CompuLign User Guide - V2.0

I. Overview

The CompuLign computer driven alignment tool as developed by L. J. Haskell was designed and built as a multi-functional test device to help radio hobbyists align antique and vintage radios and vintage audio equipment. The design is based on one Arduino Nano micro controller as the main processor plus 2 frequency generation modules based on the AD9850 frequency generator chip. There are 4 outputs and 1 input accessed via BNC type connectors. The functions of the device are:

1. A sine wave generator of 1 volt P-P with output frequency from 1 Hz to 40 MHz set in steps of 1 Hz.
2. A square wave generator of 5 volts P-P with the same frequency range
3. An RF generator of 1 volt P-P with a frequency range of 20 KHz to 40 MHz AM modulated from 0-100% by the sine wave generator output.
4. An RF sweep generator with above output and frequency range that can be swept at multiple rates up to about 50 Hz.
5. A sweep voltage output generating a ramp voltage that can be used to drive an oscilloscope X-axis for a sweep alignment display
6. An input via BNC connector to measure the radio response during sweeps which allows for an internal display of the response displayed on the LCD screen thus eliminating the need for an oscilloscope.

II. Functional Block Diagram

The design of the device consists of multiple functional components. These are shown in Figure 1.

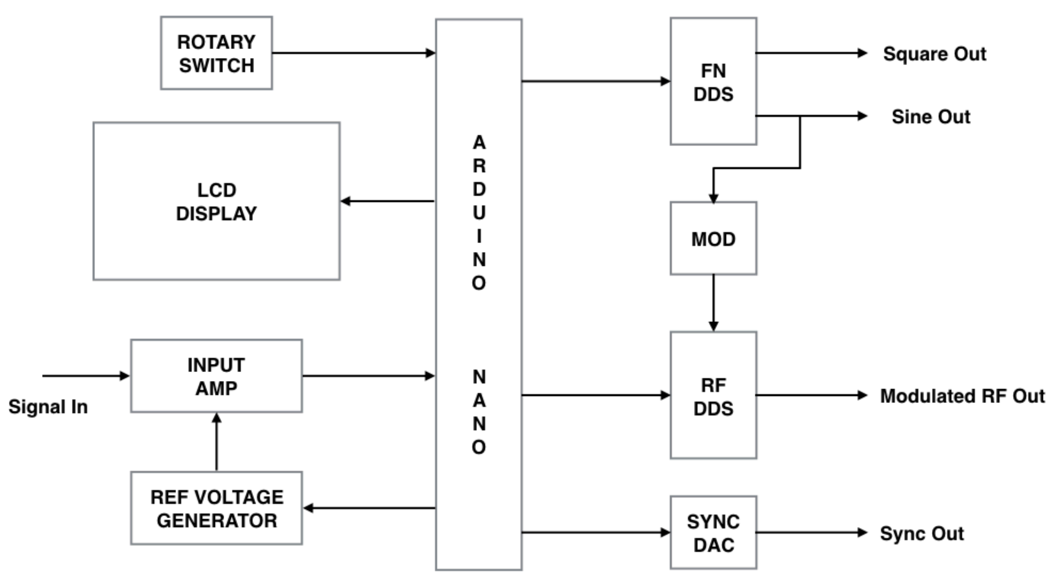

Figure 1 - Circuit diagram schematic of DDS module

At the center is the Arduino Nano micro controller which contains all of the controlling software and has interfaces to all of the programmable components. The Nano drives 2 DDS function generator modules, one used to generate sine and square waves of a wide range of frequencies and one to generate a sweepable RF output. The first generator is also used as an input to the MOD, i.e. modulation component to control the AM modulation of the RF output generator. The SYNC DAC (digital to analog converter) is used to generate a saw tooth ramp voltage signal to drive the horizontal sweep of an oscilloscope display when doing a sweep operation. An input amplifier is provided for accepting the input signal from the radio under test for operations where the internal display is used. A reference voltage generator is used for shifting the input voltage to a range of voltages that can be measured by the Arduino Nano's internal analog to digital converter. The LCD display provides the user interface for all of the mode and frequency settings as well as a display of the output during internal display operations. Finally, the Rotary Switch is used to select and change all of the required settings.

Thus the total functionality of the device allows the radio technician to do a full alignment of an AM or FM radio in conjunction either with an oscilloscope or as a stand alone device. As a stand alone, the device performs the functions of 3 devices - RF sweep generator, frequency counter, and oscilloscope - and can function as the single device needed for an alignment.

III. Circuit Design

Refer to the schematic diagram in Figure A in the Appendix. Component U1 is the Arduino Nano micro controller that is programmed to provide all of the control and generates the settings for the other main components. DDS1 is the module that generates the sine and square waves and is based on the Analog Devices AD9850 chip. Likewise, DDS2 is a modified DDS generator that provides the RF output that is also amplitude modulated and can be set to generate a sweep of frequencies for the alignment operation. Component DAC1 is a digital to analog converts chip that is used to generate the ramp voltage signal for the oscilloscope X-axis display sweep while the signal is input on the Y-axis of the scope. These chips are then surrounded by support circuitry.

At the top left is the 7805 regulator chip that supplies the 5volts for the rest of the board. Diodes D3 and D4 are used to drop the input from 9 volts to 7.5 volts so that the 7805 will need to drop less voltage and thus operate cooler. If a 7.5 volt wall plug is used, these diodes must be removed and replaced with jumper wires. Component U5 is a 3 volt regulator to provide power to the LCD display. The IC marked U3 is a level shifter to buffer 5 volt signals to the required 3 volts signals to the LCD display.

The circuitry surrounding FET transistor Q1 takes the signal output from the DDS1 generator module and uses that as an input to Q1 to provide a variable resistance and thus a variable current to the DDS2 output gain stage. In this manner, the output of DDS1 will cause AM modulation of the output of DDS2. Transistor Q2 provides a buffered low impedance output of the RF signal from DDS2.

The op amp U2.2 is used to buffer the input signal from the radio into the analog input of the Arduino Nano. Resistor R12 and R13 provide high input impedance while diodes D1 and D2 provide over and under voltage protection. The combination of R18 and C12 connected to Nano pin 10, provide a DC reference signal for level shifting of the input so that a negative signal found in AGC circuits can be translated or shifted to a positive signal for the Nano pin A0 analog to digital converter.

IV. Hardware Construction

The hardware design consists of a single printed circuit board containing all of the components. By placing all components on the board, the case construction is simplified to simply bolting the board to the case enclosure. No additional wiring is required. Power is supplied by a 9 volt wall module supply into a standard power jack. A parts list is supplied in the appendix along with the download URL of the Gerber file for constructing the circuit board. Thus construction simply consists of populating the circuit board and inserting it into the enclosure. This guide assumes the user has knowledge of tools and techniques for building the circuit board.

An enclosure has been designed by the author using clear acrylic material cut using a laser machine.

Before the DDS9850 module used for the RF generator is inserted onto the circuit board, it must be modified. Note that ONLY the DDS2 module is modified. The circuit diagram of the module is shown below in Figure 2 for reference on the parts on the DDS module. A link to the application note which explains how to do the AM modulation is provided as a reference in the Appendix as AN-423.

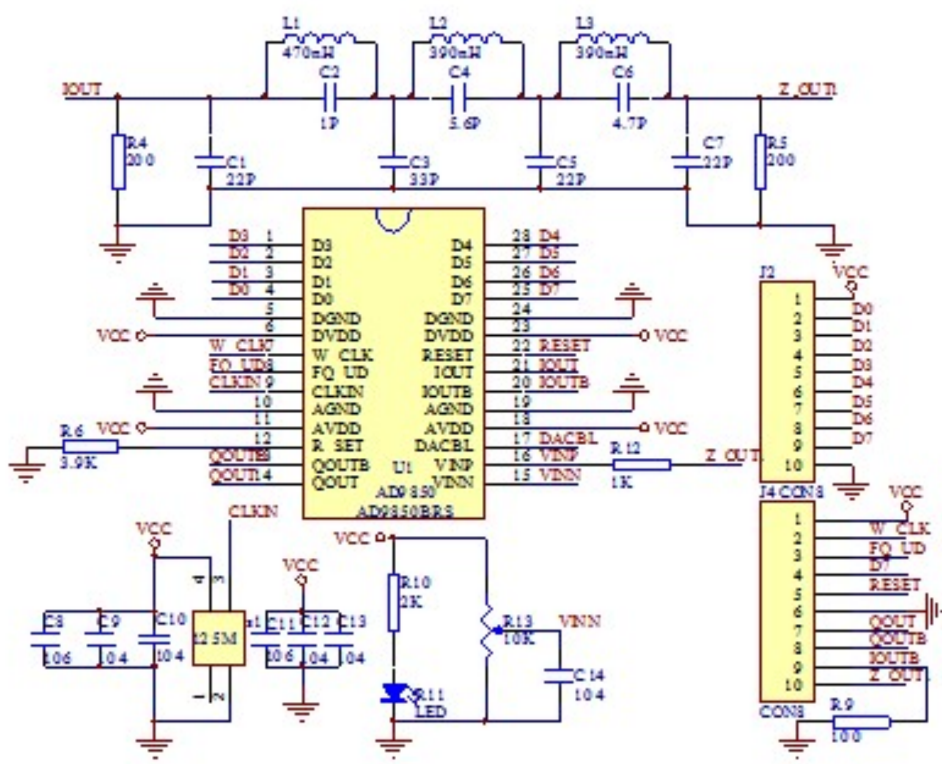

Figure 2 - Circuit diagram schematic of DDS module

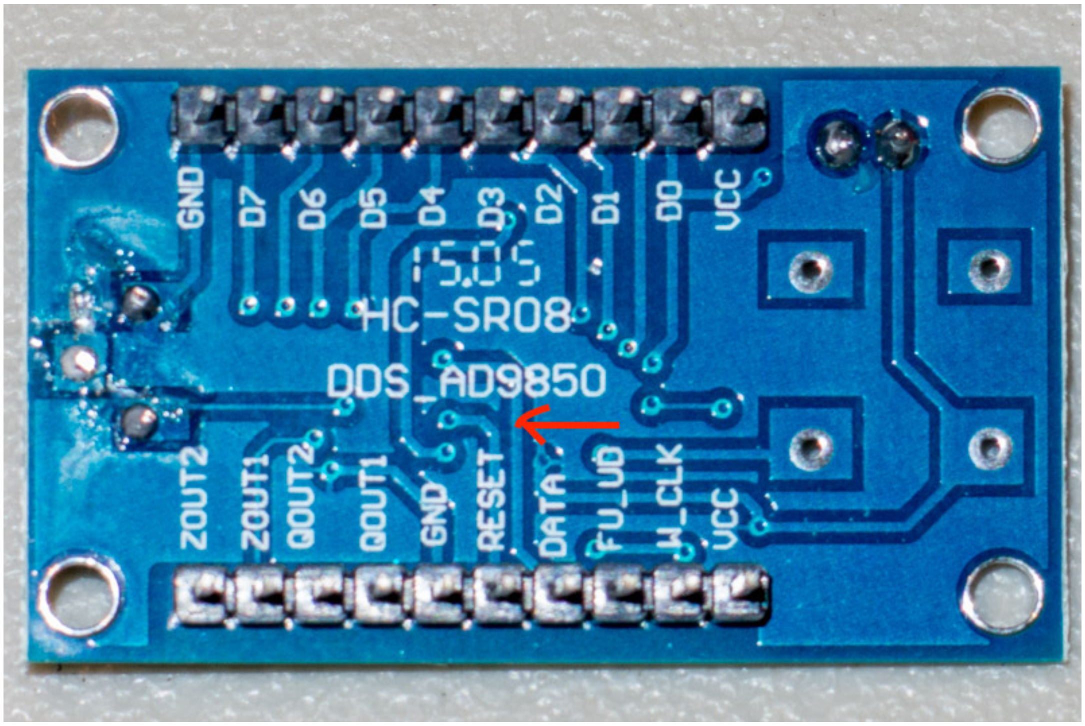

Figure 3 - Bottom view of DDS module

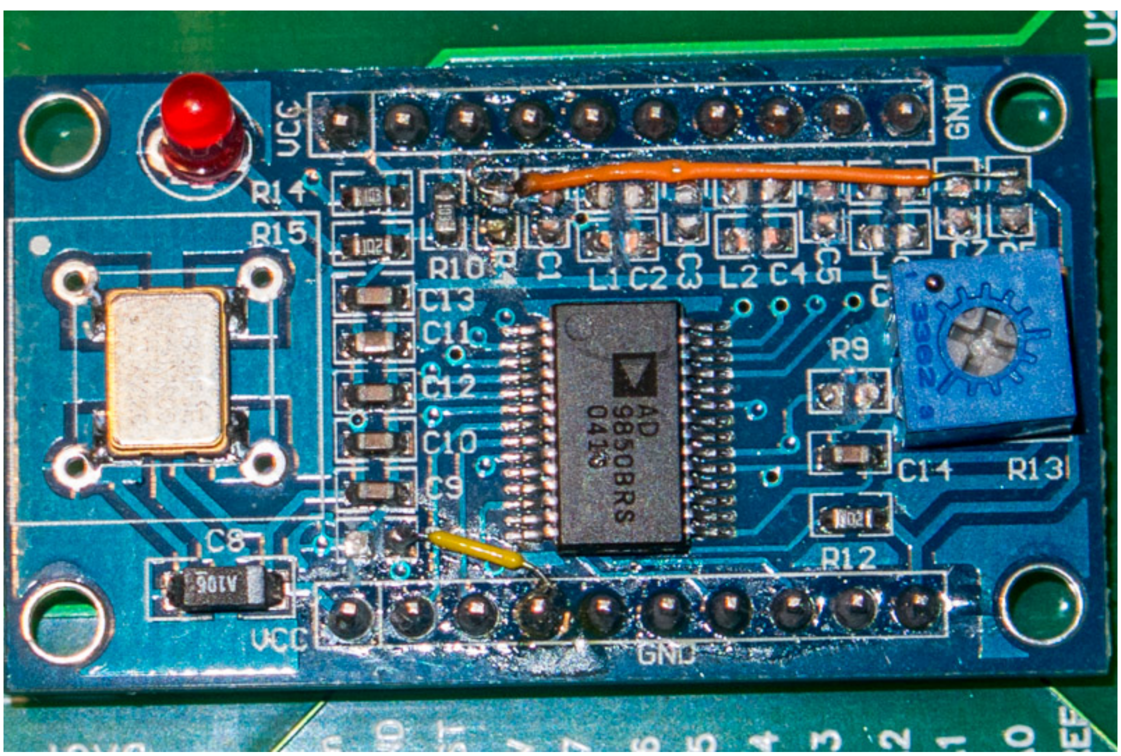

Figure 4 - Top view of DDS module

The first job is to bring the RSET pin (12) out to the connector. To free up the pin you have to cut the trace pin labeled as DATA, which is the same as pin D7 so that pin is now used as the serial data pin. Cut the trace where the red arrow points. See Figure 3. Then remove the 3.9K resistor, R6. Finally solder a wire from 3.9k resistor R6 pad closest to the AD9850 chip to the freed up DATA pin. See the photo in Figure 4.

The second mod brings the current output pins directly, without load resistors connected to them, out of the board so that they can be hooked to the transformer as shown in schematic. The output filter on IOUT output (pin 21) also needs to be eliminated. Simply remove all filter components and load resistors from the board - R4, R9, C1, L1, C2, C3, L2, C4, C5, L3, C6, C7, R5. I used a fine needle nosed pliers to crush and remove the components rather than risk de-soldering and damaging other components or causing solder bridges all over the place. Then to connect the IOUT to ZOUT2 pin of the module you simply solder a wire from a pad closer to board edge of R4 resistor to pad of R5 resistor, also closer to the board edge. Don't worry if you accidentally bridge the solder to the pad of C7 since R5 and C7 are connected on the board. This completes the modification of DDS2.

As the components are placed onto the main printed circuit board, note the orientation of each part. As you likely know, parts like resistors have no polarity and can be inserted in either of 2 orientations. The top of the circuit board is stenciled with guides to show which part goes where and how it must be inserted. Refer to figure A2 in the Appendix. Note the red arrows that mark keys on the components that are guides for proper placement, e.g. a dot on pin 1 for ICs and a plus sign for the positive lead of an electrolytic capacitor. The LCD is mounted offset from the surface of the board using 1/2" spacers. This places it closer to the top cover of the enclosure for easier viewing. The header that is used is 8 pins whereas the LCD has 9 pins. That 9th pin is placed outside of the connector and hence makes no contact since it is not needed (MISO signal). There is a hole on the circuit board for it if the LCD is mounted directly on the board as you wish.

V. Software installation

All software is contained in the single Arduino Nano micro controller. The device is normally sold with an onboard boot loader installed. The Arduino Development Environment is freely downloadable from the website arduino.cc . This tool provides a code editor, management of libraries, and an uploader to place compiled code onto the Arduino Nano module.

Software is supplied as both source code and a pre-built image by the author and hosted on the author's website. The web address is shown in the Appendix.The software can be downloaded onto your local PC or Mac and compiled then downloaded onto the Nano using a micro USB cable connected to the USB port on the Arduino Nano module. It is expected that software updates will be issued from time to time as users get experience and bugs are fixed or new features added. Each release has a README file which explains the changes in the software as well as instructions to compile and upload the code to the Arduino.

It is possible as previously mentioned to upload the code from a pre-compile file supplied in the release software without the need for a full development environment. This is done using a program called XLoader. This can be obtained at the website listed in the Appendix. It is recommended however, that the user become familiar with the development environment so that local modifications and a deeper understanding of the code can be learned.

After the software is installed, the DDS module boards must be adjusted for waveform duty cycle. Each board has a small square blue pot for this. For each of the FN and RF generators , set a frequency value, and feed the output to an oscilloscope. Adjust the blue pot for a 50% duty cycle.

VI. Case Assembly

The case is made from 1/8" clear acrylic plastic panels that were laser cut into 6 pieces with edge teeth to form a pressure fit case. There are 4 bolts that hold the circuit board and the top and bottom panels together. The other 4 panels, left, right, top, and bottom are fitted into place with the edge teeth and then clamped down to hold in place by the 4 bolts. The case can be assembled in 2 ways. The easy way is to have the bolt heads on the bottom panel and the nuts showing on the front panel. This is done by placing the screws through the bottom panel, then placing the spacers, circuit board, nut, then top panel in place. The 4 other panels are then placed as the assembly proceeds.

For a more aesthetic look with the bolt heads on top, the assembly is a little trickier but worthwhile for appearance. Follow these steps (refer to assembly photos in figure A4):

1. First thread the 4 bolts into the front panel and secure with nuts gently up against the front panel holding the bolts in place. See upper left photo in figure A4.
2. Next thread the circuit board onto the bolts, then spacers, and finally the back panel. Note carefully that the back panel has the holes closer to the bottom edge than at the top edge.Thread the nuts onto the bolts, holding the front, circuit board, and back panel in place. The nuts should be threaded so that the bolt shaft barely comes through the nut.
3. Place the left side panel between the front and back panels. This will require some jiggling of the panel to get the power connector to seat into the cut out hole. You will likely need to loosen the nuts on the bolts to give enough room for the left panel to snap into place.
4. Next place the right panel with the BNC connector holes on the assembly. Note that the BNC hole at the bottom is closest to it's edge. Again loosen the nuts at the back of the back panel slightly to allow the panel to snap into place.
5. Next, move the nuts on the back of the front panel down to the circuit board to tighten the circuit board up against the spacers holding the board tight to the back panel. The assembly now should look like the tall photo at the right of figure A4.
6. Finally, place the top and bottom panels onto the assembly, loosening the nuts as needed to allow room for the panels to snap into place. When every panel is in place, tighten all the nuts on the back using a screwdriver in the top bolt slot and a socket on the back nut. Tighten well but no too much as to harm the plastic.
7. Note that , as software updates need to be applied in the future, the bottom 2 bolts can be loosened and the bottom panel removed, exposing the usb connector on the Arduino Nano for use in downloading new software.

The final assembly is now as shown in figure A5.

VII.Operation Modes

A. User Interface Overview

The user interface consists of the LCD screen and is controlled by the rotary selector. There are 3 sections of the display - mode settings on the upper left, frequency settings on the upper right, and internal graph display at the lower half of the screen. In the right column are the settings for the FN, i.e. the function generator which sets the frequency for the sine, square, and the modulation frequency. Next is the RF generator setting, and finally, the BW or bandwidth setting for sweeping the frequency.

Figure 5 - Basic screen overview

On the left column are the settings for mode (functional mode) which can be set to one of 3 modes:

- **FIX**, which is a fixed frequency output for the RF generator (the Function generator is always fixed and not swept)
- **SWe**, which is the external sweep mode where the RF generator is swept across a range of frequencies, and a sync signal is generated for the X-axis of an oscilloscope
- **SWi**, where the RF generator is swept and the display for the response is set on the LCD screen itself with internal software providing a sweep for the display.

Next in the left column are the **Rate** setting which sets the sweep rate, then the **Mark** setting for the sweep markers on the internal display or the center mark intensity on the external display.

Finally the **Bias** setting for the level shift on the input voltage. These setting will be discussed in the sections below.

The graph display at the lower half of the screen is only used during internal sweep operation. This will display the response seen at the input connector. When moving to either the **FIX** or **SWe** settings, this area will be blanked.

To change any of the settings, the rotary selector is used. This is the control directly below the screen. As the selector is rotated, a selected digit is shown in the color white rather then the default color for that field. For example, in the display shown, the value of the Rate field is highlighted. The selector will thus highlight , as it is rotated, each digit of every field, including both the frequency fields and the function/mode fields. After a digit is selected, the rotary is pushed down to set it's switch to modify. While the switch is held pushed down, rotating the selector will change the value of that digit. In this way, each digit of every field can be modified to the value required for the needed operation. The action may be a little awkward at first, but practice will make the operation go smoothly.

B. Fixed Mode for Function and RF Generator Operation

The FIX mode of operation is used to generate fixed frequencies on both the function generator and the RF generator. Note, of course, the the function generator always generates a fixed frequency. With the mode set to FIX, the frequency is set for the FN setting for the function generator and by modifying the RF setting, the frequency of the RF generator is changed. While in this mode the BW, Rate, Mark, and Bias settings have no affect of the operation. However, Amplitude Modulation of the RF generator by the frequency of the FN generator is active. To control the level of modulation, the R1 Pot (furthest left) is rotated to the desired level. To change the level of the FN generator sine wave, the R11 pot (lower center on the board) is used. The square wave output is not able to be adjusted but is fixed at 5 volts peak-to-peak. Finally, the level of the RF generator is set using the R6 pot, the furthest right control.

C. External Sweep Operation

In the external sweep mode, the device will output an RF signal at the set center frequency across a range of frequencies according to the bandwidth setting. In addition, the modulation is active and is set by the FN generator for the frequency and R1 for the modulation level. For example, is the display overview in Figure 5, we have an RF frequency of 455KHz and a bandwidth of 40KHz. So the sweep will run from 435KHz to 475 KHz. As the frequency is sweep, the voltage output on the Sync output, BNC 4, is ramped from approximately 0 to 5 volts. This is connected to the X-axis of the oscilloscope to show a proper X-Y graph of response. See the section on alignment examples. There is a single marker at the center frequency which is set by a small delay on the ramp sync signal. This shows up as a bright spot on the scope allowing for precise settings. The Marker control (Mark) will make the marker brighter with a higher set number. The Rate setting is used to decrease or increase the rate of sweep. Currently, the rate is a relative number from 0 to 9 used to specify the rate of the sweep from about 0.5Hz to about 50Hz.

D. Internal Sweep Operation

The internal sweep operation removes the need for an external oscilloscope. The LCD display is used to show the radio's response to the generated RF signal. The function generator and RF generator as well as the bandwidth are all set as above for the external sweep. The rate is also chosen to specify the sweep rate. However, for the internal sweep, the sync output is disabled since it is not used. In addition, two other settings are needed. First the marker setting is used to set the width of the markers on the display to show the output bandwidth of a radio response. Currently, the marker value is a number from 0 to 9. Each number adds 10% of the bandwidth to the marker position. So, if the bandwidth is set to 20KHz and the RF frequency set to 455KHz, a marker position of 5 would shows markers at 445KHZ and 465KHz.

The bias setting is used to specify a vertical offset to the display. The bias varies the level shifting of the input voltage by 0 to 4.9 volts in 0.1 volt steps. Thus a setting of 2.5 would cause an input voltages of +/- 2.5 volts to be seen as an input of approximately 0 to 5 volts. The best value of this setting is discussed in the operational examples section.

VIII.Operational Examples

1. AM IF Alignment - External Display

Certainly, the RF generator can be used as a fixed modulated source for the classic IF alignment using a voltmeter to measure the peak of the response signal from the radio's IF stage. To do this, simply set the mode as FIX and set the RF frequency to the proper value, typically 455KHz , the FN generator to a modulation frequency such as 400. Then adjust the modulation level to about 30% and use this as the signal source as specified in the radio's alignment instructions.

But we want to discuss the sweep alignment process here to show the sweep functionality of the device. For an AM sweep with an external display, the RF frequency should be set to the radio's IF frequency, e.g. 455KHz, according to the circuit schematic. The FN frequency is set to 400Hz typically, and modulation level to about 30%. The mode is set to SWe and the Rate to 0 initially. The BW is set to a wide range initially such as 40KHz. The SYNC output is connected to the X input of an oscilloscope (typically channel 1) and the Y axis is connected to the output of the detector, usually the top of the volume control. Set the scope sweep to the X/Y setting. One of the probes is connected to circuit ground on the radio. Of course, be sure to run an AC/DC radio through an isolation transformer for power to prevent damage to the scope. Follow the directions for radio alignment on the best way to align each stage. I prefer to tune each IF stage separately so that interaction of the stages in minimized. By first aligning the detector, then the 2nd IF, then the first IF, interaction is minimized. The scope will display a signal that you will attempt to peak at the point of the bright marker which is the center frequency of the sweep. See figure 6. Change the rate to slow down the sweep for best viewing and change to BW setting to fine tune the peaking frequency

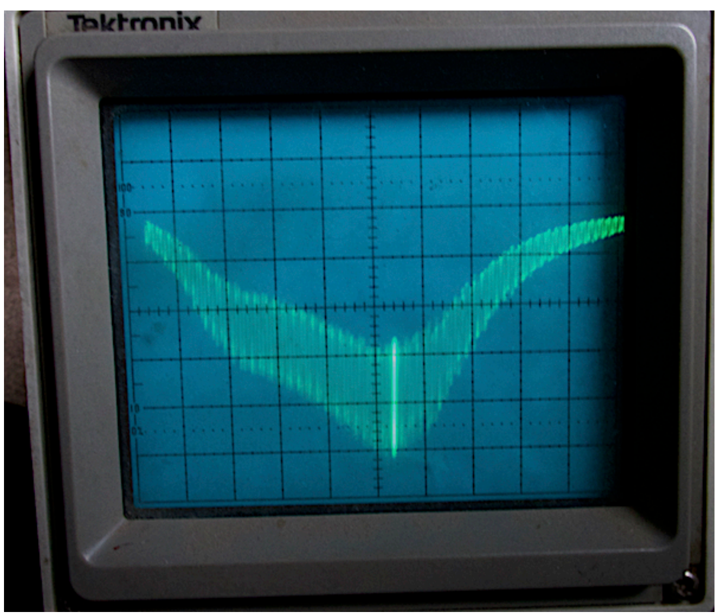

Figure 6 - AM IF Peaking on External Scope Display

2. AM IF Alignment - Internal Display

The AM IF alignment using the internal display is similar to the external mode. Set the frequency of the FN, RF, BW, and rate as stated under the external method. Set the mode to SWi. Set the Mark to a position like 5 to show the bandwidth of the response. Set the bias level to 4.9. This will level shift a negative detector voltage (think AGC) to a positive voltage so the Arduino ADC can measure it. Connect the input to the detector output, typically the top of the volume control. Adjust the Rate to get a good display. Some radios do not handle a fast sweep. For the internal display, a slow sweep works well since we do not have to worry about fiddling with a scope X/Y display. See figure 7 for a typical display that is peaked.

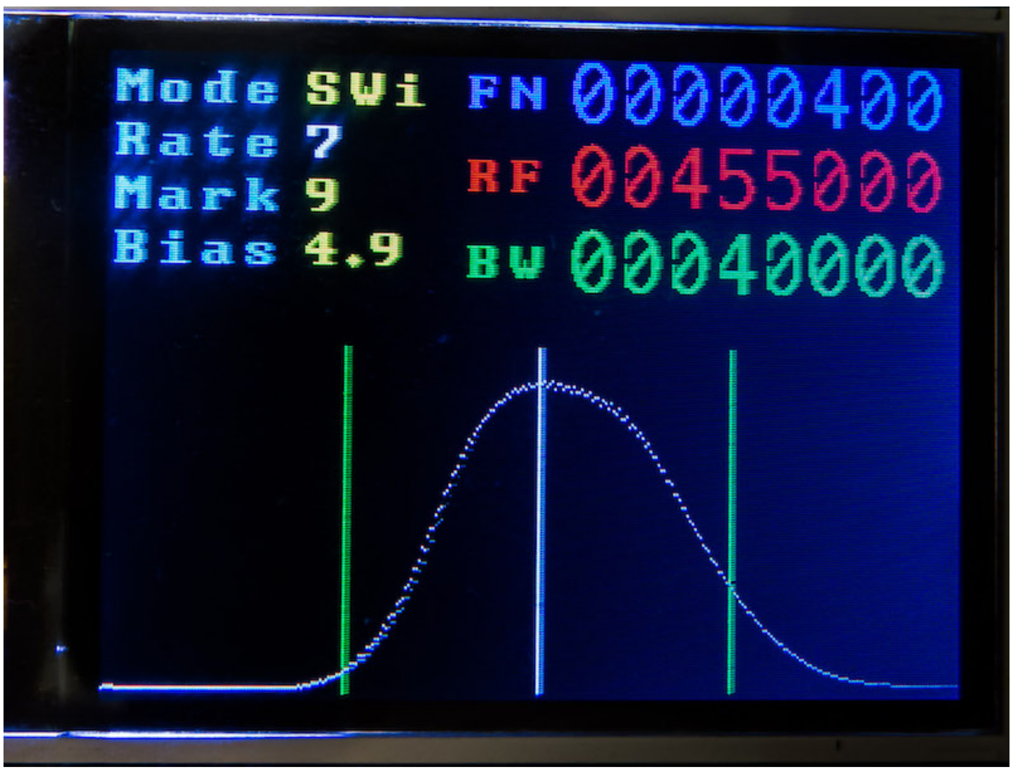

Figure 7 - Internal AM IF Peaking Display

3. FM IF Alignment

Typically, the alignment of the IF transformers on an FM radio calls for unmodulated frequency inserted at the front end of the radio and peaked using the level of the output signal on the display of the oscilloscope. The classic IF frequency for the FM radio is 10.7 MHz. As with AM IF alignment, it is best to start from the last stages, working forward, aligning each IF transformer by injecting the RF signal at the grid of the tube driving that IF stage. Thus for this operation, the mode is set to SWe, the RF generator frequency is set to 10.7MHz, and BW is set to something reasonable like 500KHz. As before the SYNC output is connected to the X-axis input of the oscilloscope and the output of the IF stage is connected to the Y-axis channel. Again, this is very similar to the AM IF sweep alignment. A classic output is shown in Figure 8.

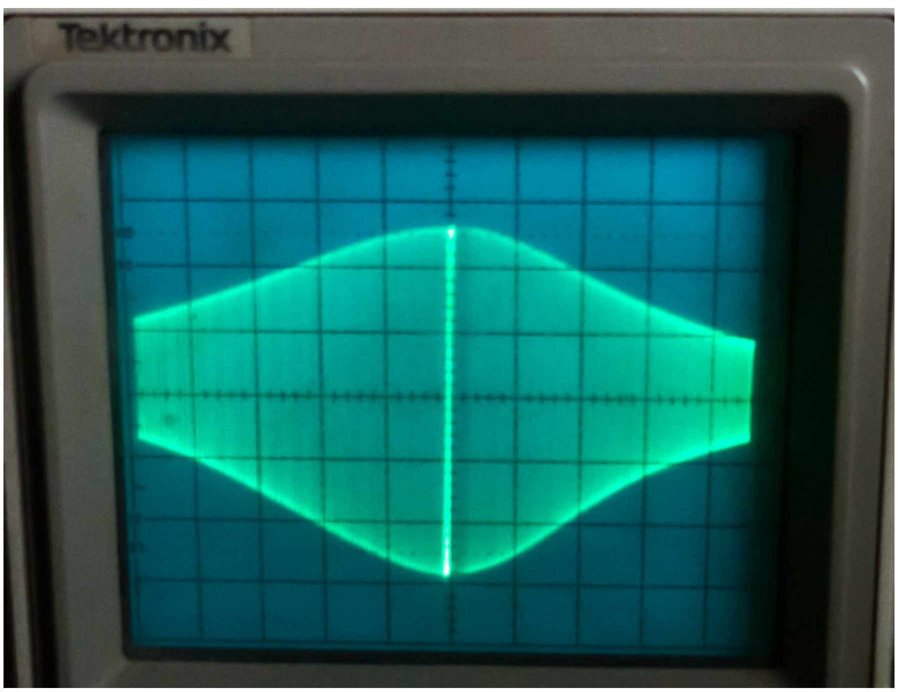

Figure 8 - FM IF Peaking Display

4. FM IF Alignment - Internal Display

If the internal display measurement is done the same as the external measurement, the limited bandwidth of the device will prevent an acceptable display. However, by measuring the voltage level at the grid of the limiter section, a display will show proper peaked response at the center frequency for the IF stages. The best probe point is shown in Figure 9 at the red arrow.

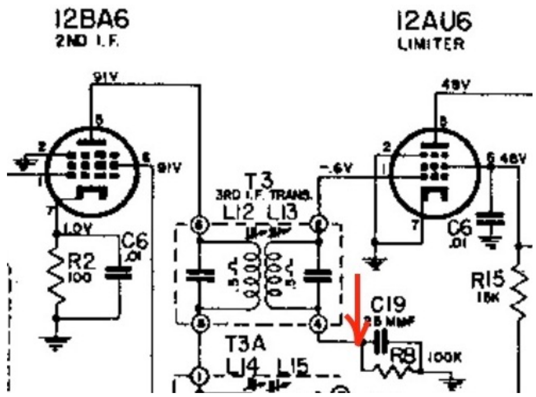

Figure 9 - Grid Resistor Probe Point for IF Internal Sweep Measurement

Using the typical sweep settings as shown in figure 10 will allow for peaking of the IF stages. There may or may not be enough output voltage from the RF generator to peak each stage individually.

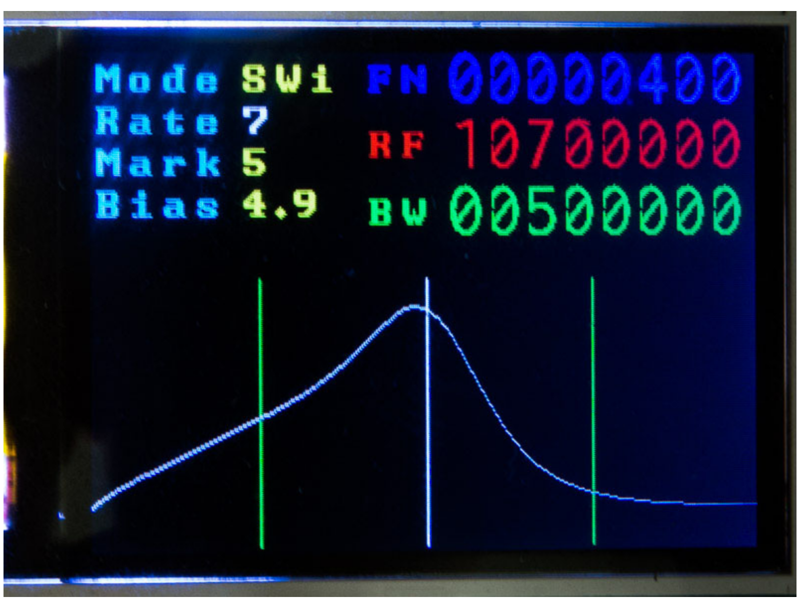

Figure 10 - FM IF Internal Measurement

5. FM Detector Alignment - External Display

The alignment of the FM detector typically generates what is known as the classic “S-curve” showing the response of the detector across the bandwidth needed centered at the IF frequency. The goal is to get a clean linear slope as the frequency is swept across the bandwidth of the IF circuit. To perform this operation, we follow the detailed instructions given for the radio under test. This typically calls for an unmodulated signal swept across a bandwidth of 500KHz centered on the IF frequency. The input to the Y-axis is taken at the center point of the discriminator. The Rate can be adjusted for the best display. The SYNC is connected as before to the X-axis channel. A typical output is shown in Figure 11.

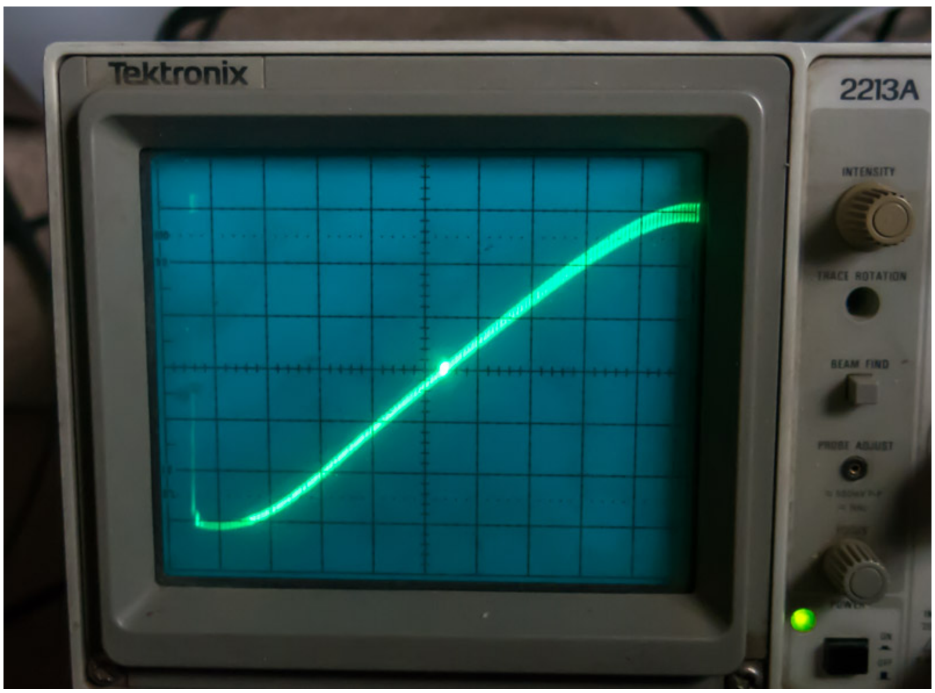

Figure 11 - FM Detector S-Curve Display

6. FM Detector Alignment - Internal Display

The alignment of the FM detector using the internal display is similar to the external operation. The RF frequency is set to the IF value, typically 10.7MHz. Bandwidth is set to 500KHz to start and can be adjusted for the best display. For the internal, the Mark can now be used to set up the markers. The Bias is set to 5 giving a 2.5 volt offset. This is used because the typical voltage off of the detector is targeted for +/- 2.5 volts depending on the RF output voltage level. Thus with a Bias of 2.5 (2.5 volts), the input voltage of +/- 2.5 is shifted to 0 to 5 volts and can then be properly converted for display. The device input is connected to the discriminator circuit as directed by the alignment instructions. See Figure 12 for a typical display.

Figure 12 - FM Detector S-Curve Display on Internal LCD

IX. Appendix

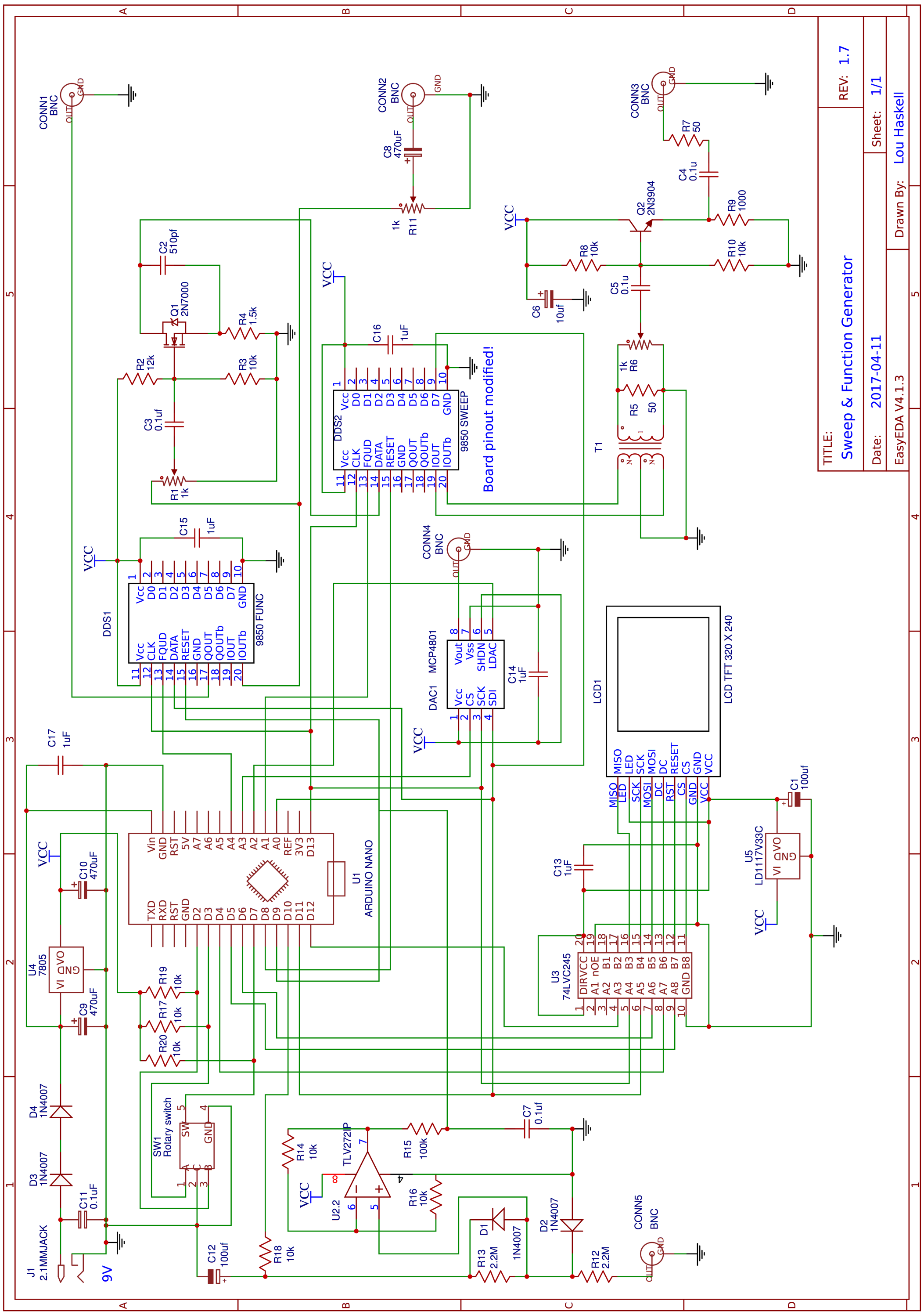

Figure A1 - Circuit Design Schematic

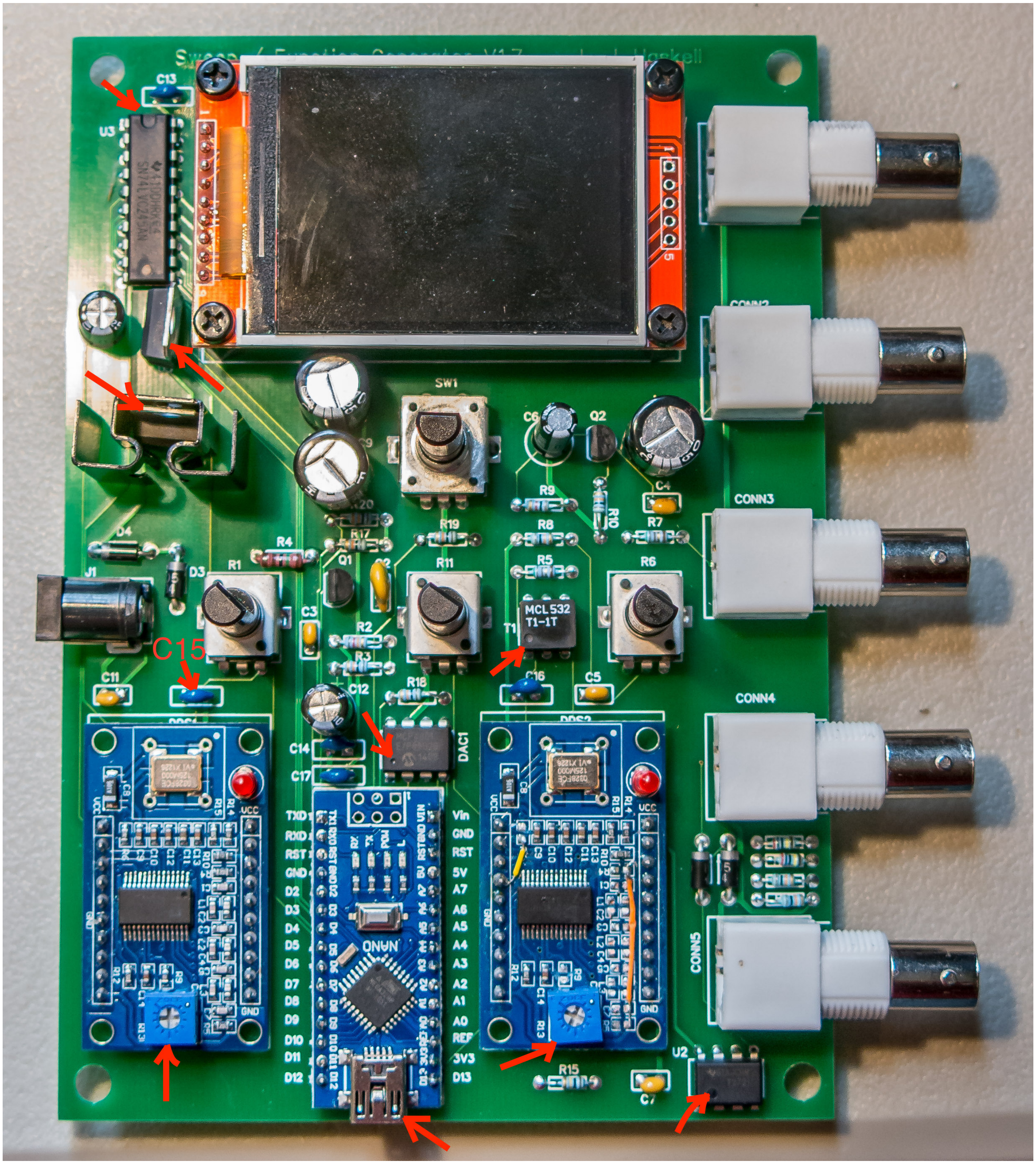

Figure A2 - Top view of Circuit Board
Red Arrows show positioning markers for certain components, e.g. pin 1 of the IC

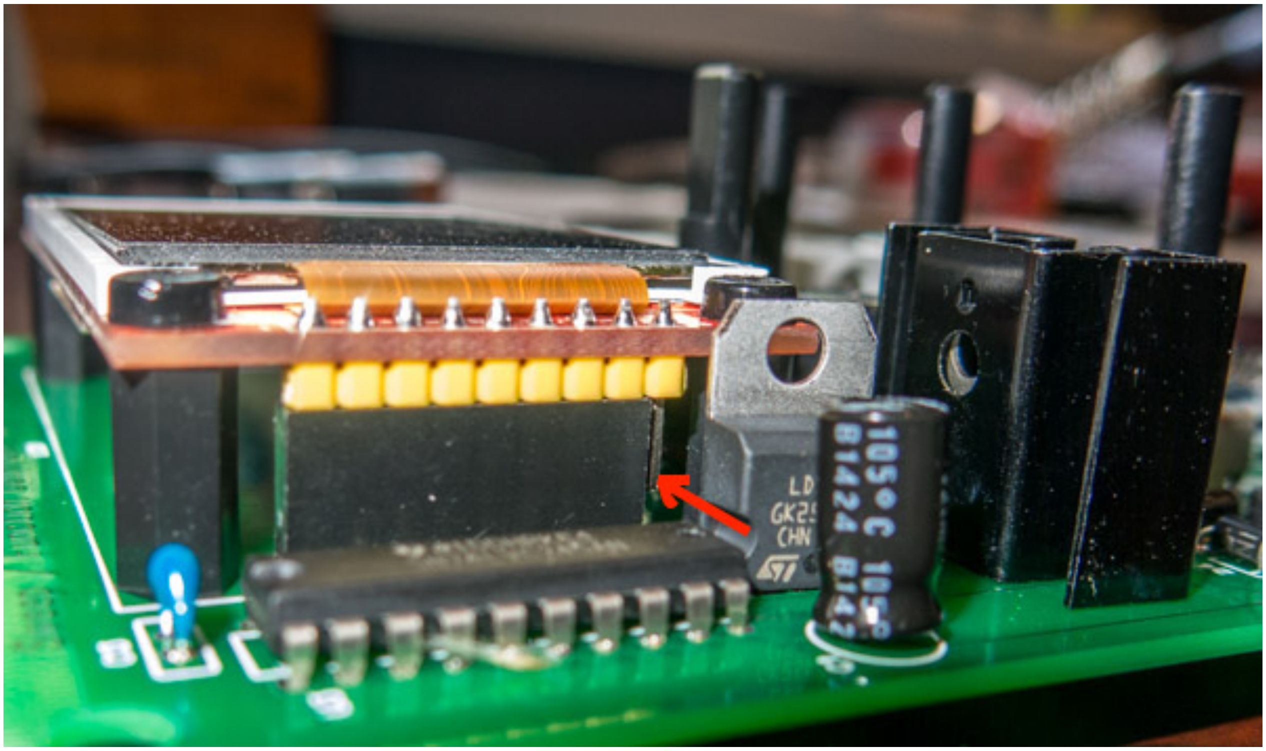

Figure A3 - Side view showing LCD header and exposed pin 9

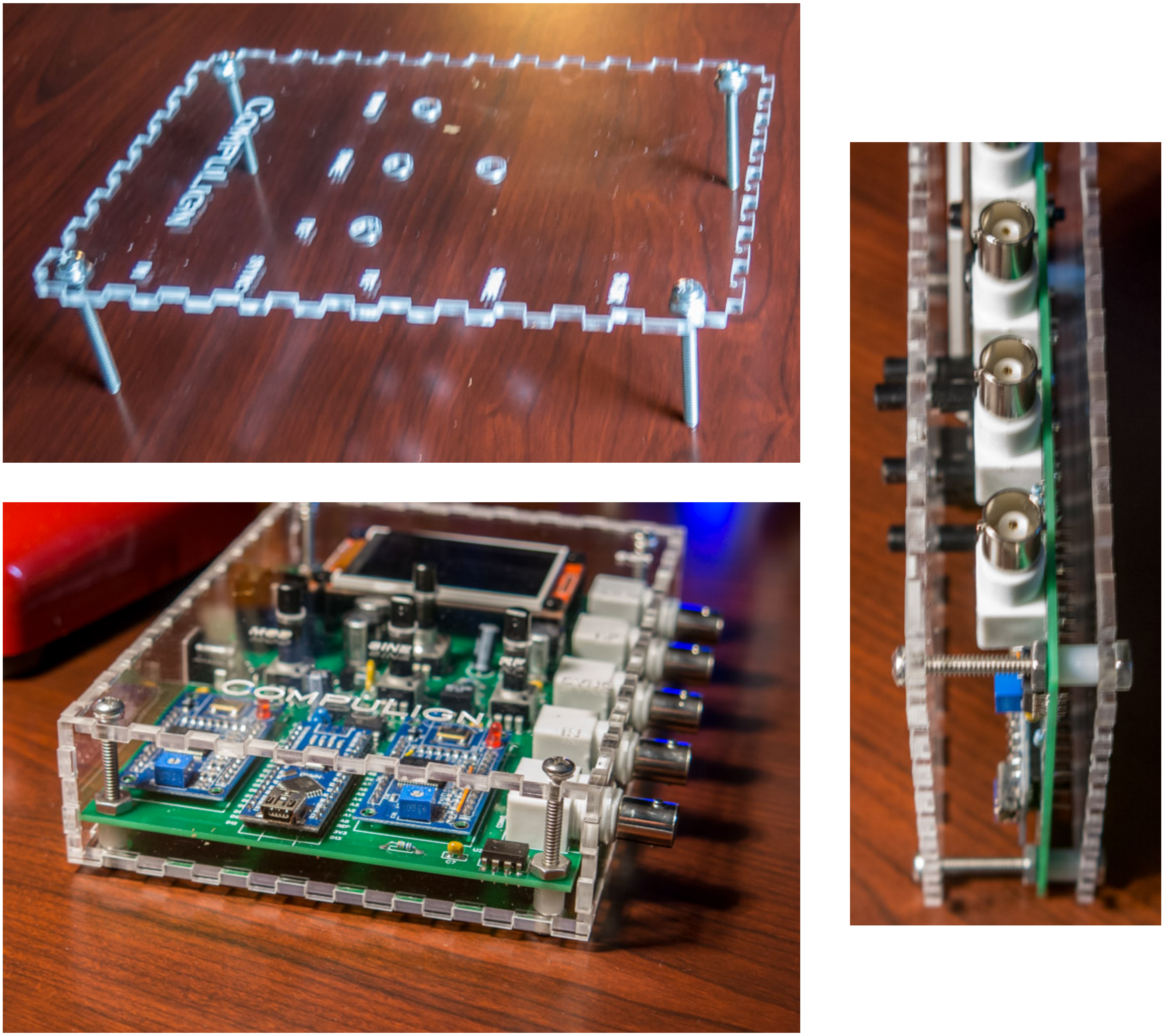

Figure A4 - Assembly Steps

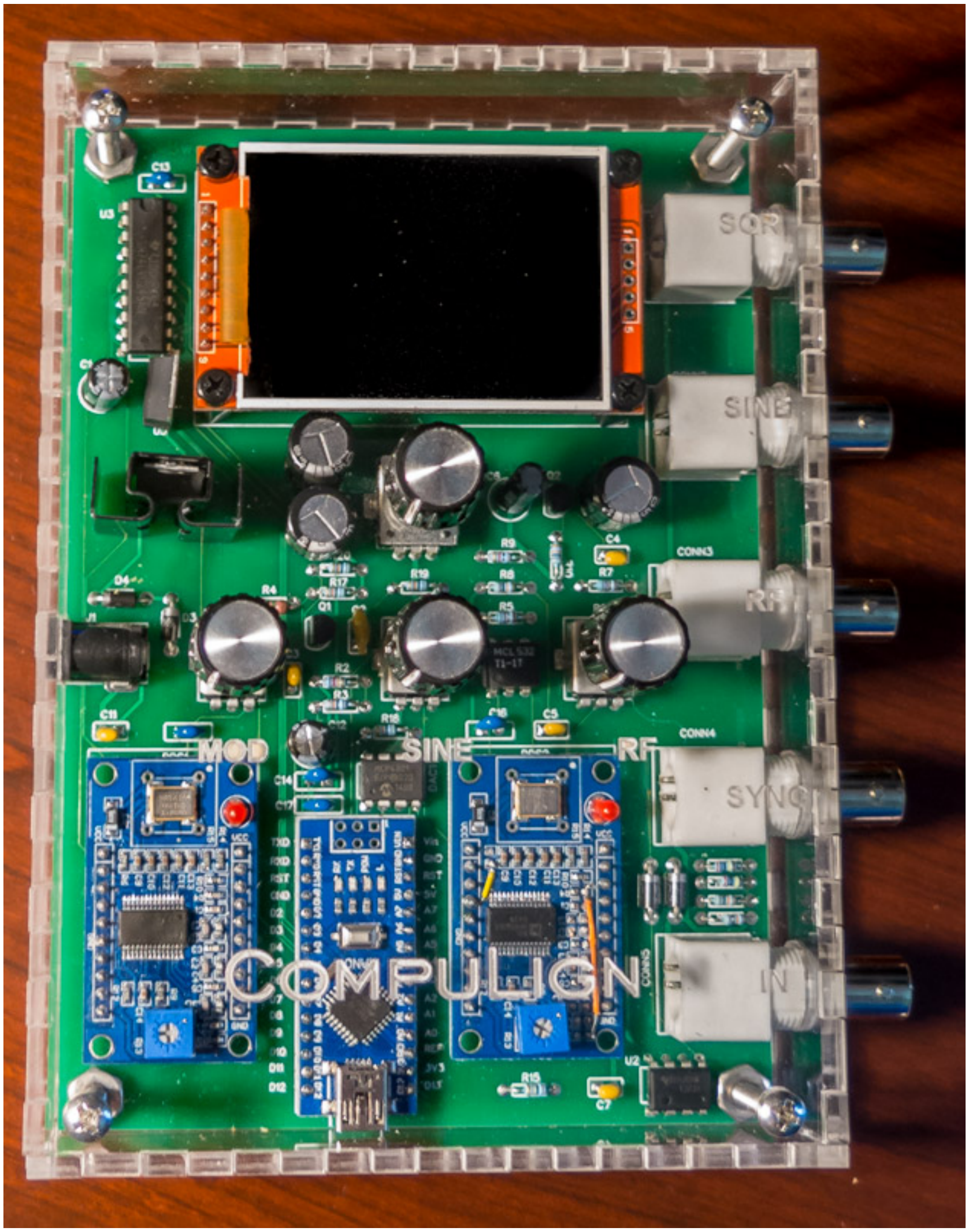

Figure A5 - Final Assembly

Here are links to important documents as mentioned in the text above:

1. Analog Devices AN-423 PDF on how to accomplish Amplitude Modulation with the AD9850 http://www.analog.com/media/en/technical-documentation/application-notes/AN-423.pdf
2. XLoader website for download http://russemotto.com/xloader/
3. Software can be downloaded at http://louhaskell.com/data/generator/Sweep-generator-Release-latest.zip
4. The Gerber files to construct the circuit board are at http://louhaskell.com/data/generator/generator-gerber.zip