The Spartan Sprint Special 40m CW Transceiver

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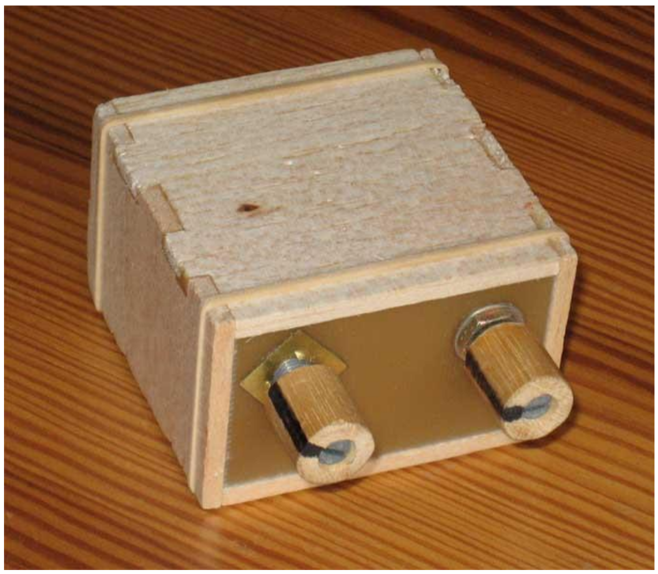
This article originally appeared in the Adventure Radio Society's on-line magazine "The Soujourner" in 2002. It was recently (2019) brought to my attention by VK4TJ that the original website was no longer functioning, so I have reproduced it here. It turned out that the only copy of the files I had was on an old computer with only 3-1/2" floppy disk compatibility, so I had to rely on the Wayback Machine (web.archive.org) for the text and photographs of the screen of the old computer for the diagrams. The Spartan Sprint contests which inspired this rig are still running – see: http://arsqrp.blogspot.com/2009/02/so-whats-spartan-sprint-and-how-do-i.html



INTRODUCTION

This transceiver developed out of an earlier transceiver that itself began as an experiment to see if I could build a direct conversion receiver using only CMOS digital ICs. The answer to that question was yes, but the CMOS chips were too noisy as audio amps to permit hearing weak signals. After adding a single bipolar transistor audio preamp the performance was good enough that I added some more CMOS chips to turn it into a transceiver. At 150 mW output, it seemed ideal for running off small batteries so I started using it for Spartan Sprints. Well, that was fun, but I have been a keen contester for years and the desire to place better took hold. The CMOS rig had not really been designed for minimum weight, so out came the data sheets, the calculator, etc. and the idea for the rig described here was hatched.

It was about this time that AA4XX's amazingly lightweight transceiver started winning the Sprints and was described in the Sojourner. However, I decided I wanted a "real" rig, in the sense that it had a case, knobs and connectors and did not require a screwdriver to operate. I also didn't want the extra pleasure of listening to shortwave broadcast stations at the same time, as AA4XX noted with his ultra-simple receiver. I spent a couple of summers working at Radio Canada International, operating transmitters with more than a million times the output power of this rig !

These short wave broadcast signals are really strong, so a more sophisticated design was called for. I started with the direct conversion design of the earlier CMOS transceiver and thoroughly revamped it to give smaller size, lower weight and lower receive current drain. It also has somewhat better receive performance as a result of not being limited to CMOS digital chips.

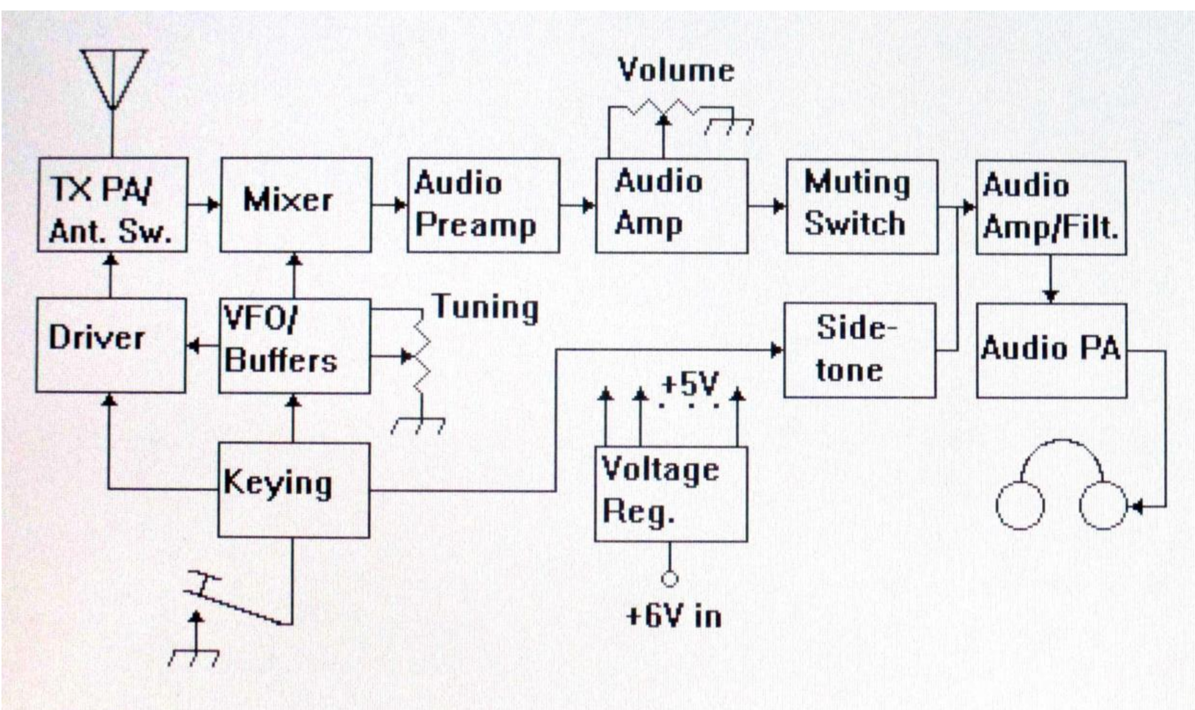
THE RESULTS

The transceiver that resulted has about 200 mW output VFO-tunable over 15 kHz of 40m around the QRP calling frequency. It is sensitive enough to copy other milliwatters. Despite a lot of audio filtering, the selectivity still does not compare very well with most superhets, but is certainly usable. It weighs about 73 g (0.16 lb) including the case. It draws about 14 mA on receive (no signal), a little more with a loud signal, and about 125 mA key down on transmit. The case is 2.4"W x 1.5"H x 2.3"D, excluding knobs and connectors. It will easily run for a full Spartan Sprint on four AAA alkaline cells. Features include fast semi-break-in and sidetone.

And, in conjunction with a 26 foot vertical antenna, it achieved the goal of getting a respectable score in the Sprint with a fourth place finish in June 2001.

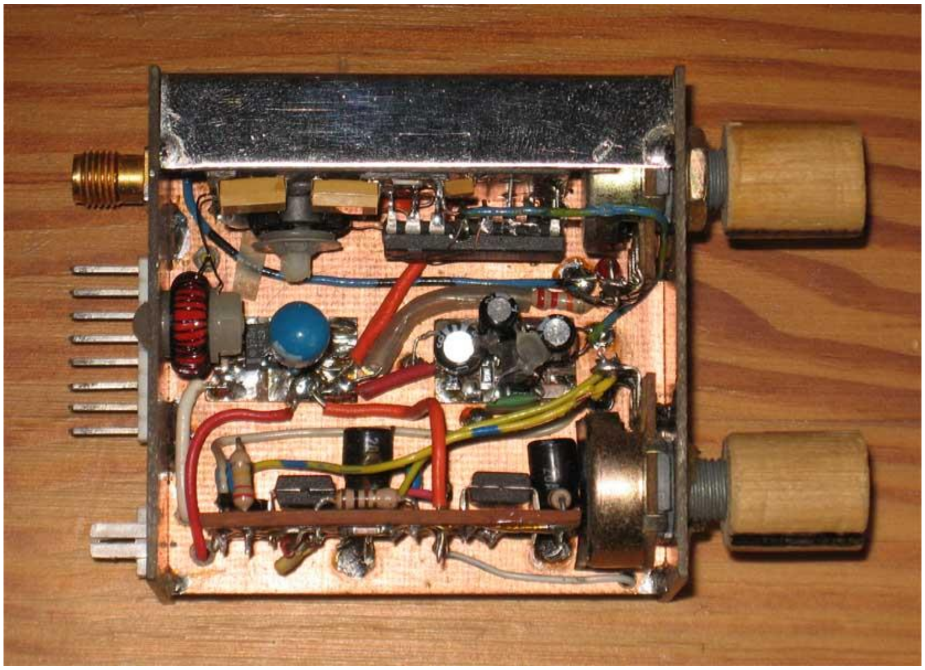
CONSTRUCTION APPROACH

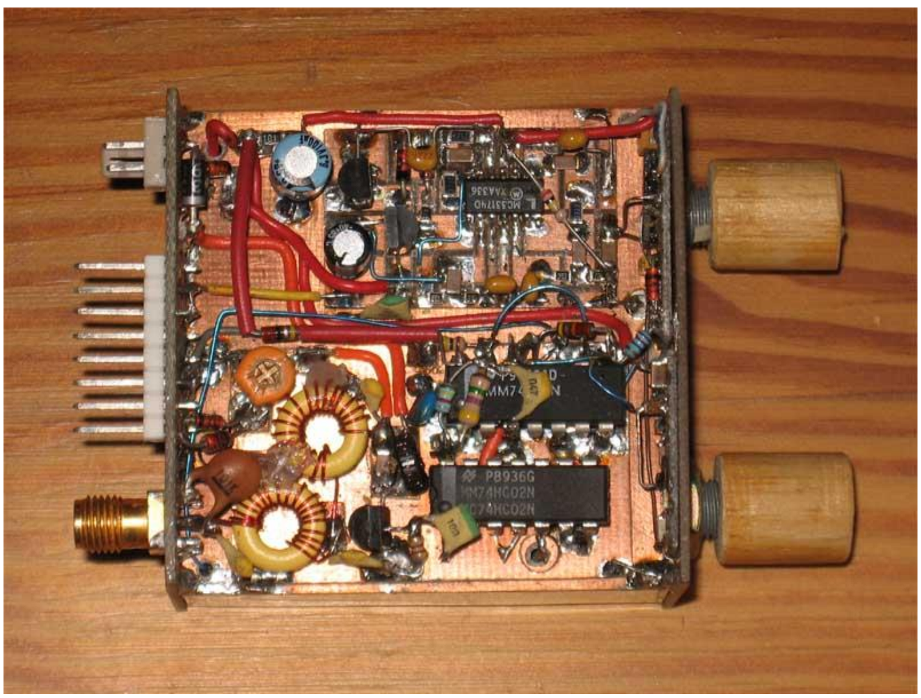
The following table summarizes the active devices used in each stage shown in the block diagram and the construction technique used for each board. Each board holds only one or a few stages of the transceiver so I could design, build and test the rig in stages. The techniques varied from board to board depending on what styles of parts were available in my junkbox or from local electronics outlets.



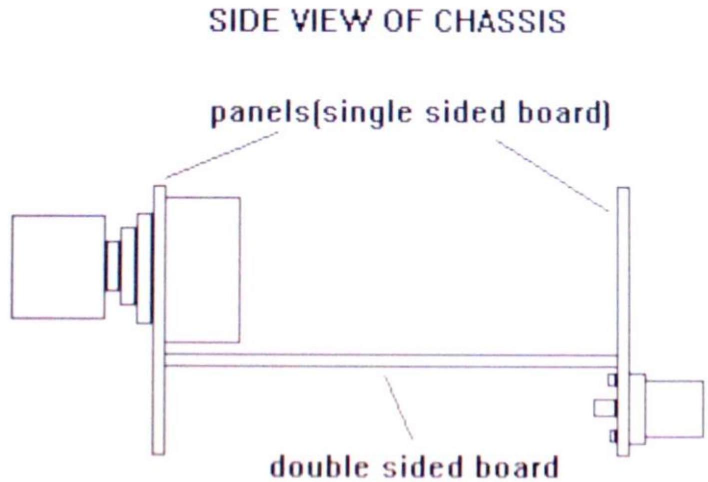
Circuit	Active Devices	Construction
VFO/Buffers	74HC04(U9)	SMT/Manhattan/Live-Bug, double sided
Mixer	74HC4053(U1)	(opposite side of VFO board)
Audio Preamp	2n3904	SMT
Audio Amp	TL072(U2)+TL062(U3)	Veroboard + SMT parts on foil side
Muting Switch	4053B(U6)	SMT
Audio Filter	MC33174(U4)	SMT
Audio Power Amp	2N3904+2N3906	(same board as Audio Filter)
Transmit Driver	74HC02(U8)	Manhattan/Live-Bug combo
TX Power Amp	2N4400	(same board as Driver)
Keying Circuit	74C04(U7)	(same board as Driver)
Sidetone Osc.	2 x 2N3904	SMT
Voltage Regulator	LM2931C(U5)	SMT

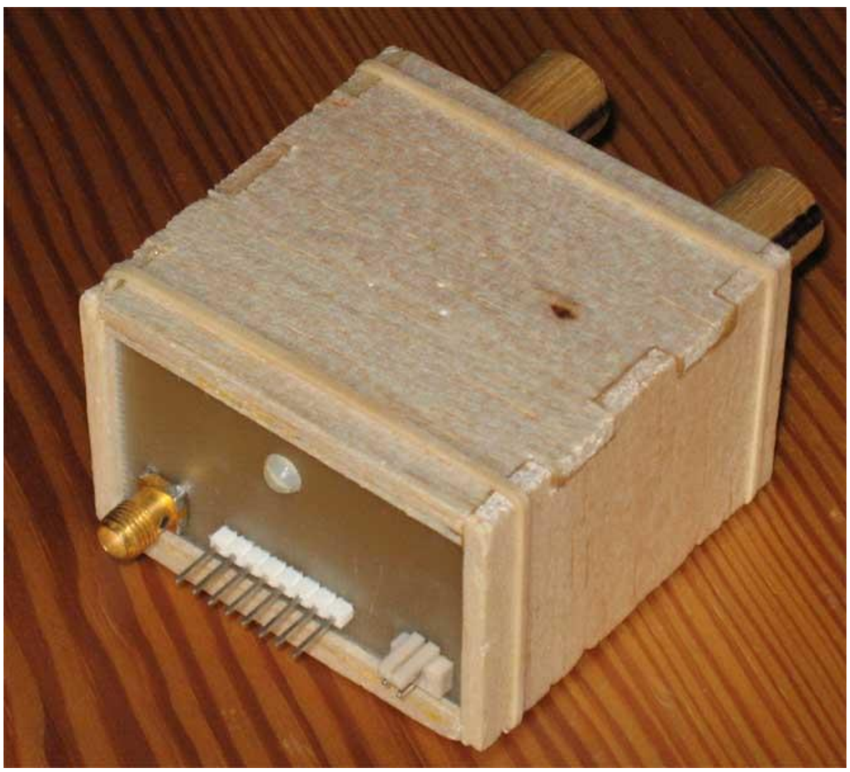
All the surface mount (SMT) boards were cut with a knife (under a large magnifying glass) rather than etched, using 1/32 inch single-sided PC-board in most cases. The audio filter/PA board is the ultimate in this kind of board making, with a 16-pin small outline IC (.025" traces and spaces) as its centerpiece. This board took forever to make; I don't really recommend this technique for complex boards except to those of you who enjoy inscribing sacred verses on the heads of pins or similar excercises. I was off work due to an injury for several weeks and had time to spare when I did mine ! Not all the components on the surface mount boards are proper surface mount parts, but they were used when available to save space. For those of you who have a hard time finding SMT parts, you will be glad to learn that nearly all the ones I used were removed from junked cordless phones, cellphones, etc. found at surplus stores or ham fleamarkets.





All these small boards were mounted to the PC-board chassis by soldering components or small wire jumpers from points on the boards to the chassis. The chassis itself is made from a horizontal piece of 1/32" double sided board soldered to front- and rear panels made of single-sided 1/32" PC-board, with enough room for attaching the individual circuit boards both above and below the horizontal part of the chassis. Some circuits are also attached to the panels. The tuning and volume pots are mounted to the front panel and the connectors are mounted to the rear panel. I used an SMA PC-board mount jack for the antenna connector and 0.1 inch spacing headers for the power, key and headphones. There is a shield over the VFO made from a piece of tin-plated sheet metal obtained from a hobby store. It is soldered in place, which helps to make the chassis more rigid.





The case is made from balsa wood sheet. Three pieces of sheet are made into a U-shape, into which the chassis is dropped. A fourth sheet drops in on top as a lid. Both the U and the lid have small pieces of balsa glued to the inside which engage the rear panel to stop the chassis from sliding back and forth. This lid is held on simply by wrapping a couple of elastic bands around the whole rig; it's not very elegant but I haven't thought of a better way.

CIRCUIT DETAILS

The circuit details are shown in the schematics, which follow the text. It turned out that the schematics were more practical to generate if I didn't stick strictly to one schematic per board. I doubt if anyone will try to replicate this rig exactly so this should not result in too much confusion. One general note to keep in mind: all the unused inputs to CMOS chips are grounded, which is not shown on the schematics in all cases. Otherwise, IC pins not shown are left unconnected.

Let's start with the VFO. This is pretty unconventional, using a high speed CMOS inverter chip for both the oscillator and buffers for the receive and transmit chains. It is varactor tuned, with a single turn potentiometer used for control. To give a comfortable tuning speed with a small lightweight knob, the tuning range is limited to about 15 kHz, which is plenty for QRP contests. Note, however, that the component tolerances will easily move the VFO several kHz from where you think it will be so you will need to juggle the tuned circuit components to hit the desired part of the band. It is surprisingly stable, given that it uses a device which was never intended for RF use. I measured a turn-on drift at room temperature of about 130 Hz in 40 minutes after which it stayed within a 30 Hz range.

Now, on to the receive chain, starting with the mixer. This is a CMOS switch balanced mixer, basically the same as many of the 74HC4066 designs that have been published. The 74HC4053 has the advantage of not needing two out-of-phase VFO inputs. The 6.8k resistor at pin 14 biases the output to about 2.5 V. I didn't bother with proper wideband termination of the mixer; rather everything above a couple of kHz is shorted to ground by capacitors. The rejection of shortwave broadcast stations is reasonably good, though there is occasionally some breakthrough. The mixer is followed by a 2N3904 common-base audio preamp, biased to about 0.5 mA to give a 50 ohm input resistance. In an effort to get maximum gain the preamp biasing ended up not very stable, so a regulated supply is essential.

Next is the main high-gain audio amplifier, which uses a TL072, for reasonably low noise, followed by half a TL062, for low current consumption. Each stage is configured as a bandpass filter (actually combined low-pass and high pass filters. These op-amps are not really specified for 5V single-ended operation but seem to have no problems.

The muting switch, uses a similar IC to that used in the mixer, but the lower speed version. The 470k resistor and 1 uF capacitor set the semi-break-in delay time. You can change these to set the timing you prefer, or perhaps use a 1 meg pot for variable delay. This circuit turned out to give nice quiet switching.

The sidetone oscillator is a classic multivibrator using two NPN transistors but with keying applied to one of the bases, rather than the supply line, in order to minimize the current required from the control line. The two capacitors C1 and C2 are around .001 uF, but can be changed to set the desired pitch.

Following this is a quad op amp set up for four more stages of audio filtering. The MC33174 was selected mostly because I had some, in surface mount packages, but it has the advantage of quite low power supply current drain and is specified for 5 V operation. The last stage is the driver for a complementary-symmetry audio power amplifier. The output transistors are inside the filter feedback loop to keep the distortion down. Building the output stage from discrete components allows a significant reduction in the no-signal current compared to the classic LM386. The current, and the distortion level, can be changed by playing with the biasing resistors and diodes for the output stage, but from my experiments, there seems no need for more than 1 mA quiescent collector current if only headphone operation is intended. Much less is often sufficient for Walkman- style phones with both sides in parallel. The output stage is run directly from the battery (through a reverse-polarity protection diode) so the varying current of this stage will not pull the VFO supply voltage.

All the transmit circuitry is shown in one schematic. The 74C04 provides various control functions driven by closing the key. It turns off the audio muting switch, turns on the sidetone, offsets the VFO by a few hundred Hertz, and keys the transmitter. The input resistors and capacitors shown are for a touch key with no moving parts, which was slightly lighter weight than my smallest microswitch. For a normal key or keyer, the resistors should be reduced (perhaps by a factor of as much as 100) so they don't affect the length of dots and dashes. Resistor R1 sets the transmit/receive offset frequency and will probably need to be selected to give the offset you want. A good starting value is 4.7 megohms. Two sections of a 74HC02 provide an extra VFO buffer and a keyed driver stage. The final is a 2N4400 in a pretty standard circuit. This transistor is run from the battery through a Schottky (low voltage-drop) reverse-polarity protection diode, so the varying current won't pull the regulated supply to the VFO. I tried both a 2N3904 and a 2N2222 in the final but the 2N4400 seemed best. I have no idea why, and the final still isn't very efficient so I recommend further experiments.

The voltage regulator selected was an LM2931C which is a low dropout voltage, low quiescent current type with built-in reverse voltage protection. As for most low-dropout regulators it requires a high quality capacitor across the output for stability. I used a 47 uF tantalum electrolytic. Using a low dropout regulator allows the use of 5 V regulated circuits with a 6 V battery. The nominal 5 V rail is actually at 4.8 V, so with a dropout voltage on the order of 0.2 V, the battery voltage can fall to 5 V before regulator problems appear.

SUMMARY

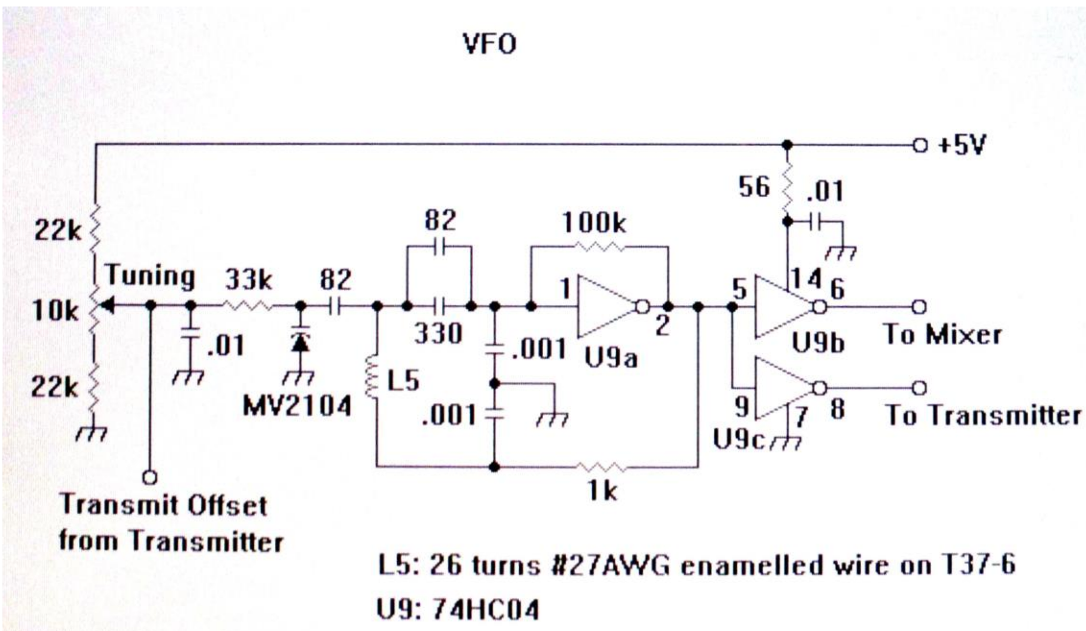
This rig showed that it was possible to build a fairly complicated direct- conversion transceiver with case, knobs and connectors that weighs less than 0.2 lb without using any etched circuit boards. The key weight saving techniques included:

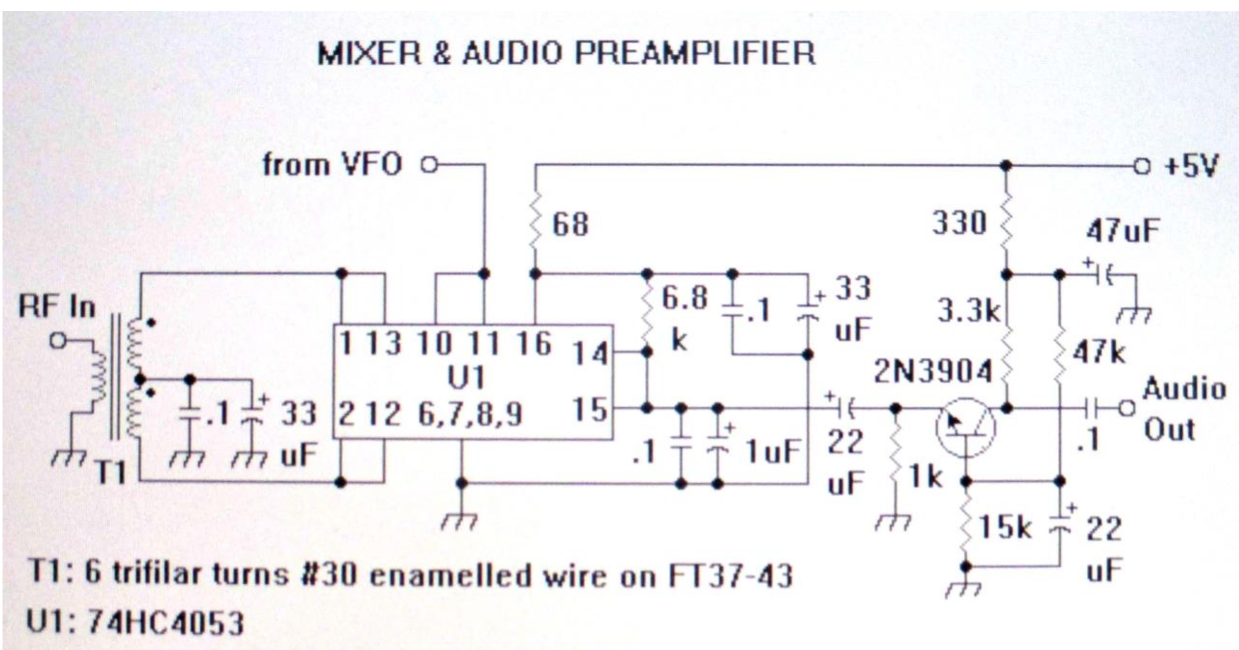
- using .032" board instead of .062" board for the chassis and boards
- using surface mount components where possible
- using lightweight connectors - using other small components (small toroids, 6.3 V electrolytics, etc.)
- eliminating all controls except tuning and volume
- using small homemade wooden knobs
- keeping the overall size as small as possible (reduces chassis weight).

The following additional techniques reduced the weight of the batteries required:

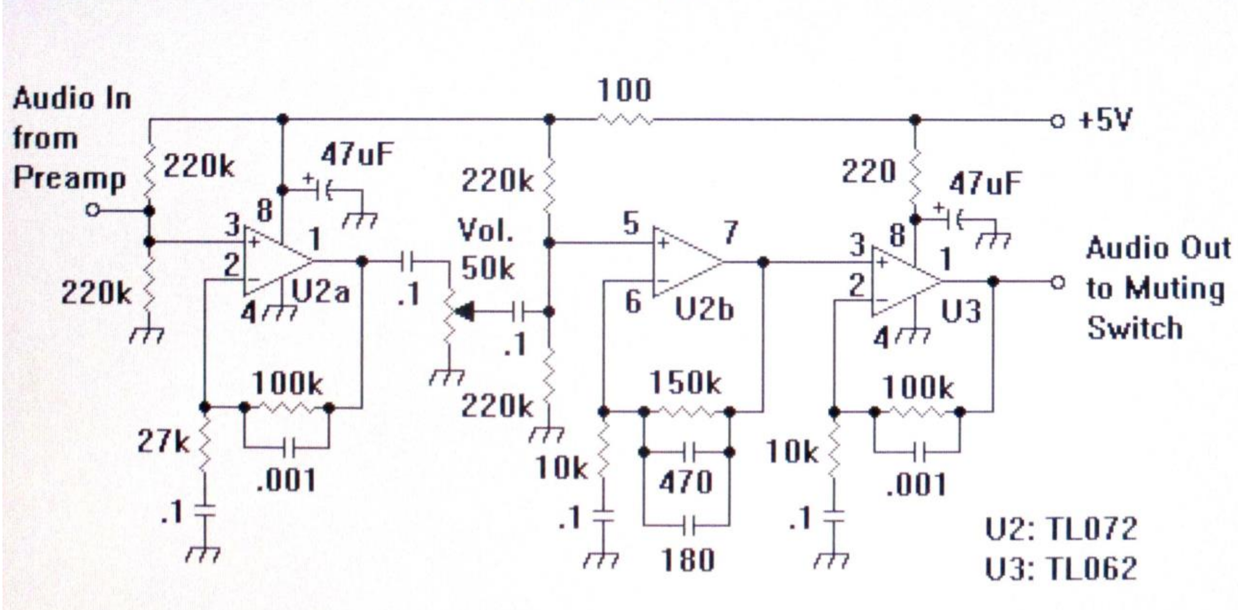
- designing every stage for low current consumption
- employing a 6 V supply voltage (most stages don't benefit from any higher supply voltage)
- running only 200 mW output.

SCHEMATICS

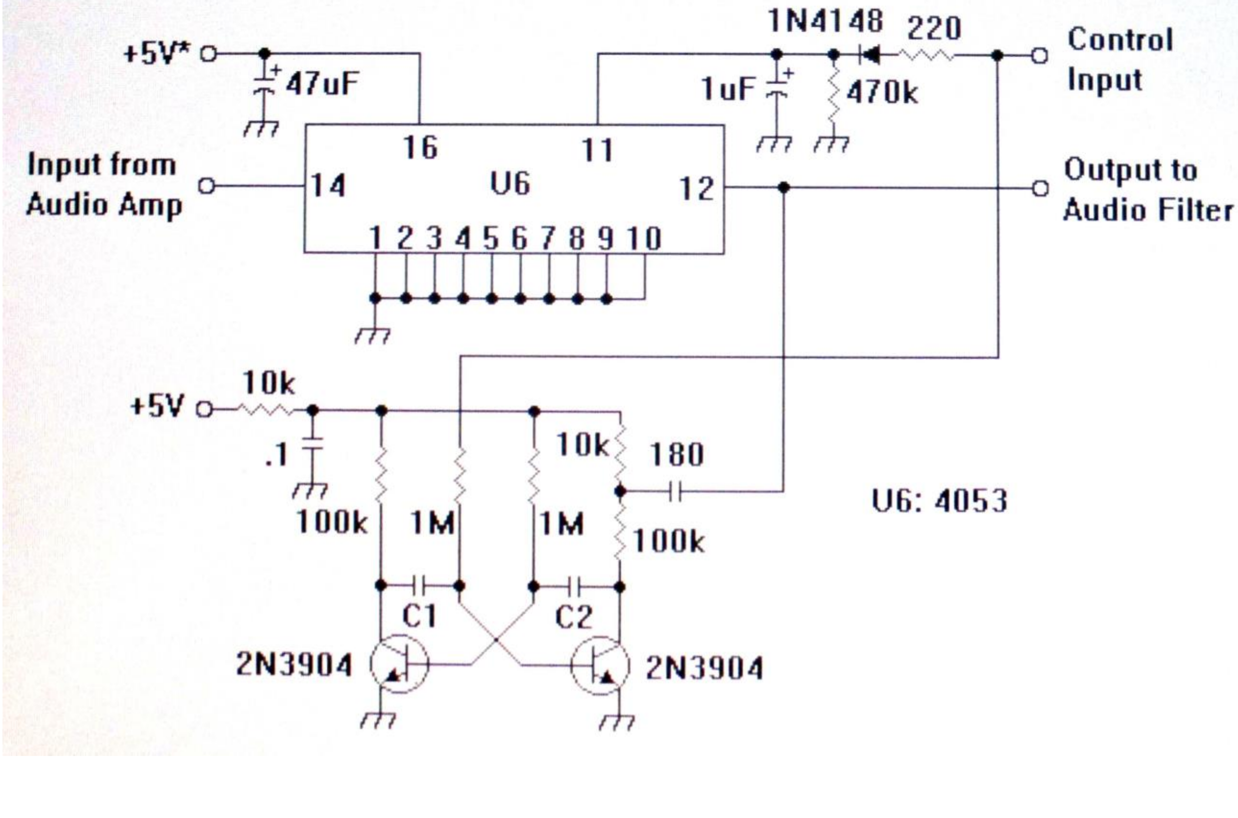




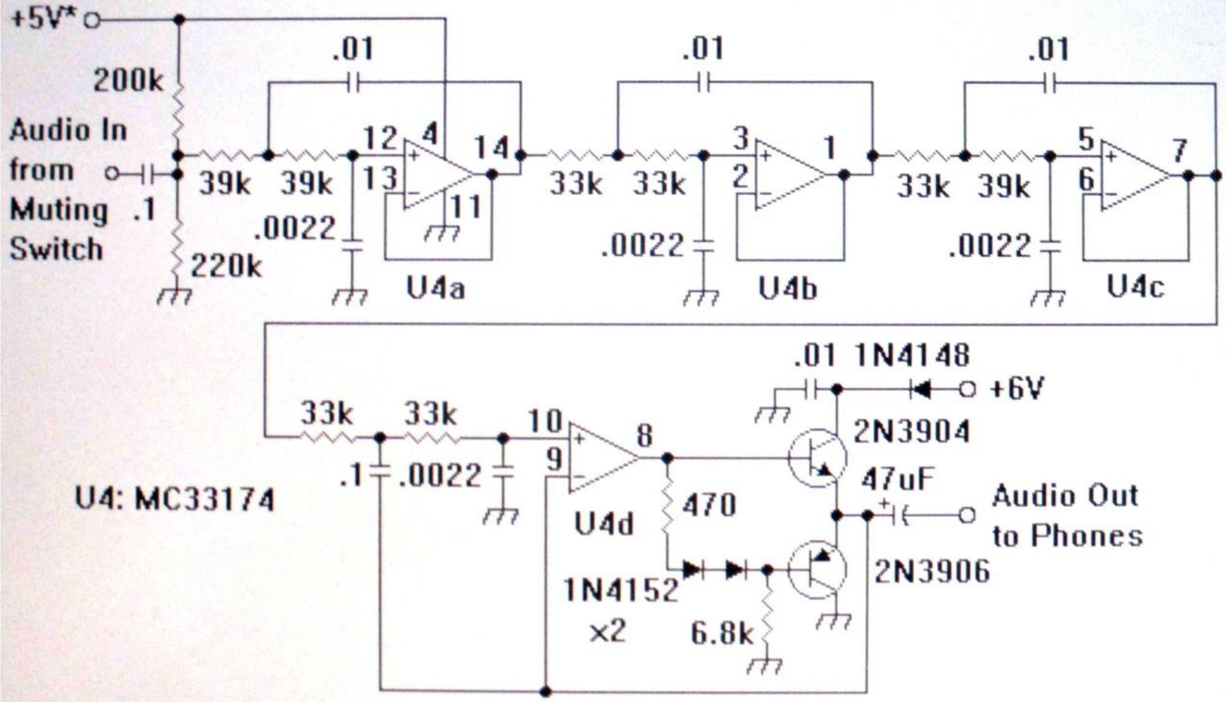
AUDIO AMPLIFIER



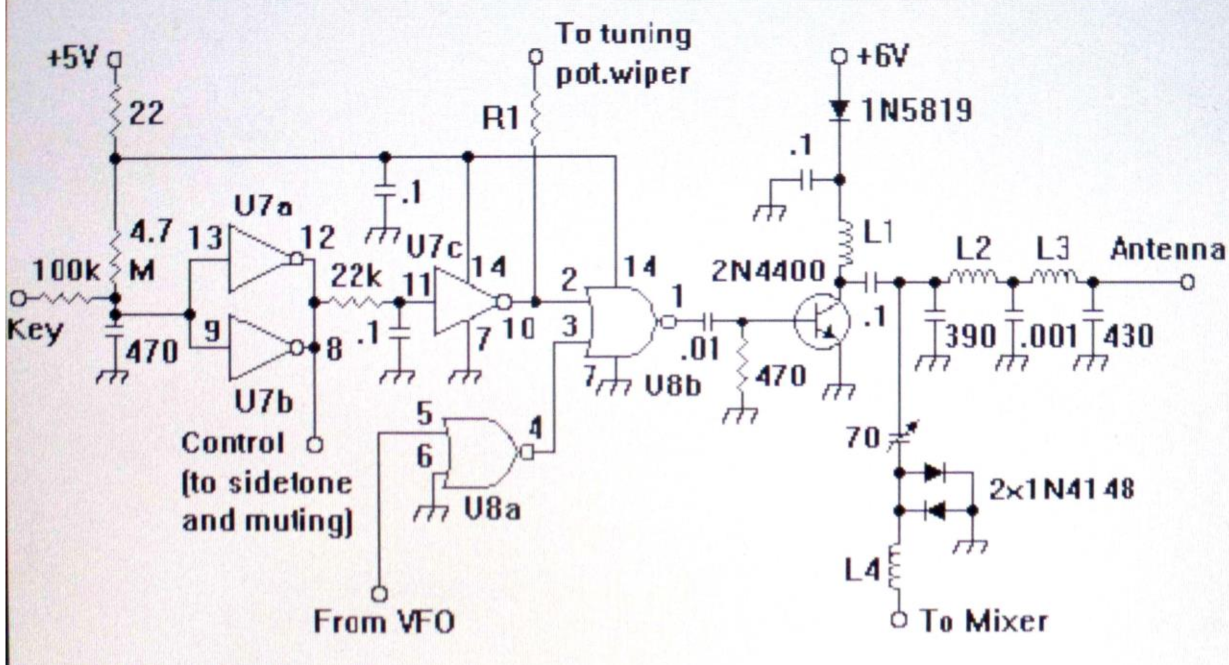
MUTING SWITCH & SIDETONE OSCILLATOR



AUDIO FILTER & POWER AMPLIFIER



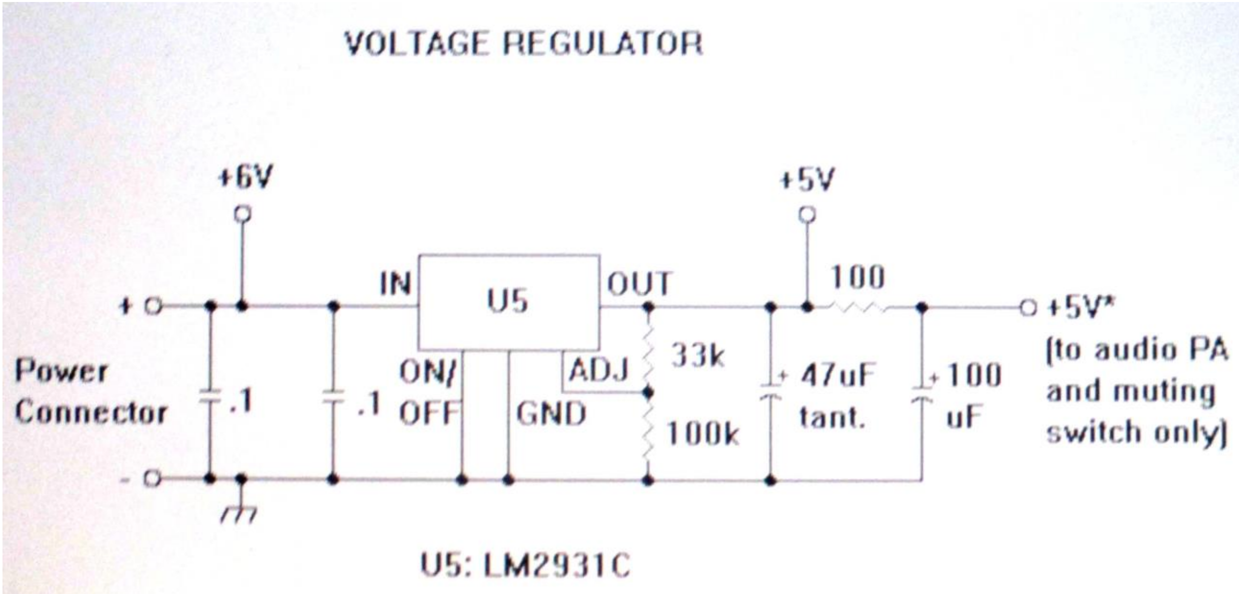
TRANSMITTER



U7: 74C04 U8: 74HC02

All Inductors #30 AWG enamelled wire. L1: 26 turns on FT23-43,

L2 & L3: 18 turns on T37-6, L4: 50 turns on T37-2.


VOLTAGE REGULATOR
+6V
+5V
IN
U5
OUT
100
+
Power
Connector
.1
.1
ON/
OFF
GND
ADJ
33k
100k
+ 47uF
tant.
+ 100
uF
+5V*
(to audio PA
and muting
switch only)
U5: LM2931C