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An Introduction to RF Analysis

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Agenda

- Goals
- *What do we want to know?*
- *How can we measure it?*
- Units of measure
- Scattering parameters
- Linearity
- RF test equipment

Who cares, anyway?

- Explore a whole new side of your hobby
- Become a more informed user and consumer of ham radio equipment
- Learn new skills and expand interests
  - Build your own equipment
  - Have new types of discussions
  - Meet new people
- Expand ham radio's influence into more aspects of your life

Goals

- Reinforce and give a deeper look into concepts familiar to most hams
- Introduce basic concepts used in the design and application of communications equipment
- Provide the basis for a more intuitive understanding of RF equipment design and operation
- Give a brief overview of some of the equipment commonly used by RF/microwave engineers

What do we want to know?

Given an unknown box with two RF ports, what would you want to know about it?

- Gain/Attenuation
  - *Does the device amplify the input signal?*
  - *Does it suppress the input signal?*
- Match
  - *How does the device interact with other devices connected to its input?*
  - *To its output?*
- Linearity
  - *Does the output look like the input?*

How can we measure it?

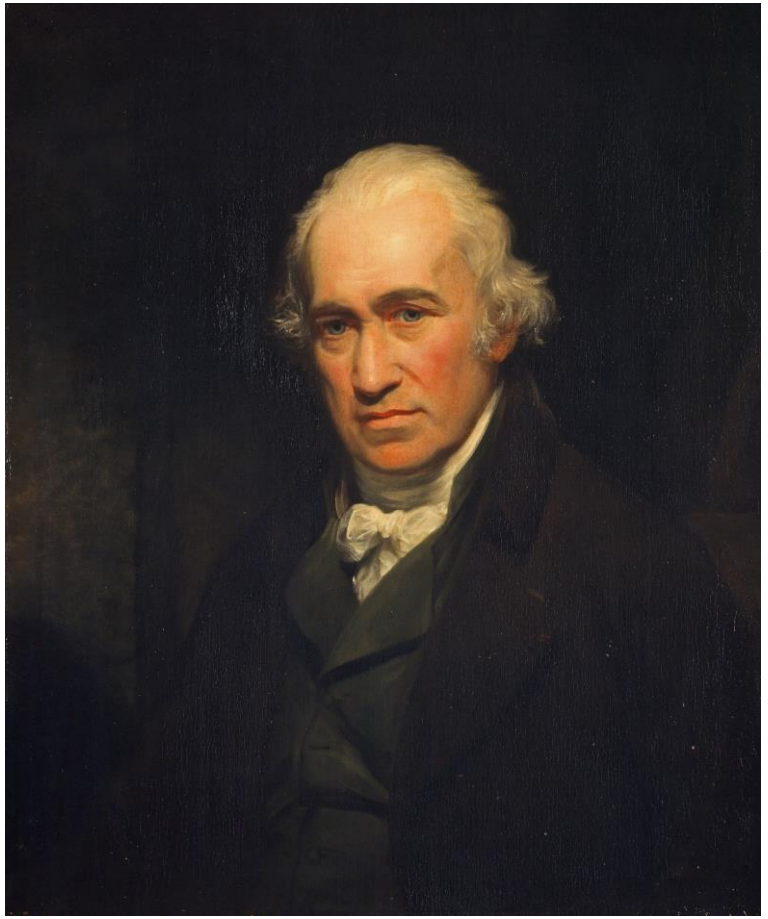
What information do we need in order to know what we want to know?

- Gain/Attenuation
  - *How much RF energy is there at one port compared to the other?*
  - *Scattering parameters S21 and S12*
- Match
  - *How effectively is power transferred between this device and others?*
  - *How much energy is accepted by the device compared to how much is reflected?*
  - *S-parameters S11 and S22, reflection coefficient, VSWR*
- Linearity
  - *Over a range of values, how much power exists at the output of the device compared to the input?*
  - *Power transfer curve, two-tone test, noise power ratio (NPR) test*

Units of Measure – The Watt

Watts (W)

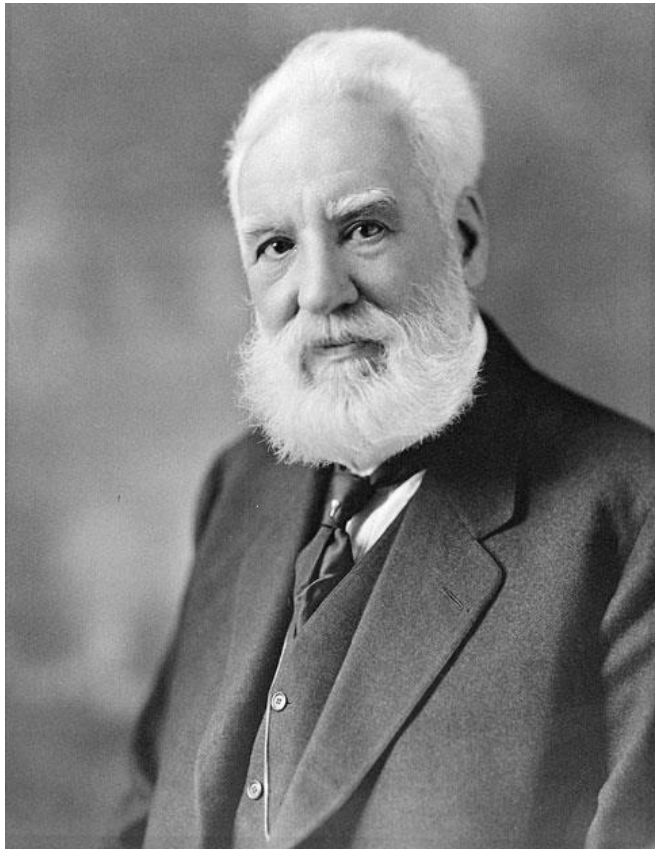
- SI unit of power
- Named for James Watt, Scottish inventor, known for his 1776 steam engine
- Defined as a power transfer of one joule per second
- In terms of base units: $kg \cdot m^2 \cdot s^{-3}$



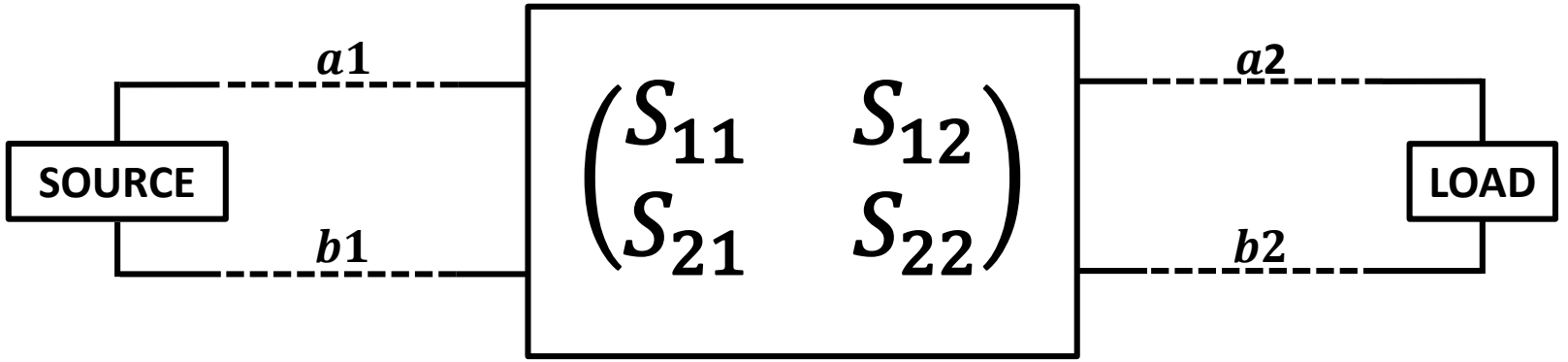
Units of Measure – The Decibel

Decibels (dB)

- Named for Alexander Graham Bell, another Scot, known for his 1876 telephone
- Defined as the logarithmic ratio of one value to another
- $dB_{power} = 10 \log_{10} \left(\frac{x}{y}\right)$
- $dBm = 10 \log \left(\frac{x}{1\ mW}\right)$
- $dBd = 10 \log \left(\frac{x}{gain\ of\ dipole}\right)$



Scattering Parameters



- "a-ports" are signal, "b-ports" are ground
- S11 – input reflection coefficient
- S12 – reverse gain
- S21 – forward gain
- S22 – output reflection coefficient

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

$$S_{11} = b1/a1$$

$$S_{12} = b1/a2$$

$$S_{21} = a2/a1$$

$$S_{22} = b2/a2$$

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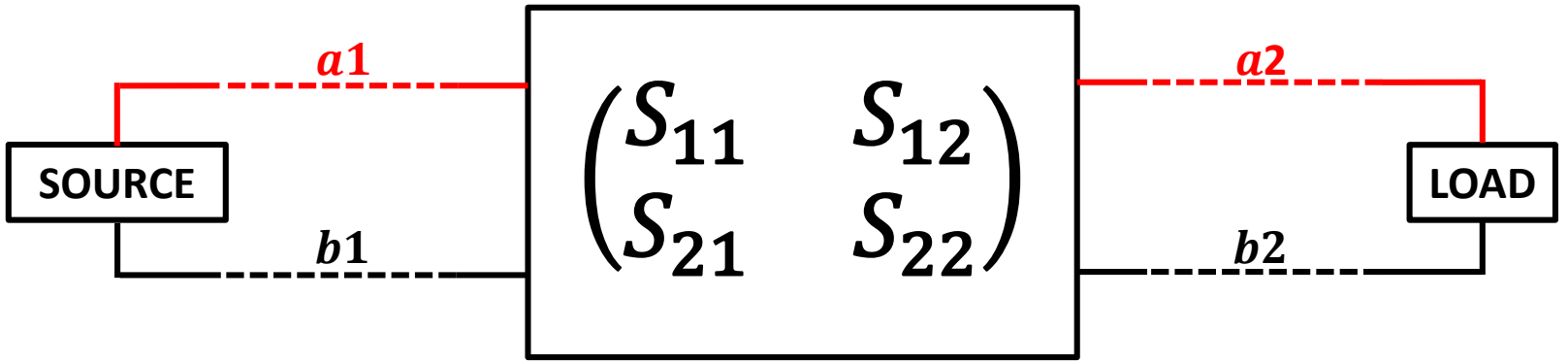
Gain – S21, S12



- Ratio of energy at signal ports
- Descriptions of device's ability to amplify/attenuate
- S21 – forward gain
- S12 – reverse gain
- Positive value indicates amplification
- Negative value indicates attenuation

$$S_{12} = b1/a2$$
$$S_{21} = a2/a1$$

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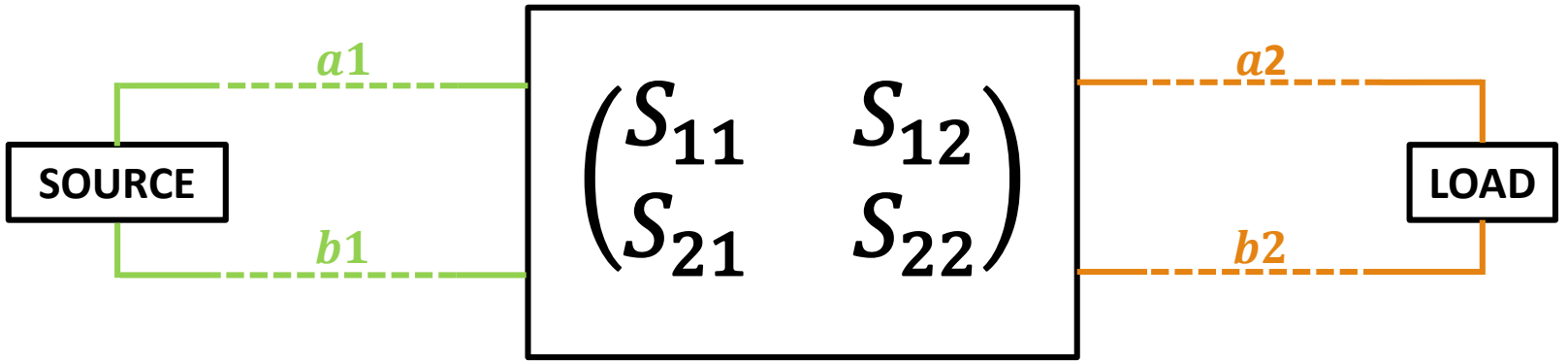
Match – S11, S22



- Ratio of energy reflected to energy applied
- S11 – input reflection coefficient (Γ_{in})
- S22 – output reflection coefficient (Γ_{out})
- High negative number (near minus infinity) – good match
- Low negative number (near zero) – poor match

$$S_{11} = b1/a1$$
$$S_{22} = b2/a2$$

Match – VSWR

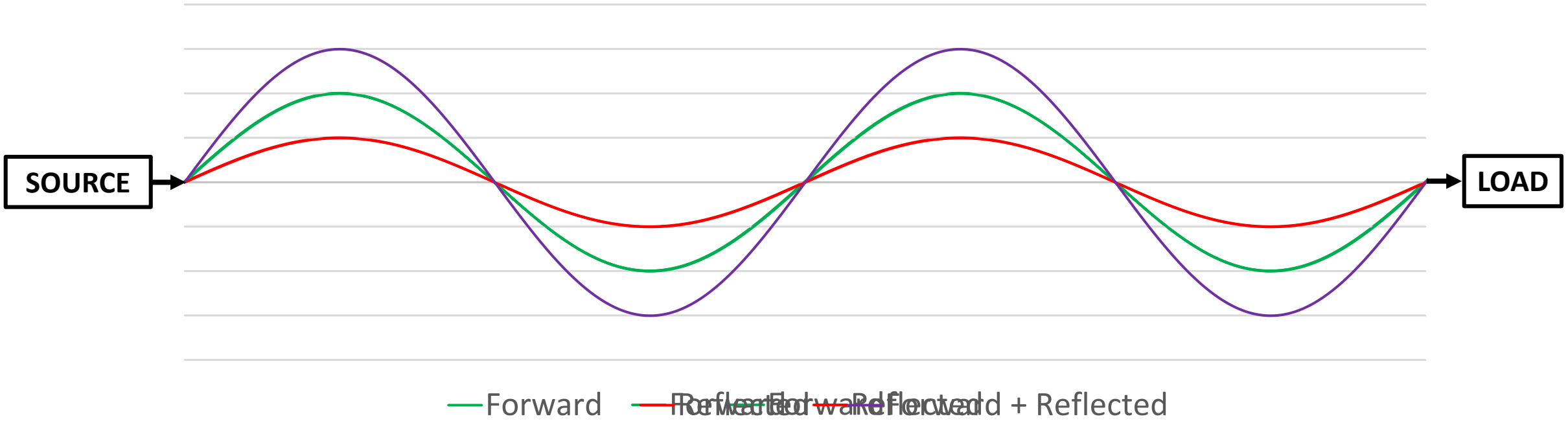
- Voltage standing wave ratio
- a.k.a. standing wave ratio (SWR)
- Ratio between maximum and minimum voltages on transmission line
- More reflected power means higher peak voltages, higher VSWR
- Directly related to impedance and reflection coefficient
- Low VSWR – good match
- High VSWR – poor match

$$VSWR = \frac{|V_{max}|}{|V_{min}|}$$

$$VSWR_{in} = \frac{1 + \sqrt{\frac{P_{ref}}{P_{fwd}}}}{1 - \sqrt{\frac{P_{ref}}{P_{fwd}}}} = \frac{1 + |S_{11}|}{1 - |S_{11}|}$$

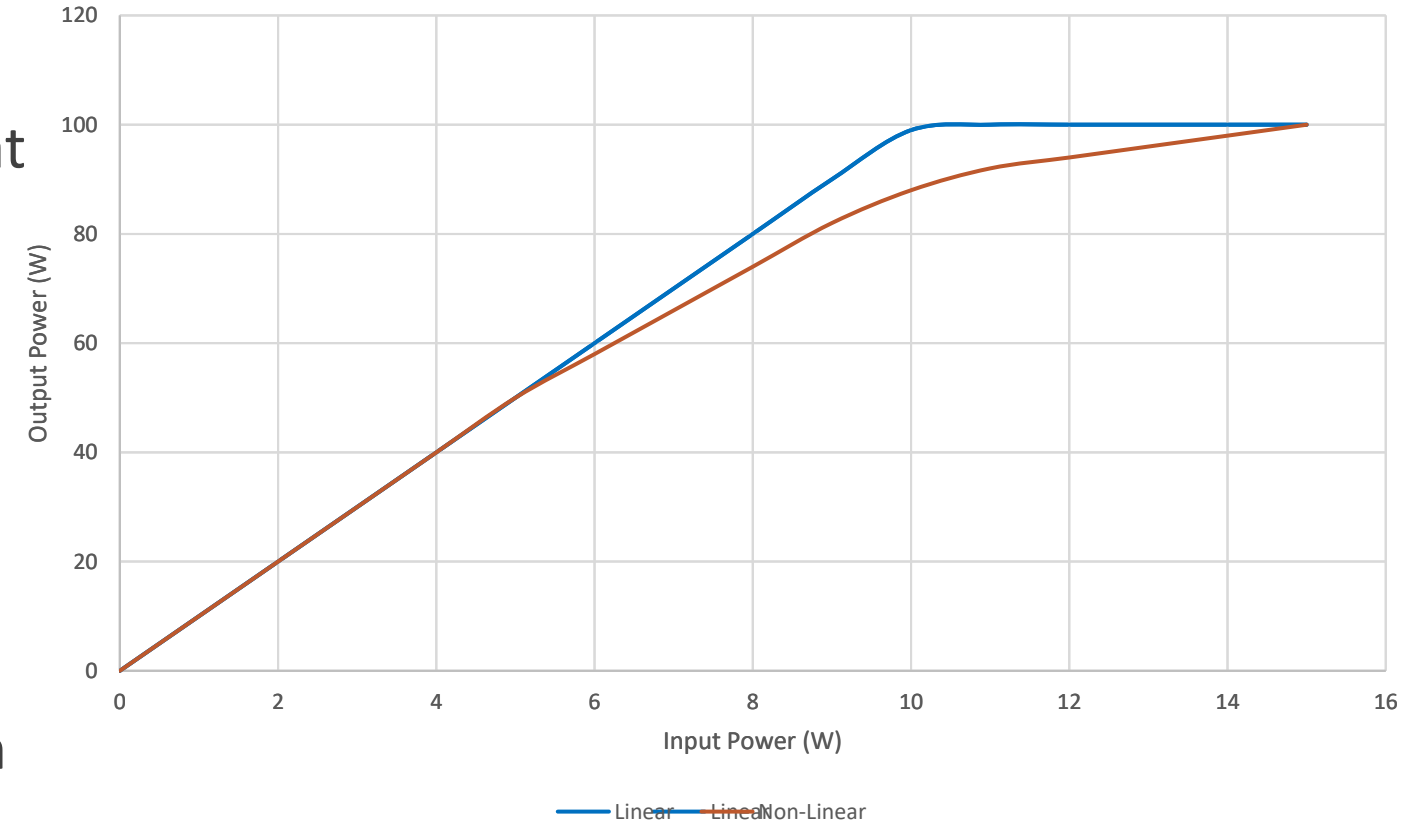
$$VSWR_{out} = \frac{1 + \sqrt{\frac{P_{ref}}{P_{fwd}}}}{1 - \sqrt{\frac{P_{ref}}{P_{fwd}}}} = \frac{1 + |S_{22}|}{1 - |S_{22}|}$$

VSWR Visualization



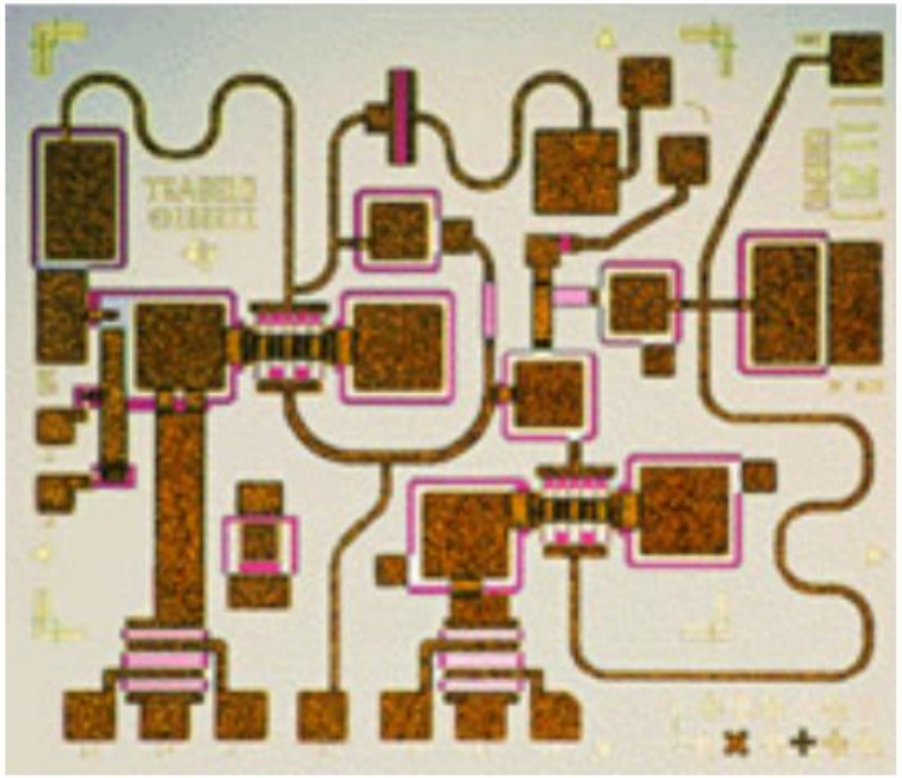
Linearity

- Description of a device's ability to faithfully reproduce the input signal
- Ideally, output power will increase at a constant rate relative to input power, until saturation is reached
- All amplifiers exhibit non-ideal power transfer characteristics
- Especially important for modes involving changing RF amplitude (SSB, AM, etc.)
- Measure power transfer, or perform two-tone or NPR tests



TriQuint TGA8810 – *On the Datasheet*

- MMIC – monolithic microwave integrated circuit
- 17 dB gain
- 2-10 GHz
- Single supply voltage
- 74 x 65 x 6 mils

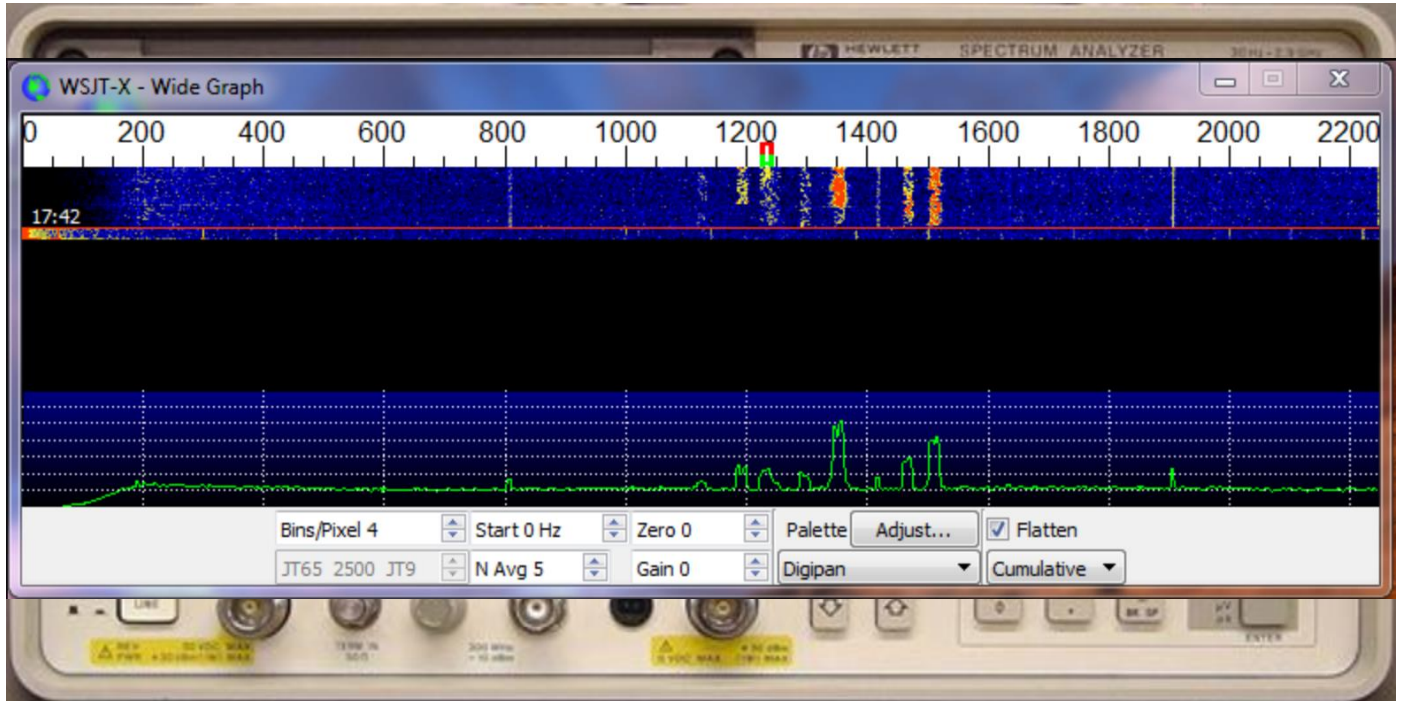


RF Test Equipment – *Network Analyzers*

- Usually have two RF ports
  - One to stimulate device
  - One to measure output
- Used primarily to measure s-parameters over a range of frequencies
- Need both ports to measure S21, S12
- Need only one port to measure S11, S22
- Antenna analyzer is a simple one-port network analyzer

RF Test Equipment – *Spectrum Analyzers*

- Usually have one RF port to observe device output
- Used to observe RF energy in frequency domain
- Measures across entire spectrum, allowing user to observe fundamental and all harmonics
- A bandscope is a spectrum analyzer that displays received RF signal



Questions?

Resources

- Carlson, A. Bruce, and Paul B. Crilly. *Communication Systems.* McGraw Hill, 2010.
- *Microwaves101.* https://www.microwaves101.com/.
- Pozar, David M. *Microwave Engineering.* John Wiley & Sons, Inc., 2012.