ICARC TDOA Antenna Switch

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User Manual for ICARC Antenna Switch.

TDOA Time Difference of Arrival

DTOA Differential Time of Arrival

It is a work-in-progress right now.

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1 The Boards

A tool that makes your handy-talkie more useful for foxhunting!

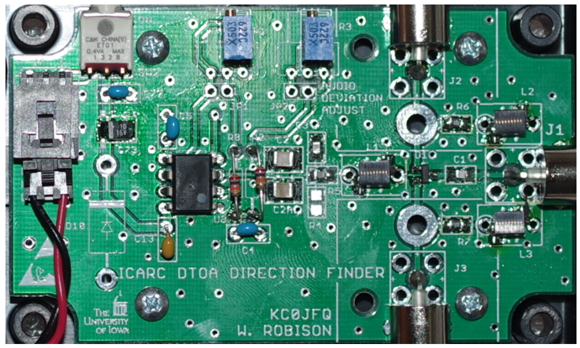

Figure 1: First Prototype

Surface mount only for the RF section, all the rest is thru-hole. Boards provided to club members with the surface mount mount parts installed.

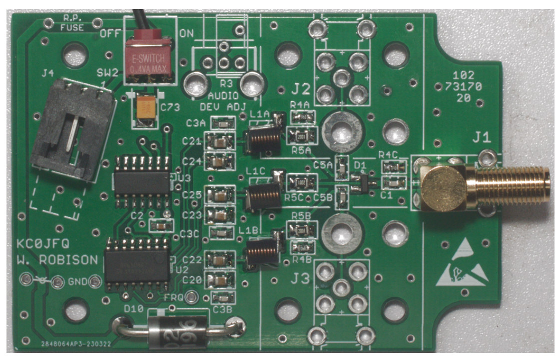

Figure 2: Second Prototype

Functions the same as figure 1, but it is all surface mount (faster to build!). Surface mount parts are less expensive than thru-hole parts.

Both versions of the board mount in the same project box, a Hammond series 1599B plastic housing. The newer board is slightly smaller, as can be seen by comparing the location of the mounting holes.

This is the incarnation of a simple PIN Diode switching circuit that inserts an audio tone (of fixed frequency) when the attached antenna array is not *normal* to the transmitter.

The *normal* line from the antenna array is the line perpendicular to the line that connectes the two antennas of the array.

So, what we're up to here, is to have a circuit that makes direction finding a bit easier when using a hand-held FM receiver. To make a direction sensitive antenna array, let us use a pair of simple monopole antennas seperated by no more than a half wavelength.

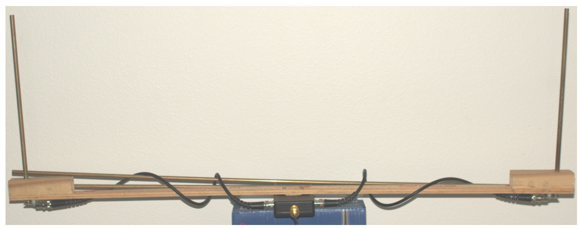

Figure 3: IMGP3324_50.png

When the antennas array (i.e. the two antennas) are oriented *normal* to the transmitter, they will be equidistant from the transmitter. Being equidistant, the two antennas of the array will see more-or-less identical signals. In particular the two antennas will see the received signals having the same phase. Nothing special happens in this case, the radio operates as you would expect; you hear the fox transmitter.

When we switch between the two antennas, the signal from the antennas are in-phase so the receiver does not notice.

As the antenna array moves away from *normal*, the antenna switching will introduce a phase error into the received signal presented to the receiver. An FM system will see this phase shift as a frequency change and introduce a discontinuity into the demodulated audio. You will hear this as a squeal at the antenna switching rate.

2 Theory of Operation

This is the section where I try to convince you that I know how this works.

This should be good for a laugh...

2.1 Revision -20

The second revision, the all surface mount edition...

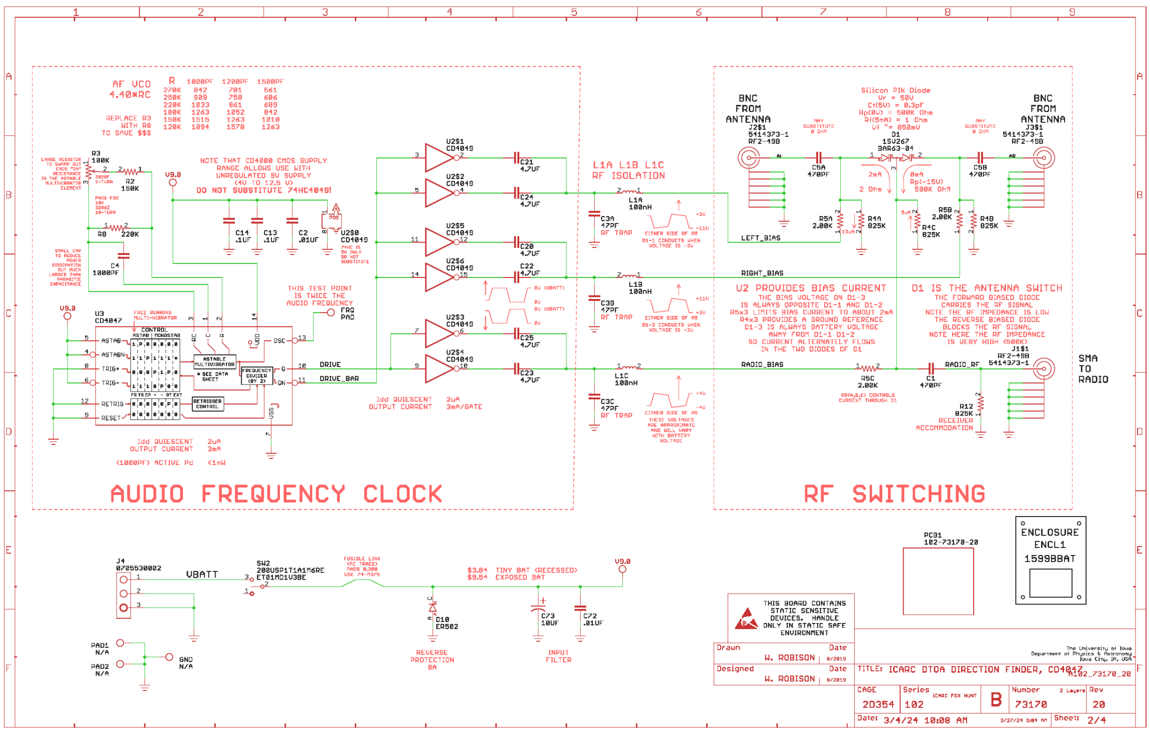

Figure 4: Revision_20_Schematic

This is a rather simple circuit; it must be, it all fits on one page. Text in red is descriptive, not describing the topology of the circuit.

Net connections that carry over to the circuit board are green.

Parts on the schematic correspond, of course, with those on the circuit board.

2.1.1 RF Switching

The core of the antenna switch is the PIN diode (D1) switch that is used to switch between the two elements of the antenna array.

A PIN diode, when forward biased and conducting, looks like a closed switch to the RF signal. The PIN diode takes a relatively long time to stop conducting (on the order of a microsecond), so RF (even transmit levels) doesn't bring the PIN diode out of conduction.

The PIN diode, when reverse biased, looks like an open switch to the RF signal. The PIN diode takes a relatively long time to start conducting, as well.

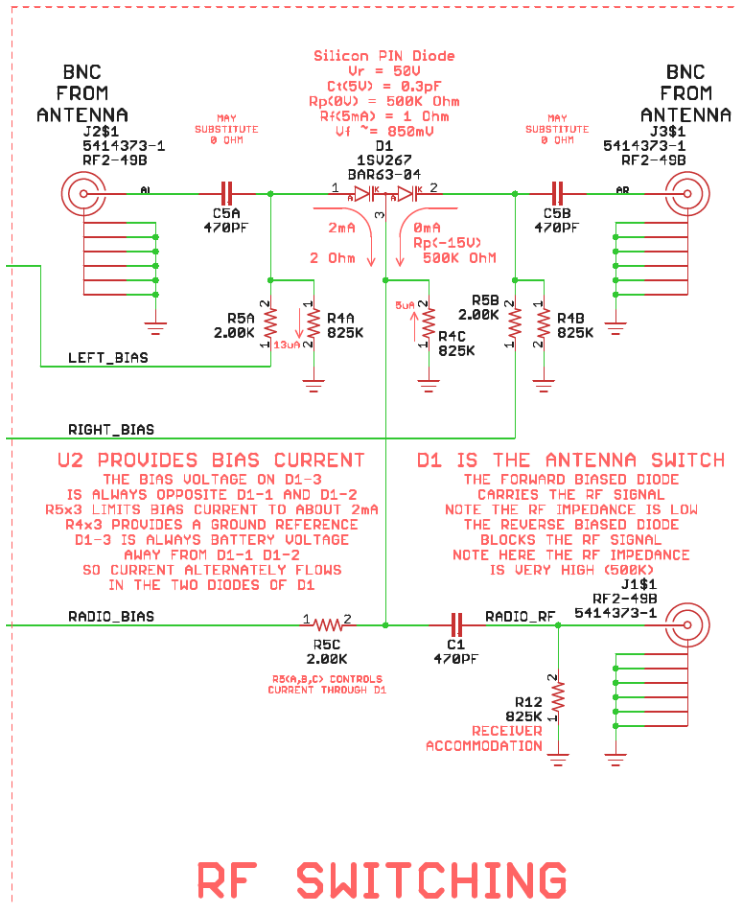

Figure 5: RF Switch

We drive a control voltage through the **LEFT_BIAS** and the **RIGHT_BIAS** nets that is the opposite polarity of the **RADIO_BIAS** net. This causes the one diode of D1 to be forward biased and other diode to be reverse biased.

When the diode is forward biased, the RF impedance of the diode is low, on the order of one to two ohms. When the diode is reverse biased, the RF impedance of the diode is quite high, in the order of hundreds of thousands ohms.

By altenating the on diode (the diode that is forward biased), we switch antennas. The loss through the reverse biased diode is quite high and through the forward biased one quite low. The diode switching time relatively slow, so the RF signal has no effect on the RF impedance of the PIN diode.

The connectors on the schematic show a large number of ground points. These parts on the circuit board will accommodate both a BNC style connecter and an SMA style connecter.

R12 is installed when necessary to keep the DC level to the hand held radio at ground. It may be omitted.

2.1.2 Diode Bias Circuit

Working our way back through the circuit, we next see the PIN diode bias control circuit. There is something providing a sqaure wave further to the left (we'll get there next).

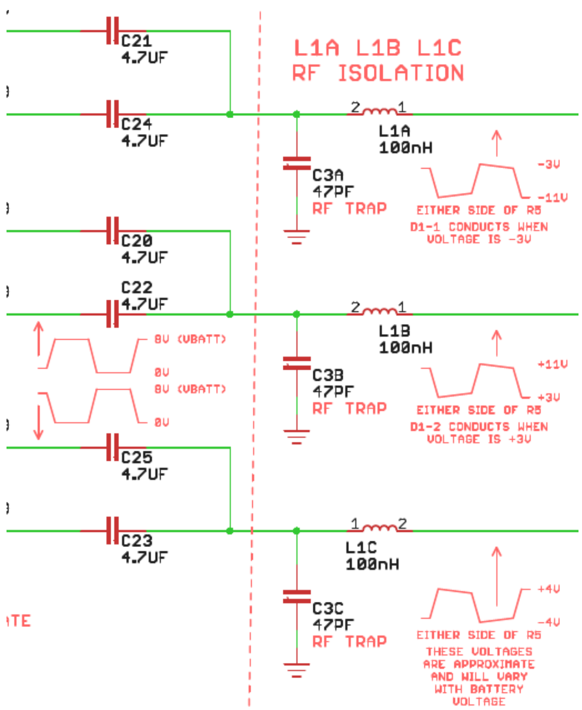

Figure 6: TDOA_-bias.png

We DC isolate the drive signals with the C20..C25 capacitors.

The L1A..L1C inductors present a high impedance to the RF signal from the antenna array, isolating the control circuit from the receiver.

Finally, the C3A..C3C capacitors shorts RF energy to ground to keep it out of the driving circuit. These caps also keep digital noise from the drive circuit out of the receiver.

The PIN diode (D1) is kept near ground by R4A, R4B, and R4C. Since **LEFT_BIAS** polarity matches **RIGHT_BIAS** polarity, both being opposite **RADIO_BIAS** polarity, current flows in only one of the diodes of D1 at any time. We will see shortly that the control signals are a square wave (see figure **??**, do we alternately turn on of the the diodes in D1 and then the other.

2.1.3 Drive Circuit

Our bias drive circuit is relatively simple, consisting of a hex CMOS buffer.

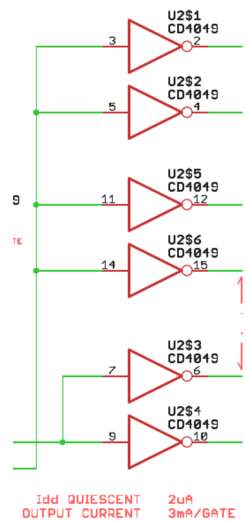

Figure 7: PIN diode switching drive

The top four gates are all in-phase and provide drive to the individual anode and cathode pins of the PIN diode (D1-1 and D1-2). The drive level is controlled by the battery voltage.

The bottom two gates are driven out-of-phase provding the drive for the common pin of the PIN diode (D1-3).

The gates are doubled for two reasons. One being to slightly improve the drive and switching time. The other being that the 4049 has six gates, and the gates would otherwise go unused.

2.1.4 Clock Circuit

We will start with the -20 revision clock circuit which makes use of a CD4047 multivibrator. The 4047 is a bit easier to deal with than the venerable LMC555 timer as the parts in the oscillator are fewer and eaasier to calculate. We also end up with a square wave out of the CD4047 with the output appearing in a true and inverted form.

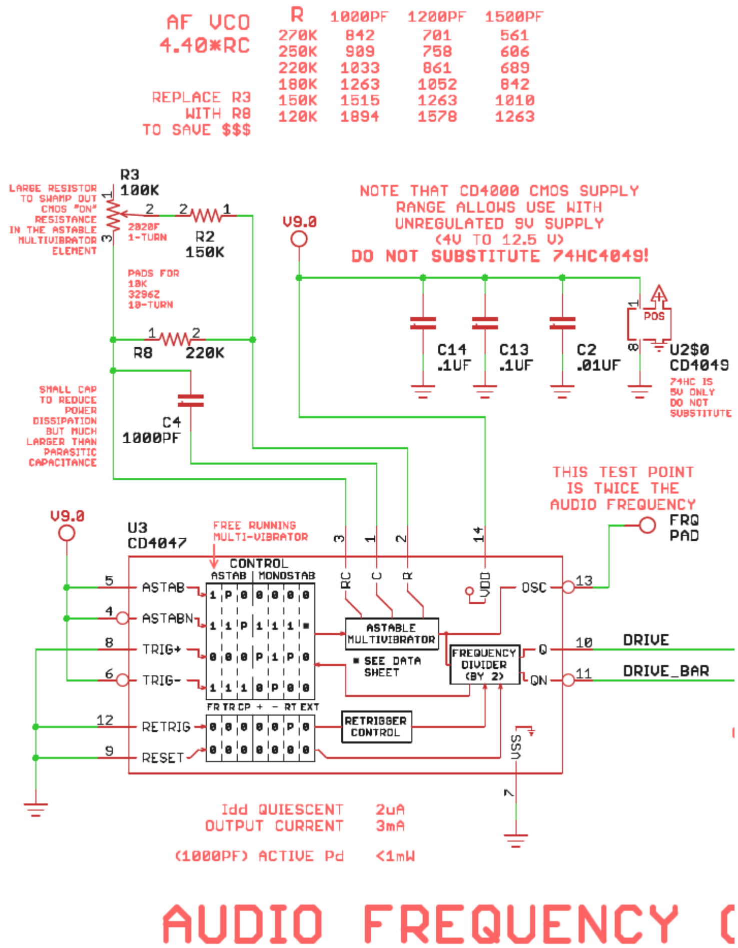

Figure 8: TDOA_-clock.png

The CD4047 has a configurable multivibrator and a divide-by-2. We strap the device to operate as an astable multivibrator that produces our base clock. This is passed through a divide-by-2 which serves to produce a nice square wave with very close to 50% duty cycle.

The true and inverted output are exactly what we needt to drive the PIN diode switch in figure **??**..

Setting the frequency is rather simple and straightforward, requiring an external resistor and capacitor. The R3/R2 parts are not populated on production boards as they were only used on the prototype to verify the value used for R8.

2.2 Revision -A

The -A revision uses a simple 555 timer and a simpler bias drive scheme.

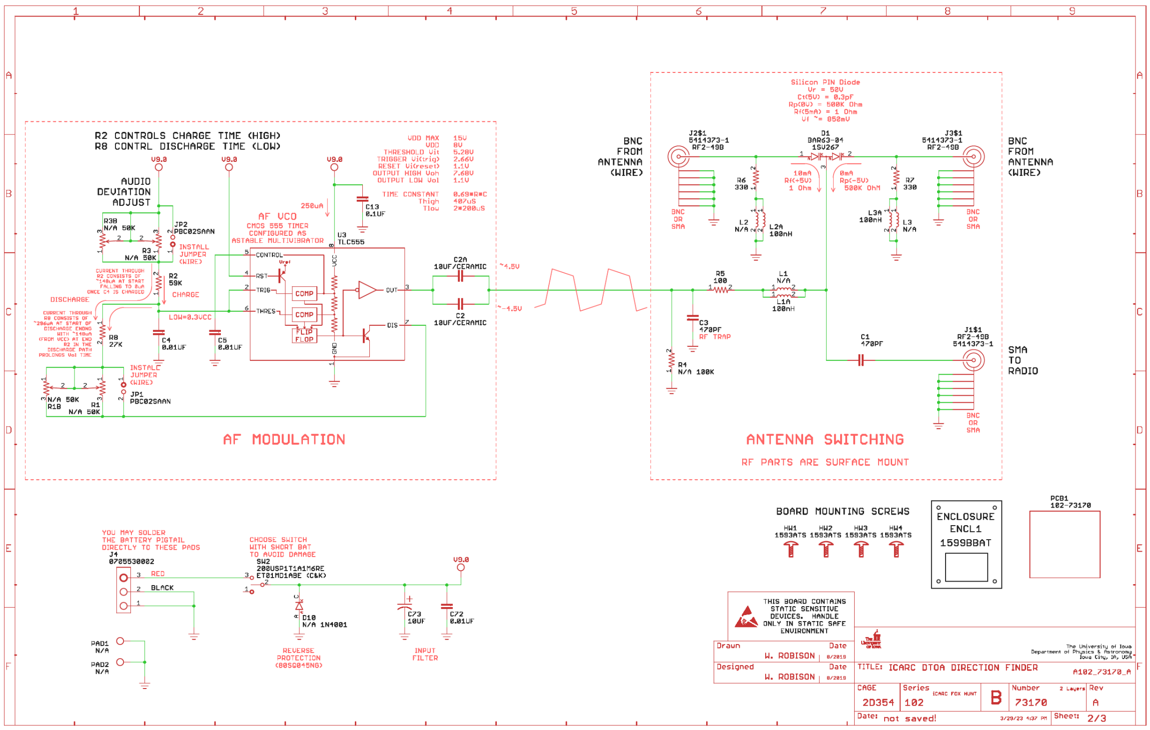

Figure 9: Revision A Schematic

This is the original circuit using a 555 timer to generate the bias control for the PIN diode.

In this circuit, the bias drive is applied to the common pin of the PIN diode array. The other two pins of the PIN diode array are (DC) grounded through R6/L2 and R7/L3.

The reverse bias voltage available here is about half of what we see on the 102-73170-20 circuit. The higher reverse bias slightly improves the isolation by increasing the apparent on resistance of one of the two PIN diodes.

The forward current available is slightly less due to the reduced forward voltage available to drive the forward biased PIN diode.

2.2.1 RF Switching

The basic antenna switch consists of the same PIN diode that is used in the -20 boards. As mentioned above, we supply the drive to the common pin of the PIN diode array. When this node is positive one of the PIN diodes conducts and when this node is negative the other PIN diodes conducts.

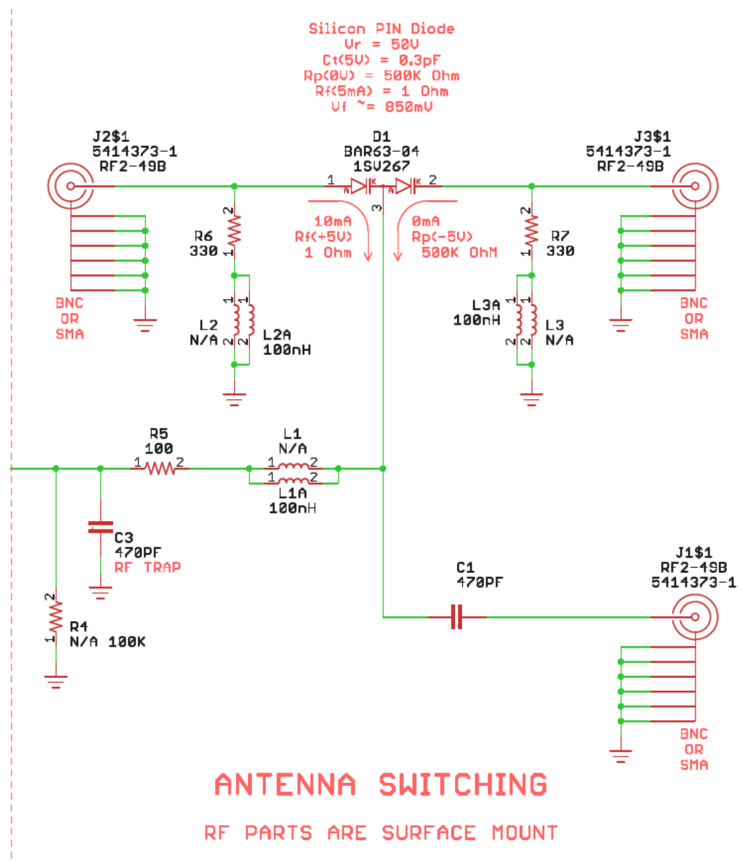

Figure 10: OLD_-switch.png

The drive for this version of the circuit is far simpler.

We couple the anode-cathode junction of the PIN diode to the bias drive signal and provide a DC path to ground at either end of the PIN diode.

Inductors L1, L2 and L3 provide the RF isolation. Resistors R5 R6 and R7 limit the current through the individual diodes of D1 when forward biased.

C3 is the RF shunt to keep RF out of the 555 timer.

2.2.2 Diode Bias Circuit

Again, working our way back through the circuit to the diode bias.

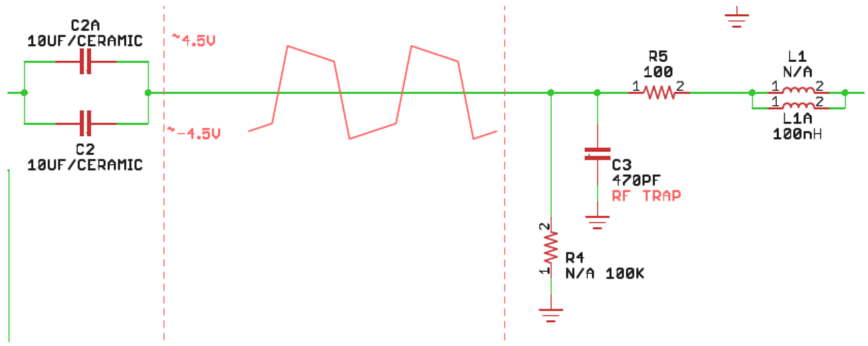

Figure 11: OLD_-bias.png

We DC isolate the drive signal with the C2/C2A capacitors.

The L1A/L1 inductor present a high impedance to the RF signal running to the receiver.

Finally, the C3 capacitor shorts RF energy to ground to keep it out of the driving circuit. This cap also keep digital noise from the drive circuit out of the receiver.

2.2.3 Clock & Drive Circuit

The timing control elements for the 555 timer are a bit more involved.

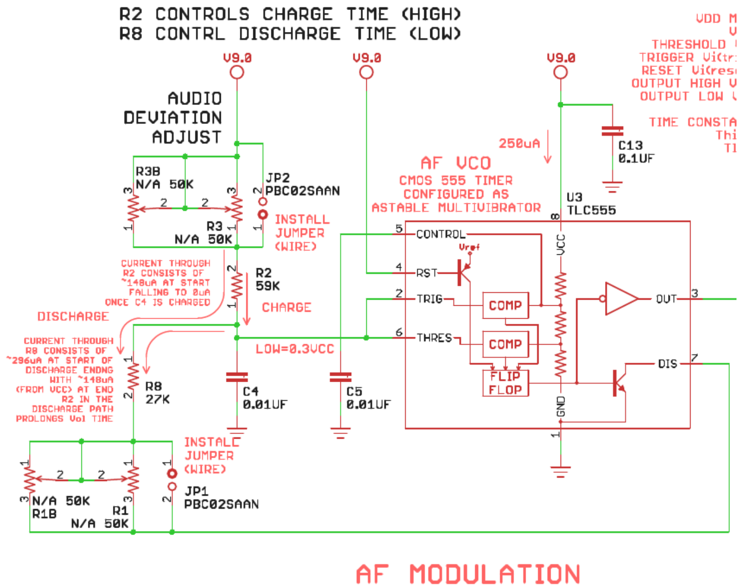

Figure 12: OLD_-clock.png

The charge and discharge path for the timing componants are seperated to allow the duty cycle to be trimmed.

The prototype unit was provisioned with trim pots to set the modulation frequency. The values measured and then updated to use fixed parts to reduce cost.

3 Construction

The -A revision has part of the board as through-hole parts. Resistors and capacitors are predominantly thru-hole.

The RF section is surface mount.

The -20 revision is predominantly surface mount to keep costs down and to fit on the smaller board.

Install low-profile parts first.

Ceramic capacitors and resistors.

PIN diodes.

Install tantalum capacitors and large diodes.

The battery connector can be installed at this point. Note the pads toward the bottom of the board that may be used to capture the battery leads and provide strain relief.

Install active devices.

Integrated circuits.

Install connectors and switches.

Recheck battery polarity. The revision -20 boards have a narrow trace in the battery net that should be damaged if you install the battery backwards.

I haven't done this intentionally, so I don't have advice other than check before you solder the battery connector.

Always switch the unit off when connecting the battery!

3.1 Prototyping: 102-73170-20

You may, if the mood strikes you, install R2 and R3 to allow changing the audio *squeal* heard in the radio.

R8 must be removed for this to work.

R3 can be installed as a 10-turn pot (Bourns **3296Z-1-104LF**) that would require a tiny screwdriver to adjust (and a plump wallet). R3 can also be fitted with a Bourns **PTV09A-2020F-A104** or **PTV09A-2020F-B104** (about $1.00) with a shaft that will protrude well past the edge of the housing.

3.2 Prototyping: 102-73170-A

Similar audio fun & games may be had on this revision hardware.

R1/R1B and R3/R3B may be installed and R2/R8 shorted to experiment with audio. The same Bourns **3296Z-1-104LF** or a Bourns **3296Z-1-503LF** may be installed in the R1B/R3B positions (and you now have a skinny wallet) or a Bourns **3310-001-503L**.

Both of the these parts are in the $3 to $5 range.

3.3 Parts List -20

The parts list:

Listing 1: A102_73170_20_PROD.packing.txt

```
Packing List PROD iCARC FOX HUNT ICARC DTOA DIRECTION FINDER, CD4047
 (102-73170) derived from A102_73170_20.sch,
  Idx    Qty    Part (Ref Des)           Value            Package
  ---    ----   ---------------   ---------------   ---------------
    6      2            C2 C72            .01UF            SM0603
    7      2           C13 C14             .1UF            SM0805
    8      1                C4           1000PF            SM0805
    9      1               C73             10UF           SMP1210
   10      6   C20 C21 C22 C23            4.7UF            SM0805
                       C24 C25
  ---    ----   - - - - - - - -   - - - - - - - -   - - - - - - - -
   11      3        C1 C5A C5B            470PF            SM0603
   12      3       C3A C3B C3C             47PF            SM0603
   13      1                D1           1SV267          SOT23-3
   14      1               D10            ER502        DO-201-AD
   15      1             ENCL1         1599BBAT         ENCLOSURE
  ---    ----   - - - - - - - -   - - - - - - - -   - - - - - - - -
   18      1               GND              N/A           PAD0062
   19      2             J2 J3              DNI     COAX_SMA_BNC
   20      1                J4              DNI   HDR_50-57-9403
   21      1                J1          RF2-49B     COAX_SMA_BNC
   22      3       L1A L1B L1C            100nH        AIAC-1812
  ---    ----   - - - - - - - -   - - - - - - - -   - - - - - - - -
   23      1              PCB1     102-73170-20  HAMMOND_1599BSHO
   26      2         PAD1 PAD2              N/A           PAD0062
   27      3       R5A R5B R5C            2.00K            SM0805
   28      1                R8             220K            SM0805
   29      3       R4A R4B R4C             820K            SM0603
  ---    ----   - - - - - - - -   - - - - - - - -   - - - - - - - -
   30      1                R3              DNI          PTV09-A2
   31      1                R2              DNI            SM0805
   32      1               R12         N/A 820K            SM0603
   33      1               SW2  200USP1T1A1M6RE           SW_ET_A
   34      1                U3           CD4047              SO14
  ---    ----   - - - - - - - -   - - - - - - - -   - - - - - - - -
   35      1                U2           CD4049              SO16
  ---    ----   ---------------   ---------------   ---------------
                                    Line Items 26
```

3.4 Parts List -A

The

Listing 2: A102_73170_A_PROD.packing.txt

```
Packing List PROD iCARC FOX HUNT ICARC DTOA DIRECTION FINDER
 (102-73170) derived from A102_73170_A.sch,
  Idx    Qty     Part (Ref Des)          Value            Package
  ---    ----    ---------------    ---------------    ---------------
    6      3      C4 C5 C72            0.01UF             AXX150
    7      1            C13            0.1UF              AXX150
    8      2         C2 C2A       10UF/CERAMIC            SM1210
    9      1            C73             10UF             SMP1210
  ---    ----    - - - - - - - -    - - - - - - - -    - - - - - - - -
   13      2          C1 C3            470PF             SM0805
   15      1             D1         BAR63-04            SOT23-3
  ---    ----    - - - - - - - -    - - - - - - - -    - - - - - - - -
   16      1            D10       N/A 1N4001          DO-201-AD
   17      1          ENCL1         1599BBAT           ENCLOSURE
  ---    ----    - - - - - - - -    - - - - - - - -    - - - - - - - -
   23      1            HW5              232    HARDWARE_BATTERY
  ---    ----    - - - - - - - -    - - - - - - - -    - - - - - - - -
   29      3             J1         RF2-49B         COAX_SMA_BNC
   30      3    L1A L2A L3A           100nH           AIAC-1812
  ---    ----    - - - - - - - -    - - - - - - - -    - - - - - - - -
   33      1           PCB1        102-73170    HAMMOND_1599BBAT
   37      1             R5              100             SM0805
   38      1             R8              27K            CF0.400
  ---    ----    - - - - - - - -    - - - - - - - -    - - - - - - - -
   39      2          R6 R7              330             SM0805
   40      1             R2              59K            CF0.400
   43      1             R4         N/A 100K             SM0805
  ---    ----    - - - - - - - -    - - - - - - - -    - - - - - - - -
   44      1            SW2  200USP1T1A1M6RE            SW_ET_A
   46      1             U3           TLC555              DIL08
  ---    ----    ---------------    ---------------    ---------------
                                 Line Items 37
```

3.5 Antenna Base 102-73170-31

A mounting base for the antenna elements.

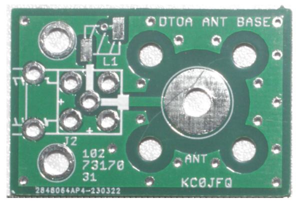

Figure 13: 102-73170-31

The coax connector, on the right side of the image, fits both a SMA style connector and a BNC style connector.

The SMA connector is a commmon right angle SMA connector. Many mechanically compatible parts may be used.

The number from *Adam Tech* for a low cost connector **RF2-49B-T-00-50-G-HDW**. Digi-Key number is **2057-RF2-49B-T-00-50-G-HDW-ND**.

A BNC part may also be fitted using a part from *TE Connectivity AMP Connectors*. The part number is **5414373-1** available from Digi-Key using their part number **A32274-ND**.

The board has six mounting holes available all 0.125" diameter. The two adjacent to the connector are bonded to ground shold there be a need to bond to a metal chassis.

The 4 holes adjacent to the large pad have the copper relieved.

For most applications a nylon or other similar spacer is reccomended along with an insulating washer.

The prototype antenna array, shown in figure 3 on page 2 used #4 pan head sheet metal screws and 0.250" nylon spacers from Digi-Key to attach the antenna base board to the rather crude antenna spacer (a pair of yardsticks glued together).

3.6 A Box to live in

Both boards are made to fit in a Hammond project box, part number **1599B**.

Several variants are offered by Hammond and the board will fit in any of them. A battery access door is convenient, but you will find that battery life is rather long and opening the box to replace batteries is not particularly time consuming.

One variation of these boxes are a bit more expensive due to the use of thread inserts to fasten the halves together. The other having self tapping screws.

The antenna connector locations match on all revisions of the boards. Once you correctly locate the connectors, you can switch boards without having to relocate these holes.

The power switch, on the other hand, was moved on the new board revision to deal with the smaller board. This should be obvious when looking at the image in figures 1 and 2 starting on page 1.

4 Testing

The

4.1 Using Oscilloscope

The

4.2 -20 Revision

There is a test pad near the big diode labelled ”FRQ”. That net should have a square wave that is close to 2 KHz. Actual frequency is not critical.

Using a ’scope on the *_BIAS* nets, you should see waveforms approximating what is shown on the schematic.

4.3 -A Revision

U3-3, the output pin of the 555 timer, should have a square wave at near 1000Hz. Dutycycle should be close to 50

Looking at either side of L1 you should see a square wave (duty cycle will match U3-3) that has a 0V DC value. It should be above and below ground roughly the same amount.

Seeing the signal all above ground or all below ground indicates a bad diode in D1.

5 Operation

Be aware that SMA connectors have a limit to the number of mate/demate cycles that is relatively small (typically 500 cycles). Don't *play* with the antenna on your handie-talkie! For example, don't remate the rubber-ducky to the radio until you're ready to use it. Similarly, don't attach the DTOA cable until ready to use it and don't detach it when you're done; wait until you need to use it!

5.1 Hints

Don't leaqve the battery on when you're done. (duh!!!, but it happens)

Having the antenna array attached with the switch electronics powered off will give you an indication of where the transmitter is located. If your antenna base is close to 1/2 λ wide, pointing the antenna array along its length toward the transmitter will severely attenuate the signal received by the handie-talkie. One antenna element will see the incoming signal almost 180° out of phase with the other; viola! attenuation!

The PIN diode, when unbiased, shows a resistance of around 500Ω to 1KΩ, not satisfactory for transmitting, but we're not transmitting. This is conductive enough for strong signals.