The Bodger's Guide to Scattering Parameters

or

Understanding measurements on SHF networks and devices for the mathematically challenged!

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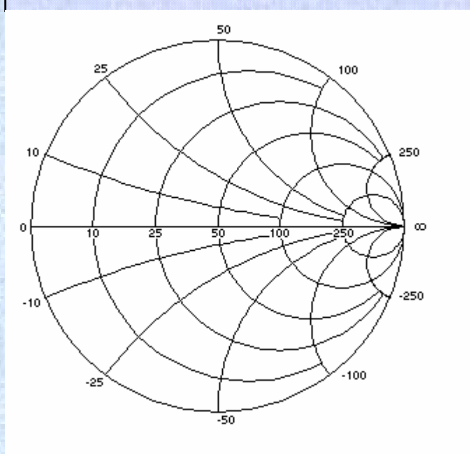
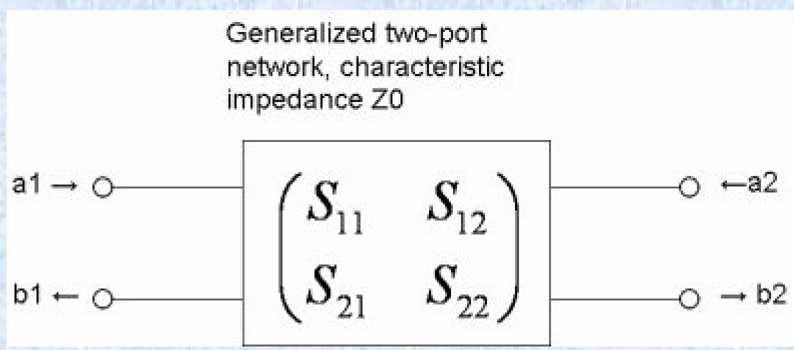
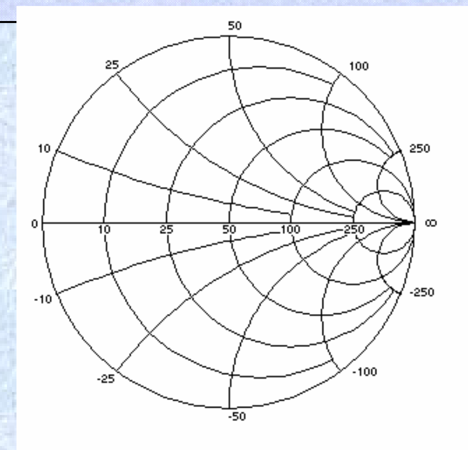




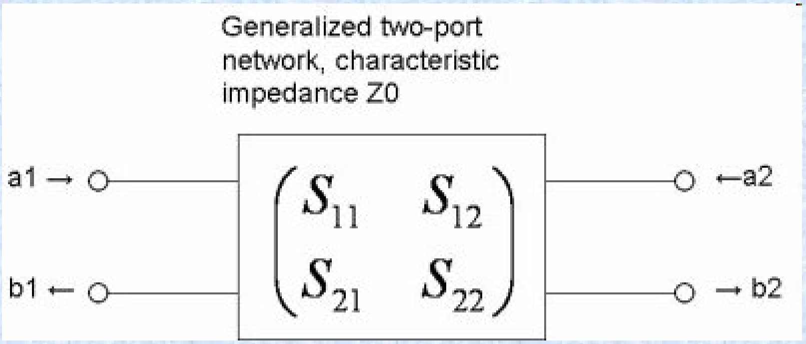


Consultancy, Writing and all things Wireless

S-parameters for Bodgers

- Bodger – (noun)
  - A highly skilled itinerant wood-turner, who worked in the beech woods on the chalk hills of the Chilterns, in England
- Bodging (Br. Slang)
  - an inexpertly or roughly done job, typically in the field of DIY.

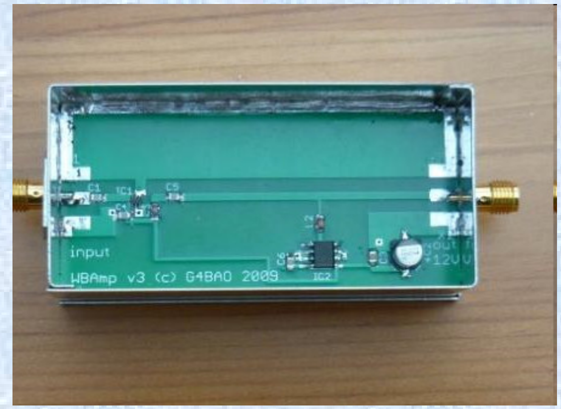
What are S- parameters?

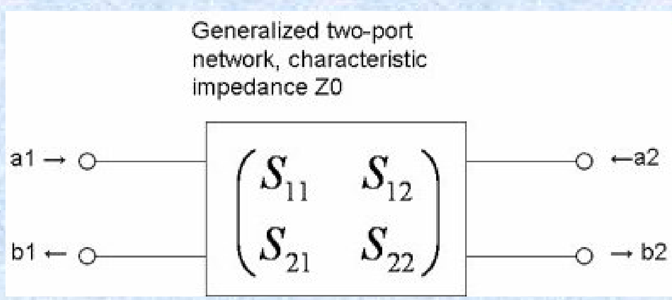


- **Formal definition:**
- *"S-parameters describe the response of an N-port network to voltage signals at each port".*

- **They allow us to describe the properties of incredibly complicated networks as "black boxes"**

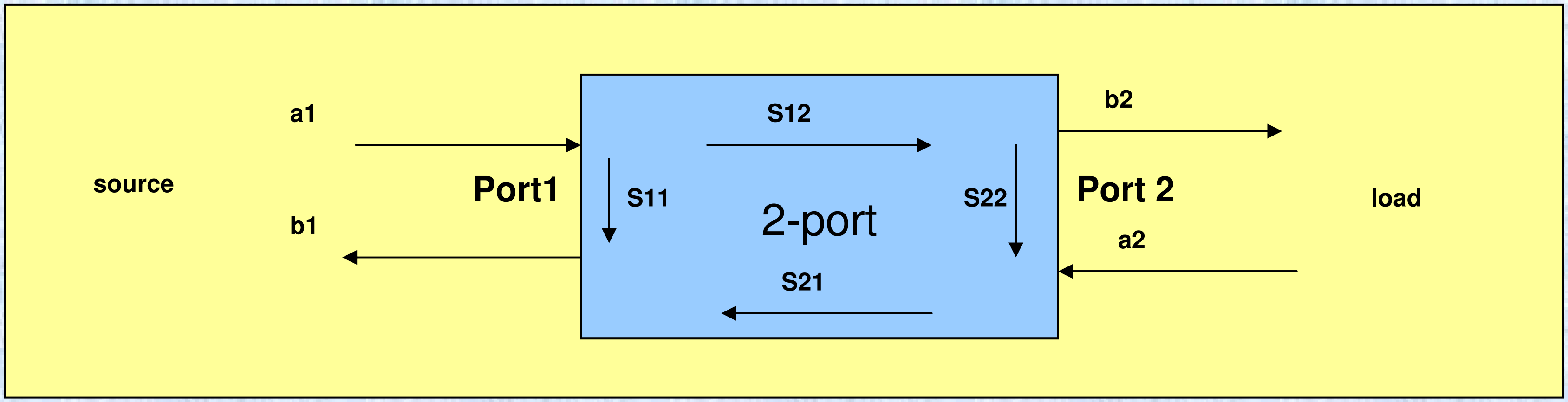
Some 1 and 2 –Port networks





What are S- parameters?

- For an RF signal (a_1 or a_2) incident on one port, some fraction of the signal bounces back out of that port, some of it *scatters* and exits other ports and some of it disappears as heat or electromagnetic radiation.
- S parameters are the familiar reflection and transmission coefficients
- Transmission is related to gains and attenuations
- Reflection is related to VSWR and impedance



What are S- parameters?

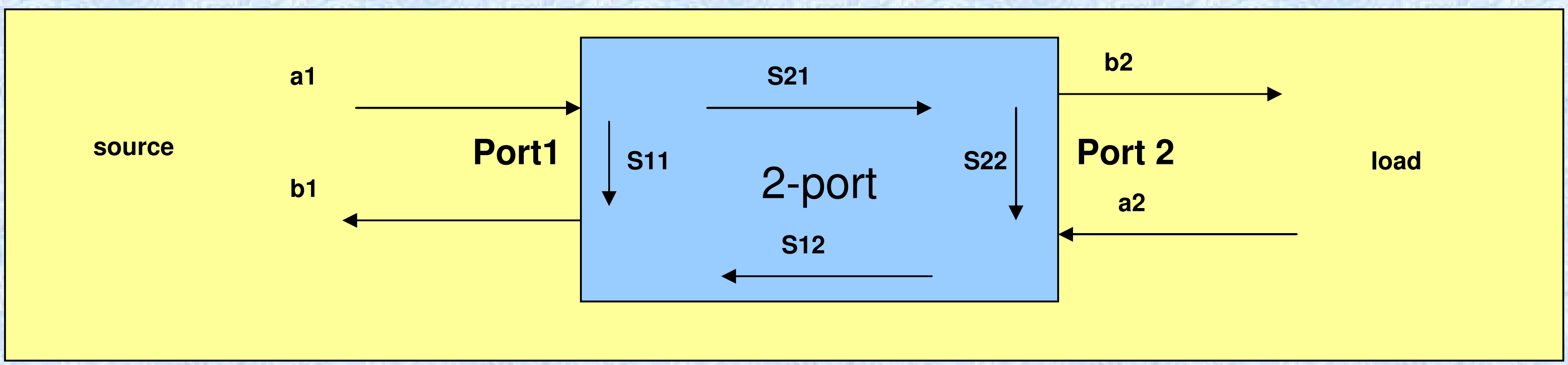
- In the diagram below, a and b represent the square root of power, so a_1^2 is the power incident at port 1, b_2^2 is the power leaving port 2, etc.

- The outputs can be related to the inputs by

$$b_1 = s_{11}a_1 + s_{12}a_2$$

and

$$b_2 = s_{21}a_1 + s_{22}a_2$$



What are S- parameters?

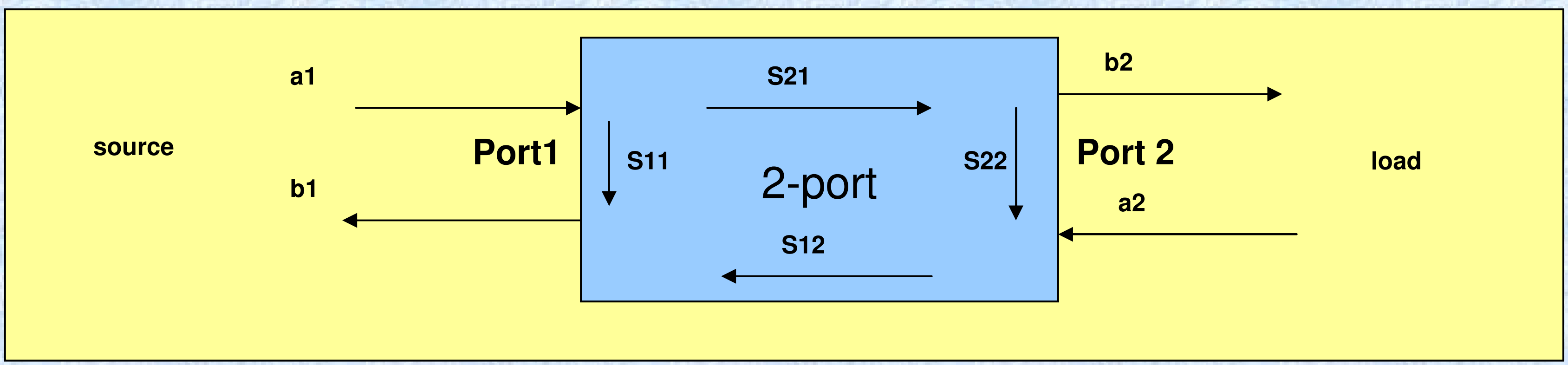
$$b_1 = s_{11}a_1 + s_{12}a_2$$

and

$$b_2 = s_{21}a_1 + s_{22}a_2$$

- **Or for those of you who left school after 1973, as a matrix.**

$$\begin{vmatrix} b_1 \\ b_2 \end{vmatrix} = \begin{vmatrix} S_{11} S_{12} \\ S_{21} S_{22} \end{vmatrix} x \begin{vmatrix} a_1 \\ a_2 \end{vmatrix}$$



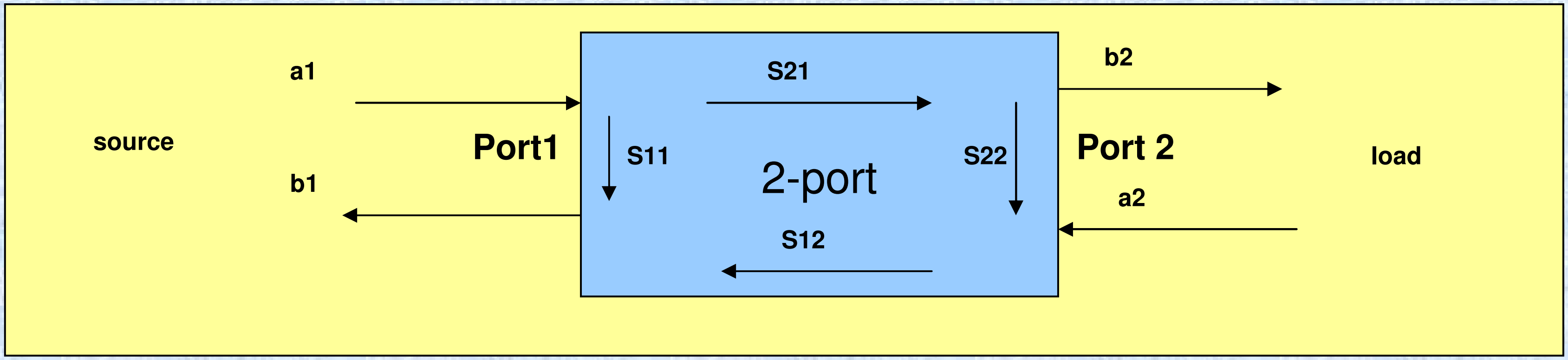
What are S- parameters?

$$b_1 = s_{11}a_1 + s_{12}a_2$$

and

$$b_2 = s_{21}a_1 + s_{22}a_2$$

- Now what happens when port 2 is terminated in Z_0?
- **That sets a_2** = 0
- **s_{11} = b_1/a_1 i.e the input reflection coefficient**
- **s_{21} = b_2/a_1 i.e the forward transmission gain/loss**



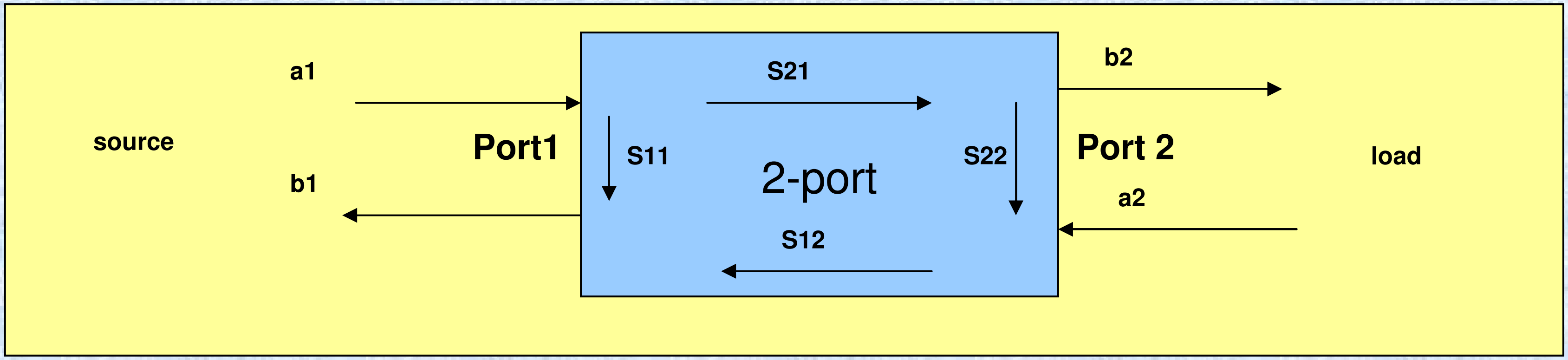
What are S- parameters?

$$b_1 = s_{11}a_1 + s_{12}a_2$$

and

$$b_2 = s_{21}a_1 + s_{22}a_2$$

- Now what happens when port 1 is terminated in Z_0?
- **That sets a_1** = 0, and
- **s_{22} = b_2/a_2 i.e the output reflection coefficient**
- **s_{12}= b_1/a_2 i.e the reverse transmission gain/loss**

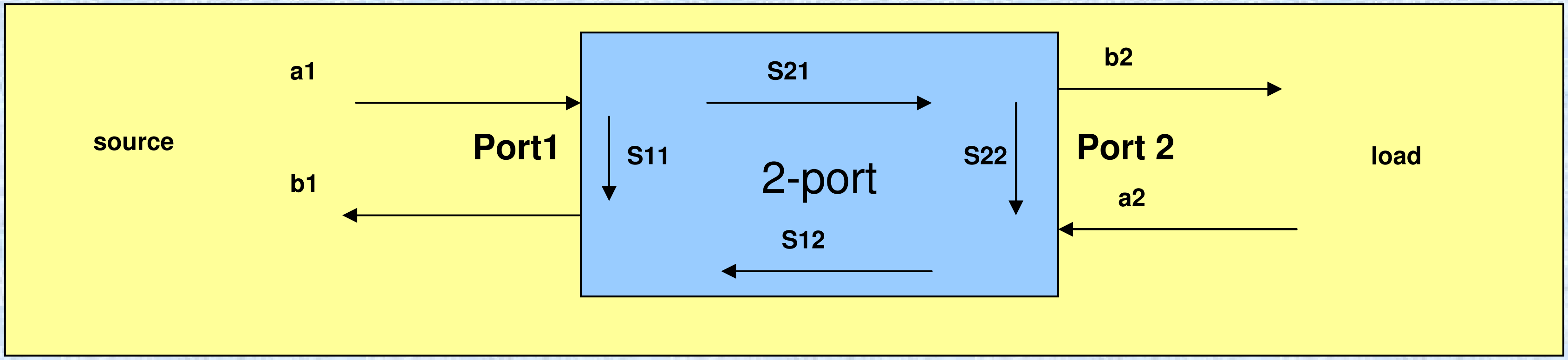


What are S- parameters?

So to summarise….. *with network ports terminated in Z_0*

- **S_{11} = input reflection coefficient**
- **S_{12} = reverse transmission coefficient (port 1/port 2)**
- **S_{21} = forward transmission coefficient (port 2/port 1)**
- **S_{22} = output reflection coefficient**

- **These include magnitude and phase angle**

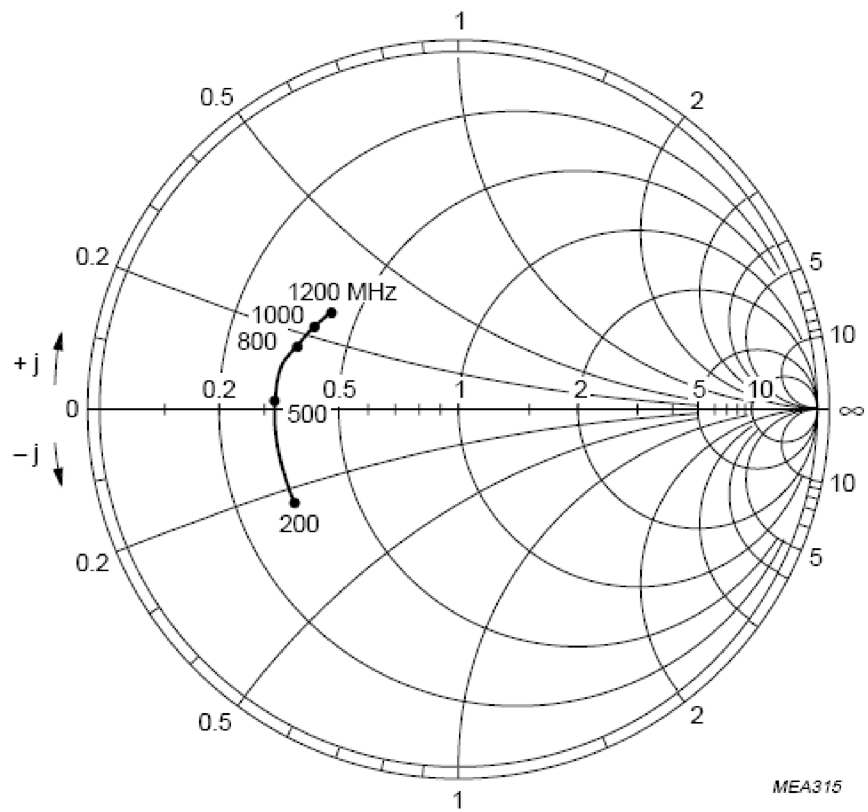


Typical parameter data

AT-42036 Typical Scattering Parameters,
Common Emitter, $Z_O = 50\ \Omega$, $T_A = 25°C$, $V_{CE} = 8$ V, $I_C = 10$ mA

Freq. GHz	S_{11} Mag.	S_{11} Ang.	S_{21} dB	S_{21} Mag.	S_{21} Ang.	S_{12} dB	S_{12} Mag.	S_{12} Ang.	S_{22} Mag.	S_{22} Ang.
0.1	.72	-46	28.3	26.09	152	-37.0	.014	73	.92	-14
0.5	.59	-137	20.9	11.13	102	-31.0	.028	44	.58	-27
1.0	.56	-171	15.4	5.91	80	-28.2	.039	47	.51	-29
1.5	.56	169	12.1	4.03	67	-26.6	.047	52	.50	-33
2.0	.58	155	9.7	3.06	55	-24.2	.062	55	.48	-38
2.5	.59	147	8.0	2.50	48	-22.6	.074	61	.47	-42
3.0	.61	137	6.5	2.10	38	-20.8	.092	65	.46	-51
3.5	.63	128	5.2	1.82	27	-19.6	.105	62	.47	-63
4.0	.63	117	4.0	1.60	17	-18.0	.126	57	.49	-72
4.5	.63	106	3.1	1.43	7	-16.5	.149	53	.51	-80
5.0	.64	93	2.3	1.30	-3	-15.4	.169	48	.52	-87
5.5	.67	79	1.5	1.19	-13	-14.3	.193	41	.51	-94
6.0	.72	70	0.6	1.07	-23	-13.4	.215	35	.46	-105

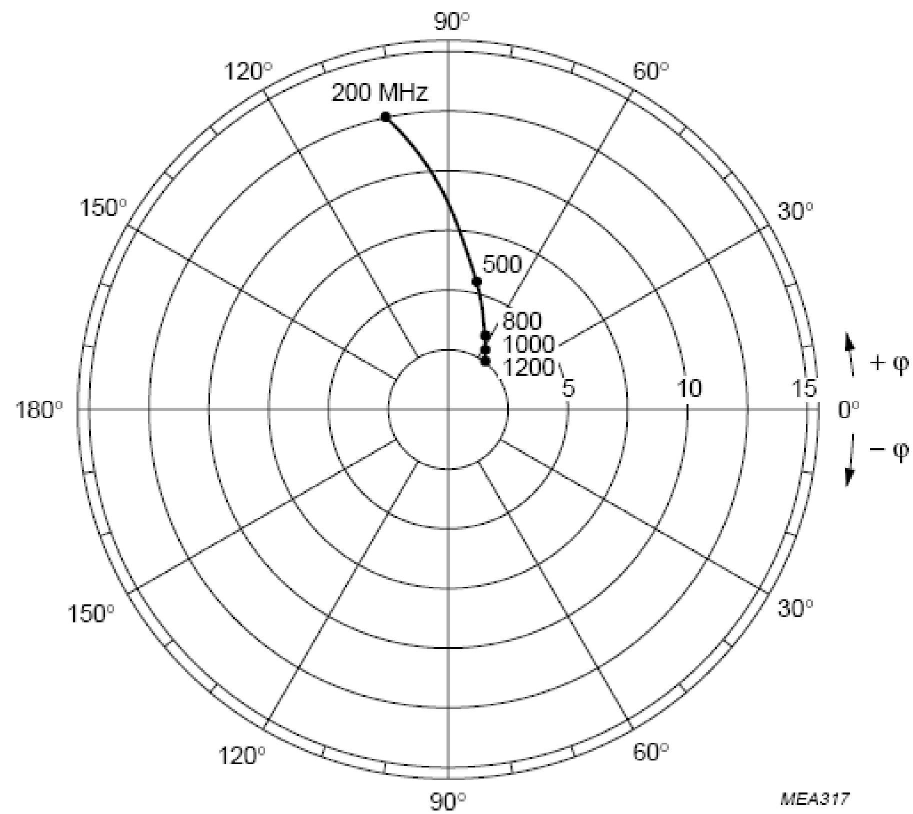
Typical parameter data



I_c = 120 mA; V_{CE} = 15 V; T_{amb}= 25 °C.
Z_o = 50 Ω.

Fig.8 Common emitter input reflection coefficient (S_{11}).

Typical parameter data



I_c = 120 mA; V_{CE} = 15 V; T_{amb}= 25 °C.

Fig.9 Common emitter forward transmission coefficient (S_{21}).

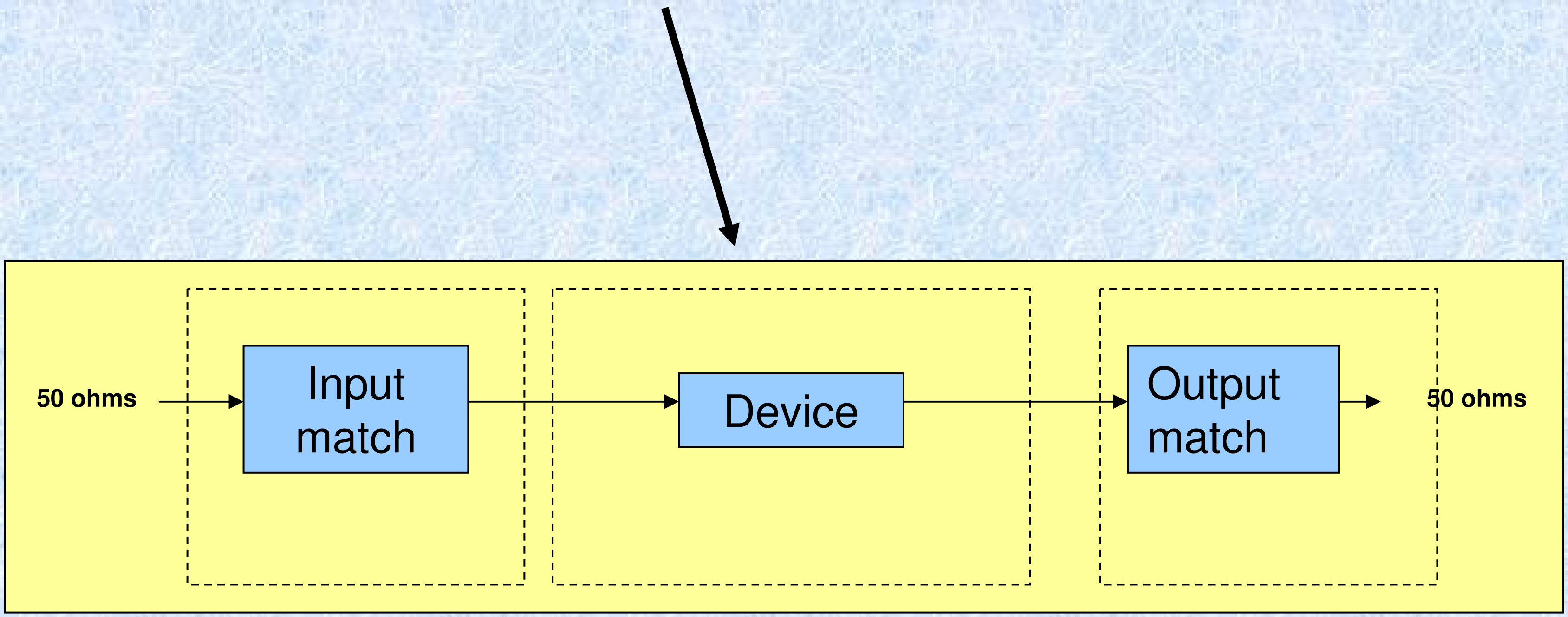
Why S- parameters?

They are defined ….. *<u>with network ports terminated in Z_0</u>*
so are

- ***Easy to measure***
  - ***Device is terminated in system measurement impedance***
  - ***Termination is resistive and can be very accurate at SHF***
  - ***No tuning required to terminate in Z_0***
  - ***Broadband swept measurements possible***
  - ***Can measure the device at the end of long coax leads***
  - ***Resistive termination is more likely to be stable***
  - ***Different devices can be measured on the same setup***
- ***Easy to use***
  - ***Overlay a Smith chart on a polar plot of s_{11} or s_{22} and you can read off the device Z_{in} and Z_{out}***

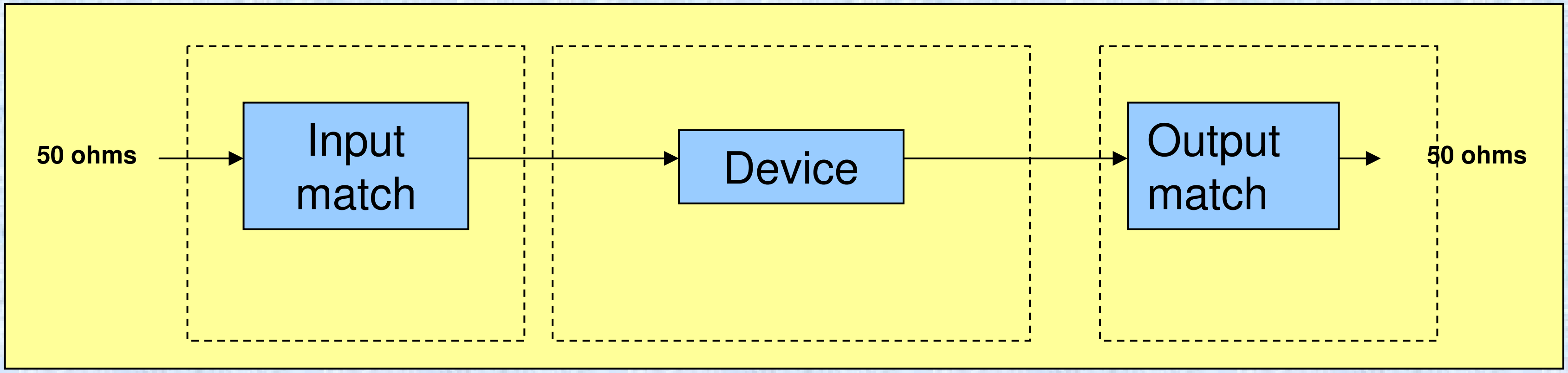
Why S- parameters?

- So what good to a designer is a measurement of a transistor terminated directly in 50 ohms then?
- In most case, the device does not "see" 50 ohms

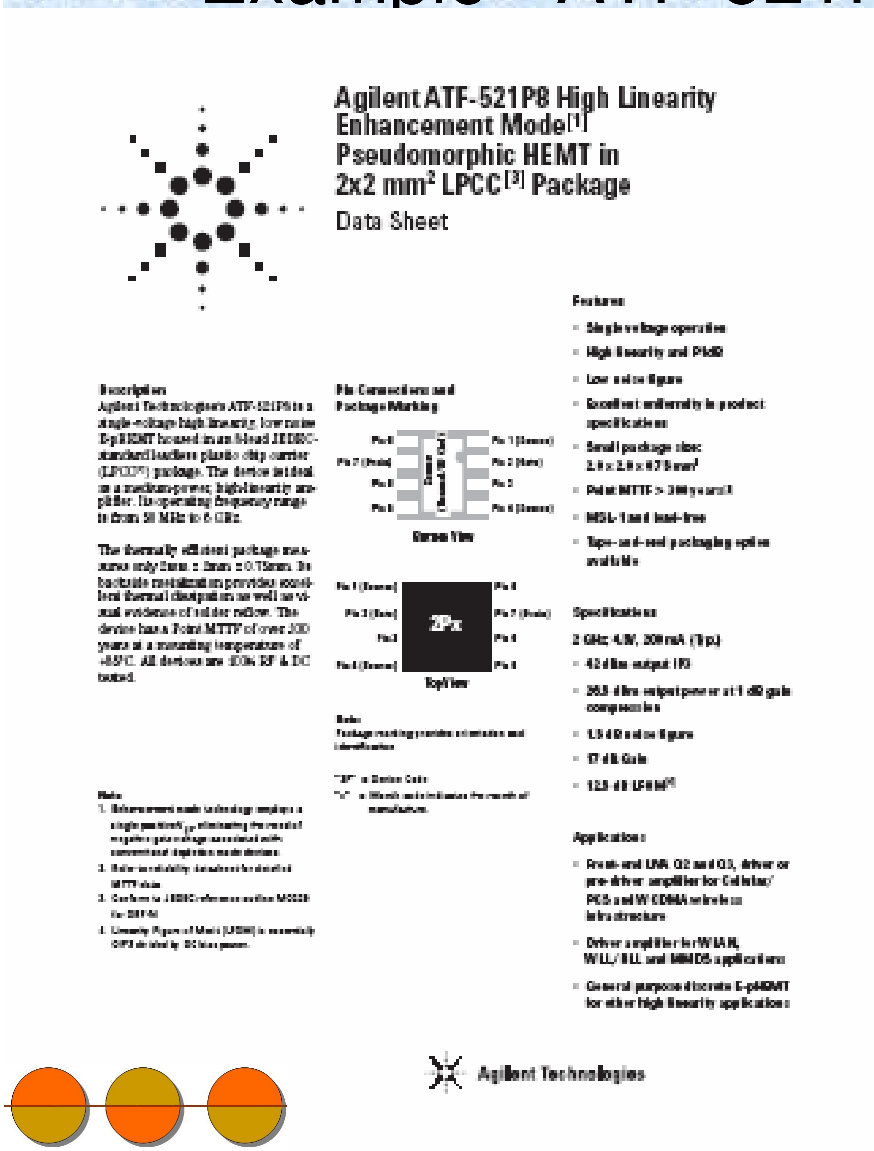


Why S- parameters?

- This is where the Maths come in, (and I run for the computer!)
- From S parameters you can derive:
  - Maximum available gain (Maximum stable gain).
  - Stability factors
  - Input and output impedances for a given gain
  - Optimum match for best noise figure
- And hence the input and output matching circuits



Example - ATF-521P8 P HEMT @ 3.4GHz



Agilent ATF-521P8 High Linearity Enhancement Mode[1] Pseudomorphic HEMT in 2x2 mm² LPCC[3] Package

Data Sheet

Description

Agilent Technologies's ATF-521P8 is a single-voltage high linearity, low noise E-pHEMT housed in an 8-lead JEDEC-standard leadless plastic chip carrier (LPCC[3]) package. The device is ideal as a medium-power, high-linearity amplifier. Its operating frequency range is from 50 MHz to 6 GHz.

The thermally efficient package measures only 2mm x 2mm x 0.75mm. Its backside metalization provides excellent thermal dissipation as well as visual evidence of solder reflow. The device has a Point MTTF of over 300 years at a mounting temperature of +85°C. All devices are 100% RF & DC tested.

Pin Connections and Package Marking

Bottom View

Top View

Features

- Single voltage operation
- High linearity and P1dB
- Low noise figure
- Excellent uniformity in product specifications
- Small package size: 2.0 x 2.0 x 0.75 mm³
- Point MTTF > 300 years[2]
- MSL-1 and lead-free
- Tape-and-reel packaging option available

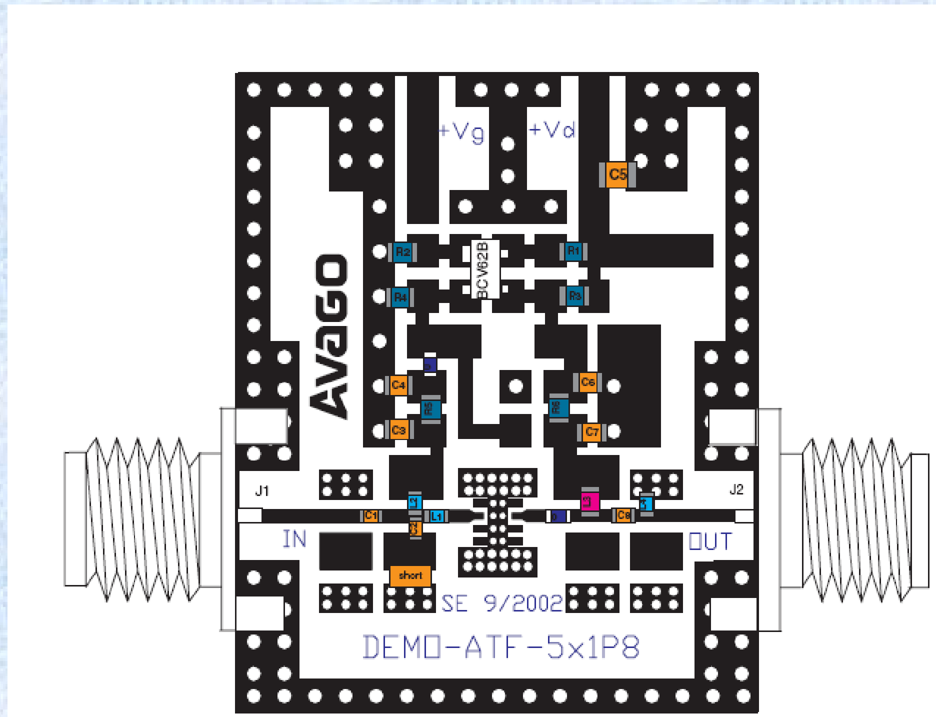
Specifications

2 GHz; 4.5V, 200 mA (Typ.)

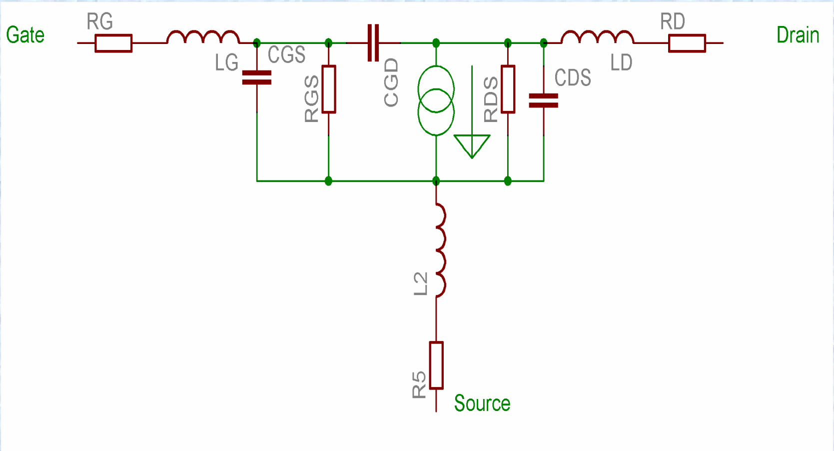
- 42 dBm output IP3
- 26.5 dBm output power at 1 dB gain compression
- 1.5 dB noise figure
- 17 dB Gain

Applications

Agilent Technologies



Easy!


Gate
RG
LG
CGS
RGS
CGD
RDS
CDS
LD
RD
Drain
L2
R5
Source

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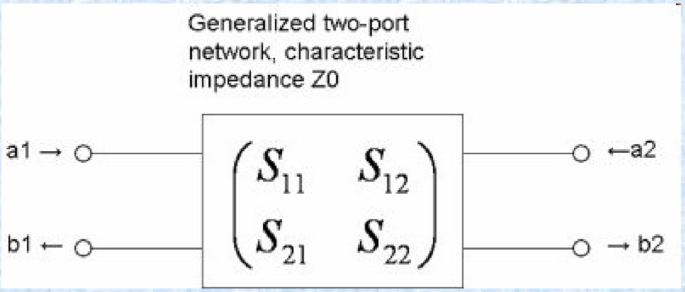
Generalized two-port network, characteristic impedance Z0
a1 →
b1 ←
←a2
→ b2
$\begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}$

Acknowledgements

- Hewlett Packard Application note 95, Sept 1968
  "S-parameters, circuit analysis and design"
- Or the updated version from Agilent. Application note 95-1
  "*S-parameter techniques for faster more accurate network design"*
- www.microwaves101.com
- Appcad program