Heathkit of the Month #104:
by Bob Eckweiler, AF6C

Heathkit

ELECTRONIC TEST EQUIPMENT

Heathkit SQ-1 Square Wave Generator

Introduction:
In its September 1951 flyer Heathkit introduced six new test equipment products for 1952. The kits are listed in **Table I**. Among them was the SQ-1, Square Wave Generator. Prior to the release of the SQ-1, Heathkit had manufactured two audio generators that had both sine and square wave outputs – the G-2 (circa March 1948 - late 1950) and the AG-7 (circa February 1951 - late 1952). During the lifetime of the SQ-1 two additional sine / square wave generators were sold – the AO-1 (circa March 1952 - mid 1957) and the AG-10 (circa late 1957 - late 1962). The SQ-1 kit sold for $29.50 throughout its lifetime. It remained in production into 1959.

New Heathkits for 1952
As listed in the September 1951 Flyer

Model	Name	HotM
O-7	Oscilloscope	#087
V-5	Vacuum Tube Voltmeter	#019
SQ-1	Square Wave Generator	#104
AV-1	AC VTVM	#047
IM-1	IntermodulationAnalyzer	–
AF-1	Audio Frequency Meter	–

Table I

1. Notes appear on page 8.

Here is a link to the index of Heathkit of the Month (HotM) articles:

http://www.w6ze.org/Heathkit/Heathkit_Index.html

Figure 1: Heathkit SQ-1 Square Wave Generator

The SQ-1 was a successful attempt to design a square wave generator that offered a large frequency range and a fast rise-time square wave. It covers 20 cps to 100 kc while the other Heath generators went up to only 20 kc.

Even before the digital era, where pulse and square wave generators are used to generate clock pulses, square waves were used to test amplifiers for frequency response and ringing. In the post-war fifties Hi-Fi was becoming common in the average middle-class household. With its popularity, many small TV repair shops found themselves also servicing Hi-Fi equipment and needed test equipment to do the task – equipment that was better than the current square wave generators Heathkit was selling. Heathkit's response was the SQ-1.

Why Square Waves?:
It can be mathematically shown that a square wave is composed of an infinite series of ODD harmonics of a sine wave[1], the first harmonic[2] being the fundamental frequency of the square wave. Thus a 100 Hz square wave with an amplitude of A is composed of:

1. 100 Hz sine wave of amplitude (4/π)(A/1)
2. 300 Hz sine wave of amplitude (4/π)(A/3)
3. 500 Hz sine wave of amplitude (4/π)(A/5)
4. 700 Hz sine wave of amplitude (4/π)(A/7)
5. 900 Hz sine wave of amplitude (4/π)(A/9)
6. 1100 Hz sine wave of amplitude (4/π)(A/11)

7. 1300 Hz sine wave of amplitude (4/π)(A/13).
8. 1500 Hz sine wave of amplitude (4/π)(A/15).
9. 1700 Hz sine wave of amplitude (4/π)(A/17).
10. 1900 Hz sine wave of amplitude (4/π)(A/19).
11. … to infinity.

See sidebar on page 10 for further discussion.

Thus, if a square wave (**Fig. 2A**) is fed into an audio amplifier, and the properly loaded amplifier output is displayed on a wide-band oscilloscope, distortion of the square wave gives an indication of the performance of the amplifier. The shape of the distortion to the square wave is an indication of what the deficiencies are. The Heathkit manual shows seven drawings of distorted waveforms: **Fig. 2B** represents a lack of high frequency response **Fig. 2C** boosted high frequency response, **Fig. 2D** a lack of low frequency response, **Fig. 2E** boosted low frequency response, **Fig. 2F** ringing / damped oscillation (and a clue to the oscillation frequency), **Fig. 2G** leading phase-shift in the amplifier and **Fig. 2H** lagging phase-shift in the amplifier.

It is interesting to note that the indications of the square wave distortion generally are useable from its fundamental frequency through its 10th harmonic. Thus, the testing of an SSB transmitter mike amplifier with a bandwidth of 100 Hz to 3,500 Hz should be tested first at 100 Hz and again at 350 Hz. If both of these show a good square waveform the amplifier has good bandwidth. To be sure the amplifier doesn't have excessive bandwidth it can be checked with square waves below 100 Hz which should begin to show a loss of low frequencies, and above 350 Hz which should begin to show a loss of high frequencies above ten times the square wave frequency.

Phase shift (Figs. 2G & 2H) is not a problem of concern for audio amplifiers; however it is a concern for other types of amplifiers such as those used in an oscilloscope.

The SQ-1 Specifications:

The SQ-1 specifications are shown in **Table II**. It is surprising that no specifications are given in the manual (dated 9/8/52) for the square wave rise-time. Also surprising is

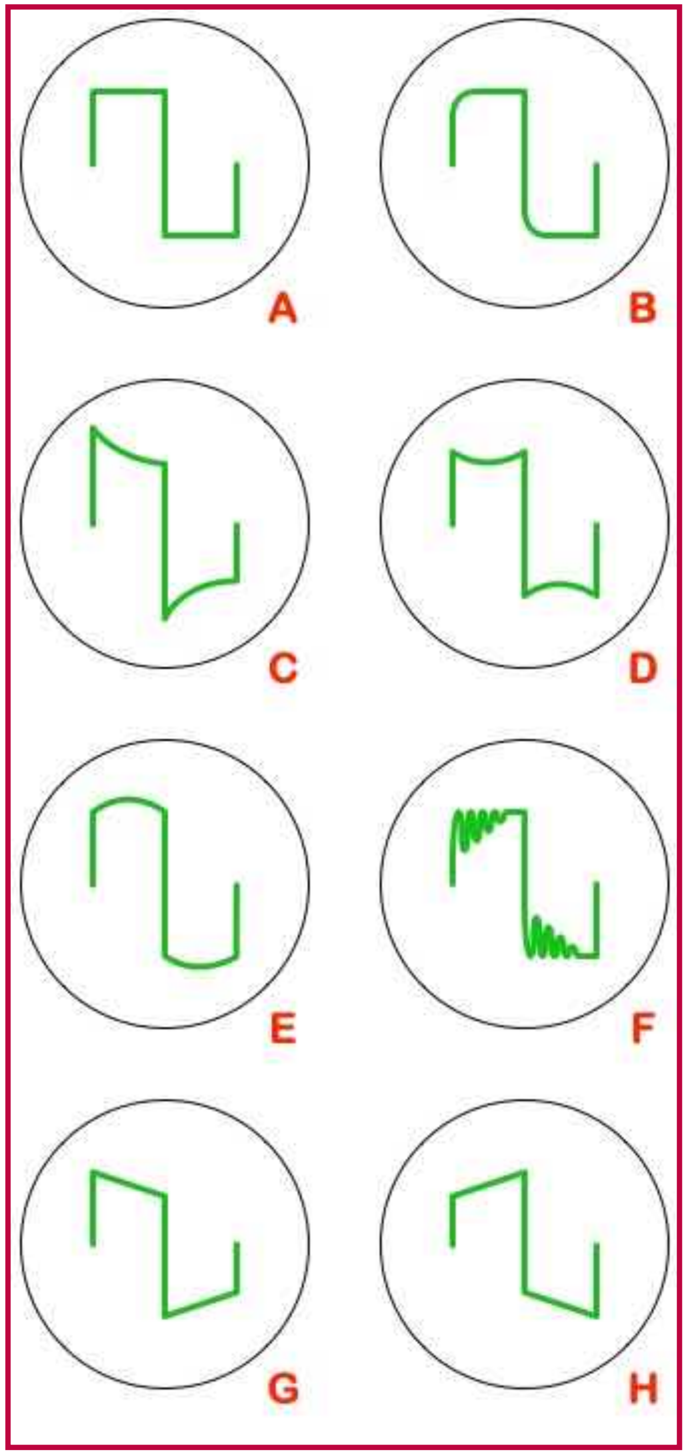

Figure 2: Various diagnostic wave-shapes. (See Text)

there are no specifications for output voltage, output impedance, sync input level or sync input impedance. However the output voltage is given in ad copy. **Table III** shows the four vacuum tube lineup used in the SQ-1.

SQ-1 Square Wave Generator Specifications

Frequency Ranges:	10 – 100 cps
	100 – 1000 cps
	1 – 10 kc
	10 – 100 kc
Rise-Time:	<not given>
Output Voltage:	0 – 20 V Referenced to Ground (Found in ad copy, not in specs.)
External Sync:	Front Panel Terminals
Power Requirements:	105 – 125 VAC, 50 – 60 cps 10 W
Size:	12½ W x 7" H x 7½" D
Net Weight:	11 lbs.
Shipping Weight:	12 lbs.

Table II

The SQ-1 Controls and Connections:

The front panel layout of the SQ-1 (**Figure 3**) is uncluttered and straight forward. Centered horizontally and slightly above center vertically sits the main dial with a non-linear 100 - 1000 scale. A total of seven controls, indicator and terminals are arranged horizontally along the lower fourth of the panel. **Table IV** lists them. Note that in the table front panel wording is shown in bold.

SQ-1 Square Wave Generator Tube Layout

6X5	Dual Diode	Full Wave CT Rectifier
6SL7	Dual Triode	Multivibrator
6AC7	Pentode	Amplifier-Limiter
6V6	Beam Power Tetrode	Cathode Follower Output

Table III

SQ-1 Square Wave Generator
Front Panel Layout

Single control centered horizontally, 45% vertically from top:	
Frequency	Dual 100KΩ potentiometer w/ scale: 15 tics at: Full CCW, **100**, **110**, **125**, **150**, **200**, **300**, **400**, **500**, **600**, **700**, **800**, **900**, **1000**, Full CW (not linear)
Seven items equally spaced along the bottom (L to R):	
SYNC. INPUT	Dual Binding Posts lower post Gnd.
SYNC. LEVEL	Potentiometer - 50KΩ w/ 300° two headed arrow circling control
RANGE	Four-position rotary switch marked: **10 | 100 | 1K | 10K | 100K**
Pilot Lamp Ass'y	Red Jeweled #47 lamp.
POWER	Two-position rotary switch: **OFF ON**
OUTPUT	Potentiometer - 2KΩ w/ 300° two headed arrow circling control
OUTPUT	Dual Binding Posts lower post Gnd.
Other Lettering:	
Top Center:	*Heathkit* **SQUARE WAVE** *Generator*
Left 45% from top:	**THE HEATH COMPANY** (small font)
Right 45% from top:	**BENTON HARBOR, MICH.** (small font)
Under Pilot:	**MODEL SQ-1** (small font)

Table IV

There are no controls on the rear skirt, just the power cord exiting via a ⅜" rubber grommet. Internally there are two potentiometers. These are neither labeled nor named. The 5K pot (located closer to the front panel) adjusts the frequency calibration. The 10K pot adjusts the wave-form.

SQ-1 Assembly and Wiring:

In HotM #102 (The QM-1 'Q' Meter) it was noted that the QM-1 manuals lack step-by-step instructions, though other manuals in the same period used the full step-by-step format. There was no mention in the QM-1 manual of why this was done. QM-1 assembly was briefly summed up in a section called "Notes on Construction". The SQ-1 manual is similar, with the addition of this explanation:

Because the SQ-1 is a laboratory type instrument, it is assumed that the builder will have some experience in the construction of technical equipment. With this thought in mind, the usual very detailed "step-by-step construction" found in most Heathkit manuals has been replaced by a section entitled "Notes on Construction." This more generalized construction procedure will be found more interesting and less tedious by the experienced builder.

The whole "Notes on Construction" text for the SQ-1 is reproduced in **Figure 4**. The text is supported with four detail drawings showing the mounting of the terminal assemblies, pilot light assembly, can capacitor mounting and controls and switches, along with a brief drawing of the parts location that mount to the top of the chassis and a large detailed drawing showing the under-chassis wiring. These drawings are in the manual in a small size and are also reproduced on a single separate 21" W x 16" H pictorial sheet. A small version of this sheet is shown in **Figure 5**. Do not accept a manual without the separate large pictorial; in the opinion of this author, it would be difficult to wire the kit using the manual's smaller under-chassis wiring drawing. The manual also has a page with an under-chassis photo print of an assembled SQ-1.

SQ-1 Square Wave Generator Circuit:

The SQ-1 circuit may be divided into four sections: the power supply; the multivibrator; the limiter and the output cathode follower. **Figure 6** on page 21 shows the schematic.

The Power Supply Circuit:

The power supply is a bit unusual for a Heathkit. It is a standard full-wave rectifier using an octal dual-diode 6X5 rectifier tube.

NOTES ON CONSTRUCTION

When building the SQ-1, follow the pictorials and photoprint very closely. Deviating from the design shown may produce unwarranted operating difficulties.

Begin construction by mounting on the chassis those parts shown in the chassis layout pictorial. Watch carefully to get the tube socket keyways in the right direction and the electrolytic condenser in the proper position.

Next the pilot light and binding post assemblies may be mounted on the panel. Also mount the dual control. The detailed drawings illustrate the assembly of the pilot light and binding posts.

The panel is attached to the chassis at the same time the controls and switches across the front are mounted. Here again, see the detail for attaching these parts. Check the position of the terminals on controls and switches before tightening the nuts.

With the larger parts mounted, the actual wiring can begin. Many manufacturers supply parts with leads much longer than necessary. The leads on each part should be trimmed to fit the particular location as the part is wired in. This will produce a neater looking unit and also reduce stray coupling between circuits.

First wire in the transformer leads and the filament wiring. Next put in all the plain wire leads. Do not overlook the short ground connections needed on many of the tube sockets.

Next the resistors should be wired into place. Follow the pictorial and photoprint closely when wiring-in small parts. The color code chart on the inside cover will help in identifying resistors.

Use spaghetti on all leads where there is a possibility of shorting.

After the resistors are mounted, the condensers can be wired in. Use care to get the condensers in the correct locations.

The last step is connecting in the line cord. The pictorial illustrates how a knot is used to provide strain relief.

This completes the wiring. A careful check should now take place to be certain no connections have been missed. Tracing each lead in colored pencil on the pictorial as it is checked in the instrument will prevent overlooking some leads.

With the wiring known to be correct, the control and switch knobs can be mounted. Turn each shaft to the extreme counter-clockwise position and lock the pointer knob so that it is indicating the proper end marking.

Plug the tubes into their respective sockets and the instrument is ready for test and adjustment.

Figure 4: Text from SQ-1 manual showing the complete text of the assembly portion of the manual. This manual does not use step-by-step instructions. It, along with the pictorial sheet shown on the next page (Figure 5) and a photo print of the underside of the completed chassis are all that's given for assembly instructions. The original pictorial (shown in Figure 5) measures 21" W x 16" H and gives good detail. However, the COMPLETE WIRING PICTORIAL drawing in the manual is even smaller than shown in Figure 5 and would be hard to use for accurate construction.

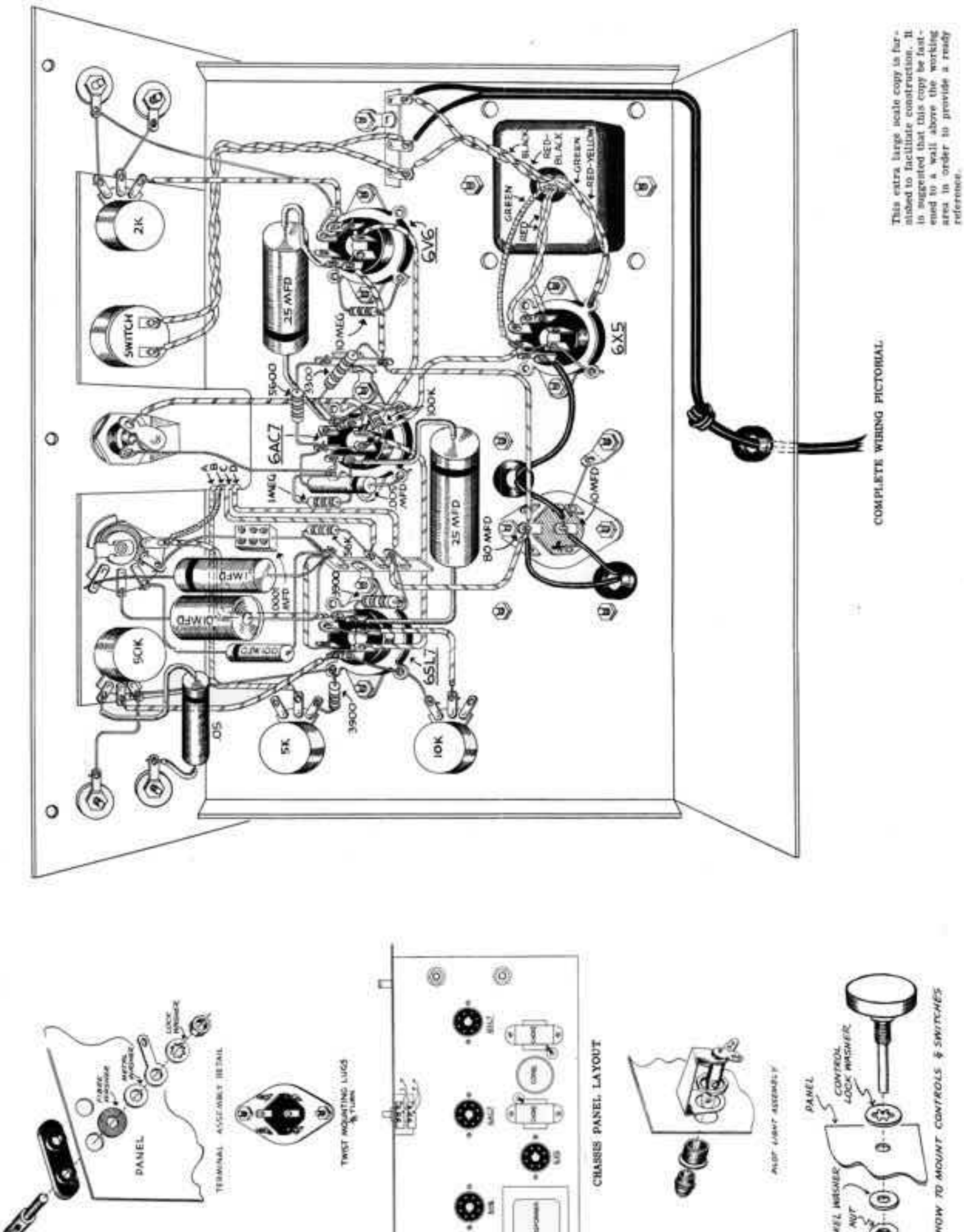

Figure 5: (See Figure 4) Pictorial Drawing accompanying Manual.

This is followed by rather high quality filtering consisting of a two section LC filter, each filter utilizing a 4.5 Henry choke; the first section employs a 10 µf capacitor and the second section an 80 µf capacitor. This two-stage choke input filter is required to present a very low ripple to the remaining circuits to prevent waveform distortion. The power transformer is rated at 464 VCT @ 60 mA and 6.3 VAC @ 2.8 A. B+ voltage at the output of the second filter with a nominal line voltage is 185 VDC.

The Multivibrator Circuit:
The multivibrator uses a 6SL7 dual triode vacuum tube. The triodes are coupled through a common cathode resistor, and an RC circuit determines the frequency of oscillation. One of four timing capacitors is switched in by the range switch. Each capacitor is a decade apart from the previous one. (0.1 µf, 0.01 µf, 1000 pf and 100 pf). The R part of the frequency determining circuit is split between two 100 KΩ potentiometers that are ganged to a single shaft. One of the ganged potentiometers has a second low value potentiometer in series that allows calibrating the oscillator frequency. The cathode resistor is also a potentiometer; it is an internal control that adjusts the waveform.

An external signal can be applied to the SYNC INPUT terminals on the front panel. This signal is AC coupled to the 50 KΩ SYNC LEVEL control. The wiper of the control is connected to the grid of the first section of the multivibrator. If the free-running multivibrator is operating near the sync signal frequency (or a multiple of it) the multivibrator will sync with a harmonic of the sync frequency.

The Limiter Circuit:
The limiter is a 6AC7 high gain pentode amplifier that is driven into saturation to provide a well shaped waveform. The multivibrator output is AC coupled to the limiter.

The Output Cathode Follower Circuit:
The high impedance output of the limiter is fed to a 6V6 beam power tetrode. (It is interesting to note that the schematic shows the tube drawn as a pentode.) The tetrode is wired as a cathode follower with a low impedance version of the input signal appearing across the cathode resistor. This resistor is a potentiometer and the tap is directly coupled to the output terminals producing a fast rise-time square wave adjustable to over 20 volts peak into a high impedance load.

Calibrating the Heath SQ-1:
Proper calibration of the SQ-1 requires an oscilloscope. Prior to calibration the square wave should be set at about 400 cps (uncalibrated) as viewed on the scope to make sure it is functioning. You may need to adjust the two internal potentiometers to get a signal.

To proceed requires a direct connection to the vertical deflection plates of the CRT so the vertical amplifier, which does not have the needed bandwidth, is bypassed. At the time only the O3 and O4 featured a way to bypass the vertical amplifier and it is not a direct connection. Thus, in the manual there are instructions on how to connect the SQ-1 output directly to the vertical plates of the scope. The vertical amplifier response on many of today's scopes are flat out to more than 2 MHz, so no direct connection will be required. Needless to say, this section includes a lot of high voltage warnings.

Once the connection is made, the RANGE switch and frequency dial are set to 60 cps and a 60 cps signal is applied to the horizontal amplifier. With the SYNC LEVEL at minimum and the OUTPUT LEVEL at maximum, the 5 KΩ pot (marked **FREQ. ADJ** on the attached schematic) is adjusted *until a stationary square pattern is viewed on the scope.*[3]

Next, the waveform is adjusted, first at 10 kc and then touched up at 50 kc. This is done by first using the scope's internal sweep oscillator so a couple of cycles of the square wave are synced on the screen. Then the 10 KΩ pot (marked **WAVE SHAPE** on the attached schematic) is adjusted *until the best proportioned square wave is obtained.*[4] Heath recommends you do the procedure twice, as there is some control interaction.

With these steps completed the instrument may be mounted in the cabinet, ready for use.

Conclusion:

If you are an audiophile, having a square wave generator and scope, can help you be sure your equipment is working properly. With today's digital ICs and multivibrators the SQ-1 probably has little use in the solid-state world other than testing amplifiers for bandwidth.

Comments:

I had hoped to have this article ready for the January issue of the OCARC RF newsletter but am still rather busy.

QM-1 Update (HotM #102)

The restoration of my QM-1 Q-Meter has been completed except for seeing if I can remove some of the white paint that was splattered on the top and side of the cabinet and even a little on the face. I'm hoping it is a different type of paint and I can find something that removes it but not the base coat put on by Heathkit. I assume it is house paint and maybe latex based?

Electrically the unit operates fine and calibrated easily. The 12AT7 signal generator tube was soft and gave reduced output at the higher end of the top band, but a replacement brought everything up to snuff. The generator tracks the scale on the front within Heathkit specs of less than 3%. Most of that error is at the top and bottom ends of the scale on each range.

I was able to get both of the variable capacitors with a vernier drive freed up. Luckily, the way the capacitors mount in the chassis it was easy to get to them for the fix. Unfortunately, in most other equipment the capacitor will need to be removed prior to freeing up and re-lubricating of the vernier drive.

April is fast approaching, so I'm asking for suggestions for an unusual Heathkit to tie in with April 1st.

73, from AF6C

Notes:

1. The mathematics behind this involves the Fourier Series and Fourier Analysis. See the Fourier Series Sidebar for further information.
2. The first harmonic of a sine wave is the fundamental frequency. It is the second harmonic that is twice the fundamental frequency.
3. The italicized text is a note from the manual.
4. See Note 3.
5. (Sidebar) - Definition is from the Merriam-Webster online Dictionary: https://www.merriam-webster.com

Remember, if you are getting rid of any old Heathkit Manuals or Catalogs, please pass them along to me for my research.

Thanks - AF6C

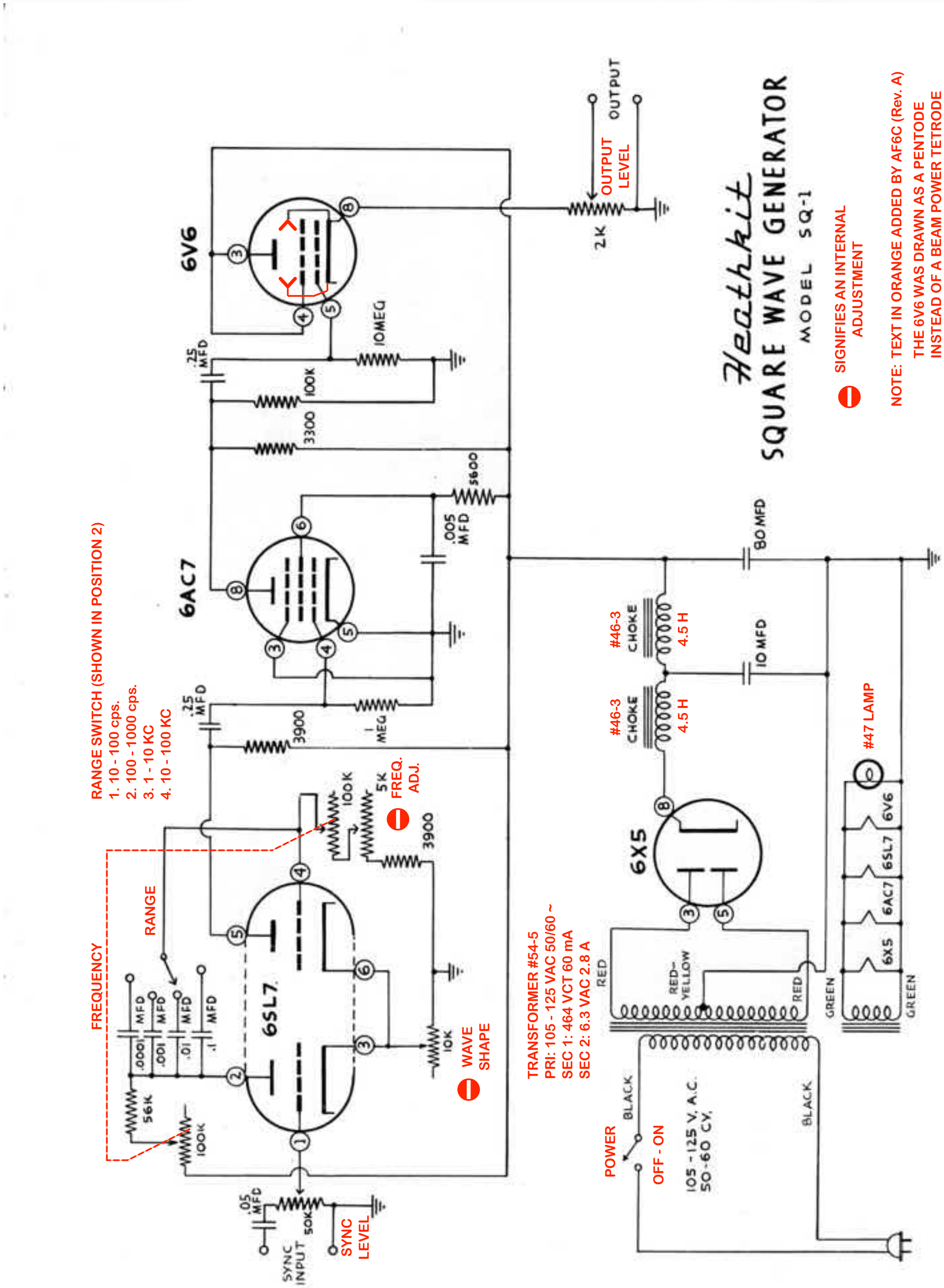

Figure 6: Annotated Heathkit SQ-1 Schematic

Fourier Series…

This series, named for Jean-Baptiste Joseph Fourier (1768-1830), *is an infinite series in which the terms are constants multiplied by sine or cosine functions of integer multiples of the variable and which is used in the analysis of periodic functions.*[5]

In other words, any periodic function can be replicated by summing infinite harmonic sine or cosine waves of varying amplitudes. Today, Fourier, analysis is taught in electrical engineering school and is used in the study of periodic waves. Fourier Transforms allow one to study a periodic function (or wave) in the frequency domain instead of the time domain. (i.e. the X-axis of a graph is in frequency instead of time).

Mathematically, the amplitude of a **square wave** with respect to time can be shown to be equal to:

$$x_t = \frac{4}{\pi} A \sum_{n=1,3,5\cdots}^{\infty} \frac{1}{n} \sin(n\omega t) \qquad \textbf{(Eq 1)}$$

where:

- X_t is the amplitude of the square wave at time t.
- π (pi) = 3.1415926…
- A is the amplitude of the square wave.
- n is a series of odd numbers starting at one and continuing to infinity.
- $\omega = 2\pi f$ (where f is frequency).
- $\sum_{n=1,3,5\cdots}^{\infty}$ is the sum of all the values of the equation to the right for each value of n.

Figure A shows a graph of each solution for odd values of n =1 through n =19. The first five values are shown in green and the second five are shown in black. The sum of all these waves is shown in red. Notice that it is already beginning to take the shape of a square wave.

5. See Notes on page 20.

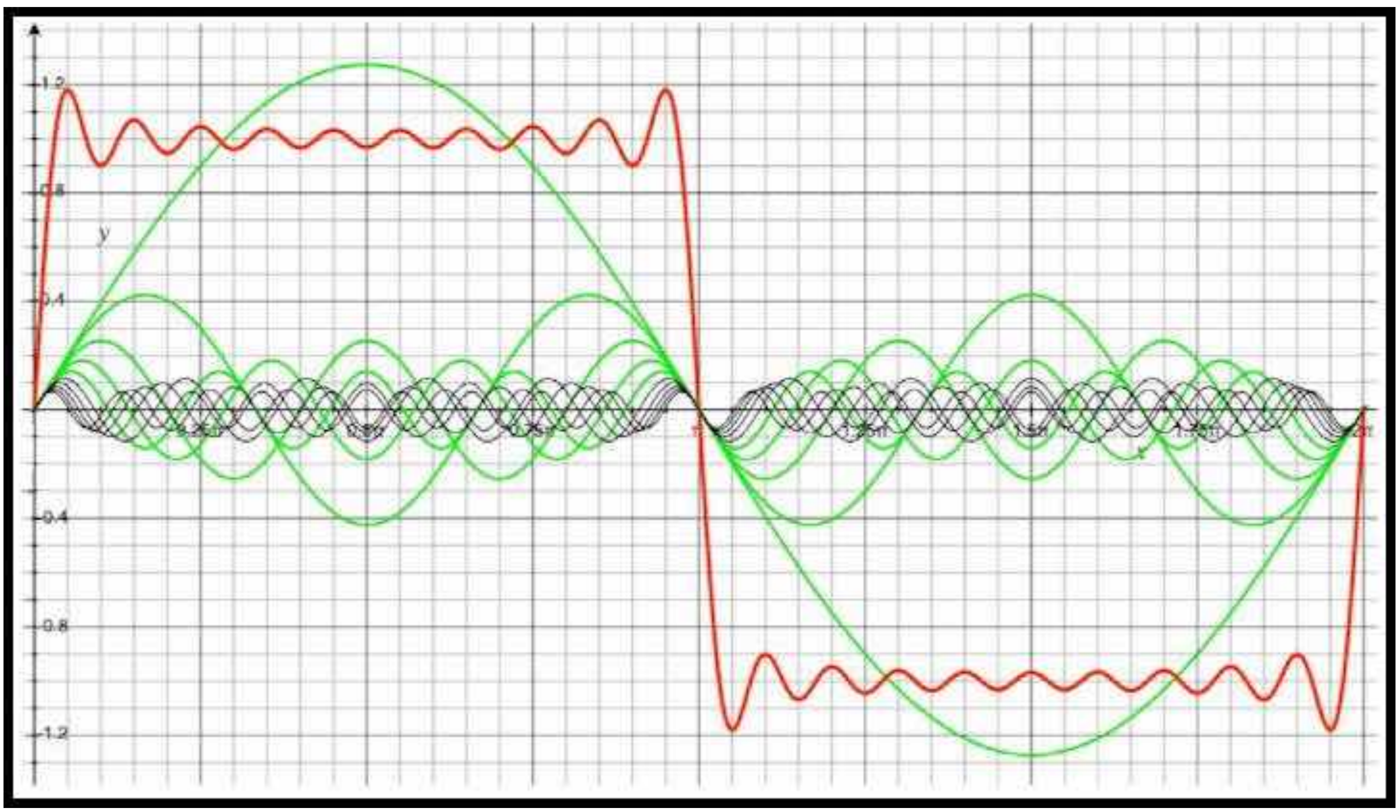

Figure A: Solutions for equation 1 for the first ten values of n (n= 1, 3, 5,…, 19). The first five are shown in green (n = 1, 3, 5, 7, 9), and the second five are shown in black (n = 11, 13, 15, 17, 19). The red line is the sum of the ten traces. Notice after only ten sums the wave is taking on the appearance of a square wave.

REVISIONS

Rev. A. 4/4/2021:

1. Correct page numbers in text. They were referencing the pages in the RF Newsletter version.
2. Page one, corrected the last sentence of the introduction to read: *Heathkit's response was the SQ-1*.
3. Corrected the schematic on page 9 to reflect the correct transformer specifications as mentioned in the text:
   Was: SEC: 424 VCT 0.6A
   Is:SEC: 464 VCT 0.06 A
4. Minor typos and punctuation fixed.