# Microwave Measurement

- Types of Measurements
  - Frequency
  - VSWR
  - Power
- Equipments
- Procedure

- Understand types of measurements.
  - Draw the block diagram of instrument in microwave testing.
  - Explain the function of each block and the overall measurement process:

a. Frequency measurement using wave meter.

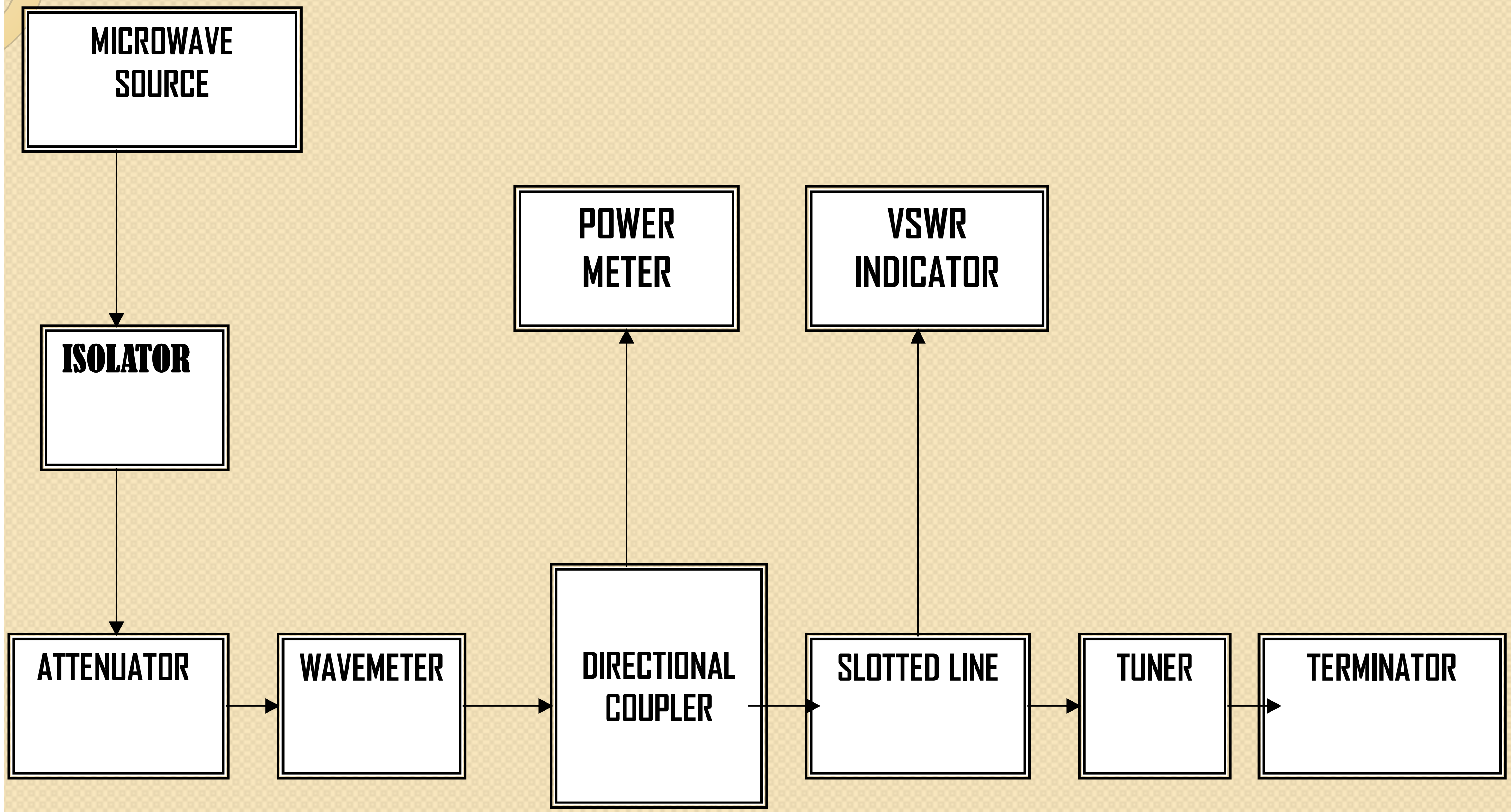
b. VSWR measurement using slotted line.

c. Power measurement using low powered Bolometer or Crystal Rectifier.

# TYPES OF MEASUREMENT

| TYPES OF MEASUREMENT | EQUIPMENTS |
|---|---|
| FREQUENCY-DOMAIN | ➢ Wavemeter s (absorption, transmission or reaction).<br>➢ Slotted lines.<br>➢ Spectrum analyzer, frequency sweepers and frequency counters. |
| DISPLAY OF TIME-DOMAIN | ➢ Sampling oscilloscope.<br>➢ Oscilloscope. |
| VSWR | ➢ Slotted lines ( direct method or double minimum method) |
| POWER | ➢ Power meters.<br>➢ Detectors with oscilloscopes.<br>➢ Spectrum analyzers. |
| WAVELENGTH | ➢ Coaxial and waveguide slotted lines |
| NOISE | ➢ Noise meters. |
| | ➢ Network analyzer – multifunctional test equipment. |

# BLOCK DIAGRAM OF INSTRUMENT IN MICROWAVE TESTING.



# FUNCTION OF EACH BLOCK

**MICROWAVE SOURCE** – generates microwave source in X-band (8 – 12 GHz);

*e.g klystron, magnetron or traveling-wave tube* (*TWT*)

**ISOLATOR /CIRCULATOR** - Allow wave to travel through in one direction while being attenuated in the other direction or it is use to eliminate the unwanted generator frequency pulling (*changing the frequency of the generator*) due to system mismatch or discontinuity. (*to prevent reflected energy from reaching the source*)

- **ATTENUATOR -** Control the amount of power level in a fixed amount, variable amount or in a series of fixed steps from the from the microwave source to the wavemeter.
- **WAVEMETER -** Used to select / measure resonant cavity frequencies by having a plunger move in and out of the cavity thus causes the the cavity to resonate at different frequencies.
- **DIRECTIONAL COUPLER -** Samples part of the power travelling through the main waveguide and allows part of its energy to feed to a secondary output port. Ideally it is used to separate the incident and reflected wave in a transmission line.
- **SLOTTED LINE -** Used to determine the field strength through the use of a detector probe that slides along the top of the waveguide.

- **VSWR INDICATOR -** Denotes the value of VSWR measured by the slotted line.
- **TUNER -** Allows only the desired frequency to appear at the output. Any harmonic frequencies that appear at the output are reduced to an acceptable level.
- **TERMINATOR -** May range from a simple resistive termination to some sort of deep-space antenna array, active repeater or similar devices. 3 special cases of transmission line i.e short circuit, open circuit, match impedance.

# FREQUENCY MEASUREMENT

- The frequency meter used has a cavity which is coupled to the waveguide by a small coupling hole which is used to absorb only a tiny fraction of energy passing along the waveguide.
- Adjusting the micrometer of the Frequency Meter will vary the plunger into the cavity. This will alters the cavity size and hence the resonance frequency.
- The readings on the micrometer scales are calibrated against frequency. As the plunger enters the caviy, its sized is reduced and the frequency increases.

- The wavemeter is adjusted for maximum or minimum power meter readings depending on whether the cavity is a transmission or absorption type device. With the transmission-type device, the power meter will be adjusted for a maximum. It only allows frequency close to resonance to be transmitted through them. Other frequencies are reflected down the waveguide. The wavemeter acts as a short circuit for all other frequencies.

- For the absorption-type wavemeter, the power meter will be adjusted for a minimum. Its absorp power from the line around resonant frequency and act as a short to other frequencies.

- The absorbing material used is to absorb any unwanted signal that will cause disturbance to the system.

# VSWR ( VOLTAGE STANDING WAVE RATIO ) MEASUREMENT

- Used to determine the degree of mismatch between the source and load when the value VSWR ≠ 1.
- Can be measured by using a slotted line. **Direct Method Measurement** is used for VSWR values upto about 10. Its value can be read directly using a standing wave detector .
- The measurement consists simply of adjusting attenuator to give an adequate reading, making sure that the frequency is correct and then using the dc voltmeter to measure the detector output at a maximum on the slotted section and then at the nearest minimum.

The ratio of the voltage maximum to the minimum gives the VSWR i.e

$$\mathbf{VSWR = V_{max} / V_{min}}$$

$$\mathbf{ISWR = I_{max} / I_{min}}$$

$$\mathbf{= k (V_{max})^2 / k (V_{min})^2}$$

$$\mathbf{= (V_{max} / V_{min})^2}$$

$$\mathbf{= VSWR^2}$$

$$\boxed{VSWR = \sqrt{I_{\max} / I_{\min}} = \sqrt{ISWR}}$$

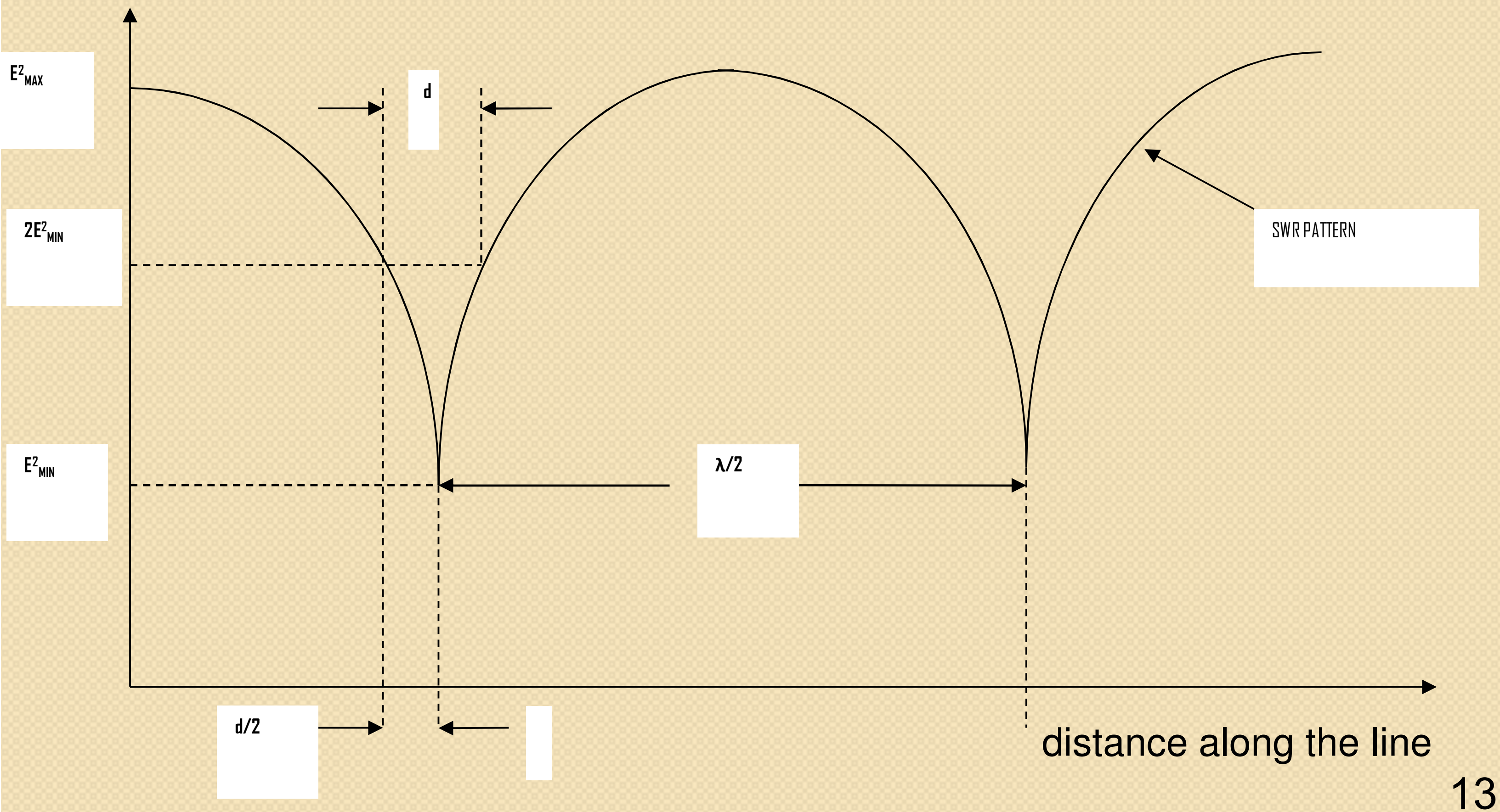
- Methods used depends on the value of VSWR whether it is high or low. If the load is not exactly matched to the line, standing wave pattern is produced.

- Reflections can be measured in terms of voltage, current or power. Measurement using voltage is prefered because of its simplicity.

- When reflection occured, the incident and the reflected waves will reinforce each other in some places, and in others they will tend to cancel each other out.

# DOUBLE MINIMUM METHOD MEASUREMENT ( VSWR > 10)

- 'Double Minimum' method is usually employed for VSWR values greater than about 10.



- The detector output (proportional to field strength squared) is plotted against position. The probe is moved along the line to find the minimum value of signal.

- It is then moved either side to determine 2 positions at which twice as much detector signal is obtained. The distance d between these two positions then gives the VSWR according to the formula :

$$S = \sqrt{1 + 1/\sin^2\left(\pi d / \lambda\right)}$$

# POWER MEASUREMENT

- Power is defined as the quantity of energy dissipated or stored per unit time.
- Methods of measurement of power depend on the frequency of operation, levels of power and whether the power is continuous or pulsed.
- The range of microwave power is divided into three categories :-

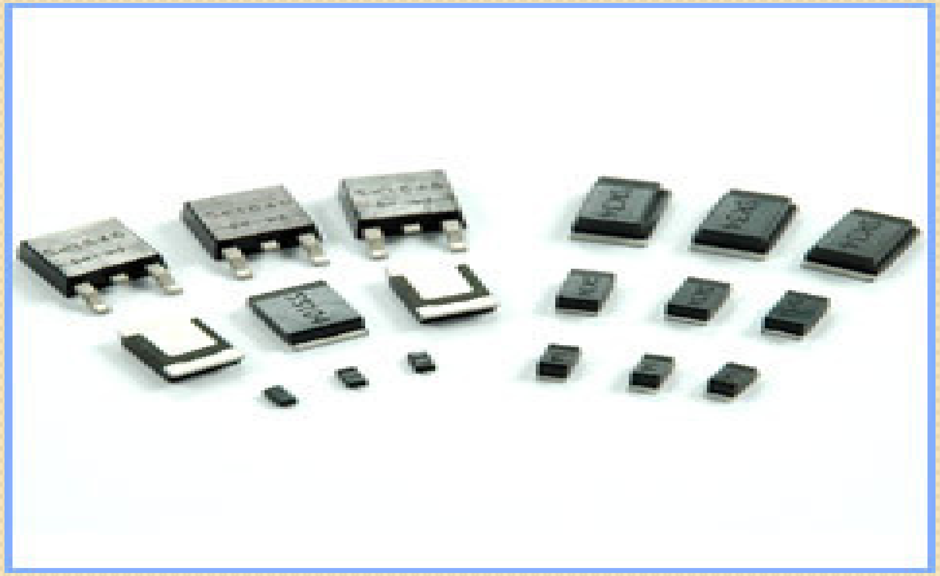
  i. Low power ( < 10mW @ 0dBm)

  ii. Medium power ( from 10 mW - 10 W @ 0 – 40 dBm)

  iii. High power ( > 10 W @ 40 dBm)
- The microwave power meter consists of a power sensor, which converts the microwave power to heat energy.
- The sensors used for power measurements are the Schottky barrier diode, bolometer and the thermocouple.

# SCHOTTKY BARRIER DIODE

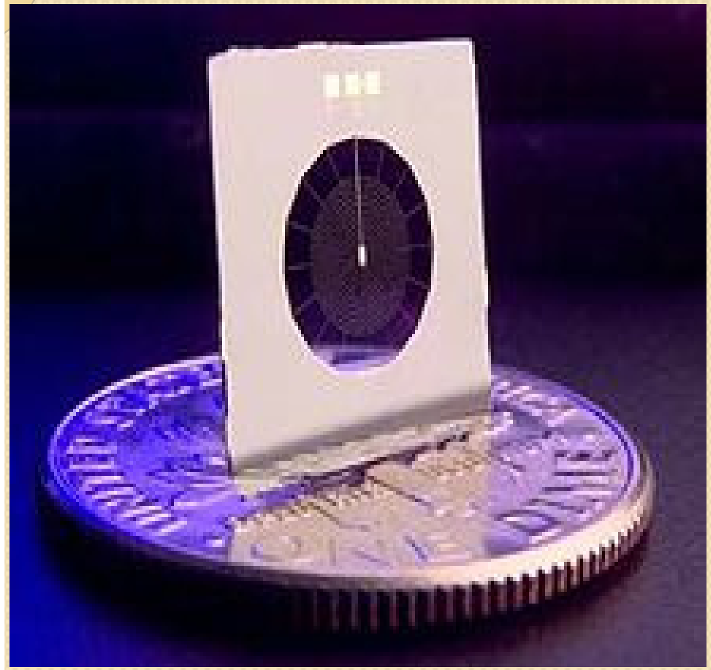
- A zero-biased Schottky Barrier Diode is used as a square-law detector whose output is proportional to the input power.
- The diode detectors can be used to measure power levels as low as 70dBm.

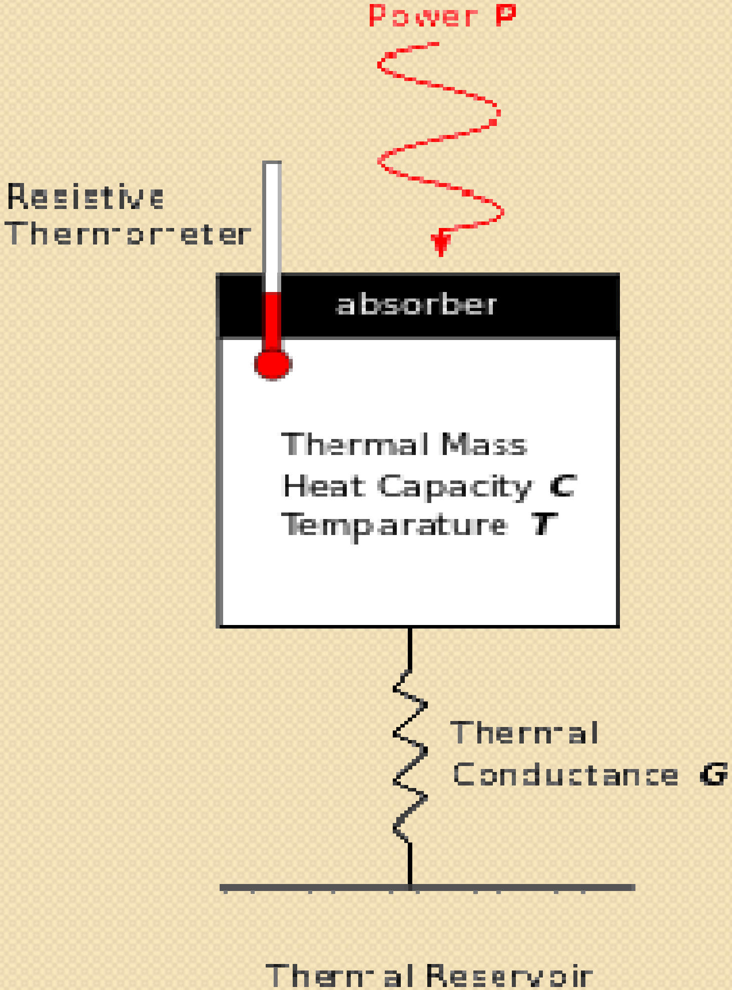


# BOLOMETERS

- A Bolometer is a power sensor whose resistance changes with temperature as it absorbs microwave power.
- Are power detectors that operate on thermal principles. Since the temperature of the resistance is dependent on the signal power absorbed, the resistance must also be in proportion to the signal power.
- The two most common types of bolometer are, the barretter and the thermistor. Both are sensitive power detectors and is used to indicate microwatts of power. They are used with bridge circuits to convert resistance to power using a meter or other indicating devices.

# BOLOMETER




Power P
Resistive
Thermometer
absorber
Thermal Mass
Heat Capacity C
Temparature T
Thermal
Conductance G
Thermal Reservoir

# BARETTERS

- Are usually thin pieces of wire such as platinum. They are mounted as terminating devices in a section of transmission line. The section of transmission line with the mounting structure is called a detector mount.
- The increase of temperature of the baretter due to the power absorbed from the signal in the line causes the temperature of the device to increase.
- The temperature coefficient of the device causes the resistance to change in value in proportion to the change in temperature of the device (positive temperature coefficient i.e the resistance increases with increasing temperature; $R \propto T$).

# BARETTER


LGC
LGC
MODEL 2677
0.1-20 GHz SWITCH
S/N 07032571
GENERAL ®
MICROWAVE
08415-60057
MADE IN ISRAEL
J3-COM
J1
J2

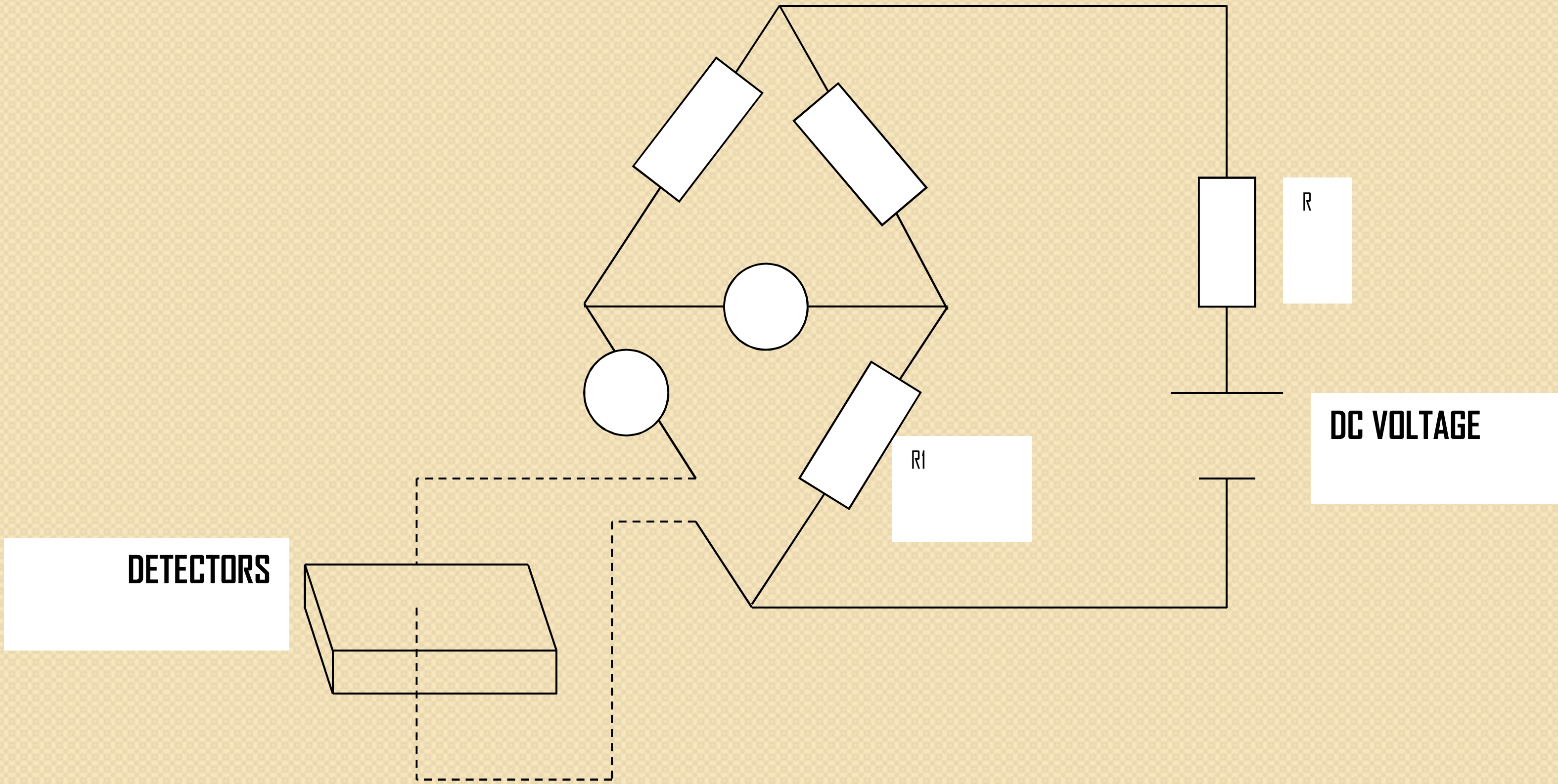
# THERMISTOR

- Are beads of semiconductor material that are mounted across the line._They have a negative temperature coefficient i.e the resistance decreases with increasing temperature; $R \propto T^{-1}$.

- The impedance of baretters and thermistors must match that of the transmission so that all power is absorbed by the device.

# Thermistor mount

- Variations in resistance due to thermal-sensing devices must be converted to a reading on an indicating device such as a meter. This can be done accurately using a balanced bridge arrangement as shown below:-



- With no power to the detector that contains the sensor element, the sensor-line R1 is adjusted to zero reading through the meter M1 and the bridge circuit is balanced.

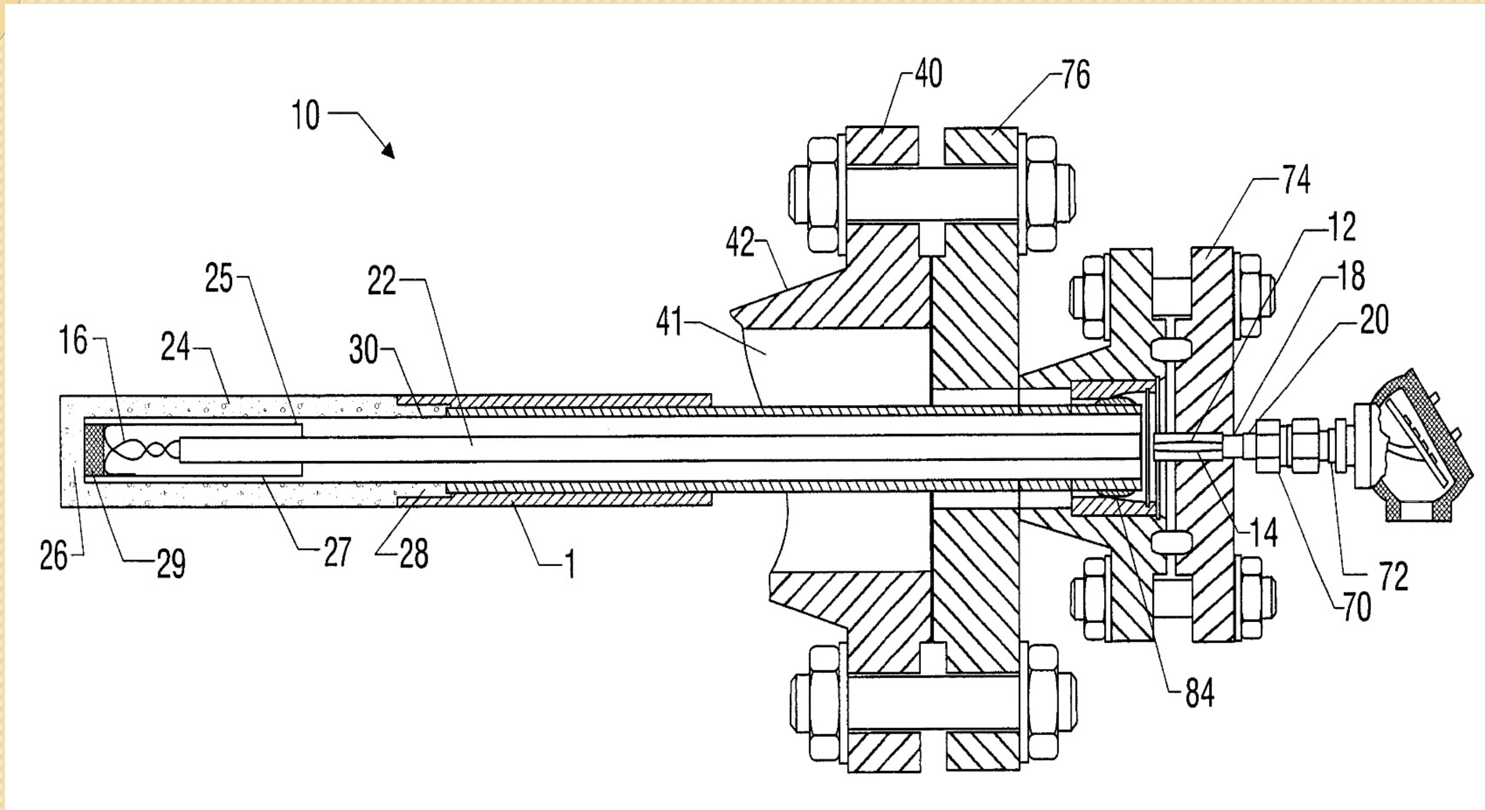
- When signal is applied to the sensor element, causing its temperature to change, the sensor resistance changes, causing the bridge to become unbalanced.

- Resistor R1 is adjusted to balance meter M1. The change in the reading of meter M2 in the sensor element leg is a direct measure of the microwave power.

# THERMOCOUPLES

- Are used as power monitors in the low-to-medium power regions and are very sensitve.
- Is a thin wire made of two disimilar metals. Hence there will be two junctions (hot & cold).
- When the temperature at two junctions are different, a voltage is developed across the thermocouple (i.e across both junctions). This developed voltage is proportional to the difference between the two junction temperatures.
- When the temperature at both junctions are the same, the difference in voltage = 0.

# Thermocouple



# MICROWAVE CRYSTALS

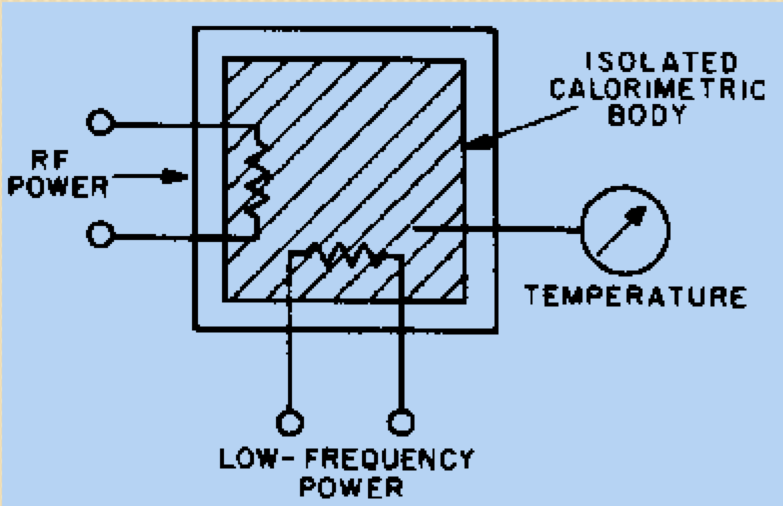
- Are non-linear detectors that provide current in proportion to the power. It is limited to making low-power measurements.
- The current is proportional to the power due to the square-law characteristic of the crystal. This square-law characteristic only occurs for small signal levels.
- At larger signal levels the relationship is linear, as with any diode. Therefore the proportional relationship between power and current output is only true at power levels below 10mW.

# Microwave Crystal

# CALORIMETERS

- The calorimeters are the most accurate of all instruments for measuring high power. Calorimeters depend on the complete conversion of the input electromagnetic energy into heat. Direct heating requires the measurement of the heating effect on the medium, or load, terminating the line. Indirect heating requires the measurement of the heating effect on a medium or body other than the original power-absorbing material. Power measurement with true calorimeter methods is based solely on temperature, mass, and time. *Substitution* methods use a known, low-frequency power to produce the same physical effect as an unknown of power being measured. Calorimeters are classified as STATIC (non flow) types and CIRCULATING (flow) types.

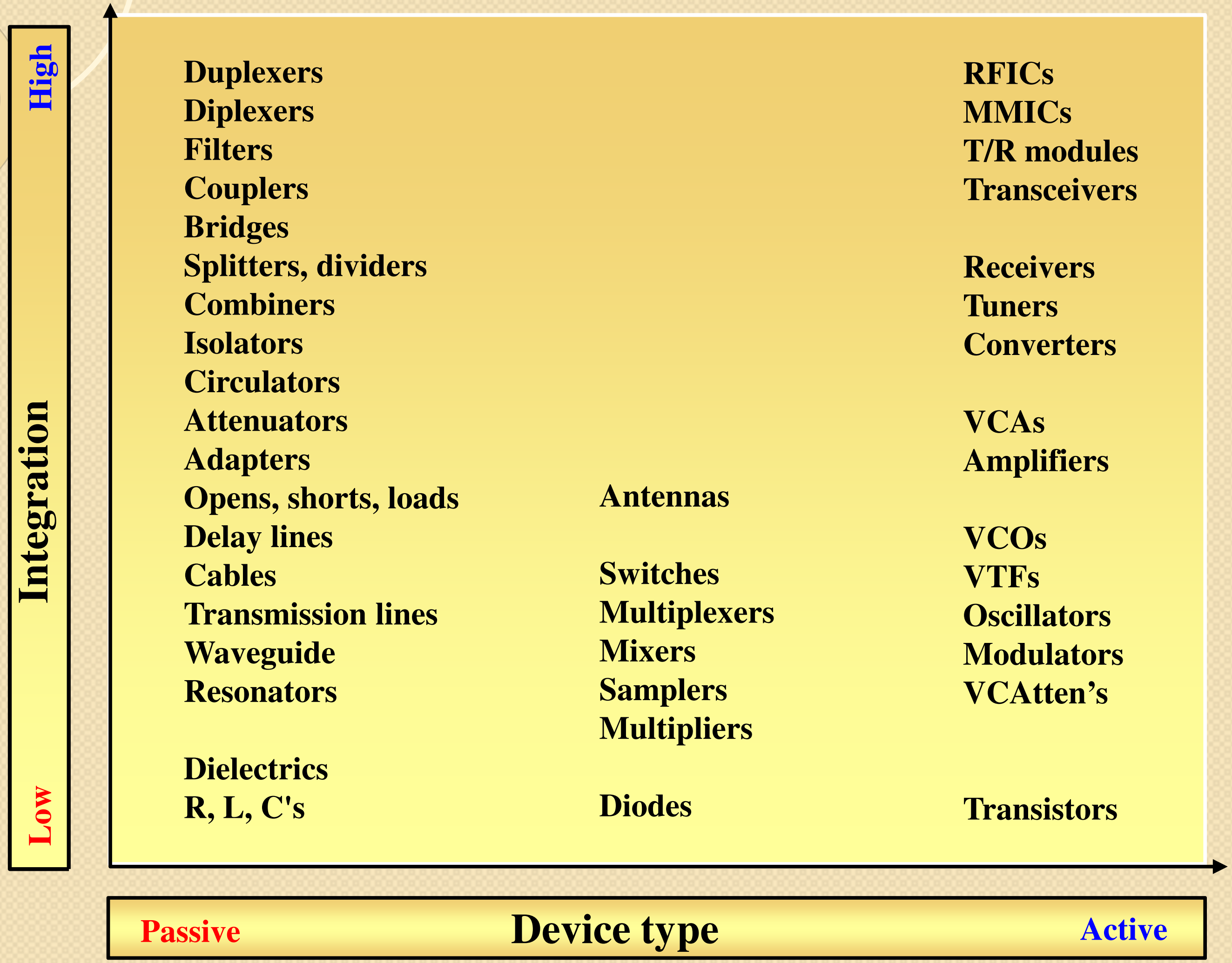
# CALORIMETER



# Vector Network Analyzer (VNA)

- Scattering parameters can be measured with a VNA.
- 2-(or 4-) channel microwave receiver designed to process the magnitude and phase of the transmitted and reflected waves.
- Accuracy can be improved by calibration.
- Scattering parameters can be used to calculate SWR, return loss, impedance and so on.

# Introduction –
## Types of Devices Tested by VNA

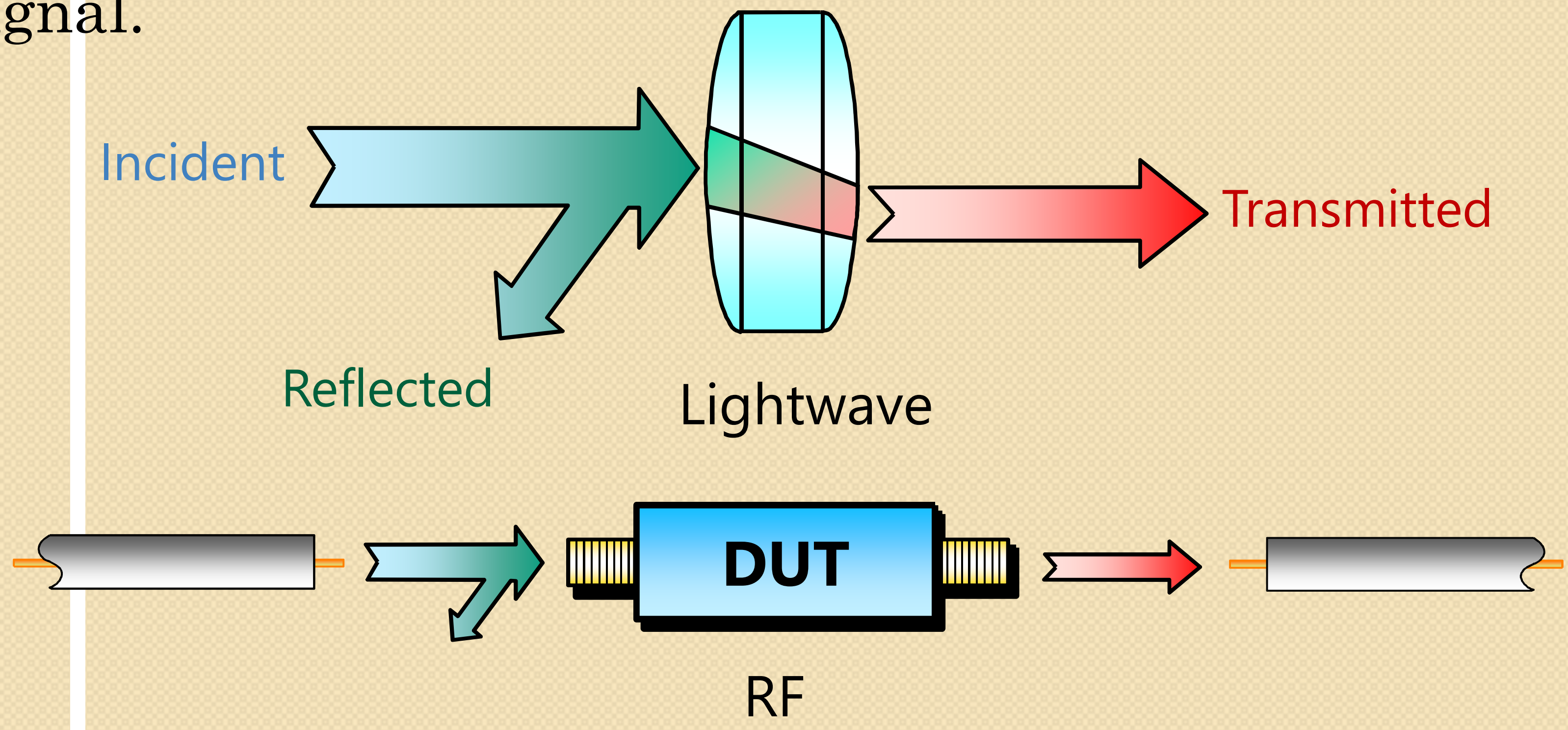


# Reasons for testing component

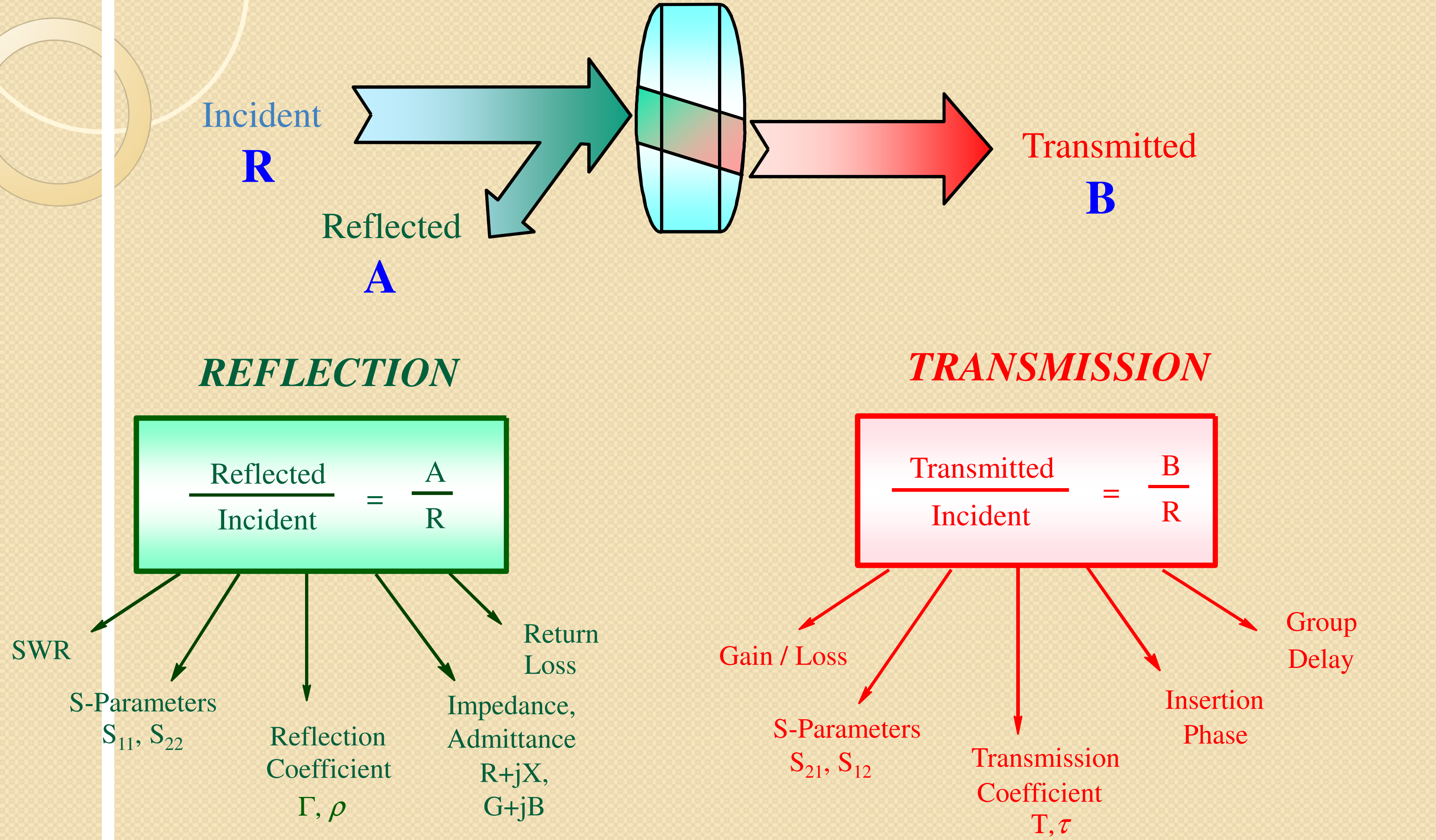
- To verify specifications of building blocks in a complex RF systems such as amplifiers and filters in a transceiver
  - Measured hardware prototype compared to simulation model
- To ensure component or circuit cause no distortion in the transmission of communications signals
  - Linear : constant amplitude, linear phase / constant group delay versus frequency
  - Nonlinear : harmonics, intermodulation, compression, AM-to-PM conversion
- To ensure good matching for absorbing energy efficiently (such as good matching antenna)

# Lightwave Analogy to RF Energy

- Network analysis is concerned with the accurate measurement of the *ratios* of the reflected signal to the incident signal, and the transmitted signal to the incident signal.



# High Freq. Device Characterization



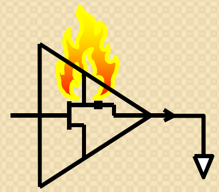
# Transmission Parameters


$$\text{Transmission Coefficient} = T = \frac{V_{\text{Transmitted}}}{V_{\text{Incident}}} = \tau\angle\phi$$

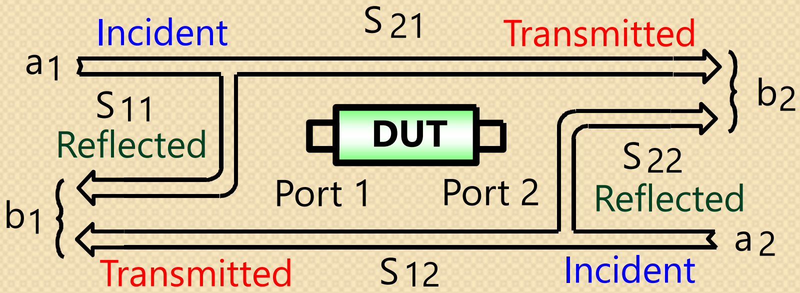
$$\text{Insertion Loss (dB)} = -20\ \text{Log}\left|\frac{V_{\text{Trans}}}{V_{\text{Inc}}}\right| = -20\log\tau$$

$$\text{Gain (dB)} = 20\ \text{Log}\left|\frac{V_{\text{Trans}}}{V_{\text{Inc}}}\right| = 20\log\tau$$

# Why Use S-Parameters?



- relatively easy to **obtain** at high frequencies
  - hard to measure total voltage & current at the device ports at high frequency
  - measure voltage traveling waves with a vector network analyzer
  - don't need shorts/opens which can cause active devices to oscillate or self-destruct
- relate to **familiar** measurements (gain, loss, reflection coefficient ...)
- can **cascade** S-parameters of multiple devices to predict system performance
- can **compute** H, Y, or Z parameters from S-parameters if desired
- can easily import and use S-parameter files in our **electronic-simulation** tools

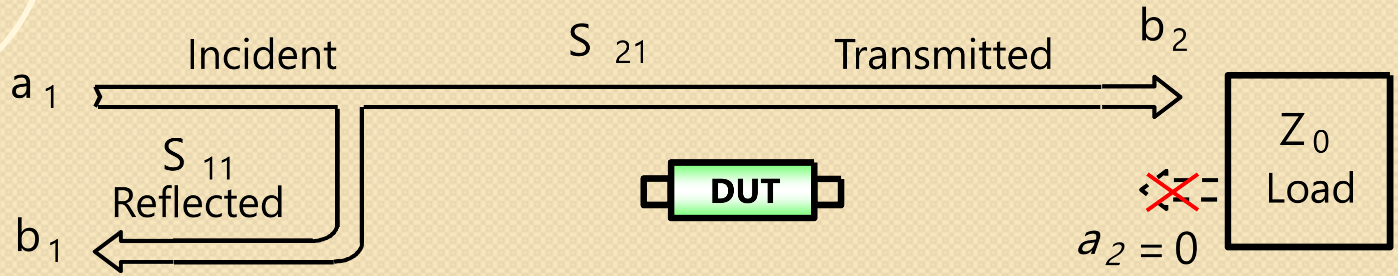



$$b_1 = S_{11} a_1 + S_{12} a_2$$

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

# Measuring S-Parameters

**Forward**

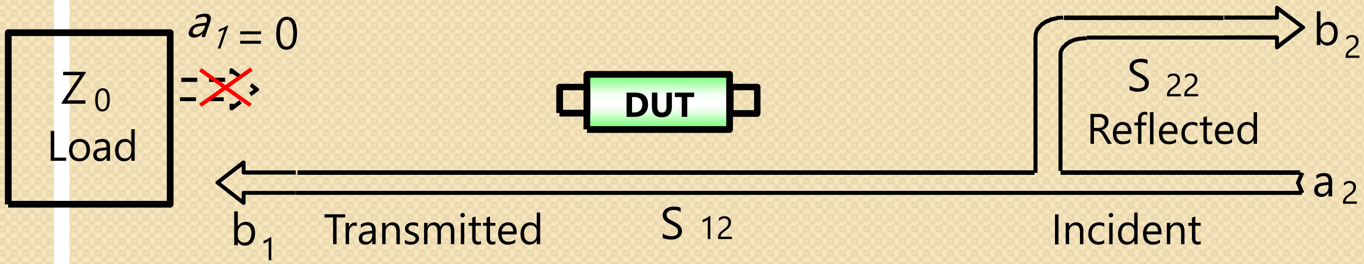



$$S_{11} = \frac{\textit{Reflected}}{\textit{Incident}} = \left.\frac{b_1}{a_1}\right|_{a_2 = 0}$$

$$S_{21} = \frac{\textit{Transmitted}}{\textit{Incident}} = \left.\frac{b_2}{a_1}\right|_{a_2 = 0}$$

$$S_{22} = \frac{\textit{Reflected}}{\textit{Incident}} = \left.\frac{b_2}{a_2}\right|_{a_1 = 0}$$

$$S_{12} = \frac{\textit{Transmitted}}{\textit{Incident}} = \left.\frac{b_1}{a_2}\right|_{a_1 = 0}$$




**Reverse**

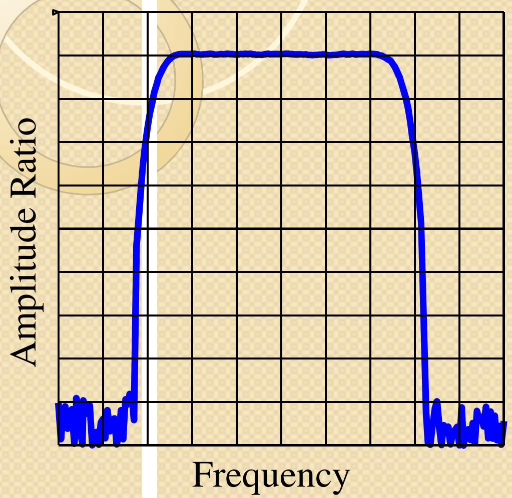
# Equating S-Parameters with Common Measurement Terms

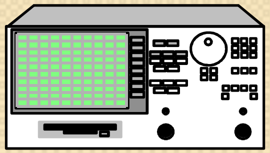
$S_{11}$ = forward reflection coefficient (*input match*)
$S_{22}$ = reverse reflection coefficient (*output match*)
$S_{21}$ = forward transmission coefficient (*gain or loss*)
$S_{12}$ = reverse transmission coefficient (*isolation*)

Remember, S-parameters are inherently complex, linear quantities. They are expressed as real and imaginary or magnitude and phase pairs

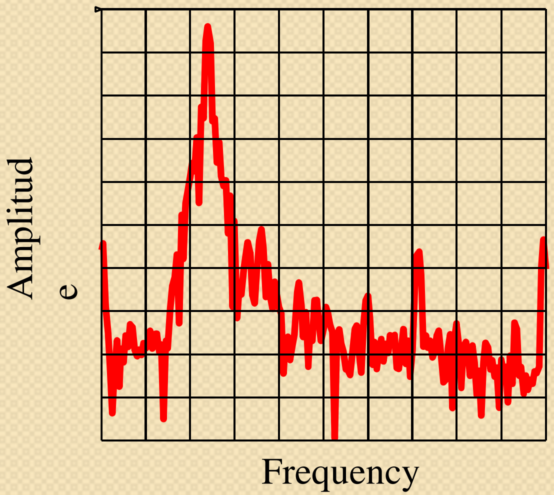
However, we often express them in a log magnitude format

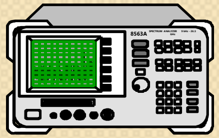
# Network Analyzers Vs Spectrum Analyzers



Measures known signal



Measures unknown signals

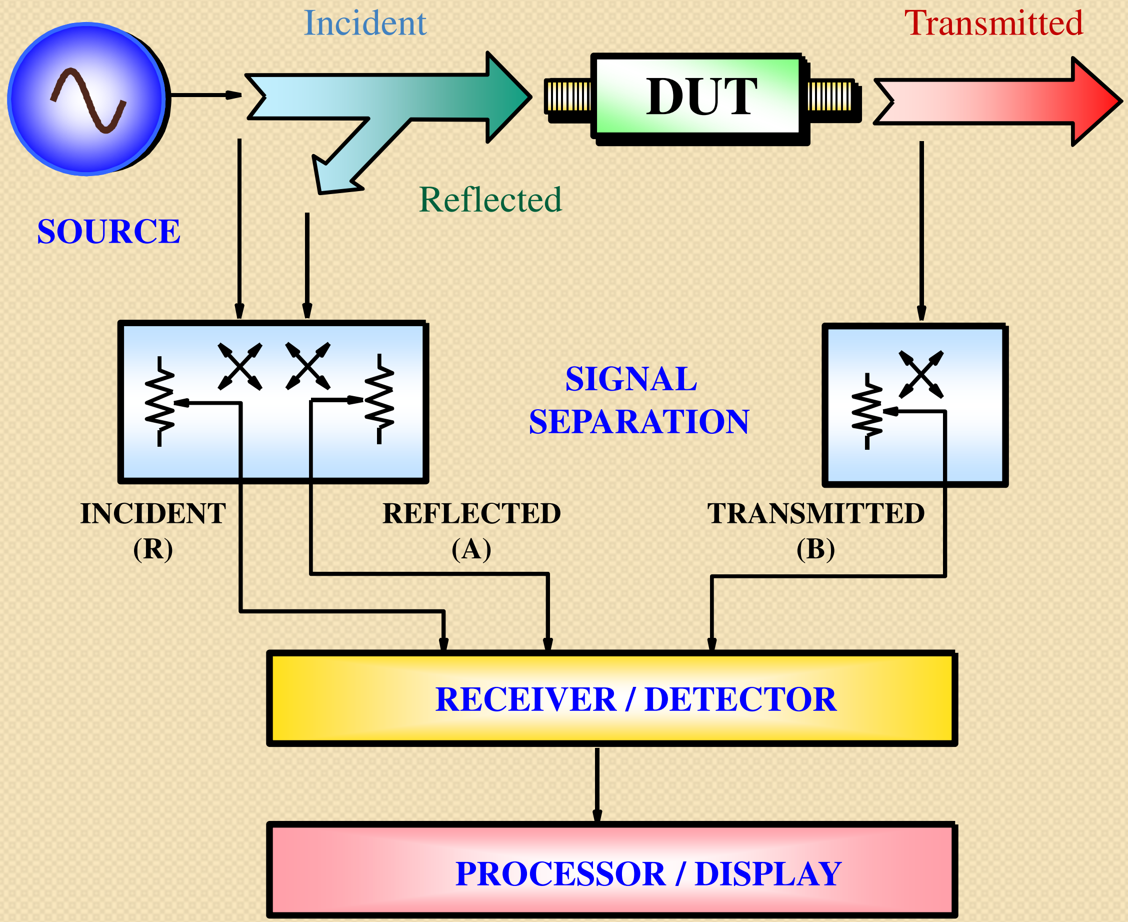
**Network analyzers:**

- measure components, devices, circuits, sub-assemblies
- contain source and receiver
- display ratioed amplitude and phase (frequency or power sweeps)
- offer advanced error correction

**Spectrum analyzers:**

- measure signal amplitude characteristics carrier level, sidebands, harmonics...)
- can demodulate (& measure) complex signals
- are receivers only (single channel)
- can be used for scalar component test (*no phase*) with tracking gen. or ext. source(s)

# Network Analyzer Hardware - Generalized Network Analyzer Block Diagram



# Types of Network Analyzer

**Scalar**

- Magnitude only
- Broadband Detector with higher noise floor
- Lower Price
- Normalization – Less Accurate
- Measures RL, SWR, Gain/Loss

**Vector**

- Phase and Magnitude
- Tuned Detector with lower noise floor
- Higher Price
- Complete Error Correction – More Accurate
- Measures all