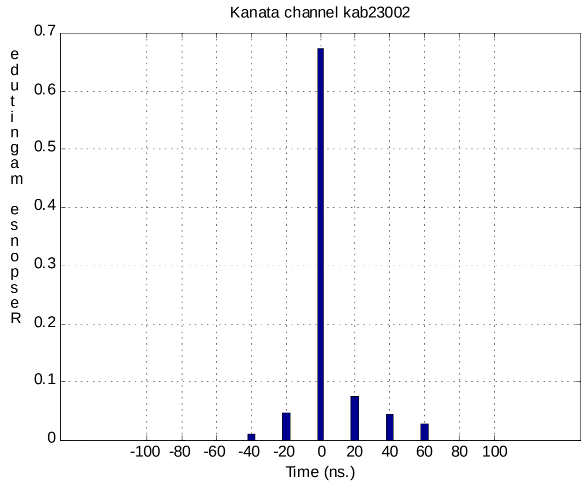


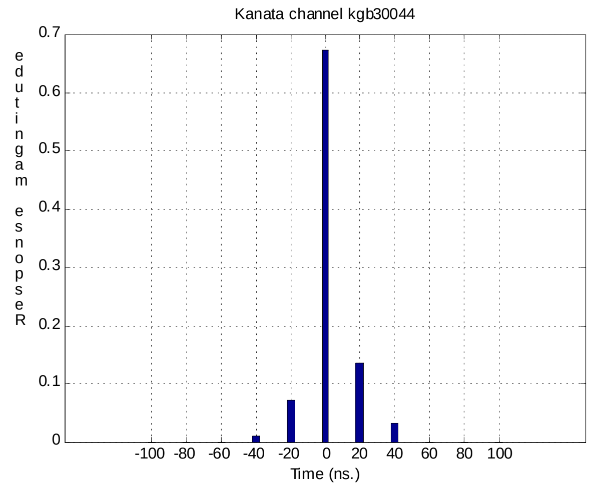
L7/Papazian:

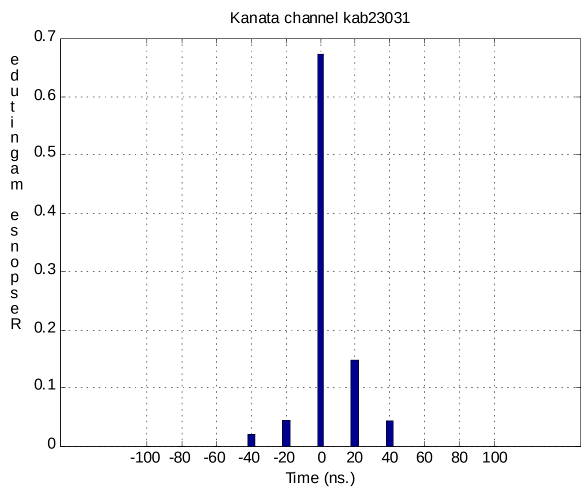


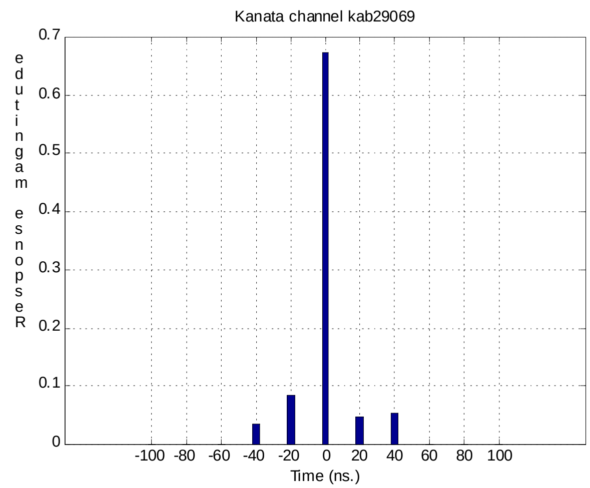
$\varphi=\pi(1-0.8(20\text{ ns.})/T_{symbol}))$

Some Measured Kanata Responses



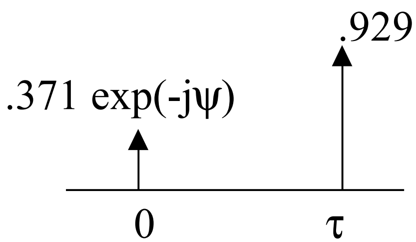




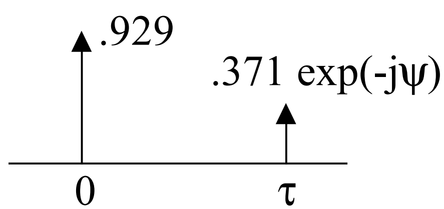


Proposed Multipath Models

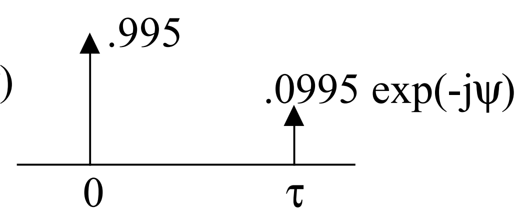
Model A1:



Model A2:



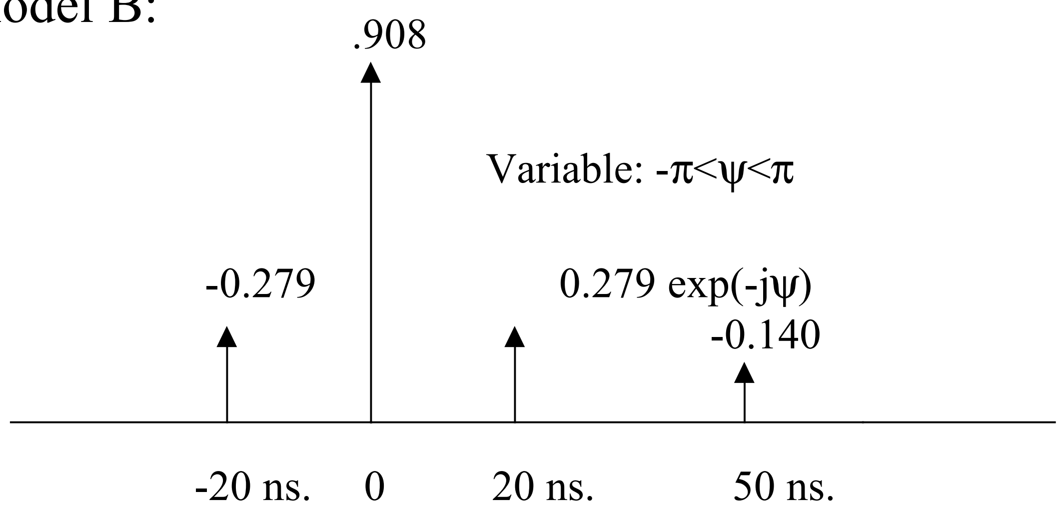
Model A3:



Variables:
$-\pi<\psi<\pi$
$0<\tau<50$ ns.

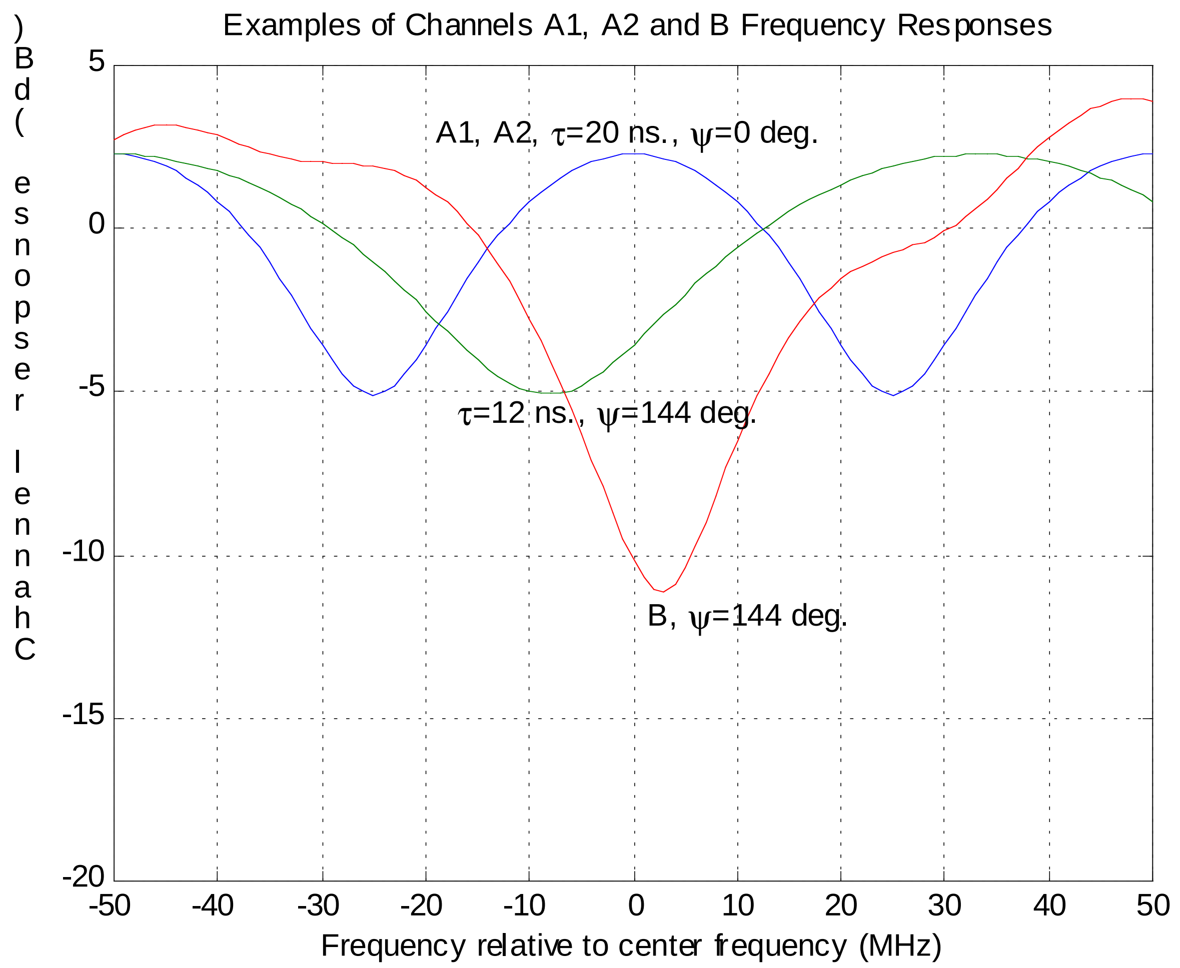
Proposed Multipath Models (cont.)

Model B:

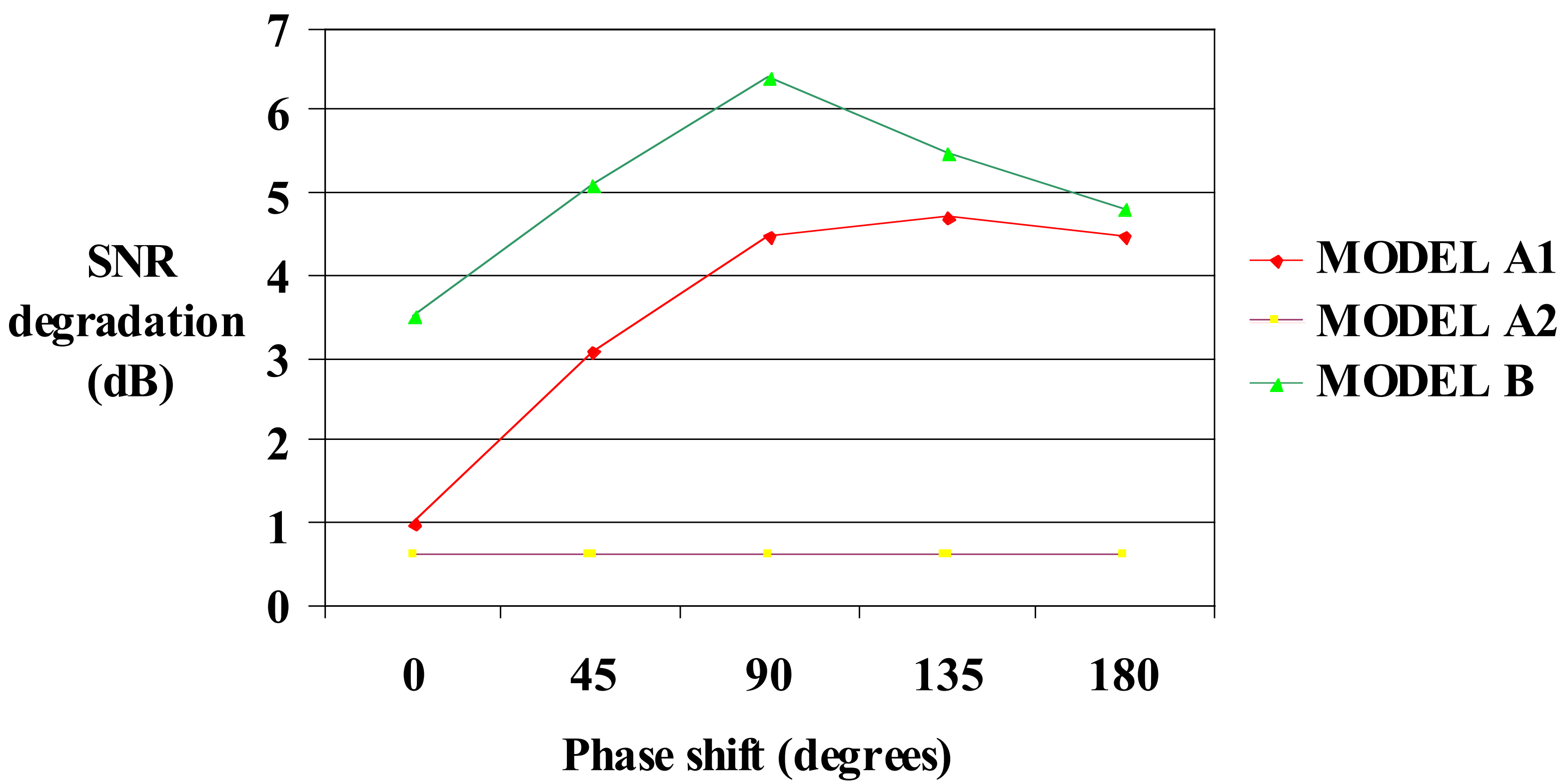


Time variation? -- slow compared to symbol rate

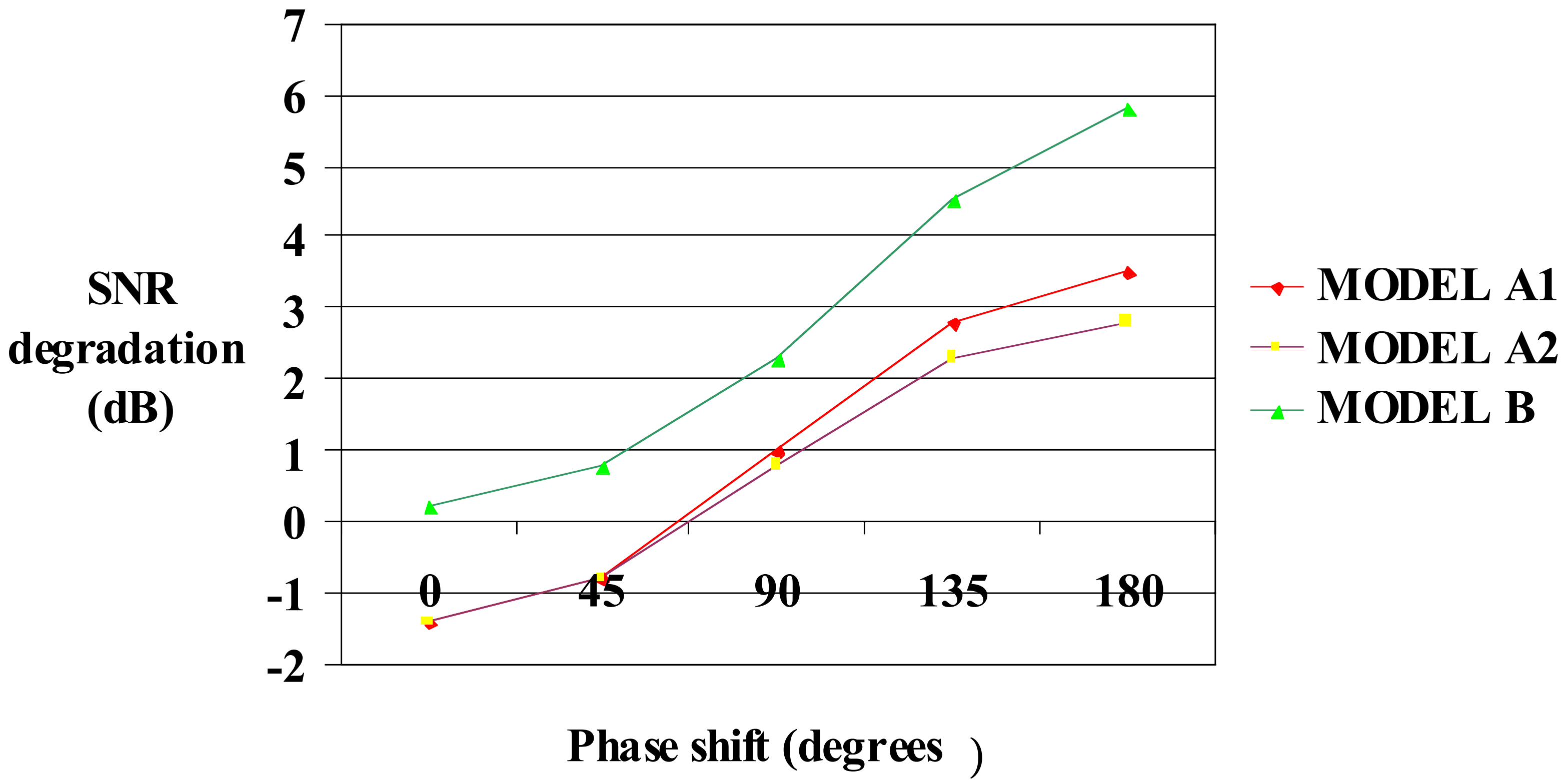
Frequency Responses



SNR Degradation for (8,1) DFE (50 Megasymbols/s)



SNR Degradation for (8,1) DFE (25 Megasymbols/s)



Conclusions on Multipath Modeling

- Three 2-tap and one 3-tap models proposed for PHY evaluation purposes, with variable phase and delay parameters.
- "Worst case" channels, including some with precursors (non-minimum phase). Examples of equalizer performance (not optimized).
- Fairly consistent with others' models in terms of delay spread and echo magnitudes.