FOX RF Amplifiers

Experimenting with low power RF amplifiers

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Job: fox˙present˙6

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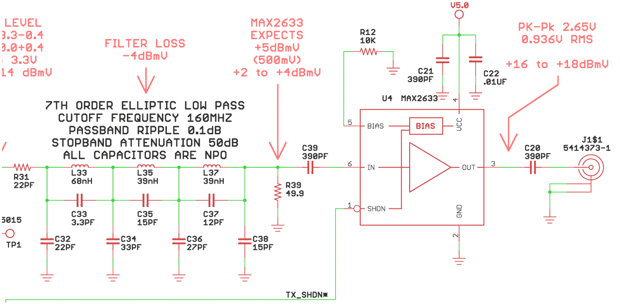
Outline

In the beginning

This all started with the 102-73161-7 **Fox Transmitter** that used a MAX2633 IF amplifier to generate a low power RF signal .

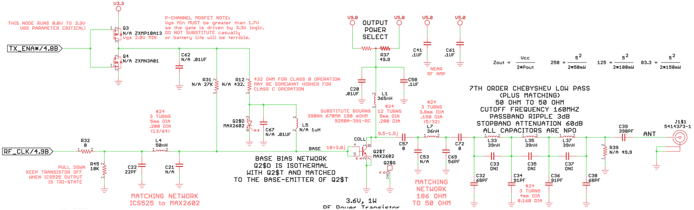


It didn't work...
so on to 102-73161-12

In the beginning

The 102-73161-12 board switched to an RF transistor, MAX2602.
The MAX2602 incorporates a diode on the same die as the transistor so the two parts are iso-thermal.
This was intended to make biasing the device simple.

It didn't work either... ARRRGH!!!



Well... screw it! Lets just move the RF section off of the main board and play with the RF design external to the **fox transmitter** board.

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Some Progress

OK then, the 102-73161-25 board fixes all these accumulated errors and moves the RF section off of the main board.

We will, however, keep the low-pass filter on the main board. Don't need to re-implement this again-and-again.

The low-pass filter topology is that of a 7th. order **elliptic filter** with the shunt capacitor first.

The filter can be populated as a **Chebyshev** as the **elliptic** is, topologically, a super-set with capacitors in parallel with the inductors.

We send out RF from the clock generator through one connector.
Switched power on a second connector.
A third connector returns the amplified RF to the main board to be filtered.

A working Design

The 102-73181-10 board is the culmination of this design effort. We keep the mechanical design of earlier models to keep the enclosure interchangeable.

We keep the daughter-board connectors locations from the 102-73161-25 mother board, again to keep the RF amplifier boards interchangeable.

To accommodate the DRA818/SA818 transceiver module, we add a connector for the the modulation signal (audio). A second connector for the serial data to/from the DRA818/SA818 transceiver module. And, just for fun, we expand both the RF-in and the RF-out connector

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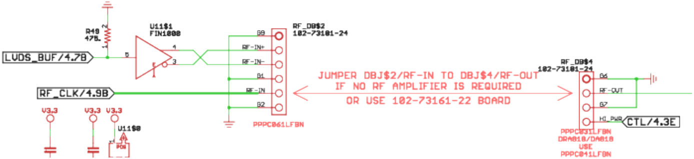
Amplifier Interconnect

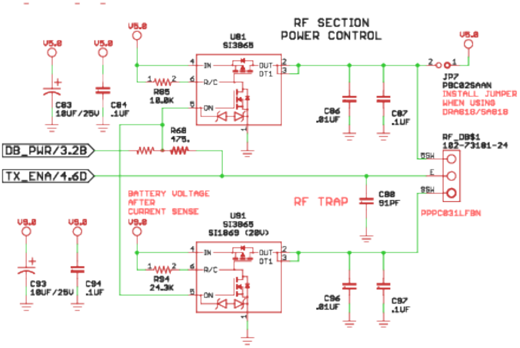
The expanded motherboard connectors are as follows:

- RF_DB$2: RF in (from SI5351 clock generator)
  - Single ended RF signal (85Ω)
  - Differential (LVDS) RF signal
- RF_DB$4: RF out (back to filter on mother board)
  - Single ended RF signal (50Ω)
  - Second Digital Control Line



Amplifier Interconnect

RF_DB$1: Switched Power
+5V and +9V (both switched)
Digital Enable Signal



Note the addition of a second control path to the SI3865 power switch.

This solves some issues presented when controlling the SA818/DRA818 modules.

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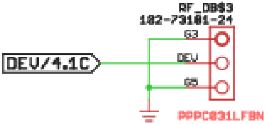
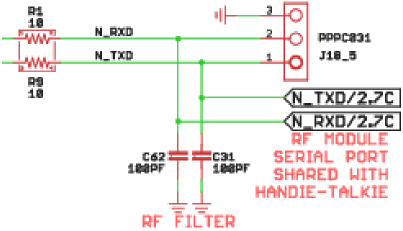
Amplifier Interconnect

RF_DB$3: Deviation
Audio Deviation
(for the SA818.DRA818)



J18_5: Serial Control
TxD and RxD from UART-0



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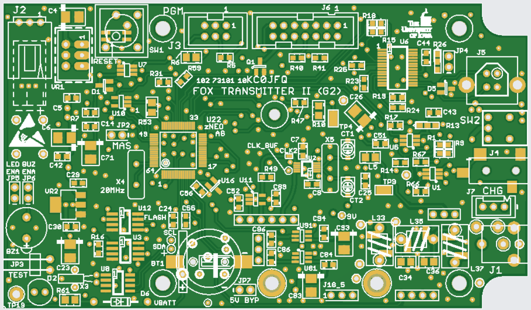
102-73181-10 Mother Board

The RF daughter board mounts in the lower right corner, note the plated holes.
A third mounting hole up near the legend "FOX TRANSMITTER II"

The output filter is under the daughter-board, lower right.

The interconnect is scattered around the lower right corner, all the single row sockets



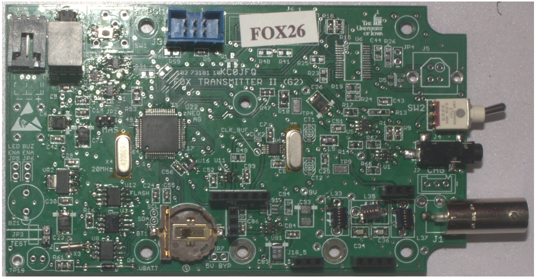
The Fox Transmitter mother-board

102-73181-10 Mother Board

Here is one of the working transmitter motherboards with the RF amplifier removed.

Note, in the lower right corner of the board, the 5 black socket connetors.

These form the RF amplifier interconnect.



A working mother-board

The low-pass filter is under the RF amplifier, just left of the BNC connector.

Amplifier: DRA818/SA818

The SA818/DRA818 is a complete transceiver module.
No RF carrier clock is required from the mother board.

Connectors:

RF_DB$2: RF not required (not populated on 102-73181-36)

RF_DB$4: 102-73181-36 has attenuator pad in this path
The *control net* connects to PD on
the SA818/DRA818.

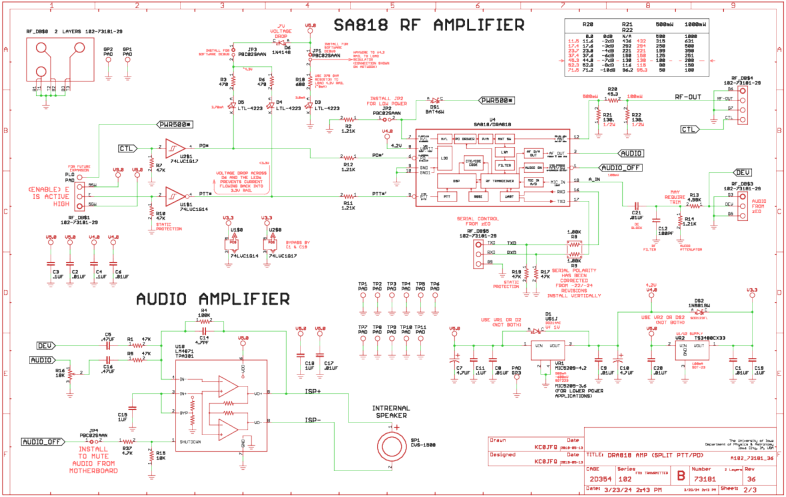
RF_DB$1: The *enable net* connects to PTT on
the SA818/DRA818. The SA818/DRA818 is
powered down between messages

RF_DB$3: Connected to audio pin on the SA818/DRA818

J18_5: Provides frequency selection

The transceiver module is powered using the switch on
the motherboard. The *control net* brings the
module out of sleep. The *enable net* causes
the module to transmit.

Amplifier: SA818 Schematic



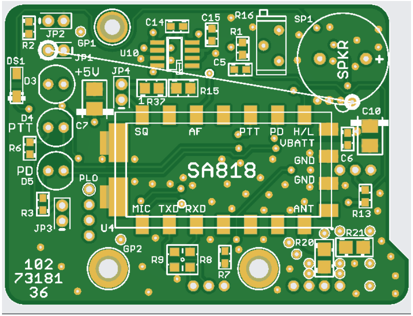
Amplifier: SA818 Board

This board needs all three mounting holes for stability.

The connector that brings in RF carrier from the mother-board is not needed so it is not present.

This board has debugging features (LEDs and audio amplifier) that are usually not populated.

An output attenuator network, R20, R21, and R22 (on opposite side) is provided should the need arise.



The final SA818 Board

The SA818 module uses castellated vias for mouting.

Amplifier: MMIC

This series of amplifiers are available in a convenient SOT89 package. Not too difficult to hand solder.

Input and output impedance is controlled at 50Ω. Input matching, from RF generator, is probably required. The output impedance, already at 50Ω, is ready to go.

Single 5V supply (already present on the mother board). All that is required is DC isolation (an inductor).

Described as an IF amplifier in the datasheet, so very low power.

BIF7 spec sheet indicates +27dBm

Targeting 50mW to 100mW.

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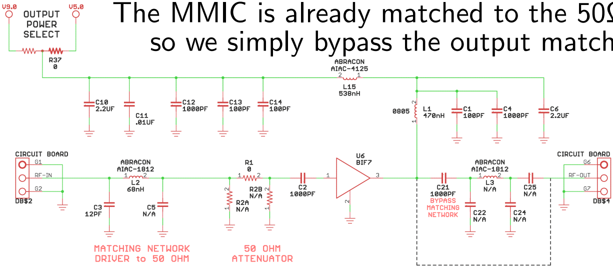
Amplifier: Basic MMIC

This is the 102-73161-28 board.
This uses an MMIC **(Monolithic Microwave Integrated Circuit)** in a small **(SOT89)** package.

The circuit is broadband, operating from about the 6 meter band up past the 70cM band. Input and output impedance are both controlled at 50Ω.

The 102-73161-28 provides both input and output matching networks. There is also an input attenuator.
The SI5351 output is 85 ohms so performance is slightly improved using a 10pF cap and 47nH inductor at the input.

The MMIC is already matched to the 50Ω antenna so we simply bypass the output matching network.



Amplifier: Basic MMIC

Are we running class-A or class-C ???

Is **L1** acting like a resistive element because we don't have sufficient bandwidth to keep U6 out of it's linear region. (reduced harmonics)

Or is **L1** storing energy to be released when U6 is off ???
Is there sufficient bandwidth to keep U6 out of its linear region ???
(rich in harmonics)

In practice, it works, so we don't really care (do we?)

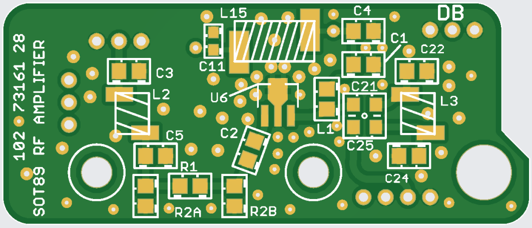
Remember we're not powered when RF drive is not present.

Amplifier: Basic MMIC

RF Input pads above C3, output pads below C24.

Power pins to the left of C3 and L2.

Clearance hole, lower right, provides access to one mounting screw on the motherboard.



The first MMIC Amplifier

Note the C21/C25 pad array is symmetric.
Install cap vertically across C21 and C25 left pads.
to bypass matching network.

Amplifier: Chirping MMIC

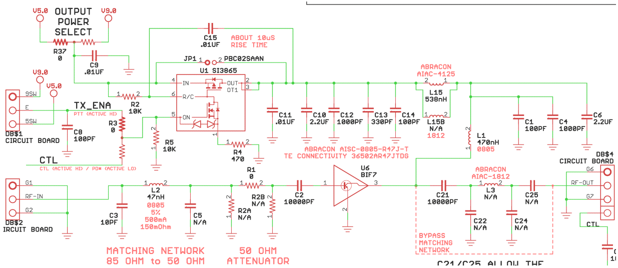
This is the 102-73181-28 board.

This uses the same MMIC as the 102-73161-28.

Use the same topology as the 102-73161-28 board adding a power switch controlled by the *TX_ENA net* or the *CTL net*.

The board operates much like the SA818/DRA818 module.

The mother board power switch will then be controlled by the *DB_PWR net* (mother board R68 must be re-positioned).



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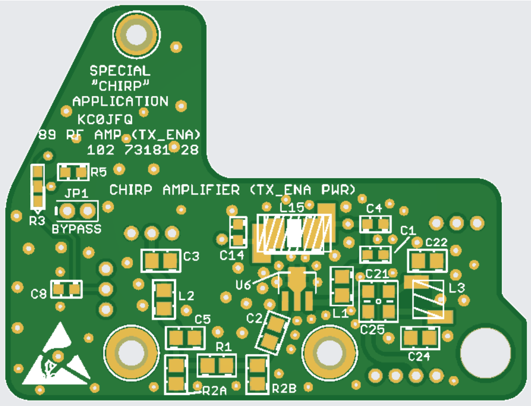
Amplifier: Chirping MMIC

Same interconnect to the mother board as the 102-73161-28 board.

We add a third mounting screw at the top.

The "BYPASS" jumper is across the power switch.

The boards can be built without the SI3865 switch installed.



The second ("Chirping") MMIC Amplifier

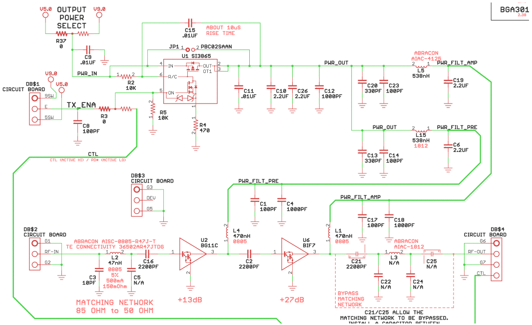
Amplifier: Dual MMIC

This is the 102-73181-71 board.

This uses the same MMIC as the 102-73181-28 and adds a second as a pre-amplifier.

Here we drop the input attenuation network to make room for a second, low gain, MMIC.

We hope to get an amplifier that produces a bit more than



100mW while keeping the power use below that of the SA818/DRA818 module.

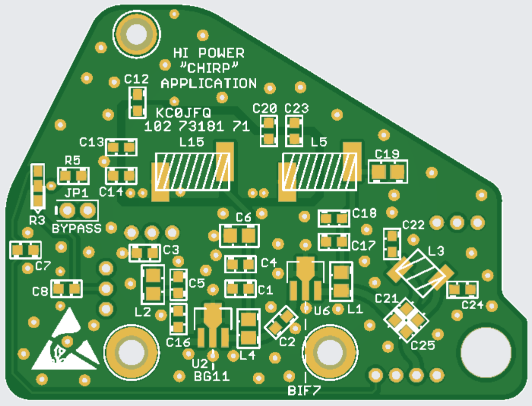
Amplifier: Dual MMIC

Same interconnect to the mother board as the 102-73161-28 and the 102-73181-28 boards.

The same third mounting screw at the top.

Same "BYPASS" across the power switch.

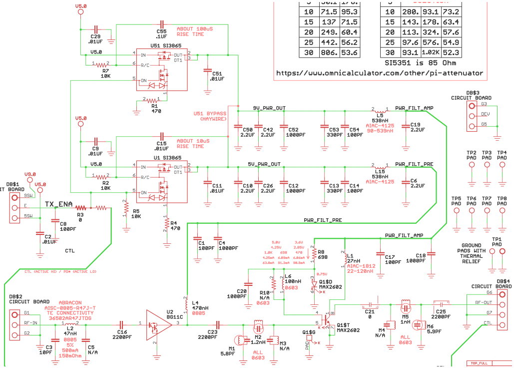
First prototype achieved about 135mW.



The third (high gain) MMIC Amplifier

Amplifier: Back to the MAX2602

This is another attempt to make use of the MAX2602 RF transistor. A bit easier to experiment with in this format.



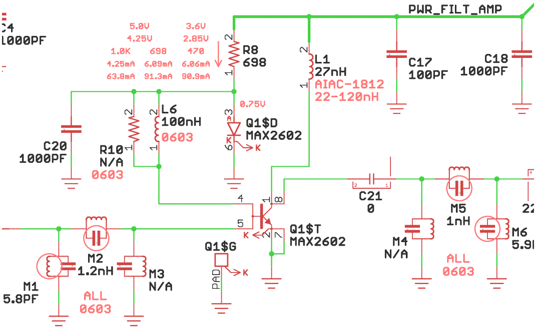
Add an independant power switch for the MAX2602.

Topology right out of the application note.

The data sheet doesn't provide much help for operating at 145MHz.

Amplifier: Back to the MAX2602

The MAX2602 is an 8-pin SOIC package. Both the transistor and diode are in the one package. The diode and transistor, living together on one die, are isothermal.



Q1$D provides thermal stability for setting the device collector current.

R8 sets the idle currrent through Q1$T

M1..M6 are the matching networks.

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Amplifier: Back to the MAX2602

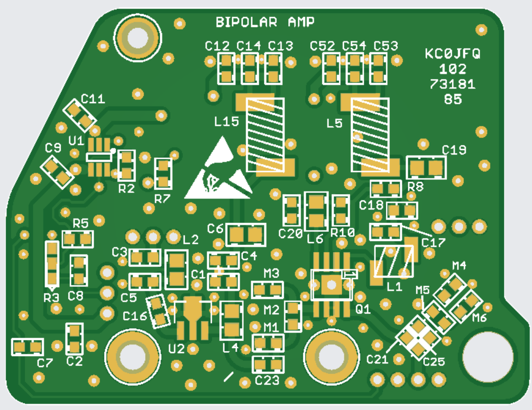
Same interconnect to the mother board as all the previous boards.

The same third mounting screw at the top.

No more "BYPASS" across the power switch.

This first prototype blows 800mA fuses as fast as you can replace them :-(

Still playing with the bias current that is set by R8!



Yet another (high gain) Amplifier

Frame

The
- end
- of *it* **all**.

Text
- indent
- yakkity-yak
- **Don't Talk Back**

Text
- Have you seen the
- missing CASSINI Probe?

- I think it ran into Saturn

Text
- JUNO/WAVES
- is going strong in orbit around Jupiter
- It uses a Z180 described in Verilog

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Frame 2

The other **END**

- 5 mm in
  - another 5mm in.
    - 10 mm in.
    - When you need glasses.
- There is nothing to see past this point!

Scary Notes for the Presenter

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

In the begining

This is the 102-73161-7 RF section, the first board. The MAX2633 is a low power IF amp.

This is how I screwed up the first two 102-73161 designs. I took a wild-ass guess at the RF amplifier. I was looking for a relatively low output power, but the RF amp on the main board just wan't cutting it.

In the 102-73161-25 design, I finally said *screw it, RF amplifier is moving to its own board* and the daughterboard came into existence.

Another failed attempt in the 102-76161-12 board. ARRRRGH!

The MAX2602 should have allowed for much bettwe output power, but I wasn't able to match it and it didn't work.

It is an interesting chip, however. Note that **Q2$D** and **Q2$T** share the **Q2** reference designator. **Q2** is an 8-pin SOIC with the transistor and diode living together in sin, under the covers together (they're isothermal!). We'll get back to this later...

Some Progress

There were omissions and false starts in the -7 and -12 revisions. All the accumulated haywires move into the artwork and we move the RF amplifier off-board. A respin of a small 2-layer board ismuch less expensive than a 4-layer main board.

We do, however, keep the low-pass filter on the main board. Topologically it is a 7-pole Elliptic, but it can be also be populated as a 7-pole Chebyshev. The filter uses commercial inductors (102-73161-7 used hand-wound parts that were also hand tuned.

Connectors to the RF daughterboard are simple 0.025-inch square post (i.e. wire-wrap size posts). In-line sockets are rugged and provide convenient inter-board spacing.

The RF daughterboard interconnect

Both single-ended and LVDS signals presented to the RF daughterboard.

The zNEO switches power to the RF daughterboard. RF board is **not powered** when not actively transmitting.

We also provide a audio signal to the RF daughterboard to provide more flexibility in how the RF board operates (more coming up!).

ANd, to finish up with this page, there is a serial connection from the zNEO to the RF daughterboard. We'll get to this in a page or two.

We also encounter parts availability issues. Parts are always a PITA!

RF synthesizer starts out as an ICS525. Not particularly effective for RF, it simply operates up in the 2M frequency range. Frequency selection is **very** limited.

The 102-73181-10 Board

That part goes extinct, and I move to a slightly (emphasis on slightly) newer part in the ICS307. This is the 102-73181-0 board. Same architecture as the ICS525, but an extra bit or two in the feedback divisor register. Also, not particularly effective for RF, it simply operates up in the 2M frequency range.

And it goes extinct as well (battin' 1000 here so far).

A working Design

Not willing to be ignored, ZiLOG eliminates production of the zNEO processor chip in the 80-pin package.

ARRGH! here we go again...

Respin the 102-73181-5 board to switch from 80-pin to 64-pin package. We'll move the host control port where we load sequences, audio data, and local time. Now it's externally accessible so no longer necessary to open the encolsre when setting up for the hunt the night before.

The other major change is stumbling into the SI5351 RF synthesizer. The little gem gets us access to the entire 2M band. We can calculate register values to give us access to 5KHz channels.

We also correct for crystal offset error. This eliminates the need for expensive trim capacitors on the SI5351 crystal.

This little gem also opens up 6M and 10M operation by changing the low-pass filter.

The image lacks (as you can see) the RF daughterboard. The low-pass filter in the lower right.

Quite a few unpopulated parts for features we don't need for fox hunting.

USB serial interface dropped for simple 3.5mm jack.

Diagnostic buzzer and LED for software development.

Amplifier: DRA818/SA818

Now for some interesting fun things!

The SA818/DRA818 VHF/UHX tranceiver module.

Complete radio in a convenient module.

Up to 1000mW out? (well, not that I've noticed anyway).

Entire RF subsystem in the module. All that is required is serail commanding and a low-pass filter. Fortunately for us we have both!

Well, we planned for it, so...

Only the 102-73181-10 revision fully implements the interface required for successful operation.

Since the entire RF board is powered down between messages, we drive the SA818/DRA818 power-down pin and the SA818/DRA818 PTT pin independantly.

The zNEO implements programmable delays to deal with the time SA818/DRA818 requires to wake up in the morning. It isn't a morning person.

The schematic for the board has pads for LED indicators and an audio amplifier. These are there to support software development. They don't get populated on deployed hardware.

The DRA818 has *odd power requirements* that are satisfied by the 4.2V regulator (VR1). The SA818 can bypass the regulator.

This board needs the 3rd. mounting hole. It barely fits within the area allowed by the daughterbaord interconnect pins.

We don't provide pins for RF synthesizer outputs, they're not needed! And, they're in the way.

Amplifier: MMIC

Having controlled impedance really makes life easy!

Originally I though I picked out that the SI5351 could produce a 50Ω output but it turns out I mis-read it. In reality it was 85Ω which should be easy to matchto the 50Ω input of the MMIC.

All of the MMIC boards have a PI metwork on the input so it is relatively easy to populate a simple impednace matching network. Controlled ipedance really make life easy!

Amplifier: Basic MMIC

Here is that last update to the simple MMIC amplifier. Input matching, input attenuation, and a DC block from the single-ended output from the SI5351. This assumes the SI5351 channel-0 output drive strength is set to the maximum of 10mA.

All of the generally available parts are 5V parts so we populate the connection to 5 volts. L15 and all the adjacent capacitors are power filters. In particular, we do what we can to keep RF away from the processor.

Downstredam of the MMIC we provide an output attenuator and a DC block. The C21/C25 capacitor pair are mechanically located and oriented to allow the PI network to be directly bypassed. Artwork shows up in a couple of slides.

Rich, W3ACO, estimate of operating mode???

Notice we have only two mounting holes. This is a small board, so that's all we need. The 3rd. hole on the right provides access to the mounting hole in the corner of the motherboard.

Amplifier: Chirping MMIC

What do I mean by **Chirp** here?

Chirp like a bird **not** a RADAR chirp.

By adding a local power switch, we can emulate the behavior of the SA818/DRA818 module where the power-enable and PTT functions are seperate.

This enables an interrupted carrier mode of operation.

Carrier is only enabled when an audio tone is being sent. Much like traditional CW, although in this case we are FM modulating the carrier.

The power switch on the CHiRP board is slew-rate limited. This reduces the delta-I load on the regulator where we're constantly switching the amplifier on and off.

If you want an audio chirp, where the audio tone sweeps from low to high (think of 400Hz ro 2000Hz) you can generate the waveform, load it into flash, and use the **TALK** command to send it.

The configuration flag that enables this CW-like mode of operation works the same for voice clips.

Amplifier: Dual MMIC

MORE POWER!

Although the SA818/DRA818 module has the potential to give us output levels up to 1000mW, the module is low to start after power is applied and draws quite a bit of power.

The single MMIC, with the input drive provided by the SI5351, produces output levels from 50mW to just over 100mW.

Can this be improved by increasing the drive to the MMIC?

We can simply gang 2 MMIC together to try to get a bit more output. The intent being that this draws a bit less than the SA818/DRA818 module.

This amplifier is a superset of the basic MMIC amplifier. As such, it is the standard amplifier used in the ICARC Fox Hunt units.

We start with the *Chirping MMIC* to get the soft-start feature and add the second MMIC stage.

All the power supply filtering is duplicated, again to try to keep RF away from the main board.

The input network and the output network remain unchanged.

Our footprint is set by the mounting holes on the main board, so we can't alter these locations. Here we increase the area a bit over the *Chirping MMIC* design and plop down a second amplifier stage.

The amplifiers are inverting, so current spikes are 180°out of phase.

Amplifier: Back to the MAX2602

Back to the beast!

The **MAX2602** is intended as an RF power transistor. The datasheet indicates it operates up to 900MHz, which is good enough for us!

Output power of up to 1000mW is also claimed in the datasheet.

Output gain is indicated at 11.6dB

Thermal compensation is built in to the device. The die contains a bipolar NPN transistor and a diode. Emitter and Cathode both connected to the ground pins and the package thermal pad.

The package thermal pad is connected to a pad on the circuit board (with large via) to pull heat from the die.

The MAX2602 high-performance silicon bipolar RF power transistor and a thermally matched biasing diode that matches the power transistor's thermal and process characteristics. This diode is used to create a bias network that accurately controls the power transistor's collector current as the temperature changes

The biasing diode is a scaled version of the power transistor's base-emitter junction, in such a way that the current through the biasing diode is 1/15 the quiescent collector current of the RF power transistor. Supplying the biasing diode with a constant current source and connecting the diode's anode to the RF power transistor's base ensures that the RF power transistor's quiescent collector current remains constant through temperature variations

The table in red, to left of R8 in the schematic, is the calculated quiescent collector current.

The 5 volt column for the 698Ω resistor shows current through R8/Q1 a 6mA which gives a collecter current of 91mA.

Well shit, that doesn't seem to work out!

We have DC isolation at C23 and the matching network at M1..M3 can't inject current (parallel inductors can only suck current away from the base).

Why is is sucking so much current? It's blowing the 800mA battery fuse on the main board !