Everything you've always wanted to know about Hot-S22
(but we're afraid to ask)

Jan Verspecht

Slides presented at the Workshop
Introducing New Concepts in Nonlinear Network Design
(International Microwave Symposium 2002)
Everything you’ve always wanted to know about “Hot-S_{22}”
(but were afraid to ask)

Jan Verspecht
Agilent Technologies
Purpose

- Convince people of a better “Hot $S_{22}$”
- Show that technology is fun (sometimes)
• Introduction: What is “Hot $S_{22}$”?
• Getting and interpreting experimental data
• Confront classic approaches with data
• Derivation of the extended “Hot $S_{22}$” theory
• Confront extended “Hot $S_{22}$” with data
• Conclusion
What is “Hot S$_{22}$”? 

• D.U.T. behavior is represented by pseudo-waves ($A_1, B_1, A_2, B_2$)

• “Hot S$_{22}$” describes the relationship between $B_2$ and $A_2$

• Valid under “Hot” conditions ($A_1$ significant)
Experimental investigation

- Take a real life D.U.T. (CDMA RFIC amplifier)
- Apply an $A_1$ signal
- Apply a set of $A_2$’s
- Look at the corresponding $B_2$’s
- Mathematically describe the relationship between the $A_2$’s and $B_2$’s
- Repeat for different $A_1$’s
Experimental set-up

- synth1 generates $A_1$
- synth2 generates a set of $A_2$’s
- LSNA measures all $A_1$’s, $B_1$’s, $A_2$’s, $B_2$’s
Interpretation of the data

- IQ-plots of the $A_2$’s and $B_2$’s for a constant $A_1$ ($x$-axis = real part, $y$-axis = imaginary part)
Phase normalization is good

- Normalize the phases relative to $A_1$

$$P = e^{i \arg(A_1)}$$
Varying the amplitude of $A_1$
Varying the amplitude of $A_2$

$B_2.P^{-1} (V)$

$A_2.P^{-1} (V)$

* Linear dependency versus $A_2$
Data interpretation as loadpull

Increasing amplitude of $A_1$
Classic S-parameter description

\[ B_2 \cdot P^{-1} (V) \]

- \[ B_2 = S_{21} (|A_1|) \cdot A_1 + S_{22} \cdot A_2 \]
Simple “Hot $S_{22}$” description

$B_2 \cdot P^{-1} (V)$

- $B_2 = S_{21}(|A_1|) \cdot A_1 + S_{22}(|A_1|) \cdot A_2$
Model linearity & squeezing

• We look for a mathematical model which
  – is linear (superposition valid)
  – squeezes

• Squeezing implies that the phase of $A_2P^{-1}$ matters

• We need different coefficients for the real and the imaginary part of $A_2P^{-1}$

• More elegant expression results when using $A_2P^{-1}$ and its conjugate
**Mathematical expression**

- \( B_2.P^{-1} = S_{21}(|A_1|).A_1.P^{-1} + S_{22}(|A_1|).A_2.P^{-1} + R_{22}(|A_1|).\text{conjugate}(A_2.P^{-1}) \)

- \( B_2 = S_{21}(|A_1|).A_1 + S_{22}(|A_1|).A_2 + R_{22}(|A_1|).P^2.\text{conjugate}(A_2) \)
Extended “Hot $S_{22}$”

\[ B_2 = S_{21}(|A_1|)A_1 + S_{22}(|A_1|)A_2 + R_{22}(|A_1|)P^2\text{.conjugate}(A_2) \]
Quadratic “Hot $S_{22}$”

- Further improvement is possible by using a polynomial in $A_2$ and $\text{conj}(A_2)$
- E.g.: quadratic “Hot $S_{22}$”
  \[ B_2 = F.P + G.A_2 + H.P^2.\text{conj}(A_2) + K.P^{-1}.A_2^2 + L.P^3.\text{conj}(A_2)^2 + M.P.A_2.\text{conj}(A_2) \]
- Note the presence of the P factors
  (theory of describing functions)
Comparison (highest $A_1$ amplitude)

$B_2.P^{-1}$ (V)

Classic $S_{22}$

Extended “Hot $S_{22}$”

Simple “Hot $S_{22}$”

Quadratic “Hot $S_{22}$”
Conclusion

- An accurate “Hot $S_{22}$” exists
- It has a coefficient for the conjugate of $A_2 P^{-1}$
- It can accurately be measured
- It describes the relationship between $A_2$ and $B_2$ under large-signal excitation
More information

- More detailed information on this kind of measuring and modeling techniques:

  http://users.skynet.be/jan.verspecht