

The ICARC FOX Tracker

Prototype FOX Tracker

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Outline



Overview

The Synchronous Detector

Antenna Switching

Daughtercard Images

SA818 Receiver Module

Electronic Antenna Rotator

Operator Display

Timekeeping (GPS Module)

The UNIVERSAL module

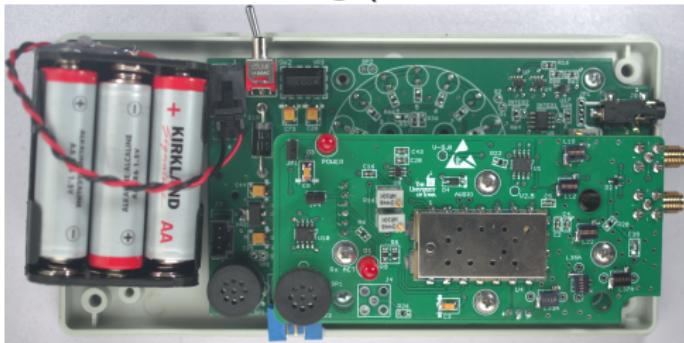
Done

Overview



Yet another winter project is upon us...

TDOA direction finding (ICARC FOX Tracker)



Time Difference Of Arrival our 2-antenna switch with a processor added!

Processor driving LEDs is less \$\$\$ than a mechanical meter

Implementation of a synchronous detector

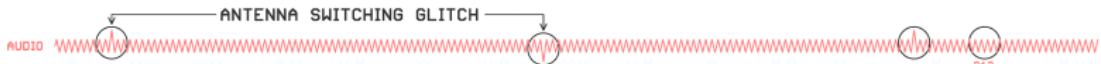
External or Internal Receiver

Processor allows for an electronic antenna rotator

Lets Build a Synchronous Detector!



What a synchronous detector *is looking for*:



Two antenna elements spaced less than $1/2$ wavelength apart.

Use receiver that detects phase shifts (due to antenna switching),

The FM demodulator converts these phase-shifts to audio (*squeal*)

Phase error occurs when antennas **not** equidistant from transmitter

The phase shifts are in opposite directions as we switch back-and-forth

Integrate (audio signal) only during antenna switching events

Use hardware to control antenna switch and
the analog gating to the integrator.

RF signal at the Antenna (nominally 144-147MHz)



What the two antenna elements see (when **not** normal to the transmitter):

When *one* antenna is 1/4 wavelength closer to the transmitter

Reference antenna



The *other* antenna



Antenna switch



What the receiver sees



Receiver after AGC



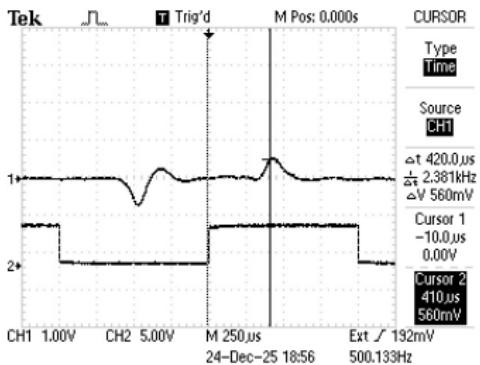
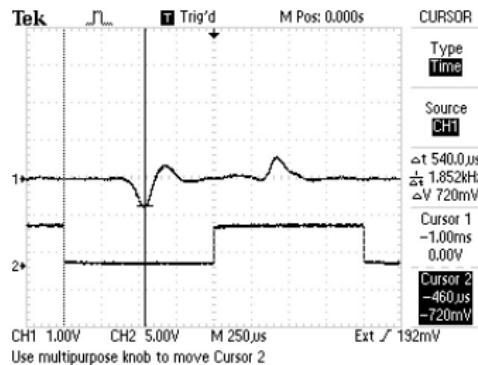
So, the demodulator in the receiver sees, in this case, an instantaneous change in frequency (increase).

The demodulator will output a hi-going spike (in the audio).
(the demodulator or the audio path may be inverted!)

Audio signal from the receiver



What the receiver sends out (SA818 audio):



The top channel is audio from the receiver.

The bottom channel is the antenna switching signal.

Note the time the receiver needs to demodulate! DSP latency

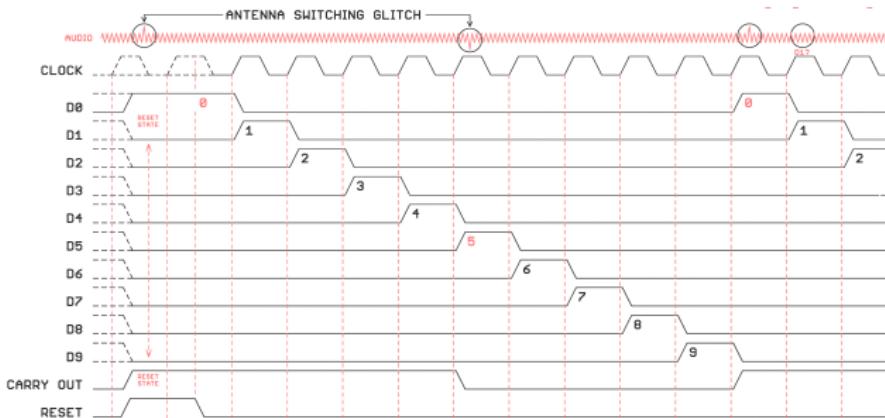
540 μ s from falling edge...

410 μ s from rising edge...

Synchronous Detector Timing



The Master Timing Diagram:



This is the timing we're going to try to work with

This timing comes from a 74HC4017 10-bit Decade Counter

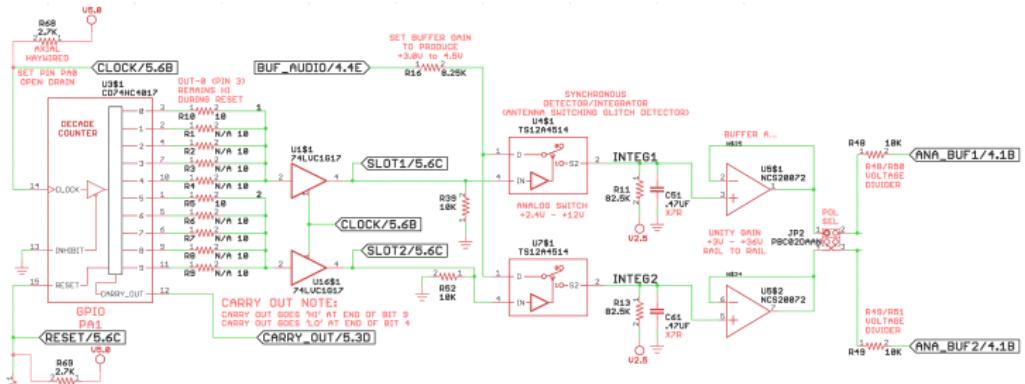
Keep in mind where the antenna switching glitches occur

as we move on to the next sheet

The Detector (102-73174-51)



The synchronous detector circuit

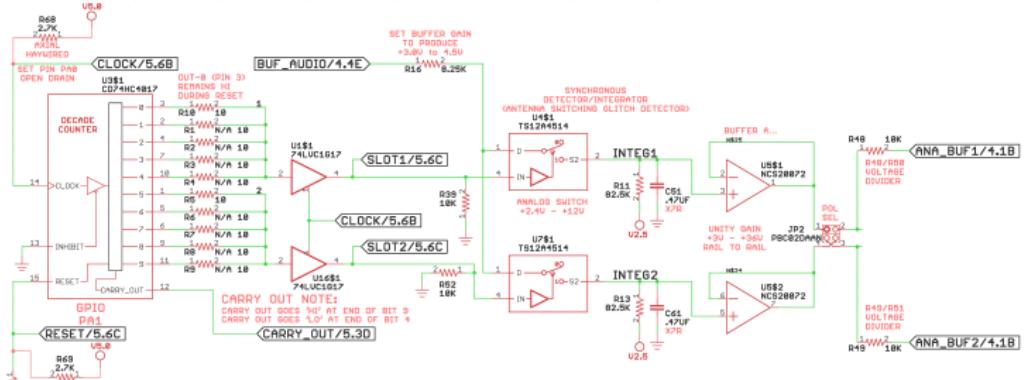


Decade counter allows selecting a small slice of audio to integrate
Clock Buffer may be used to reduce sampling window (by half)
Analog Switch plus R/C integrator
Follower (unity gain buffer to isolate the integrator)
CARRY_OUT controls the antenna switch
BUF_AUDIO comes from the receiver





The software deals with non-critical timing



The zNEO uses a hardware timer to generate the **CLOCK** signal
the detector depends on the 74HC4017 for critical timing

R1..R10 select the sampling slot (only one installed for each *SLOT*)

zNEO interrupts at end of each slot to sample **INTEG1** and **INTEG2**

zNEO interrupts at end of **CARRY_OUT** (when center element selected)

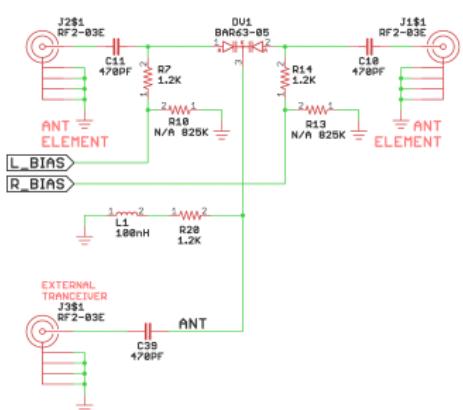
to switch to next antenna element on the rotator



Antenna Switching (102-73174-82 and 102-73174-97)



Antenna switching using PIN diode (same as 102-73170-20):



L_BIAS and **R_BIAS** are
opposite polarity (+5V/-5V)

R10/R13 are not populated
(DC bias set by bias driver)

Forward biased diode
sits about 2V above ground

Reverse biased diode
sees about -7V

Daughtercard mounts above the main board (receives 5V)

External (HT) or internal (SA818) receiver module

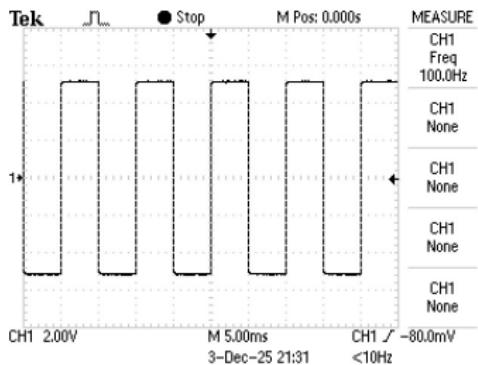
Uses 2 antenna elements (like 102-73170-20)

PIN Diode Waveforms



'scope images:

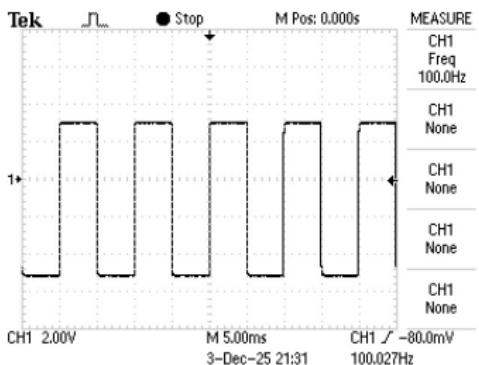
Driver waveform



Driver (TLV1812) output
+5V and -5V

Cathodes linger at around +2V

Anode waveform



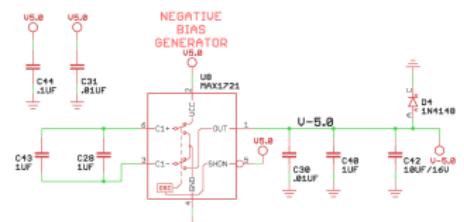
Forward biased
I-limit resistors floats
that diode above ground
Reverse biased (no current)

Negative Bias Supply and Antenna Control

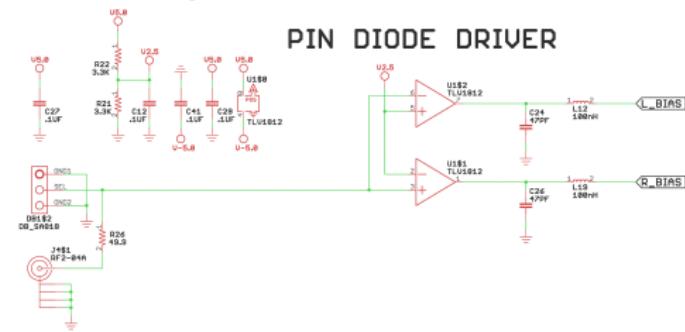


Negative bias and PIN driver:

-5V SUPPLY



PIN DIODE DRIVER



Simple switched-capacitor charge pump

Very limited current capability

Only used to reverse bias the PIN diode

Comparator powered by +5V and -5V rail

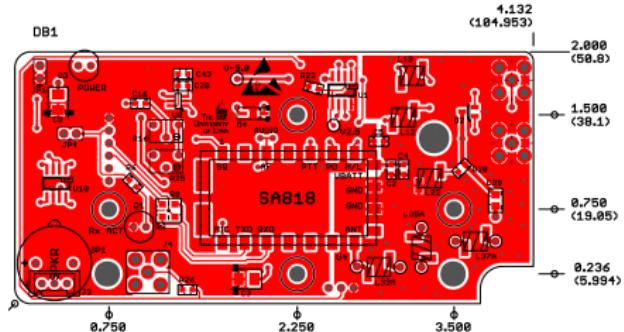
Comparator output rail-to-rail on anodes of the PIN diodes

Daughtercard Images



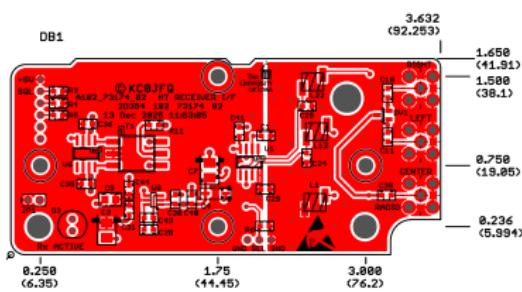
SA818 Receiver: (all the electronics are in the one box)

102-73174-97



Antenna Switch: (for external transceiver)

102-73174-82

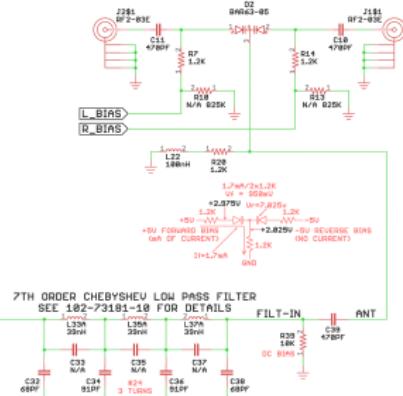
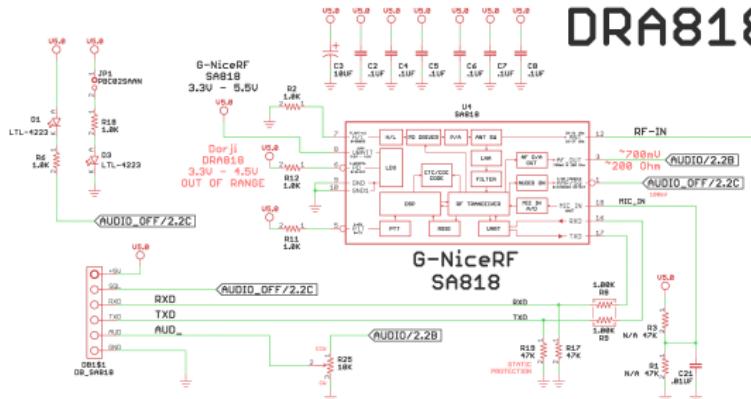


Internal Receiver Module (102-73174-97)



Using our SA818 RF module:

DRA818 RECEIVER 2



zNEO on mainboard controls SA818 (i.e. selects frequency)

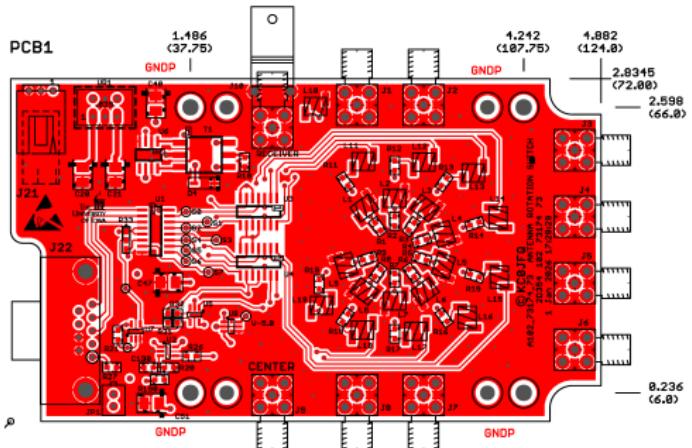
Low Pass Filter for receive from Fox Transmitter

Same PIN switch

Antenna Rotator Artwork



The board (8+1 channels):



9 elements: one center element, eight radial elements.

DE9 control cable, SMA/BNC coax back to control board.

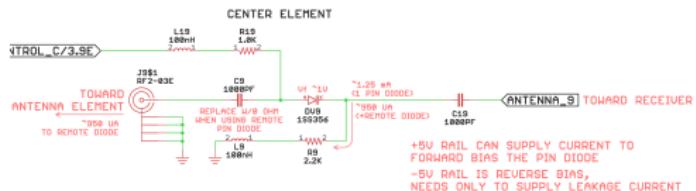
Center/radial spacing should be slightly less than 1/2 wavelength.

-5V (switched cap) (-9V bias generator not populated).

Electronic Antenna Rotator (102-73174-73)



Switched Antenna Array:



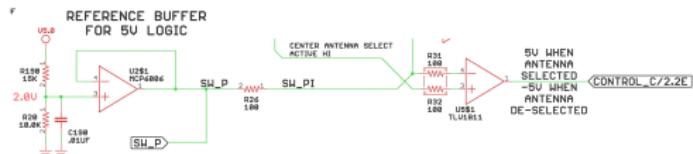
PIN diode antenna select

Same design
repeat 9 times

Bias current only
on -5V rail

Reverse bias voltage
-5V or -9V

Same Comparator
design to bias
the PIN diodes



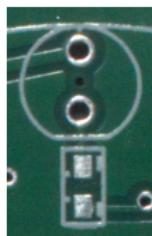
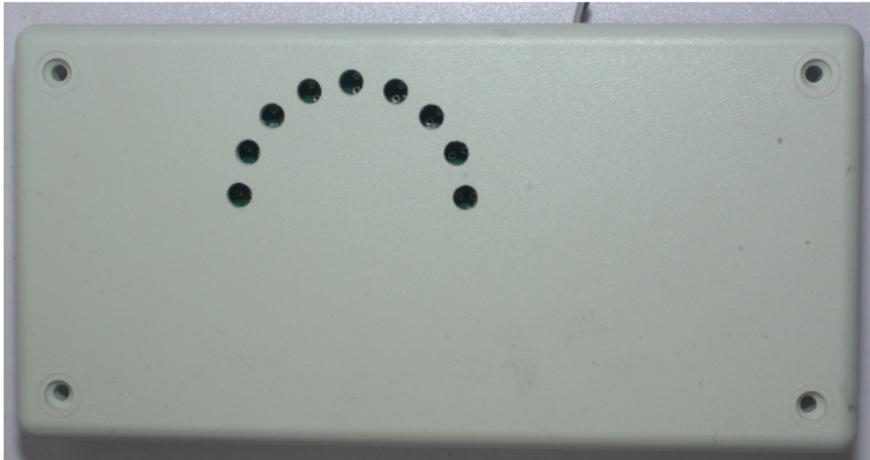
PIN diode driver



Imitation Panel Meter



Almost Done...



LED array on main board sticks out through bottom panel

← Use extra circuit board as drill jig

LEDs just fit between housing and circuit board

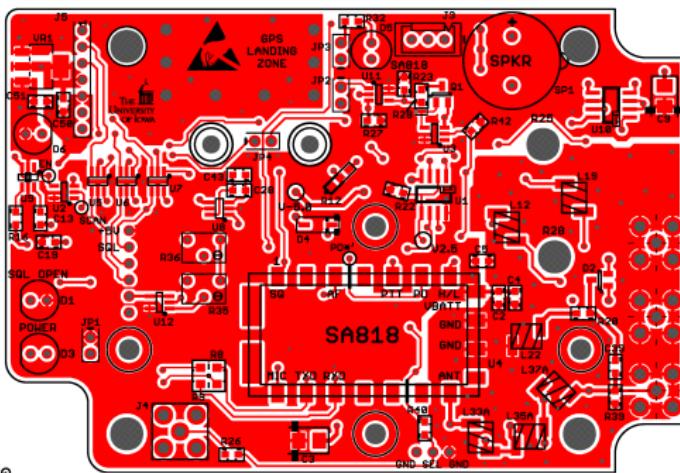
LEDs protrude only about 1mm through panel

LEDs may be color selected, if you wish

GPS Module for Timekeeping (102-73174-99)



Add a GPS Module to synchronize time:



Mounting space and control switching for GPS Module

Same size as mainboard
in the Y dimension

Access to mainboard:

Potentiometers

Mounting screws

zNEO pgm header

Shared serial channel

CARRY_OUT

activity selects SA818

remove GPS power

idle selects GPS

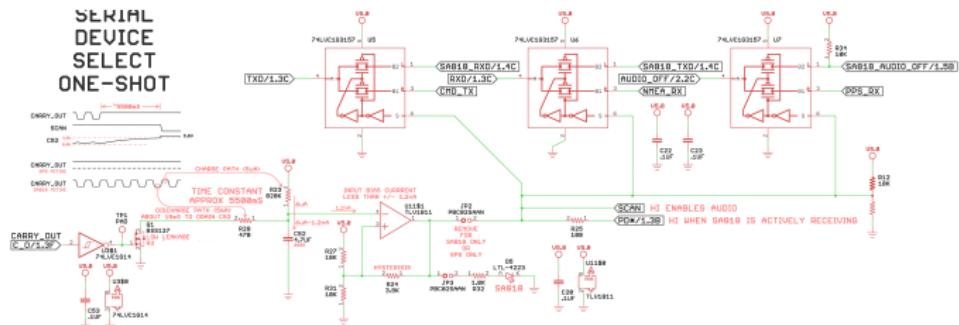
SA818 power-down mode

Serial Channel Control



Serial channel switching

CARRY_OUT may be called **C_O** in this drawing...



CARRY_OUT must be switching to send/receive data to/from the SA818

The SA818 is (internally) powered-down when **CARRY_OUT** is inactive (**PD****)

CARRY_OUT must be idle to receive data from the GPS module

The GPS module is powered-down when **CARRY_OUT** is active

The GPS module provides NMEA sentence traffic to set time



The UNIVERSAL module



The 102-73174-99 *Universal Module*

Changes to the 102-73174-99 design address all applications!

Dual Antenna using Internal Receiver

SA818 with two antenna elements

2 SMA connectors and two matched coax

Dual Antenna using External Receiver

handheld transceiver with two antenna elements

3 SMA connectors and two matched coax and a third unmatched coax

Rotating Array using Internal Receiver (with remote 102-73174-73)

one DE9 and one coax cable from 102-73181-73 to 102-73174-51

9 matched coax from 102-73174-73 to antenna elements

Rotating Array using External Receiver (with remote 102-73174-73)

one DE9 and one coax cable from 102-73181-73 to handheld transceiver

one 3.5mm audio cable from handheld transceiver to 102-73174-51

9 matched coax from 102-73174-73 to antenna elements

Done



Audio waveforms go here...

We are finished!

Indented Line

Scary Notes for the Presenter

These are my crib notes. I sure hop I rememberd to print them off and bring them along...

Page Title

notes.

Overview

An expansion of the simple 2-antenna switch that has been seen at recent fox hunts. Acknowledgement to Mike Mladejovsky (WA7ARK) from whome the idea of using the CD4017...

Processor progressed from simple ZiLOG Z8, which I couldn't program successfully, to the zNEO used in the FOX TRANSMITTER. zNEO provides substantially more program space (which is used!)

Able to share a large part of the software with the Fox Transmitter!!!

We will get to receivers and the rotator!

Lets Build a Synchronous Detector!

TDOA antenna switch *glitches* the audio signal as it switches back and forth. You can hear it in the audio of the receiver.

Use some hardware gating to *listen* to the audio signal only when the antenna switching interference occurs.

Design based on notes by Mike Mladejovsky WA7ARK.

The meter movement is what initially pushed the processor into the design; LEDs and a SOC (i.e. the zNEO) are cheaper and more available than a mechanical meter!

Meters are very expensive, or can be had from hobby outlets...
Hobby outlet never has the same part 6-months later :-(

RF signal at the Antenna (nominally 144-147MHz)

An attempt to illustrate what happens when we switch antennas.

When the antennas are **not** equidistant, we get a phase lag in the antenna that is further away.

Note that the receiver can't tell the difference between a 90°shift and a 270°shift. **Must** limit antenna separation to less than 1/2 wavelength. **Must** use equal delay coax segment from antenna to receiver switch.

FM AGC and detector: amplify amplify amplify until signal clips. We're looking at frequency, not amplitude, so the front-end is somewhat less work. At some point, we end up with a signal that is very easy to extract frequency information from.

Our example here, the receiver has no problem noticing the phase discontinuity in the received RF and demodulating it. We hear the continuous stream of switching events as a *squeal* in the audio.

The *squeal* **must** occur at a predictable point in time, so we should, in theory, be able to find the audio that is associated with the switching event.

Audio signal from the receiver

Real live 'scope images, take late December 2025.

Receiver is one of those *cheap* SA818 tranceiver modules from eek-bay!

zNEO uses hardware time to clock the decade counter that, in turn, produces the top trace. The decade counter further divides that clock into 10 parts. Clock appears to be running at 500Hz (note 500uS/Div) in this capture.

Here you can see the regular *glitch* that shows up in the audio. You will also notice the glitch is displaced from the actual antenna switching event. It looks to be about 450uS. The SA818 is rather slow to process audio (i.e. it's not real-time) and we will have to account for that! (The circuit has a way to deal with this)

It looks like the phase change decoding delay is **not** equal (low-to-high vs. high-to-low).

Demodulation oddities (or issues?)

SA818 does the demodulation in the digital domain!

It's a \$10 SDR radio! Because a chunk of flash (i.e. program) memory is far cheaper than the parts needed to do this in the analog domain.

The downside being, there is considerable latency in the decoding process:

Receive/downconvert → digitize RF(A/D) → demodulate(software) → digitize(D/A) → audio

The A/D step is probably done 1 buffer at a time, so collecting 1024 samples with 4KHz bandwidth takes about 1/8 second, so we don't start the demodulation step until 1/8 second after the first sample arrives.

Add in the time required to demodulate (i.e. all the math) and it adds up.

Faster with more powerful processor (i.e. FlexRadio), but that costs \$\$\$ and power!

Synchronous Detector Timing

We are into the **guts** of the timing control logic on the main board.

This drawing is intended to illustrate what happens during **RESET** as well as normal operation. For use with the SA818, we will see the glitch down in columns 1/6 or 2/7.

Look over toward the right side at the rising edge of **CARRY_OUT**. Slot zero is the same as all the rest after **RESET** goes away.

Antenna switching frequency affects operation when there is a fixed decoding delay in the receiver... We will have to *tune* the audio frequency.

The Detector (102-73174-51)

So, to *detect* we gate the audio signal to form a simple integrator (C51 and C61). We only pass the audio through to the integrator around when the antenna switching interference appears in the audio signal.

R11 and R13 de-integrate during the 90% when the audio signal is not gated on. We may need to tune R16 and R11/R13 values to achieve optimal performance.

U5 is simply a buffer-amp to isolate (i.e. avoid loading) the integrator.

Both the INTEG1 and INTEG2 nets touch pins on the zNEO to allow the zNEO to do a quick de-integrate by programming the pins as outputs to drive the integrator one way or the other.

more to it? (102-73174-51)

Of course there's more to it!!!

The zNEO needs to read the integrator before the charge bleeds off the integrator. The SLOT1 and SLOT1 signals also touch the zNEO and are used to generate an interrupt at the end of the integration period.

zNEO reads the buffered integrator voltage on the **ANA_BUF1** and **ANA_BUF2** nets.

We also use the **CARRY_OUT** signal to generate an interrupt to allow switching the antenna rotator at just the right time.

Also notice we have a way to use any of the outputs from the 74HC4017 as slot control. This is how we deal with receiver latency!

Antenna Switching (102-73174-82 and 102-73174-97)

Back to our good-old PIN switch!

Here we switch over to using a comparator to generate the bias voltages for the PIN diode. The comparator operates from the +5V and -5V rails and puts up with logic levels without complaint.

We (U of I Physics&Astronomy) have used RS232 (i.e. DS1488/DS1489) interface device to switch from TTL levels to the negative logic of the old Univac 418 at work. We could use a DS1488 as a driver, but it is a bit slow. We would be stuck with a 14 pin package as well. In the boards that make up the tracker, 1, 2 and 4 channel devices are used. The 1 and 2 channel devices reduce the board footprint considerably.

Run the simulation or run the calculations to discover that the forward biased diode of the pair dictates the cathode voltage. Since one of the two is always forward biased, the cathode floats about 2V above ground. This gives us just a bit more reverse bias on the other diode (slightly better isolation).

Voltages on the PIN diode

The PIN diode depends on the reverse voltage for isolation. Likewise, the forward current determines the ohmic resistance seen by the RF signal.

When driving current through one of the diodes (one is always forward biased) two of the current limiting resistors ($R7/R20$ or $R14/R20$) will pull that diode to half way between ground and the positive supply, around 2.5V.

The reverse biased diode, then, sees -5V on its anode and about 2V in its cathode (diode drop, common cathode arrangement). In other words, the reverse bias is around 7V, somewhat improving the isolation provided by the diode.

PIN Diode Waveforms

As noted these traces look at the voltage on either side of the driver-side resistors.

The resistors control current through the diodes while the inductors provide a high-impedance path to the RF signal.

BIAS drive is always present, so we don't need DC restoration. R10 and R13 are, in this case, unnecessary and are left unpopulated.

Negative Bias Supply and Antenna Control

The 102-73174-82 design, if you look on the web, has **two** negative supplies.

The **unused** transformer based design and this switched capacitor supply.

The (unpopulated) transformer design is rather expensive (control chip and transformer are \$7-\$10) and overkill for this.

The switched capacitor design is simple and we don't notice any issues so far (i.e. you don't see the switching on the negative rail).

The PIN Diode driver is a simple comparator that is powered from +5V and -5V. We provide a trivial voltage driver to establish the trip point. The incoming signal, from a 74HC device, is quite fast eliminating the need for hysteresis to the TLV1812 (can-of-worms to implement).

The isolation inductor is hanging on in this schematic fragment.

That extra SMA connector is there to provide a connection to the 'scope for testing and evaluation of the circuit.

Daughtercard Images

These are artwork images of the two working daughter cards. These are the daughtercards installed into the two test/evaluation boards that are being passed around.

One for use with a handheld (the bottom image).

The second (on top) has an on-board SA818 receiver module.

The 102-73174-82 is just a rework of the 102-73170-20 antenna switch from 2023/2024 that uses the mainboard interface for the antennas switching clock. This uses an external receiver and expects the receiver audio to be delivered to the main board. All the 102-73174-82 board provides is the antenna switching.

The 102-73174-97 is new, and draws on the RF board from the Fox Transmitter. It has 2 SMAs to connect to the antenna pair and everything else is on the daughter card. It looks rather littered with inductors, half of which are the RF isolation for the antenna switch. The other half is the low-pass filter for the SA818 antenna, again taken from the 102-73181-10 board.

I screwed up on the 102-73174-97 board by placing the SMA connectors too far up (i.e. +Y direction) on the board.

The audio connector on the main board is not installed so I can't easily switch daughter cards.

ARRGH!

There exists artwork that addresses this issue. If the design works out well, I may get these daughtercards produced.

Internal Receiver Module (102-73174-97)

Our good-old SA818! The refugee from eek-bay... For about \$12 each

The DRA818 is probably (not) compatible! It seems to want less than 5V supply!!!

Transmit capability is disabled on the 102-73174-97 circuit card! We don't have any audio to transmit, we don't have anything to say!

zNEO on main board controls the SA818. The zNEO picks frequency, sets squelch level and sets the volume level.

Squelch is **open**, it isn't adjustable enough to be of any use.

Volume can be controlled by the zNEO (serial command) to let the audio levels be set by the zNEO. This allows the software to obtain the desired direction finding results. There is also a mechanical volume control on the daughter card; a tiny 10-turn pot (yes it's a PITA to adjust).

We don't implement power-down control of the SA818 receiver on the 102-73174-97 board. Didn't really seem necessary although the SA818 is a bit of a pig, power-wise.

The SA818 is programmed through the serial port (**RxD** and **TxD**). The target frequency has to come from the zNEO which doesn't have a manual frequency selection method.

With knowledge of time and the hunt schedule, this could be managed by the zNEO, but will require using a GPS to set time (102-73174-00).

Antenna Rotator Artwork

Now the elusive antenna rotator! **OVERKILL 101**

Place a semicircular array of antenna elements on the roof with a center element for a total of 9 antenna elements.

The overall diameter must be a bit less than **1 wavelength**... A bit less than $1/2$ wavelength between center element and the outside circumference of the array. All coax lines from these 9 elements must be the same **electrical** length.

We can then switch between the center element and one of the outside elements, just as we do on the dual element setup. The zNEO can then change the outside element selection and perform the direction analysis again. Repeat for all eight outside elements and we have a pretty good idea of direction.

If we characterize the receiver, we may also have a gross idea of the transmitter direction. The polarity of the audio *glitch* gives us a notion of which element is closer to the transmitter.

This analysis will need a bit of deep thought and software development.

Text 1151

Electronic Antenna Rotator (102-73174-73)

How it Works! RF

Similar PIN diode switching, using the same comparator in a multi gate package. Uses the same biasing scheme.

The logic switching point reference is buffered to allow that voltage to be sent back to the main board. The main board routes this to the A/D so we may be able to play some configuration games by varying the voltage we send back. That voltage has to be between the logic levels used on the antenna rotator board, anything between about 1V and 4V should work fine as the 74HCT138 is running off of the 5V rail. The comparator doesn't

PIN diode reverse bias is somewhat less on this board. Since we have only one PIN diode per channel, the reverse bias case works directly against the ground path, limiting the reverse bias voltage to the negative supply.

The artwork for this board retains the transformer based negative bias supply, so we can populate it to provide an increased negative voltage should that be required.

How it Works! Software

Looking back at **Synchronous Detector Timing**, note that **CARRY_OUT** is a nice 50% duty cycle as this is used to switch between antenna elements. For our rotator, we select between the center element and **one** of the radial elements. The particular radial element determined by the **SEL_A0 .. SEL_A2** signal on the main board.

When the **CARRY_OUT** signal switches from radial element to center element, the zNEO is interrupted. The affected interrupt service routine can then change the setting on the **SEL_A0 .. SEL_A2** nets to select a new radial element without generating a glitch on the receiver antenna line.

As long as the zNEO software synchronizes with the **CARRY_OUT** signal, all works well and the zNEO can keep track of which direction the antenna pair is pointed. The zNEO should also be able to discern direction by tracking the polarity of the audio glitch.

With an 8 element array arranged in a semi-circle about the center element, we should be able to estimate the direction of an incoming signal within 20° to 30°.

Imitation Panel Meter

Here is the meter substitute/replacement.

At the start of the project, I tried to find a mechanical meter...

They were:

- 1) expensive
- 2) Hard to find, other than hobby outlets which deal in overstock making it almost impossible to buy the same movement next year...
- 3) difficult to mount in the Hammond enclosure

LEDs on top of the main board preclude mounting anything but the H.T (102-73174-82) antenna switch. All the other boards protrude into the LED array.

The layout and prototype are laid-out with T1-3/4 (5mm) package in mind. One could use T-1 (3mm) package as well.

In either case, An extra main-board is used as a drill guide. Drill the center hole in the LED pads with a 1/16 bit. With the board mounted in the housing drill the 1/16 through the drill guide into the housing. You may then open the holes in the housing to 3mm or 5mm to match your LED selection.

You will probably find that 3mm LEDs can be mounted flush or slightly recessed so as not to damage them in handling. The 5mm package will end up very close to the circuit board. On the prototype the LEDs were not mounted until the board had been verified functional (simply to avoid bending them as the board was handled to change resistors and capacitors).

GPS Module for Timekeeping (102-73174-99)

More overkill...

The SA818 can share the serial channel with a GPS module to set the system time in the tracker. This would allow the tracker to run on the same schedule as the Fox Transmitter and do some frequency tracking.

The scheme is to use the antenna switching signal to select the device that will be connected to the zNEO. More about this scheme on the next slide.

This board covers the same dimension as the main board; top-to-bottom in our view here.

The 4 mounting holes align, as you would expect. We also add a pair of standoffs in the middle of the LED array for just a bit more stability, if you find it necessary.

We also have access to the 4 main-board mounting screws, it is not necessary to redismount this board to remove the electronics from the enclosure.

Two holes are also located above the potentiometers on the main board, although they are looking more and more superfluous.

Finally, the lower left corner is relieved to provide access to the programming header on the mainboard. This avoids the need for a right-angle header that will end up penetrating the side of the enclosure.

Serial Channel Control

How we share the serial channel.

And a PPS channel.

We form a retriggerable one-shot to select between the SA818 module and a GPS module. We want to be able to access the SA818 with antenna switching disabled in order to characterize the receiver. We don't have to look at it for long, just a second or two.

So we use an open-collector driver, a comparator with very low input bias current, a capacitor, and two resistors to implement our one-shot.

Start with antenna switching disabled, such as when we apply power. **CARRY_OUT** (by some magick) will be high and allow R23 to charge C52. This will take several seconds (the calculation indicates a bit over 5 seconds). Once U11-4 rises above U11-3 the output (U11-1) will be driven low and stay there until **CARRY_OUT** goes low.

Once the decade counter starts running **CARRY_OUT** will cycle hi/lo (50% duty cycle) and drain the charge on C52 when **CARRY_OUT** is low. This will take about twice the calculated time as the **CARRY_OUT** is 50% duty cycle. The calculation indicates about 15mS.

Once enough charge has been drained out of C53 the output (U11-1) will be driven high. This not only connects the SA818 to the zNEO, it also brings the SA818 out its power-down state.

In the comparator loop, R24 provides a good deal of hysteresis, shifting the trip point between 3.9V and 1.1V.

The discharge path, though R28, makes operation very asymmetric. Charge time is seconds and discharge time is a few milliseconds. This asymmetry allows the zNEO to suspend the **CARRY_OUT** clock for a few seconds to look at noise levels without switching interference.

The UNIVERSAL module?

Late updates to 102-73174-99:

First:

Add a third SMA connector that touches the antenna port on the SA818 module.
This is the first step in making this module useable for pretty much everything.

Second:

Move the SMA connectors to the same vertical locations as the 102-73174-82 board so they don't interfere with the audio jack. The SMA connectors are mounted on the bottom side in order to fit inside the housing.

Third:

Dump the transformer based negative bias supply. It doesn't seem to be necessary, so we get it off the board to free up some space.

GPS Support

Serial switching to share the channel between the SA818 and a GPS module.

With these changes it is possible to configure the 102-73174-99 daughter card for use with an external receiver, and internal receiver. This daughter card can also be used with the 102-73174-73 antenna rotator to use an internal receiver.

Done

Phew!