Advanced Course Ch. 11 Test Equipment

de VE1FA 2019

Covers:

1. **Material in advanced textbook**
2. **Practical test equipment too recent for advanced textbook**

The basic test instrument: the d'Arsonval meter movement (1882)

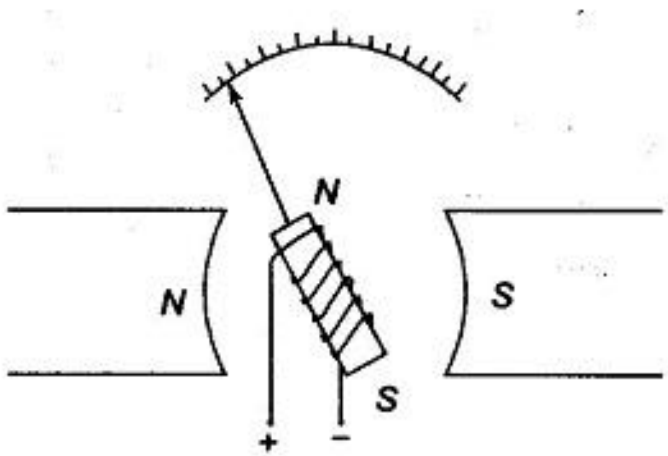
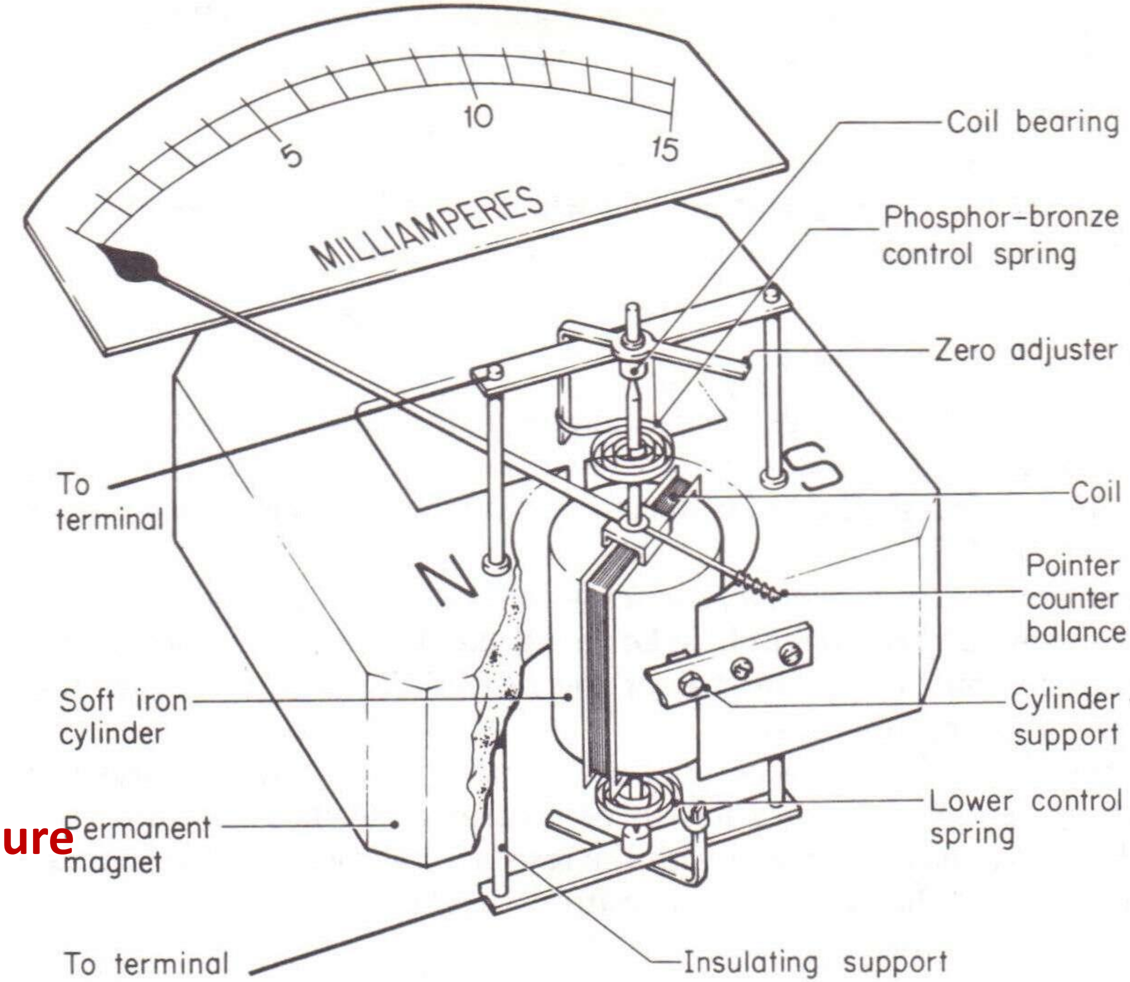


Fig. 2.1 ▬ D'Arsonval Principle



-Measures DC current <u>only</u>
-Full-scale: 1.00 mA or 50 µA commonly
-similar to DC motor
-placed in right circuit , can measure
1. voltage
2. current
3. resistance
4. frequency
5. almost any physical parameter

Modern multimeter + knowledgeable user →
will find 60-70% of station electronic problems

VOM (Volt-Ohm-Milliammeter) –not a modern multimeter

-popular for >100 years

-D'Arsonval current meter, with circuits for V, A, and Ω

-meter still best for nulling, peaking circuits

Shortcomings:

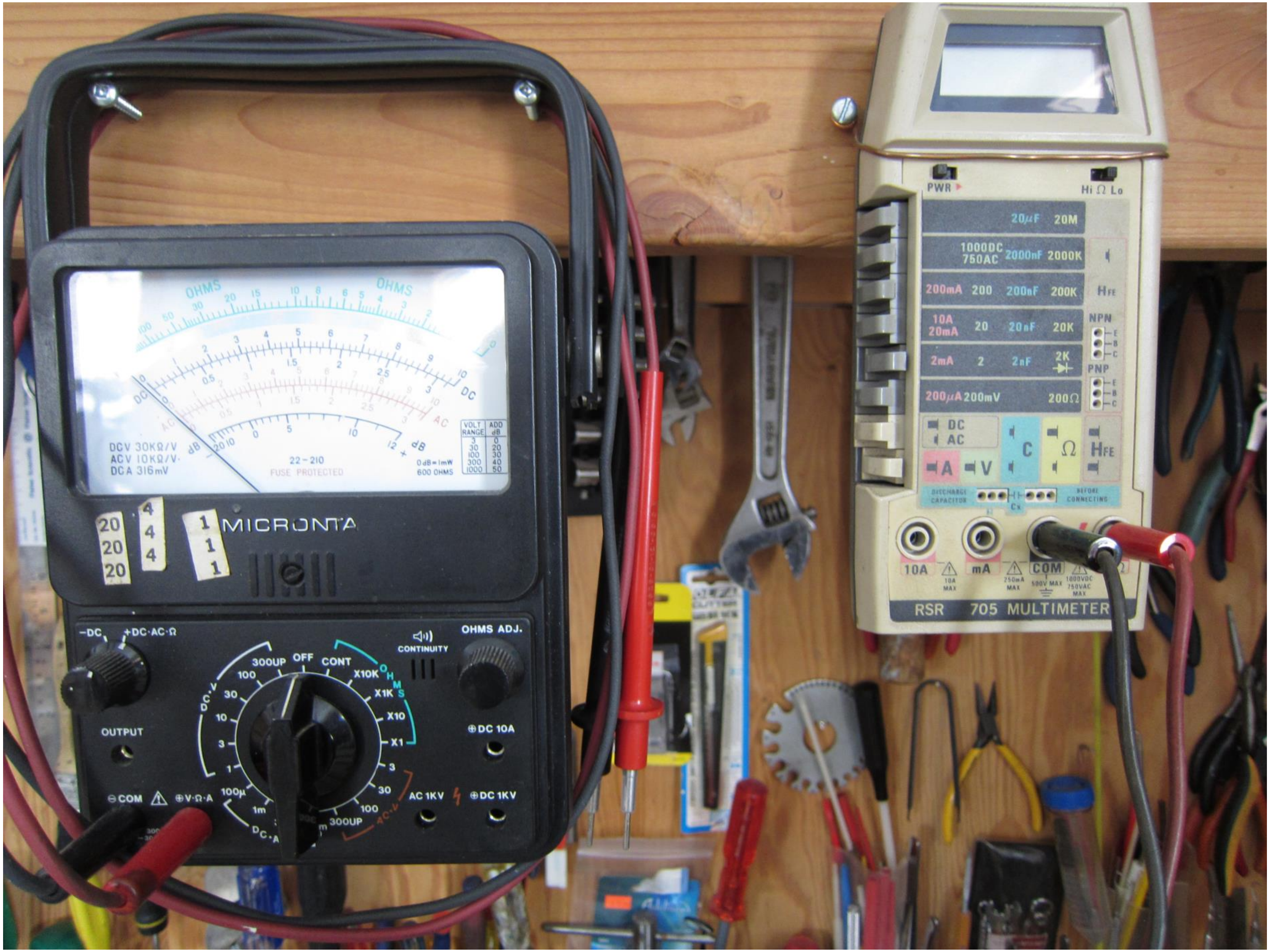
-low input Z (1,000-50,000 Ω/V)

-much less accurate + precise than DMM

-can't read very small A and V values, or very high Ω values

-draws power from the circuit under test

Both analog and digital meters have their place!



Basic DC voltmeter

Voltmeter is used in across (in parallel with) the voltage to be measured. Range resistors are in series with meter

$E = I \times R_T$

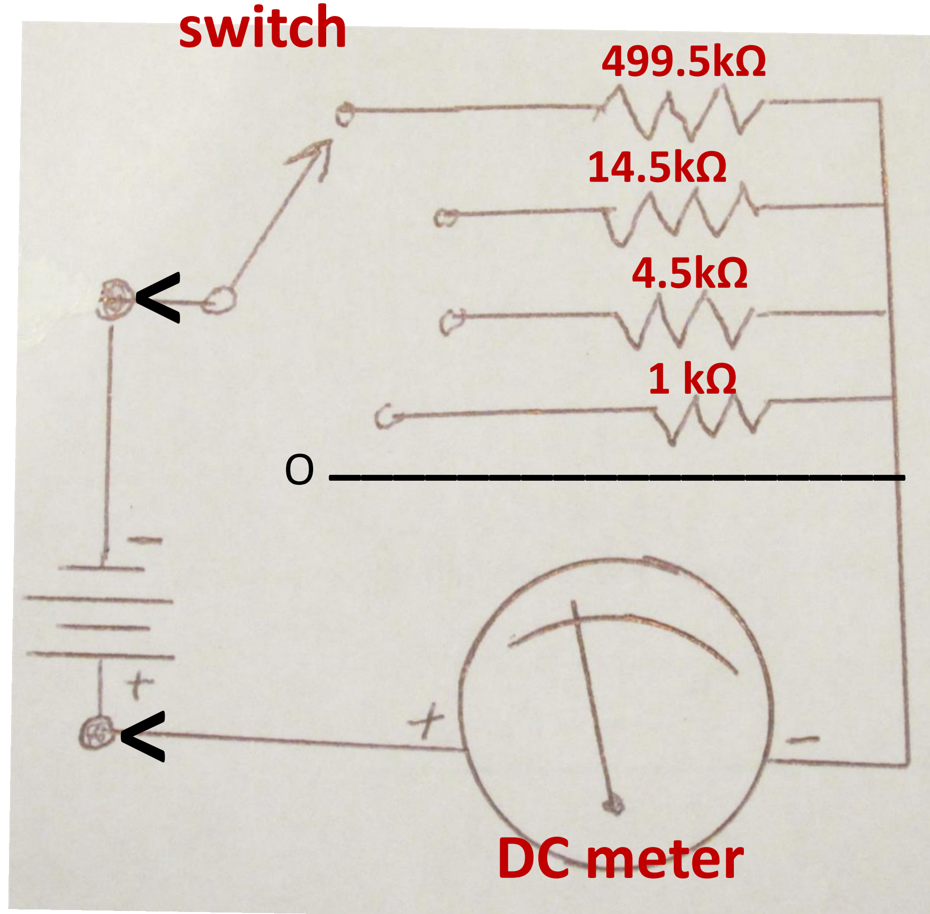
R_T = meter Z + series R

What series R for 5 V full-scale?

$5.0 = 0.001 \times R_T$

$R_T = 5000$

$R_T - 500 = 4500\ \Omega$



Using d'Arsonval 0-1.0 mA "panel meters" in projects

<u>What series resistor to measure 0-100 V?</u>

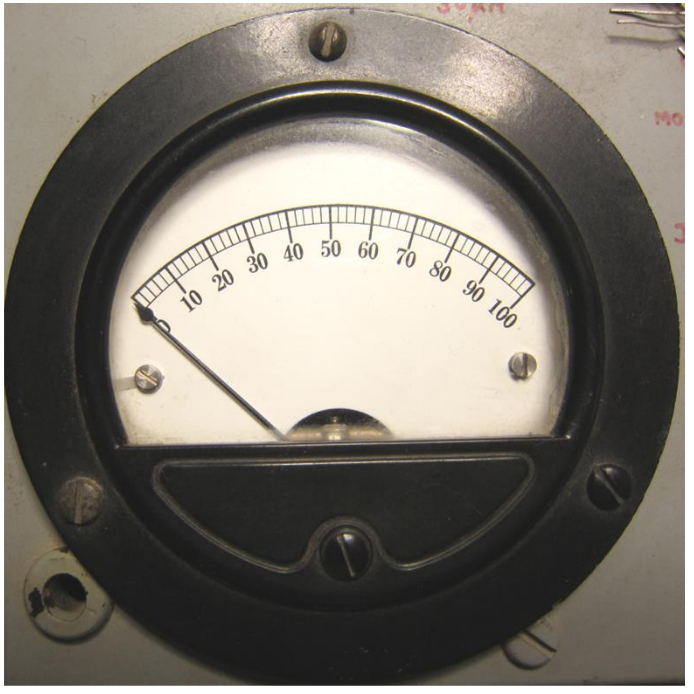
$R_T = E/I$

$R_T = 100/.001$

$R_T = 100k\Omega\ (100{,}000\Omega)$

If meter R= 500Ω, then external series resistor will be 100k – 500, or 99.5kΩ

<u>But</u> ½% error can't be seen on meter, so use standard 100kΩ 1% tolerance resistor



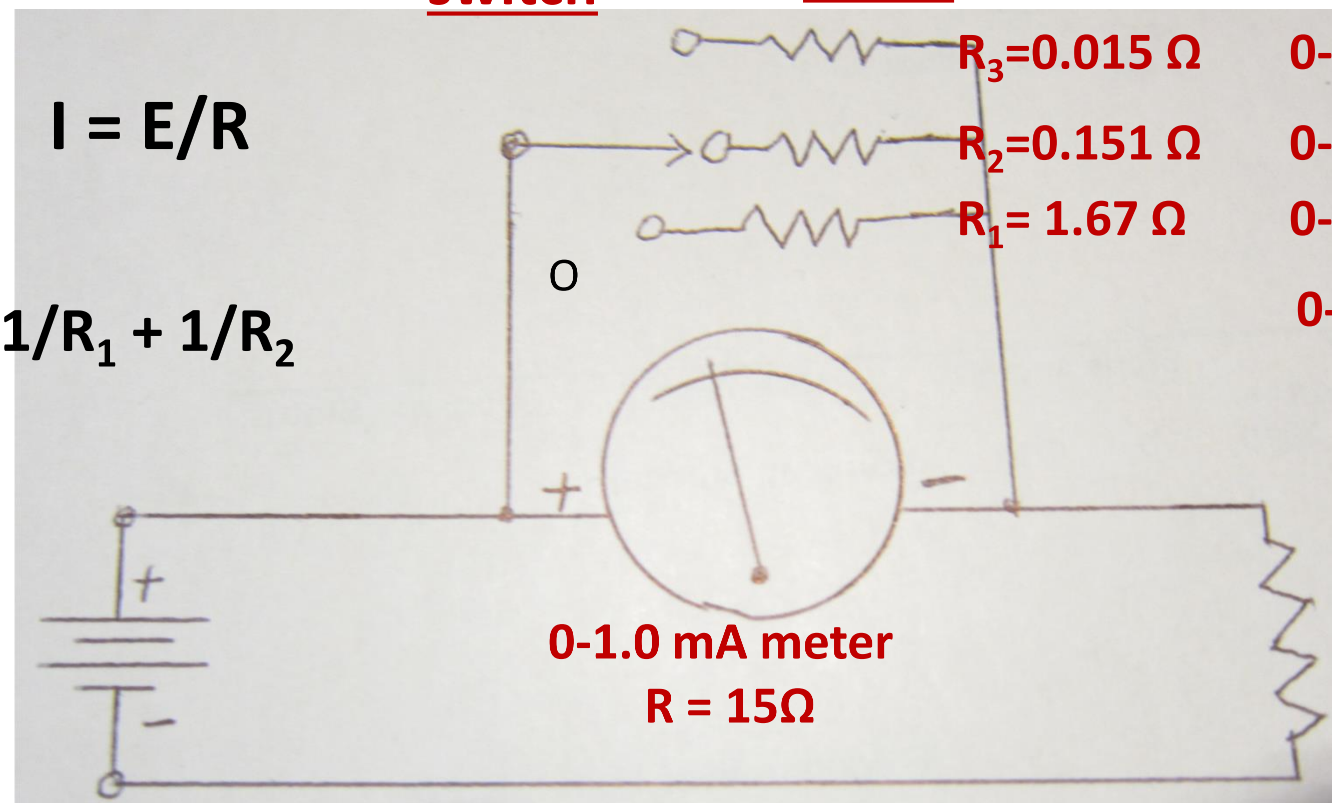
Calibrated as multi-range meter

Basic Ammeter

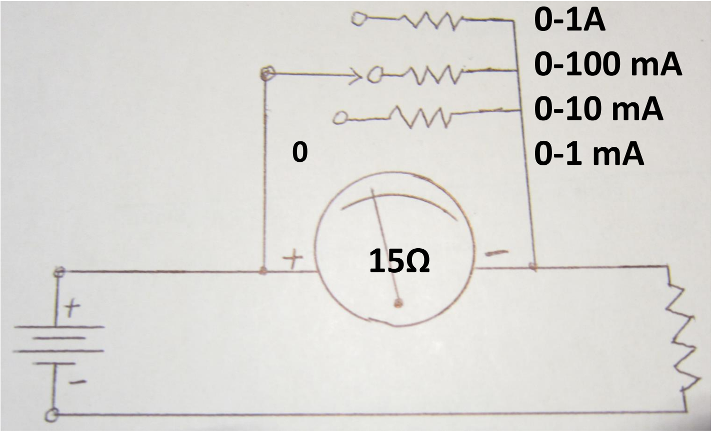
NB: an ammeter is ALWAYS in SERIES between the voltage source and the load!! You forget → you need a new meter!!

$$I = E/R$$

$$R_T = 1/R_1 + 1/R_2$$



Calculating the ammeter shunt resistors



Resistors in <u>parallel</u>: $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$ +......

Resistors in <u>series</u>: $R_T = R_1 + R_2 + R_3$ +.....

What value of shunt R will expand the meter scale from <u>0-1.0 mA to 0-10 mA</u>?

Max I through meter = 1.0 mA; therefore R_{SHUNT} must carry 9.0 mA

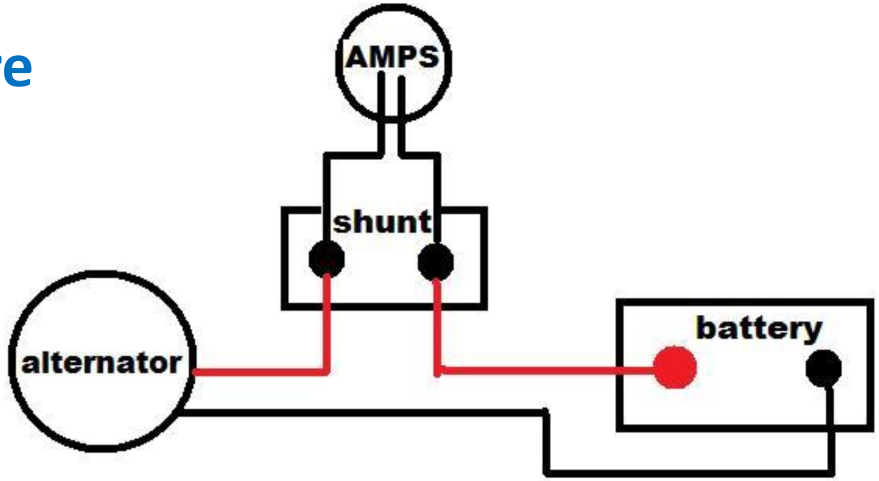
I and R are inversely proportional, so R_{SHUNT} = 1/9 = .111 of 15Ω = **1.67Ω**

<u>For 0-100 mA full-scale</u>: R_{SHUNT} = 1/99 of 15Ω = **0.152Ω**

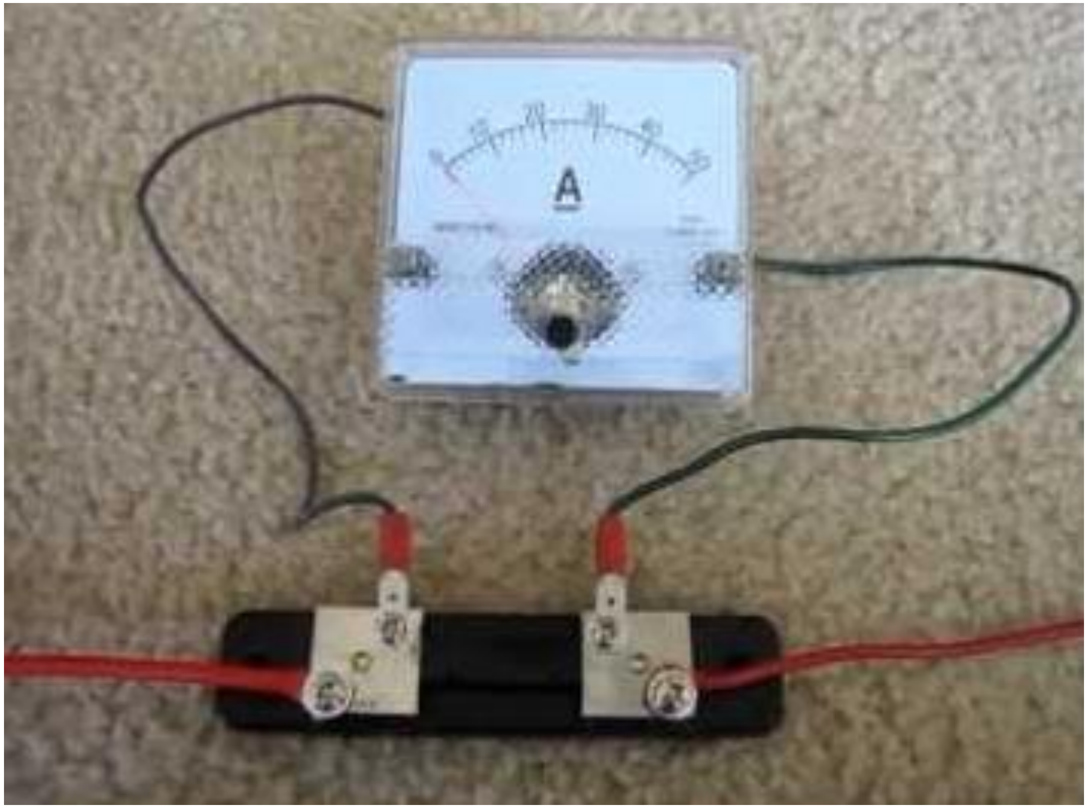
<u>For 0- 1.0 A full-scale</u> : R_{SHUNT} = 1/999 of 15Ω = **0.0150Ω**

How low-current meters measure high currents

R = E/I



500 A shunt resistor

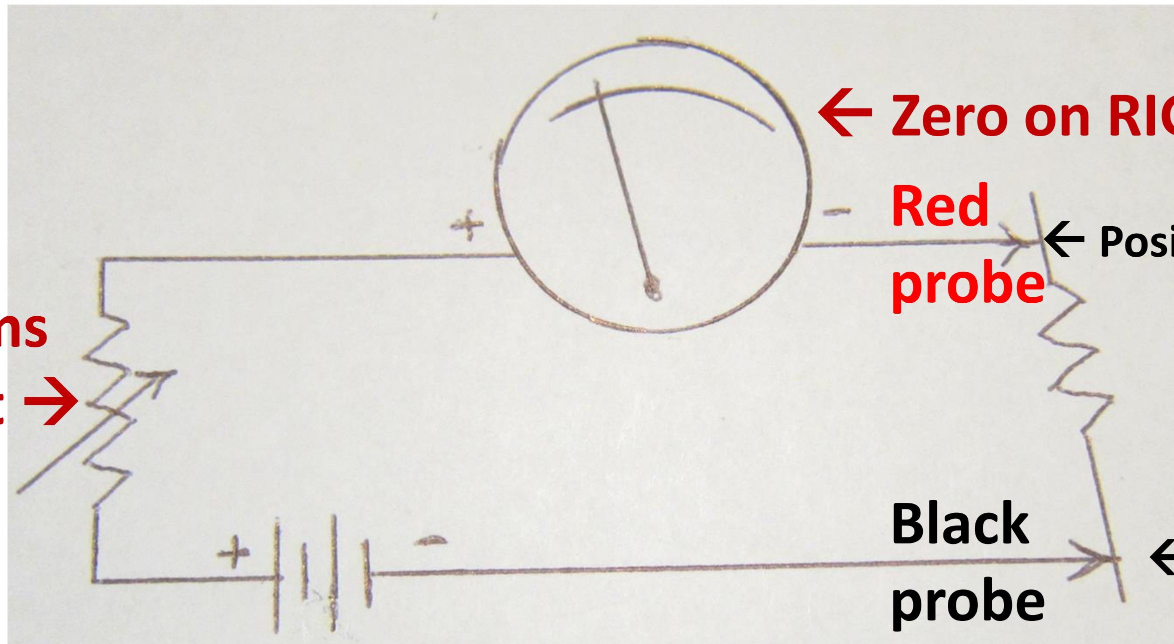


R = E/I = 0.05/500

R = 0.0001 Ω

Basic series-type ohm-meter

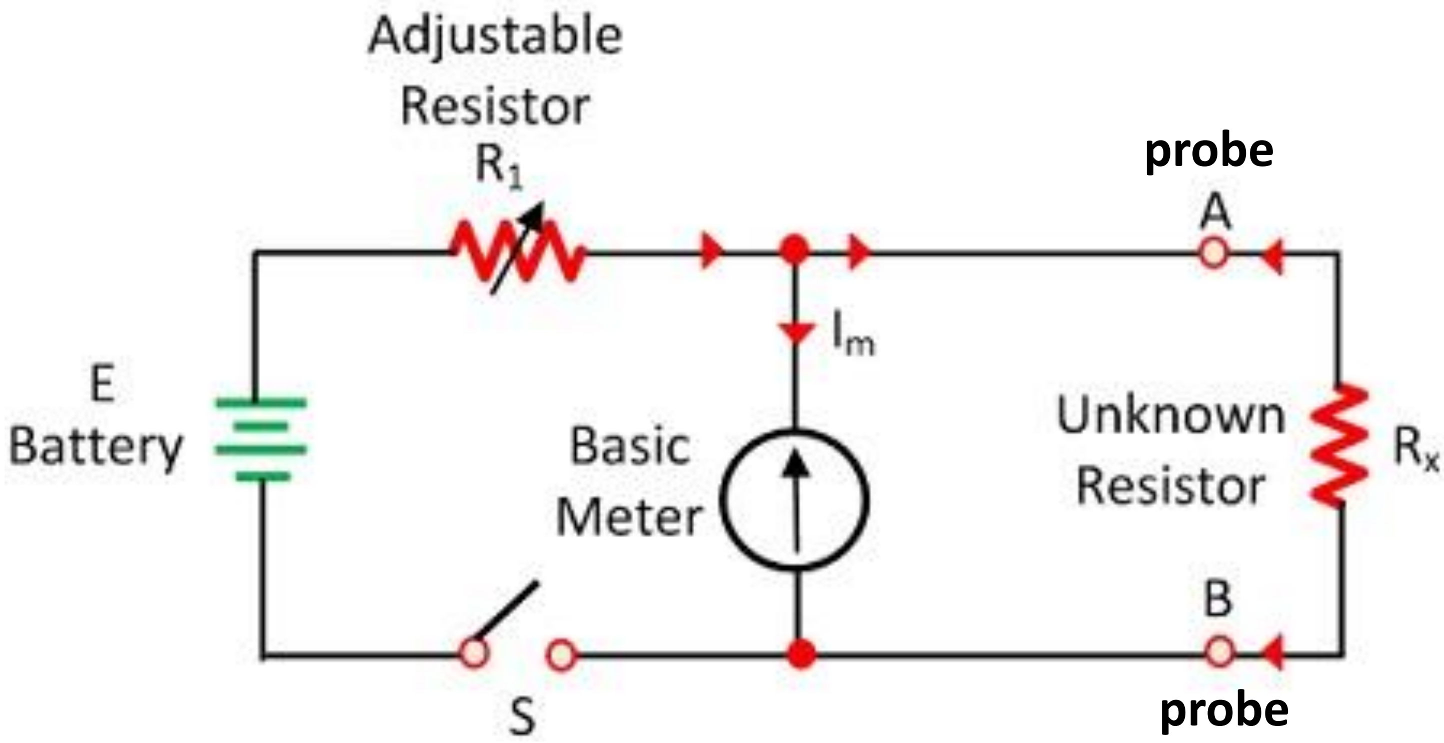
NB: unlike volt and current meters, ohm-meter applies voltage to circuit tested



-probes shorted before use to set meter zero

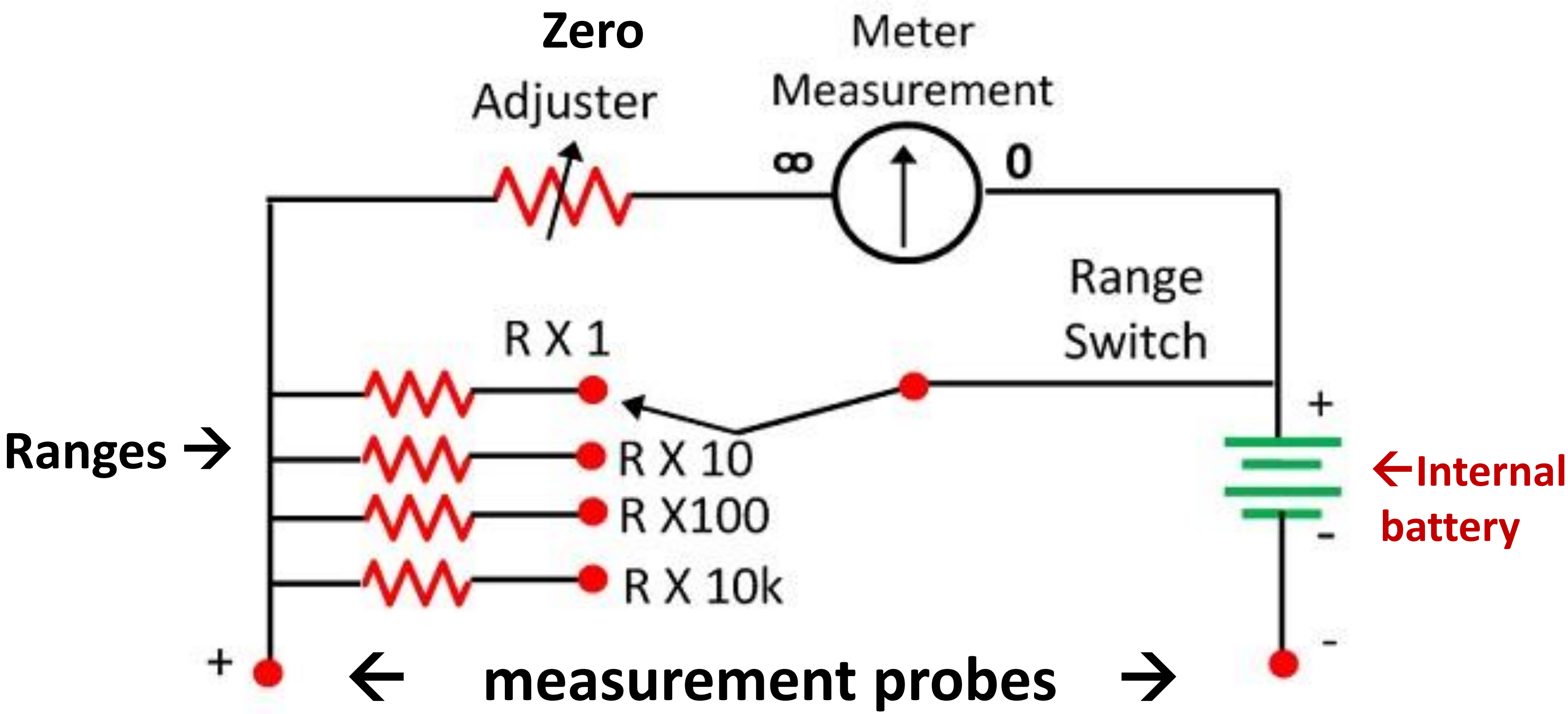
-single range: not sufficient for typical uses

Shunt-type ohm-meter



NB: Always store your multimeter with the function switch “OFF”!

Practical series-type ohmmeter, as found in many VOMs



R x 10k: means multiply ohm scale reading by 10,000 for correct value of resistance

Volt-ohm-milliammeter (VOM) or multi-meter face

Notice:

-Linear L→R scales: volts + milliamps scales

-Non-Linear R→L scales: resistance (ohms) scales

-for best accuracy: choose range putting reading near middle of scale; set mechanical zero; and read squarely facing the meter

-usable only for audio and lower ACV

Limits to d'Arsonval (moving coil) meter accuracy

1. Accuracy of the movement itself
   - -readability
   - -tracking
2. Resistor tolerances
3. <u>Circuit loading</u>: meter always draws power from measured circuit

<u>Example of circuit loading:</u>

Before measurement E across 56kΩ =100V

IR = E 56k x .00179 = 100

IR = E 56k x .00279 = 44 V

The book's analysis is WRONG →

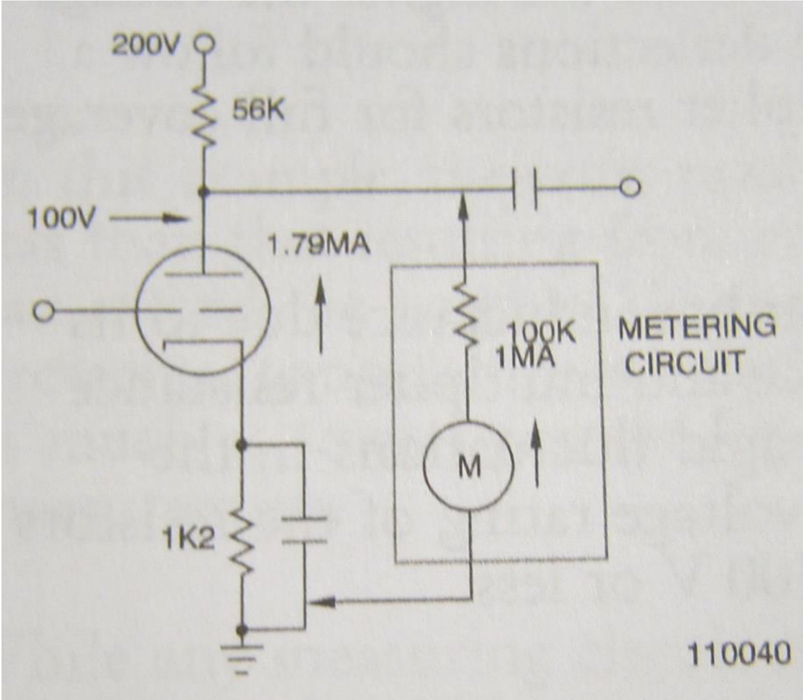


Fig 11-5

<u>During measurement</u>:

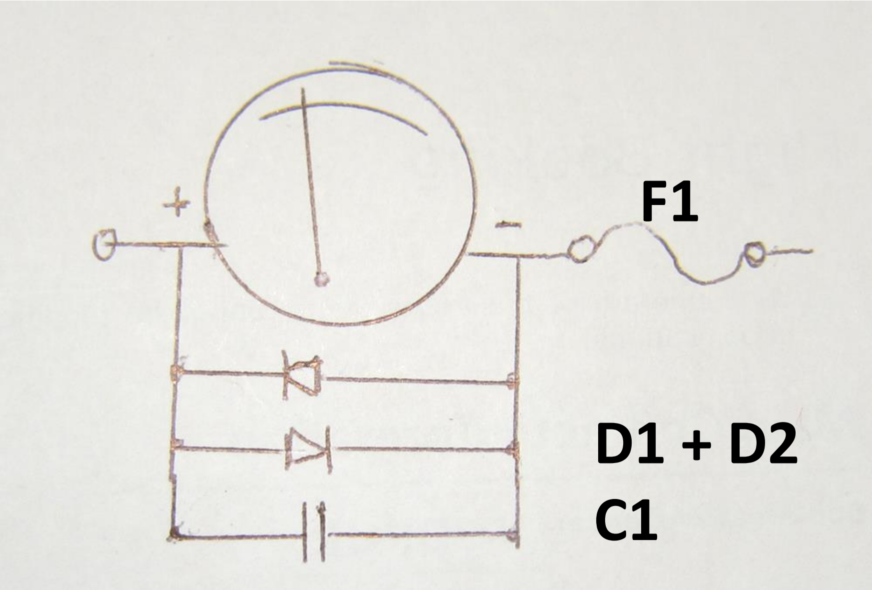
If Ip drops to 44V, the meter will draw 0.44 mA

If Ip drops to 44V, the tube will draw less I, the exact figure dependent on the tube characteristics.

The cathode bias on the tube will decrease, further changing the grid bias.

Meter protection

Basic d'Arsonval movement usually 1.00 mA, 50µA, or 20-25µA for full-scale needle deflection



What size?

Ge or Si??

What size?

Vacuum-Tube Voltmeter (VTVM): an improved VOM

-11 MΩ input Z (all V ranges)

-tube grid makes excellent high Z input

-far less loading → gives more accurate measurements of high Z circuits

-reads high Ω (to > 100 M)

-doesn't measure current

-more accurate AC volts

Hewlett-Packard 410C VTVM: solves VOM shortcomings

Measures millivolts and nA (precision amplifiers)

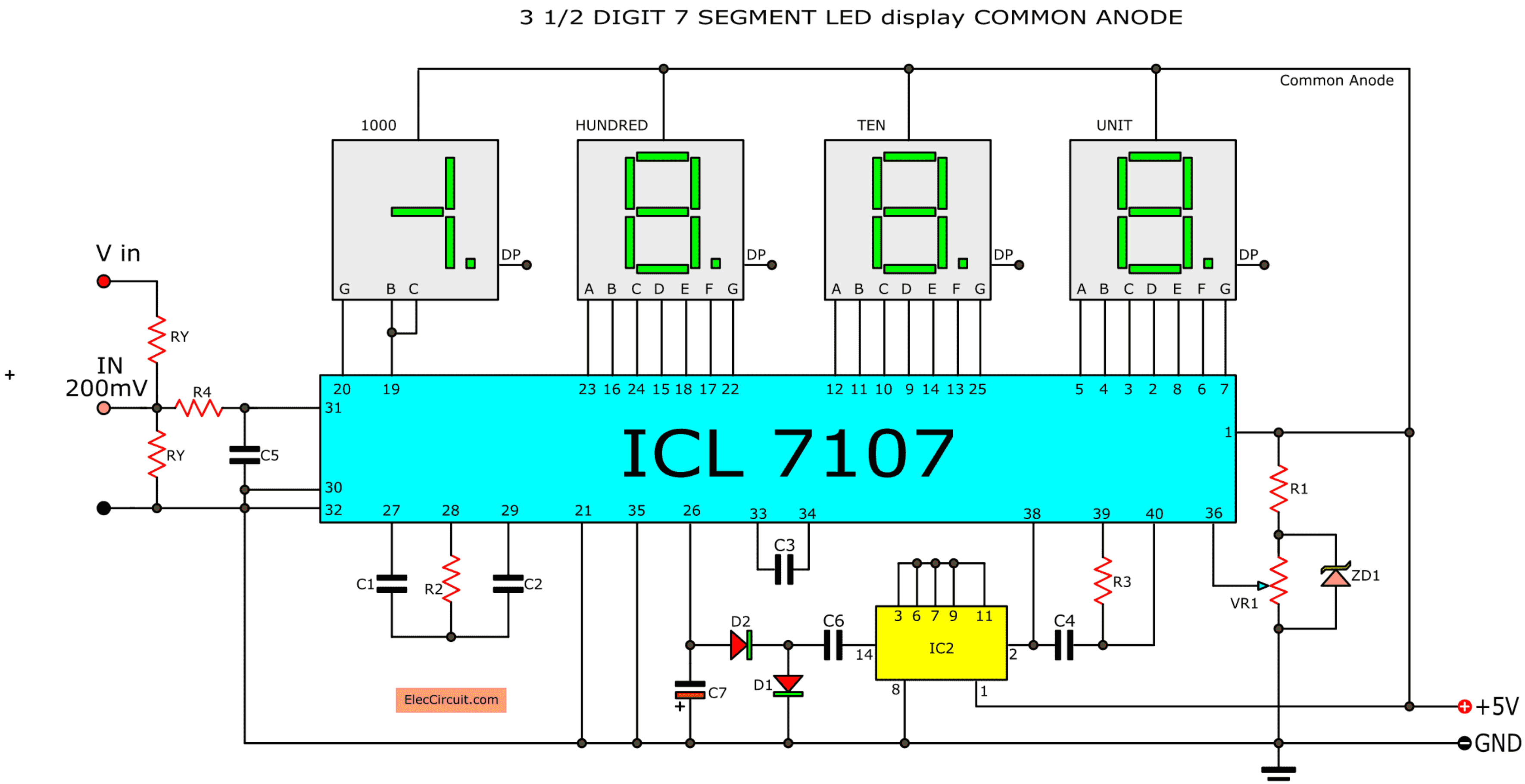
100 MΩ input Z

Taut-band meter, (precision components)

RF volts up to 500 MHz
Ohms to 500 MΩ
Amps down to 1.5µA FS

Bigger, older version

3.5 digit DVM (digital voltmeter)....less the range + function circuitry



Digital Voltmeter using ICL7107

Digital voltmeter/multimeter (DVM/DMM)

-based on ICL-7107 chip running on 5 VDC using LED or LCD display
-DVM IC + display replaces the d'Arsonval meter
-has a 0-200 mV basic range, is cheap and rugged

-high input Z (typ. 10-11 MΩ on all V ranges) (draws little power from measured circuits)

-typical accuracy of 1-2% on DC ranges
-2-3% accuracy on AC + assumes RMS

-greater precision + accuracy than d'Arsonval meter

-becomes multimeter using similar circuits to d'Arsonval meter

-for peaking circuits and devices, d'Arsonval meter often preferred

Cheap ($35-80) Digital Multimeter (DMM)

-rugged + portable, 9V battery
-1-2% accuracy (ohms, DC)
 -3-5% accuracy (AC)

-10-12 MΩ input Z
-precise, easy to read
-holds readings

-extra features:
  capacitor, diode, continuity,
  + transistor testers

32 ranges!

-not waterproof, cheap main switch,
-cheap test leads
-can't be re-calibrated, poorly repairable

Quality DMM: Fluke Model 117 $280

Advantages over "El Cheapo" DMM

-auto-range, good manual

-water + dirt resistant/proof

-better accuracy, specifications

-repairable, can be calibrated

-better switch, better materials

-more rugged

Digital panel meters: cheap (mostly), and available to measure anything!

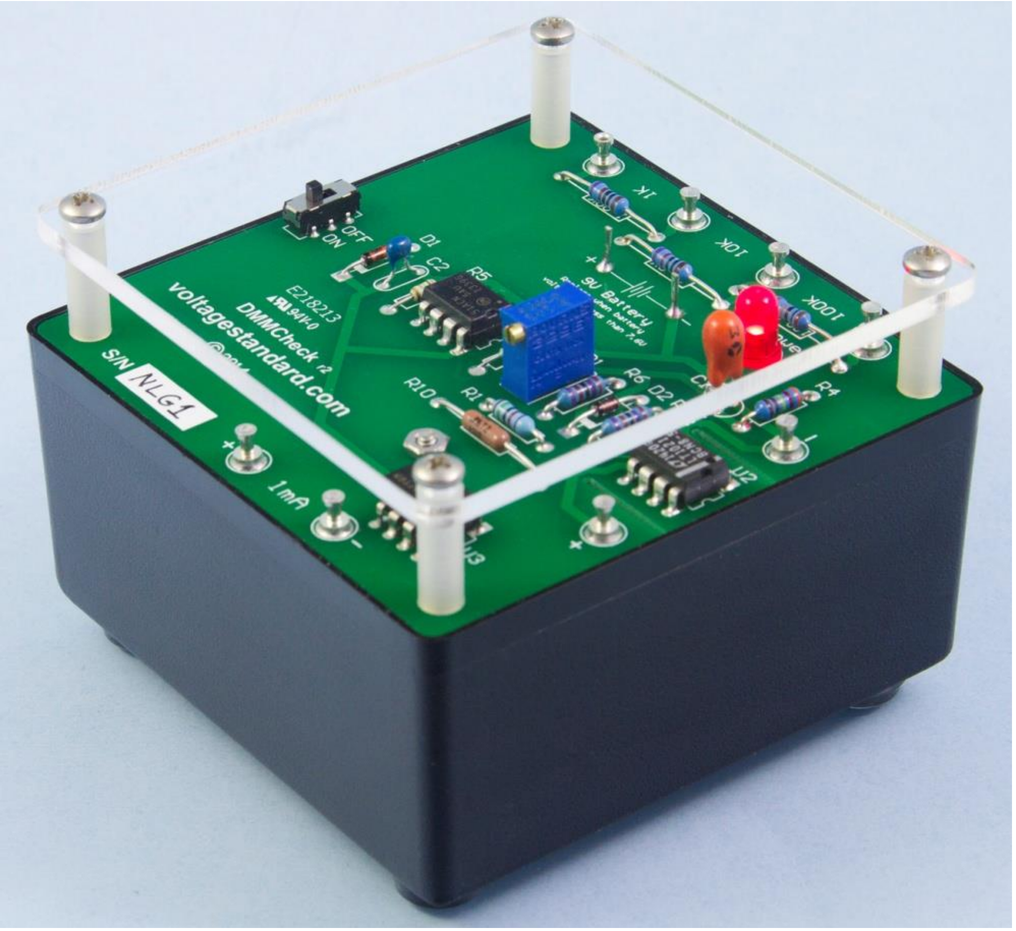
LCD

LED

Self- vs. externally-powered....watch out!

Are your instruments accurate?

Reference standard
-measured at 68°F/20°C



Resistance: (+/- 0.1%)
-100,001 ohms
-10,000 ohms
-999.8 ohms

Current: (+/- 0.1%)
-1.000 mA

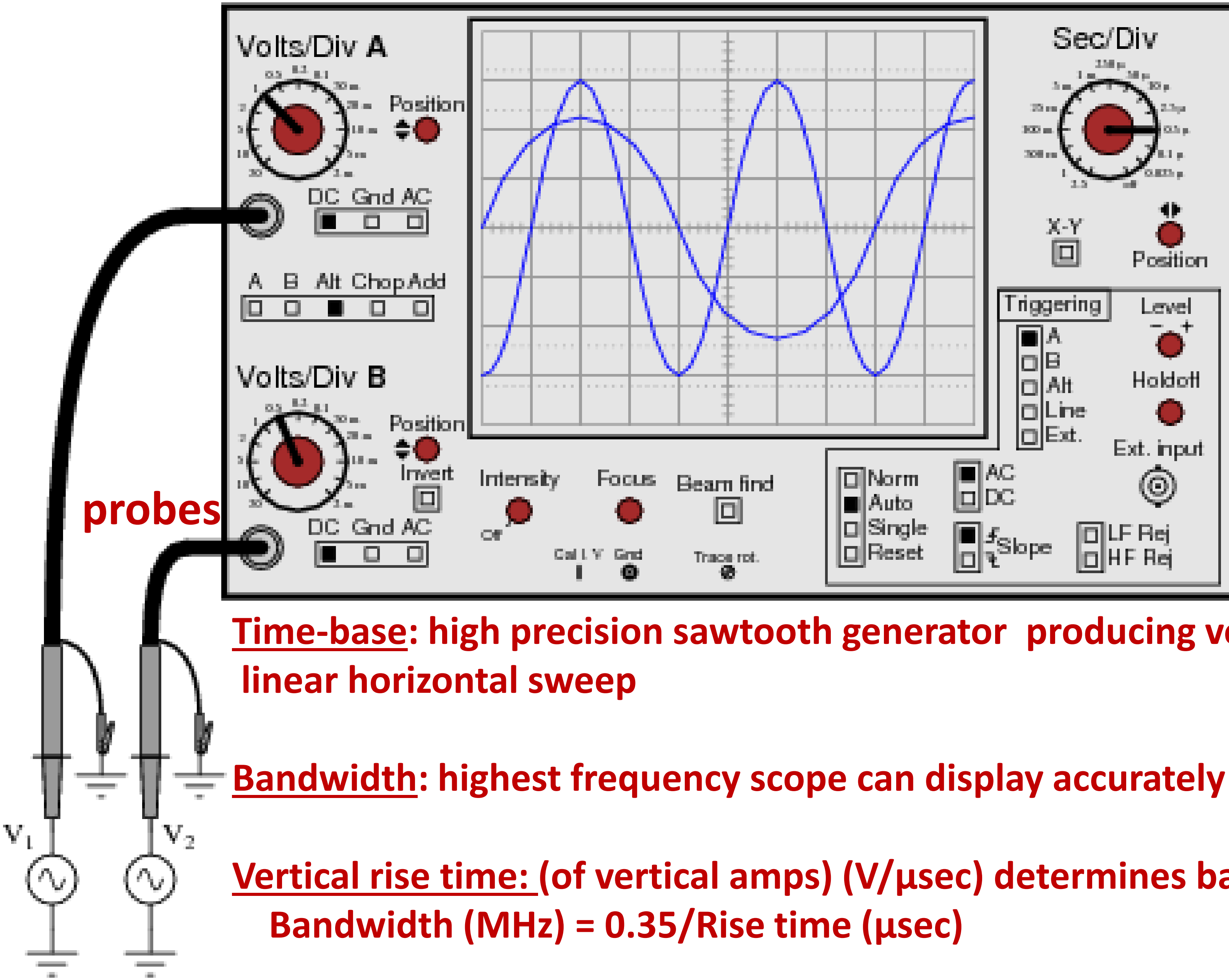
DC voltage:
-5.0000 VDC +/- 0.01%

Frequency? Zero-beat with CHU or WWV

DMMCheck $35

Malone Electronics
Voltagestandard.com

Visualizing AC + RF waveforms   Typical dual-trace oscilloscope



Time-base: high precision sawtooth generator producing very linear horizontal sweep

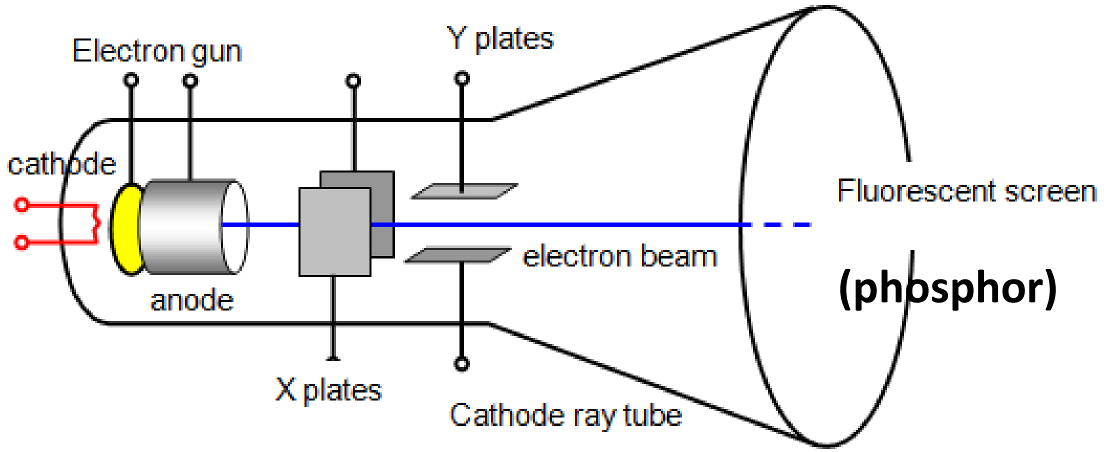
Bandwidth: highest frequency scope can display accurately (-3 dB point)

Vertical rise time: (of vertical amps) (V/µsec) determines bandwith

Bandwidth (MHz) = 0.35/Rise time (µsec)

Oscilloscope cathode ray tube (CRT)

-cylindrical beam of electrons fired at phosphor screen
-accelerated by 1500 VDC+ through round hole in anode
-beam deflected by voltages on X and Y plates



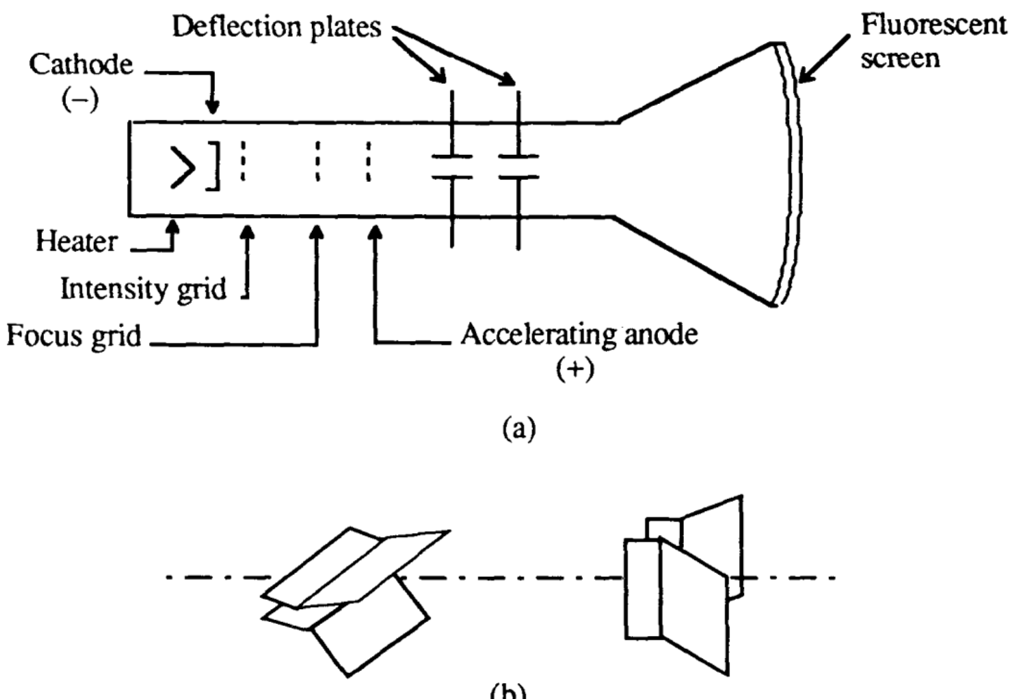
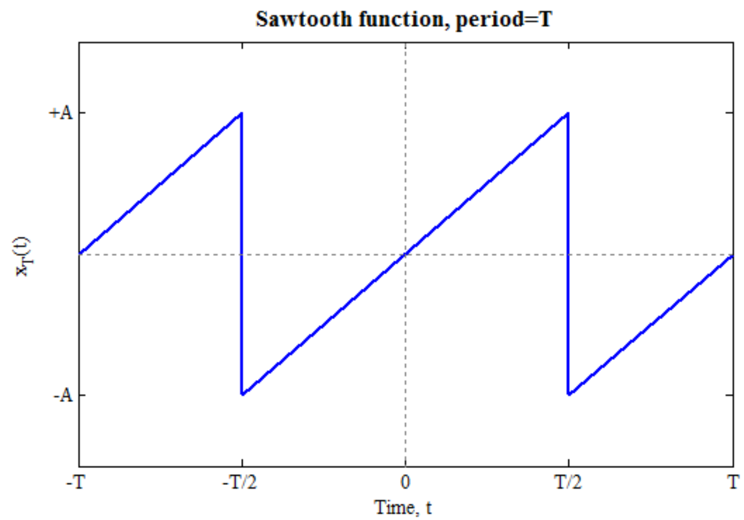


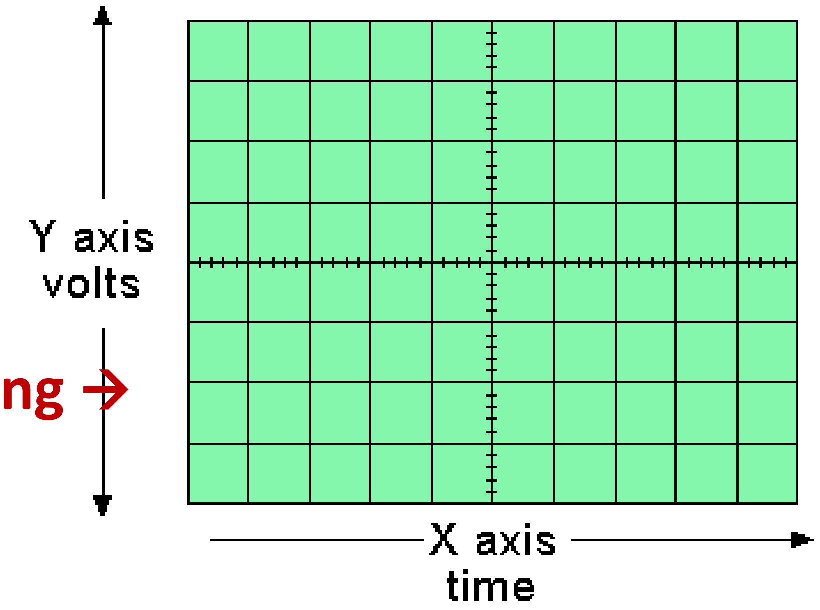
Figure 1. Cathode-ray tube: (a) schematic, (b) detail of the deflection plates.



Horizontal sawtooth sweep voltage
(Time-base oscillator driving X plates)

Oscilloscope screen

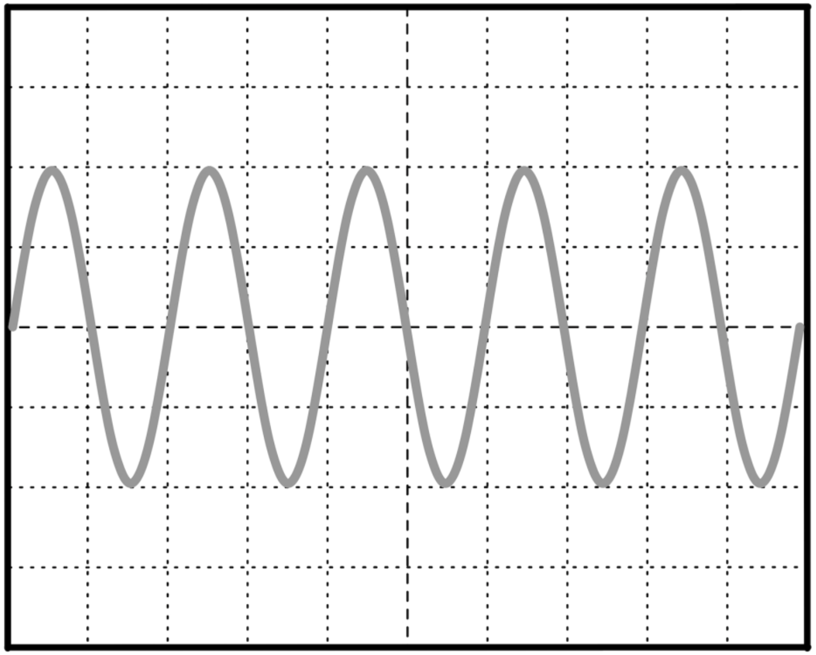
Graticule (usually 1 cm squares)
Removable by turning off side lighting →



Vertical scale in V/cm or mV/cm

Horizontal scale in seconds, msec, or µsec/cm

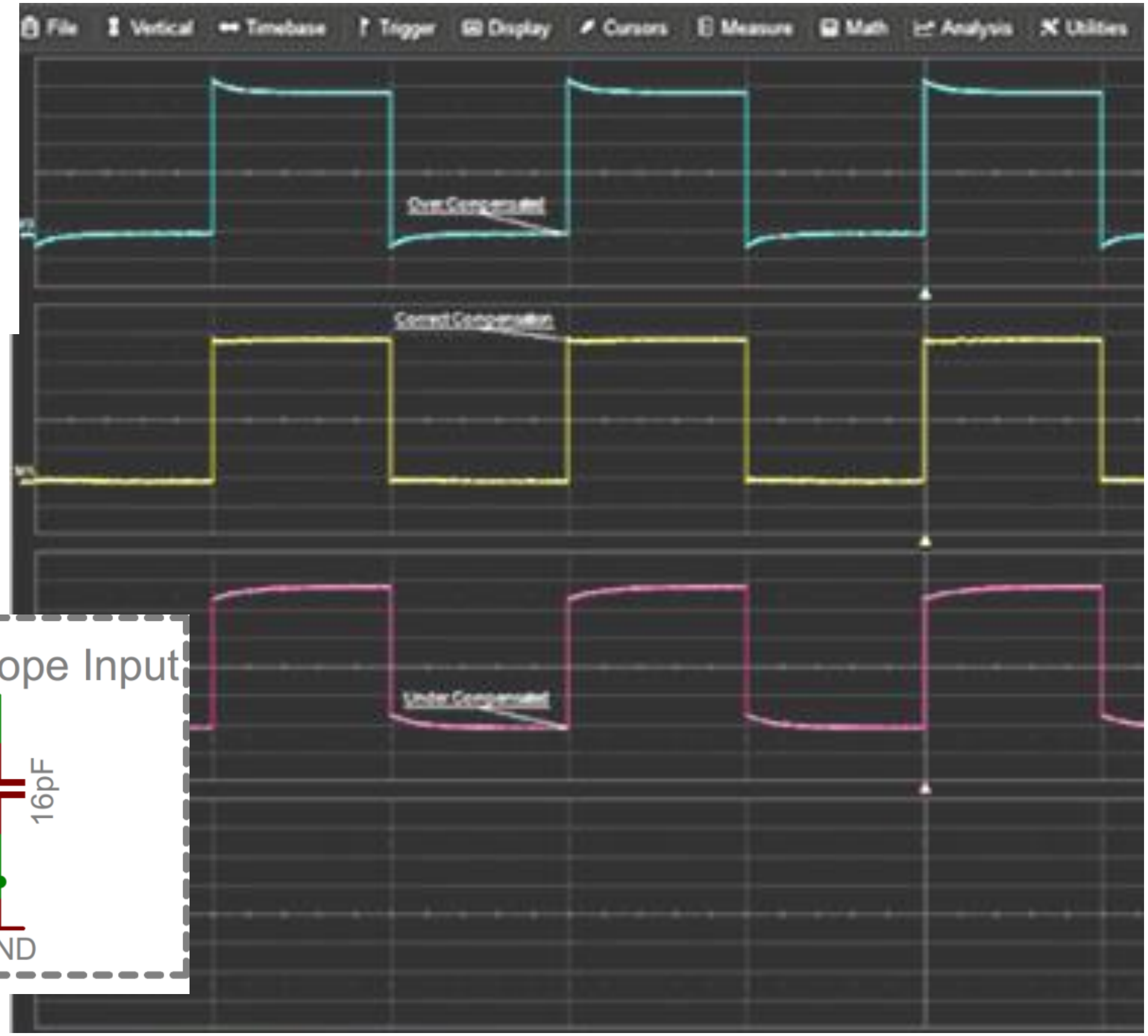
Center of vertical scale is usually 0 V, unless two vertical channels are being used

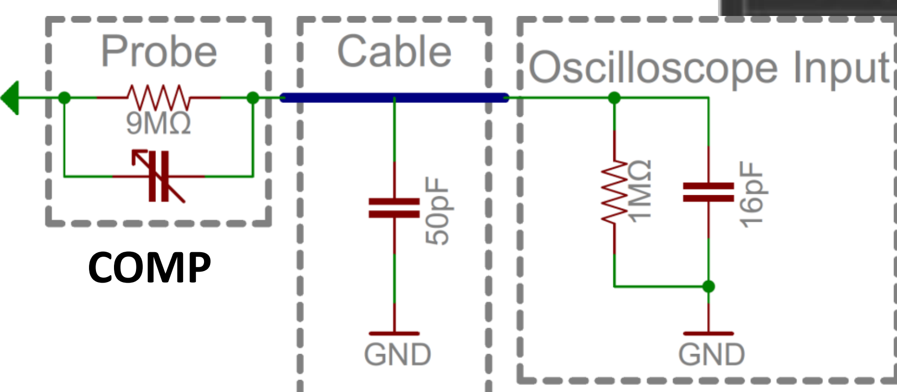


Adjusting an oscilloscope <u>probe compensator</u>: perfect square wave = maximum flat band-pass through the probe

-10 dB signal reduction

-Input Z rises from 1 to 10 MΩ

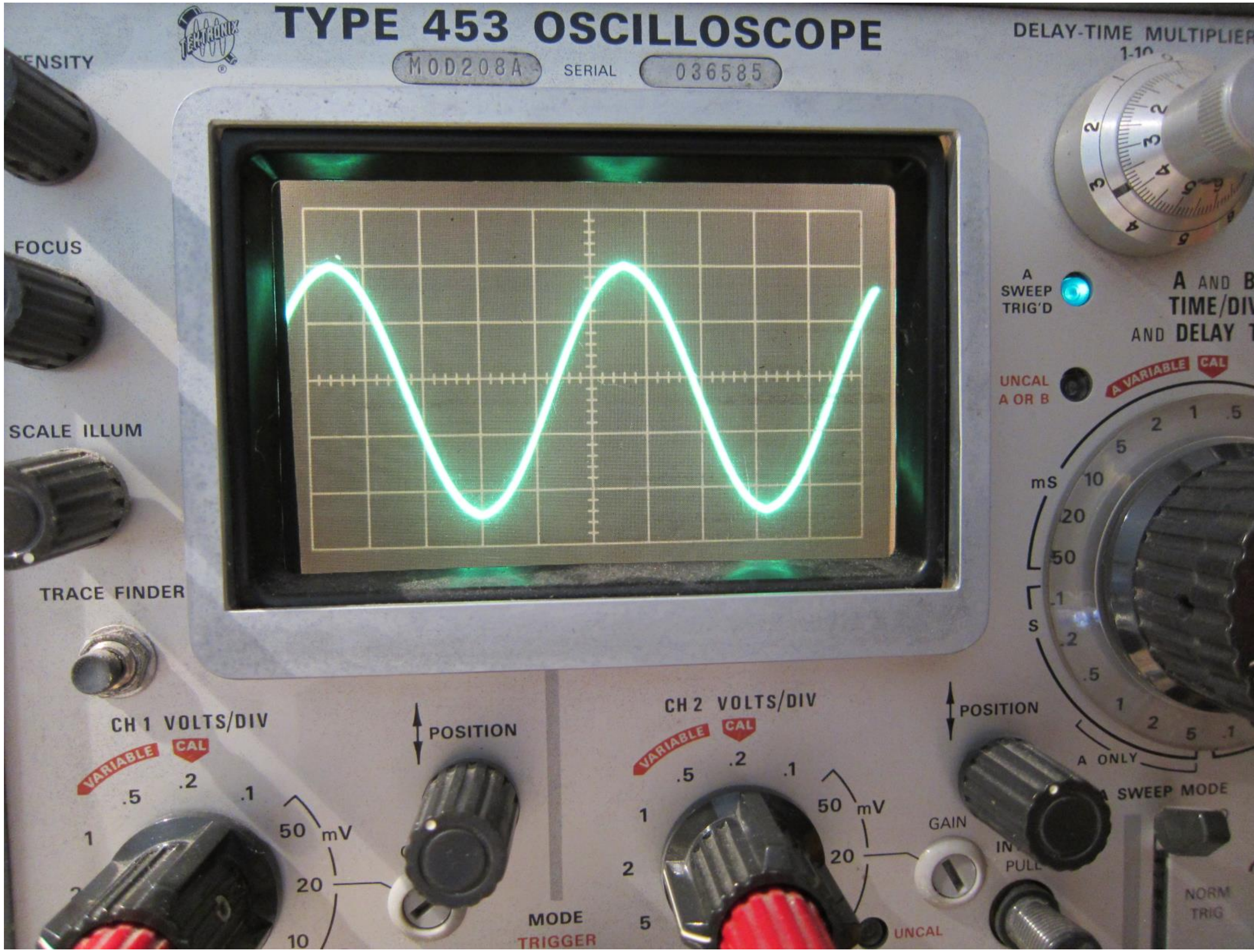




COMP

Use of the graticule, precision vertical amp (Y-axis) and precision time base (X-axis) gives waveform:

1. Shape
2. P-P voltage
3. Frequency
3. RMS voltage
4. Purity/ distortion



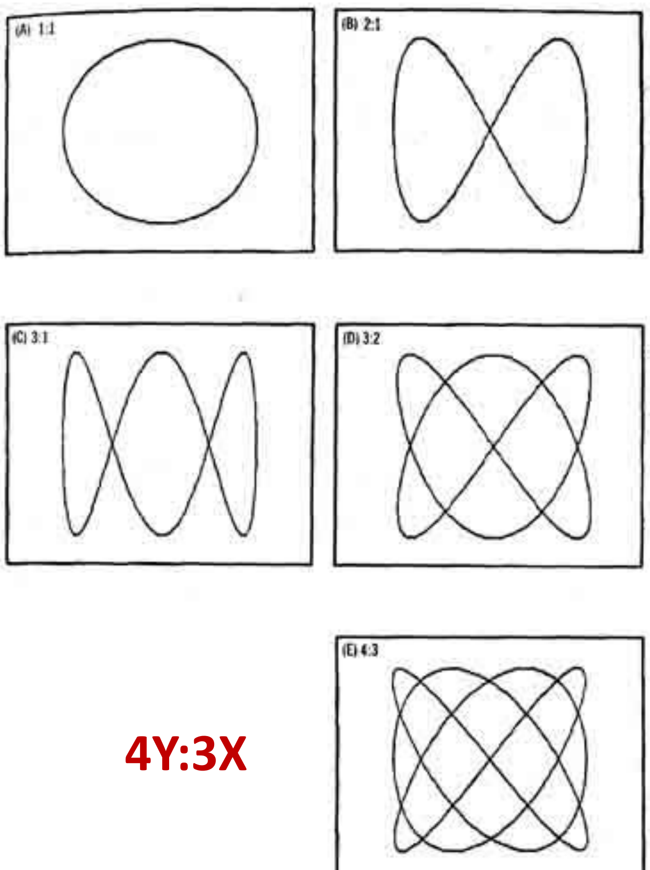
Frequency + phase measurements with Lissajous patterns

One frequency inserted across the X-deflection plates; a second across the Y-plates (same amplitude)

If F1 frequency known, and F2 is a simple multiple or fraction of it, F2 can be determined

Ratio comparisons

1:1
In phase +
Same
amplitude

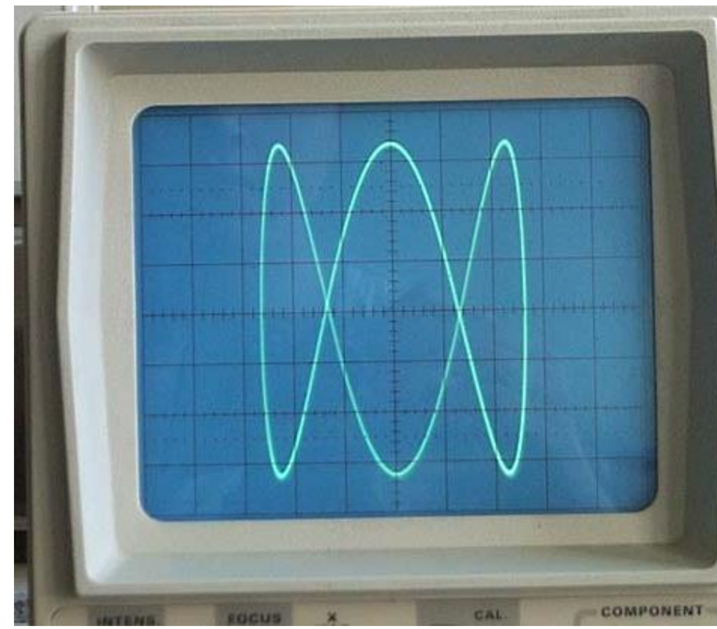


2Y:1X

3Y:1X

3Y:2X

4Y:3X



-both X + Y inputs must be sine waves!

Measuring the phase shift between X and Y signals

Useful for building phase-shift networks

X and Y sine wave signals should have the same peak amplitude

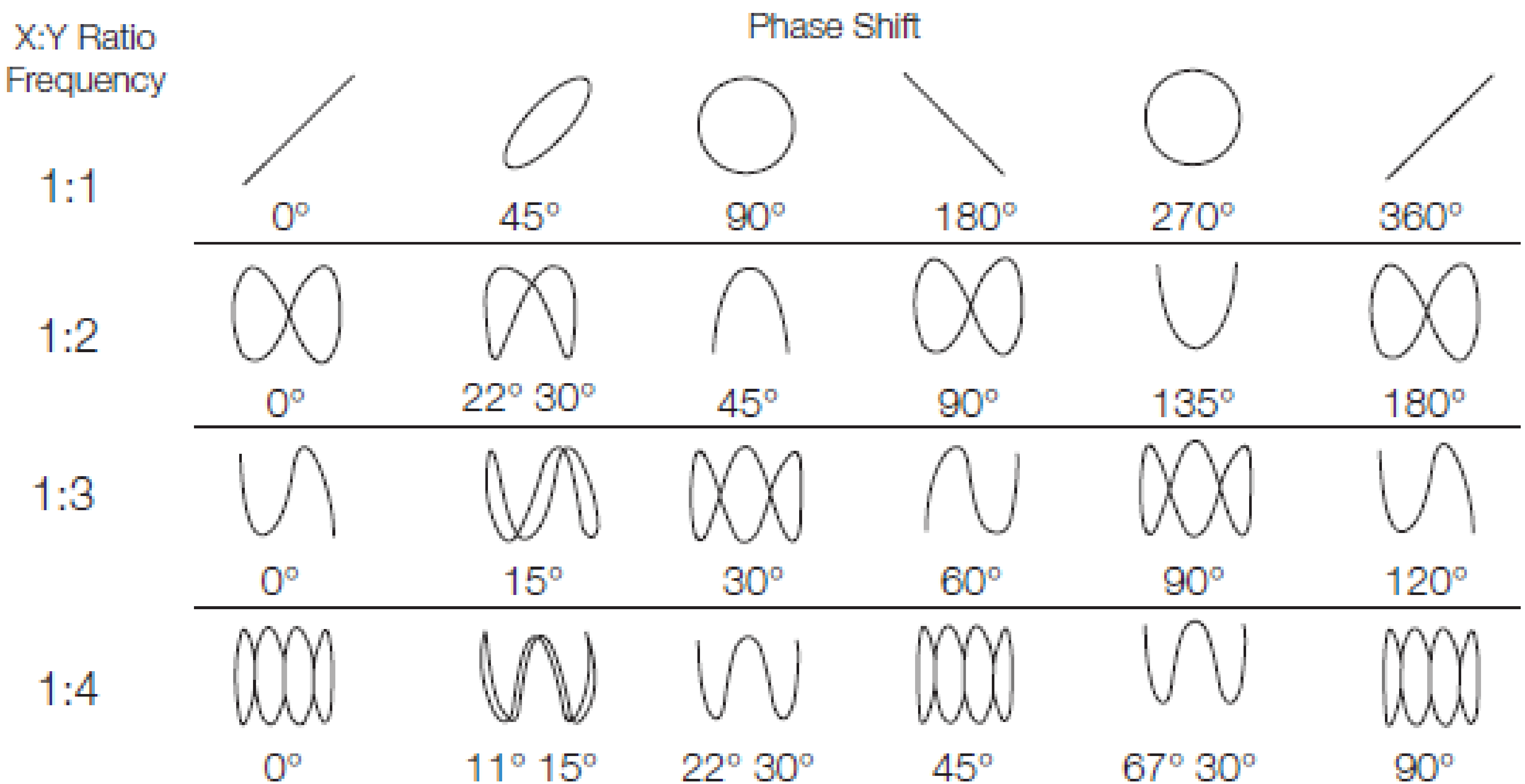


Figure 70. Lissajous patterns.

Modern Digital Scopes

-digital storage

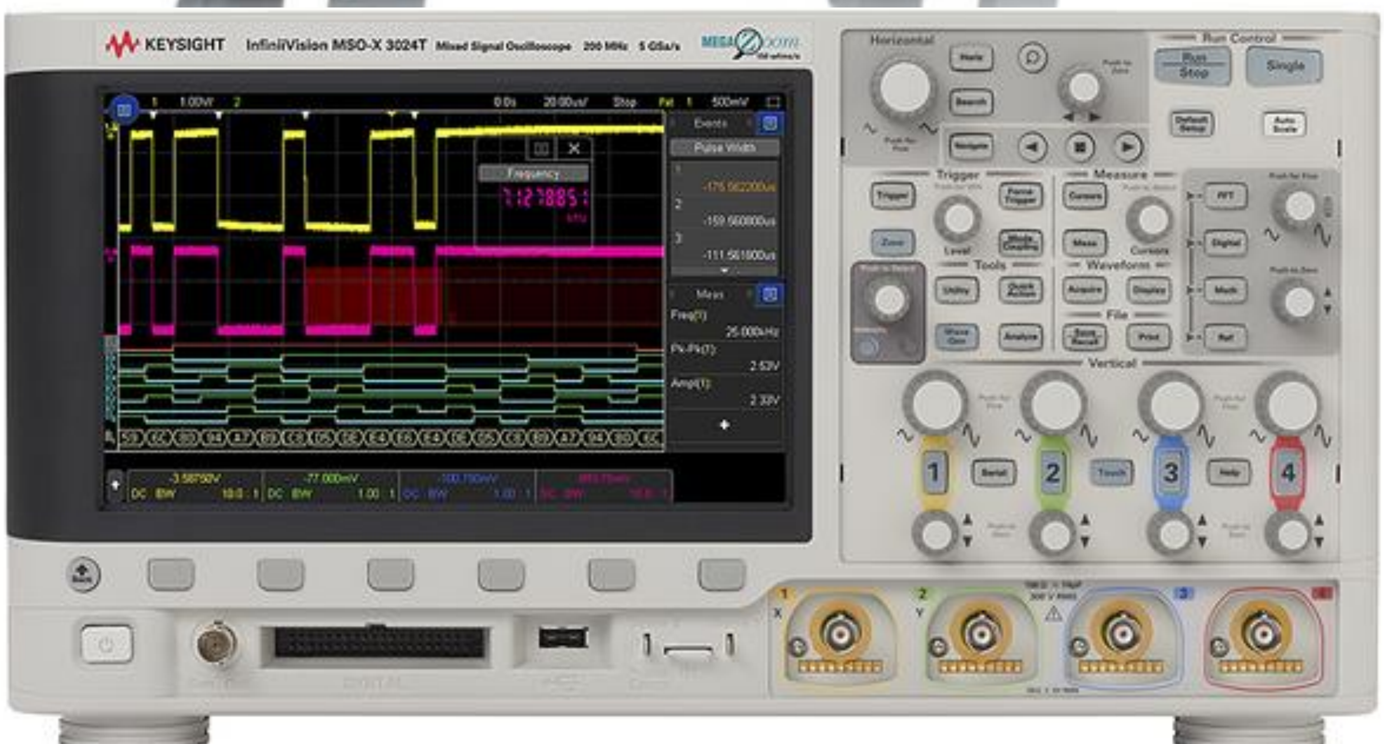
-digital V,A, time, freq.

-no CRT

Rigol 200 MHz

-2-channel

(note depth)



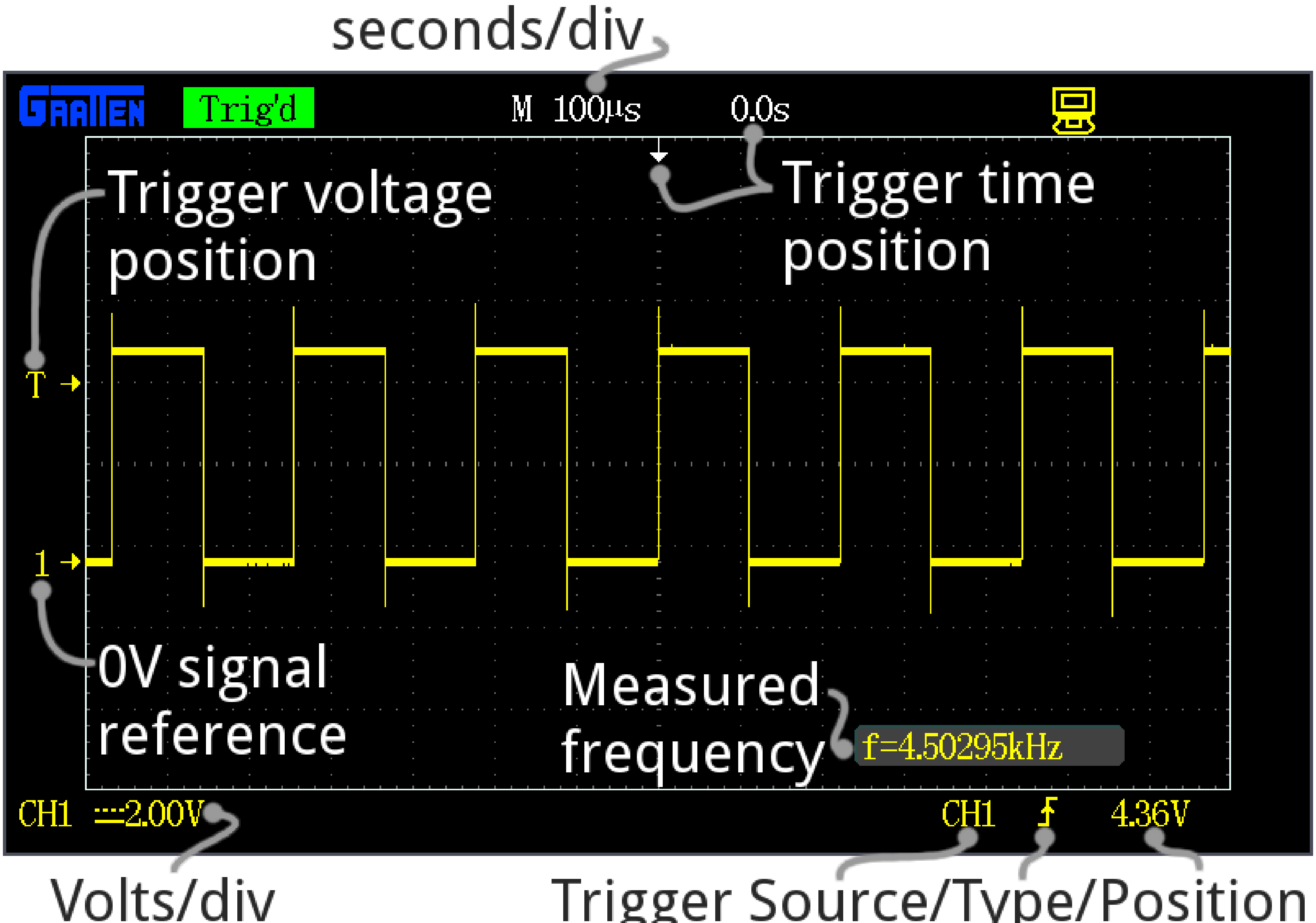
Keysight 200 MHz

-4-channel

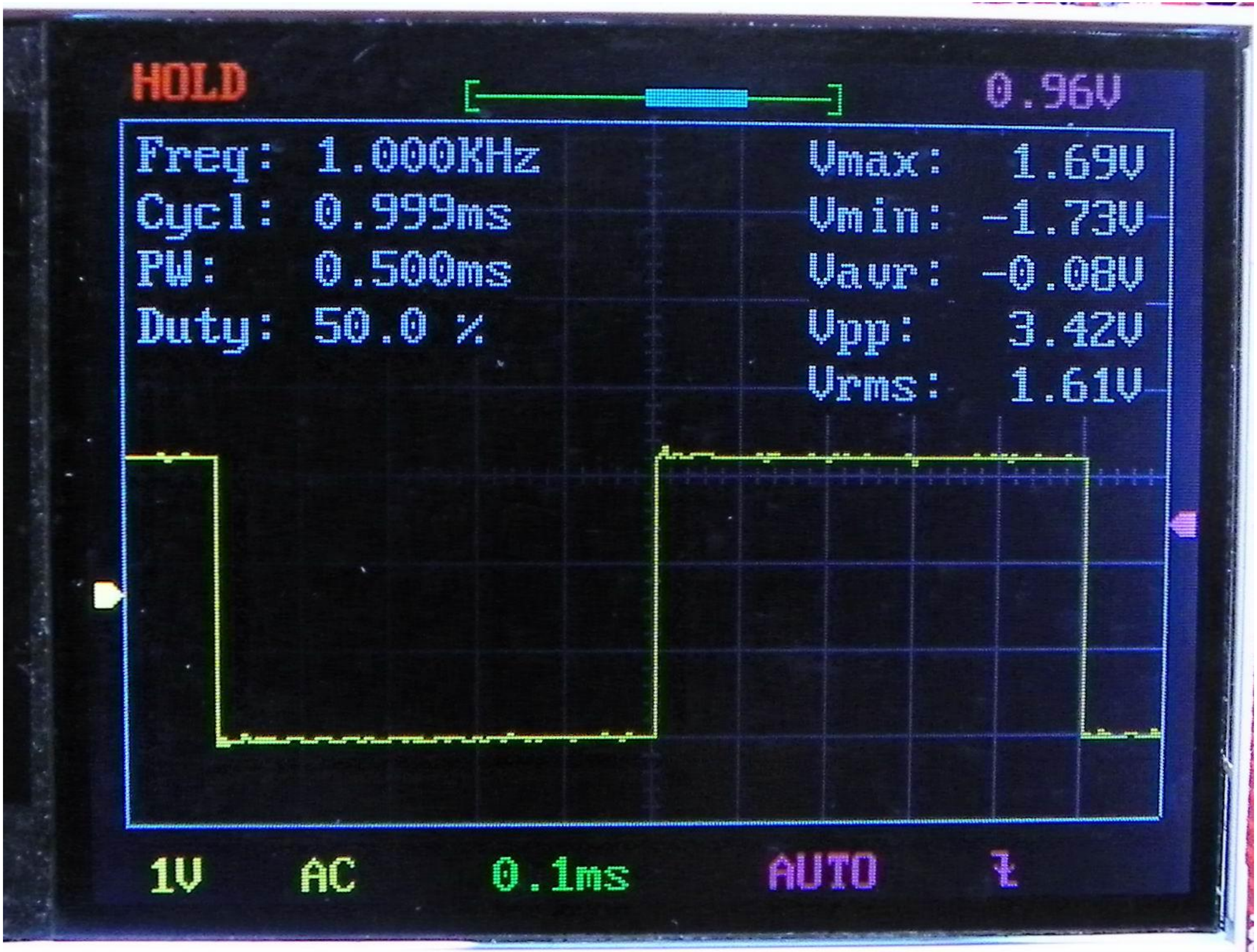
-note USB, SD card ports

-color-coded traces

Digital scope can provide a LOT of accurate data!



Modern scope accuracy + precision!



“Multimeter Format” Digital Oscilloscopes

Computer-based oscilloscopes

-usually USB compatible

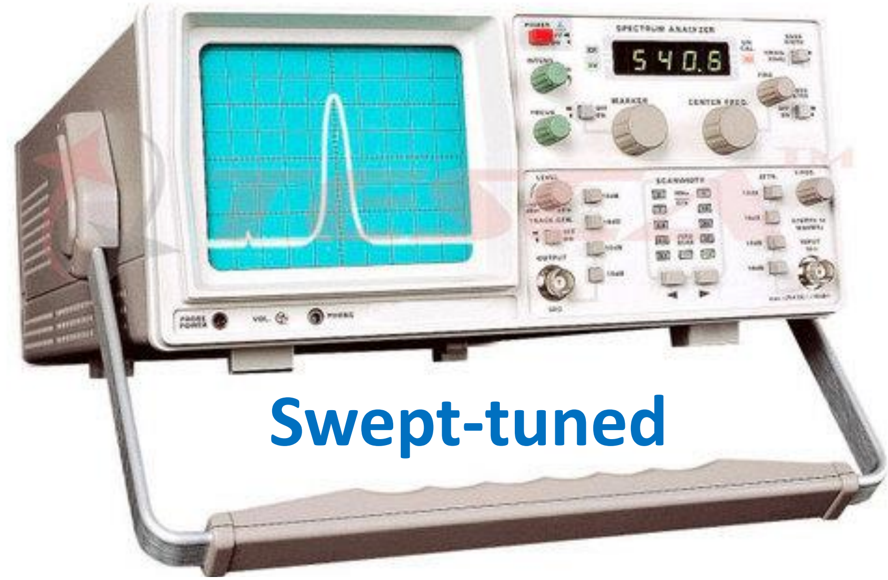
Spectrum Analyzers

Good for viewing/measuring:

-spectral purity of RF emission
-strength of harmonics
-IF strip bandpass
-filter band-pass, band reject
-amplifier bandwidth

-view all detectable signals in any segment of the RF spectrum

-response profile of any circuit



Swept-tuned

Real time

$330 USD

<1 MHz-3.0 GHz

Frequency counter (1 Hz-525 MHz)

-counter + gating time base + display

8-digit <u>precision</u>, 7-place <u>accuracy</u> **TTL chip counter**

10.000000 MHz internal precision oscillator (time base) calibrated against WWV

-can be "GPS disciplined" for extreme accuracy

Frequency counter accuracy

-cannot be more accurate than its crystal "gating" oscillator

-if 6-place accuracy, and 8 display digits, last 2 digits are meaningless

-crystal gating oscillator error increases with frequency measured

e.g.: if +/- 5ppm error,

Measured frequency	Error (uncertainty)
100kHz	+/- 0.5 Hz
8 MHz	+/- 40 Hz
21 MHz	+/- 105 Hz
146 MHz	+/- 730 Hz
440 MHz	+/- 2.2 kHz

Dirty signals with high harmonic content often count falsely high

Counter sensitivity

-should be able to count down to 10 or 15 mV P-P signal

-sensitivity falls as frequency rises

-many cheap counters need hundreds of mV or more to count

RF signal generator: produces wide range of clean, stable signals with controlled amplitudes

A good RF generator will produce RF outputs:

-over a wide range of frequencies, e.g. 10 kHz-50 MHz, or 0.2 MHz-520 MHz

-from 0.1 µV to 0.5 V @50 Ω (>1 dBm to <-140 dBm @ 50Ω) amplitude (cheap + old generators use single-layer shielding and leak too much RF to meet the low-level specifications)

-that can be FM or AM modulated @400 Hz or 1000 Hz

- that are amplitude and frequency stable, are accurate, and can be set precisely

Analog RF signal generators: 3 vintage, 1 current

-all good for older radios, but <u>not adequate</u> for full testing/alignment/repair of modern transceivers and receivers

<u>Weaknesses</u>

-low frequency stability/accuracy/readout precision

-inadequate shielding for sensitivity measurements

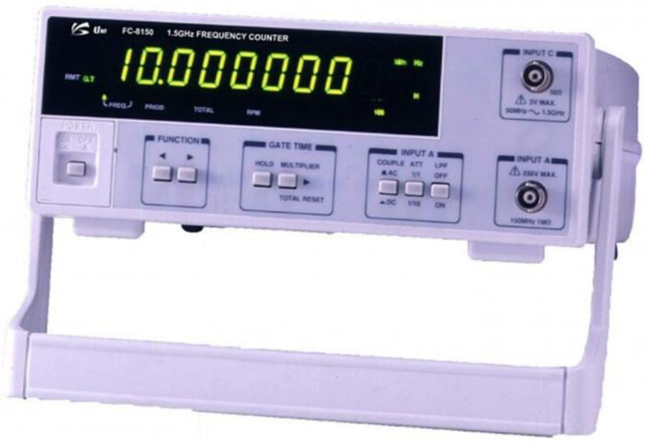
-no good for VHF, UHF

Wavetek M-3001 RF frequency generator

- -0.2 to 520 MHz, 0.001% stability + accuracy
- -.01 µV to 1.00 V rms output @ 50Ω (triple shielded)
- -PLL technology (signal has some distortion)
- -AM, FM, or no (CW) modulation
- -calibrated against WWV

URM-25F RF signal generator: 10kHz-50 MHz

-so-so stability, but pure, clean signal, good attenuator
-frequency counter accuracy (with added counter)
-compliments the Wavetek (high stability, 0.2-520 MHz)



+

Hewlett-Packard (H/P) 8656B: 1980s RF signal generator: good for servicing modern transceivers!

-typical of many high-quality older units

Function generator: based on dedicated IC: XR-2206

-generates sine, square, triangle and sawtooth (sweep) waveforms

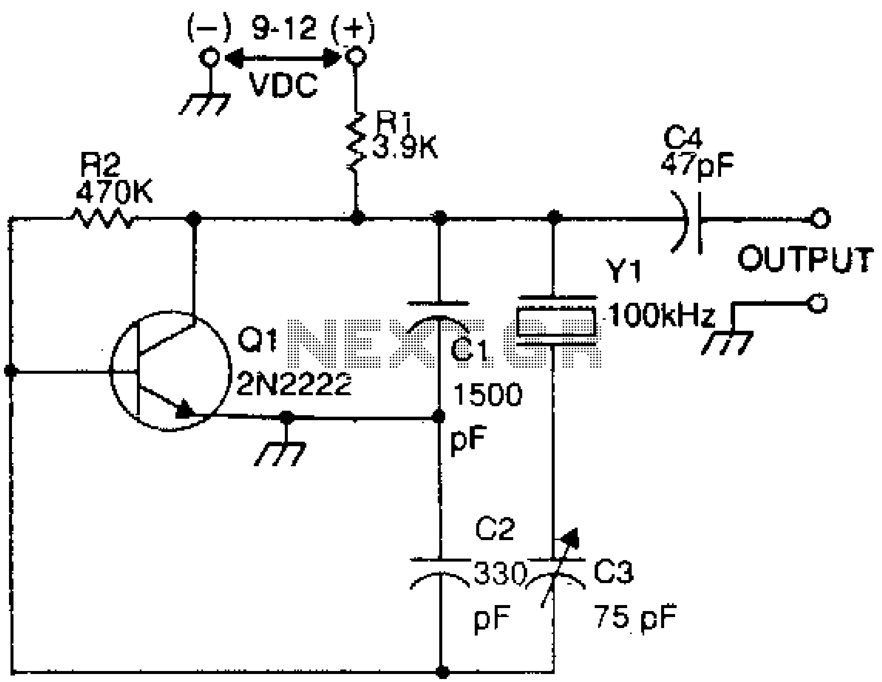
-0.2 Hz to 2.0 MHz

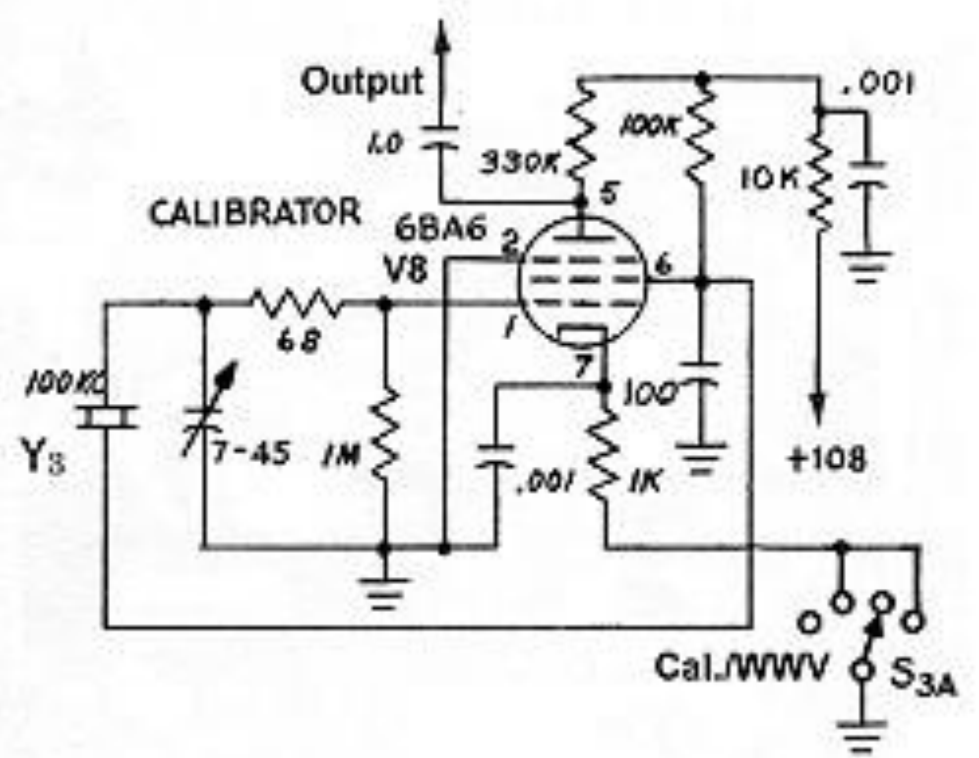
- useful for both analog and digital

-sweep can be used with O-scope to sweep a band of frequencies (IF alignment)

The crystal calibrator: increases the frequency accuracy of your older TX or RX

-calibrator "zero-beat" against 10 MHz WWV frequency standard (100th harmonic)



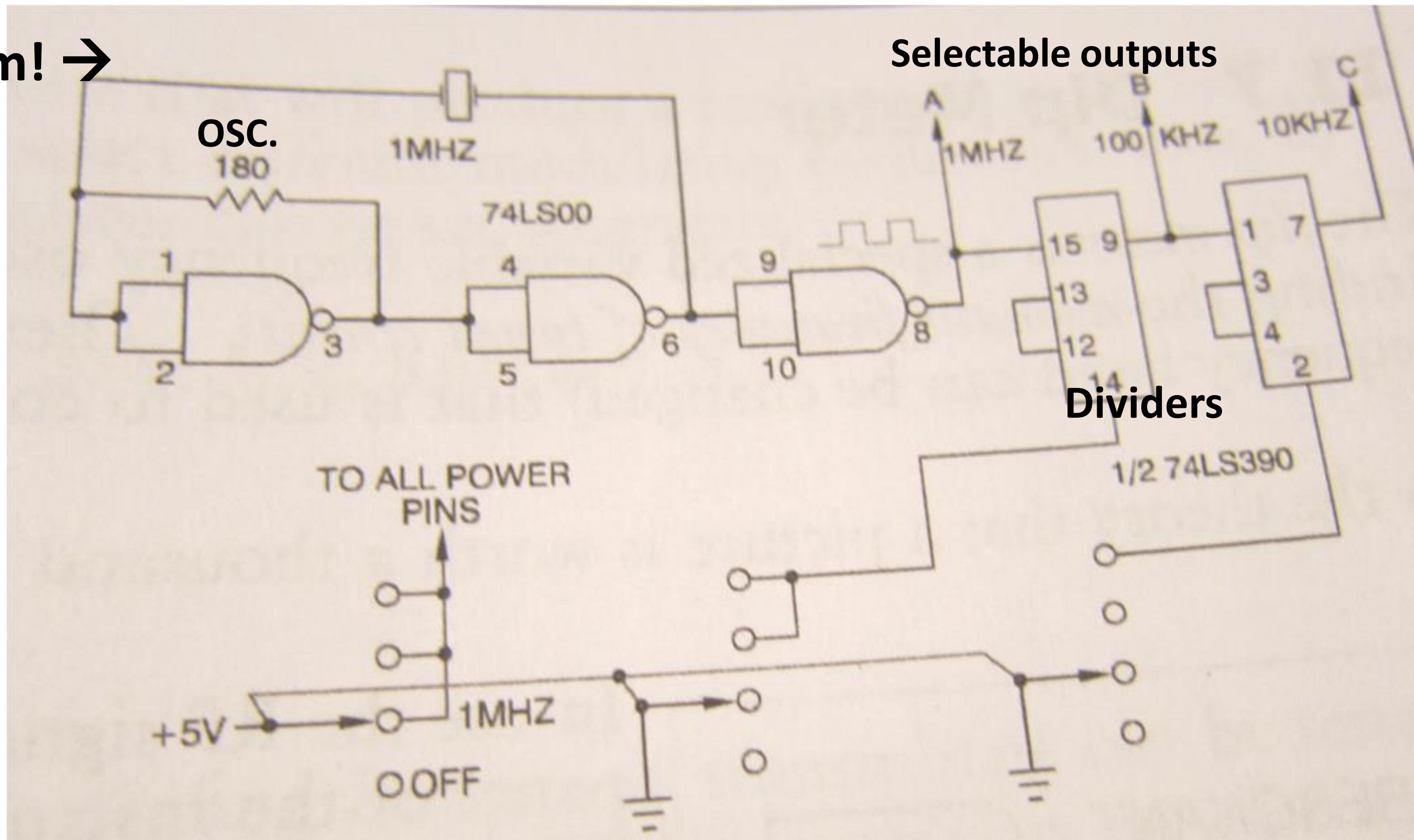


Time Base/ Crystal calibrator/Frequency Marker

-can put exact multiples of the output frequency (A or B or C) through the HF bands

-listen on your RX, compare center of harmonic to RX frequency display, and see how accurate your RX frequency display is.

NO osc. trim! →



Audio test generator

H/P "Wein Bridge" low distortion audio gen. →

Pure sine wave: 5 Hz→500 kHz

For building, testing all kinds of audio frequency circuits + amplifiers

Two-Tone audio test generator

-used to test linearity of SSB transmitter

-two sine waves injected at mike input

-700 and 1900 Hz used often

-when second audio tone is added, TX signal power should double

-if it doesn't, the TX response isn't linear

Grid/gate-dip meter

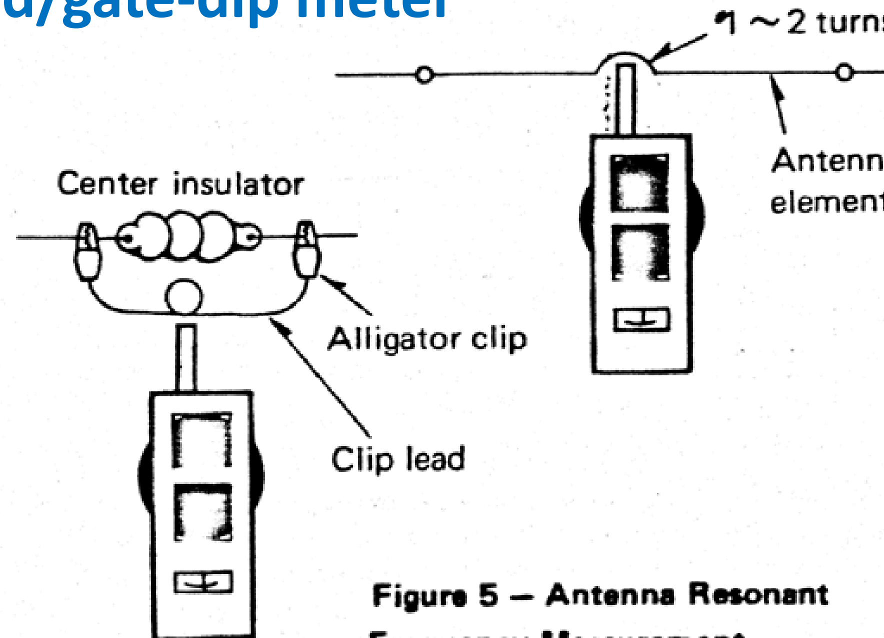
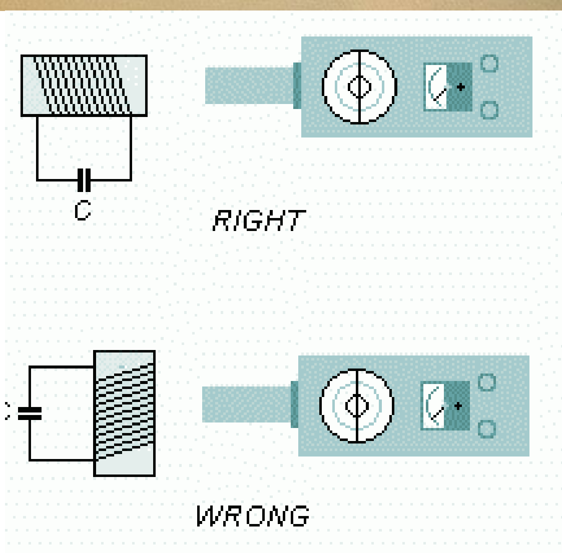
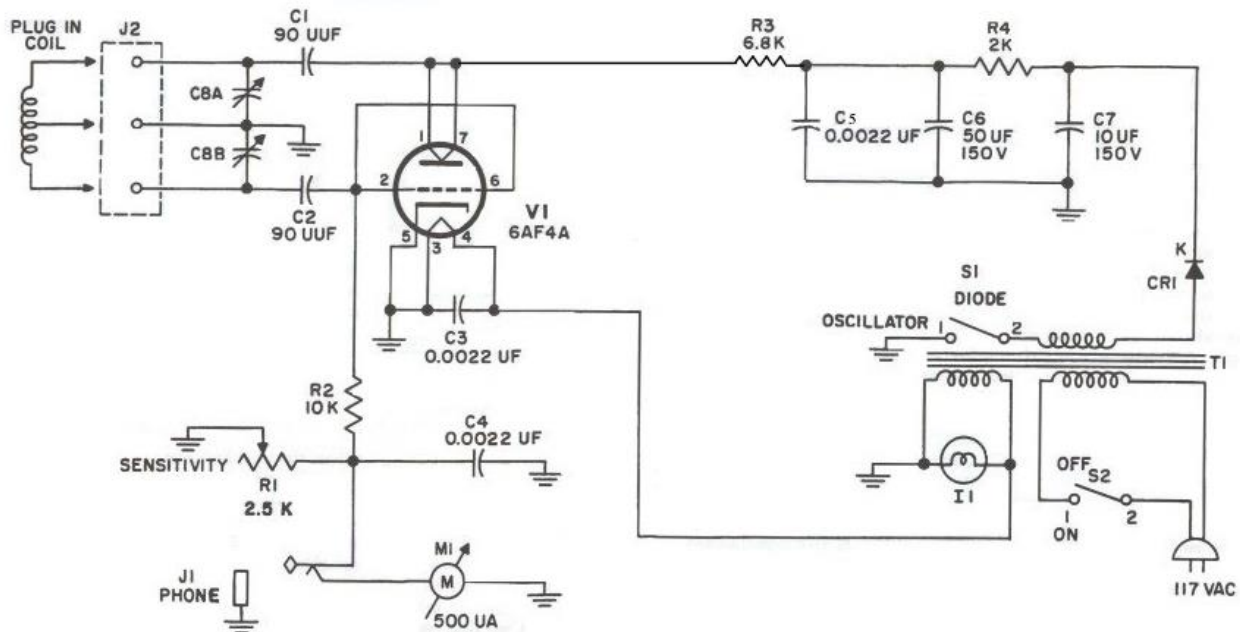
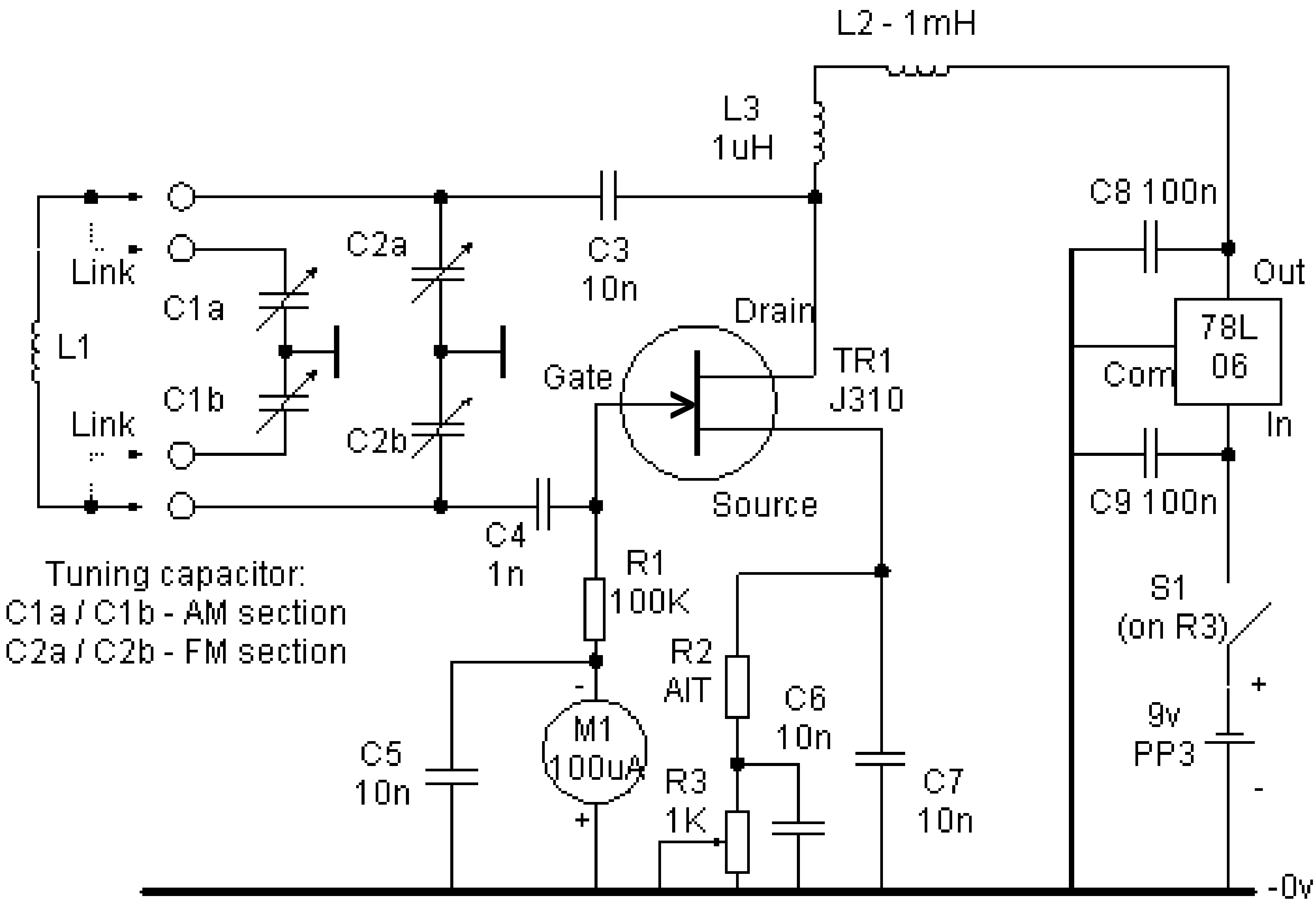


Figure 5 – Antenna Resonant Frequency Measurement.



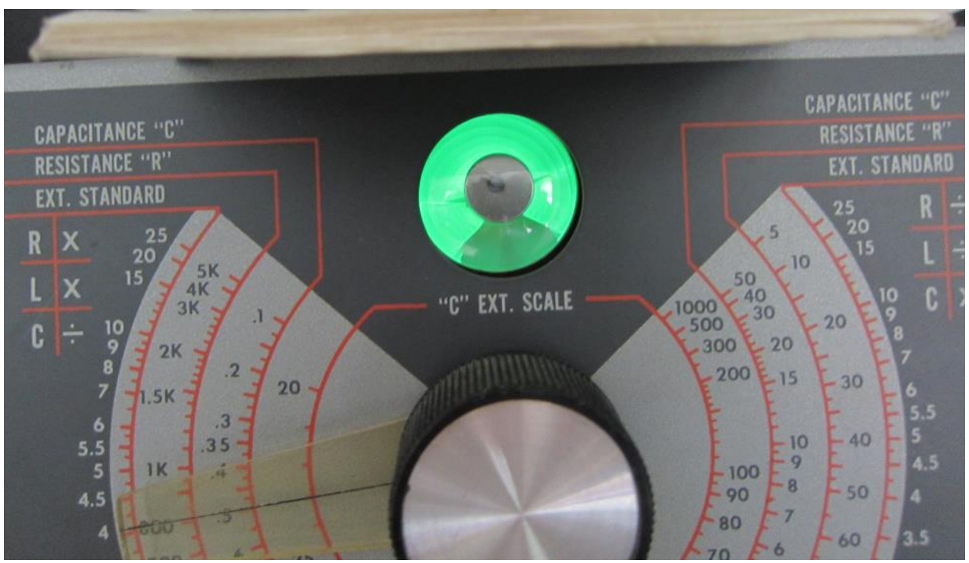


Gate-dip Oscillator



Capacitor tester + re-former

-capacitance (15pF-500 µF)
-tests for leakage up to 1000 MΩ
-tests capacitor at rated voltage
-allows gradual re-forming of electrolytics
-allows long-term testing of electrolytics



Variable Power Supply: 0 to +/- 20 VDC @ 1 A

-essential for testing components, new circuits, building projects
-can limit current to 10 mA -1000mA
-can run op-amps needing both + and - voltages

RF power reference: Bird #43 →

-with the right "slugs", good from mW to kW, and from LF to UHF

-designed for Z = 50Ω, 5% accuracy

-a reference from which to calibrate other Pwr/SWR meters

50Ω 100W dummy load with RF sampler

-sampler: 100 x voltage attenuation @ 50Ω

A good dummy load:

-non-inductive

-VSWR = 1:1.0

-shielded

-can handle power applied

Good quality 50Ω Power/SWR meters

Accuracy? Precision? Readability?

Daiwa
CN-801

1.8-200 MHz
0-20, 0-200, 0-2000 W
Peak or Average

1.6-60, 125-525 MHz
0-200 W

Also very useful for Amateur TRX, TX, and RX testing and repair:

Tuner - power meter - dummy load - antenna switcher:
excellent for HF transceiver evaluation+ repair!

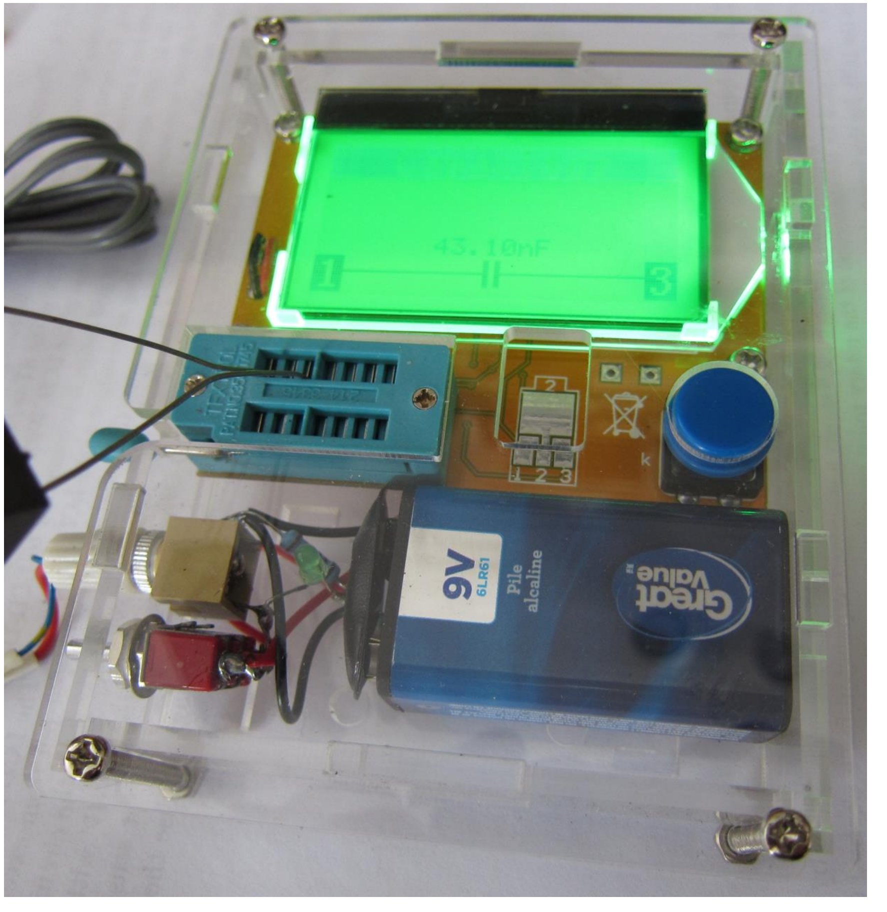
Modern HF transceiver can: listen to signals + modulation, generate precision RF

The "Component Tester" -$26 CAD on Amazon.ca

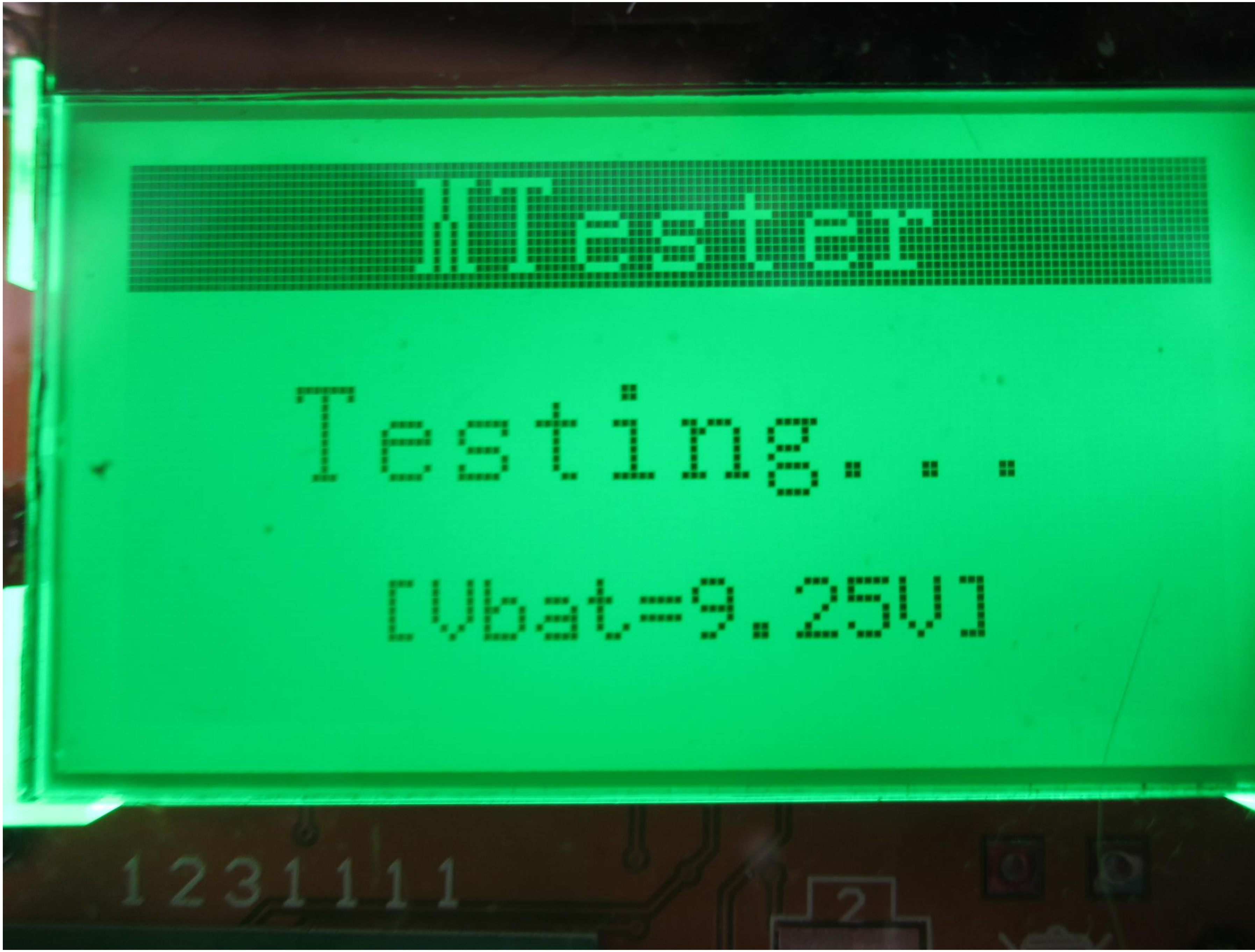
-accurately tests wide variety of electronic components
-based on AT Mega 8 Microcontroller with 32kb flash,
2kb SRAM, 1kb EEPROM
-Karl-Heinz Kubbeler manual on line (kh_kuebbeler@web.de)

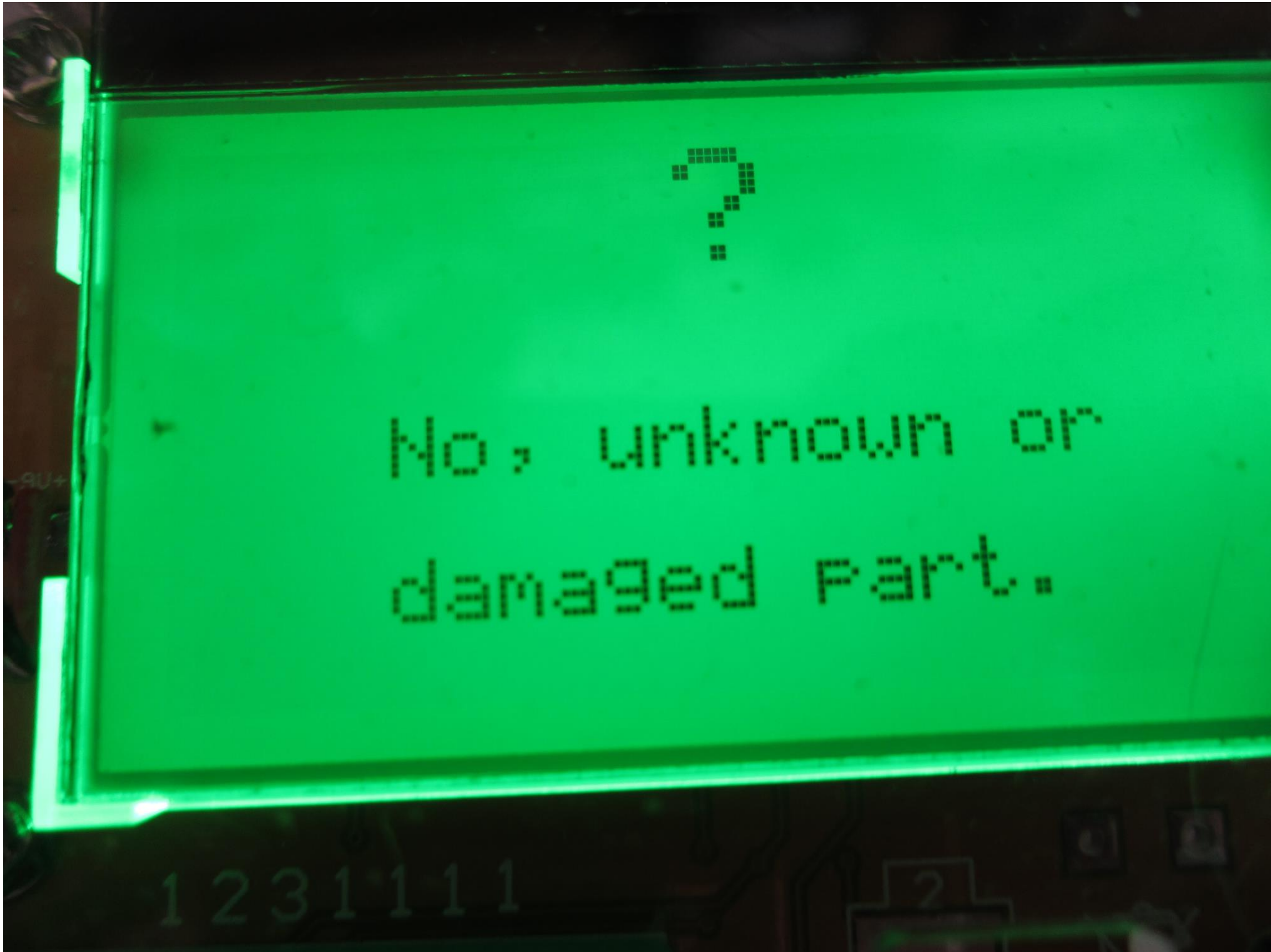
Programmed functions measure:

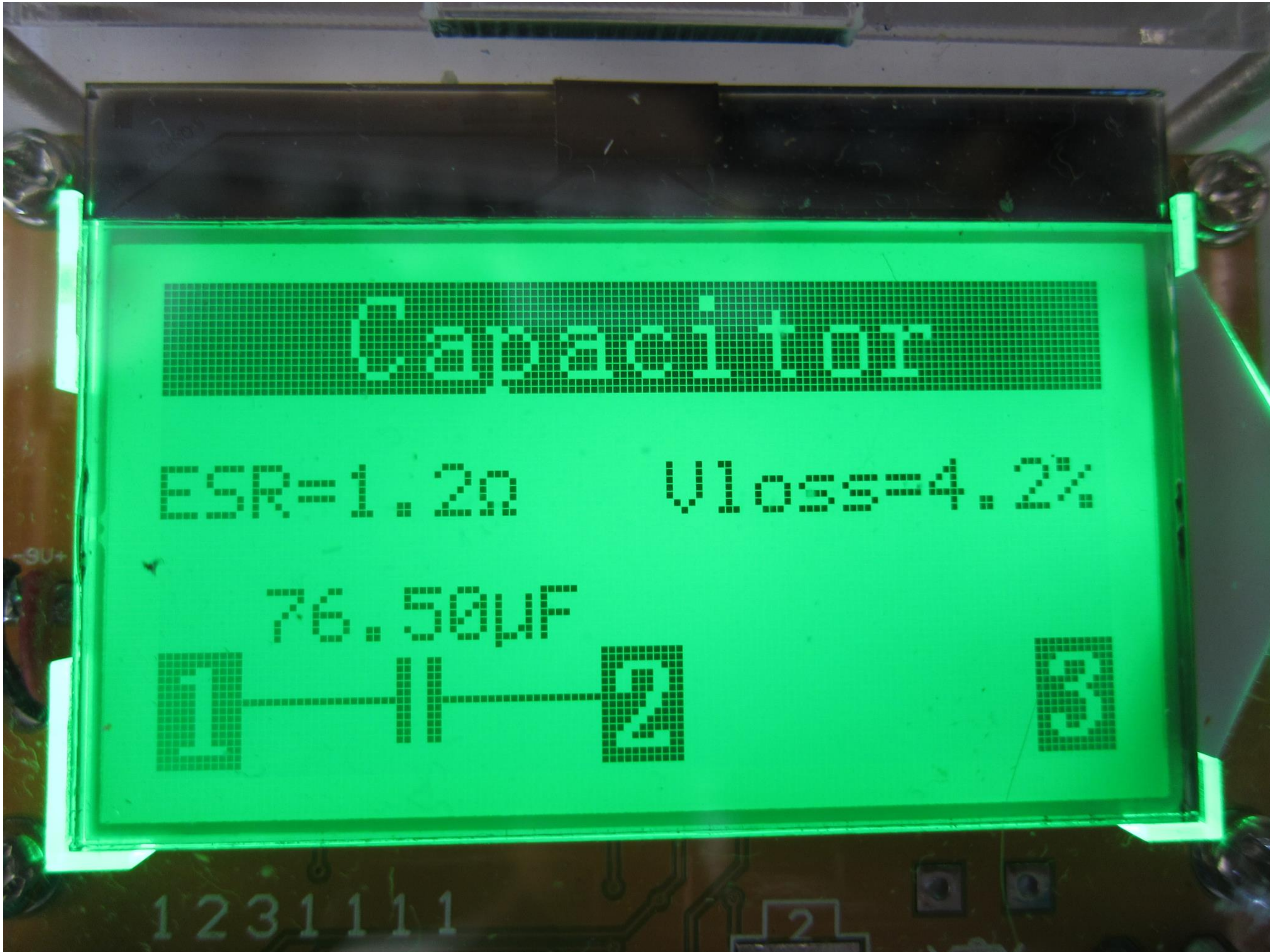
-resistors, R-voltage dividers
-inductors
-capacitors (30pF* → 10,000 µF)
-PNP + NPN bipolar transistors
-JFET, MOSFET (N+P-channel)
-diodes (power, Zener, signal, LED)



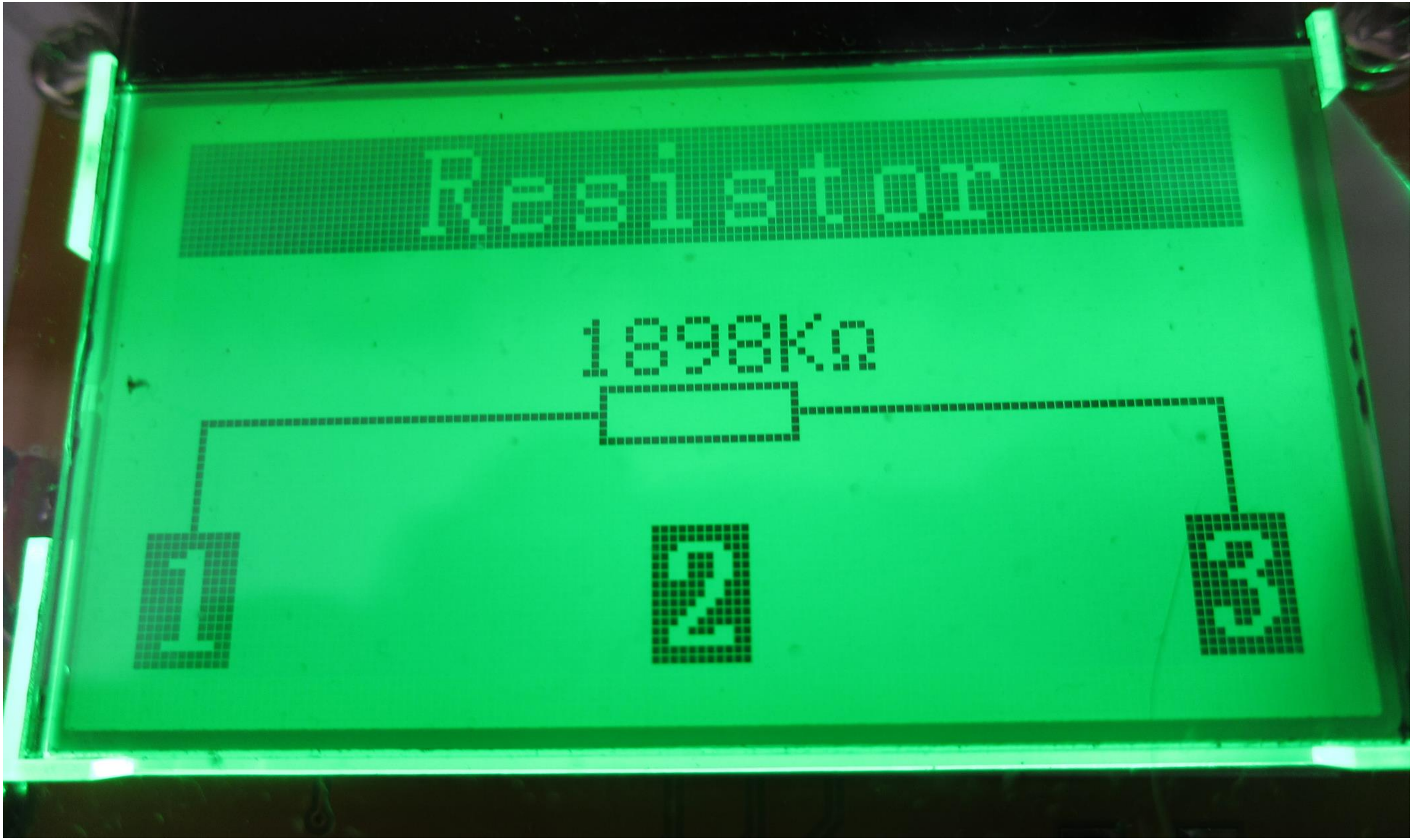
1. Determines what each device is.
2. Identifies the leads.
3. Provides advanced information on device.

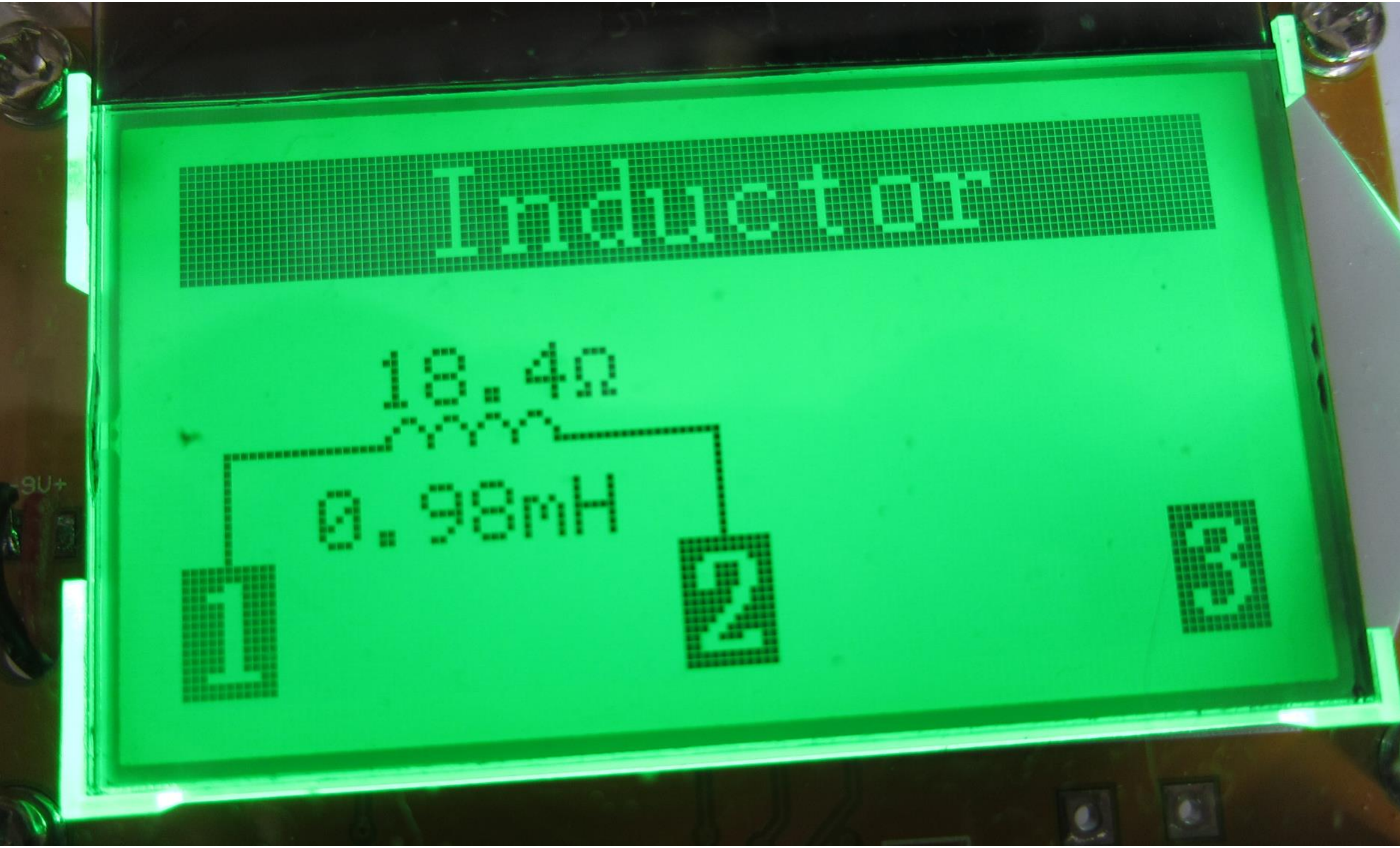

Tester
Testing...
[Vbat=9.25V]

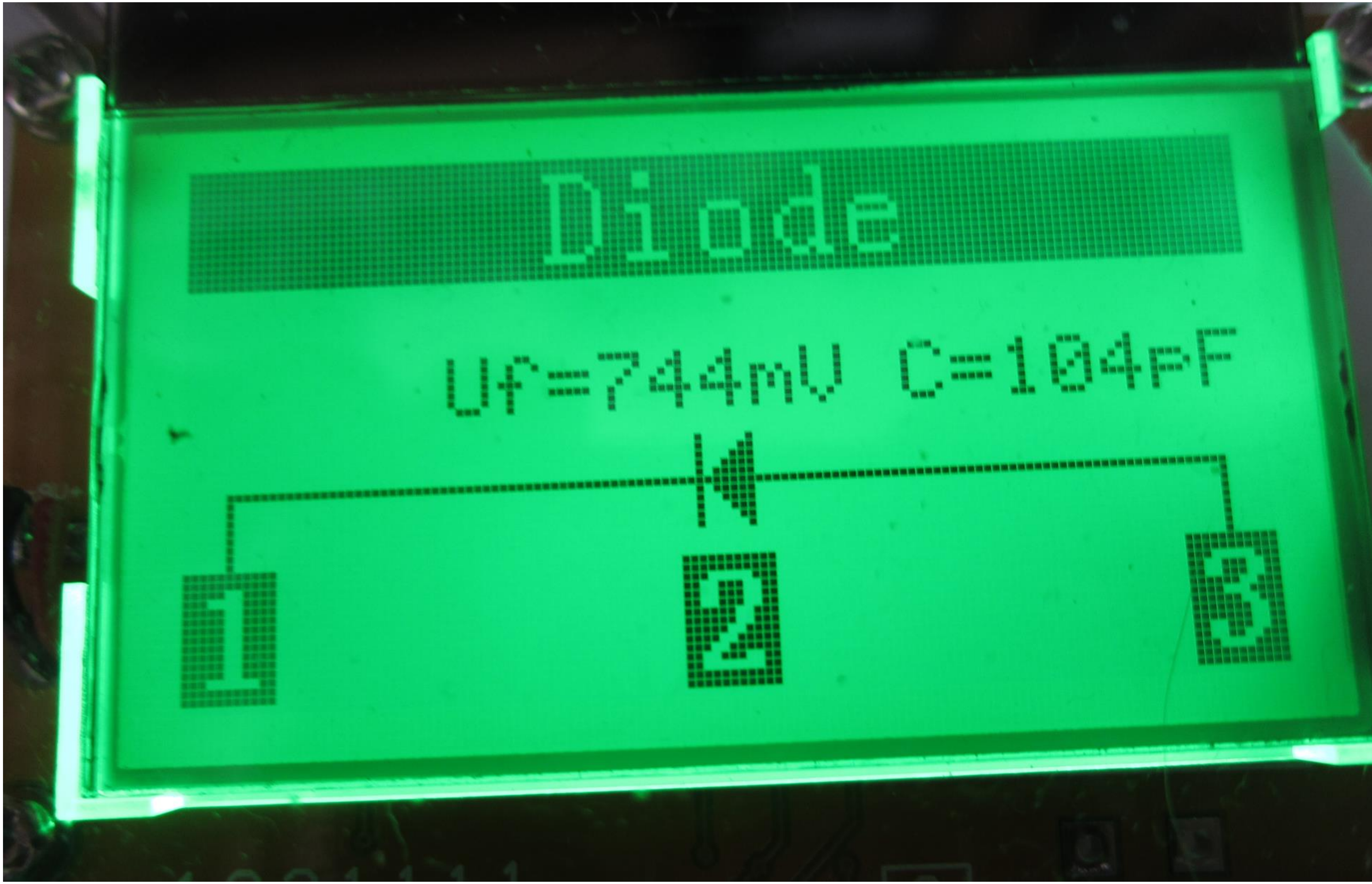

?
No, unknown or
damaged part.
1231111

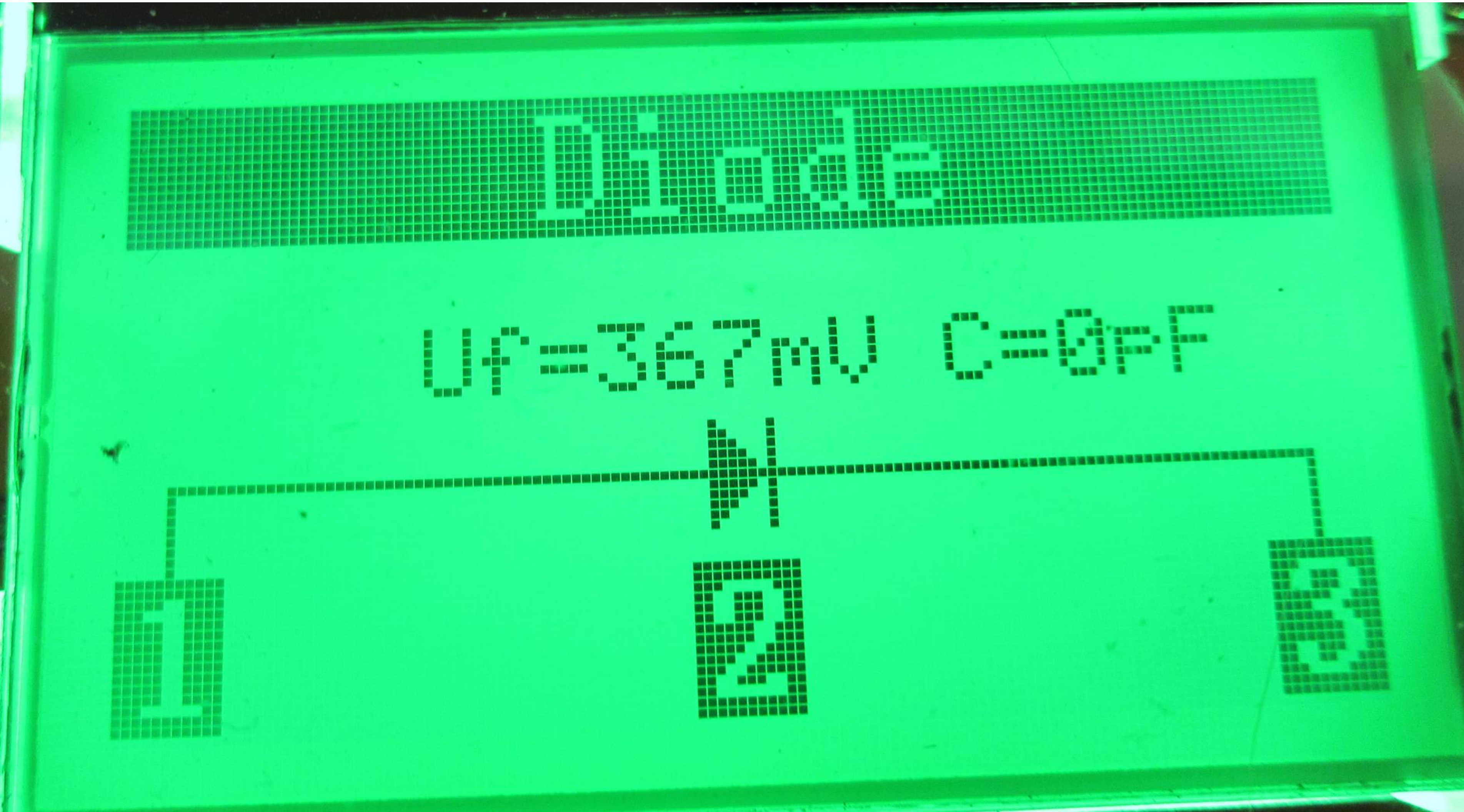


Capacitor
ESR=1.2Ω Vloss=4.2%
76.50µF
1
2
3
1231111
2

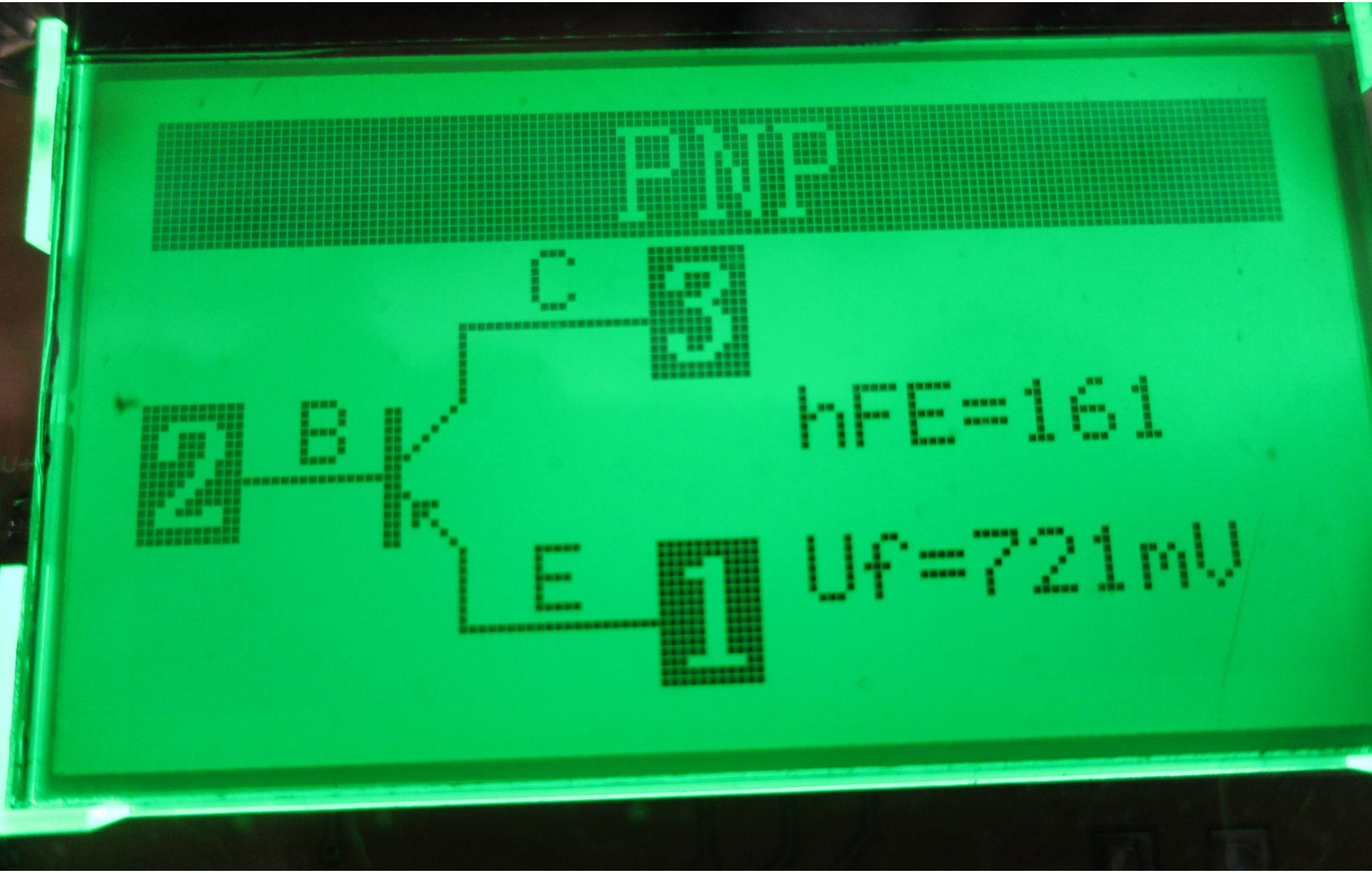

Resistor
1898KΩ
1
2
3


Inductor
18.4Ω
0.98mH
1
2
3


Diode
Uf=744mV C=104pF
1
2
3

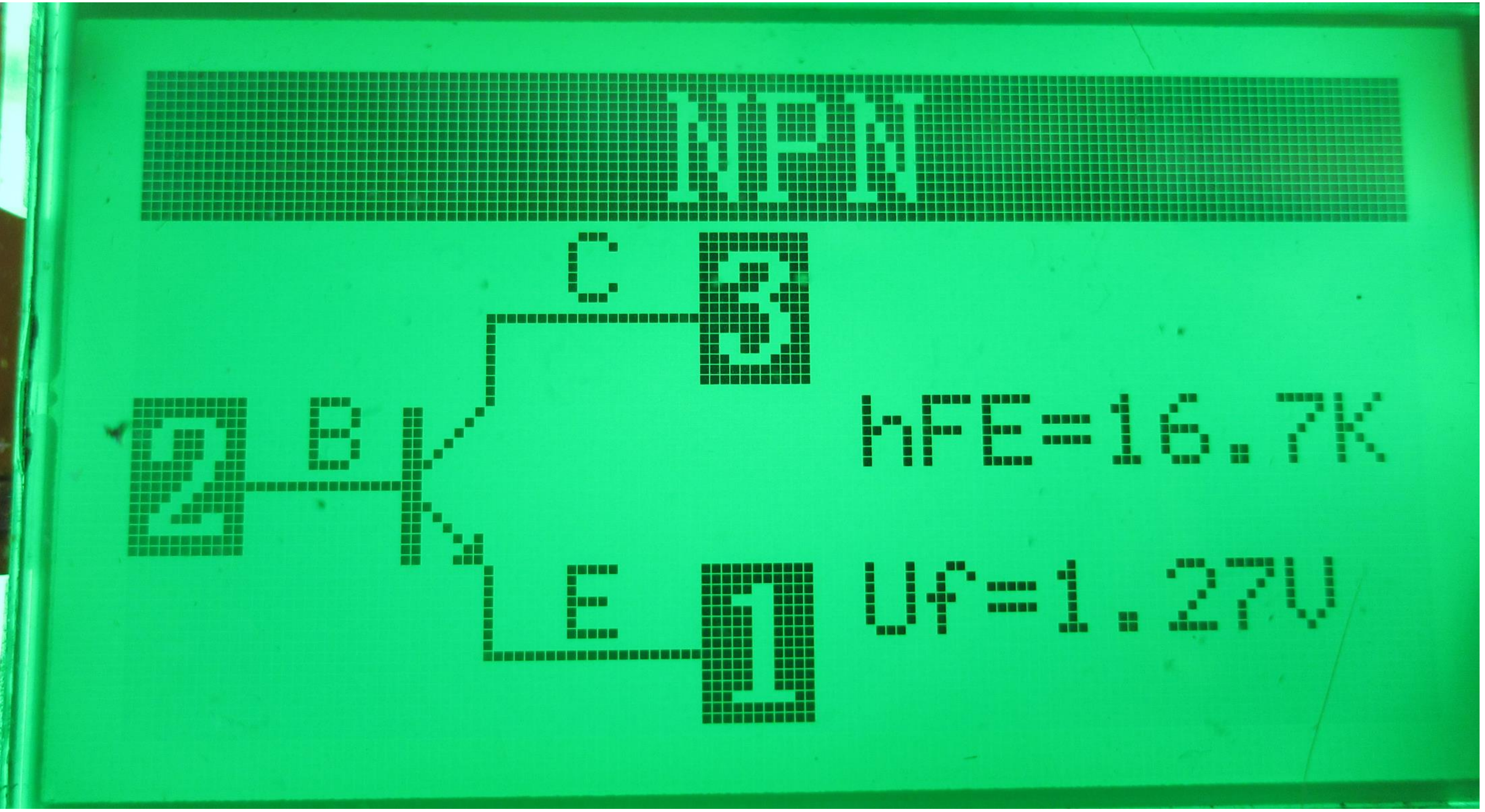

Diode
Uf=367mV C=0pF
1
2
3

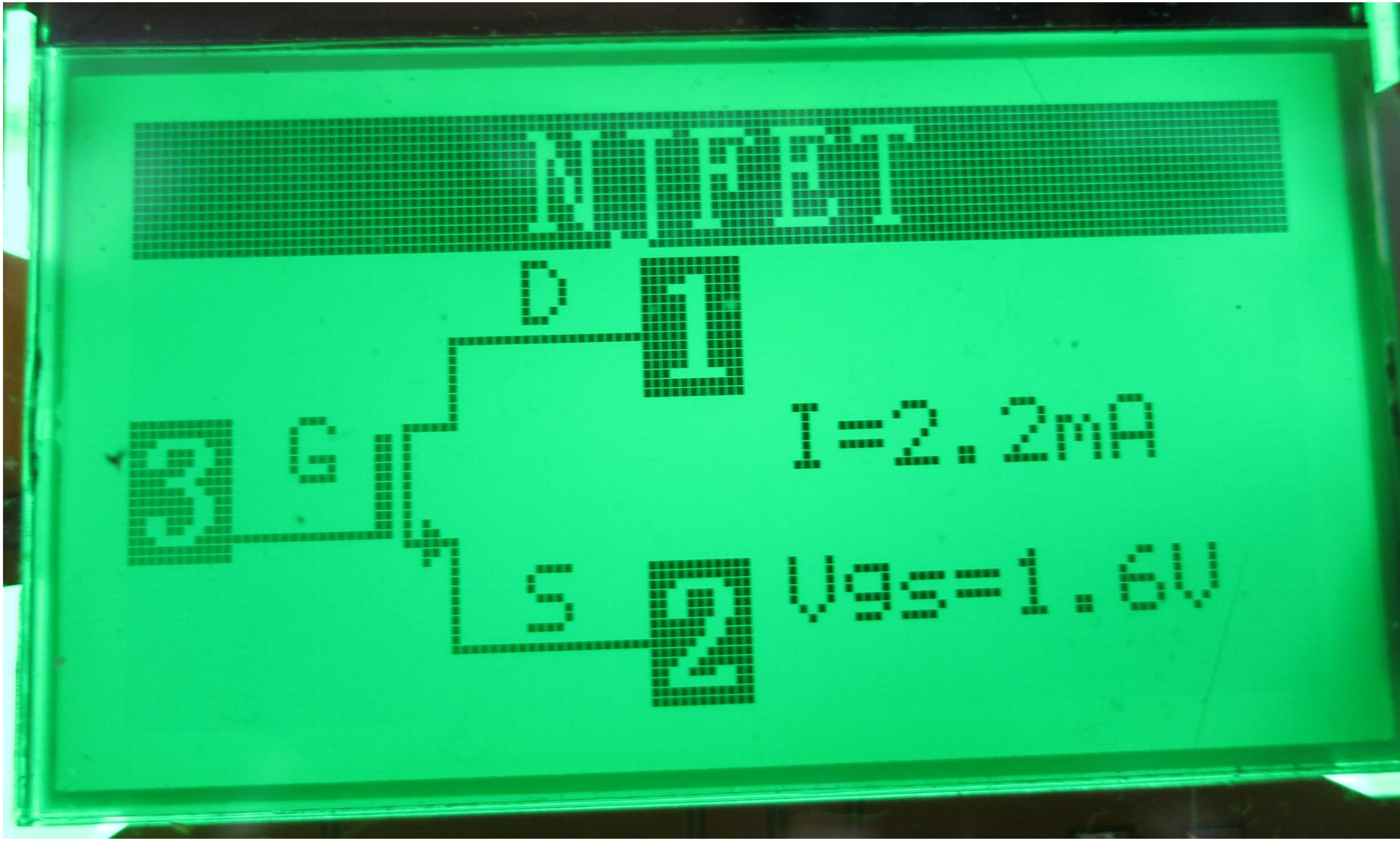
h_{FE} (current gain): great for matching transistors!



What is it??

16,700 = 129^2





NJFET
D
1
3
G
S
2
I=2.2mA
Vgs=1.6V

End Test Equipment (Ch. 11)