Practical Amateur Radio Measurements

RM Ham University – December 2018

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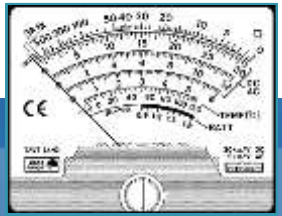


Bob Witte KØNR

Electrical Engineer

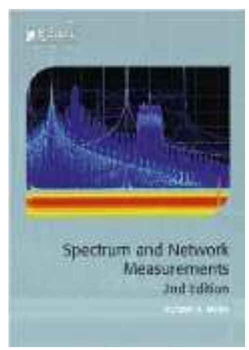
40 years in the Test and Measurement Industry

HP, Agilent, Keysight Technologies

Author of

Electronic Test Instruments

Spectrum and Network Measurements



Agenda

Topic	Comments	Time
1. Introduction	Frequency, measurement concepts, trends	8:00 to 8:30
2. Digital Multimeters	Voltage, current and resistance measurements	8:30 to 9:20
Break		
3. SWR Measurement	SWR, reflection coefficient, SWR measurements, antenna analyzers, vector network analyzers	9:30 to 10:20
Break		
4. Oscilloscope measurements	Time domain, bandwidth, scope probes	10:30 to 11:00
5. RF Measurements	Frequency domain, spectrum analyzers, SDR receiver, transceiver tests, power measurement	11:00 to 11:30
Discussion and wrap up		11:30 to noon

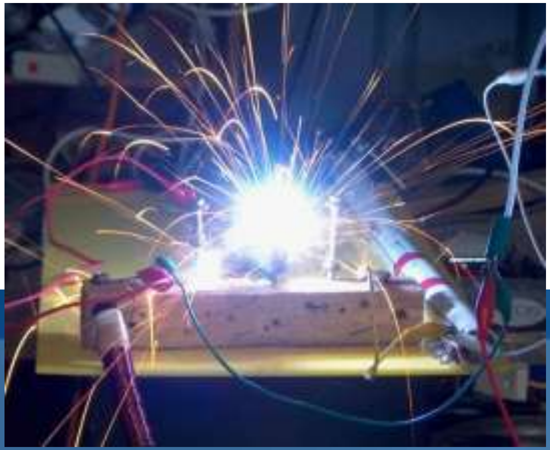
Why do we need electronic measurements?

- Bob's First Law of Electronic Measurement

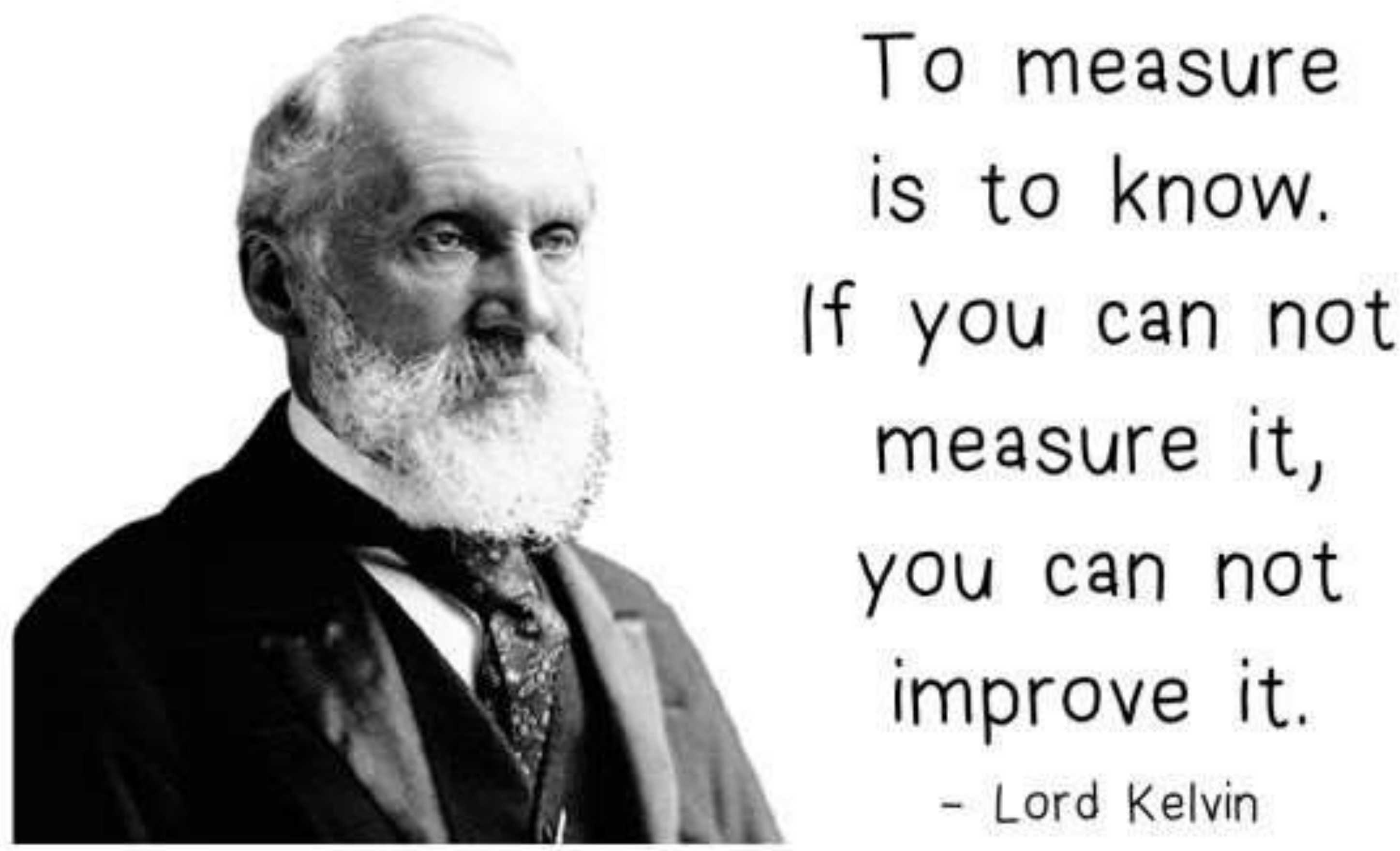
  With electricity, most of the time we cannot observe what is going on without measuring instruments.

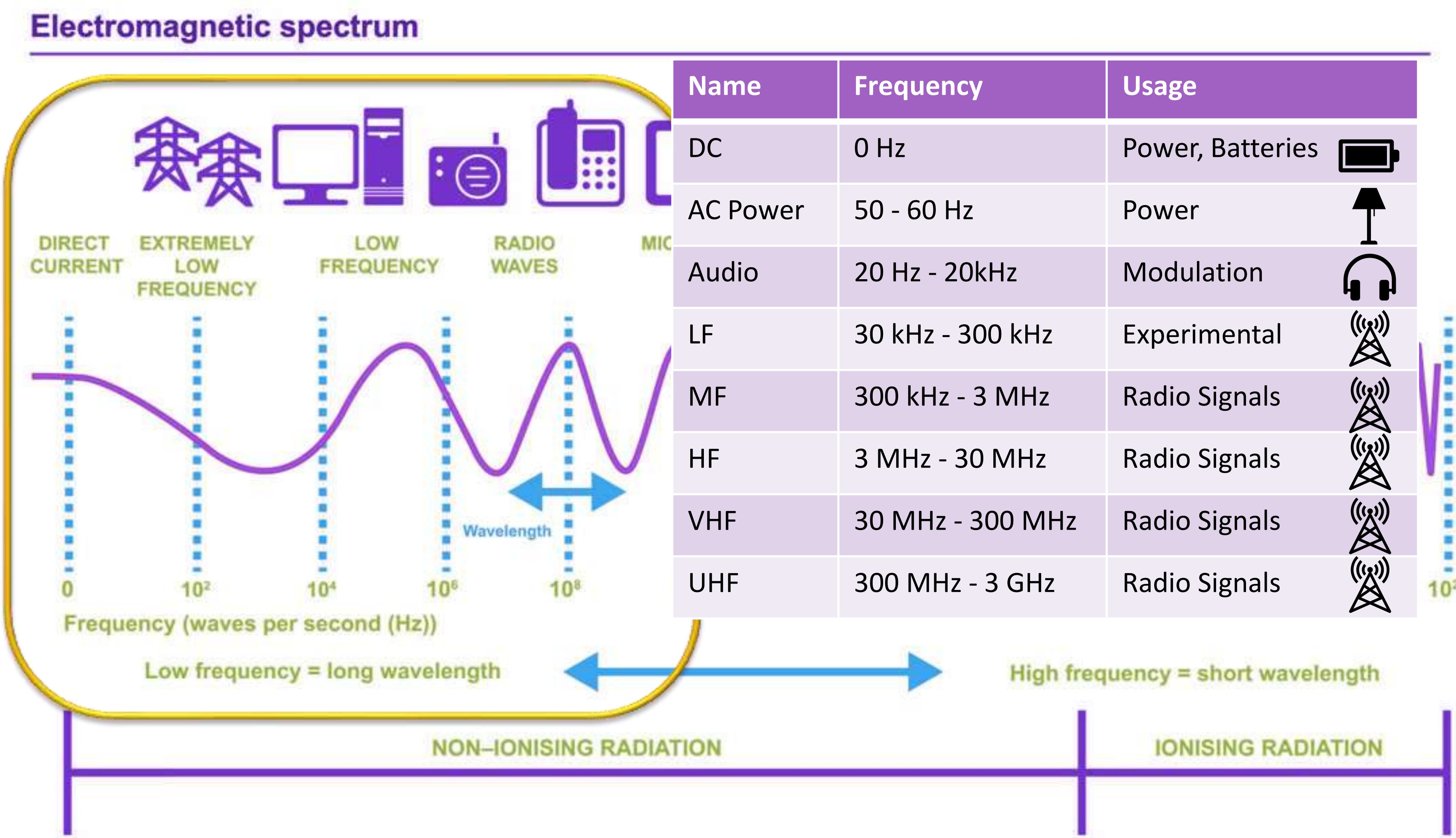
- Bob's Second Law of Electronic Measurement

  When we can observe electricity directly, it is often a bad thing.



- Bob's Third Law of Electronic Measurement
  - Lord Kelvin was right





Name	Frequency	Usage
DC	0 Hz	Power, Batteries
AC Power	50 - 60 Hz	Power
Audio	20 Hz - 20kHz	Modulation
LF	30 kHz - 300 kHz	Experimental
MF	300 kHz - 3 MHz	Radio Signals
HF	3 MHz - 30 MHz	Radio Signals
VHF	30 MHz - 300 MHz	Radio Signals
UHF	300 MHz - 3 GHz	Radio Signals

Name	Frequency	Usage
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VHF	30 MHz - 300 MHz	Radio Signals
UHF	300 MHz - 3 GHz	Radio Signals

Digital Multimeter

SWR/ Power Meter

Antenna Analyzer

Other test instruments: Oscilloscopes, signal generators, RF Communications Testers

Measurement Terminology

All measurements contain some error.

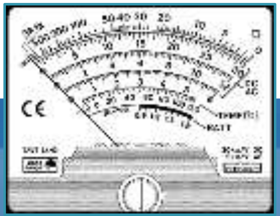
<u>Accuracy</u>: closeness of the agreement between measurement result and true value

<u>Uncertainty</u> of measurement: quantified doubt about the result of a measurement

<u>Repeatability</u> (of an instrument or of measurement results): closeness of the agreement between repeated measurements of the same property under the same conditions

<u>Resolution</u>: smallest difference that can be meaningfully distinguished (e.g. a change of one (1) in the last place of a digital display)

Reference: A Beginner's Guide to Uncertainty of Measurement, Stephanie Bell, National Physical Laboratory, UK, March 2001



Decibels

Handy Rules:
Twice the power = 3 dB
10x the power = 10 dB

Decibels are defined in terms of pow

$A_{dB} = 10 \log (P_1/P_2)$

Examples:

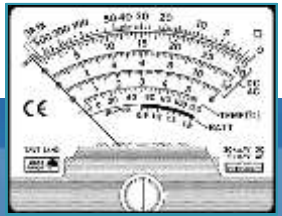
P_1= 10 watts, P_2= 5 watts $A_{dB} = 10 \log (10/5) = 3.01$ dB

P_1= 5 watts, P_2= 10 watts $A_{dB} = 10 \log (5/10) = -3.01$ dB

Examples:

P_1= 100 watts, P_2= 10 watt $A_{dB} = 10 \log (100/10) = 10.0$ dB

P_1= 10 watts, P_2= 100 watts $A_{dB} = 10 \log (10/100) = -10.0$ dB



Decibels

Decibels can also be used for voltages

$A_{dB} = 10 \log (P_1/P_2)$

$$A_{dB} = 10 \log \frac{(\frac{V_1^2}{R})}{(\frac{V_2^2}{R})} = 10 \log (\frac{V_1}{V_2})^2 = 20 \log(\frac{V_1}{V_2})$$

Handy Rules:
Twice the voltage = 6 dB
10x the voltage = 20 dB

Examples:

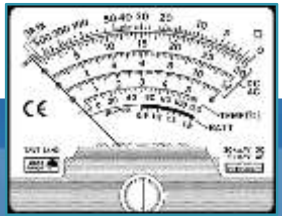
V_1= 10 volts, V_2= 5 volts A_{dB} = 20 log (10/5) = 6.02 dB

V_1= 5 volts, V_2= 10 volts A_{dB} = 20 log (5/10) = -6.02 dB

Examples:

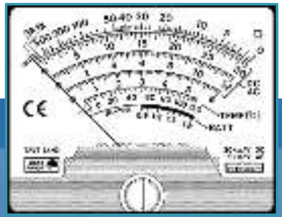
V_1= 100 volts, V_2= 10 watt A_{dB} = 20 log (100/10) = 20.0 dB

V_1= 10 watts, V_2= 100 watts A_{dB} = 20 log (10/100) = -20.0 dB



Trends in measuring equipment

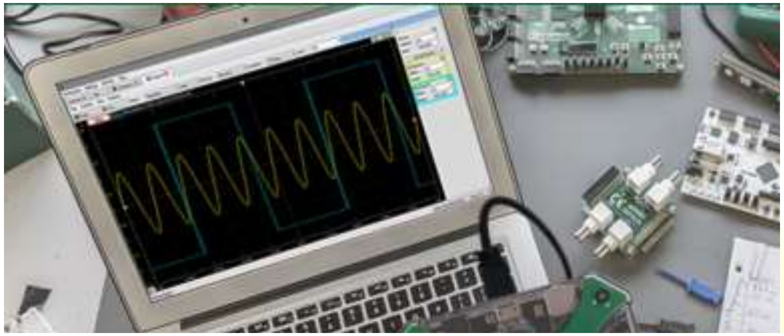
- Low cost equipment
- PC-based instruments
- Software Defined Instruments



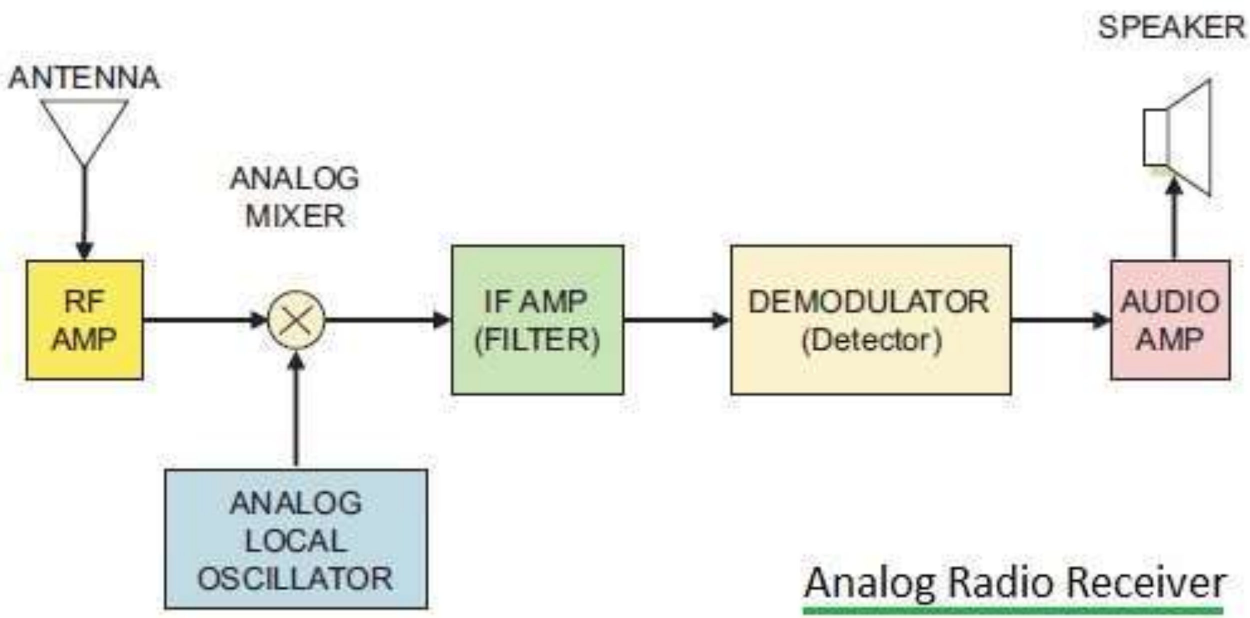
Low Cost Instruments

Typically from China
Low cost
Typically lower quality but maybe good enough
Disruptive technology

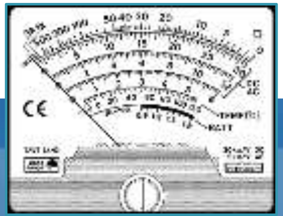
PC-based Instru



Software Defined ~~Radio~~ Instruments



Traditional analog block diagram
Receiver is shown here but same concepts apply for sources (transmitters)



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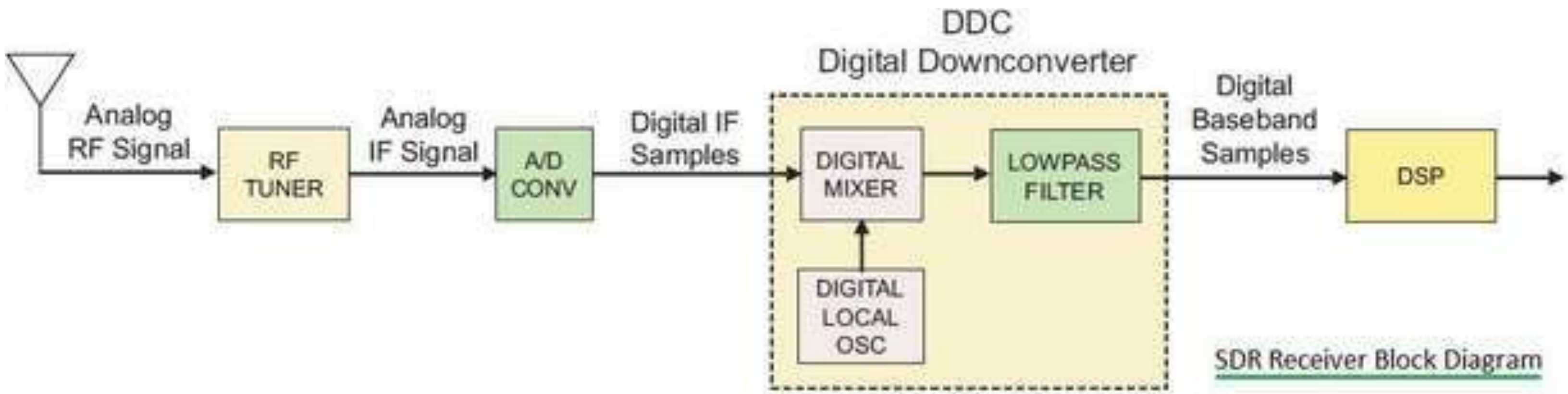
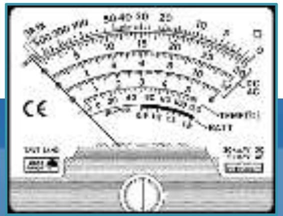


The Analog-to-Digital Converter (ADC) is moving forward in the block diagram.
Ultimately, the ADC just samples the input directly.

Universal Instrument: just sample the signal and use software to perform time domain, frequency domain analysis, etc.
(not quite there yet)



2. Digital Multimeters

Practical Amateur Radio Measurements

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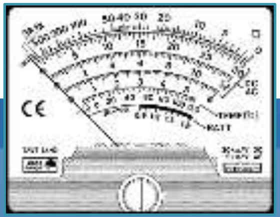
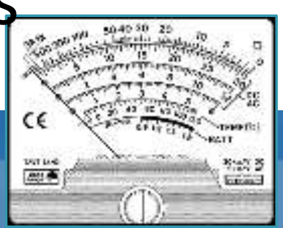


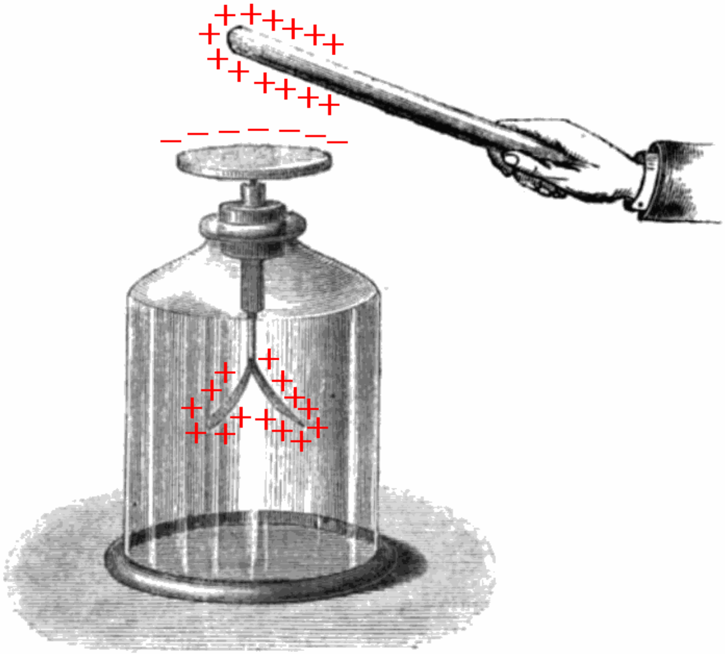
The Multimeter

- Also known as voltmeter, VOM (Volt-Ohm-mA meter),DVM (Digital Voltmeter), or DMM (Digital Multimeter)
- Voltmeter, ammeter and ohmmeter combined into one instrument
- DC and AC measurements
- Some models have diode test, continuity, capacitance, inductance, frequency, temperature
- Bench or handheld form factor
- Mostly digital meters, some analog meters

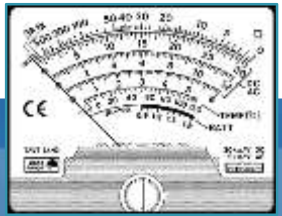


Gold Leaf Electroscope

Abraham Bennet
1749 - 1799

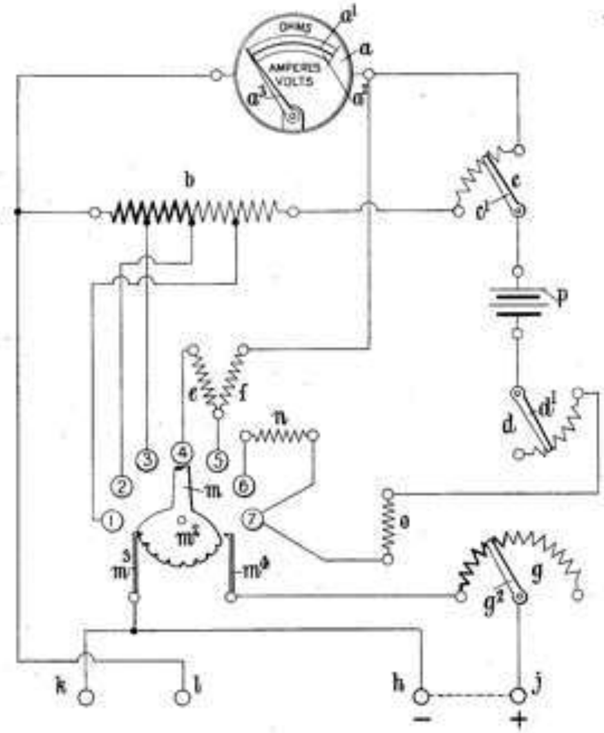


When the metal terminal is touched with a charged object, the gold leaves spread apart in a 'V'. This is because some of the charge on the object is conducted through the terminal and metal rod to the leaves. Since they receive the same sign charge they repel each other and thus diverge. If the terminal is grounded by touching it with a finger, the charge is transferred through the human body into the earth and the gold leaves close together.



AVO Meter

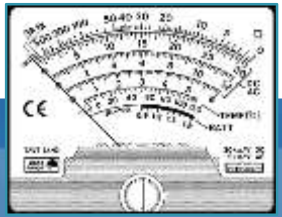
AVO = Amperes Volts Ohms



Donald Macadie invented the AVO Meter in 1923

Lots of Meters Out There

A classic analog multimeter: Simpson Model 260



Multimeter,TACKLIFE DM03 Auto Ranging Multi Tester, Measures AC & DC Voltage and Current, Resistance, Continuity, Frequency, Diode Electronic Tester, Digital Multimeter with Backlit LCD

by TACKLIFE

★★★★☆ 184 customer reviews | 78 answered questions

Price: $13.97 ($0.01 / Count) ✓prime

Get $70 off instantly: Pay $0.00 upon approval for the Amazon Prime Rewards Visa Card.

Note: Available at a lower price from other sellers, potentially without free Prime shipping.

Arrives before Christmas.

Size: **DM03**

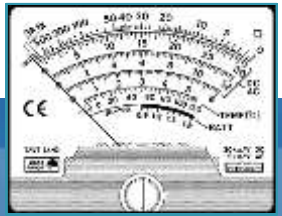
DM03	DM08
$13.97 ($0.01 / Count)	$9.97
✓prime	✓prime

Ten Amateur Radio Applications of a DMM

1. Check the power supply voltage on the new power supply you just purchased.
2. See if your HT battery pack is fully charged.
3. Measure the current that your transceiver draws to estimate how long your emergency power system will last during a blackout.
4. Sort the bag of resistors you purchased at the swapfest.
5. Check a fuse to see if it is blown.

Ten Amateur Radio Applications of a DMM (2)

6. Troubleshoot your broken rig by checking the bias voltages against the service manual.
7. Figure out if the AA batteries the kids left for you are dead.
8. Verify that your coax is not shorted between the shield and center conductor.
9. Check the level of the power line voltage in the ham shack.
10. Check for good DC continuity between the ends of the cable you just soldered.

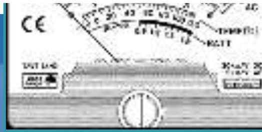


Safety First

"Digital" is derived from the word "Digit" which means finger.

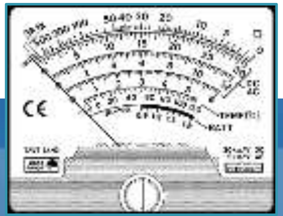
Be careful where you put your digits when using a Digital Multimeter

Graphic courtesy of Agilent Technologies



Quick Guide to Buying a DMM

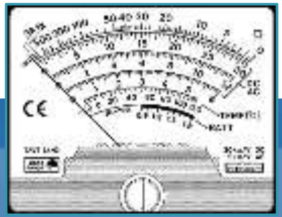
- What? You don't have a Multimeter?
- Buy a digital meter (forget the analog ones)
- Should have a minimum of 600 V Cat II (IEC 1010) rating
- Should have DC volts, AC volts, resistance and DC current (might not have *AC current)*
- Other features to consider:
  - Continuity test mode ("beeper")
  - Diode test mode
  - Autorange
  - "Analog" Bar graph
  - Battery test mode
  - True RMS



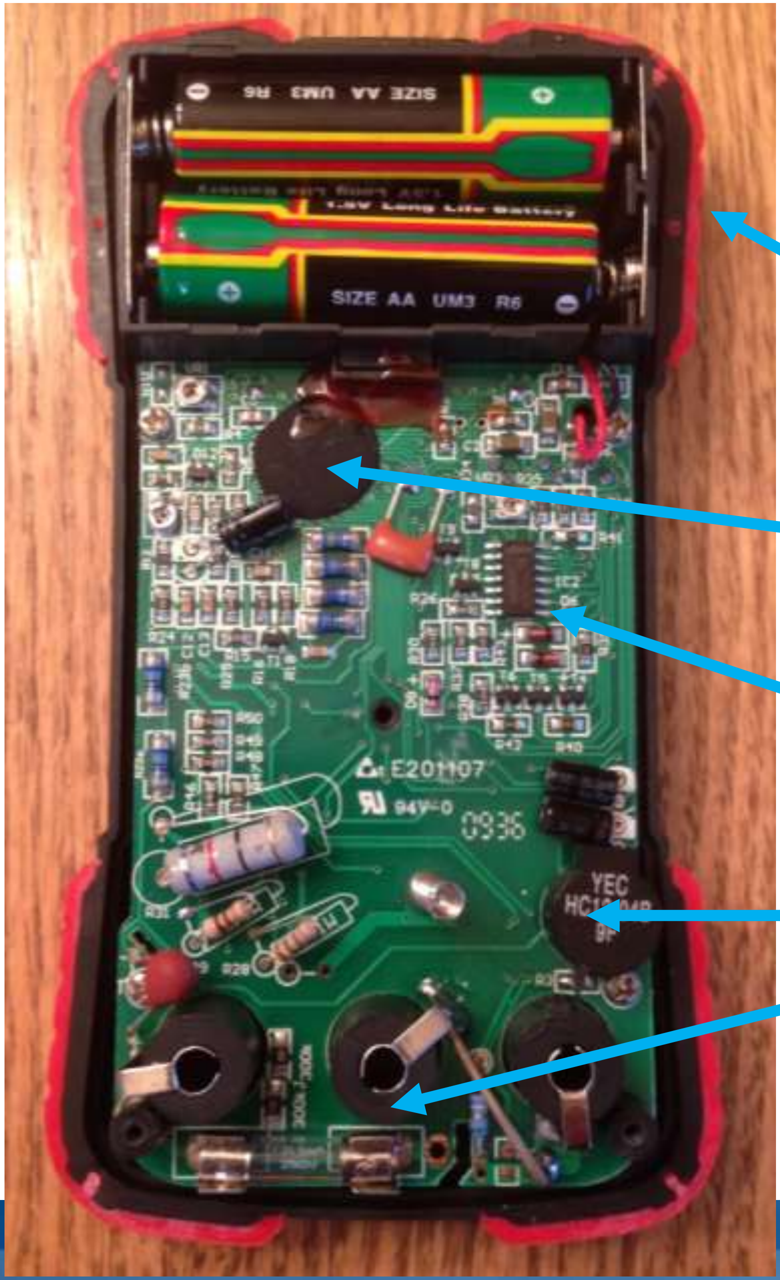
A Typical Low Cost DMM

Innova 3320

- Price ~$20
- 3½ Digits
- 0.8% to 1.5% Accuracy (depends on range)
- Diode test
- Continuity test
- Autorange
- Battery test
- IEC 1010 Cat II - 600V



Inside the meter



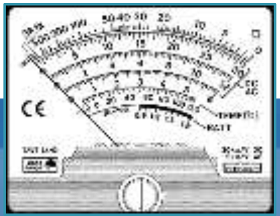
Two AA batteries

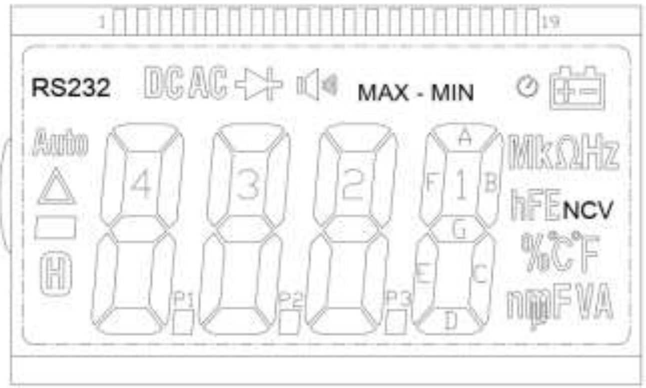
DMM IC
(under glop)

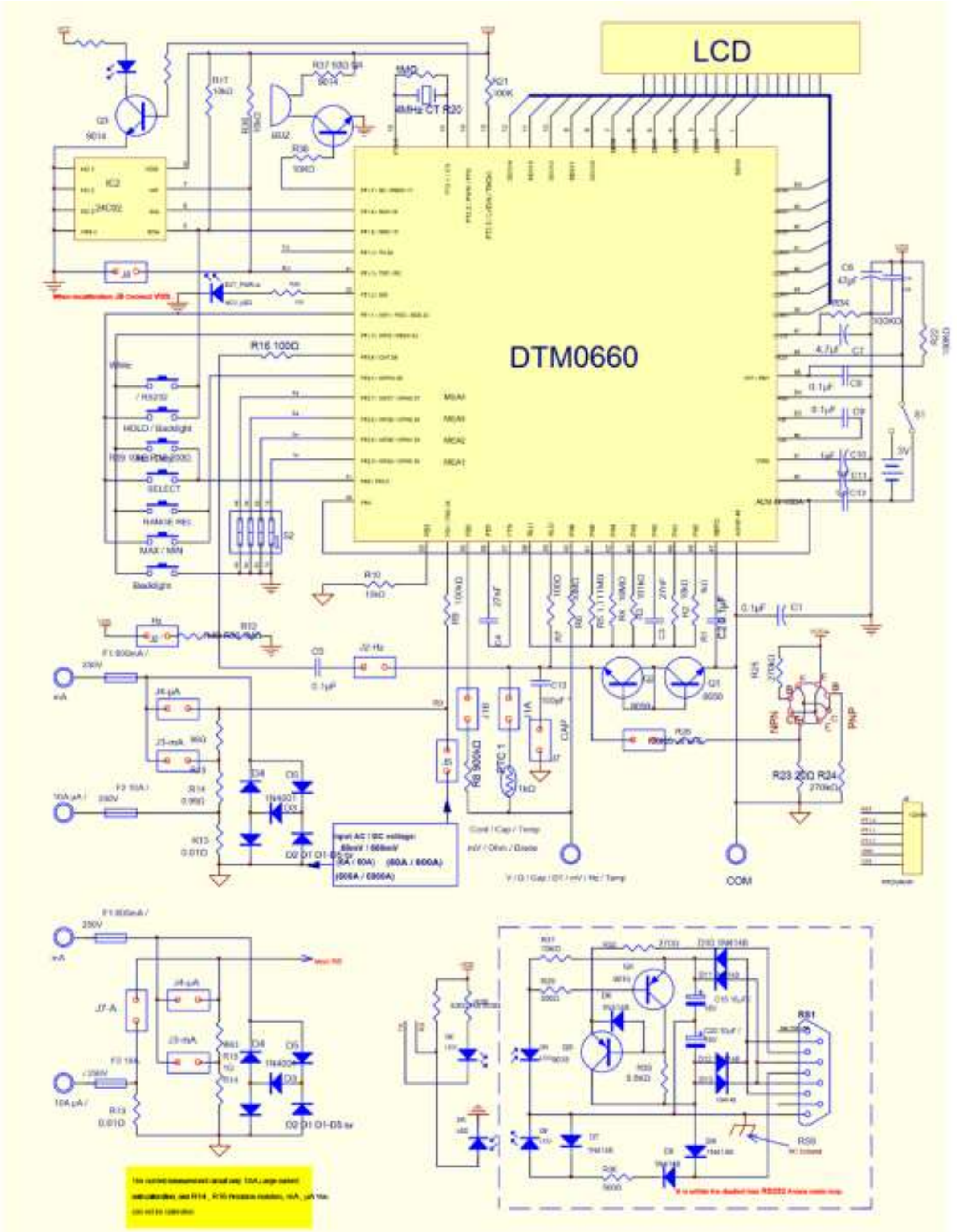
Quad Op Amp
(LM324)

Beeper

Protection Fuse







Autorange
Operating voltage: 2.4V to 3.6V.
True RMS equipped with a digital processor, no external rectifying circuit, a bandwidth of 1kHz, error is less than 0.5%
built 100ppm / °C 1.2V low temperature drift voltage reference.
MAX / MIN data logging.
Automatic shutdown 2.16: 15 or 30 minutes (adjustable).
tone frequency: about 1.95kHz.
DC voltage, AC voltage, DC current, AC Current, Resistance, Capacitance, Frequency,
Diode, Continuity, Temperature Measurement: °C / °F, Transistor

Georg Simon Ohm

- 1789 to 1854

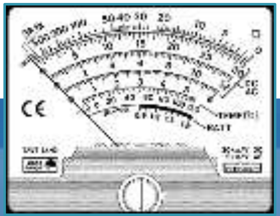
“Messen ist Wissen”

Measurement is knowledge

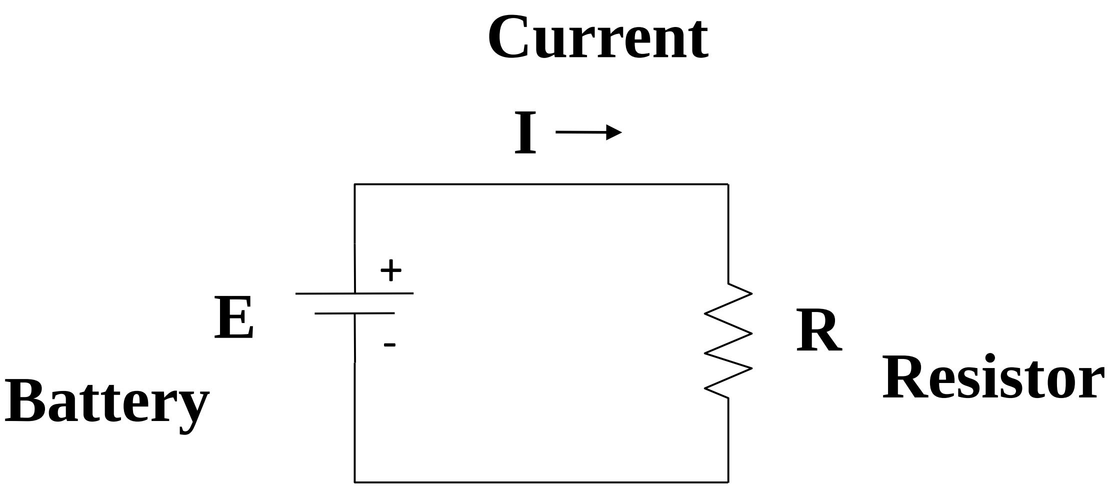
Ohm noted that the current through many devices was proportional to the applied voltage.

Ohm’s Law

$V = I R$ or $I = V/R$ or $R = V/I$

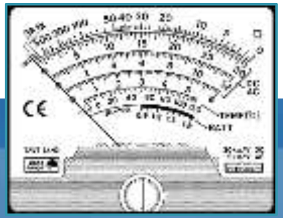


Circuit with Battery and Resistor

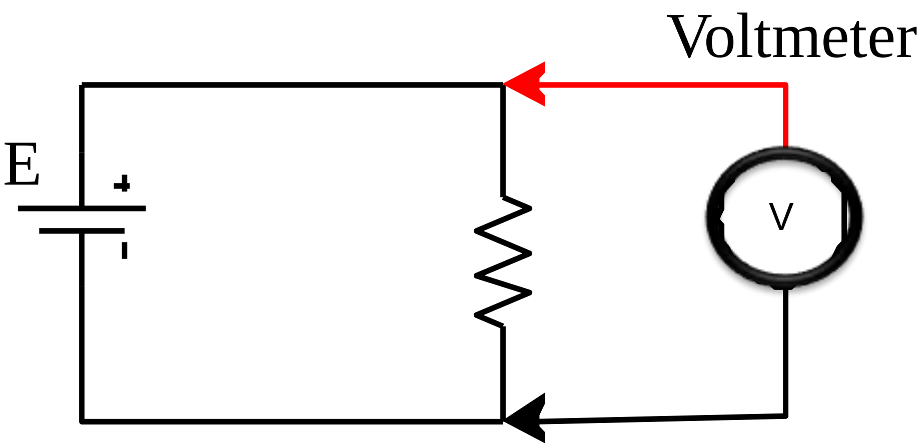


Ohm's Law: I=E/R

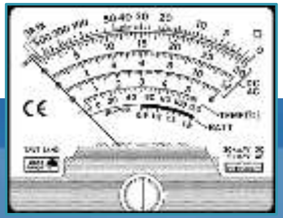
Note: Positive current convention used



Voltage Measurement

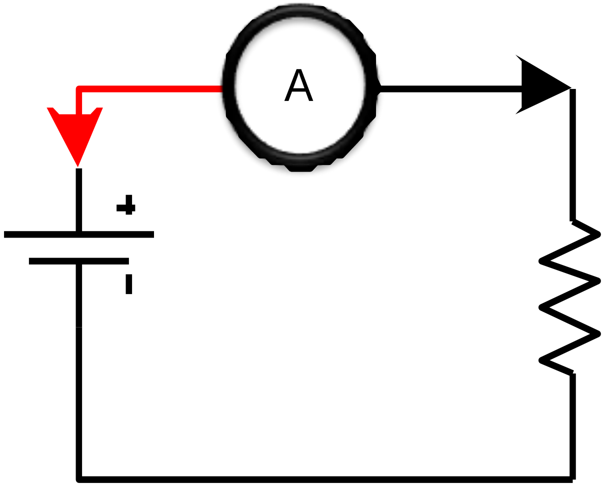


- Configure DMM to DC voltage
- DMM appears as "open circuit"
- Connect DMM in parallel with voltage to be measured



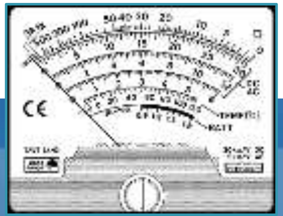
Current Measurement

- Configure DMM to DC Current
- DMM appears as **short circuit**
- Connect DMM in *series* with current to be measured



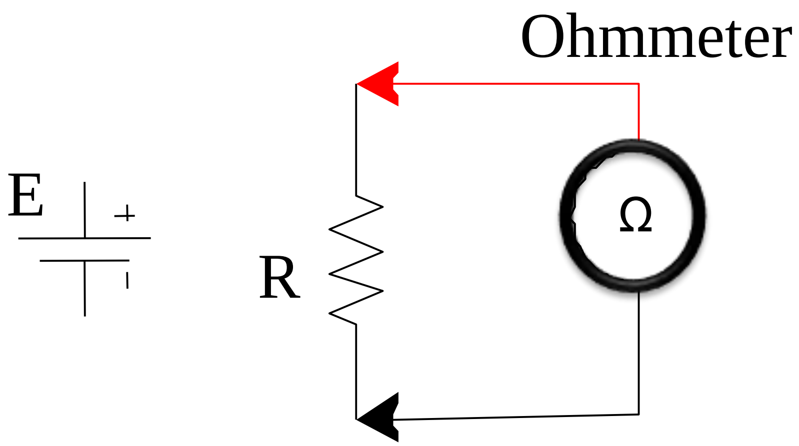
- *Don't select current mode by mistake*
- *Be very careful how you connect when in current mode*
- *Short circuits can cause big problems!*

Be Careful !!!!!!!



Resistance Measurement

- Configure DMM to Resistance
- **Remove power** from the circuit
- DMM provides power to the circuit being tested
- Connect DMM in parallel with the resistance to be measured
- Make sure there is nothing else in parallel with the resistor



These principles also apply to diode test, capacitance test, inductance test, continuity test, etc.

Experiment: What is the AC line voltage in the US?

120 Volts RMS
± 6 V

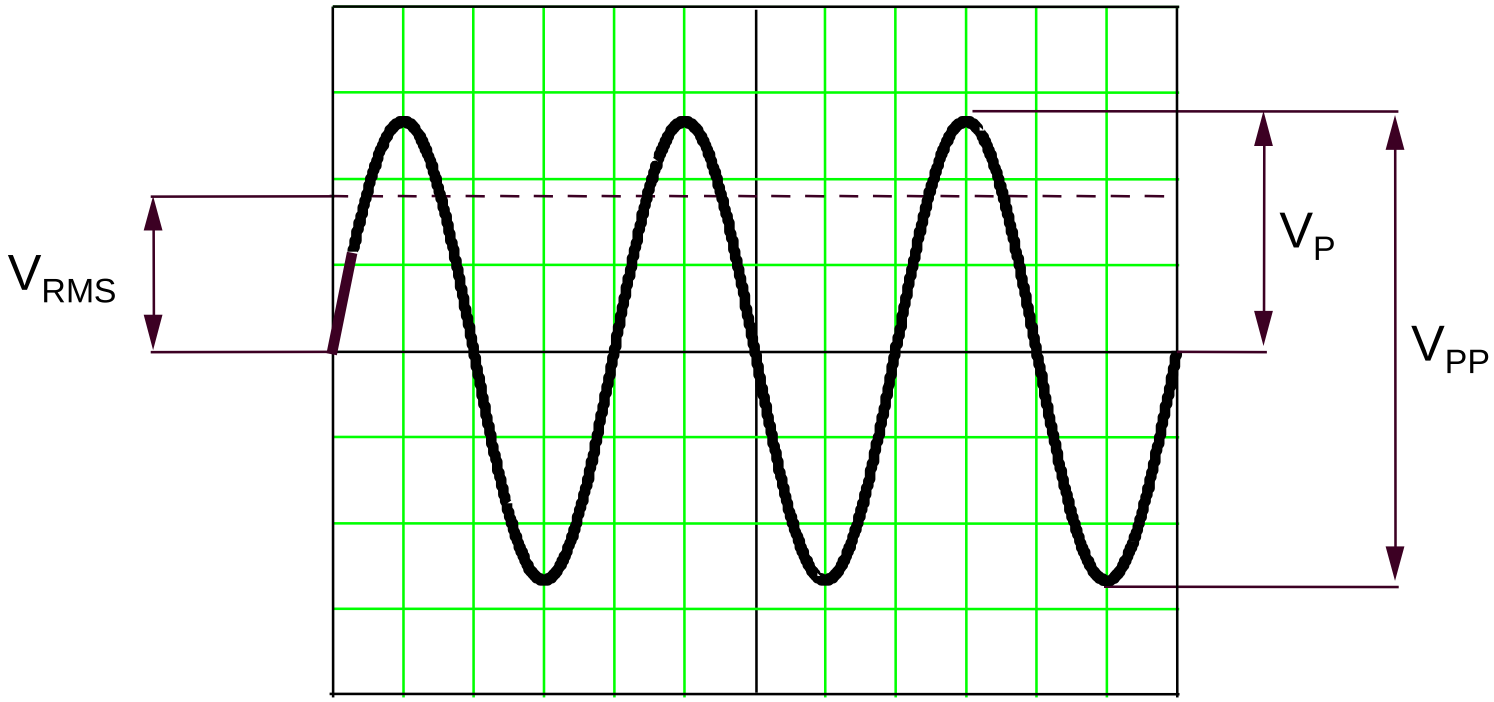
Let’s measure it.

Put DMM in AC Voltage mode and plug ‘er in

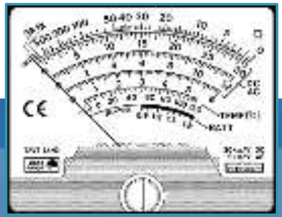




Sine Wave Voltage Measurements



$V_{RMS} = 0.707\ V_P$ $V_P = 1.414\ V_{RMS}$ (sine wave)



Some Superfluous Math Equations

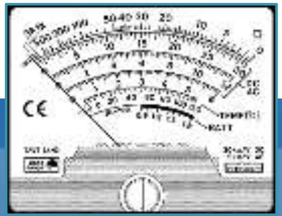
General Equations

$$V_{RMS} = \sqrt{\tfrac{1}{T}\int_0^T v^2(t)\ dt} \qquad V_{AVG} = \frac{1}{T}\int_0^T \left|v(t)\right| dt$$

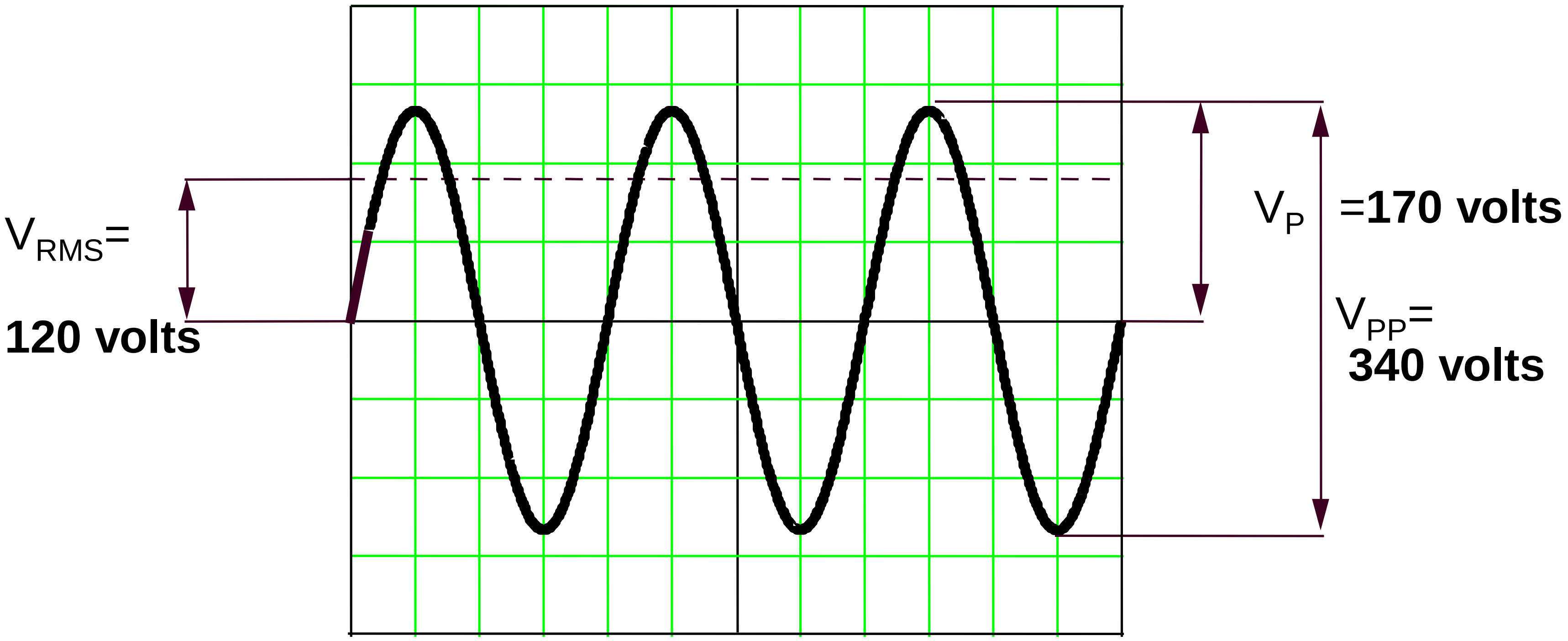
For Sine Wave

$$V_{RMS} = \sqrt{\tfrac{1}{T}\int_0^T V_p \sin^2(2\pi f t)\ dt} = \frac{1}{\sqrt{2}} V_P = 0.707 V_P$$

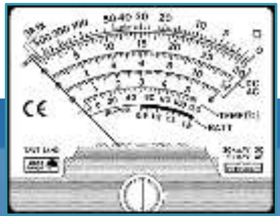
$$V_{AVG} = \frac{1}{T}\int_0^T \left|V_P \sin(2\pi f t)\right| dt = \frac{2}{\pi} V_P = 0.637 V_P$$



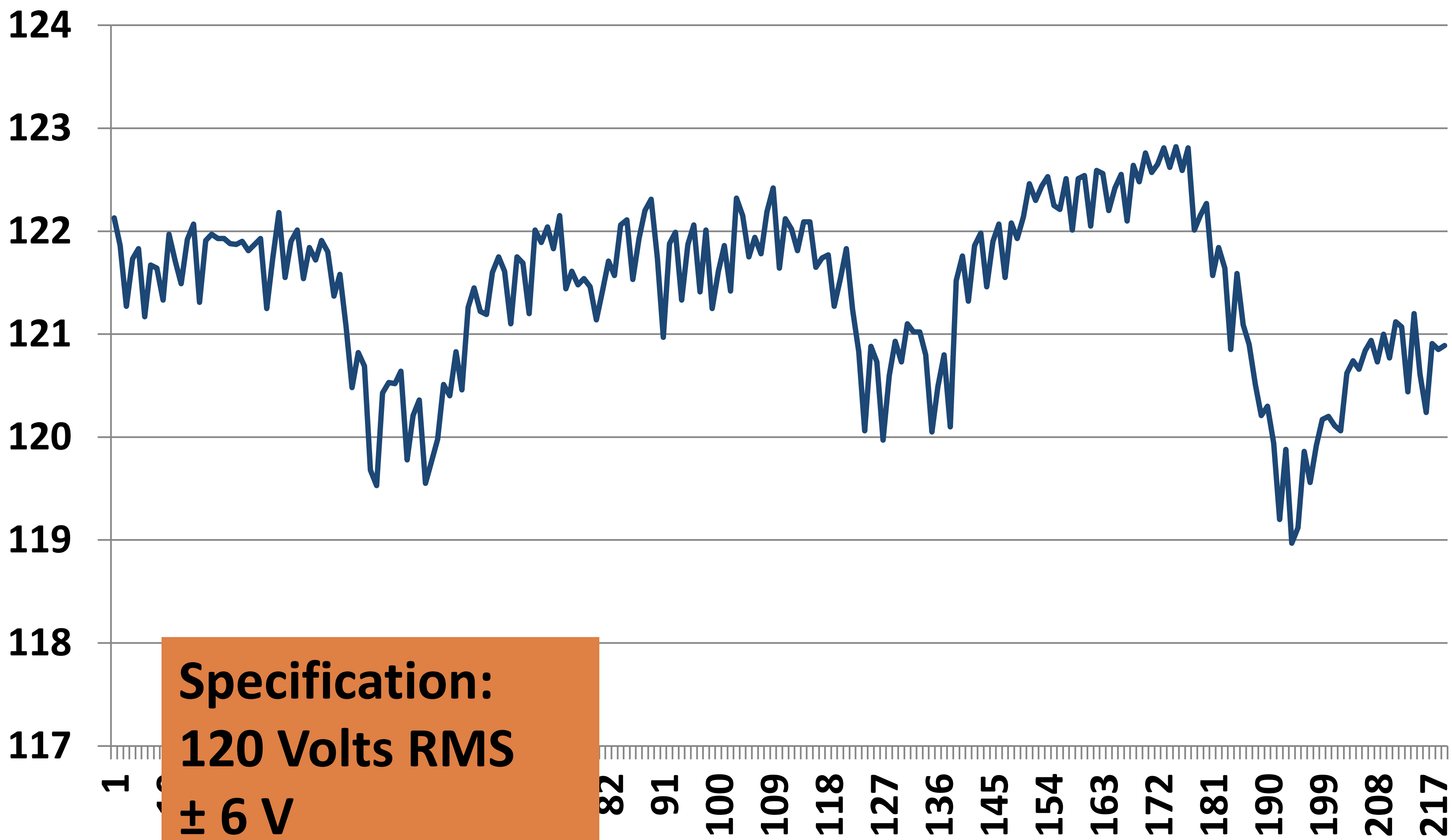
Example: AC Line Voltage



$V_{RMS} = 0.707\ V_P$ $\qquad V_P = 1.414\ V_{RMS}$ $\qquad$ (sine wave)



AC Line Voltage (40 hours)



Specification:
120 Volts RMS
± 6 V

Multimeter with AC Current Clamp

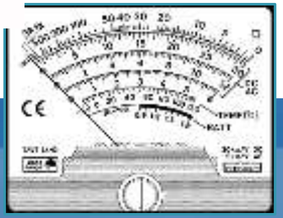
Current measurement is done via clamping the wire

The clamp acts as the core of a transformer

AC-only current measurement

Uni-Trend UT202A $28 on Amazon

Clamp meters are available that measure DC current but are more expensive



AC Line Splitter

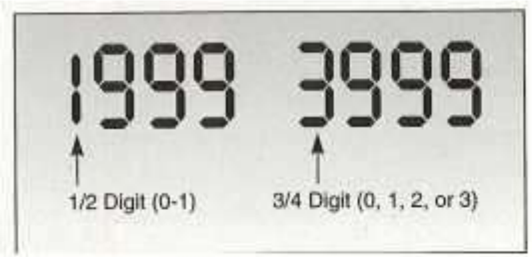
Inserted inline with AC power cord

Allows easy attachment of clamp-on ammeter

Also has slots for probing voltage

Multimeter Accuracy/Resolution

Typical 3-1/2 Digit Multimeter
2000 count
Accuracy: 0.8 to 1.5% (depends on range/function)

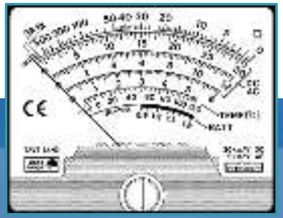


Example: Measuring 13.8 VDC power supply with 3-1/2 digit multimeter

```
Actual value:        13.83850 volts
Measured value:      13.84
Resolution:           0.01

Accuracy (1%):       13.84 x 0.01 = 0.138 volts
Our measured value of 13.84 has an uncertainty of
0.138, so the actual value could be between
13.84 - 0.138 = 13.702 volts
13.84 + 0.138 = 13.978 volts
```

Instrument resolution is usually much better than the accuracy
Relative measurements (small changes) are usually very accurate
(depends on instrument repeatability)

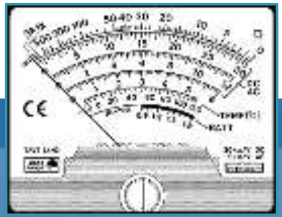


Experiment: Multiple DMMs

"A man with one clock knows what time it is. A man with two clocks is never sure."

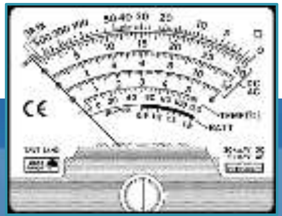
Measure the same battery with multiple DMMs and compare the results.

Which one is right?



Experiment: Multiple DMMs

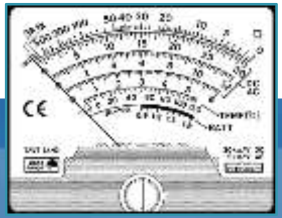
Multimeter	Voltage	Error	% Error
Reference (Agilent)		0.0000	#DIV/0!
Meter 1		0.0000	#DIV/0!
Meter 2		0.0000	#DIV/0!
Meter 3		0.0000	#DIV/0!
Meter 4		0.0000	#DIV/0!
Meter 5		0.0000	#DIV/0!
Average	#DIV/0!	0.0000	#DIV/0!



3. SWR and Power Measurements

Practical Amateur Radio Measurements

Bob Witte, KØNR
bob@k0nr.com
Monument, CO



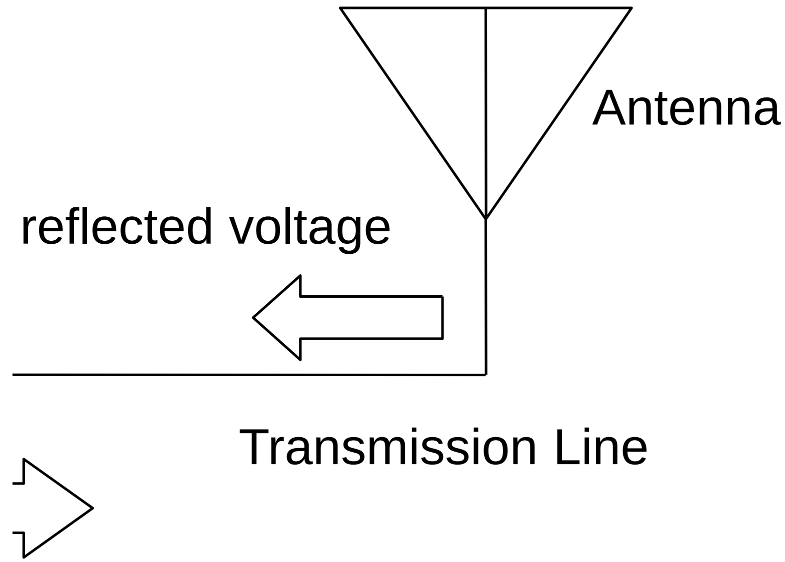
Show SWR video
https://youtu.be/w1eE13UXAKs

Antenna Measurements

- SWR = *Standing Wave Ratio,* more properly called *Voltage Standing Wave Ratio (VSWR)*
- Measures the match between source (transmitter) and load (antenna).
- Perfect match is SWR = 1.0   (1:1)
- Anything greater than 1.0 is less than perfect
- SWR is always $\geq$ 1.0

SWR Measurement

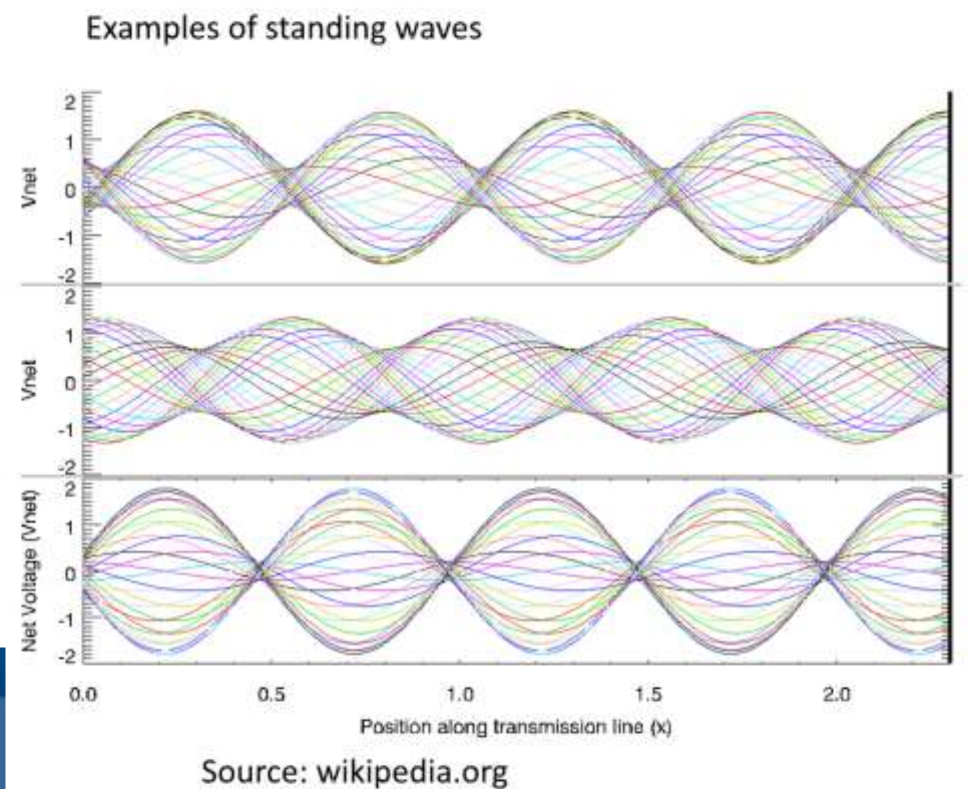
$$SWR = \frac{V_{max}}{V_{min}} = \frac{V_F + V_R}{V_F - V_R}$$

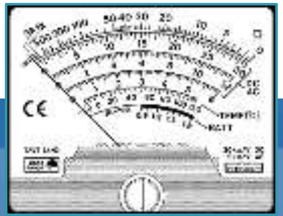


V reflected voltage

rd voltage

itenna are all nominally the
eur radio work).





The Fundamental Measurement

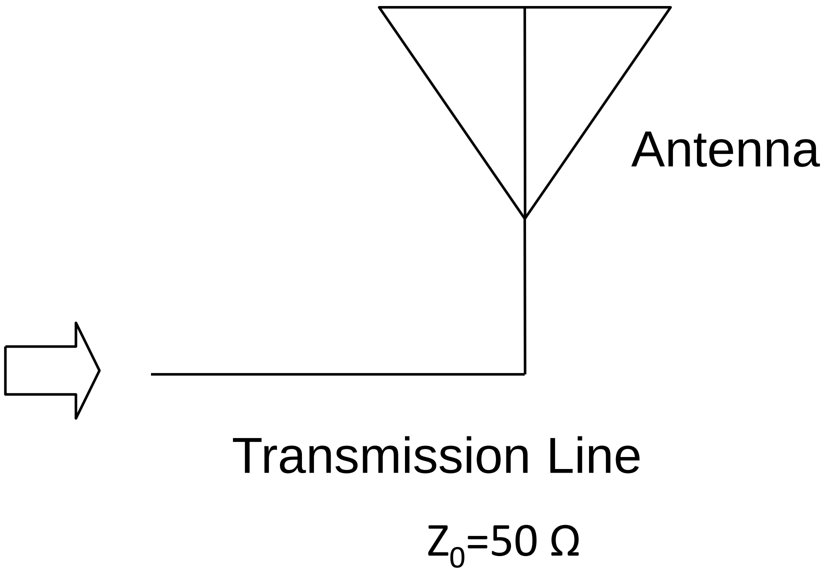
What is the impedance looking into this port?

$Z = R + jX$

$SWR = Z_L/Z_0$ or Z_0/Z_L

whichever is ≥ 1, for Z_L real

Example:
What is the SWR with Z_L=100Ω ?
SWR = 100/50 = 2

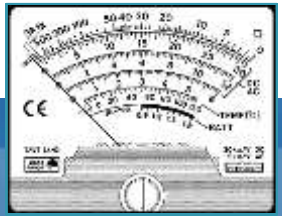


ρ = reflection coefficient= V_R/V_F

RL = return loss (dB) = -20 log (ρ)

SWR Readings

- Perfect match is SWR = 1.0
- Anything greater than 1.0 is less than perfect
- SWR is always ≥ 1.0
- SWR is sometime shown in this format 1:1, 2:1 or even “1 to 1” and “2 to 1”.
- SWR < 2 is a pretty good match
- SWR >3 is a poor match
- SWR >5 is a very poor match



SWR, Reflection Coeff., Return Loss

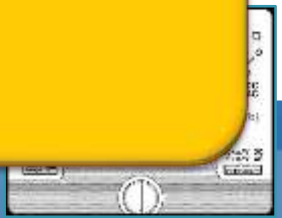
TABLE 11-1. TABLE OF REFLECTION COEFFICIENT, RETURN LOSS AND STANDING WAVE RATIO

Reflection coefficient	Return loss	Standing wave ratio
1.00	0.00	∞
0.90	0.92	19.00
0.80	1.94	9.00
0.70	3.10	5.67
0.60	4.44	4.00
0.50	6.02	3.00
0.40	7.96	2.33
0.30	10.46	1.86
0.20	13.98	1.50
0.10	20.00	1.22
0.09	20.92	1.20
0.08	21.94	1.17
0.07	23.10	1.15
0.06	24.44	1.13
0.05	26.02	1.11
0.04	27.96	1.08
0.03	30.46	1.06
0.02	33.98	1.04
0.01	40.00	1.02
0.00	∞	1.00

<u>50 Ω Load</u>
SWR = 1.0
ρ = 0
RL = ∞

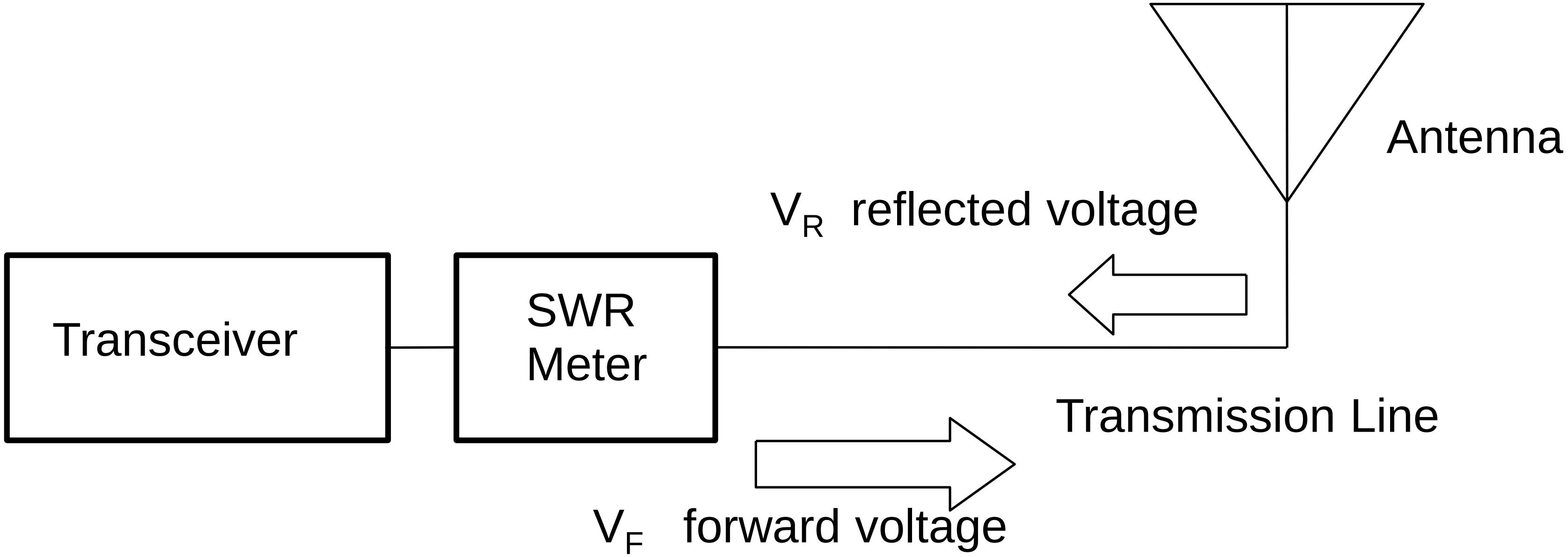
<u>150 Ω Load</u>
SWR = 3.0
ρ = 0.5
RL = 6.02 dB

<u>Open</u>
SWR = ∞
ρ = 1
RL = 0 dB



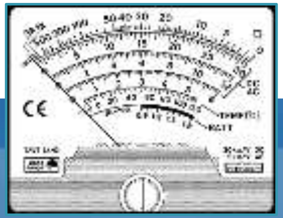
SWR Meter

Sometimes called a *Reflectometer*



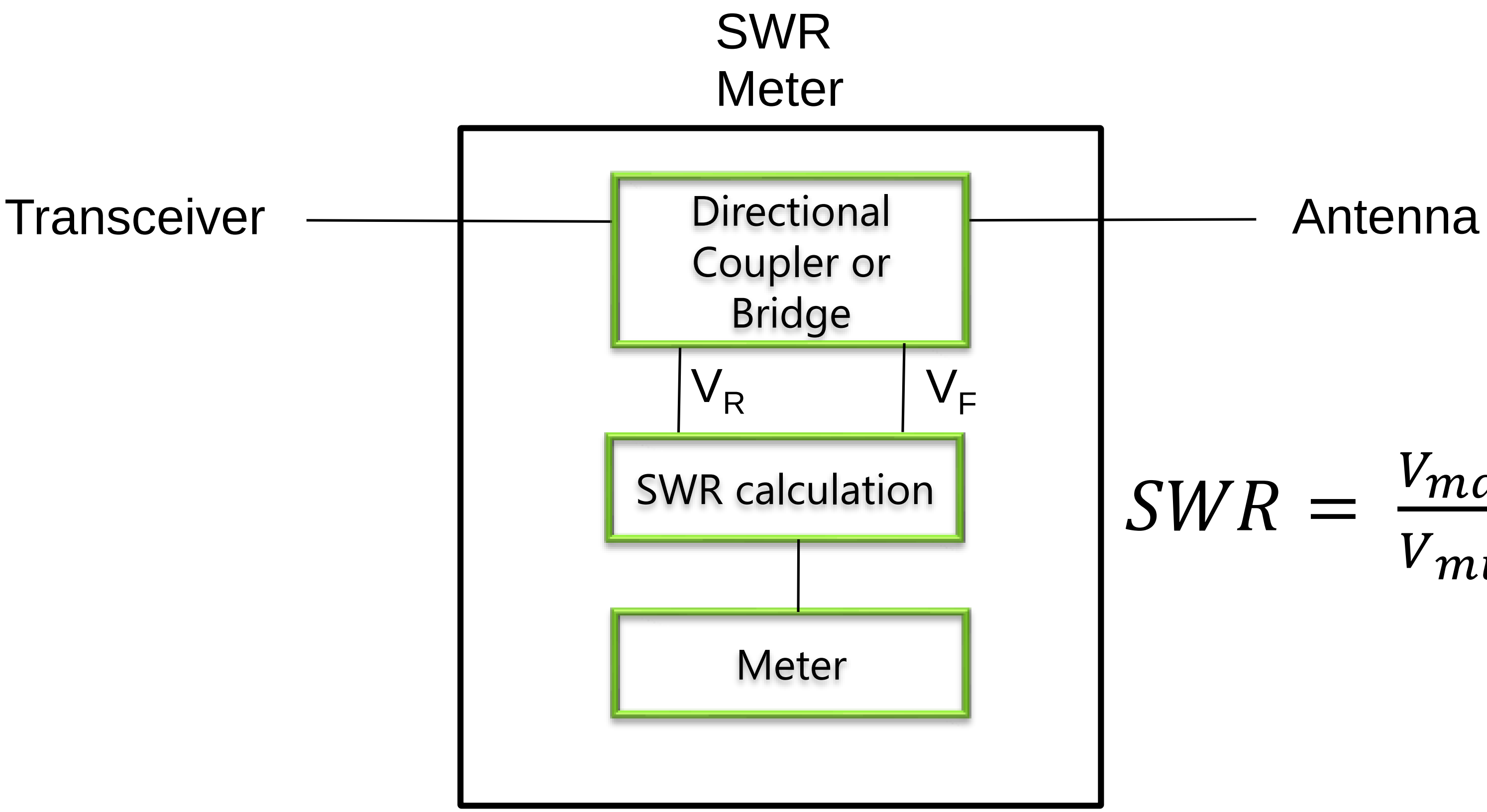
SWR meter is inserted into the transmission line, which usually requires an additional cable between transceiver and SWR meter.

The SWR Meter might be built into the transceiver.

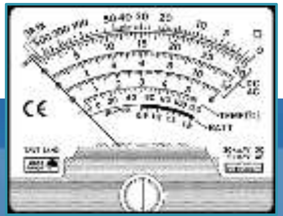


SWR Meter

Sometimes called a *Reflectometer*



$$SWR = \frac{V_{max}}{V_{min}} = \frac{V_F + V_R}{V_F - V_R}$$



SWR Meters

Diamond SX-200 SWR/Power Meter

SWR and Power Meter

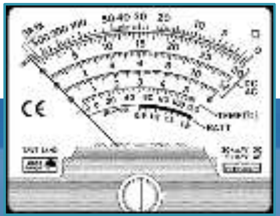
Freq Range:
  1.8-200 MHz

Power Ranges:
  5W, 20W and 200 W

Price: ~$100

Cal
Adjust

Power
Cal
SWR



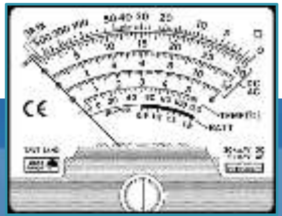
Astatic PDC2 SWR & Power Meter

Power meter
SWR meter
Calibration knob
$23 on Amazon

"CB grade"
No frequency range specified

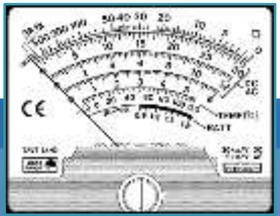
Comet CMX-400

Note the use of the cross-needle meter to avoid the need to “cal” the measurement



Telepost LP-100A Digital Vector Wattmeter

Advanced meter with digital bar graph, power and SWR in real time

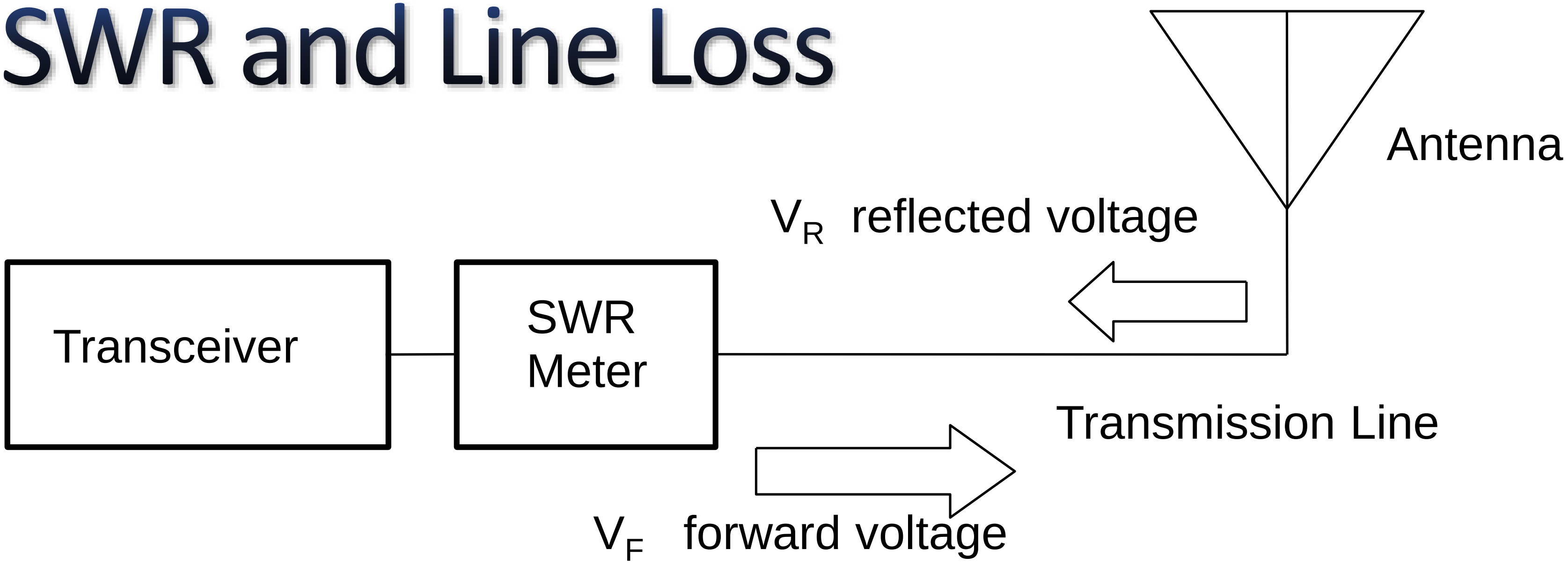


Surecom SW-33 SWR/Power Meter

Mark II 100 W 125-525 MHz
Mini Digital VHF UHF
Two-Way Radio Handheld
Power & SWR Meter

$36 amazon.com

SWR and Line Loss

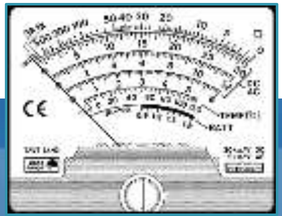


With no transmission line loss, the SWR measurement is the same anywhere on the line (ideal conditions)

With line loss, the reflected voltage may be significantly attenuated, resulting in a lower SWR reading.

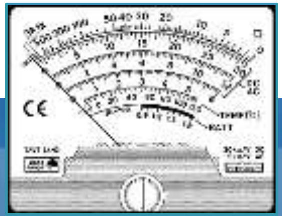
→ High transmission line loss makes your antenna system seem better

→ Move the meter closer to the antenna



Some comments on SWR measurements

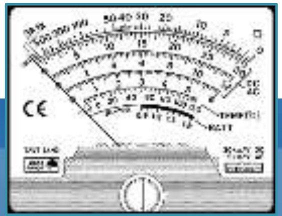
- SWR meters measure the match at the point of insertion.
- When measuring/adjusting an antenna, put the SWR meter as close to the antenna as possible.
- Make sure the SWR meter is spec'd for the frequency of interest.
- Long, lossy coax makes the SWR look better.
- How low should the SWR be? Depends on the situation...what can be reasonably expected? It might be OK to run high SWR.



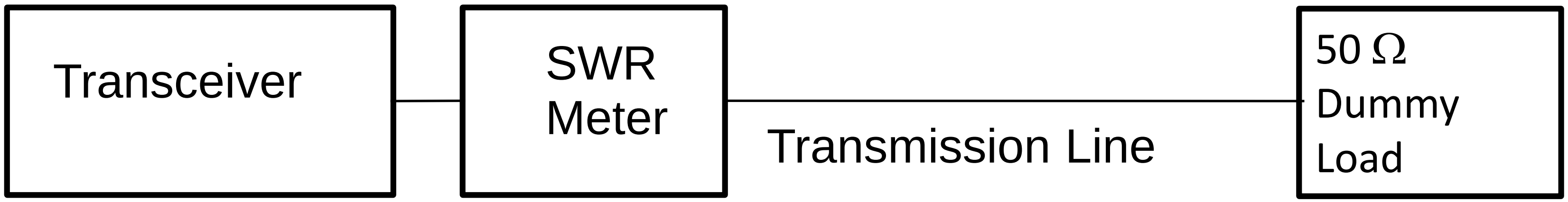
SWR Myths

- SWR does not (always) indicate whether your antenna is resonant
- SWR does not measure the efficiency of your antenna
- SWR does not indicate how well your signal is being radiated

An SWR measurement just tells you the impedance match (reflection) at the point the meter is inserted into the transmission line



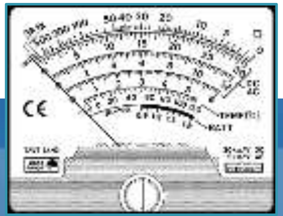
SWR Thought Experiment #1



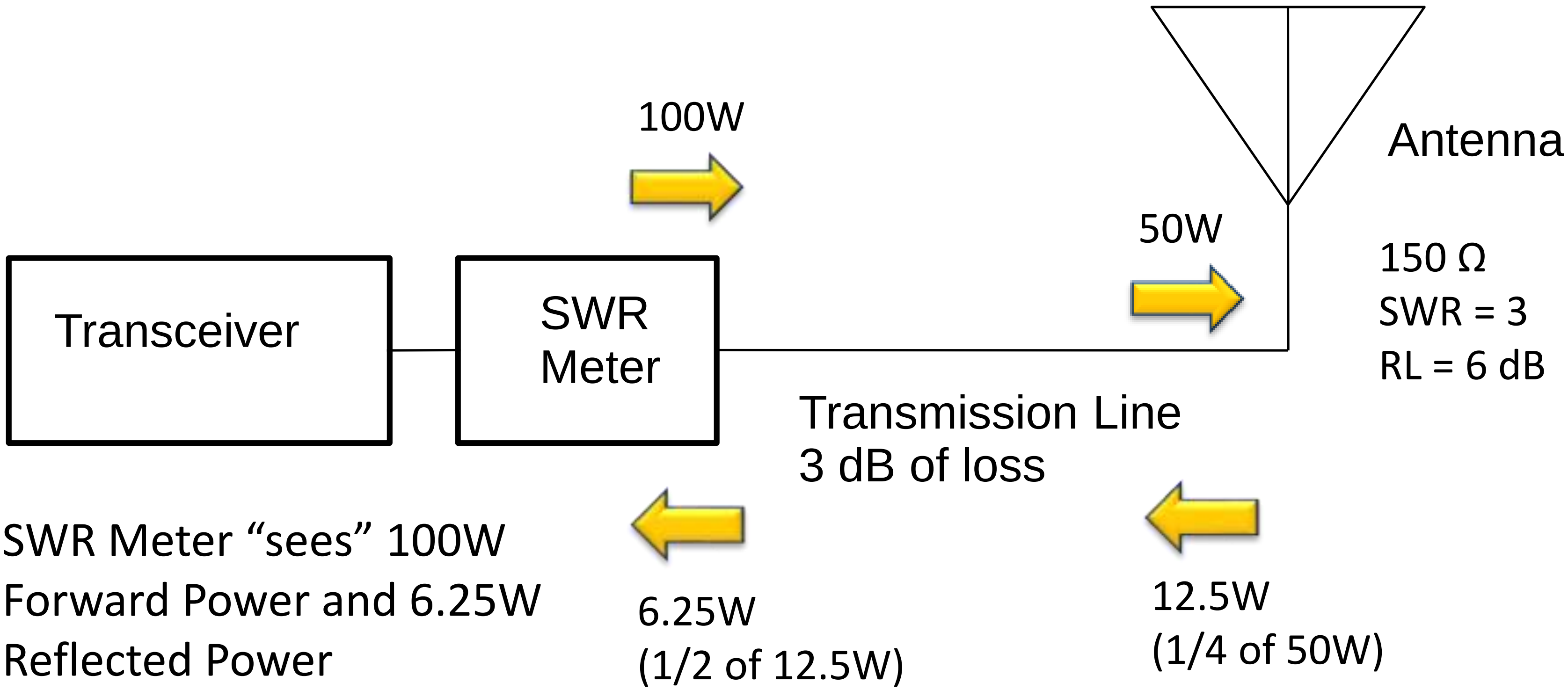
SWR = 1

How well does this station radiate a signal?

Not very well.



SWR Thought Experiment #2

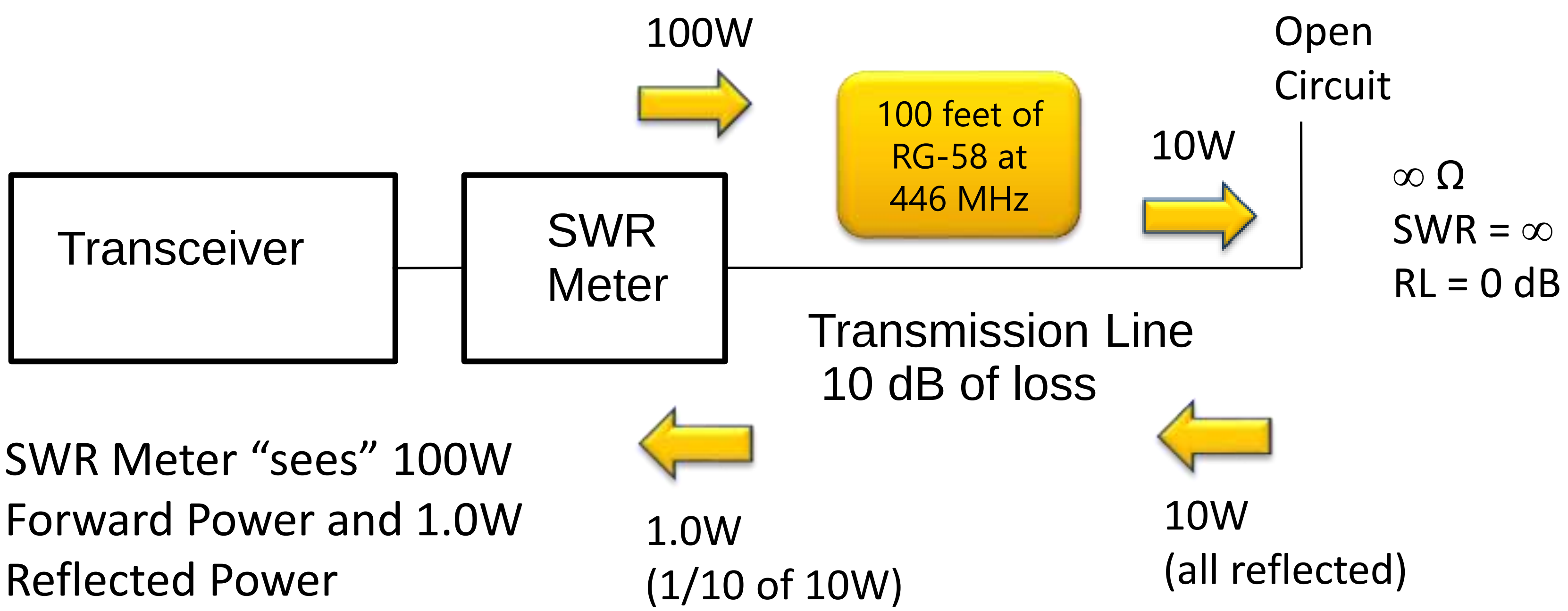


SWR Meter “sees” 100W Forward Power and 6.25W Reflected Power

$$SWR = \frac{V_{max}}{V_{min}} = \frac{V_F + V_R}{V_F - V_R} = \frac{\sqrt{P_F} + \sqrt{P_R}}{\sqrt{P_F} - \sqrt{P_R}} = \frac{\sqrt{100} + \sqrt{6.25}}{\sqrt{100} - \sqrt{6.25}} = 1.67$$

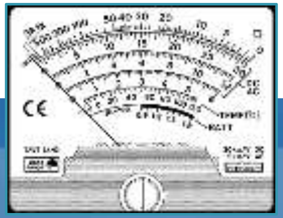
Transmission line loss makes SWR look better.

SWR Thought Experiment #3

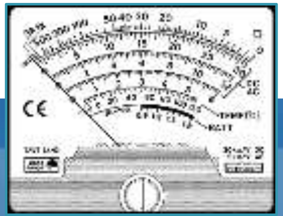


$$SWR = \frac{V_{max}}{V_{min}} = \frac{V_F + V_R}{V_F - V_R} = \frac{\sqrt{P_F} + \sqrt{P_R}}{\sqrt{P_F} - \sqrt{P_R}} = \frac{\sqrt{100} + \sqrt{1}}{\sqrt{100} - \sqrt{1}} = 1.2$$

With enough line loss, an open circuit looks good.



Antenna Analyzers

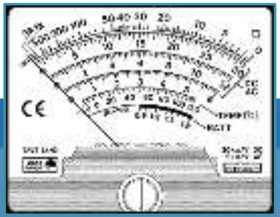


MFJ-259B Antenna Analyzer

Frequency Range: 1.8 – 170 MHz
Price: ~$250
Measure:
SWR, Return Loss
Impedance, Reactance, Resistance

Default measurement mode is:
- Impedance, Z = R + j X
(R= resistance, X = reactance)
- SWR

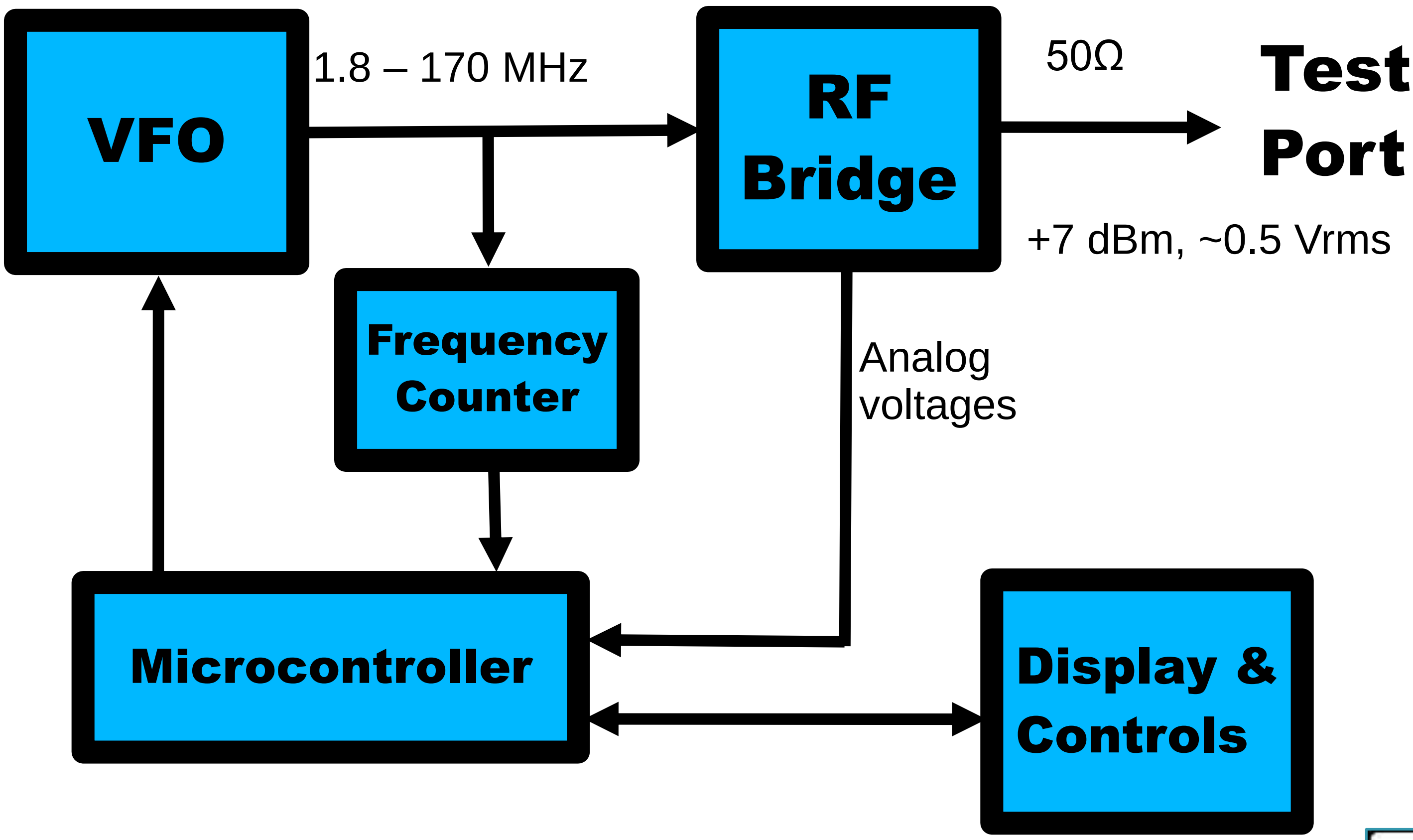
Also:
Impedance, $Z = Z_{mag} \angle\theta$
Reflection coefficient
Return Loss

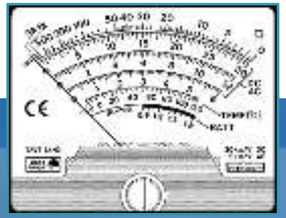


MFJ-259B Antenna Analyzer

MFJ-259B Antenna Analyzer

MFJ-259B Block Diagram

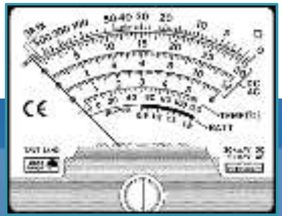




MFJ-259B Antenna Analyzer

Usage Tips

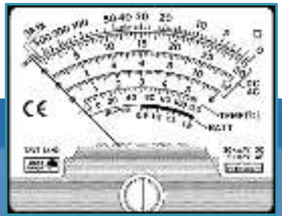
- Best accuracy near 50 ohms (SWR=1)
- Don't use in high RF environment
- Input circuitry is sensitive
- Discharge antennas before connecting
- Do not apply external voltages to test port
- Don't over-interpret the results (the analyzer is just looking at the impedance match against 50Ω)



Comet CAA-500 Antenna Analyzer

Frequency Range:
1.8 to 500 MHz

Price: ~$430



Rig Expert AA-230 Antenna Analyzer

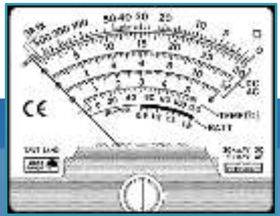
Measure SWR, Return Loss, Cable Loss

100 kHz to 230 MHz.

Graphical display plots SWR versus frequency

Time Domain Reflectometer mode can be used to locate the precise location of a fault within the feedline system.

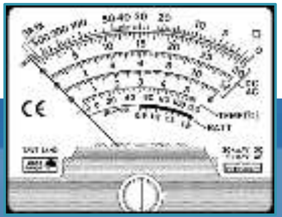
~$550



AAI N1201SA RF Vector Impedance Analyzer

Frequency Range: 137.5 MHz to 2.7 GHz
Measured parameters:
Resistance, reactance, SWR, s11
Connector SMA-K
Impedance measurement range: 0.1 to ~1000

$160 ebay.com

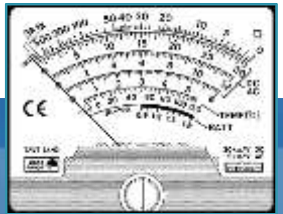


VHF/UHF Antenna Analyzer (AAI N1201SA)

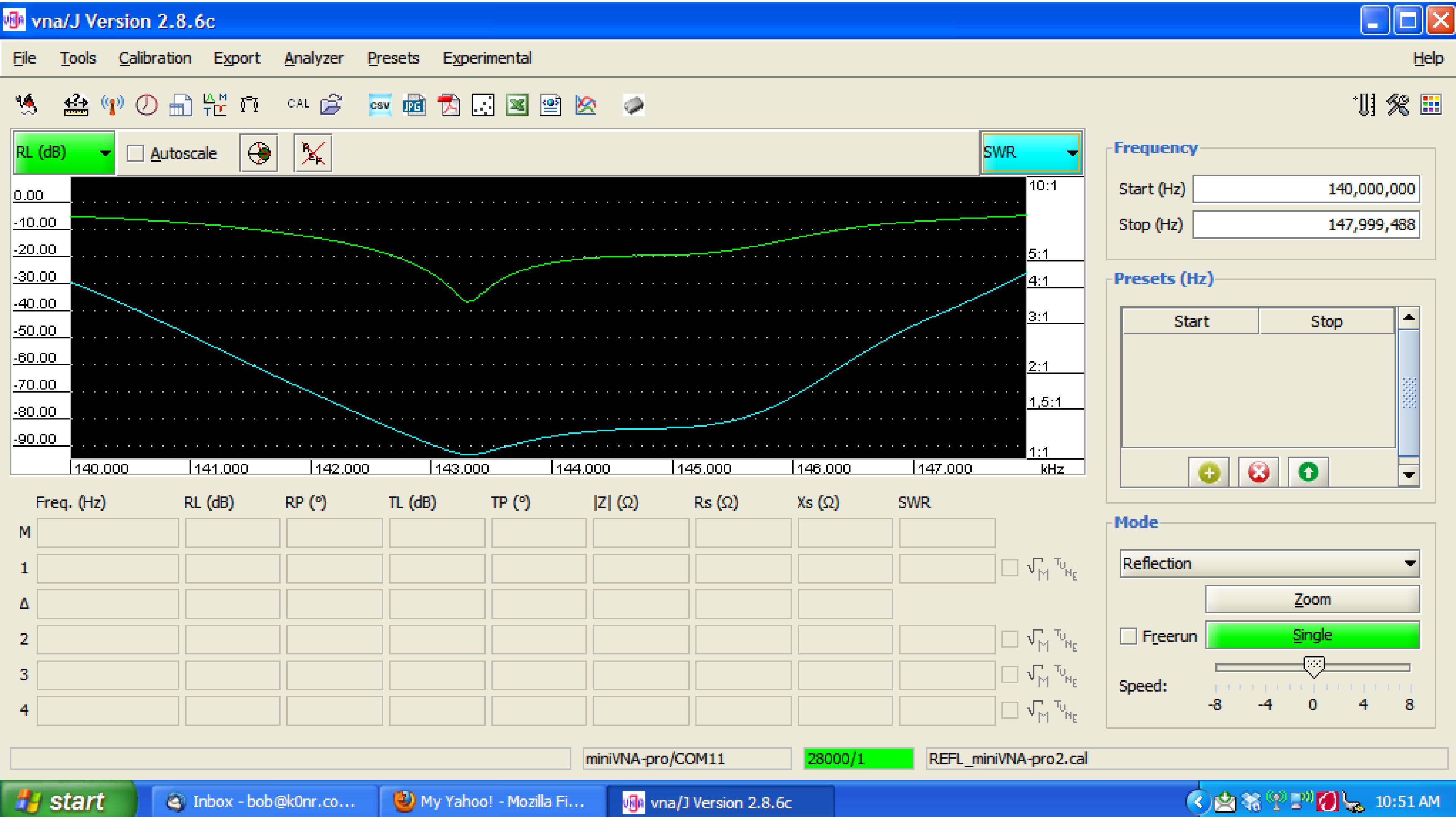
Vector Network Analyzer (VNA)

Freq range:
100 KHz to 200 MHz
Range of Z: 1 to 1000 ohm
Dynamic range:
up to 90 dB in Transmission
& 50 dB in Reflection
Two port VNA with S11 and S21

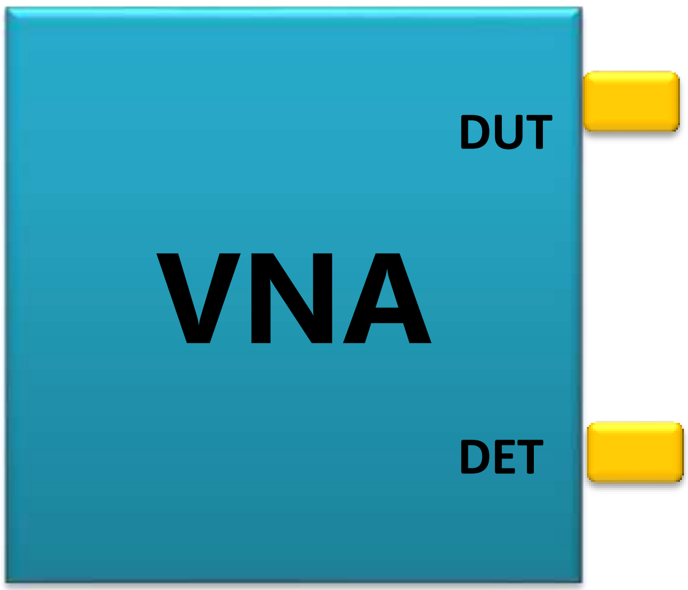
Price: ~$550



VNA Software

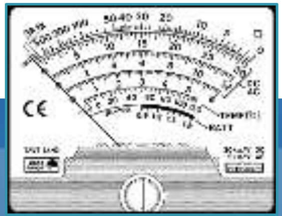


VNA Calibration

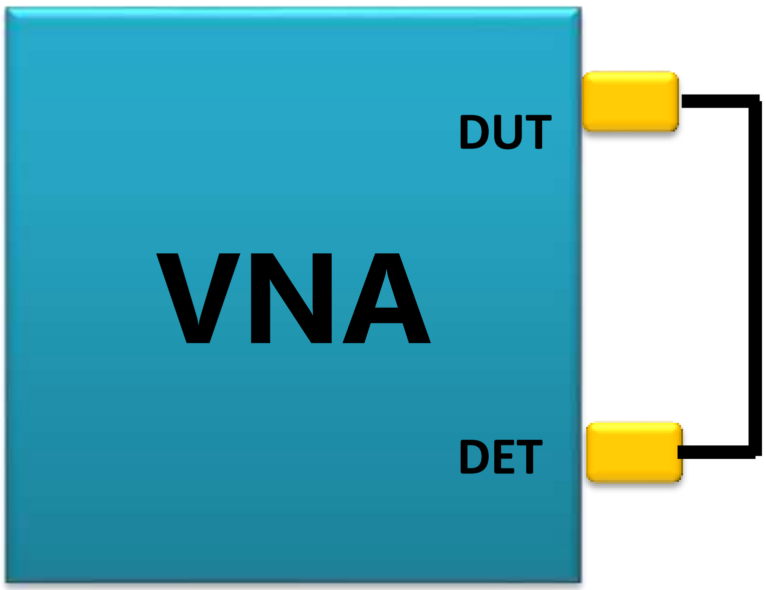


Reflection

1) Open
2) Short
3) 50Ω Load



VNA Calibration



Transmission

1) Open
2) Through

M² 2M9SSB

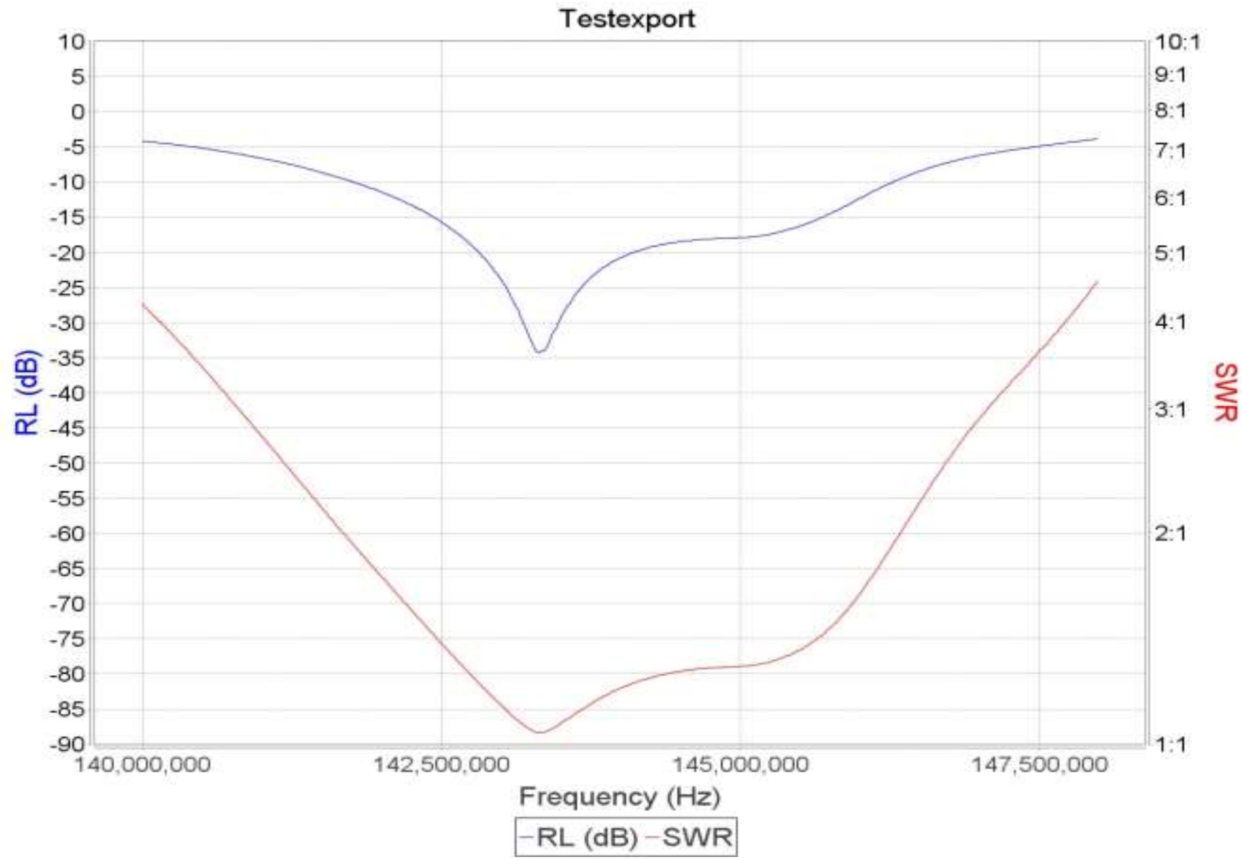
VNA Measurement – 2M Antenna

Measured

SWR

and

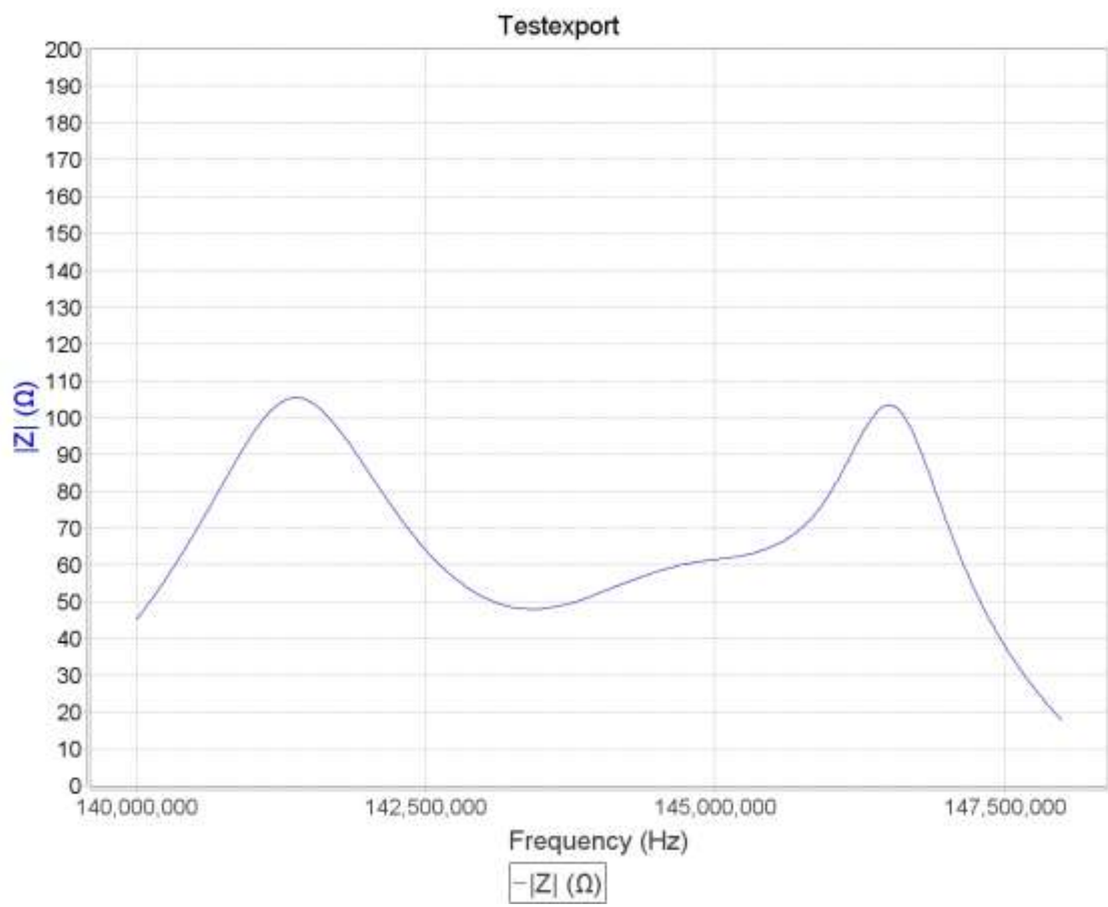
Return Loss

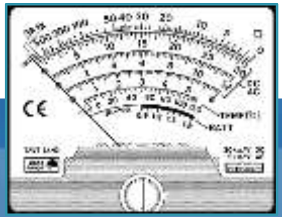


VNA Measurement – 2M Antenna

Measured

|Z|

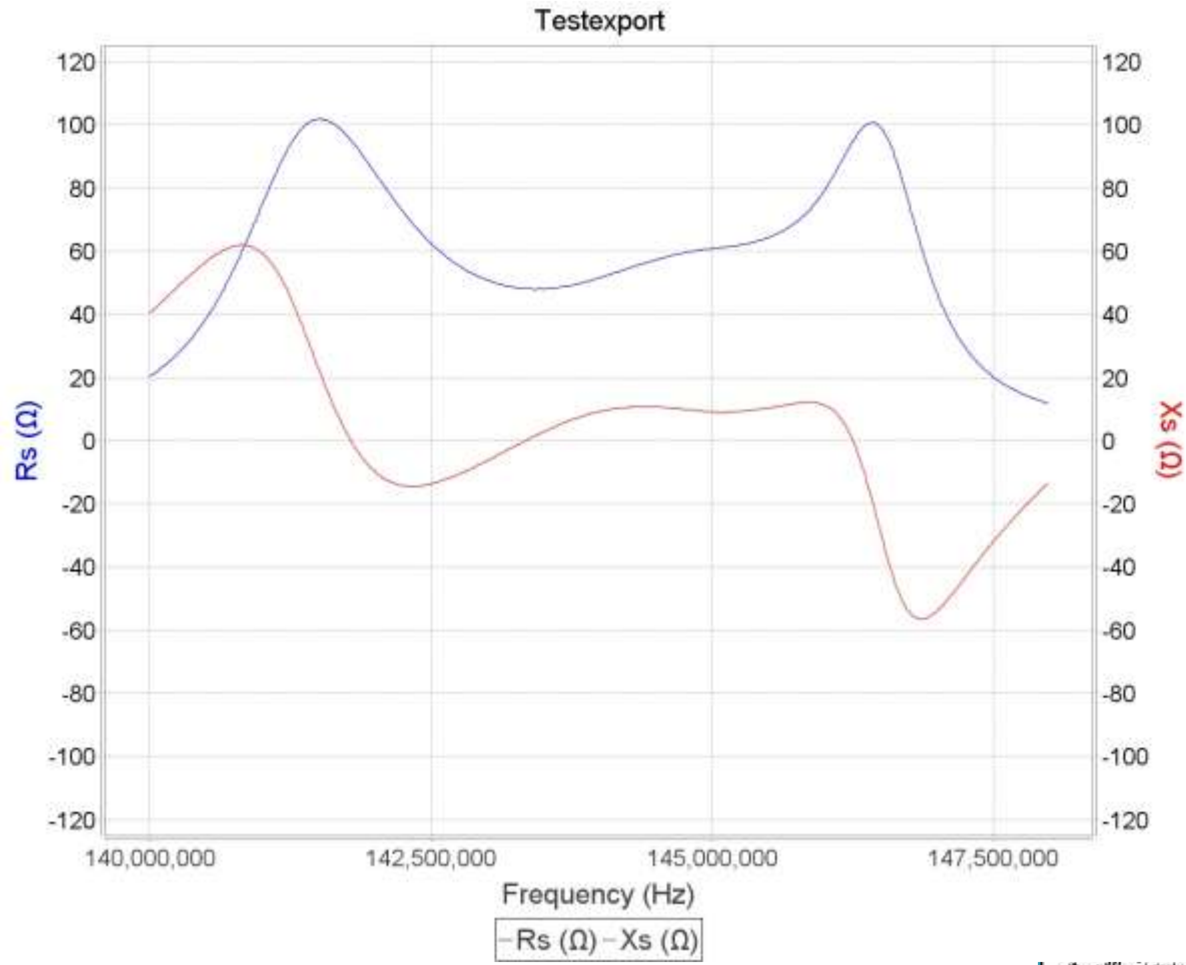


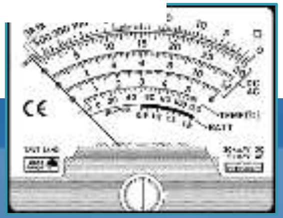


VNA Measurement – 2M Antenna

Measured

R and X

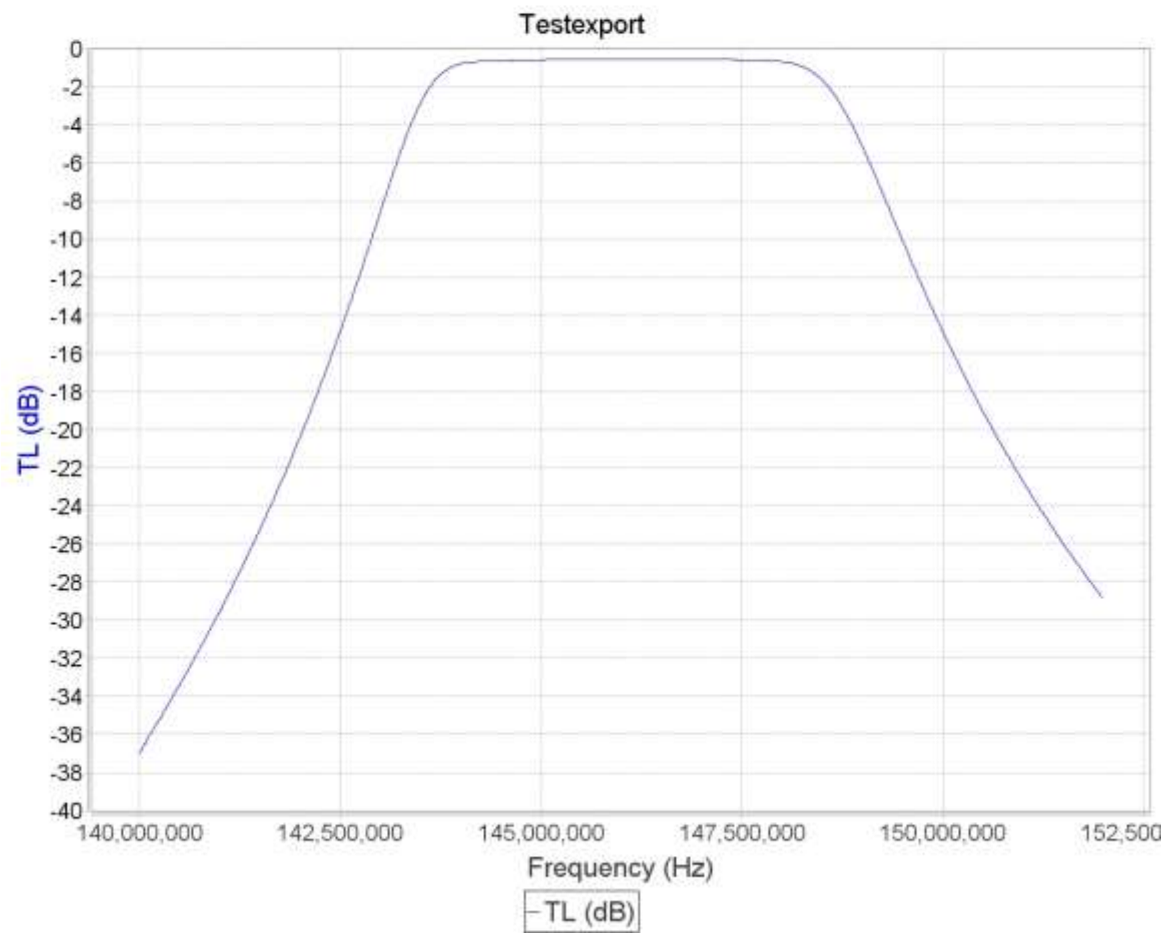


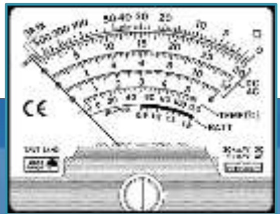


VNA Transmission Measurement

DCI

2 Meter Filter

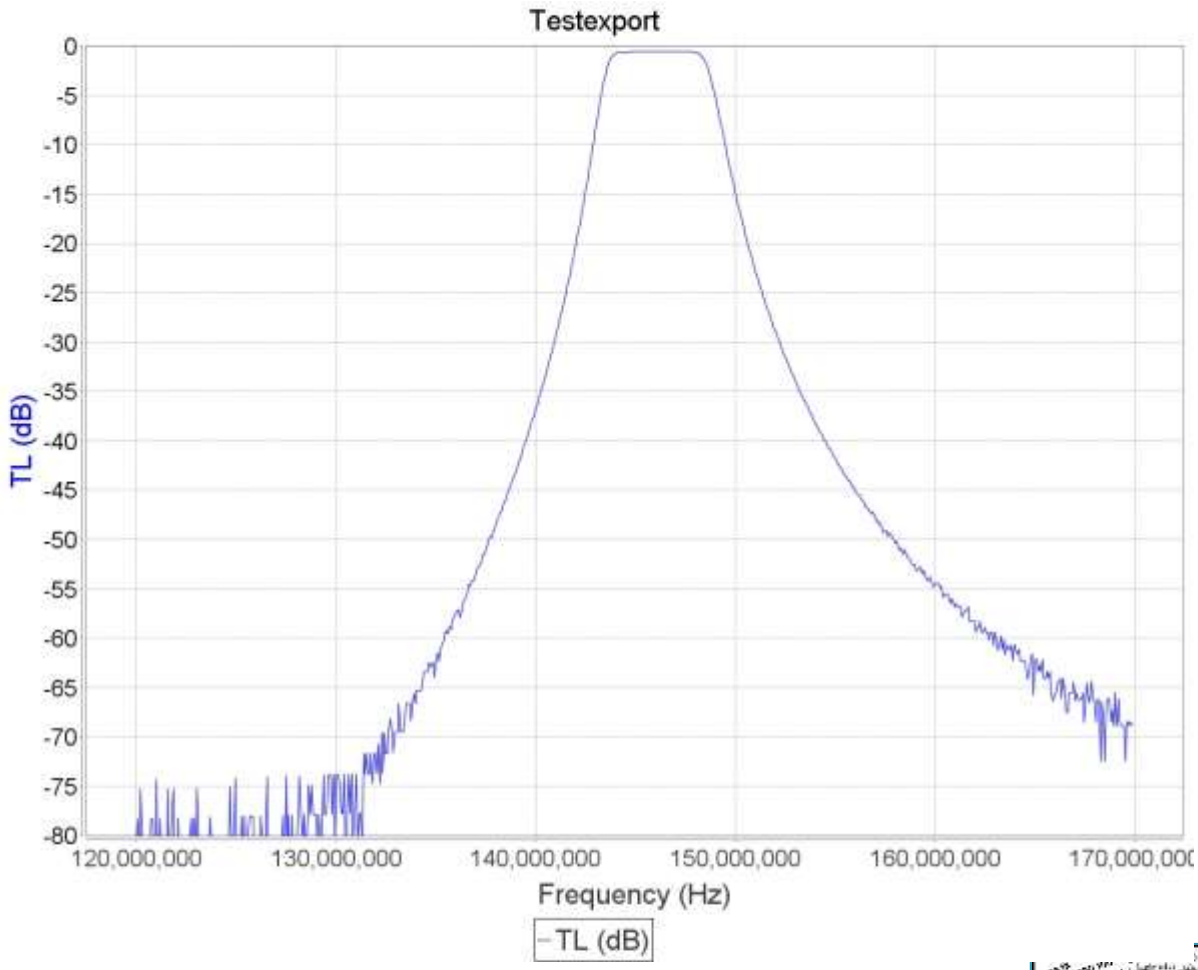


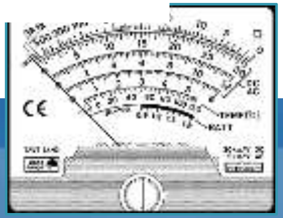


VNA Transmission Measurement

DCI

2 Meter Filter



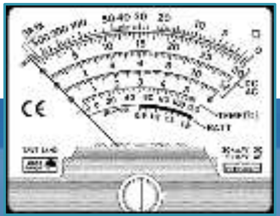


4. Oscilloscopes

Practical Amateur Radio Measurements

Bob Witte, KØNR
bob@k0nr.com
Monument, CO

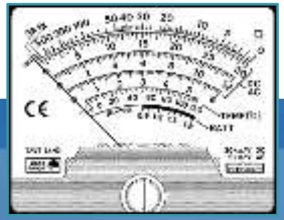
Many of these slides are adapted from Keysight Technologies slides



What is an oscilloscope?

os·cil·lo·scope (ə-sĭl'ə-skōp')

- Oscilloscopes convert electrical input signals into a visible trace on a screen.
- Oscilloscopes display voltage vs time (time domain) of dynamic waveforms.
- Oscilloscopes are used by engineers and technicians to test, verify, and debug electronic designs.

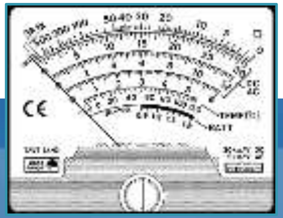


Name	Frequency	Usage
DC	0 Hz	Power, Batteries
AC Power	50 - 60 Hz	Power
Audio	20 Hz - 20kHz	Modulation
LF	30 kHz - 300 kHz	Experimental
MF	300 kHz - 3 MHz	Radio Signals
HF	3 MHz - 30 MHz	Radio Signals
VHF	30 MHz - 300 MHz	Radio Signals
UHF	300 MHz - 3 GHz	Radio Signals

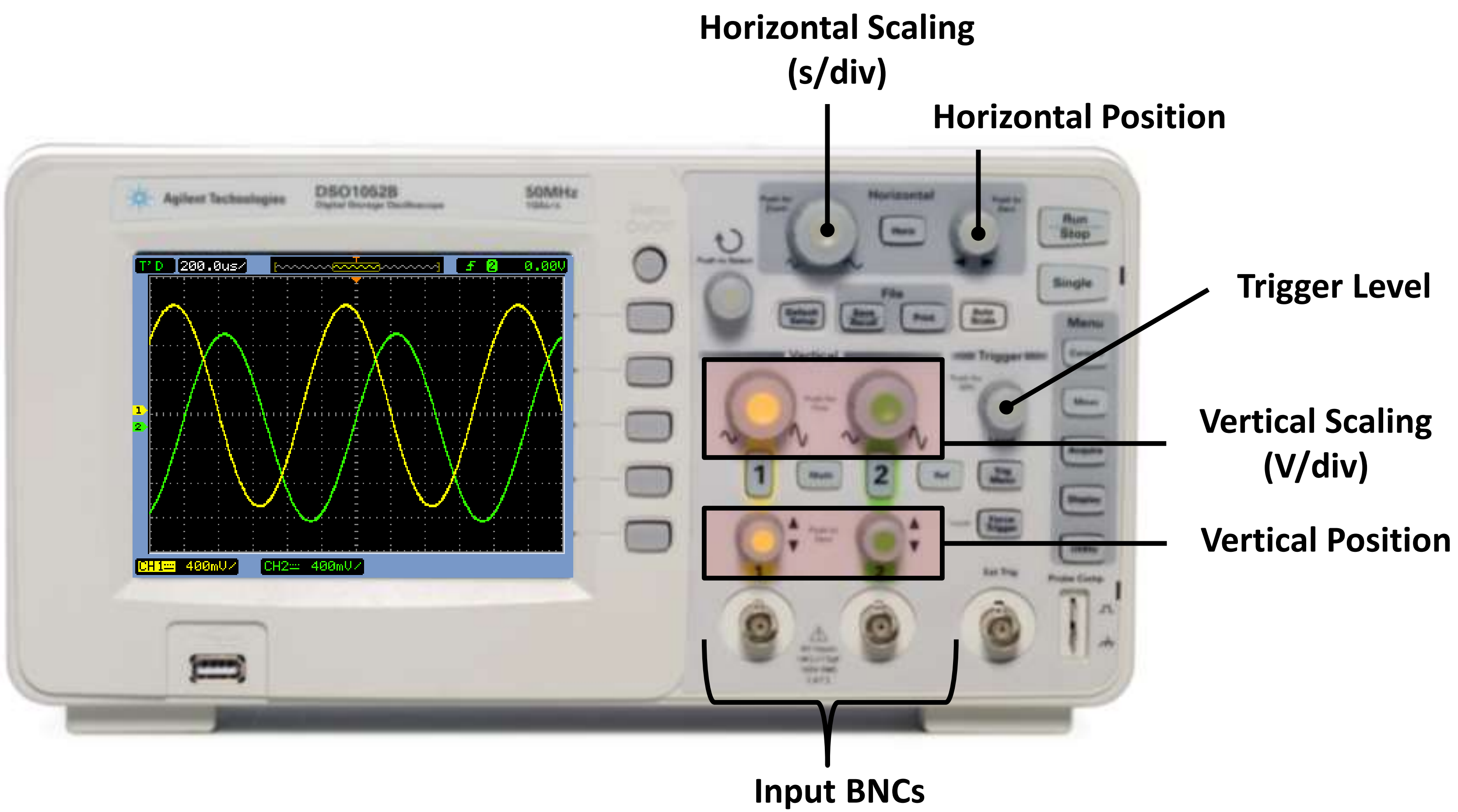
Oscilloscope

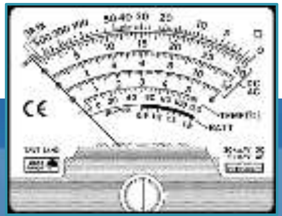
Names for Oscilloscopes

- Scope – Most commonly used terminology
- DSO – Digital Storage Oscilloscope
- Digital Scope
- Digitizing Scope
- Analog Scope – Older technology oscilloscope, but still around today.
- CRO – Cathode Ray Oscilloscope (pronounced “crow”).
- O-Scope
- MSO – Mixed Signal Oscilloscope (includes logic analyzer channels of acquisition)

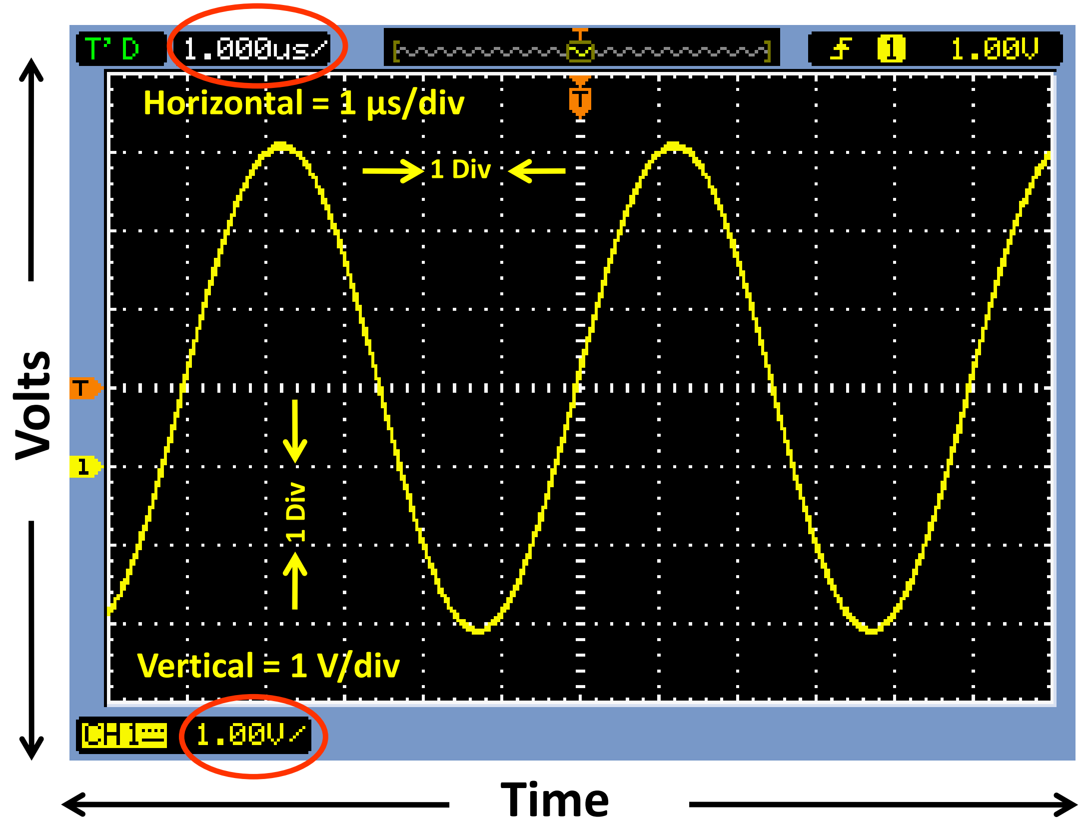


Primary Oscilloscope Setup Controls



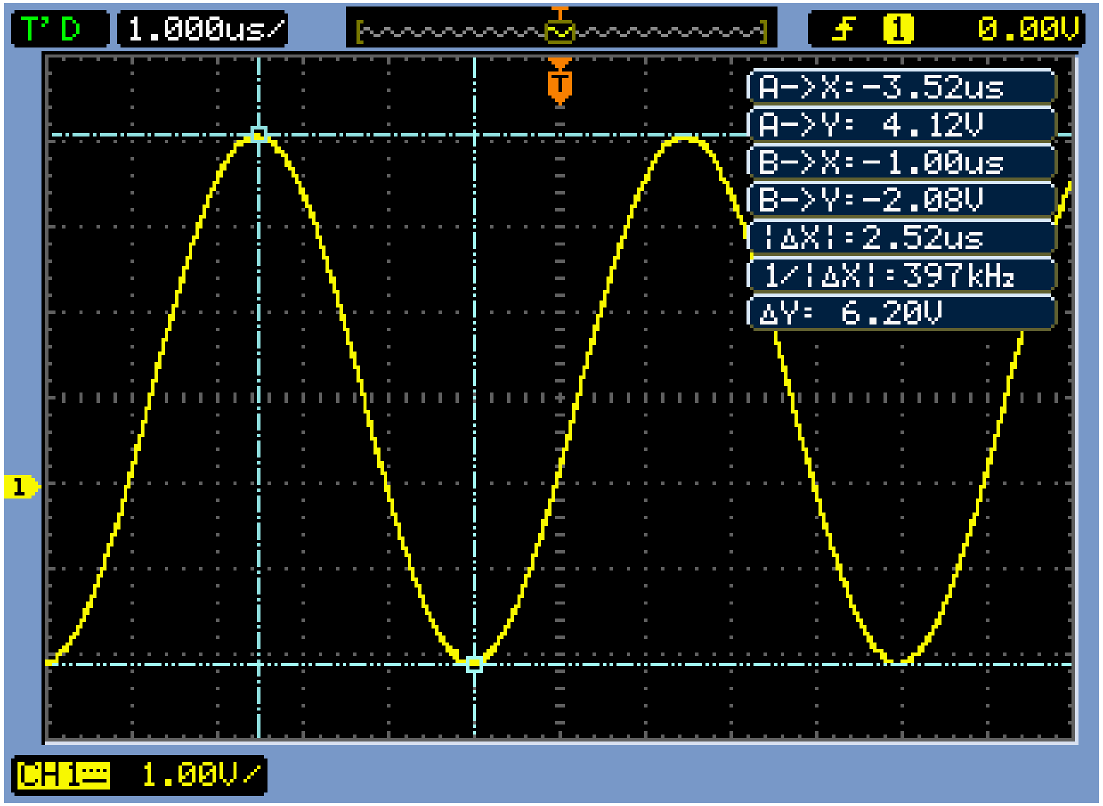


Understanding the Scope's Display

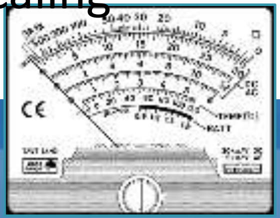


- Waveform display area shown with grid lines (or divisions).
- Vertical spacing of grid lines relative to Volts/division setting.
- Horizontal spacing of grid lines relative to sec/division setting.

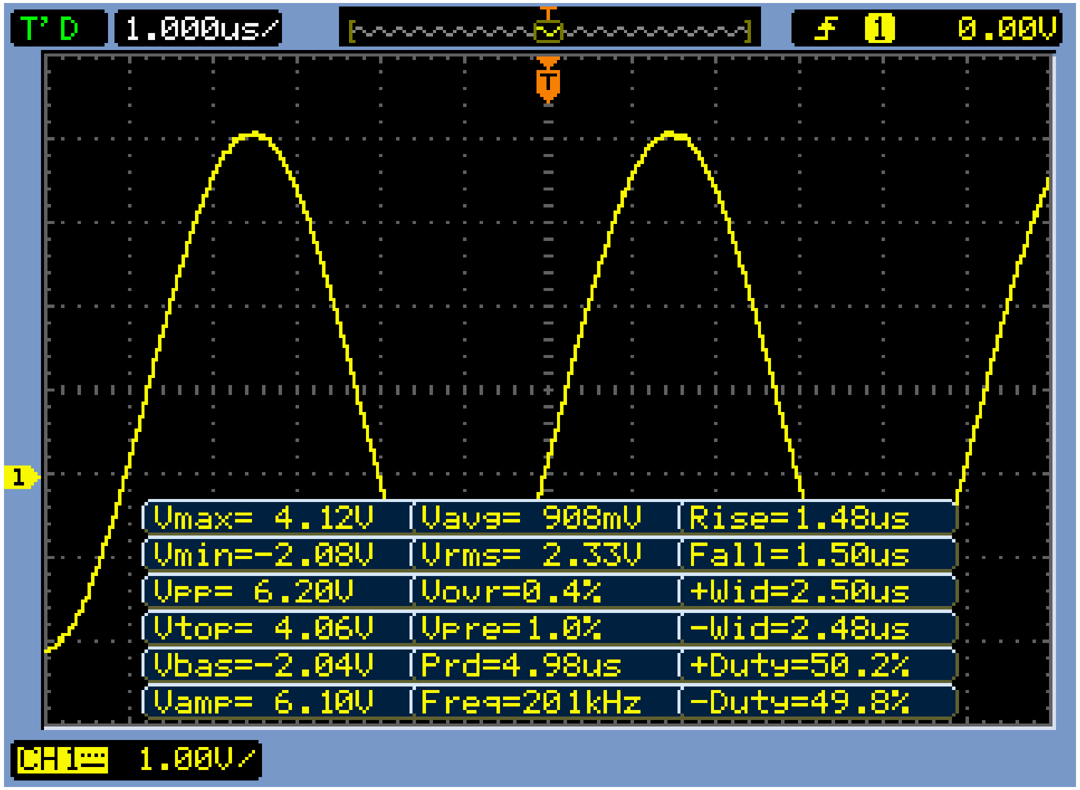
Making Measurements – using cursors



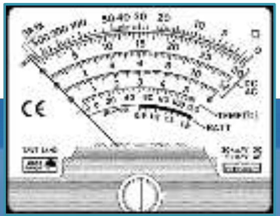
- Manually position A & B cursors to desired measurement points.
- Scope automatically multiplies by the vertical and horizontal scaling factors to provide absolute and delta measurements.



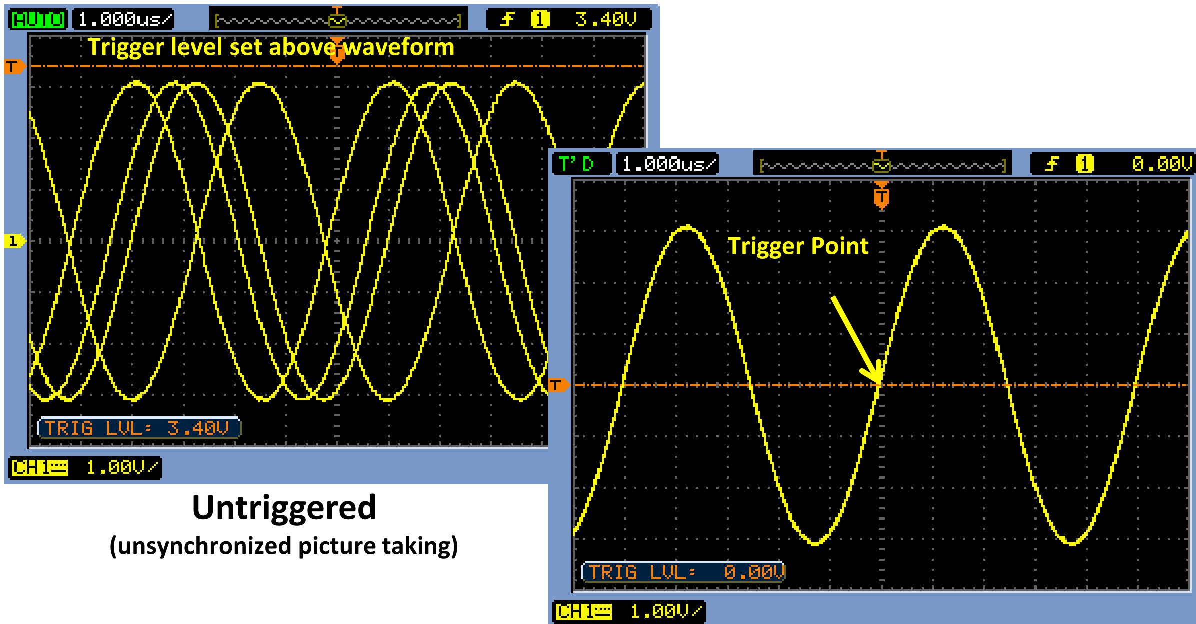
Automatic Waveform Measurements

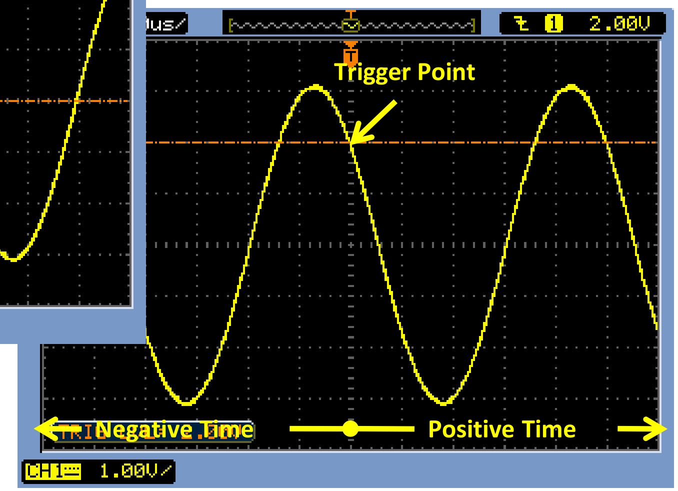


- Select automatic parametric measurements with a continuously updated readout.



Triggering Examples





Untriggered
(unsynchronized picture taking)

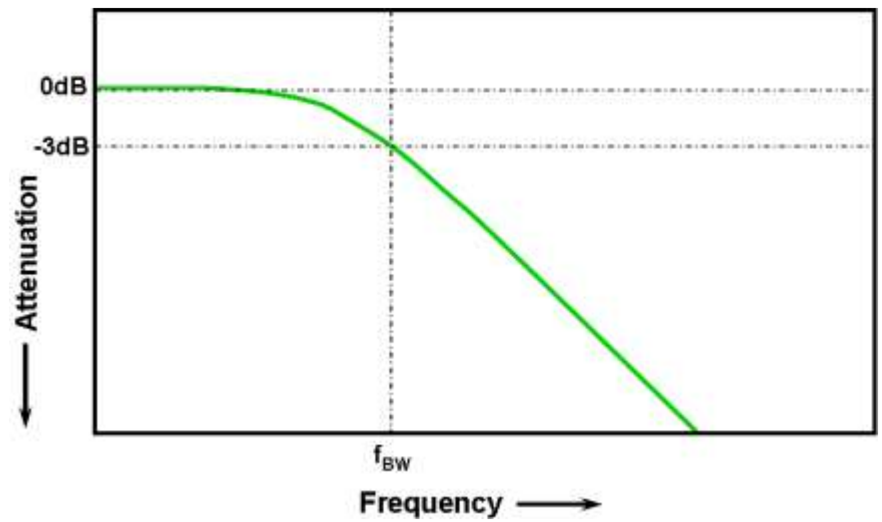
Trigger = Rising edge @ 0.0 V

Trigger = Falling edge @ +2.0 V

Edge Trigger is most common: rising or falling edge, voltage level

Oscilloscope Performance Specifications

"Bandwidth" is the most important oscilloscope specification

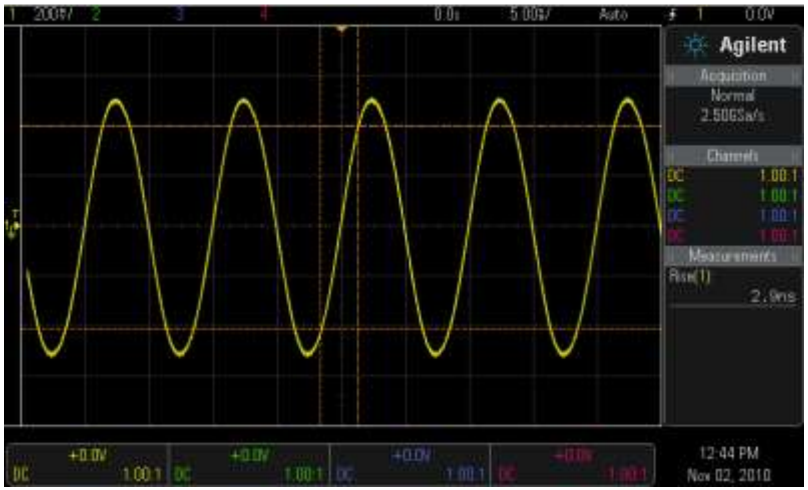


Oscilloscope "Gaussian" Frequency Response

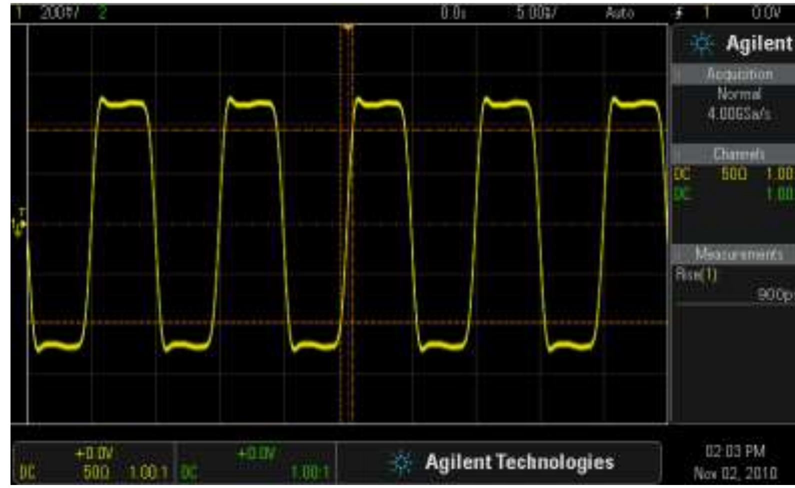
- All oscilloscopes exhibit a low-pass frequency response.
- The frequency where an input sine wave is attenuated by 3 dB defines the scope's bandwidth.

Selecting the Right Bandwidth

Input = 100-MHz Digital Clock

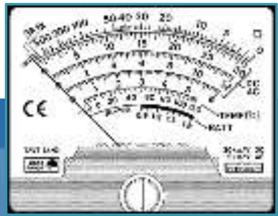


Response using a 100-MHz BW scope

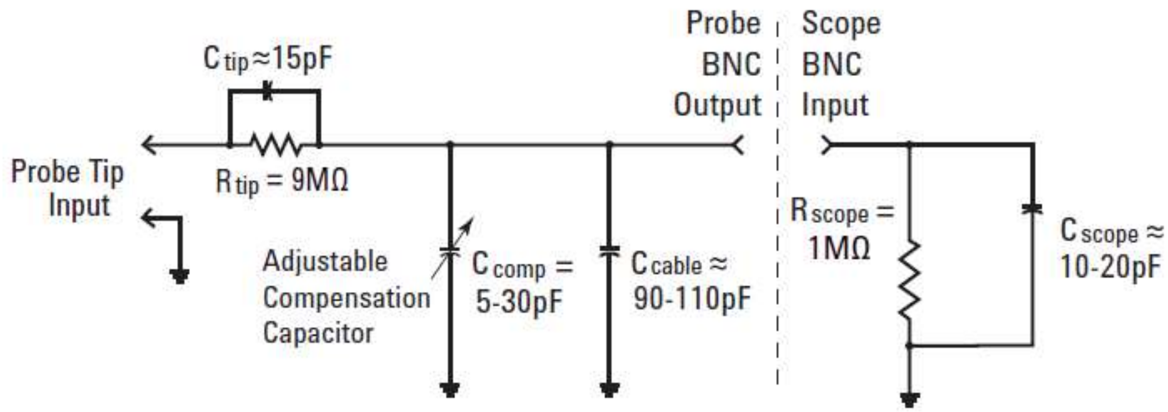


Response using a 500-MHz BW scope

- Required BW for analog applications: ≥ 3X highest sine wave frequency.
- Required BW for digital applications: ≥ 5X highest digital clock rate.
- More accurate BW determination based on signal edge speeds (refer to "Bandwidth" application note listed at end of presentation)



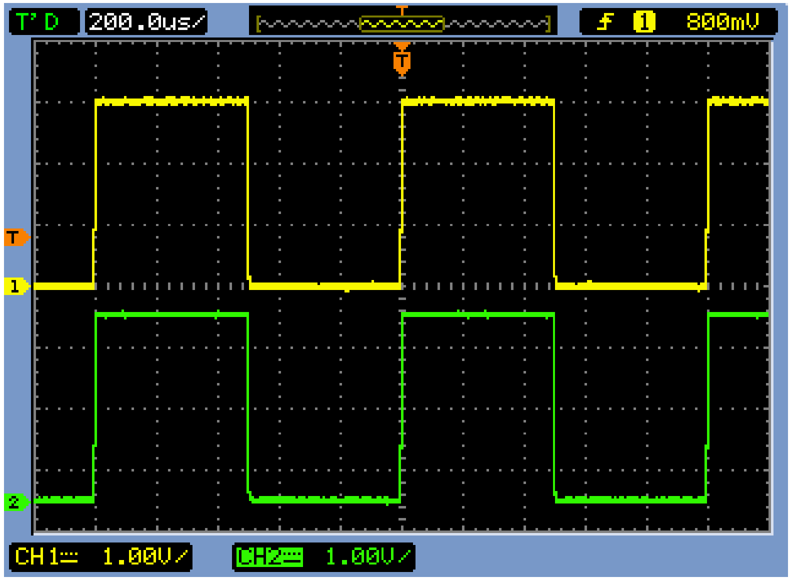
Passive 10:1 Voltage Divider Probe



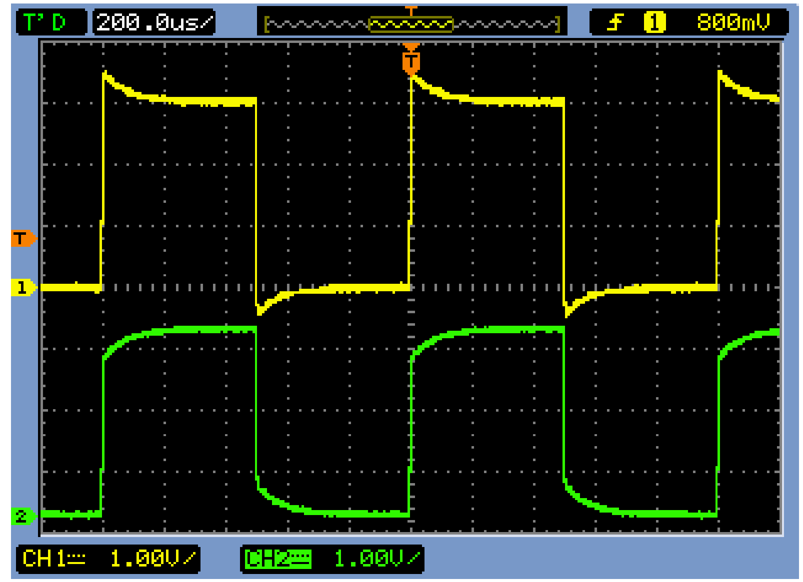
Passive 10:1 Probe Model

- <u>Passive:</u> Includes no active elements such as transistors or amplifiers.
- <u>10-to-1:</u> Reduces the amplitude of the signal delivered to the scope's BNC input by a factor of 10. Also increases input impedance by 10X.
- ***Note: All measurements must be performed relative to ground!***

Compensating the Probes

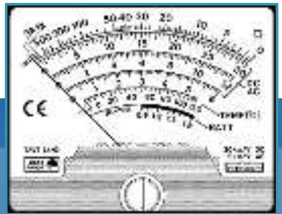


Proper Compensation



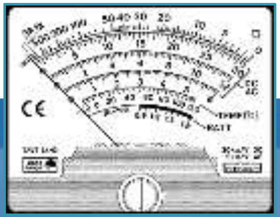
Channel-1 (yellow) = Over compensated
Channel-2 (green) = Under compensated

- Connect Channel-1 and Channel-2 probes to the “Probe Comp” terminal.
- Adjust V/div and s/div knobs to display both waveforms on-screen.
- Using a small flat-blade screw driver, adjust the variable probe compensation capacitor ($\boldsymbol{C}_{comp}$) on both probes for a flat (square) response.



Practical Ham Radio Scope Usage

- Measuring audio signals (modulation, receiver audio, sound card audio)
- Measuring digital signals (Raspberry Pi, serial ports, I^2C, SPI, etc.)
- Monitor transmitted RF (needs connection method and sufficient bandwidth)

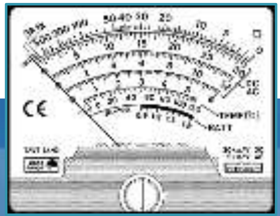


Affordable Digital Scopes

Keysight 1000 X-Series
2 Channel, 50 MHz, 1 GSPS
$459

Tektronix TBS1000B Series
2 Channel, 50 MHz, 1 GSPS,
2.5 kpts
$400

Rigol DS1054Z
4 channel, 50 MHz, 12 Mpts
$400



BitScope Micro

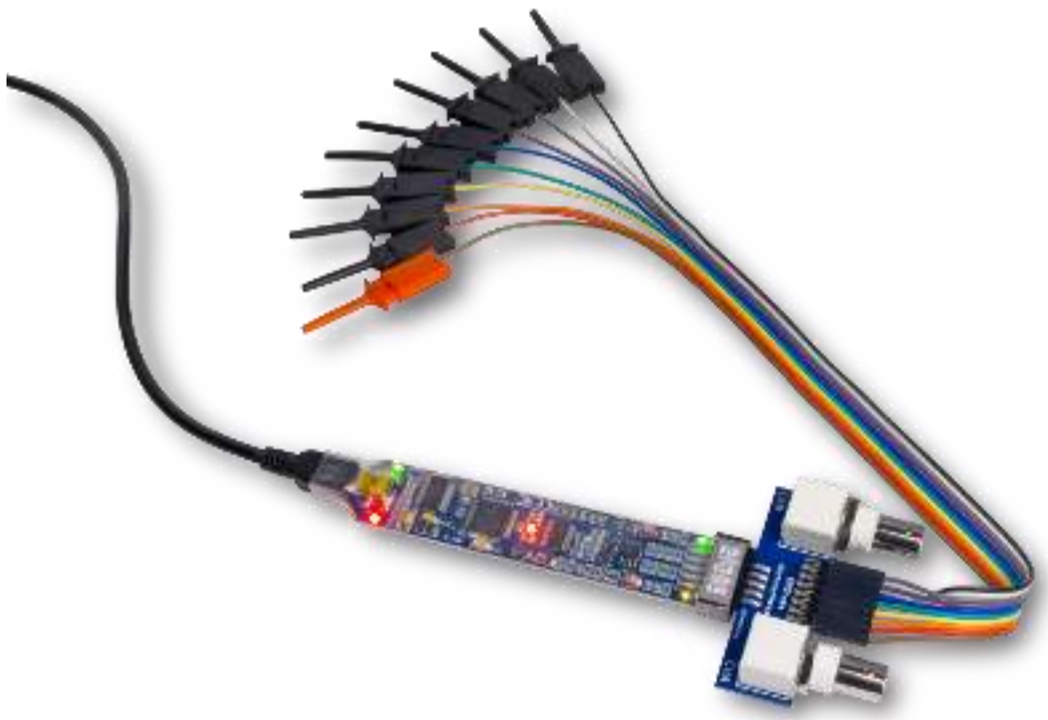
20 MHz bandwidth
2 analog channels

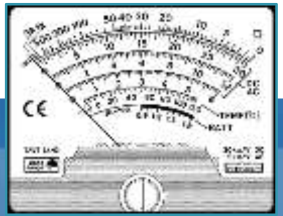
6 digital channels

Mixed signal scope
Waveform generator

Sample rates to 40 MS/s
12 kB buffer

USB cable
Price $165



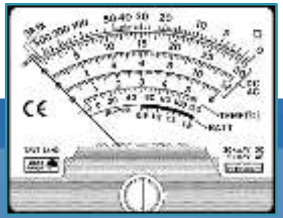


Digilent Analog Discovery 2

- 2-channel oscilloscope (100MS/s, 30MHz bandwidth)
- Two-channel arbitrary function generator (100MS/s, 12MHz bandwidth)
- 16-channel digital logic analyzer
- 16-channel pattern generator (3.3V CMOS, 100MS/s)
- Single channel voltmeter (AC, DC, ±25V)
- Network Analyzer – Bode, Nyquist, Nichols transfer diagrams of a circuit. Range: 1Hz to 10MHz

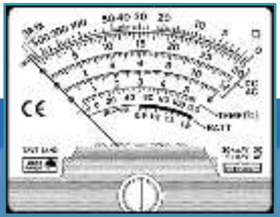
- Spectrum Analyzer
- Digital Bus Analyzers (SPI, I²C, UART, Parallel)

- Protocol Analyzer - SPI, I2C, and UART
- Price $279



What about analog scopes?

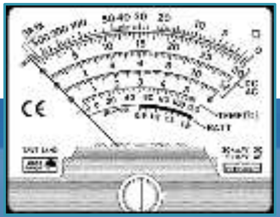
Sure, why not?
Lots of good used gear available
Missing modern “digital” features
(waveform storage, pre-trigger information, automatic measurements)



5. Radio Frequency Measurements

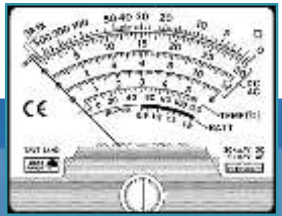
Practical Amateur Radio Measurements

Bob Witte, KØNR
bob@k0nr.com
Monument, CO



Name	Frequency	Usage
DC	0 Hz	Power, Batteries
AC Power	50 - 60 Hz	Power
Audio	20 Hz - 20kHz	Modulation
LF	30 kHz - 300 kHz	Experimental
MF	300 kHz - 3 MHz	Radio Signals
HF	3 MHz - 30 MHz	Radio Signals
VHF	30 MHz - 300 MHz	Radio Signals
UHF	300 MHz - 3 GHz	Radio Signals

RF Instruments



What RF measurements?

Antennas: SWR measurements ☑

Transmitters:

- Transmitter power ☑
- Transmitter frequency
- Transmitter modulation
- Transmitter spectral content

Receivers:

- Receiver sensitivity

Spectrum analysis:

- Transmitter spectral content
- Spectrum monitoring

RF Equivalent of a Multimeter?

Keysight FieldFox RF Analyzer

Frequency Range: 30 kHz to 4 GHz

Spectrum Analyzer

Vector Network Analyzer

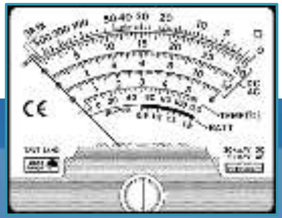
Antenna / Cable Analyzer

Vector Voltmeter

Power Meter

Frequency Counter

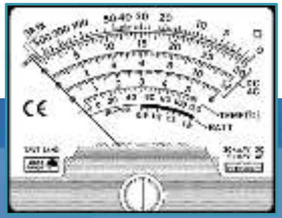
Price: Starting at $10k



RF Communications Test Set

Signal Generator
Modulation Analyzer (AM/FM)
Internal Dummy Load
Frequency Counter
Power meter
Spectrum analyzer

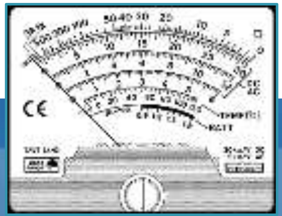
Used market: $2k to $5k?



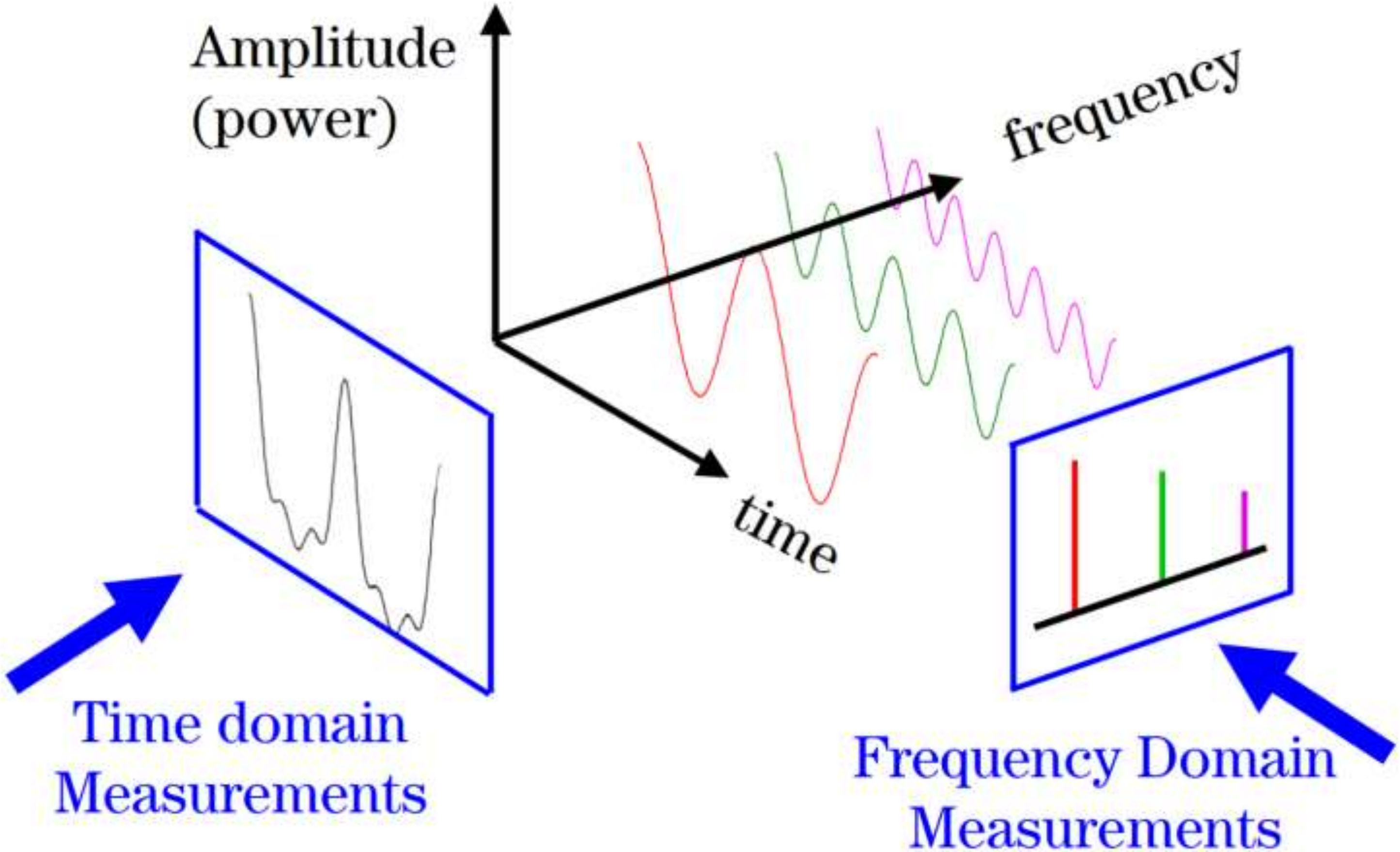
Transmitter Frequency

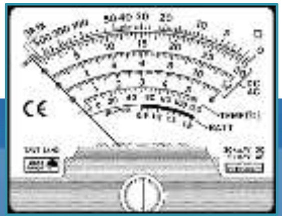
Surecom SF401 Plus
27 to 3000 MHz
CTCSS/DCS Decoder
Price $49

Over the air measurement

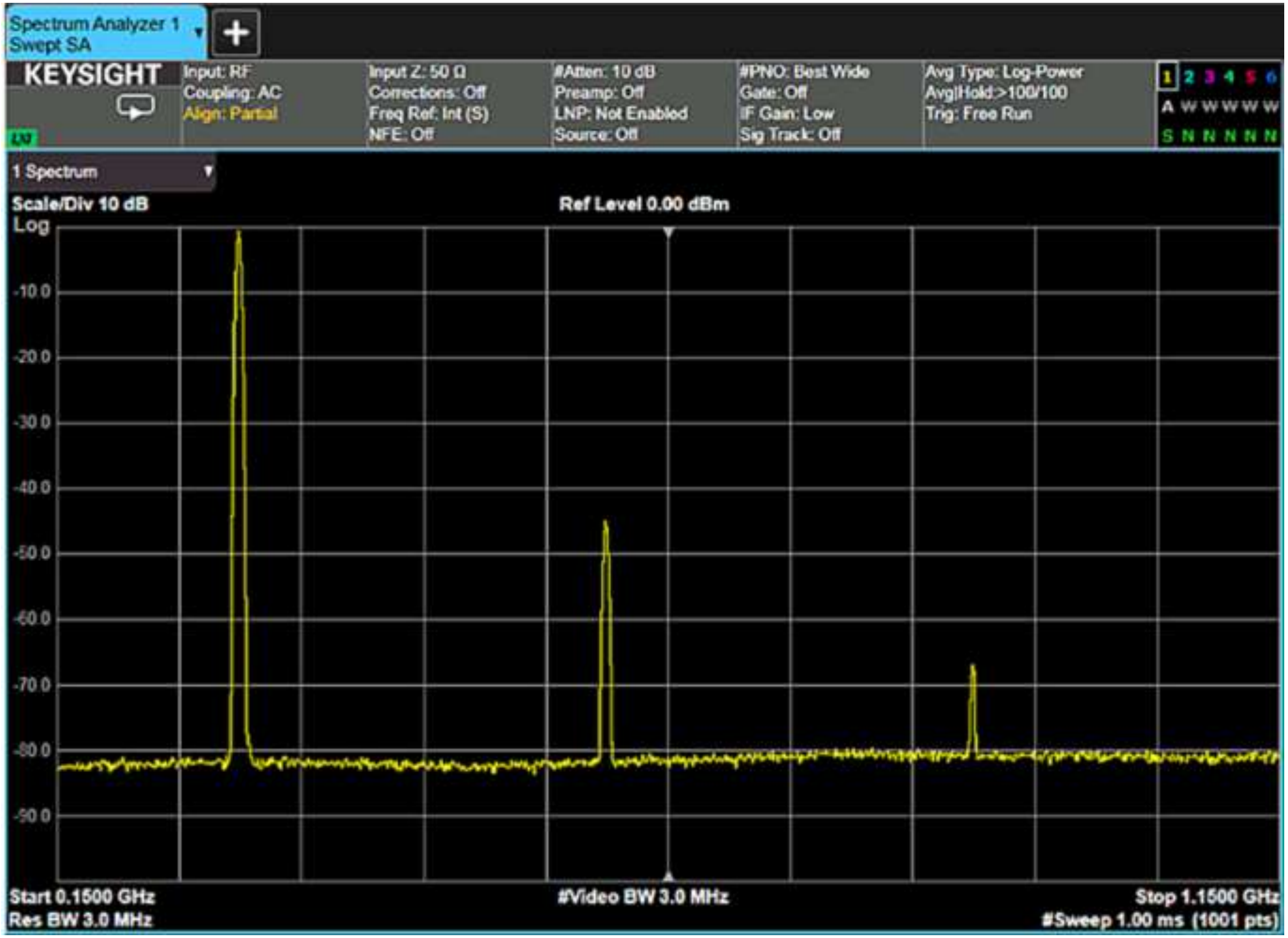


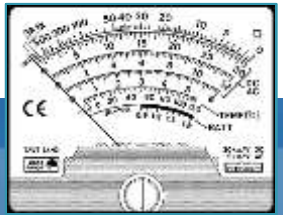
Frequency Versus Time Domain





Harmonic Distortion Measurement





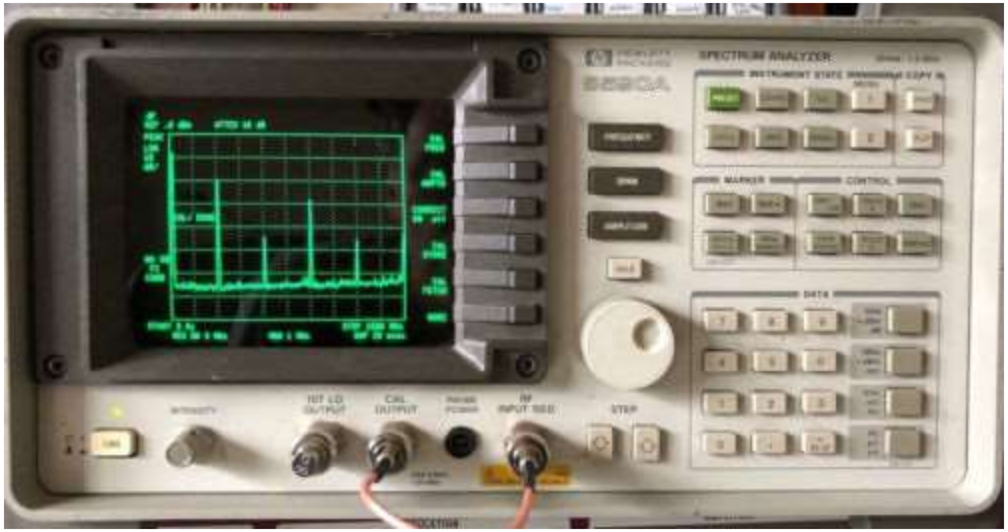
Affordable Spectrum Analyzer

Rigol DSA705
Spectrum Analyzer

Frequency range
100kHz to 500MHz

Price $700

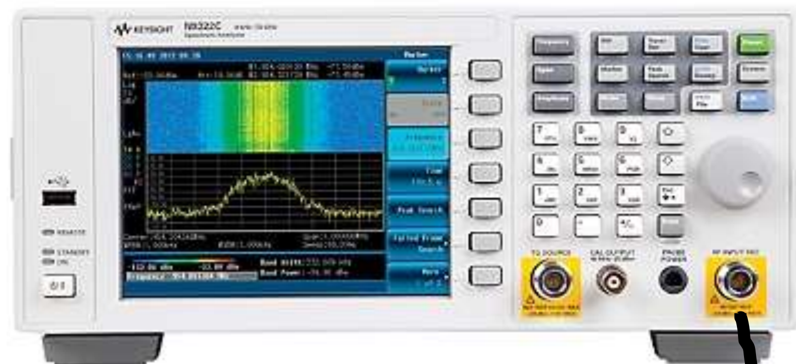
Used Spectrum Analyzer



HP 8590A
Spectrum Analyzer

Frequency range
10 KHz - 1.5 Ghz
Price $1k ?

Connecting to Transmitters

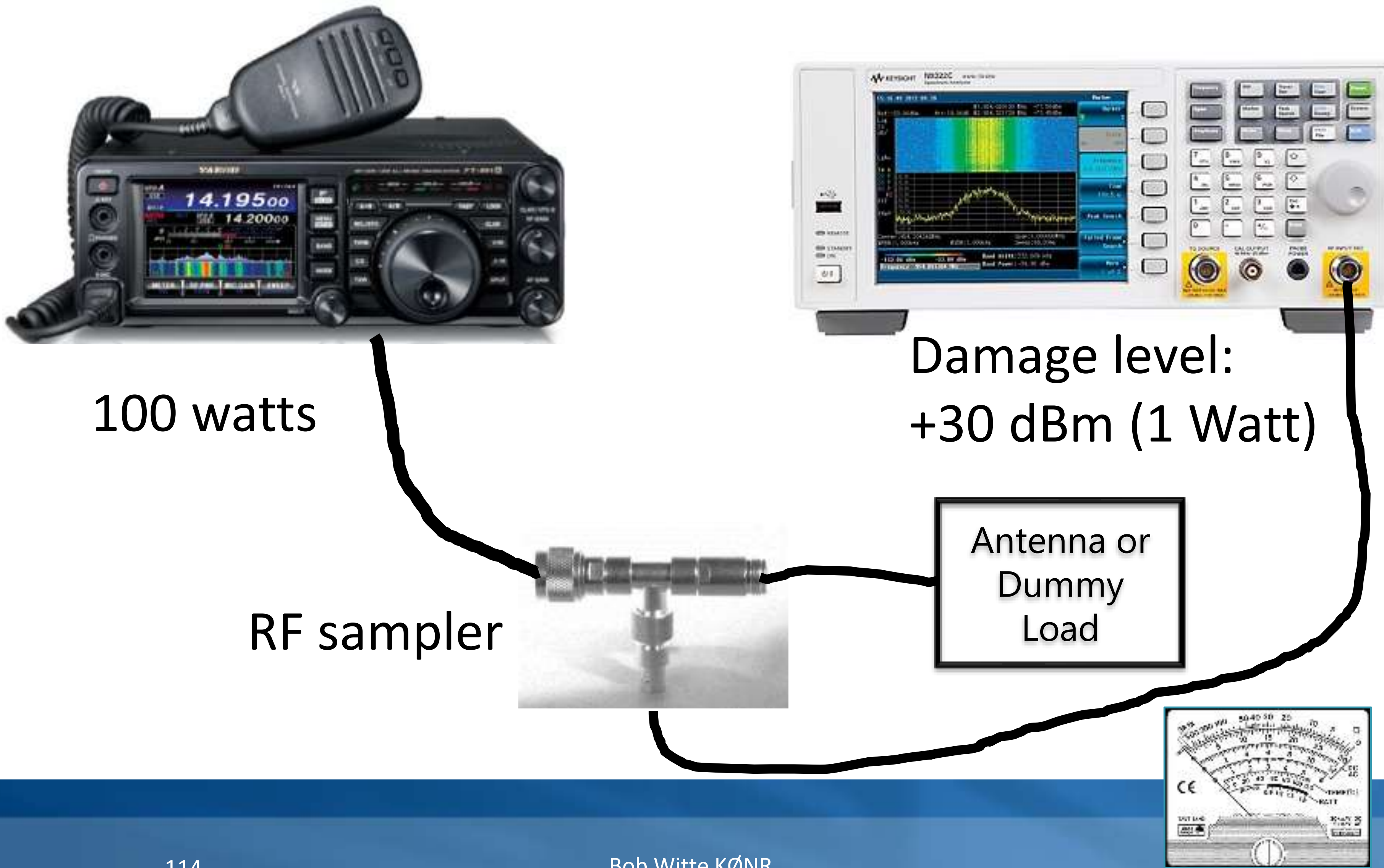


100 watts

Damage level:
+30 dBm (1 Watt)

20 to 30 dB power attenuator

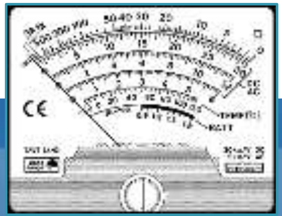
Connecting to Transmitters



Software Defined Radio (SDR)

Mini USB
RTL-SDR

R820T tuner IC
25MHz-1750MHz
~$20



Radio Spectrum Processor 1A
14-bit SDR

SDRplay

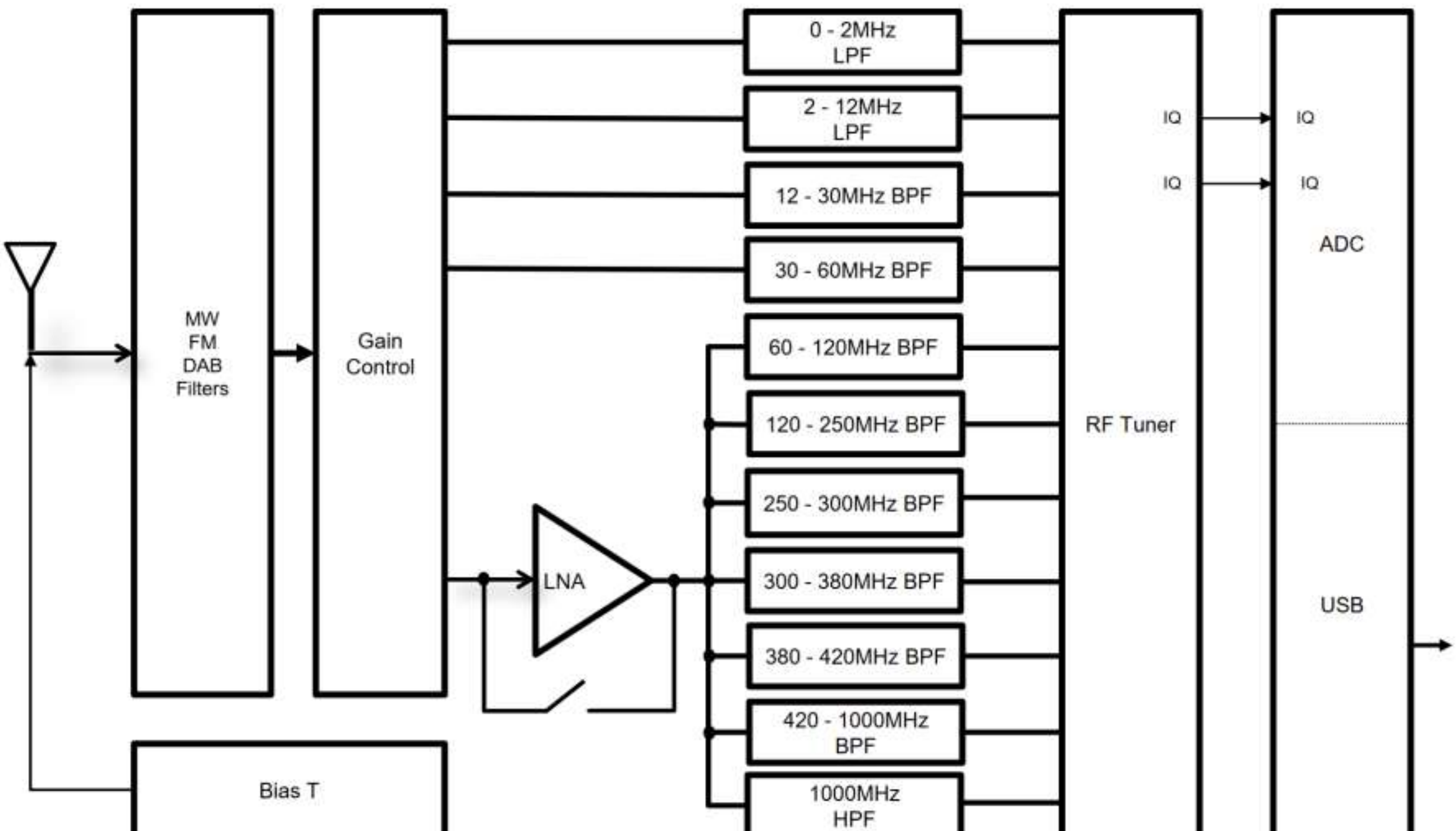
The SDRplay RSP1A is a major upgrade to the popular RSP1—it is a powerful wideband full featured 14-bit SDR which covers the RF spectrum from 1kHz to 2GHz. All it needs is a PC and an antenna to provide excellent communications receiver functionality. Combined with the power of readily available SDR receiver software (including 'SDRuno' supplied by SDRplay) you can monitor up to 10MHz of spectrum at a time. Documented API allows developers to create new demodulators or applications around the platform.

RSP-1A
Price
$109

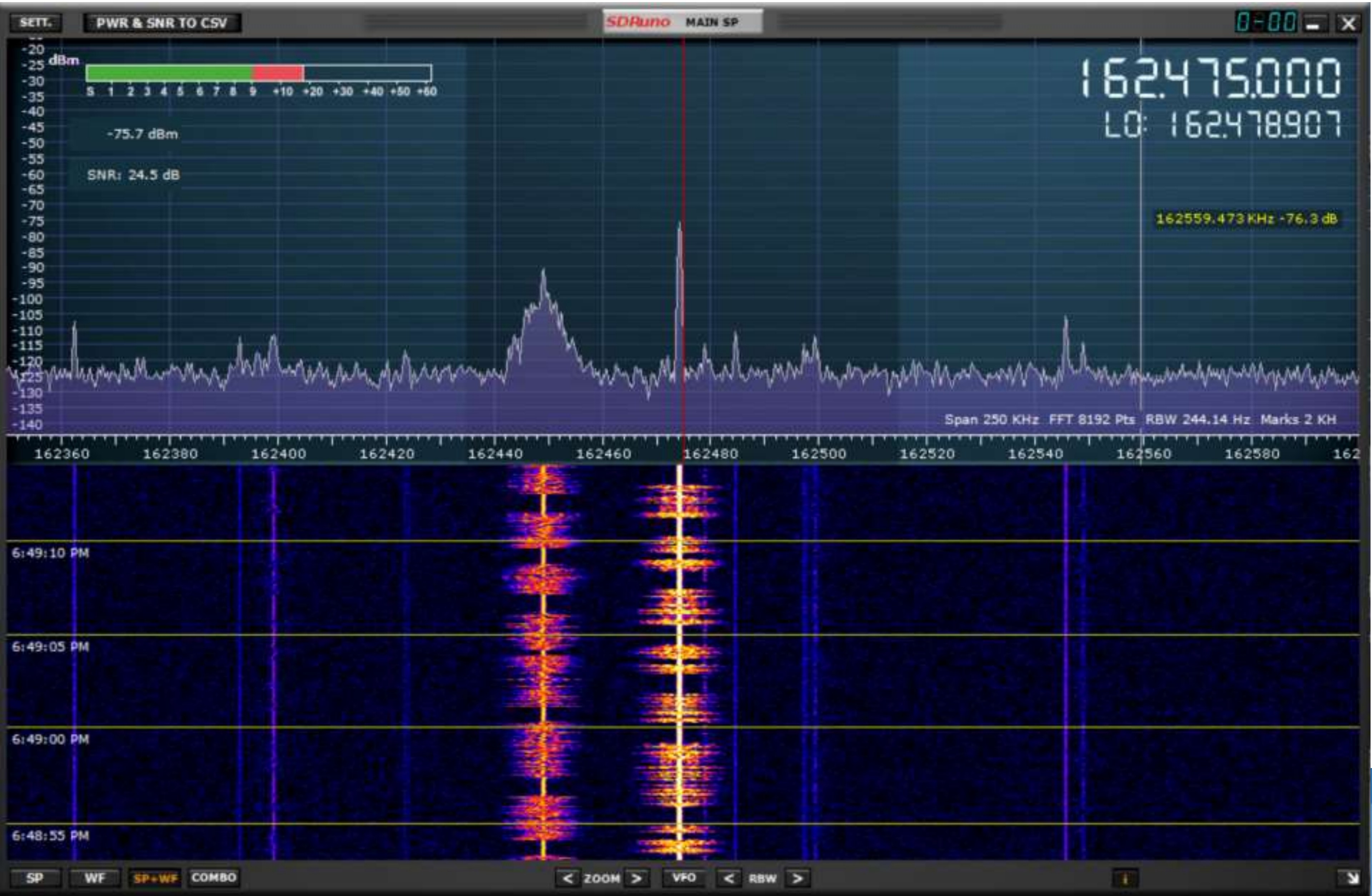
KEY BENEFITS

- Covers all frequencies from 1kHz through LF, MW, HF, VHF, UHF and L-band to 2GHz, with no gaps
- Excellent dynamic range for challenging reception conditions
- Low levels of spurious responses
- Works with all the popular SDR software (including HDSDR, SDR Console, Cubic SDR and SDRuno)

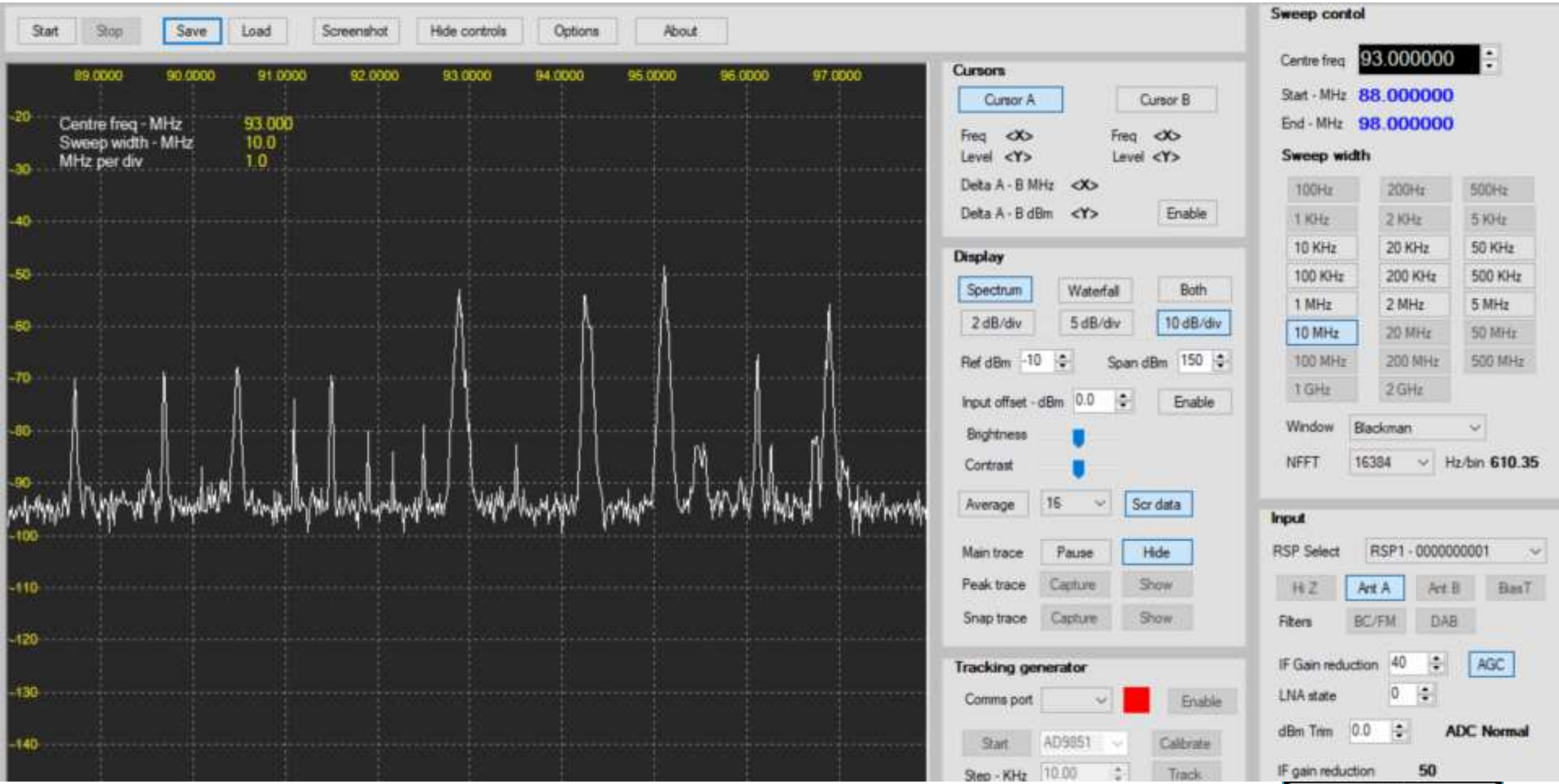
Block Diagram

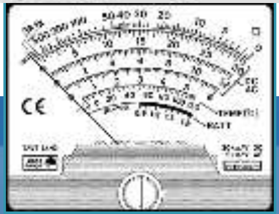


SDRuno Software



SDR Spectrum Analyzer Software





Thank You !!!