The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

RF POWER MEASUREMENT

EMPIR 15RPT01 RFMICROWAVE

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March, 2019
Turkey

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- What is RF Power
- Standards for RF Power Measurement
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What is RF Power

Definitions of Power

In the International System of Units (SI), power is defined as energy consumed per unit time and its unit is named as Watt.

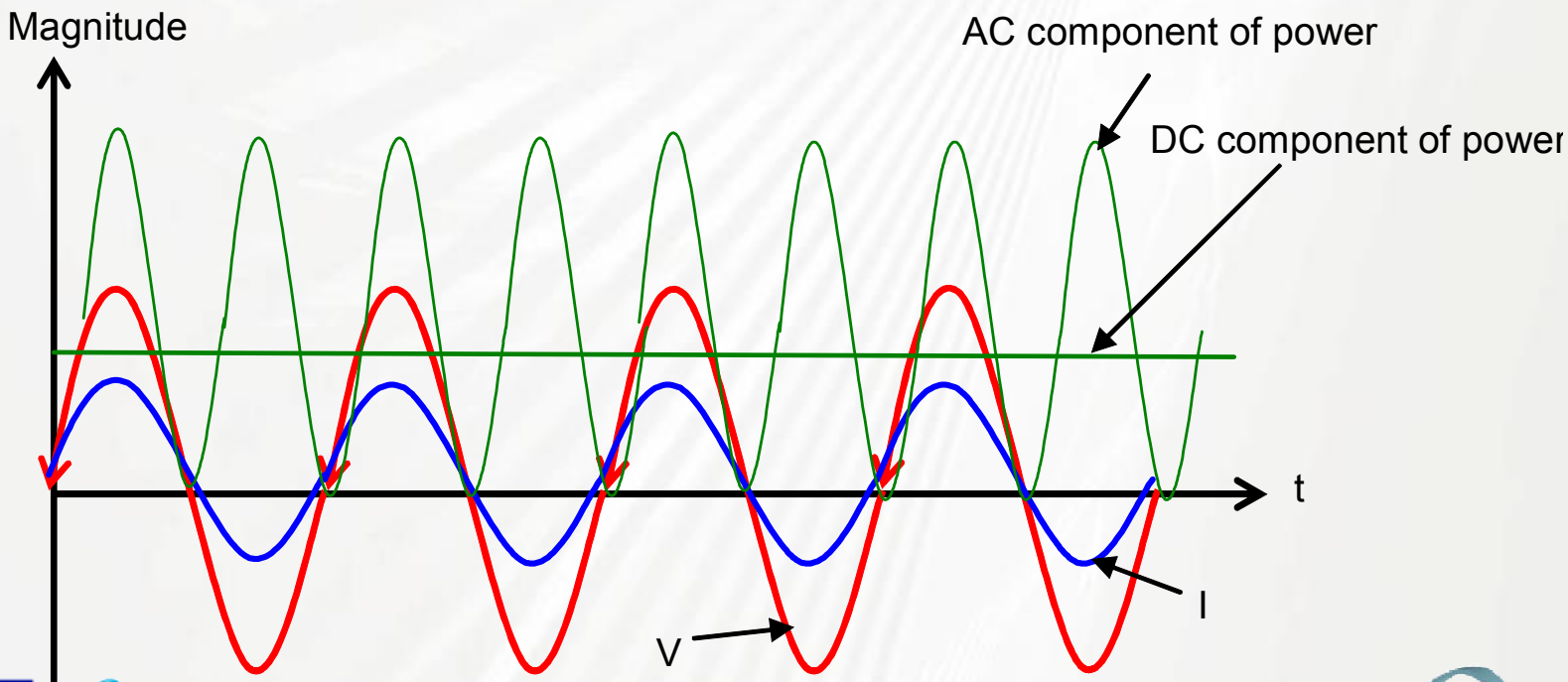
According to electronic circuit theories, power consumed at a load is the multiplication of current passing through circuit and voltage on the load

$$P=VI$$

What is RF Power

Definitions of Power

$$P = \frac{1}{nT}\int_0^{nT} v(t).i(t)dt = \frac{1}{nT}\int_0^{nT} v_p Sin(\frac{2\pi}{T}t).i_p Sin(\frac{2\pi}{T}t+\phi)dt$$



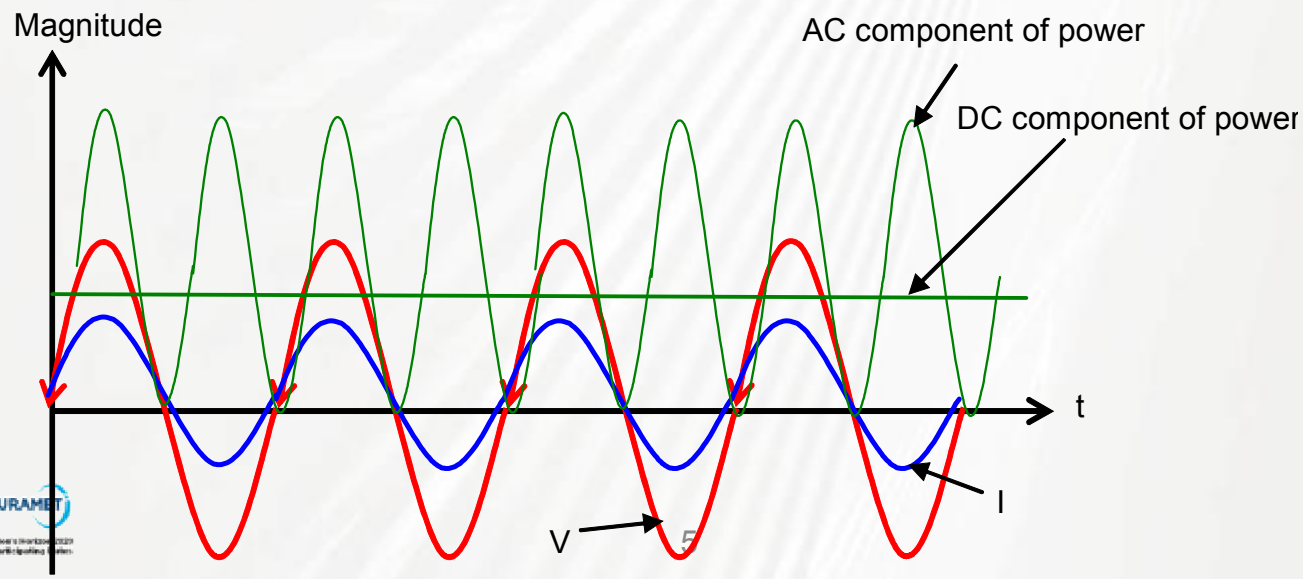
What is RF Power

Definitions of Power

$$P_a = \frac{v_p i_p}{2} \, Cos\phi$$

$$v_p = \sqrt{2} V_{rms} \qquad i_p = \sqrt{2} I_{rms}$$

$$P_a = I_{rms} V_{rms} \; Cos\phi$$



What is RF Power

Definitions of Power

Average Power (Pa)

Average power is the mean value of whole power of a continuous wave (CW) over a certain time interval. On the other hand, for a modulated signal, it is the mean value of the signal with the lowest frequency over a certain time interval.

This average power is equivalent to DC power component mentioned above.

$$P = \frac{1}{nT}\int_0^{nT} v(t).i(t)dt = \frac{1}{nT}\int_0^{nT} v_p Sin(\frac{2\pi}{T}t).i_p Sin(\frac{2\pi}{T}t+\phi)dt$$

Puls Power (Pp)

It is the mean value of power over the pulse width of pulse signal

$$P_P = \frac{1}{\tau}\int_0^{\tau} v(t).i(t)dt \qquad P_P = \frac{P_a}{DutyCycle} = \frac{P_a}{\tau.f} = \frac{P_a T}{\tau}$$

What is RF Power

Definitions of Power

Decibel (dB)

In many cases, such as when measuring gain or attenuation, the ratio of two powers, or relative power, is frequently the desired quantity rather than absolute power. The ratio is dimensionless because the units of both the numerator and denominator are watts. Relative power is usually expressed in decibels (dB)

$$P(dB) = 10Log(\frac{P}{P_{Ref}})$$

dBm

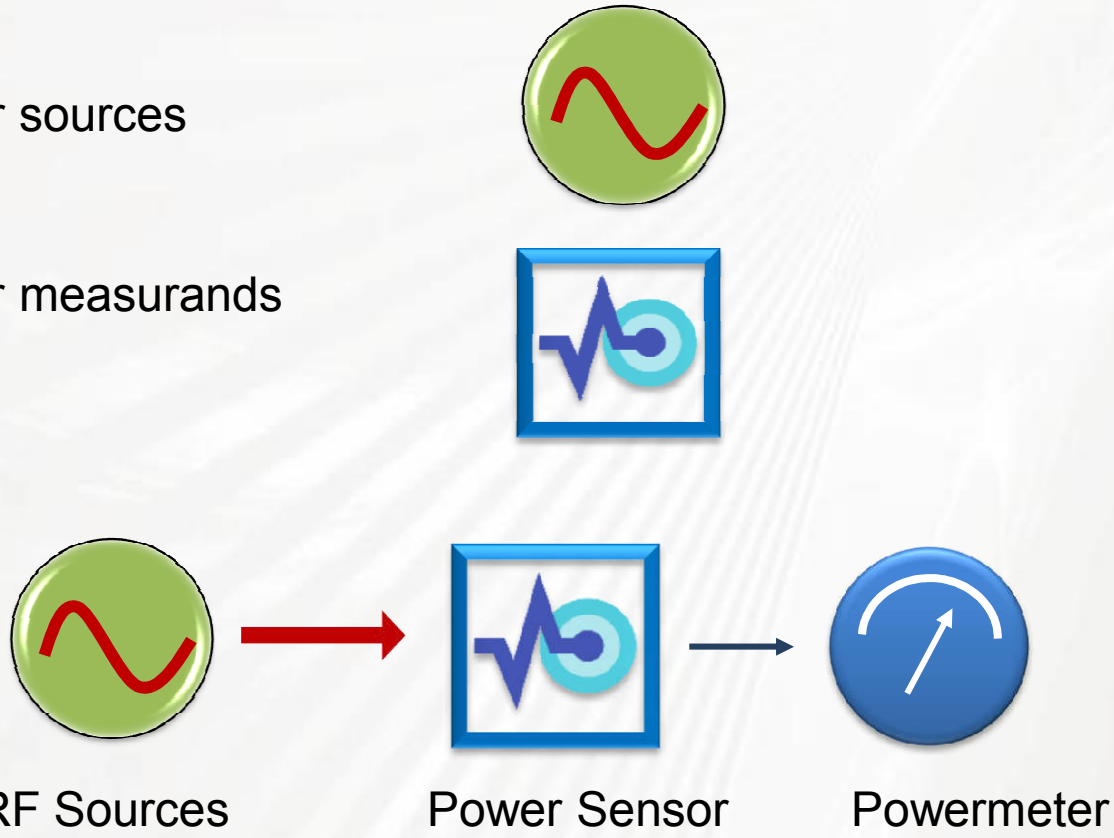
The popular usage has added another convenient unit, dBm.

P_{Ref} is always one milliwatt in dBm

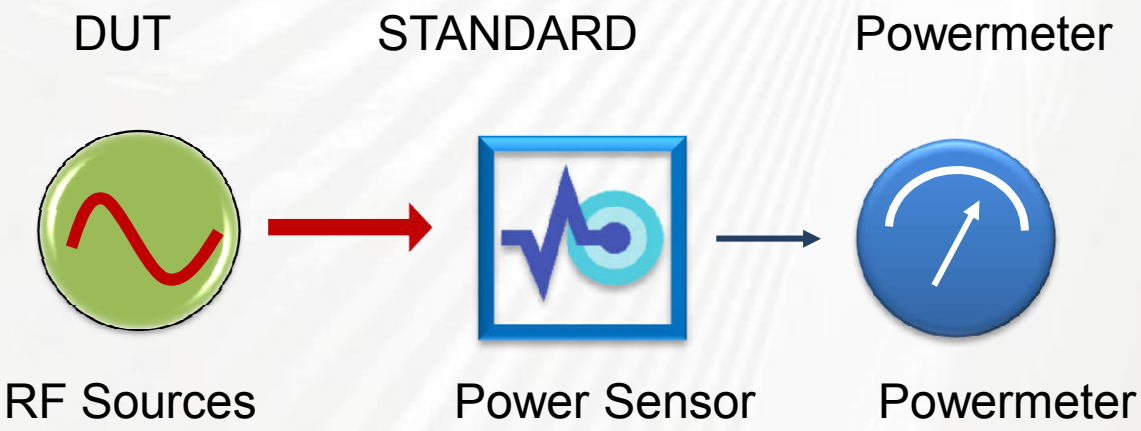
$$P(dBm) = 10Log(\frac{P}{1mW})$$

Standards for RF Power Measurement

- RF power sources
- RF power measurands



Standards for RF Power Measurement



Standards for RF Power Measurement

The RF power sensors are the important element of any RF power meter, and the choice of the type of sensor is depend of the applications.

The RF power meter technologies can be separated into two basic categories:

- Heat based
- Diode detector based

- Heat based;

  more applicable to applications where an integrated measurement is required

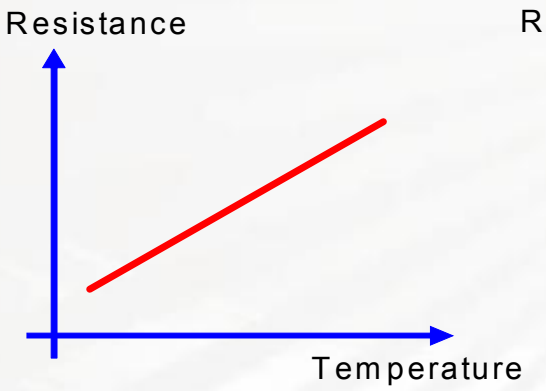
- Diode detector based;

  more suitable where low level measurements are needed

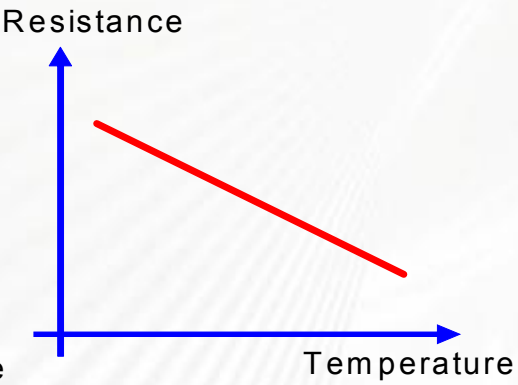
Power Sensor Types:

- Bolometer
  - Barretter
  - Thermistor mount
- Thermocouple
- Diode

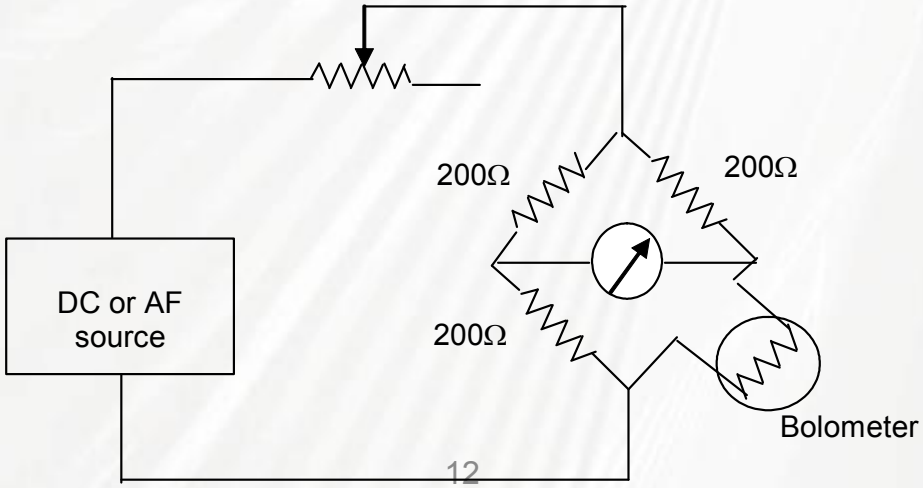
Bolometer (Barretter / Thermistor Mount) Power Sensors



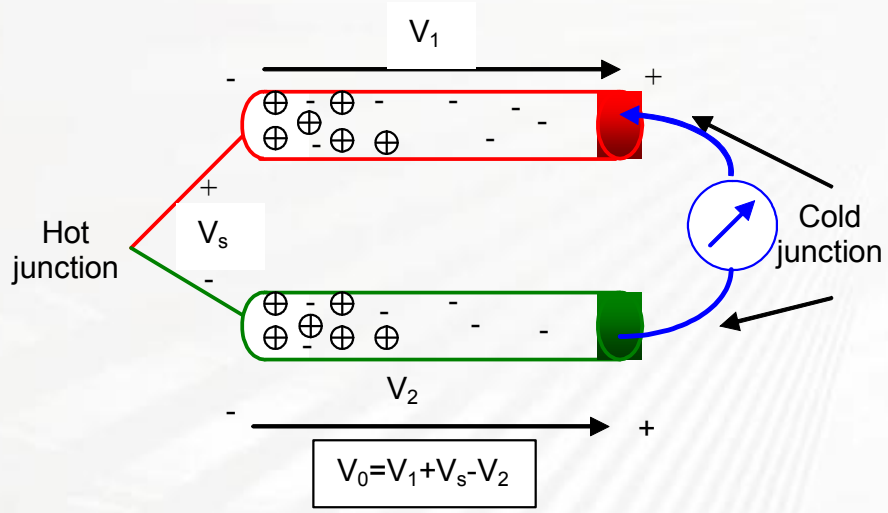
Temperature coefficient of barreter

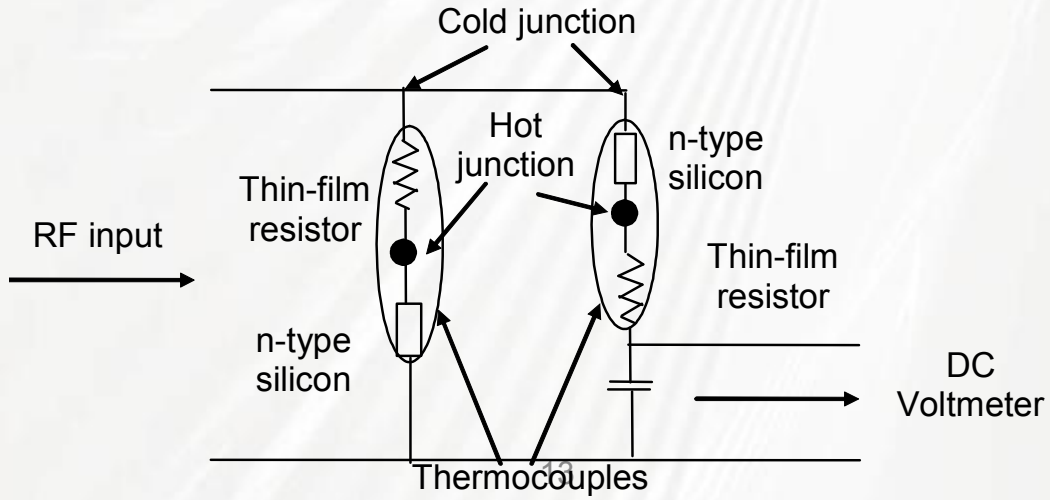


Temperature coefficient of thermistorun

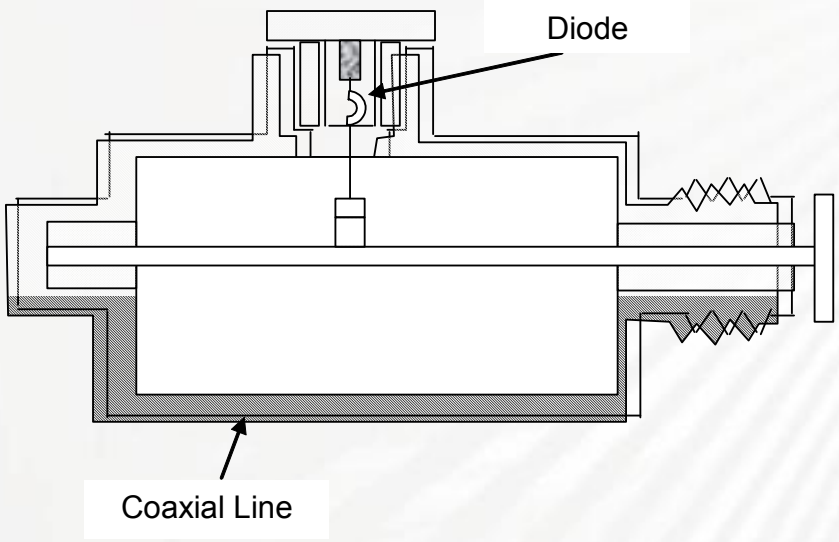


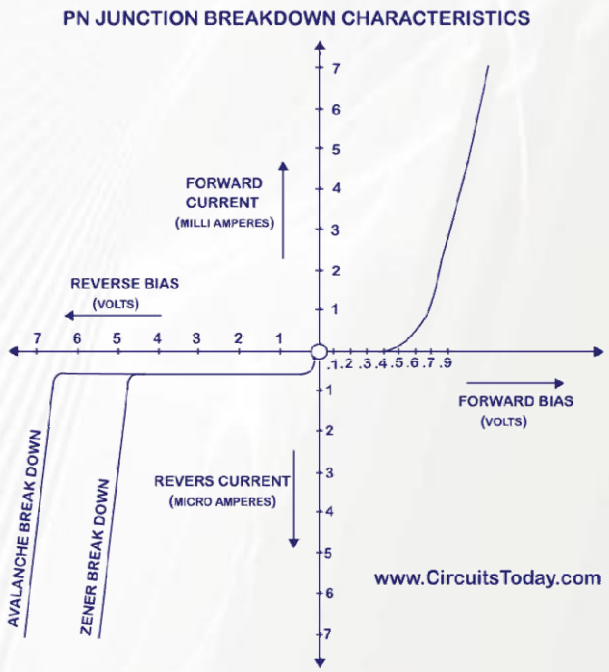
Termocouples Sensors

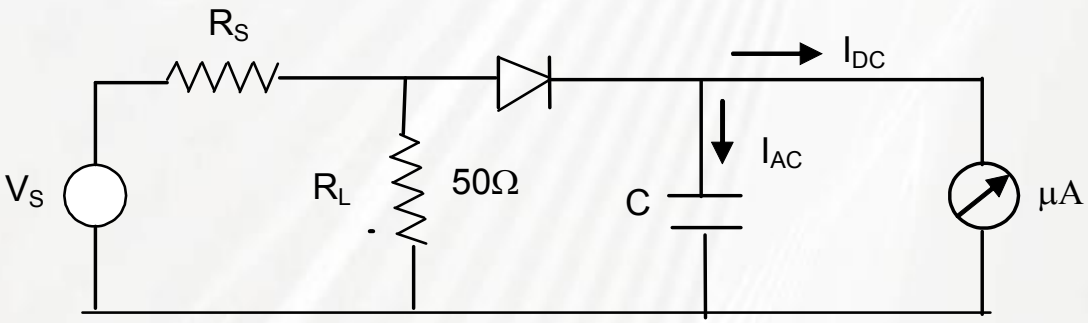




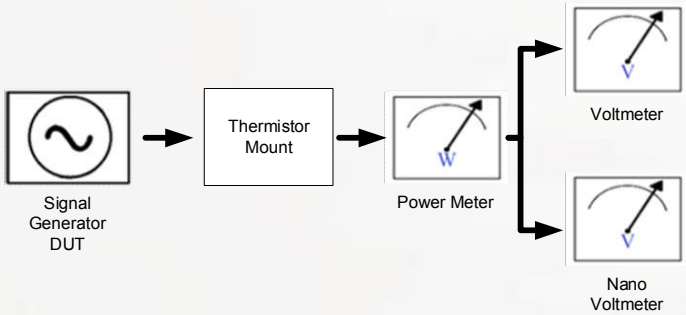
Diode Sensors



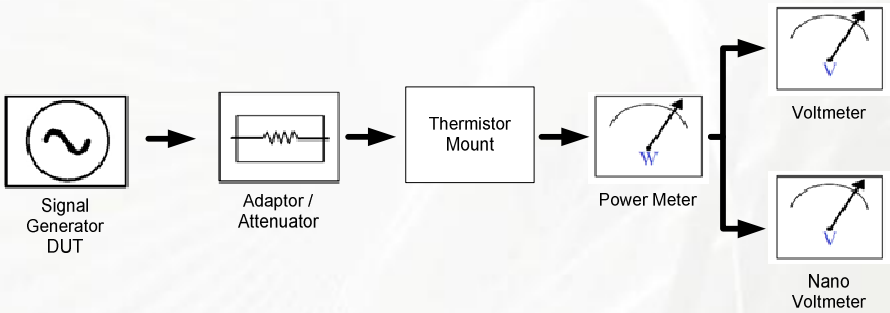




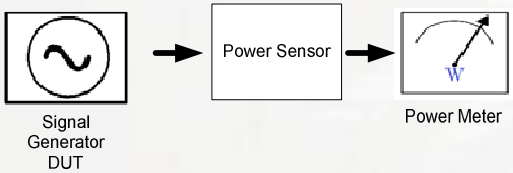
Standards for RF Power Measurement



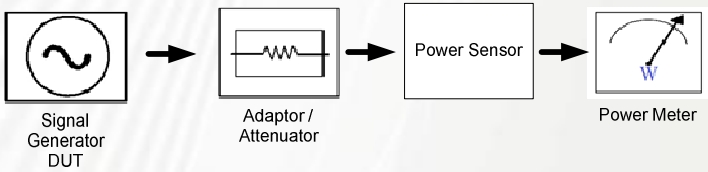
Block diagram of RF power measurement using thermistor mount



Block diagram of RF power measurement using thermistor mount and attenuator



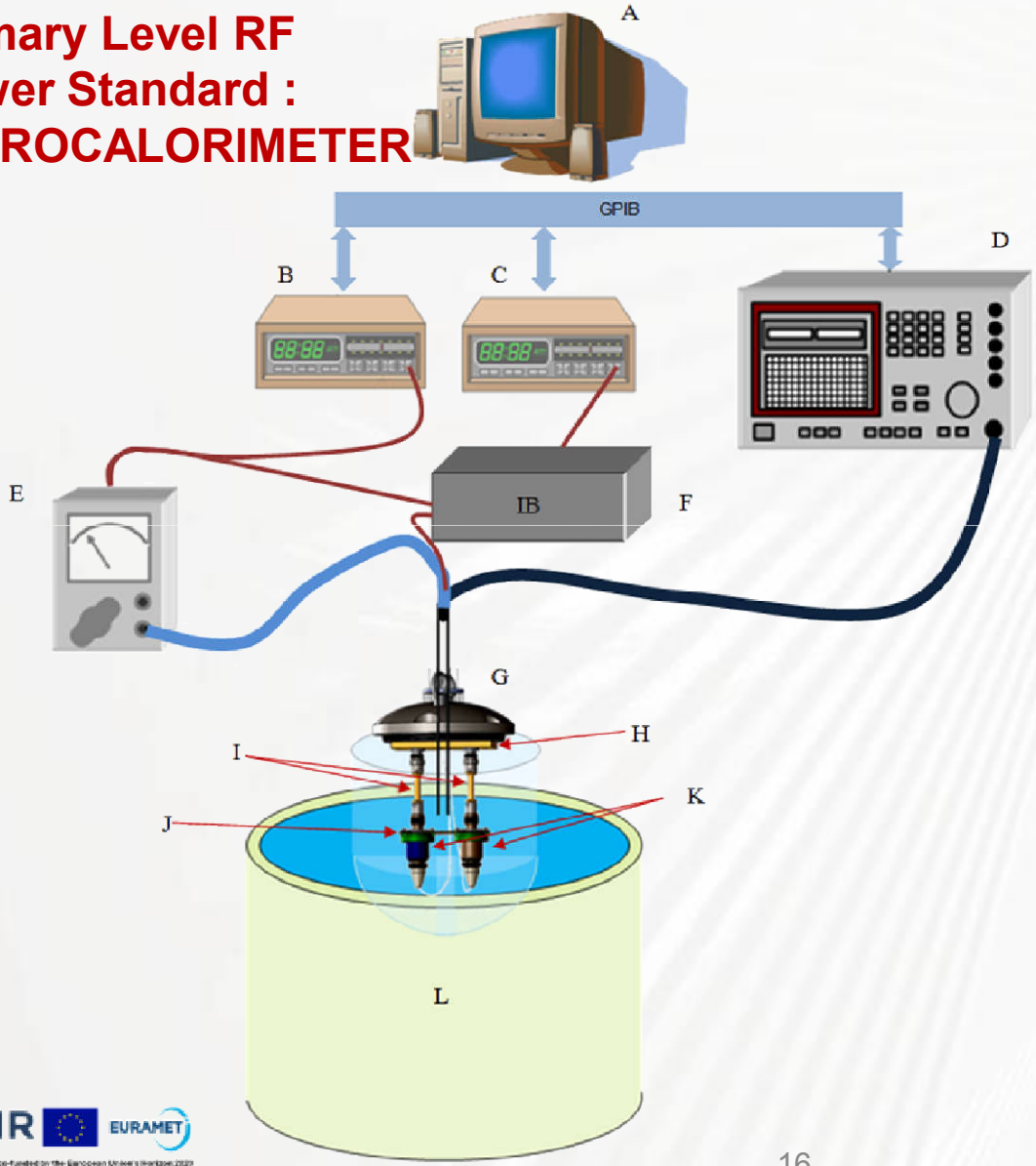
Block diagram of RF power measurement using power sensor



Block diagram of RF low power measurement system with power sensor

Standards for RF Power Measurement

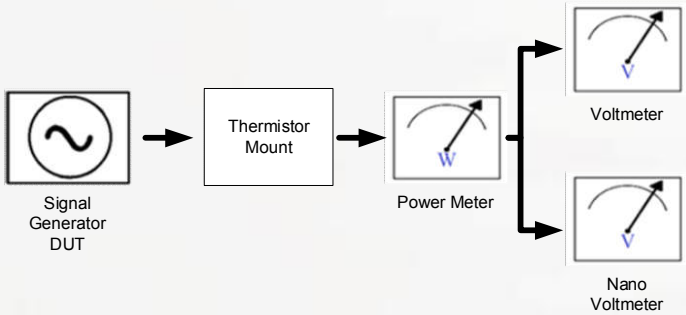
Primary Level RF Power Standard : MICROCALORIMETER



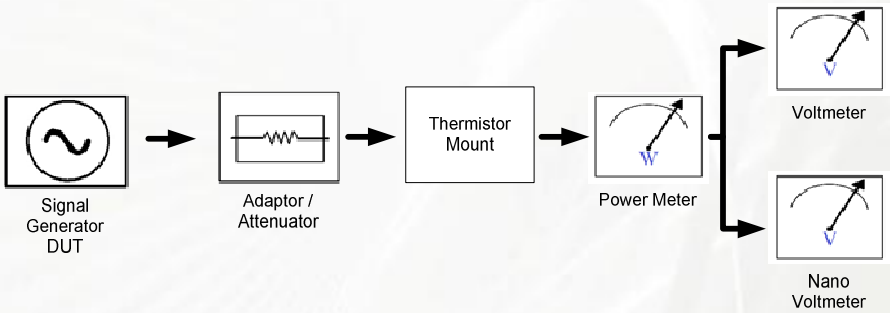
Microcalorimeter System

A. PC,
B. Voltmeter,
C. Nano voltmeter,
D. RF Signal Source,
E. Powermeter,
F. Connection Box,
G. Microcalorimeter head/body,
H. Heat Absorber,
I. Thin Line (2 pieces),
J. Thermopile,
K. Thermistor Mount (2 pieces),
L. Water pool

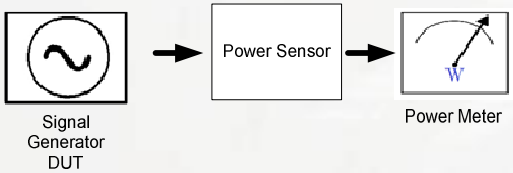
RF Power Measurement



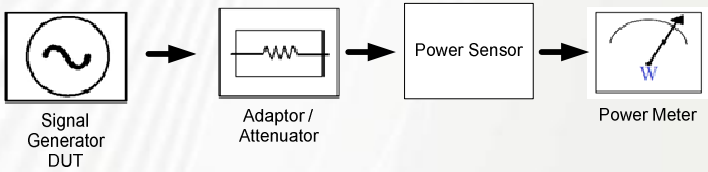
Block diagram of RF power measurement using thermistor mount



Block diagram of RF power measurement using thermistor mount and attenuator

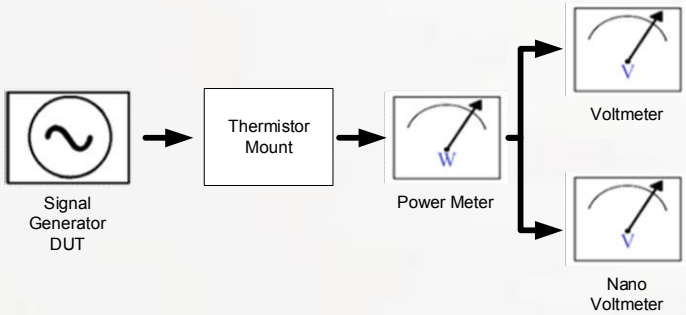


Block diagram of RF power measurement using power sensor



Block diagram of RF low power measurement system with power sensor

RF Power Measurement



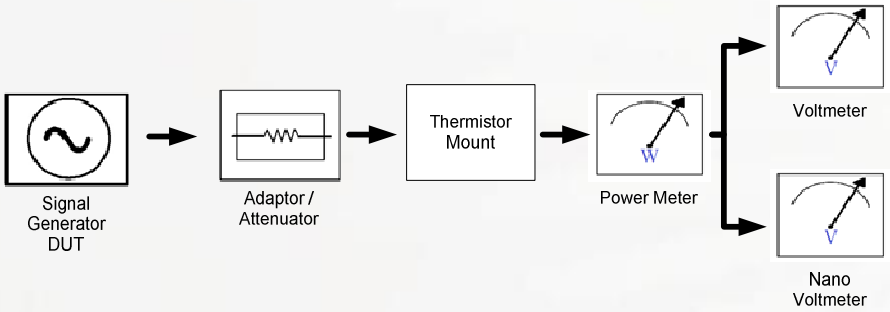
Block diagram of RF power measurement using thermistor mount

- Thermistor Mounts need a wheastone bridge to measure the RF power
- Old generation powermeter which contains the bridge needs two voltmeters
- Every different type powermeter has different power calculation formula

$$P = \frac{2 \cdot V_{Comp} \cdot \left(\left(V_{Comp} - V_{RF} \right)_{RFON} - \left(V_{Comp} - V_{RF} \right)_{RFOFF} \right) + \left(V_{Comp} - V_{RF} \right)_{RFOFF}^{2} - \left(V_{Comp} - V_{RF} \right)_{RFON}^{2}}{4 \cdot R}$$

@ HP 432 Powermeter

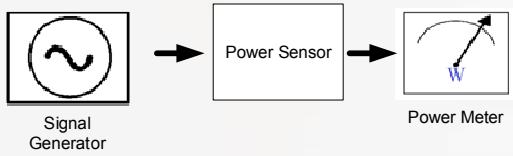
RF Power Measurement



Block diagram of RF power measurement using thermistor mount and attenuator

- In order to measure the high power with Thermistor Mounts, it is required an attenuator

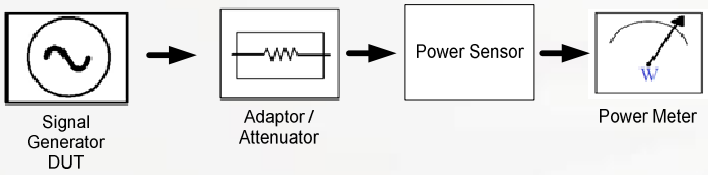
RF Power Measurement



Block diagram of RF power measurement using power sensor

- Power sensor generates a DC power and It needs a power meter which contains a DC voltmeter
- New generation power sensors have wide frequency and power range
- Powermeters Show the power dBm or Watt format

RF Power Measurement



Block diagra of RF low power measurement system with power sensor

- In order to measure the high power with power sensor, it is required an attenuator

RF Power Measurement

- ✓ The power sensors used in microwave power measurement are not ideal
- ✓ The power read on power meter display is not equal to the applied power.
- ✓ Some part of the power to be measured is lost before it reaches to sensor element (resistor, thermocouple, diode).

This results in all of the power not to be measured.

Characterization of power sensors is more important for power measurement accuracy

RF Power Measurement

Power sensors' Losses :

Mismatch Losses

- Impedance Mismatch
- Miss Connections

Inside Losses

- Transmission losses,
- Dielectric losses,
- RF-DC conversion losses

EMPIR EURAMET

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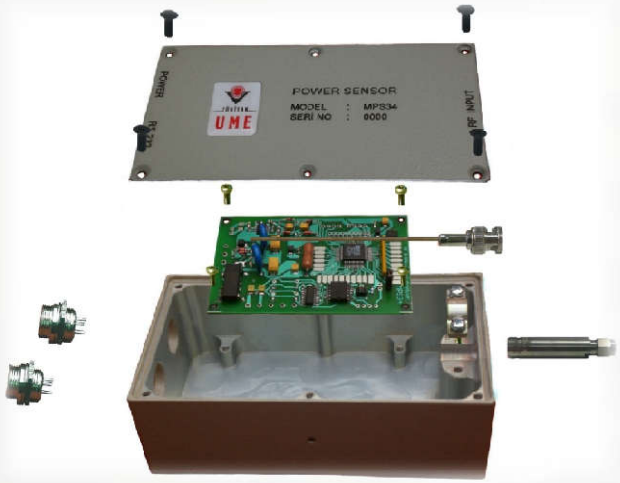
RF MICROWAVE



Losses in Power Sensor

- **Transmission losses** :
  The power applied to input of the power sensor is attenuated while passing through the transmission line inside the power sensor until it reaches the sensor element (bolometer, thermocouple or diode). The attenuation in the power is called transmission losses.

- **Dielectric losses :**
  Some losses occur due to the insulator in the power sensor

- **RF-DC conversion losses:**
  Not all amount of the microwave power applied on sensing element is converted into DC power. The losses occurred during this conversion is called RF-DC conversion losses

Losses in power sensor

The losses mentioned above are not measured and calculated separately.

However, determining the power applied and the power obtained at output, the power sensor would be characterized.

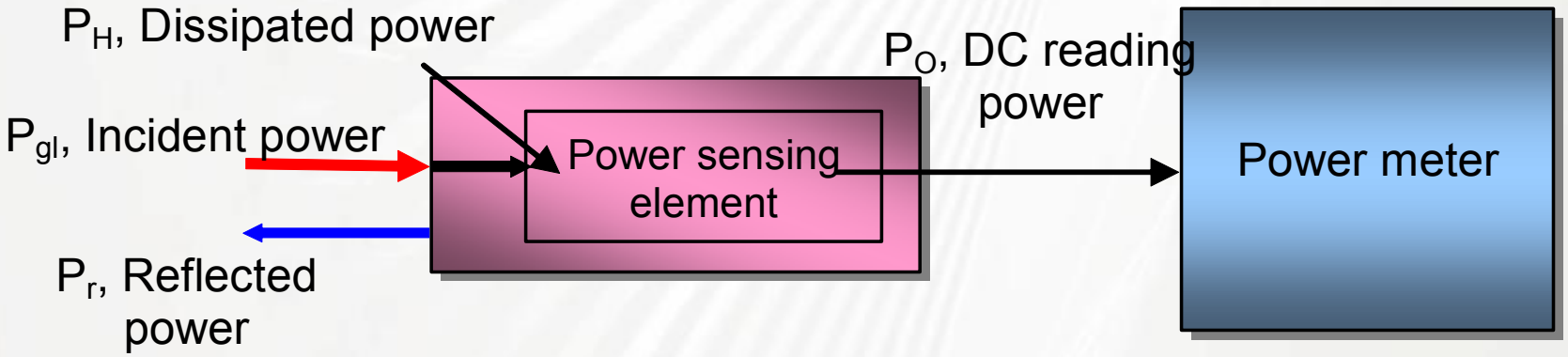
Within this scope, there are defined two parameters;

- Effective efficiency
- Calibration factor (CF)

Effective Efficiency

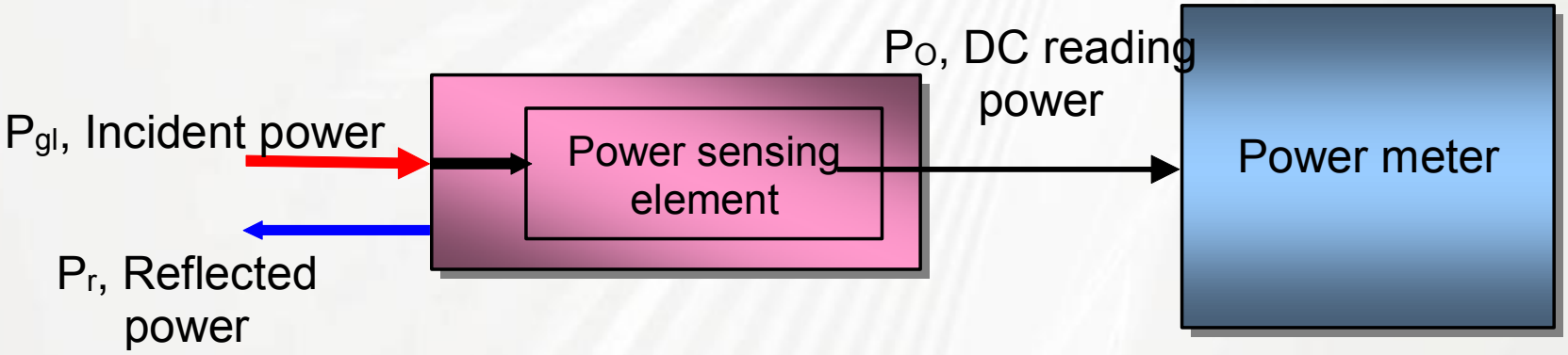
$$\eta = \frac{DC\,R.eadingPower}{PowerDissipatedInSensor} = \frac{P_O}{P_H}$$

- Transmission loss
- Dielectric Loss
- Thermistor Loss
- RF-DC Transfer loss



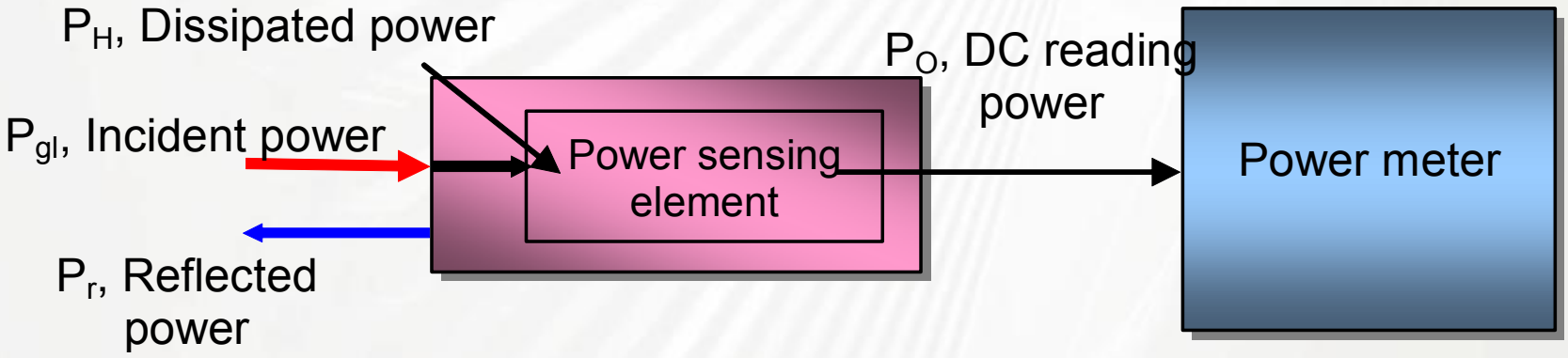
Calibration Factor

$$CF = \frac{DC\ R.eading\ \ Power}{Incident\ \ Power} = \frac{P_O}{P_{gl}}$$



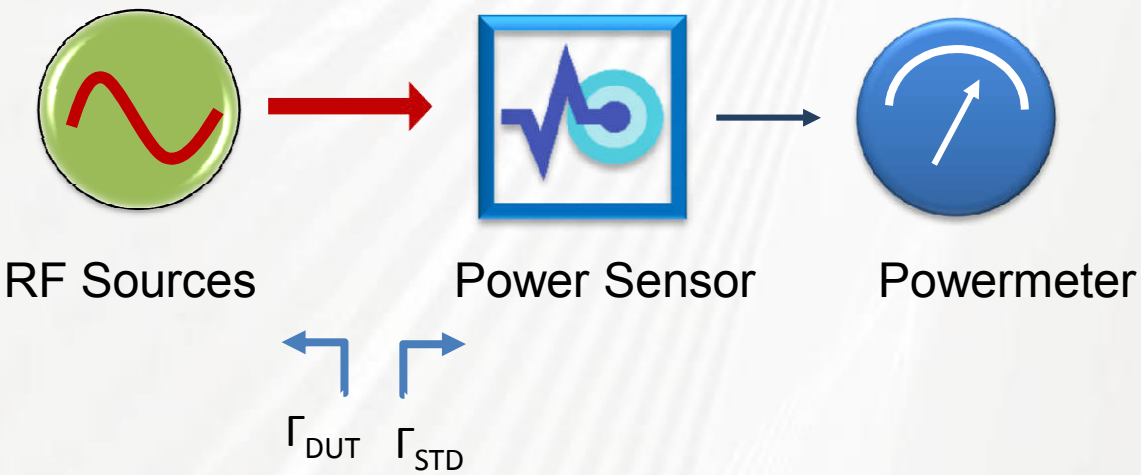
RF Power Measurement

$$CF = \eta\ (1 - \rho^2)$$



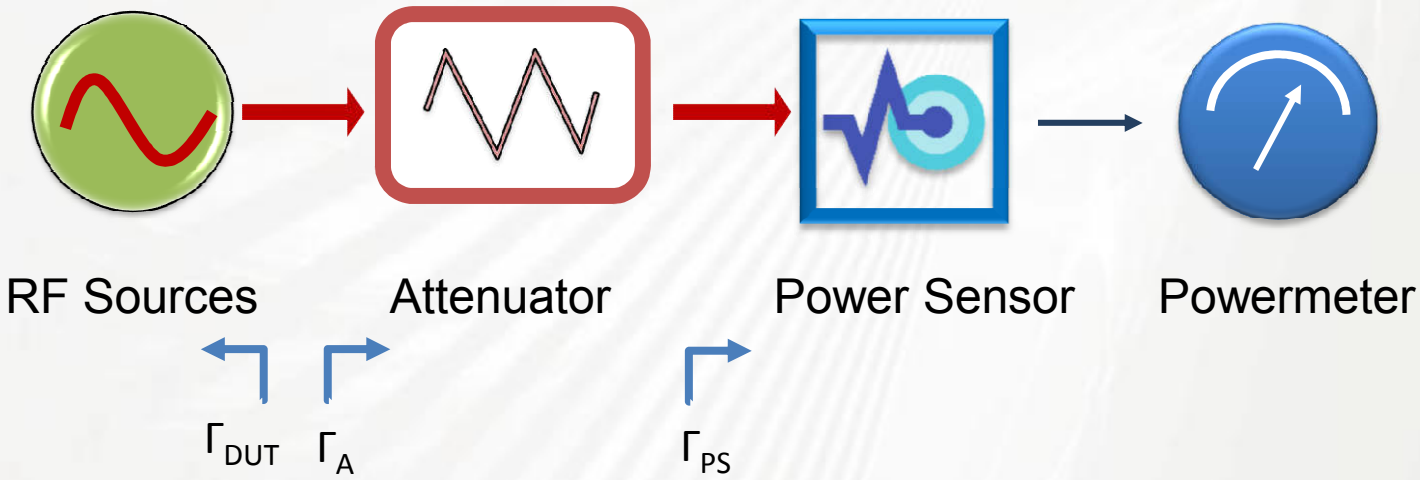
RF Power Measurement

$$P_{DUT} = \frac{P_{READ}}{CF_{STD}} \cdot \frac{CF_{REF}}{PM_{REF}} \cdot P_{CAL} \cdot \frac{\left|1 - \Gamma_{STD} \cdot \Gamma_{DUT}\right|^2}{\left|1 - \Gamma_{STD_50MHz} \cdot \Gamma_{PM_50MHz}\right|^2}$$



RF Power Measurement

$$P_{DUT} = \frac{P_{READ}}{CF_{STD}} \cdot \frac{CF_{REF}}{PM_{REF}} \cdot P_{CAL} \cdot \left| \frac{1}{S_{21A}} \right|^2 \cdot \frac{\left| 1 - \Gamma_A \cdot \Gamma_{DUT} \right|^2}{\left| 1 - \Gamma_{STD_50MHz} \cdot \Gamma_{PM_50MHz} \right|^2}$$



$$\Gamma_A = S_{11A} + \frac{S_{21A} . S_{12A} . \Gamma_{PS}}{1 - S_{22A} . \Gamma_{PS}}$$

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15RPT01 RFMicrowave
Development of RF and Microwave Metrology Capability

Thanks for attention!