RF Power Measurement

KE2N

Ole Virginia Hams – October 2021

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Background

KN4IJY asked: "Can you recommend a good new/used watt meter that can handle better than 100 milli Watts?" WSPR/QRP operation.

Typical meters used by Amateurs do not cover this the << 1 watt power range well. It's more the realm of test bench equipment.

"The other Ken" (KN4DD) suggested this would be a good basis for a presentation topic.

This presentation is not an endorsement of any product.

What does an RF Power Meter measure?

- **P = V x I x cos ϴ** where V and I are root-mean-square (rms) values
- Meter needs to measure 3 things: voltage, current and phase.
- Generically, power meters consist of:
  - Coupler (with or without load resistor) – directional/ dual directional
  - Detector – converts RF into DC
  - Indicator – calibrated in watts or dBm. Can include SWR calc. May involve µP.
- Sometimes 2 or 3 functions are combined into a single unit or are included inside the radio, or an antenna tuner.

The **ϴ** value is the angle between current and voltage in the circuit. The angle is zero when load is purely resistive, in that case cos **ϴ** is 1 – that means the current and voltage are perfectly in phase with each other – not usually the case with a real antenna.

Types of Couplers

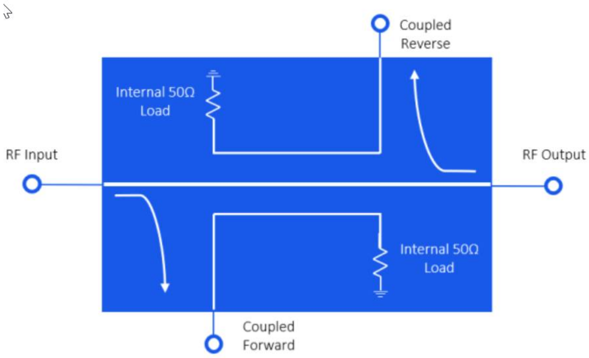
The purpose of a coupler is to take a small sample of the signal and to minimize disturbance to the circuit being sampled.

- Direct connection – usually a small coupling capacitor (not directional)
- Transformer type – usually ferrite core (a *current transformer*)
- Transmission line type – for VHF and above. Coupled lines act as a transformer.

Couplers have a *coupling factor* in (negative) dB and other specs like insertion loss, return loss and power handling. They may be *directional* in which case they exhibit *directionality* (in dB). Directional coupler is required if you are transmitting into a real antenna and not a 50-ohm dummy load.

The transformer will be a *current transformer* - the primary is connected in series with the load. The voltage on the secondary depends on the current flow and the impedance of the secondary circuit components.

Couplers: Coupled-Line type

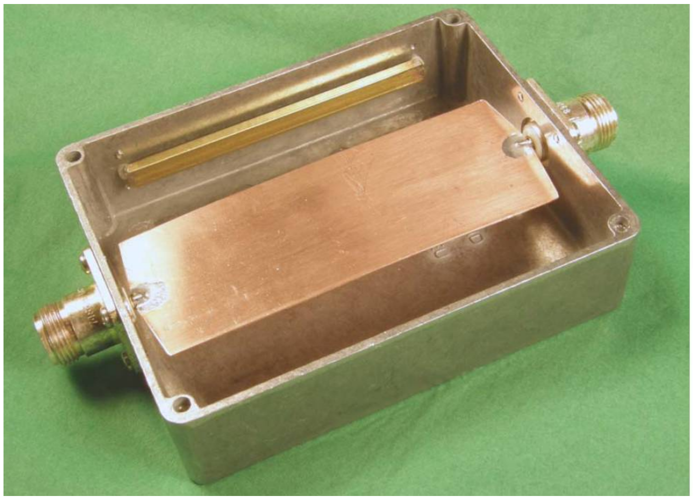


Do not confuse with circulator/isolator

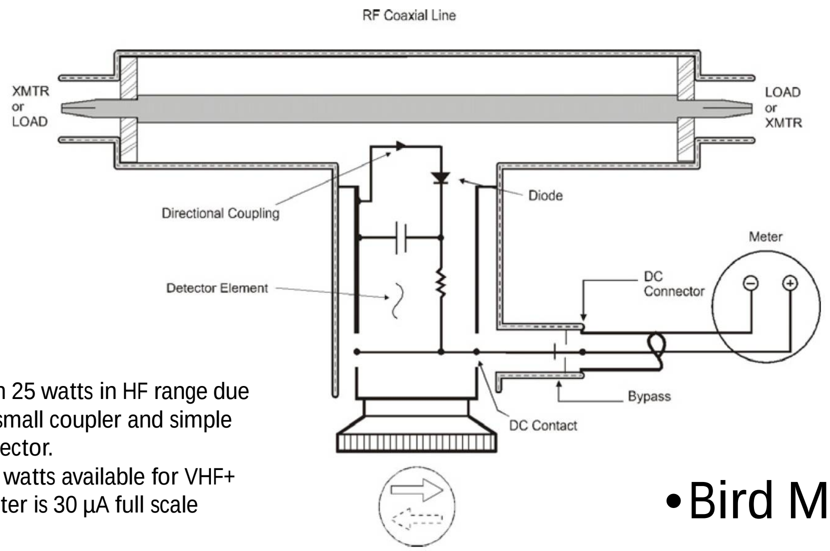
If you buy a used coupler with internal resistor be sure to check that the resistor is 50 ohms – not burned out.

High Power UHF Directional Coupler (W1GHZ)

1.5 kW @ 900 MHz



W1GHZ web site shows several designs.

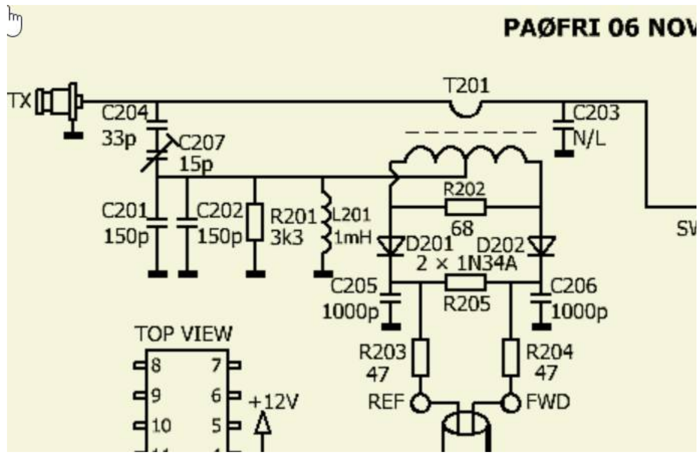


Min 25 watts in HF range due to small coupler and simple detector.
2.5 watts available for VHF+
Meter is 30 µA full scale

- Bird Model 43

The coupling element employs both inductive and capacitive coupling to get directivity. But the element is very small in terns of wavelengths at HF.

Simple HF Directional Coupler and Detector

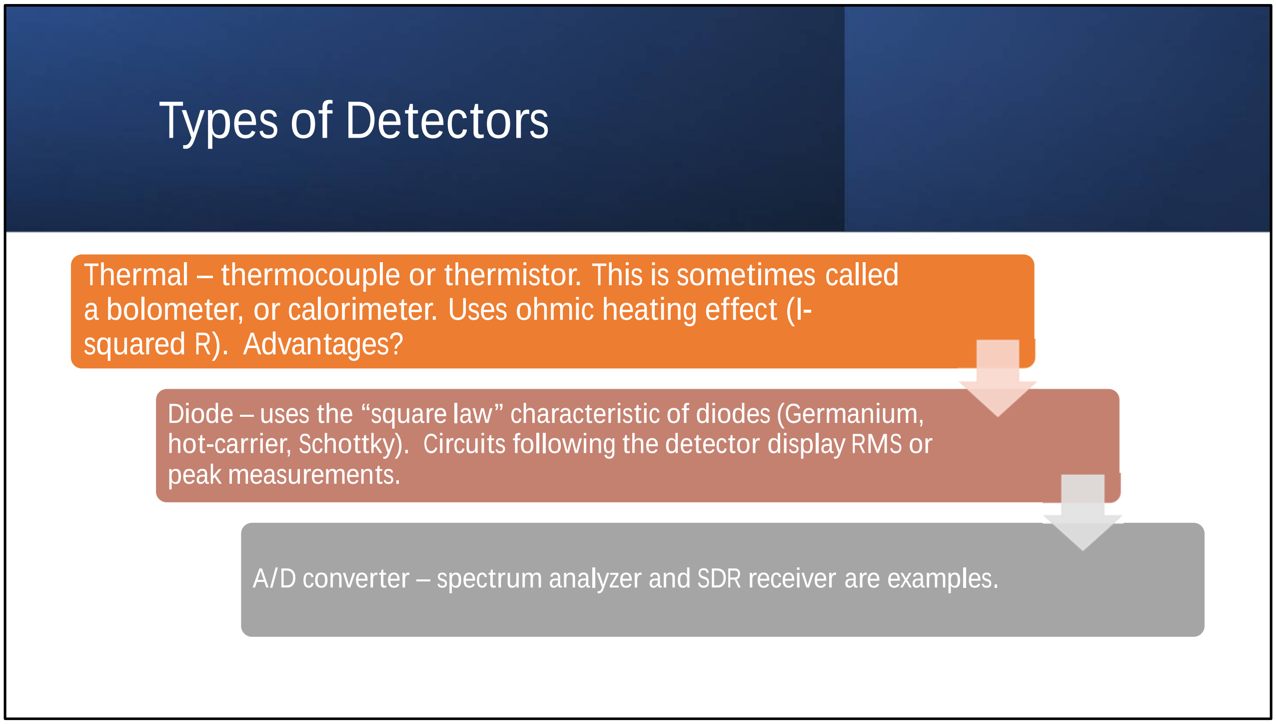


Voltage developed across R202 is connected in series with voltage from C201 C202 C204 voltage divider to get directionality. C207 allows adjustment for zero reflected indication when load is 50 ohms resistive. No provision is made for balancing in the reverse direction however. SO reflected power can affect forward power indication to some extent.

HF Tandem Directional Coupler and Detector

Note: Transformer sampling of voltage
Need to calibrate
30-40 dB directionality

Polarizing voltage is derived from a voltage transformer in this design. The spec for this board shows 30-40 dB directivity



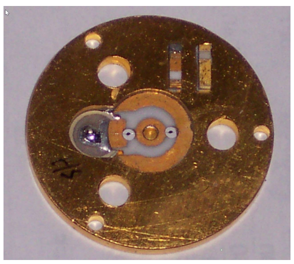
Advantage of thermal type is that they can be calibrated at DC and still work at microwave frequency.

RF Ammeter

- Used with external shunt or current transformer
- Internal heating element with thermocouple-driven meter.
- Indicates power if load impedance is known and purely resistive (matched).
- Rating 115 mA and 4.5 ohms (60 mW).
- Q: why current squared?

Power is proportional to current squared so power display is linear, not bunched up at one end of the scale.

Thermistor Type Sensor



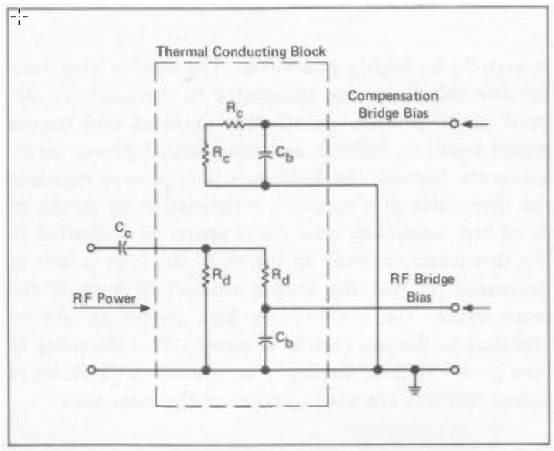
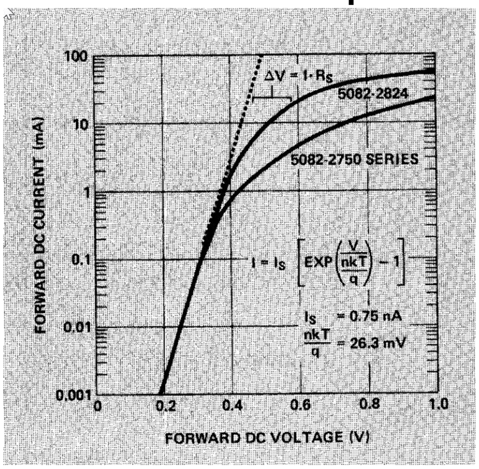


Figure 2-2. Simplified diagram of the HP 478A dual-element temperature compensating, coaxial thermistor mount.

200 ohms DC resistance
50 Ohms RF

Thermistors are the tiny black dots. Resistors are 100 ohms.. RF sees 50 ohms; DC sees 200 ohms.

Diode and "Square Law" and Linear



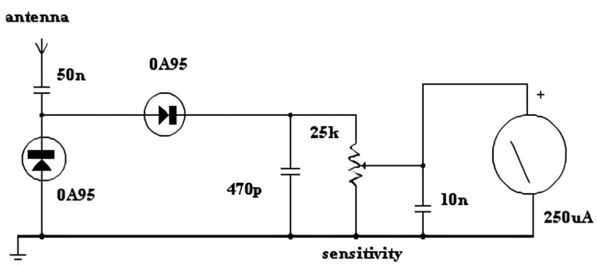
DOES THIS METER USE A SQUARE LAW DETECTOR?

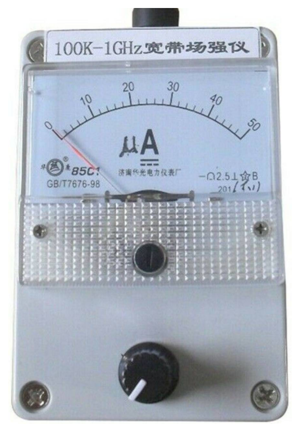
Over the lowest portion of the curve (straight line) the voltage across the diode is the logarithm of the current and represents the current squared. Current squared is proportional to power. Hence voltage readings directly represent power level.

The meter has a non-linear scale. That means it is not intended designed for a square law detector but rather one operating in a linear mode (diodes at left above 0.7 volts).

Simple RF Meter used for "Sniffing RF"

Field Strength Meter

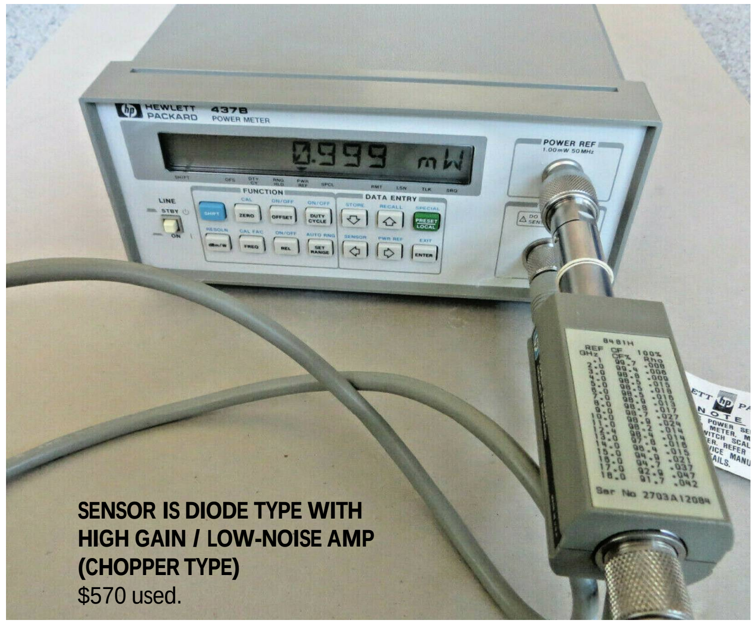




No suitable for measuring power with any sort of accuracy

HP 8484A Sensor and 437B Meter

shown in calibration mode.
10 MHz – 18 GHz



Many of these meters provide a precise 1 mW output at 50 MHz and a precision 30 dB attenuator for calibration purposes. The cable table on the sensor gives adjustment factors for frequencies above 1 GHz.

Log-amp with Limiter (A/0)

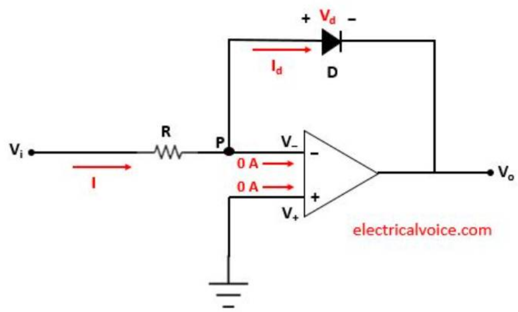


Fig. 2 Log amplifier circuit analysis

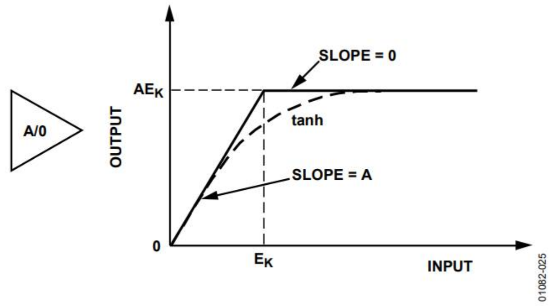
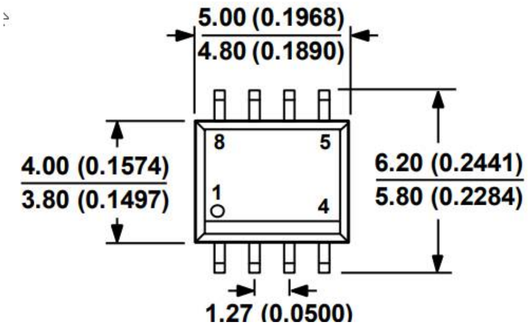


Figure 25. A/0 Amplifier Functions (Ideal and Tanh)

The output of the circuit in Fig.2 itself is logarithmic, due to the diode feedback. Fig 25 shows amplifier limiting action of the amplifier without the diode.

Cascaded Log-Amps with Summing Detector



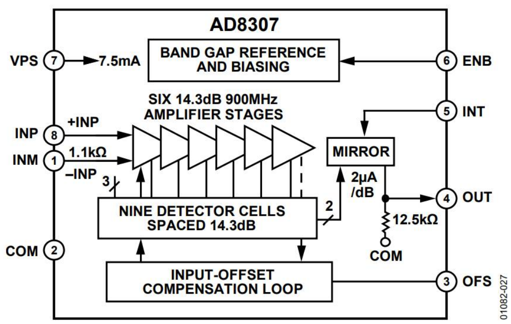
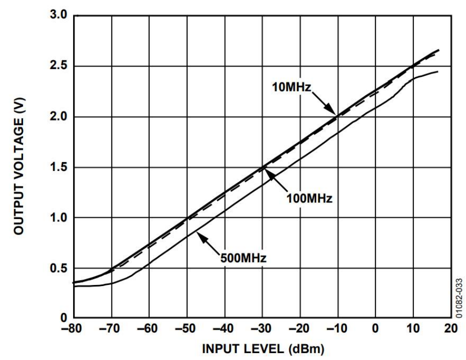


Figure 27. Main Features of the AD8307



This device can be had for a little as $5

Basics Review: Power Expressed as dBm

- The decibel (**dB**) is a dimensionless unit, used for quantifying the ratio between two values
- **dBm** or **dB$_{mW}$** (decibel-milliwatts) is a unit of level used to indicate that a power level is expressed in decibels (dB) with reference to one milliwatt (mW). It is used in radio, microwave and fiber-optical communication networks as a convenient measure of absolute power because of its capability to express both very large and very small values in a short form.

$$x = 10 \log_{10} \frac{P}{1\ \mathrm{mW}},$$

$$P = 1\ \mathrm{mW} \cdot 10^{\frac{x}{10}},$$

Recall that

$P = V \cdot I$

or

$P = I^2 \cdot R$ (100 W =1.4 A)

or

$P = V^2 / R$ (100 W = 70.7 V)

For 1 kW multiply both voltage and current by sqrt(10) or about 3.16. That means 5 amps and 200 volts.

Familiar Power Levels in Decibel-milliwatts

- 60 dBm = 1 kW everybody runs this on HF
- 30 dBm = 1000 mW = 1 watt HT Handy Talkie
- 27 dBm = 500 mW cell phone, AREDN node
- 10 dBm = 10 mW WSPR QRP level
- - - - - - negative dB means < 1 mW - - - - - - - - -
- -73 dBm = S9 signal on HF
- -93 dBm = S9 on UHF
- -113 dBm = ½ microvolt into 50 ohms (typical receiver spec).
- -139 dBm – 20 degrees C thermal noise floor @ 3 kHz b/w

Values involving noise power need to consider receiving bandwidth. 3 kHz adds 10 * log (3000) or about 35 dB to the noise floor at 1 Hz bandwidth. Amateur digital modes can operate below the voice bandwidth noise floor by creating a very narrow effective bandwidth using DSP.

Lower noise floor can be had by cooling the receive preamp – as done in radio astronomy.

Those dB Calcs

Suppose we have a 100-watt transmitter and want to use an AD8307 meter which is a terminating-type meter.

AD8307 can handle -70 to +10 dBm, but let's use -60 to +0 dBm.

100 watts is +50 dBm and we want 0 dBm. Need to reduce signal by 50 dB. One option – use a coupler with -30 dB coupling factor followed by a 20 dB attenuator.

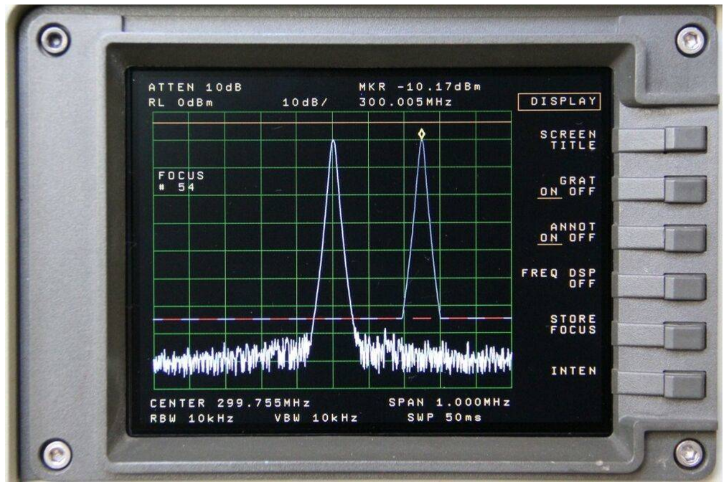
Power into attenuator is 50-30=20 dBm, or 100 milliwatts.

What is the lowest power we can read? We can read 60 dB below the maximum value or 50-60=-10dBm. That is 0.1 mW!

With two such meters, SWR could be calculated/antenna tuned while transmitting almost no power output. See the Kaune QST article in refernences.

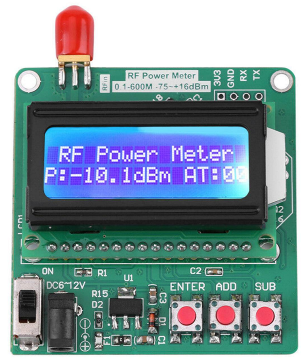
Spectrum Analyzer/ SDR

- Can find the power level of multiple signals.
- Accuracy can be an issue
- Use with external directional coupler/attenuator.



One way to get accuracy is to compare with a signal generator set to the same amplitude.

Displays



Units on the left allow switching between multiple external sensors for different bands or radios.

Summary/Conclusion

- We have covered:
  - How RF power defined/measured
  - Detector/sensor types
  - Coupling devices
  - Displays
  - Examples
- And
- New technology using integrated circuit log-amp devices. Will consumer-grade Amateur market devices follow?

- PS: I did not answer Harry's question

References

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