Heathkit of the Month:
by Bob Eckweiler, AF6C

HEATHKIT

STEREO HI-FI EQUIPMENT
Heathkit AJ-14
Solid-State Stereo FM Tuner

Introduction:

Heathkit of the Month #52 covered the AA-32 tube-type stereo amplifier. As I mentioned it was passed on to me by Ken - W6HHC. Ken also passed along an AJ-14 solid-state tuner that had developed a serious problem.

In mid-1965 Heathkit released three related solid-state stereo kits, the AA-14 amplifier, the AJ-14 FM tuner and the AR-14 receiver, all in the same style. One could either purchase the AR-14 receiver which combined the circuitry of the AA-14 and the AJ-14 in one package for $99.95 or purchase the amplifier and tuner separately for $59.95 and $49.95 respectively. These kits came less a cabinet in case the builder planned to install his stereo in a console. Heathkit sold cabinets separately and the builder had a choice of either a “genuine walnut veneer” wood cabinet or a beige metal cabinet. The AA-14 and AJ-14 both measure 12-1/2”W x 3-1/2”H x 9-5/8”D and fit the AE-35 walnut wood cabinet ($7.95) or the AE-35 metal cabinet ($3.50). The AR-14 measures 15-1/4”W x 3-7/8”H x 12”D and fits the AE-55 walnut wood cabinet ($9.95) or the AE-65 metal cabinet ($3.95).

The AJ-14 Solid-State FM Tuner:

The AJ-14, shown in the AE-35 walnut veneer cabinet in Figure 1, uses 14 transistors and 5 diodes (two are built into the detector transformer and one is in the front-end). The front-end of the tuner comes factory assembled (from Japan I surmise, as it uses Japanese 2SA series transistors), and is sealed in a soldered together metal housing. Providing a factory as-

Figure 1: Heathkit AJ-14 FM Stereo Tuner (top) and AA-14 Stereo Amplifier (bottom).

sembled front-end simplifies assembly, removes some critical assembly steps and allows pre-tuning for simplified alignment.

The front panel is styled in black and silver with an illuminated 1” high plexiglass upper section that extends to within an inch of each side. It includes a 4-1/2” slide rule tuning dial with a blue scale on a black background marking every 1/2 mc and blue numbers marking every 4 mc between 88 and 108 mc. A small red lamp left of the dial indicates that the tuner is receiving a stereo signal. Two slide switches between two controls are located below the slide-rule dial. They are, from left to right, the **PHASING** control, with an **IN/OUT** switch that is activated when the knob is pulled out (more on the PHASING control when the multiplexer section is covered), the **STEREO/MONO** slide switch, the **ON/OFF** slide switch and the **TUNING** knob. The tuning knob features a heavy flywheel for smooth tuning.

Viewing the austere rear panel of the AJ-14 (Figure 2) from left to right is the power cord with strain relief, the **RIGHT OUTPUT** and **LEFT OUTPUT** RCA type audio jacks and the two screw-terminal **ANTENNA** connections. The upper rear of the back is open and prone to collecting dust on the top of the chassis.

Most of the AJ-14 circuit is located on a large printed circuit board. Even the pre-built front-end mounts on the PC board. This simplifies construction and help assure a well constructed kit.

AJ-14 Specifications:

The AJ-14 tunes from below 88 to 108 mc. with a sensitivity rated at 5 µV. The antenna input impedance is 300Ω balanced. The superheterodyne circuit uses an intermediate frequency (IF) of 10.7 mc. Image rejection is at least 45 dB and IF rejection 80 dB. AFC (Automatic Frequency Control) correction has been incorporated to prevent drifting.

Audio output for each channel is at a common line-level of around a half-volt (20 KΩ) with a frequency response of -3 dB to +0 dB from 30 cps to 15 kc. Harmonic distortion is less than 1% and hum and noise are specified to be more than 50 dB down. Stereo channel separation is greater than 30 dB.

Heathkit AJ-14 Circuitry:

The FM tuner circuit is straightforward with perhaps the stereo demultiplexing section being the exception. The tuner can be divided into five sections: The power supply, the preassembled front-end, the IF, the FM detector, and the stereo demultiplexer. Most of these sections will be skimmed over as they have been discussed in previous articles.

Power Supply Section

The AJ-14 requires very little power to operate as opposed to earlier tube FM tuners. Power is specified at 2.5 watts from the AC line. Over half of that power is used to by the two #47 pilot lamps to illuminate the slide-rule dial. The power supply uses a transformer with a 23 volt center-tapped secondary winding. Half of the winding only powers the two #47 pilot lamps. The other half of the winding is part of a half-wave rectifier circuit, using a silicon diode and a dual can-type 1,000 µF filter capacitor. A 220 ohm 1/2 watt resistor drops about 5.4 volts between capacitor sections. The first capacitor section produces 13.4 volts which drives the STEREO indicator lamp when receiving stereo. The voltage at the second capacitor section supplies around 8 volts to the remaining circuitry. The whole tuner, less the lamps, draws about 25 mA at 8 volts.

The primary side of the power transformer is fused with a 1/4 amp pigtail fuse that is soldered to a terminal strip under the chassis.

AJ-14 Front-End Section

The front-end uses three germanium (GE) PNP transistors designed for high frequency operation. The RF amplifier is a common base circuit with the input and output tuned by a three-section main tuning capacitor. AGC (automatic gain control) voltage is applied to the base to limit gain on strong signals. The RF is then coupled to the mixer section as is a signal from the local oscillator. This oscillator operates 10.7 mc above the desired signal and is controlled by the third section of the main tuning capaci-

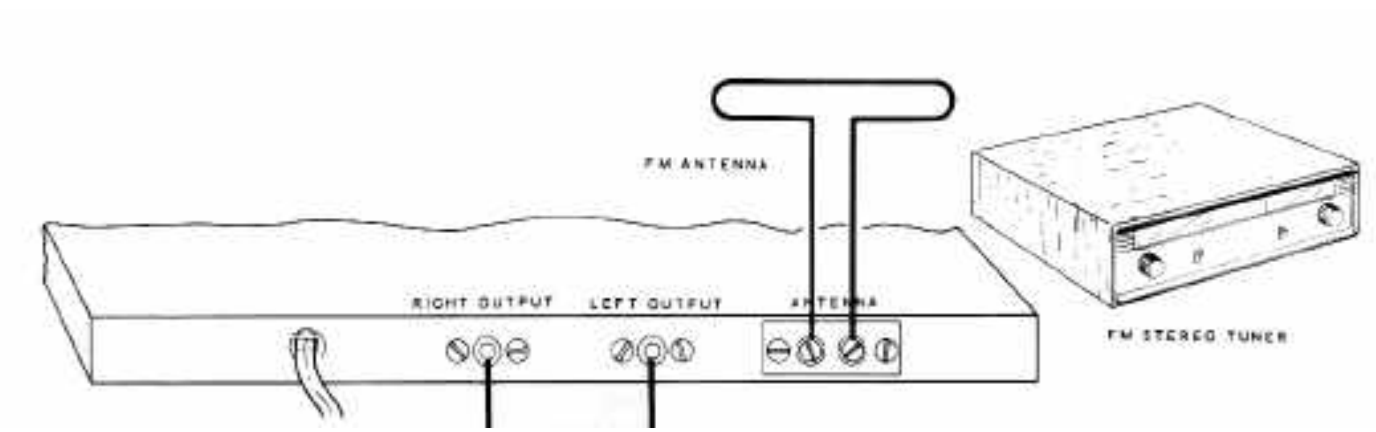

Figure 2: Heathkit AJ-14 Rear Panel Connections Drawing - Right out of the Heathkit Manual.

tor. The 10.7 mc. mixer difference signal is fed to the IF amplifier stages.

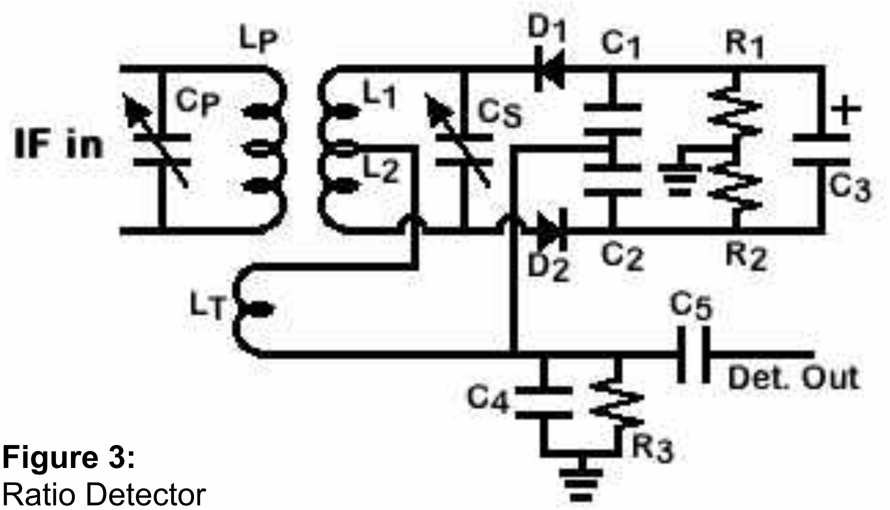

Figure 3:
Ratio Detector

AJ-14 IF Section
Four stages of IF amplify the output of the mixer. These all use 2N2654 GE PNP transistors. Output from the third stage is rectified and used to develop the AGC voltage which is fed back to the first IF. A lower impedance version of the AGC signal is coupled off the first IF emitter to control the RF amplifier. The IF is designed to provide amplitude limiting on the signal. Limiting occurs when the signal is strong enough that any amplitude modulation on the FM carrier is removed by the stage going into saturation. The stronger the signal the earlier the IF stage where limiting begins.

AJ-14 Ratio Detector Section
The AJ-14 utilizes a ratio detector which produces an output voltage proportional to the deviation of the incoming signal from the 10.7 mc IF center frequency. The frequency of the detected signal is determined by the amount of times the signal deviates from the center frequency. Variations in the amplitude of the IF signal reaching the detector are noise and most is removed by the limiting capabilities of the IF stage(s). The ratio detector further rejects IF amplitude variations by its design. Earlier FM discriminator detectors had to rely more on the limiter stages to reject IF amplitude changes.

Referring to figure 3, the heart of a ratio detector is its transformer. This transformer has four windings, a tuned primary Lp, a loosely coupled and tuned secondary winding that is center-tapped L1 and L2 (considered separate windings), and a fourth tertiary winding L_T that is untuned and coupled tightly to the base of the primary winding. The primary is tuned by Cp and the secondary by Cs to the IF center frequency. Energy transferred to the secondary windings L1 and L2 each travel in separate detector loops. The first loop is made up of L1, L_T, R3, R1 and D1, and is filtered by C1. The second detector loop is made up of L2, D2, R2, R3 and L_T, and is filtered by C2. Note that the current from each loop flows through L_T and R3 in opposite directions. When the IF frequency is at the center frequency, the loop currents are identical and the voltage across L_T and R3 sum to zero.

Since the current through R1 and R2 are identical at the center frequency, so are the voltages across C1 and C2 which are in series. A large electrolytic capacitor (C3) is across these capacitors and tends to keep the sum of the voltages across C1 and C2 constant, further rejecting any IF amplitude variations.

Due to the way L_T is coupled to the primary, the signal induced in it is in phase with the primary. However, the signals in the two lightly coupled secondary winding are out of phase with the primary by 90° at the center frequency. When the input IF frequency moves from the center frequency, the phase shift between the primary and secondaries change. Since the phase in L_T remains the same it aids the signal in one loop and bucks it in the other loop causing a voltage to appear across R3. Any remaining 10.7 mc signal is removed by C4 and the detected signal is coupled through C5 to the next stage.

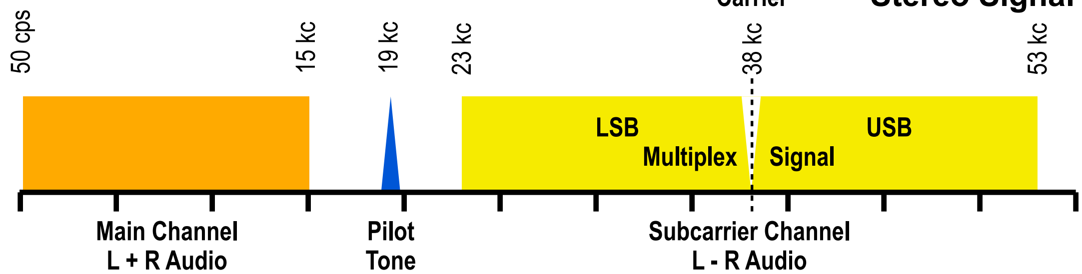

Figure 4: FM Stereo Signal Spectrum

AJ-14 De-Multiplexer Section

If this was a monaural FM tuner the signal from the ratio detector would be filtered, amplified and sent to the tuner output jack. More processing is needed to recover the two stereo channels. We'll revisit this section after a brief discussion of how FM stereo is broadcast.

FM Stereo Transmission:

I had planned to discuss in detail how FM stereo is transmitted. However, it got too deep and detailed for a Heathkit article, So here I will just touch on the basics and will go into the real details in a future Bob's Tech Talk article (hopefully next month). It really is clever how it is transmitted and recovered. Adding a second channel is not that simple; if you transmit, say the left channel on the main audio channel and the right channel as a multiplexed signal, then people with monaural radios will only hear the left channel, which means they will miss information, especially when the the station is broadcasting highly separated stereo.

The solution used broadcasts the left and right channels combined (L + R) as the main audio signal and the difference between the two channels (L - R) as a multiplexed signal. Thus those listening in monaural will hear the full (L + R) content, though not in stereo. The multiplexed (L - R) signal is transmitted as a double sideband suppressed carrier (DSB) signal on a frequency of 38 kc. A pilot tone of 19 kc is also transmitted; it is in phase and exactly one-half the frequency of the 38 kc carrier used to develop the 38 kc DSB signal. This is all shown in figure 4. The orange is the L + R main audio signal, the blue is the pilot tone and the yellow is the DSB 38 KHz multiplexed (L – R) signal.

In the receiver, the 19 kc pilot tone is used to accurately recreate the original 38 KHz carrier in frequency and phase. At the same time the the 19 kc pilot tone and any other information not required for stereo FM reception is removed from the detected signal. These include SCA and RBDS channels that are sometimes broadcast for special users (We'll discuss these other multiplexed signals in the upcoming article.)

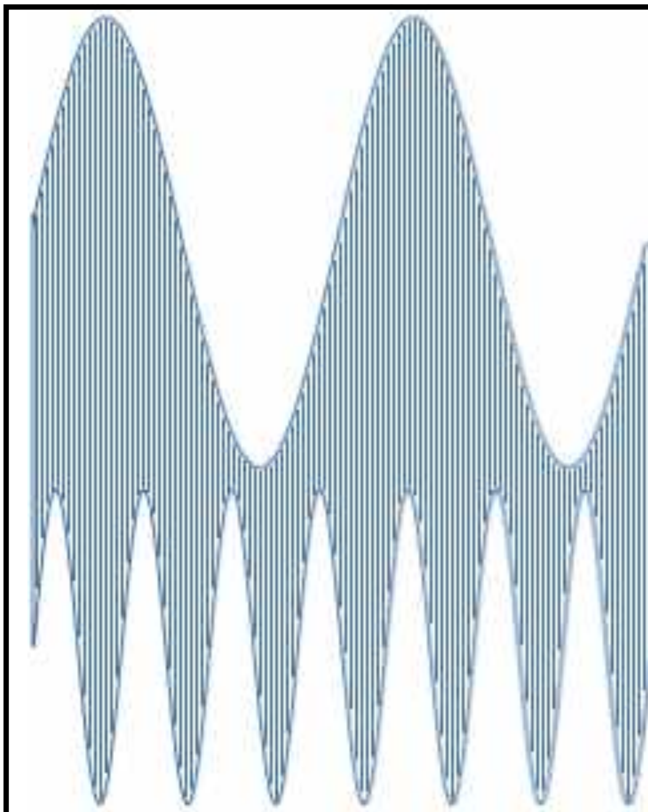
Figure 5: (L – R) multiplexed signal riding on (L + R) audio signal after the 38 KHz carrier is reinserted.

The remaining signal, which is the (L + R) audio with the 38 KHz DSB multiplexed signal, modulated by (L - R), riding on top of it has an interesting waveform. When the 38 kc carrier is reinserted, the top edge of the waveform represents one of the channels, and the bottom of the waveform represents the other channel. This is shown in Figure 5, in which two cycles of a 200 Hz. sine wave, representing the left channel, is the upper edge, and seven cycles of a smaller amplitude 700 Hz. sine wave, representing the right channel, is the lower edge. These two signals are recovered in the de-multiplexer section of the AJ-14.

AJ-14 De-Multiplexer Section Revisited

The multiplexer section is shown in Figure 6. It uses seven silicon NPN transistors; all are NPN silicon type 2N2712. The signal from the ratio detector, after being stripped of any SCA data by L6, C201 and C202, is amplified by transistor Q8 and fed to transistor Q9 which performs two functions. Its collector is tuned to 19 kc extracting the pilot tone, while the remaining (L + R) and DSB (L – R) signals are recovered from the emitter of Q8, which also acts like an emitter follower for these signals.

The 19 kc pilot tone is fed through a phasing circuit controlled by the front panel PHASING potentiometer. It is then fed as a sync-signal to transistor Q10 which operates as a free running 38 kc oscillator. The pilot signal thus locks the 38 kc oscillator to the correct frequency and corrected phase of the oscillator that created the multiplexed subcarrier.

A small amount of the 19 kc signal also is coupled to the transistor Q13. Each positive cycle of the 19 kc tone turns the amplifier Q13 on for a short period determined by an RC time constant or C221 and R219. The output drives a second transistor Q14 that pulses on and off the STEREO indicator lamp on the front panel. Since the 19 kc pilot tone is only present on stereo transmissions, the lamp indicates stereo reception.

The signal leaving the emitter of the transistor Q9 is the main (L + R) signal with the 38 kc DSB (L - R) signal riding on it. If, at this point the 38 kc carrier were reintroduced the wave

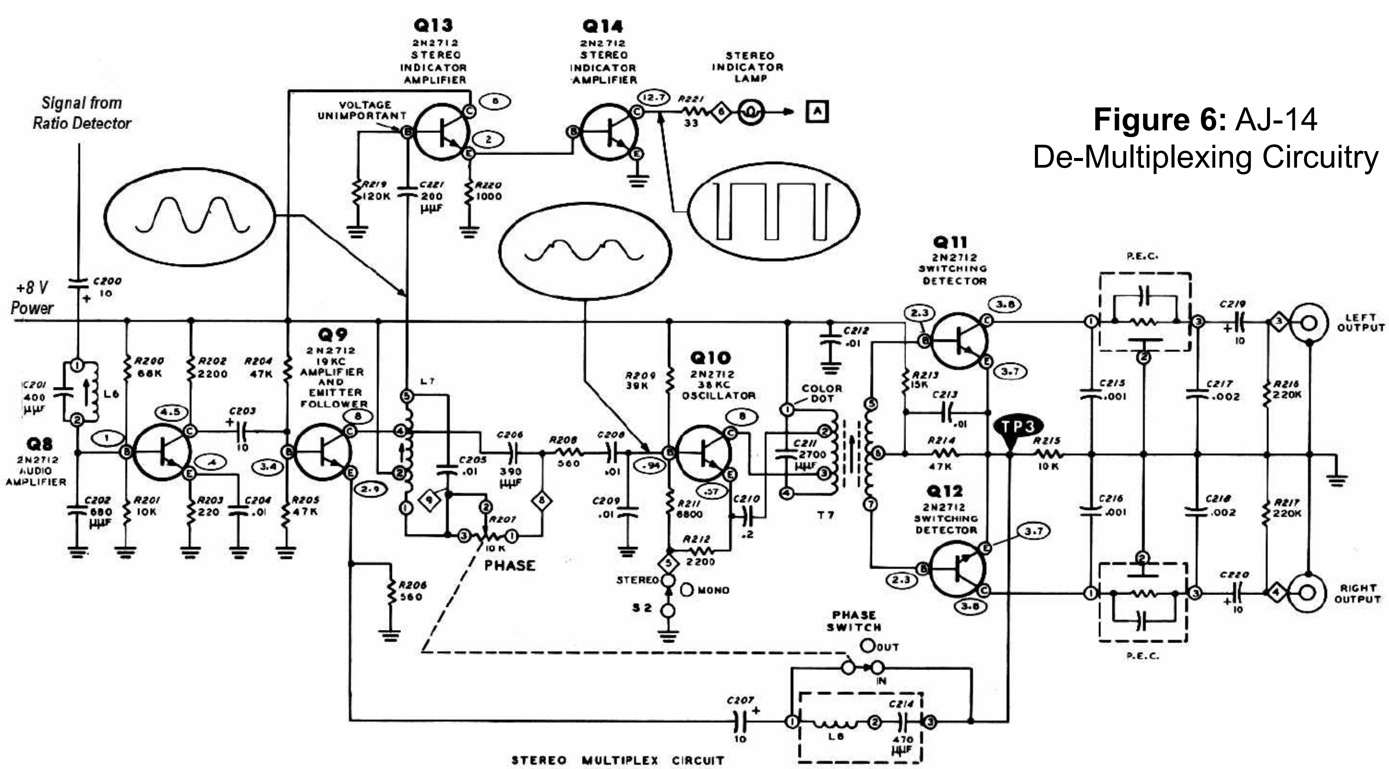

Figure 6: AJ-14 De-Multiplexing Circuitry

form of figure 5 would appear. However, it is not really necessary to actually re-introduce the carrier. Instead T7 alternately turns on Q11 momentarily at the +90° point of each cycle of the 38 kc oscillator (Q10) charging C215 to that voltage, and Q12 momentarily at the -90° point of each cycle charging C216. (The +90° point is when the waveform is at its most positive point and the -90° point it is at its most negative point). Thus the voltage across C215 follows the left channel signal and the voltage across C216 follows the right channel. These two signals are filtered to remove any residual 38 kc noise and de-emphasized. (De-emphasis will be discussed in the next article). The audio is then presented to the output jacks to be sent to the stereo amplifier.

Stereo - Monaural Switching:

When receiving monaural broadcasts the 38 kc oscillator is disabled by the STEREO MONO switch on the front panel. This disables the 38 kc oscillator and Q11 and Q12 then operate as simple emitter followers sending the monaural signal to both the left and right output jacks.

Phase Control:

For best channel separation it is important for the phase of the 38 kc oscillator in the receiver be the same as the oscillator generating the original DSB signal. In early FM stereo tuners a phase control was sometimes included to allow the user to correct for any phase errors on received signals. When the PHASE control is pulled out the PHASE SWITCH opens inserting a filter, composed of L8 and C214, between the output of Q9 and the emitters of Q11 and Q12. This filter only allows the 38 kc (L - R) signal to pass. The PHASE potentiometer provides a way to manually shift the phase of the pilot tone, hence adjusting the phase of the 38 kc oscillator. The PHASE control is adjusted for the strongest audio output with the PHASE control pulled out to assure the best channel separation. the PHASE control is then pushed in removing the filter for normal listening. In later stereo tuners this adjustment has been automated.

Summary:

The AJ-14 tuner and AA-14 amplifier, as well as the combined AR-14 receivers were very popular Heathkits. They remained in production until 1975 when ICs began to replace discrete components for IF circuitry and de-multiplexing.

So what was the problem with the AJ-14 that Ken passed on to me? Well the problem was simple, the solution was not! The problem was that the whole FM band had suddenly compressed and now tuned over about one-half inch on the big 4-1/2” dial. Looking over the kit, which was well built, I concluded the problem had to be in the factory assembled tuner. Disassembling the tuner front-end required removing it from the circuit board and unsoldering its metal covers without destroying it. I did this with much trepidation. If the kit had been returned to Heathkit for repair, I imagine they would have just replaced the whole front-end assembly.

Once the assembly came apart the problem was located after some investigation; it was a cold soldered joint that had developed an obvious crack. A few minutes with a soldering iron solved that. Putting the front-end back together was a lot easier than taking it apart. After firing it up and touching up the alignment, it played like it should, and still sits on my bedroom bookshelf and is often put to use. I find I rarely have to adjust the PHASE control from station to station.

73, from AF6C

This article originally appeared in the February 2015 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.

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

Thanks - AF6C