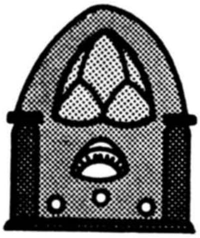
THE MID-ATLANTIC ANTIQUE RADIO CLUB



A Mid-Atlantic Antique
Radio Club Monograph

A TESTER FOR EARLY BATTERY SET VACUUM TUBES

by Gordon Symonds

MAARC Monographs: MAARC Monographs are articles of lasting value published separately from MAARC's monthly Newsletter, but mailed to MAARC members with the Newsletter at no extra cost.

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A Tester for Early Battery Set Vacuum Tubes

by Gordon Symonds

Introduction

The first antique radio event which I attended was the Antique Radio Club of America (ARCA) New Carrollton, MD, meet in June 1987, which was co-sponsored by MAARC. I thoroughly enjoyed the meet, made several new friends, and learned a lot about the technology of the '20s and '30s. One of the people I encountered there was MAARC member Charles Rhodes, who demonstrated a most interesting tester for battery set tubes. This tester, along with the excellent construction articles written for MAARC by Nevell Greenough[1], provided the motivation for the work described here.

I am of the school of persons who think that things should work. For this reason, I am interested in finding good tubes for my construction projects and radios. The difference in price between a good WD-11 and one that is on its last legs is substantial, more even than the cost of parts for this tester. For me, at least, the statement that "the filament is good" does not really convey a lot of information about a tube, certainly not $30 worth!

This article describes the features and operation of the tester and provides a general description of circuit operation. This part of a design is the most time consuming, and requires a lot of research. Duplication of this circuit will require a fair degree of technical ability to adapt it to particular requirements and available parts. A list of relevant technical publications is given in the bibliography.

Design Goals

An antique radio tube tester should be portable, which is to say it should be small, rugged, and self-powered. Desirable features for such a tester include:

- the ability to test vintage battery set tubes (including tetrodes) for filament continuity, interelectrode leakage, gas, and mutual conductance, using dc filament power.
- a continuity tester for audio transformers, headphones, speakers, resistors, capacitors, etc., would be nice if it did not complicate the design

The general philosophy used in this design was that the overall accuracy should be about 5%, the tester should behave towards elderly technology in a respectful manner, and be semi-indestructible and as general purpose as possible. In order to simplify the design and reduce the size, some of the operating procedures are manual or require a bit of mental arithmetic, but nothing too demanding!

As always, cost was a very important consideration, and the design was adapted to suit parts available at flea market and hamfest prices - the only parts purchased at retail were the 22-volt Zener diodes. Fig. 1 shows the tester in its case.

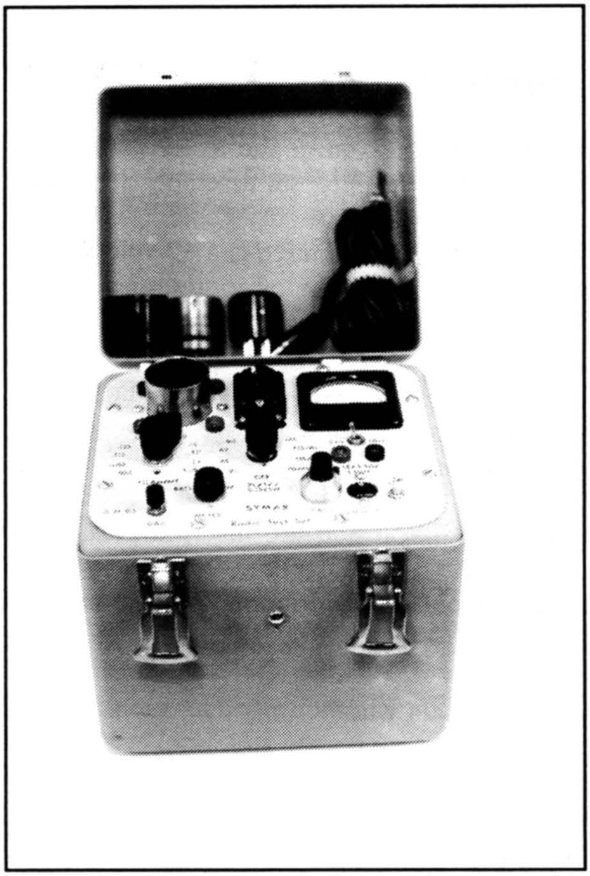

Figure 1. The tube tester in its carrying case, with adapters and test leads in the lid.

A Comment on the Emission Testing of Vacuum Tubes

It is difficult to understand why anyone would want to subject old, fragile, and valuable vacuum tubes to the rigors of emission testing. At every flea market you can find a vendor who, when asked the condition of an old battery set tube which he has for sale, will say something like "Yep, this 199 is in great shape - the emission tester jest about pegged." Possibly I exaggerate.

Commercial emission testers work by tying the grid and plate together (thus turning the tube into a diode), applying about 50 volts, and measuring the resulting plate (and grid) current. This current is the **maximum** that can be extracted from the cathode (or filament). This is rather like testing an antique car by revving the engine flat out to see how much power you can get out of it. To illustrate my point I would like to quote the Institute of Radio Engineers (IRE) on emission testing (emphasis mine):

> "In practice, anode potentials are chosen **considerably lower than would be required for total emission**. The choice of anode potential is determined to some extent by the sum of maximum peak electrode currents that will be required **in service**, or by the maximum voltage that can be applied for a reasonable length of time to tubes of a given type **without injury**.
>
> In tubes having filamentary cathodes that might be injured by passing a relatively large emission current through the filament, it is frequently desirable to obtain an **indirect** check of emission by noting the value of filament voltage for which a specified value of emission current is obtained."[2]

The test set described here performs safe mutual conductance (g_m) measurements using the grid-shift method. For an introduction to vacuum tube measurements, a good place to begin is the paper of Tuttle[3], who, incidentally, was on the committee which developed the standard in reference 2.

Circuit Description

A schematic diagram of the tester is provided in Fig. 2. Photographs of a close-up of the control panel and of the internal assembly are shown in Figs. 3 and 4.

The primary power source is a 12-volt, 6-ampere-hour rechargeable gel cell battery. A charge lasts for at least a few hours of continuous operation, depending on use (about 5 - 10 hours for 01As).

The B high voltage for the plate is obtained from a small dc to dc inverter which converts the +12 volts into about +200 volts. This B+ voltage is applied via current limiting resistor R16 to a string of regulator diodes (CR1 - CR6), providing a selection of regulated plate and screen voltages from 22.5 to 135 in 22.5-volt increments. Because 22.5-volt Zener diodes are not available, the regulator string is "shimmed" with standard silicon diodes--these have a forward voltage drop of about 0.6 volt and are inserted into the string wherever the voltage error exceeds 0.3 (half of the diode voltage). The 45-volt tap is also used as the source for leakage and continuity measurements. This is applied to the meter via 9k resistor R18, giving the required value of 5 ma. full scale.

Depending on whether a triode, such as a WD-11, or a tetrode, such as a type 122, is being tested, one of the 4 pins on the tube socket is either the grid or screen connection. To accommodate this, one half of the plate voltage switch (S6) selects plate voltages from 0 to 135, while the second half selects the voltage applied to the grid/screen pin--either grid bias for triodes or screen voltage for tetrodes. The switch used has ten positions, six of which select triode plate voltages, one is "off," and the remaining three select plate/screen voltage combinations: 90/45, 135/67.5 and 135/90. An external grid cap lead is used for the tetrode grid connection to the top cap of the tube.

A three-position function switch, S3, (BATT/OHMS/IP) is used for battery voltage tests, resistance, and mutual conductance (g_m) measurement, respectively. To reduce problems during leakage measurements, the B and C (plate and grid) voltages are disconnected from the tube socket except when a g_m or gas measurement is being performed.

The filament (A) supply is always connected, as all tests, including leakage (see comment in Measurement Section), require the tube to be at operating temperature.

The grid bias (C) voltage is derived from a Zener diode-regulated supply, which is powered by the two standard 9-volt batteries B2 and B3. The 10-volt output is applied to a 10-turn potentiometer equipped with a 10-turn dial, which permits the grid bias to be set and shifted easily and accurately to any value between 0 and -10 volts, with a precision of 0.01 volt. Since 5-volt Zener diodes are not readily available, 5.1-volt units were used, with R20 added to correct the output voltage.

The A filament supply is a current source, as suggested by Charles Rhodes. Current sources have advantages over voltage sources for powering old and fragile filaments:

- filamentary cathodes are current-operated devices, with the operating current being the most important parameter.

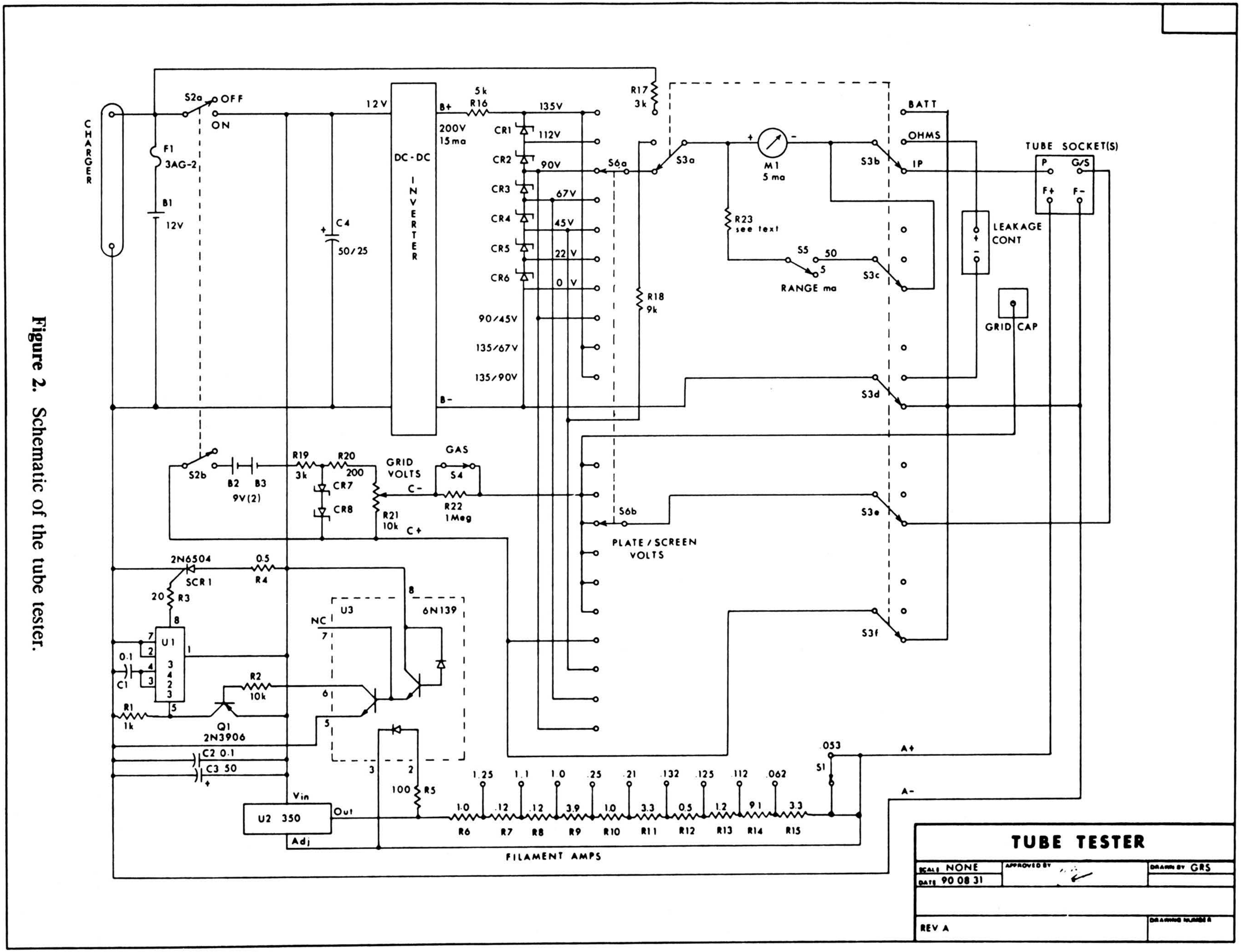

Figure 2. Schematic of the tube tester.

- a cold filament has a low resistance (about 1/10 of the hot value). If a voltage supply such as a battery or voltage regulator circuit is used, the filament is subjected to a high inrush current until it heats up (and its resistance increases), with a distinct possibility of it going "pop." A current source, on the other hand, supplies a fixed current regardless of the load, even to a short circuit. It has been suggested that initial powering up of old filaments using a constant current reanneals them.

- within reason, voltage drops due to contact and wiring resistance are automatically adjusted for and do not cause measurement errors.

The filament current supply is based on U2, an LM350 3-amp voltage regulator IC connected as a current source. The regulator attempts to maintain a voltage of 1.25 V between its "Adj" and "Out" terminals. To do this it must force enough current through the resistor string R6 - R15 to create exactly a 1.25-volt drop. This regulated value of current is then circulated through the tube filament. In this tester, the resistors in the string are selected to give the filament current values desired; the desired value is selected by switch S1. For a 1-amp current, for example, the required resistance is

$$\frac{\text{1.25 volts (regulator drop)}}{\text{1 amp (the required current)}} = \text{1.25 ohm (the value of R6+R7+R8)}$$

This circuit is somewhat fail-safe, since if S1 should fail open-circuit (which it is most likely to do, due to corroded contacts, etc.), then the entire resistor string is seen by the regulator. This results in the minimum selectable current being sent to the tube filament (.053 amp or 53 ma), which is safe for most tubes.

One potential problem for series regulators (the configuration used here), be they voltage or current sources, is that if they should fail by a short circuit (as they normally do), then all that is between the 12-volt battery and the tube filament is the resistor string mentioned above, and the tube filament is at great risk. For example, if a Western Electric 215A peanut tube is being tested and the regulator (a semiconductor device like a transistor) shorts, then the filament is subjected to a current of about 2.5 amps instead of the usual 0.25 amps. Needless to say, this is not good for the tube!

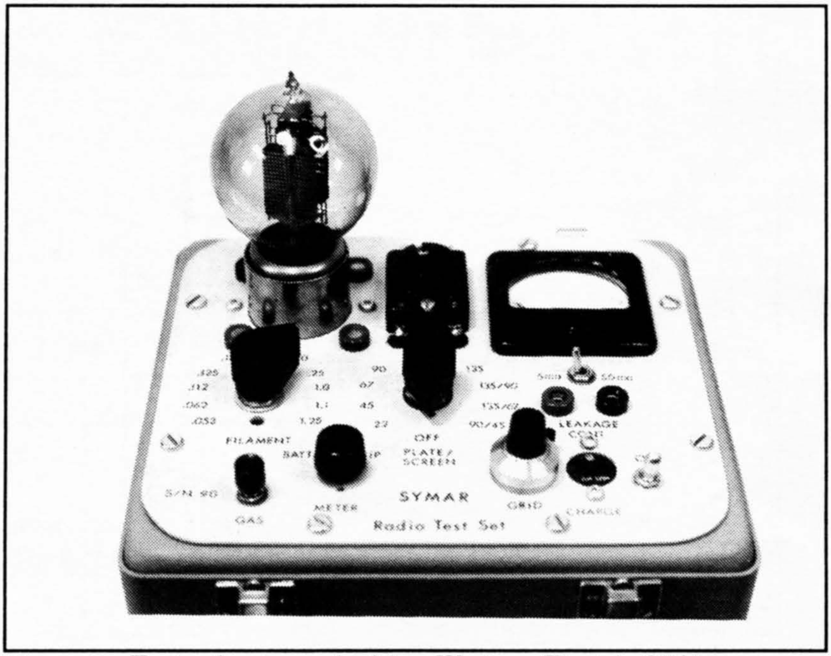

Figure 3. Tester front panel with a Western Electric 216A under test.

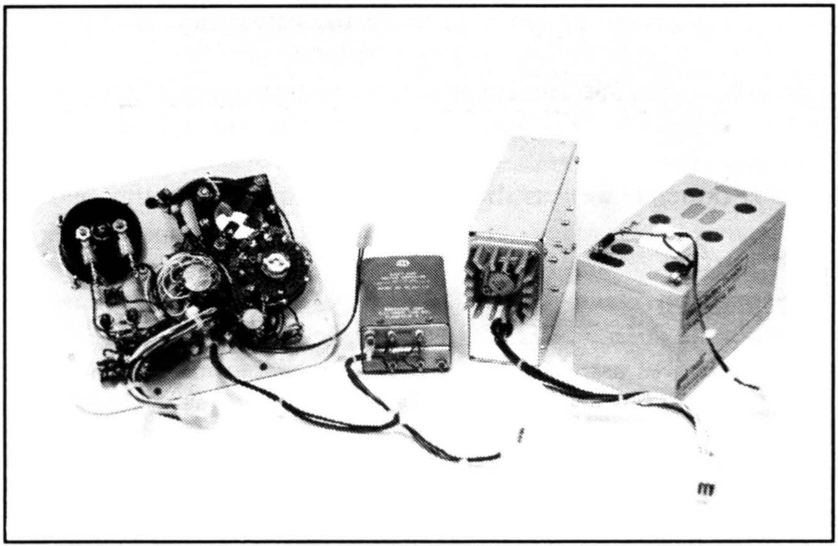

Figure 4. Internal components of the tester. Left to right: rear of front panel, dc to dc inverter for B+, subchassis showing regulator on heat sink, 12-V, 6-ampere-hour gel cell battery.

The circuit used in this tester provides short circuit protection in the form of a "crowbar." The idea behind a crowbar protection circuit is that the tube is to be protected at all costs, even at the expense of the test set. In this case, it is accomplished by shorting out (and hence removing) the battery power. A failure of the type 350 regulator IC is detected by means of the optically coupled sensor U3, whose input is the same 1.25 volts the regulator should maintain. In the event of a failure, the voltage across the resistor string would rise from its normal 1.25-volt value, "turning on" the coupler U3, and activating U1, a MC3423 crowbar control. This "fires" the silicon-controlled rectifier SCR1 and short-circuits the 12-volt battery. This blows the 2-amp fuse F1, protecting the tube. Resistor R4 (0.5 ohm) is used to protect the SCR itself from destruction due to the high current surge when it fires.

The term "crowbar" dates from the early days of radar where attempts to save the system included throwing a real crowbar across the high voltage power supply. The results must have been spectacular. Once the crowbar had been applied, the power supply was said to have been "gronked"--possibly this was the noise it made while expiring!

The circuit used to measure interelectrode leakage consists of 45 volts in series with scaling resistor R18 and the 5-ma meter. Leakage resistances as large as a megohm or so are observable as a small deflection (about 1/2 of one scale division) of the meter needle.

Gas current measurement uses the traditional method of observing the plate current change which occurs when a resistance is inserted in series with the tube grid. If there is grid (gas) current flowing, a voltage drop will be created by the resistance and this will be reflected as a change in plate current according to the familiar relationship:

$$g_m = \frac{\text{plate current change}}{\text{grid voltage change}} \qquad (1)$$

If you use the fact that the grid voltage change due to gas current is equal to the gas current times the value of the grid resistor (R22), then equation (1) may be rearranged to give:

$$\text{Gas current} = \frac{\text{plate current change}}{g_m \ * \ \text{grid resistor (R22)}}$$

If R22 is selected properly to make the calculation easy (e.g., 1 megohm), then:

$$\text{Gas current} = \frac{\text{plate current change}}{g_m \text{ (in micromhos)}}$$

This is rather clever, as the tube itself amplifies the tiny "gas" current so that you can measure it.

Construction

The tester was assembled in a rugged portable instrument case. Space, both internal and on the panel, was very tight. Several cardboard mockups were required to ensure that everything would fit and that controls were conveniently located. The following are located inside the case: the 12-volt gel cell, the high-voltage converter, a small chassis for the filament current source, and miscellaneous small parts. Tube socket adapters and test prods are stored in the lid.

There was insufficient panel space for all of the tube sockets required to test the different style bases of the tubes of interest, so only bayonet sockets for the 01A and 215A types were included. The remainder, including WD-11, UV-199 and standard (non-bayonet) 4-pin, are handled by adapters to the 01A socket, as noted below. All tube sockets are wired in parallel.

Accessories required for use include:

- a charger for the gel cell battery

- a grid cap lead for tetrodes

- a set of test prods

- adapters, 201A to: (1) alligator clips
  (2) non-bayonet 4-pin
  (3) UV-199
  (4) WD-11

The first two adapters were made up from old tube bases and sockets; the remaining two (UV-199 and WD-11) are vintage parts.

The tester may also be used to power other devices, such as one-tube battery sets. For this purpose, an adapter can be made up from an 01A tube base fitted with a 4-conductor power cord. For use with one-tube regenerative receivers, be aware that in this tester the grid bias is referred to the negative (-) side of the filament--some designs recommend connecting C+ to A+.

Duplication of this tester for a reasonable cost will require adaptation to available parts. In the prototype, for example, the dc to dc inverter (originally used to power Nixie tubes) and most of the switches and knobs were salvaged from a discarded portable test instrument. In general, I prefer used industrial or military grade components to new consumer grade ones. There is an almost unlimited supply of this material available at low cost at any hamfest or radio flea market.

Operation - Tube Testing

In the following description, references to tester functions are in CAPITALS. When no measurement is being performed, the function switch should be in the OHMS position.

(1) Select the Operating Conditions

With the tester power OFF, select the FILAMENT (current) and GRID bias. Table 3 gives suggested values for selected tubes. The PLATE/SCREEN should be set to OFF, and the function switch to OHMS. If a tetrode is being tested, leave the GRID CAP lead disconnected.

(2) Warm Up the Tube to Operating Temperature

Insert the tube and turn the tester ON. Let the tube warm up for a minute or so. Tubes using 62-ma filament current, such as the 199, 30 and 01C will never get "warm!"

(3) Check for Shorts and Interelectrode Leakage

With the tube at operating temperature and the function switch in the OHMS position, connect the test prods to the LEAKAGE/CONT jacks and make measurements between terminals on the 01A socket (P, G/S, F+, and F-) and the top (grid) cap of tetrodes. If the tube has any shorts or serious leakage (a meter reading of greater than 0.1, or about 500k ohms), then it is a dud. Do not perform any further tests.

It is very important to be aware that with the filament hot, the tube electrodes may emit electrons and thus provide erroneous (and strange) readings (this will be obvious). If this is the case, the IRE recommends[2] that the leakage be measured with the filament off and the tube cooled enough to eliminate these emissions:

(1) Tester power OFF
(2) Wait a minute for the filament to cool and then remove the tube
(3) Tester power ON, perform the leakage measurements directly on the tube pins
(4) Tester power OFF, re-install the tube, then tester power ON

In the event an interelectrode short is found, <u>certain</u> persons recommend giving the tube a sharp rap on a hard surface. This is based on the theory that shorts are often caused by flakes of getter, etc. becoming lodged between the plate, grid and filament, and that the rap knocks them loose. This is obviously not for the faint of heart!

(4) Measure the Plate Current (IP)

For tetrodes, install the GRID CAP. Set the meter range switch to 50 MA and the function switch to IP. Set the PLATE/SCREEN voltage to the lowest value indicated in Table 3. Only when everything looks OK should you try the higher voltages. It is probably a good idea not to run valuable tubes such as WD11s and DVs with plate voltages greater than 45. If the plate current (IP) is less than 5 ma, change the meter to the lower range. The plate current should approximate the values given in Table 3, but a fair amount of variation is OK. Generally speaking, a low plate current indicates a low g_m and a high plate current indicates gas. If an abnormally high reading results (e.g., over 20 ma), redo the leakage tests, as something is seriously amiss.

(5) Determine the Mutual Conductance (g_m)

If the normal plate current measured in step 4 looks reasonable, increase the GRID bias by 0.5 volt (1/2 turn of the 10-turn dial) and note the plate current. Then reduce the GRID bias by 1 volt (1 turn of the 10-turn dial) and note the **change** (increase) in plate current from the value previously noted. **The mutual conductance (in micromhos) is then equal to the change in plate current in microamperes.** Thus, each milliampere of plate current increase with the 1-volt grid bias shift represents a g_m of 1000 micromhos.

For example, if the plate current change is 0.6 ma with a 1-volt change in grid bias, the mutual conductance is 600 micromhos.

The mathematical definition of mutual conductance places two main constraints on the measurement:

- the plate voltage must be held constant. In this tester, the plate is connected directly to a low-impedance voltage source without a plate load resistor (the B supply is protected against internal shorts).
- the grid voltage must be varied only by a small differential (theoretically infinitesimal). The curve of plate current vs grid voltage (at constant plate voltage) is just that, a curve. We are trying to determine the g_m at a point on this curve. The method described above uses a grid shift from 0.5 volt below the value given in Table 3 to 0.5 volt above it, and should give reasonably good results. For example, if the nominal grid bias is 4.5 volts, the grid shift will be from 4 to 5 volts.

For grid bias shifts of other than 1 volt, use the following:

$$g_m = \frac{\text{Change in Plate Current (ma)}}{\text{Change in Grid Voltage (volts)}} \times 1000 \text{ micromhos}$$

The g_m values given in Table 3 are "bogey" (or new tube) values. As a tube is used its g_m decreases, mainly because of decreased cathode emission.

I think it is useful to standardize descriptive adjectives used to describe tube condition, and I recommend the terms shown below in Table 1:

g_m (% of bogey value)	Description
100% or greater	Excellent
80 - 99%	Good
60-79%	Fair
less than 60%	Dud

Table 1. Descriptive Adjectives for Tube Condition

An important tube characteristic is the amount of cathode life remaining. A life test can be performed by repeating the g_m measurement at reduced filament current. The degree to which the g_m is reduced at the lower current gives some idea of the condition of the cathode. The assessment of tube life remaining is subjective and requires a bit of practice, but it is very worthwhile.

In order to provide an indication of remaining cathode life, additional filament current values have been provided. These are listed in Table 2 on the next page, and are about 15% less than the nominal values.

Within the restrictions of plate and grid voltage selection, the tester may be used to determine a family of plate current vs grid voltage curves (characteristic curves).

(6) Measure the Gas Current

Return the GRID to its normal value (as in step 1). Operate the GAS button and note the change (normally an increase) in plate current. **The gas current is equal to the change in plate current divided by the mutual conductance in micromhos.** For the example tube of step 5, if the plate current changes 0.1 ma when the GAS button is pushed, the gas current is 0.1 ma/600 or 0.17 microamperes.

Nominal Value (amps)	Life Test (amps)
1.25	1.1
1.1	1.0
0.25	0.21
0.062	0.053

Table 2. Life Test Values

Normally, a gas current of less than 1 microampere for low-power tubes and 2 microamperes for higher power or output tubes is considered acceptable.

If a tube has not been used for a long time, the gases originally absorbed by the getter may have been released back into the envelope, with the result that it will test gassy. Often, if the filament is left lit for 15 minutes or so, the getter will reabsorb the gasses. This process can be observed as a reduction in gas current with time. I have seen tubes recover from a situation where the initial gas current exceeded the normal plate current. Never give up on a tube until you are certain it is beyond hope.

(7) Record the Results

After testing a tube, I use the following notation to indicate the tube condition, and write it on the tube carton, along with the test date. For the example given above, this would be:

$$\text{normal plate current} \rightarrow \frac{600}{1.2/0.17} \begin{array}{l} \leftarrow \text{mutual conductance} \\ \leftarrow \text{gas current} \end{array}$$

These 3 values give the condition of the tube at a glance.

Again, let me emphasize that you should never give up on an old and valuable tube until you are certain it is beyond hope. For example, if the filament reads open or there are other problems, try removing the base, inspecting the wires up to the envelope (repairing if necessary) and then resoldering the base.

Tube Type	Filament		Plate		Screen		Grid	Tube Parameters		
	E (V)	I (A)	E (V)	I (ma)	E (V)	I (ma)	E (V)	g_m (μmho)	μ	R_p (Ωk)
00	5.0	1.0	22.5	2.5	-	-	1.5	750	-	-
00A	5.0	0.25								
01	5.0	1.0	90	2.5	-	-	4.5	725	8	11
01A	5.0	0.25	90	2.5	-	-	4.5	725	8	11
01B	5.0	0.125								
01C	5.0	0.062								
DV2	4.5	0.26	45	1.5	-	-	1.5	320	6.5	20
DV3	3.0	0.07	90	4.5	-	-	4.5	500	6.5	13
WD11	1.1	0.25	90	2.5	-	-	4.5	425	6.6	15.5
12			45	1.1	-	-	1.5			
20	3.3	0.132	67.5	5	-		5.0	500		
22	3.3	0.132	135	1.7	45	0.6	1.5	375	270	725
			135	1.2	67.5	1.2	3.0	500	160	325
30	2.0	0.062	90	2.5	-	-	4.5	850	9.3	11
112	5.0	0.25	135	6.2	-	-	9.0	1650	8.5	5.1
			90	5.0	-	-	4.5	1575	8.5	5.4
199	3.0	0.062	90	4.0	-	-	4.5	380	6.5	17
			45	1.0	-	-	1.5	310	6.5	21
203B (VT1)	2.5	1.10	45	2.0	-	-	1.5	400	6.5	15
209A	3.0	1.25	120	0.7	-	-	1.5	500	30	60
215A	1.1	0.25	67.5	2.0	-	-	4.5	410	5.7	14
			45	1.0			3.0	340	5.7	16.5
216A	6.0	1.1	120	8.0			9.0	1000	6	6

Table 3. Suggested Test Conditions for Selected Tubes

Continuity Tester

This circuit consists of 45 volts in series with 9k ohms and the 5-ma meter. Due to the low test current (5 ma maximum), almost anything may be safely checked, including low-voltage filaments. The circuit is also useful for testing grid leaks for opens, capacitors for gross leakage or shorts and headphones, speakers, etc. To use, set the function switch to OHMS and connect a set of test prods to the LEAKAGE/CONT jacks. A mid-scale reading is approximately 10k ohms. Resistance values may be calculated from:

$$R \text{ (k ohms)} = \frac{45 \text{ V}}{\text{Meter reading in ma}} - 9\text{k}$$

Battery Test

The gel cell battery voltage may be monitored with the BATT position of the function switch. The meter range is 15 volts full scale (a mental multiplication by 3 is required). This function is available even when the tester power is OFF to permit monitoring of charging voltage. The condition of the battery may be determined from the data in Table 4 below:

Battery Voltage	Meter Reading (ma)	Battery Condition
10.5	3.5	Charge Required
12.7	4.25	Fully Charged (off charger)
13.8	4.6	End of Charge (on charger)

Table 4. Battery condition data.

Field Testing

This tester underwent a baptism of fire at the ARCA meet in Cincinnati, OH, in June 1990, and the results were a total success. A large quantity of tubes of every imaginable type was tested, including at least a boxcar load of 01As. Every imaginable case was found: tubes reputed to be good weren't and vice versa. The "find" of the meet was a de Forest DV3 which sold for about $10 to a visitor from Austria--it tested out as a new tube!

For the Future

The development work invested in this tester so far was, in part, an attempt to determine the degree of interest in the antique radio community in a tester for battery set tubes. The reactions so far have been quite positive. If there is sufficient interest shown, I will happily carry the process on to arrive at a next generation design incorporating additional features, and which can be built by the average enthusiast. This will entail:

- the modification and improvement of the design based upon your suggestions. For example, if one were to incorporate Nevell Greenough's wireless phono oscillator[1] and a simple audio oscillator (to modulate the phono oscillator and provide dynamic testing for headphones and speakers), then this really would become a universal test set. Also, the tester could be run from a car cigarette lighter in addition to or instead of the gel cell battery.
- design of a simple, one-transistor dc-dc inverter that can be made up from readily available parts
- design of a printed circuit board to simplify wiring
- the location of sources for parts, possibly the provision of kits of parts for the harder-to-find items

As a model for me to follow in any such article, I will strive to match the thoroughness of Nevell's construction article referenced above. Please send your suggestions and comments to the Newsletter editor or to me at this address:

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Ottawa, Ontario
Canada K1S 3B4

Remember, first class postage from the U.S. to Canada is now 40¢ per ounce!

Acknowledgements

I acknowledge the contributions of those who provided advice and assistance on this project, including Philip Neufeld, who did the photography, and Charles Rhodes of MAARC for the inspiration to do the work in the first place.

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Hewlett-Packard, Inc.: <u>Optoelectronics Designers Catalog</u> (6N139)
Motorola, Inc.: <u>Linear/Switchmode Voltage Regulator Handbook</u> (MC3423P)
National Semiconductor, Inc.: <u>Voltage Regulator Handbook</u> (LM350)

Parts List

Resistors (1/4 watt, 5% except as noted)

R7, R8	0.12 ohm
R4	0.5 ohm, 1 watt
R12	0.5 ohm
R6	1 ohm, 5 watt
R10	1 ohm
R13	1.2 ohm
R11, R15	3.3 ohm
R9	3.9 ohm
R14	9.1 ohm
R3	20 ohm
R5	100 ohm
R20	200 ohm
R1	1k ohm
R17, R19	3k ohm
R16	5k ohm, 10 watt
R18	9k ohm
R2	10k ohm
R21	10k ohm, 10-turn pot, with 10-turn dial
R22	1 megohm
R23	selected to give 50 ma. full-scale reading for M1

Capacitors

C1, C2	0.1 μf, 50 volt, ceramic
C3, C4	50 μf, 25 volt, electrolytic

ICs

U1	MC34239 (MOTOROLA)
U2	LM350 (NATIONAL)
U3	6N139 (HP)

Semiconductors

CR1-CR6	22 V, 5 W, 1N5358B
CR7-CR8	5.1 V, .5 W, 1N751B
SCR1	2N6504
Q1	2N3906

Miscellaneous

F1	2-amp 3AG fuse
B1	12-volt gel cell
B2 - B3	9-volt battery

dc-dc Inverter, 12 - 200 V
Tube sockets
Binding posts (3)
Charger receptacle to suit
Case and chassis
Hardware, etc.

Switches (all with knobs)

S1	1-pole, 10-pos. rotary 2 amp make/break capacity
S2	DPDT, 5 amp
S3	6-pole, 3-pos. rotary
S4	SPST pushbutton, NC
S5	SPDT
S6	2-pole, 10-pos. rotary

References:

1. For an excellent example of a construction article that illustrates Nevell Greenough's thoroughness, see "The Phono Oscillator Revisited," MAARC Newsletter, July 1988, p. 6.

2. Institute of Radio Engineers, "Standards on Electron Tubes: Methods of Testing, 1950," IRE Standard IRE 7 S1, Proc. IRE Vol. 38, No. 8, (New York, August 1950).

3. W. N. Tuttle, "Dynamic Measurement of Vacuum Tube Coefficients," Proc. IRE, Vol. 21, No. 6, (New York, June 1933), pp. 844 - 857.