The OctalMania 80 Receiver

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Introduction

Construction of the OctalMania 80 receiver shown in Figure 1 was prompted by acquisition of a mechanical filter, and a desire to spin another all-octal tube creation. This radio is a great performer. The filter is a 455 KHz unit with a 2.1 KHz bandwidth, manufactured in the 1960s by a Japanese company called Kokusai. It has the same performance specifications as a Collins S-Line filter. As far as I am able to determine, Kokusai filters were available from Lafayette Radio with their markings, and were used in some of their receivers. They were also used in some KW series radios built in the UK, and possibly some Japanese equipment.

Figure 1: The OctalMania 80 Receiver

Use of a 455 KHz filter allowed construction of a single conversion radio for 80 meters, with a variable frequency oscillator (VFO) frequency 455 KHz above the incoming signal. The filter itself is actually an upper sideband (USB) type that is designed for a carrier or BFO frequency of exactly 455.000 KHz. Because the VFO is on the high side of the signal, sideband inversion occurs such that the USB filter output is actually the lower sideband (LSB) of the received signal. Kokusai also made a matching LSB filter for the same carrier frequency that was used in my HB-75 transceiver.

The radio design includes the following features:

- Coverage of the complete 80 meter band from 3.5 to 4.0 MHz
- A total of ten octal tubes, including voltage regulator, all WWII vintage
- Rock stable, vintage vacuum tube VFO
- Digital display for accurate readout of the received frequency
- Display resolution (10 Hz or 100 Hz) selectable by front panel switch
- Self-contained, all solid state power supply
- Regulated DC voltage applied to filaments of VFO tube (to improve stability), and product detector tube (to eliminate AC hum)
- Panel mounted three inch speaker
- Rear panel jack for connection of an external speaker

From start to finish, it took about four months of almost full time effort to complete the receiver, including all documentation. The result is a homebrew radio that looks great inside and out, and works as great as it looks. It is very easy to set up and use.

Mechanical Layout

The chassis rear is shown in Figure 2.

Figure 2: Chassis Rear

Chassis top and bottom views are shown in Figures 3 and 4 respectively.

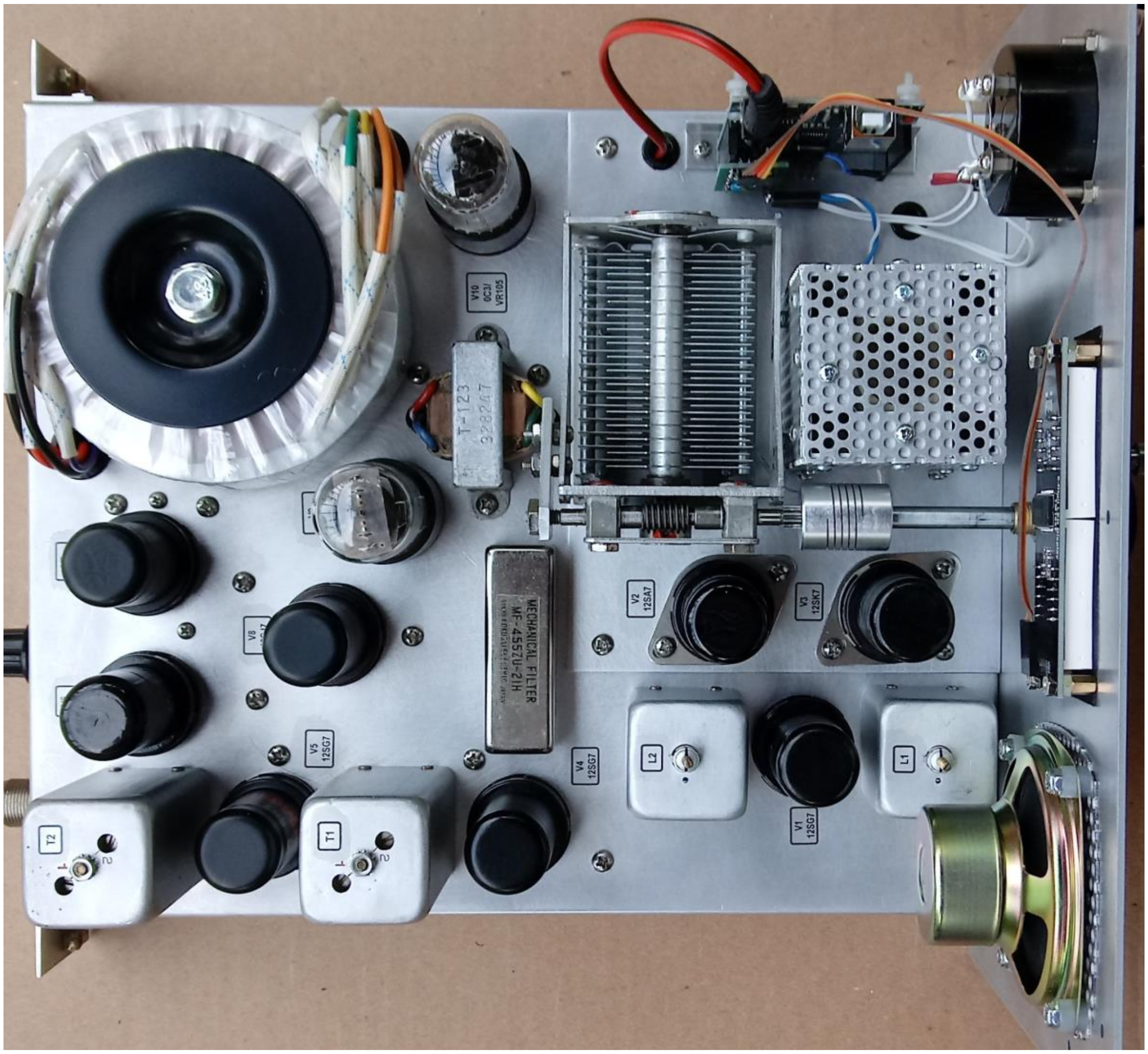

Figure 3: Chassis Top View

The radio is built on a 10 x 12 x 2 inch chassis. The front panel is 12 x 7.5 inches, and the cabinet is 12 x 12 x 7.5 inches. Total weight is 16.3 lbs. The cabinet is custom built from .062” perforated aluminum sheet, with a frame made from .75” x .062” aluminum angle stock.

Looking at Figure 3, the VFO components are mounted to a piece of tempered aluminum on top of the chassis for mechanical strength. The VFO tube and mixer tube are mounted on this plate.

The VFO tuning capacitor is from an ARC-5 transmitter. It uses the front variable from this unit, which was modified to add a preload adjustment to the worm gear shaft. The VFO coil is also from an ARC-5 transmitter, and is housed inside the perforated aluminum enclosure in front of the tuning capacitor. The four coil cans were salvaged from an ARC-5 receiver, with new coils and IF transformers fitted inside.

The Arduino Uno R3 module used for the frequency counter/display is mounted vertically just behind the meter. A toroid power transformer is used to power B+, filament and low voltage DC supplies. It is an Antek P/N AS-1T200. Directly behind the VFO tuning capacitor is the audio output transformer. A three inch speaker is mounted to the front panel, using silicon rubber isolators.

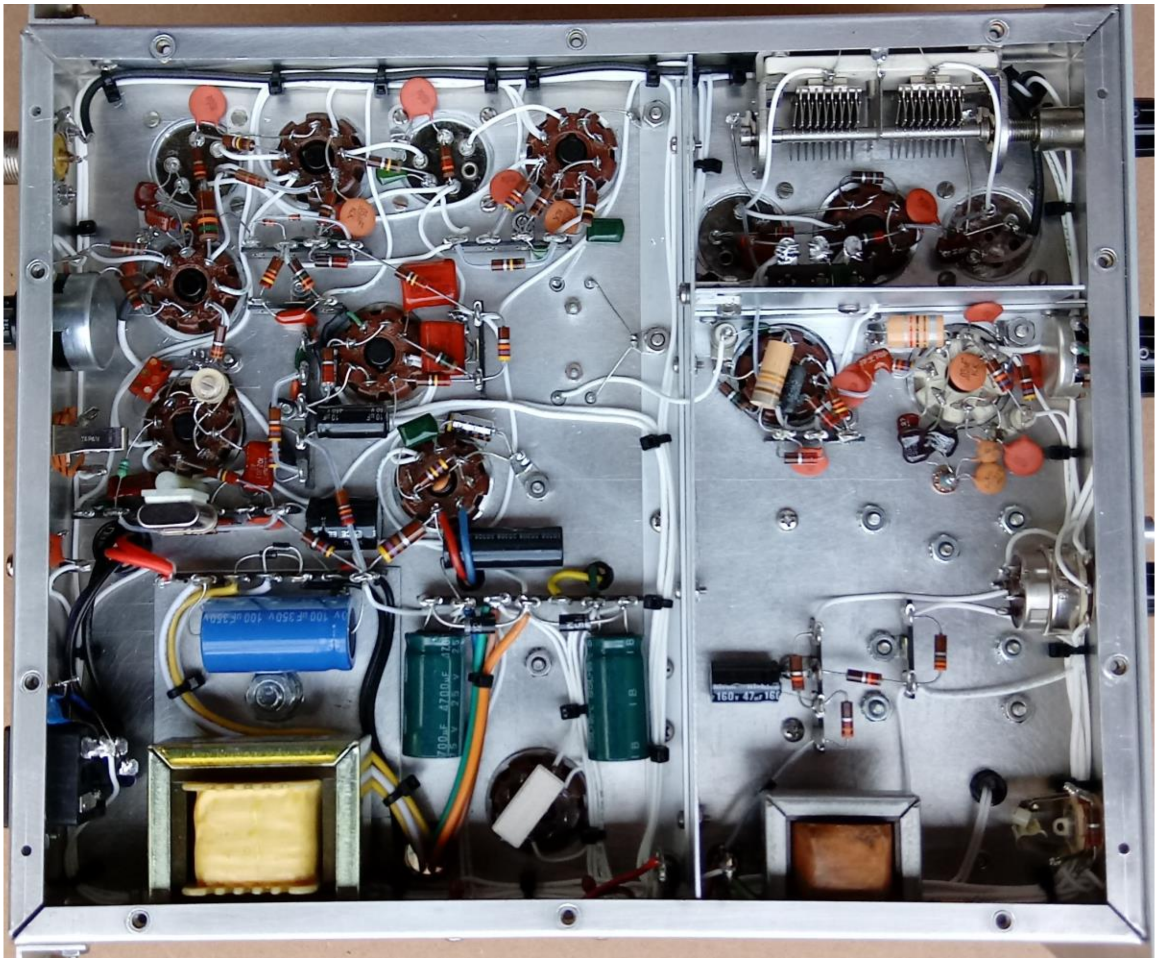

Figure 4: Chassis Bottom View

Turning to Figure 4, a shield fastened to .5" angle stock runs sideways across the chassis to provide rigidity for the VFO plate. All tube sockets except the VFO are the snap ring type salvaged from ARC-5 radios, in keeping with the WWII flavor of the set.

The B+ power supply uses a choke input, and the choke itself is mounted under the power transformer. The smaller transformer to the right is a reverse connected filament transformer that powers the bias circuits.

The 455 KHz BFO crystal is mounted vertically on a fiberglass peg, seen at the left center of the chassis. This was an expensive crystal, with wire leads that would not fit into a conventional socket. Therefore, it was securely mounted so that the leads would not break off from accidental bending.

Block Diagram Circuit Description

A block diagram of the OctalMania 80 is shown in Figure 5. The incoming signal at the ANTENNA jack is routed to an input LC circuit that feeds the grid of RF amplifier V1. The output of V1 is run through another LC circuit and then on to mixer V2. The LC circuits are tuned by a dual section variable capacitor brought out to the front panel as the PRESELECTOR control.

V2 is a pentagrid mixer that combines the amplified RF from V1 with a VFO injection voltage from V3. The injection frequency varies from 3.955 to 4.455 MHz. When an incoming LSB signal is subtracted from the VFO signal, a 455 KHz USB intermediate frequency (IF) signal results.

To illustrate how this happens, suppose an incoming LSB signal has a carrier frequency of 3.800 MHz, and a bandwidth of 2 KHz (i.e., .002 MHz). The carrier signal at the input of mixer V2 is thus 3.800 MHz, with lower sidebands extending downward to 3.798 MHz. To receive this signal, the VFO is set .455 MHz above the signal's carrier, or 4.255 MHz. The carrier signal at the output of the mixer is then .455 MHz (4.255 minus 3.800), with sidebands now extending upward to .457 MHz. (4.255 minus 3.798). Thus, sideband inversion has occurred, and what was a LSB signal at the antenna is now a USB signal that passes through the USB filter.

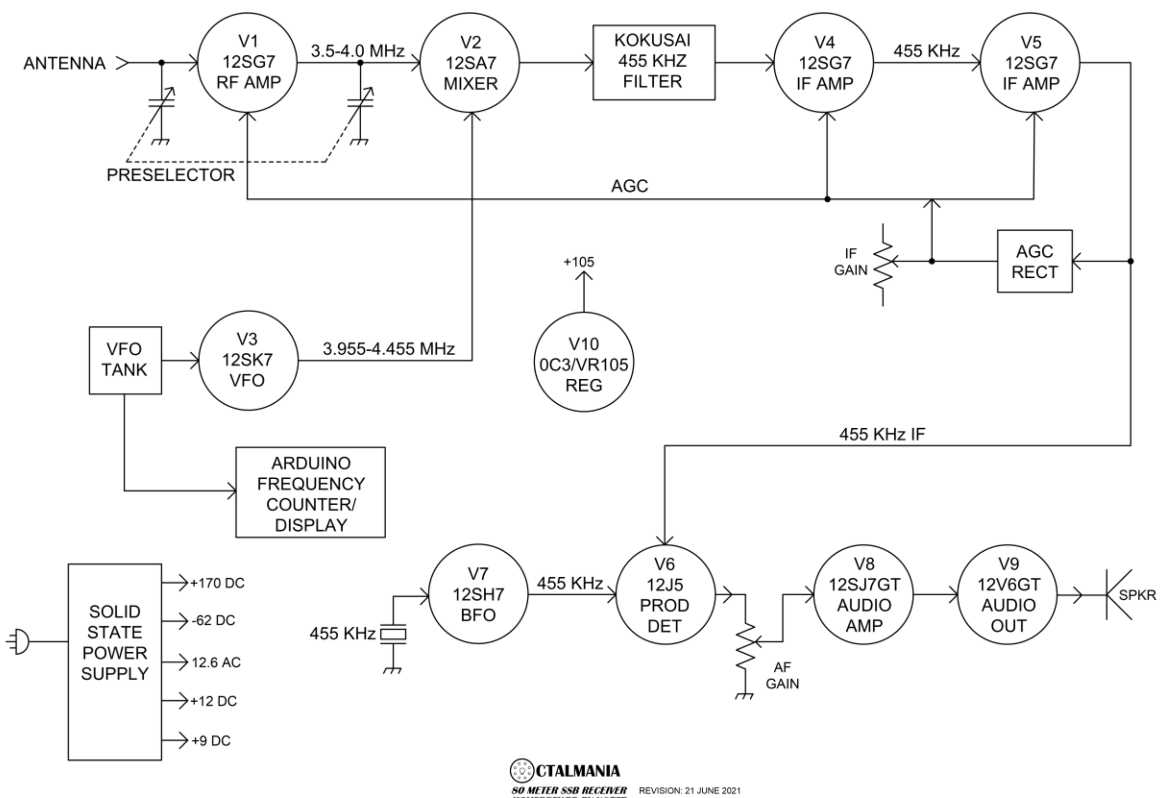

Figure 5: Block Diagram

The output of the mechanical filter is applied to the grid of first IF amplifier V4. The output of V4 is fed to the grid of V5, the second IF amplifier. The output of V5 goes to

V6, which serves as a product detector. The 455 KHz IF signal is applied to the V6 grid, and a 455 KHz BFO signal is fed to its cathode. V7 provides the crystal controlled BFO signal. The filament of V6 is powered from +12 VDC to eliminate AC hum.

Audio is recovered and filtered at the plate of V6, and then coupled to the AF gain control. From here it goes to the grid of V8, where it is amplified and fed to V9, the audio output amplifier. Output of this stage is transformer coupled to the internal speaker. The output can also be connected to external headphones or an external speaker.

The output of V5 is also rectified and filtered to generate the AGC voltage. This voltage is fed to V1, V4 and V5, and holds the audio output level virtually constant once a threshold of approximately one microvolt of RF at the antenna is exceeded. Negative bias from the IF GAIN control is added to the AGC voltage to control overall gain, and to mute the receiver in the standby mode.

V3 serves as a stable Colpitts oscillator whose output varies from 3.955 to 4.455 MHz. Output from the cathode of V3 is coupled to the injection grid of mixer V2. V10 provides regulated B+ voltage to the plate and screen of V3, while regulated +12 VDC is applied to its filament. These features produce very good VFO stability.

A small pickup probe is mounted next to the VFO coil. This signal is sent to a signal conditioning circuit, and then on to the Arduino frequency counter and display modules. The Arduino software subtracts 455 KHz from the measured VFO frequency to produce the correct frequency display.

The power supply is all solid state. A modern toroid power transformer sources all B+, filament and low voltage DC loads. A full wave rectifier feeds a choke input filter to provide +170 VDC B+. The choke input circuit provides excellent basic regulation of this voltage under varying load conditions. Additional regulation for the VFO is accomplished by V10.

Filament circuits use 12.6 VAC from a series connection of the two 6.3 VAC windings of the power transformer. This voltage is also rectified, filtered and run through solid state regulators to provide +12 VDC for the filaments of V3 and V6, and +9 VDC for the Arduino counter and display hardware. One of the 6.3 VAC windings feeds a reversed connected filament transformer whose primary is rectified and filtered to source -62 VDC grid bias.

Schematic Diagram Circuit Description

A full schematic diagram of the OctalMania 80 is available on the respective page at kg7tr.com, and should be referred to in this discussion. This information supplements the basic circuit descriptions provided in the previous section.

As mentioned previously, RF inductors labeled L1, L2, T1 and T2 are housed in repurposed aluminum cans salvaged from WWII ARC-5 Command Set receivers. L1 and L2 were part of a kit of slug tuned coils acquired at a hamfest. I added two turns of wire to the "cold" end of L1 to couple it to the antenna input. T1 and T2 use old fashioned, air wound coils with parallel mica trimmers that were a "junque box" find. These were typically used in octal tube receivers of the era. I was able to squeeze them into the Command Set IF cans.

V1 amplifies the signal from the input tank circuit and applies it to an output tank circuit connected to its plate. Both L1 and L2 are resonated by fixed capacitors and C1A and C1B. The 27k resistor across L2 lowers the Q of this circuit enough to eliminate regeneration that was encountered during testing.

V2 is used in a standard circuit for pentagrid mixers found in most old handbooks. The signal from V1 is applied to its signal grid on pin 8. The diode prevents the grid from going positive under certain unusual conditions and locking up the tube. This was a problem I ran across in my Octal Tribander transceiver. A VFO voltage is applied to the oscillator injection grid on pin 5. The mixer output on pin 3 is fed to the input of the mechanical filter through a coupling capacitor. The plate is fed B+ through a choke that isolates the RF.

I was not able to find any detailed application information for the filter. The data sheet that came with it only provided carrier frequency, bandwidth, insertion loss, and input/output impedance. However, I did discover that the input and output terminals each exhibit a capacitance of exactly 470 pf to ground. This leads me to believe that these 470 pf capacitances are part of series LC circuits, where L is actually the inductance of the electromagnetic transducer coils mechanically connected to the input and output ends of the resonant disc chain. At any rate, the input and output circuits work fine as implemented. Attempts to tune them with external capacitors, as Collins does with their mechanical filters, did not result in any improvement in amplitude or ripple.

The filter's output is capacitor coupled to the grid of V4. V4 and V5, together with T1 and T2, are capable of providing more than enough gain for the IF signal. 100k resistors are connected across the secondary of T1 and primary of T2 to reduce the gain, and tame some regeneration that occurred at higher settings of the IF GAIN control.

The IF output at the secondary of T2 is loosely coupled to the grid of V6. Very little signal is required here, since a triode product detector like this provides some gain, which is then followed by even more gain in V8. The BFO signal is coupled into the cathode. Regulated +12 VDC powers the filament of V6. The voltage regulation is of no real consequence here. Rather it is the extremely low ripple of this DC voltage that was needed to eliminate 60 Hz hum present at the output of V6 with normal 12.6 VAC on the filament.

BFO voltage is provided by V7 in an electron coupled oscillator (ECO) circuit. With an ECO, the screen grid is the active element in the feedback path, not the plate. Changes in plate circuit capacitance or inductance have virtually no effect on the oscillation frequency. The plate circuit is broadly resonated to 455 KHz by the 470 µH choke and 390 pf capacitor. Trimmer C3 is used to set the BFO frequency to exactly 455.000 KHz. The 4.7k resistor and 22 µF capacitor filter out any AC going to the plate of V7, so that the 455 KHz output going to V6 is not AM modulated.

IF signals appearing at the plate of V6 are filtered out by an RC network. The remaining audio is applied to R2, and amplified by V8 and V9. B+ going to V9 is further filtered by a series 470 ohm resistor and 47 µF capacitor to reduce 120 Hz hum in the audio output. This is especially important for headphone use.

The receiver AGC circuit rectifies the IF voltage at the secondary of T2. When the 1N4148 diode conducts, it generates a negative voltage across the .01 µF capacitor connected to pin 5 of T2. This voltage is filtered for fast attack and slow release characteristics by a network consisting of the 3.3 meg and 24k resistors, and the .22 µF capacitor. The resulting AGC voltage is applied to the control grids of V1, V4 and V5 to control their gain. Negative bias from IF GAIN control R1 is added to the AGC voltage for manual control. When muting is required for standby mode, full negative bias is applied by adding 12k of resistance to the bottom of the IF GAIN voltage divider chain. A small DC bias is applied to the cathode of the AGC diode through the voltage divider formed by the 220k and 2.2k resistors. This bias sets the AGC threshold to about one microvolt at the antenna. This is called “delayed AGC”, because the signal level must overcome this bias before the diode conducts and produces AGC voltage.

The S meter circuit is patterned after that used in the Collins 75S-3 receiver, and my own 75S-2B receiver. The screen grids of V4 and V5 are fed B+ through a 15k resistor. The 47k resistor connected to the screen of V4 puts a DC bias on the high end of S ZERO pot R3. The wiper of R3 is connected to the plus side of S meter M1, while the negative side of M1 is connected to the cathode of V5.

Under zero signal conditions, there is no AGC voltage applied to V4 and V5. R3 is adjusted to give a zero reading on the meter, i.e., the voltage on the wiper of R3 is exactly equal to the voltage on the cathode of V5.

When signal strength increases, a negative AGC voltage is generated that is proportional to signal strength. This voltage is applied to the signal grids of V4 and V5. The negative voltage causes the voltage at their screens to increase, while the voltages at their cathodes decrease. The meter sees this as a net positive voltage, and deflects upward. The 180 ohm resistor in series with the positive side of the meter provides calibration for an S9 reading. The diode across the meter begins to conduct at almost full scale deflection, which limits deflection and allows some compression at very high signal levels. The diode also prevents pegging of the needle when in the standby mode.

The S meter essentially reads AGC voltage, and was calibrated to modern standards. A reading of S9 is defined as a carrier of 50 µv present at the antenna jack, terminated in 50 ohms. The actual S meter reading for a discrete frequency will vary because of ripple in the mechanical filter. This can be seen when tuning through a CW carrier. A nominal value between peaks and valleys was used to set the calibration. Furthermore, no readings are shown below S3, because signal levels in this region (per modern standards) are insufficient to trigger AGC action and associated S meter deflection.

Like most of my homebrew radios, the VFO components are from an old ARC-5 transmitter. Coil L3 and capacitors in the tank circuit were carefully tweaked to provide the desired frequency range, with slight overlaps at each end. Normally I use the rear variable from an ARC-5 transmitter, since these have a preload adjustment on the worm gear shaft that can be used to eliminate backlash. However, I had exhausted my supply of these on previous radios. So I used one of the front variables instead. After removing all of the dial gears, I fashioned a custom preload assembly at the rear of the unit.

All of the critical VFO components are mounted to a reinforcing metal plate for extra mechanical stiffness. With the cabinet and bottom cover installed, structural rigidity is excellent. And as mentioned previously, regulated +12 VDC is applied to the filament of V3 for better electrical stability. The overall stability of this VFO is exceptional.

The power supply circuits are of conventional design. The 12.6 VAC powers most filaments, and is also half wave rectified, filtered and fed to solid state regulators U1 and U2. U1 provides +12 VDC for the filaments of V3 and V6. U2 provides +9 VDC to the the Arduino module, which in turn provides +5 VDC to the frequency counter signal amplifier and the digital display. Separate diodes and filter capacitors were found to be necessary for the two DC voltages. This was done to ensure that the regulated +12 VDC voltage supplied to V3 and V6 (300 ma total) could be maintained down to a line voltage of 105 VAC. The +9 VDC voltage has a much greater margin, and is maintained to well below this line voltage.

The Arduino counter requires a TTL type of signal at pin D5 to work. Thus, this signal needs to resemble a square wave of about 5 volts peak to peak. The VFO signal that is sampled at L3 is fed through a short twisted pair of wires to Q1. This is an N-channel FET that is connected as a source follower. As such, it presents very high impedance to the sampling probe (1 meg resistance and very low capacitance). Its output is a low impedance source that drives Q2. Amplification and clipping occurs in Q2, such that its output meets the requirement for a pseudo-TTL signal.

The software in the Arduino (aka “sketch” in Arduino lingo) implements the counter function, and sends the resulting data to the display module over a two wire bus. A TM1637 chip in the display module decodes the data, and formats it to illuminate the correct LED segments and decimal point.

A front panel DISPLAY RESOLUTION switch sets the right-most digit to represent tens of Hz or hundreds of Hz. Another way of looking at this is that 100 Hz resolution gives you four digits of accuracy to the right of the decimal point, and 10 Hz resolution gives you five digits of accuracy to the right of the decimal point.

10 Hz resolution can be used to determine exact frequency. However, it must be appreciated that an analog VFO is being used, such that 10 Hz resolution can result in digits toggling between numbers. This can be somewhat annoying, and is usually eliminated by going to 100 Hz resolution. I don’t think you will find any vintage radios with an analog VFO (tubes or solid state) and a digital readout that offer better than 100 Hz resolution because of this.

The Arduino Uno R3 module used in this radio is the type that uses a quartz crystal for the processor clock. This provides excellent stability and accuracy. This type of Arduino Uno R3 is less common than the type that uses a ceramic resonator for the clock. I have tried the latter, and with them it is not possible to get sustained accuracy to 100 Hz, let alone 10 Hz.

The Arduino frequency counter algorithm allows calibration by inputting a constant that tweaks the pulse count during the gate timeout. However, it was discovered that this feature only allowed correction down to about 35 Hz. Accordingly, the IF offset in the Arduino code is actually set to 455.020 KHz, even though the actual BFO frequency is set to exactly 455.000 KHz by C3. The result is that the displayed frequency is accurate to 10 Hz or so.