The SST: A Simple Superhet Transceiver For 40 Through 20 Meters

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Many NorCal members built the 40-9er, a 40-meter rig that ran pretty well on a 9-volt battery. The 40-9er was a ridiculously simple direct-conversion (D-C) transceiver that had its share of annoying traits, but did succeed in helping some first-time builders get started. Also—thanks to Doug Hendricks—the 40-9er brought together the Altoids Mints company and the Amateur Radio community, a marriage that seemed unlikely only a year ago.

After completing the 40-9er, I began work on a new superhet CW transceiver that I hoped would still have an extremely low parts count, but much better performance than the 40-9er. The result, the Simple Superhet Transceiver, is now on the air. The SST is available as a complete kit for either 40, 30, or 20 meters, and includes a custom enclosure, all controls, and a double-sided PC board. (See ordering details at the end of the article.)

While the accompanying schematic shows the 40-meter version, I have built SSTs for 30 and 20 meters with equally good results. Some component values for these bands are still in flux, so they'll be published in a subsequent issue of QRPp.

I like to think of the SST as a baby brother to the NorCal 40A. It clearly shares some DNA with the '40A, but it has almost 40% fewer parts! I also consider the SST my reinterpretation of a rig designed over twenty years ago: the Mountaineer (designed by Wes Hayward, W7ZOI). It was the first rig that I ever built, a 40-meter D-C transceiver intended for easy operation in the field.

Like that rig, the SST is truly pocket-size and trail-ready. It can be powered for several days from an internal 9V lithium battery, has excellent temperature stability due to the use of a VXO, and has provisions for an internal KC1 keyer/frequency counter. Unlike the Mountaineer and 40-9er, the SST has "real-rig" performance, and is a pleasure to operate.

The SST was originally to be released late in 1996. However, it turned out that Ori, AC6AN, had the 38-special up his sleeve, a very successful design that took all of Doug Hendricks's and Jim Cates's energy for several months. Since these two heroes of the QRP world were unable to take on the SST, Bob Dyer, KD6VIO (Wilderness Radio) has agreed to put together the kits for the NorCal/QRP-L field test.

Whatcha Mean, "Optimized?"

To put some numbers on it, the table below shows an approximate parts-count comparison of several well-known CW transceiver designs. (I didn't count connectors, the size and number of which vary widely.) With the exception of the 40-9er, all of the rigs listed are superhets.

Rig	# parts
NW8020	150
NN1G	150
NE4040	120
NorCal 40A	120
NorCal 40	112
38-Special	99
SST	77
40-9er	41

Clearly, this is a bit like comparing apples and oranges to pomegranates. But despite the SST's low parts count, it has performance beyond its place on the list. In addition, the SST is very easy to build. There are only four toroids, no toroidal transformers, and only two alignment steps.

SST features include:

* 1 to 3 watts out (varies w/band and supply voltage), adjustable down to zero
* fast, clean QSK with transmit monitoring
* 3-pole crystal filter at a low I.F. (about 4 MHz)
* built-in, no-adjustments AGC with received signal indicator LED
* stable VXO coverage of 10 to 20 kHz using varactor tuning (range varies w/ band)
* very low current drain—about 15mA
* stable operation from 10 to 16VDC, or internal 9V lithium battery
* works with the Wilderness KC1 keyer/ counter and BuzzNot noise blanker, both of which can be installed inside the SST
* all controls, connectors, and parts mount on a single 3.0" x 3.4" PC board
* 1.5"H x 3.2"W x 3.5"D custom enclosure (supplied unfinished)

Design Overview

The SST has essentially the same block diagram as the NorCal 40A, NE40-40, and similar rigs. However, it uses fewer parts for many of the blocks, with some minor tradeoffs in performance as a result.

Like these other rigs, the SST's receiver section an I.F. (intermediate frequency), but no I.F. amplifier. Since the receive mixer has considerable gain, I.F. gain is not really necessary. It turns out that you also don't really have to have an I.F. amplifier for attenuation. In the NorCal 40A, for example, I used two JFETs in a balanced, voltage-variable-resistance AGC circuit in lieu of an I.F. amp. In the case of the SST, the AGC circuit is much simpler; it works by reducing the bias on the NE602 product detector. A three-crystal I.F. filter provides quite respectable selectivity, thanks to the low I.F.

The transmitter has its own mixer and 4 MHz crystal oscillator. This means that what you hear when you key the rig is the actual transmitted signal, not a sidetone oscillator. By listening to received signals at this same pitch, you're guaranteed to be very close to their frequency when you call them. The usual buffer and driver stages have been replaced by a fast op-amp, but the final amplifier stage is conventional.

A varactor-tuned VXO rounds out the major functional blocks. On each band, the VXO crystal is an off-the-shelf frequency available from Digikey, as are the I.F. crystals. For example, on 40 meters, the VXO runs at 11.046MHz, and the I.F. is at 4.000MHz. This allows tuning from about 7.032 to 7.042 with an MVAM108 varactor diode, or 7.038 to 7.046 with an MV209. Both varactors are supplied with the kit.

On the other bands, the I.F. and VXO use other standard crystal frequencies. On 30 meters, an I.F. of 4.194MHz and a VXO crystal at 14.318MHz yields an operating range of about 10.105 to 10.120. On 20 meters, an I.F. of 3.932MHz is used. With an 18.000MHz VXO crystal, this translates to coverage of 14.046 to 14.064MHz.

We haven't left out the novice and tech-plus gang, either. The 40m/novice version of the SST uses the 11.046MHz VXO with the 3.932MHz I.F. to cover about 7.105 to 7.110.

I'm still amazed that Digikey has combinations of VXO/IF crystals that work out perfectly for all three bands, AND the 40m novice segment! While there are other combinations, too, these four are ideal because they cover the QRP frequencies while offering a low I.F. The resulting filter bandwidth is around 300 to 400Hz, and opposite sideband rejection can be well over 40dB. To get the same performance with an I.F. of 8MHz would take four to five low-cost crystals, and at 12MHz you might need six or more. Blow-by (signal leakage around the filter) is also harder to control with a high-frequency discrete-crystal filter.

Since the SST is a single conversion rig, when receiving at 7.040Mhz the math is: 11.040 (VXO) - 7.040 (RF) = 4.000 (IF). On transmit the rig subtracts the transmit oscillator from the VXO to get to 40 meters: 11.040 - 4.000 = 7.040.

Receiver Circuit Highlights

Please refer to the schematic (centerfold). Starting in the upper left-hand corner, you'll notice that the receiver input filter has only one tuned circuit—C1/RFC1. Since the SST's VXO runs at a high frequency, the single tuned circuit does a reasonable job rejecting the image. C1 resonates with RFC1 at the operating frequency while simultaneously providing an acceptable match to the low-pass filter (lower right-hand corner). C2 provides a match to the hi-Z input of U1. R1 is the RF gain control; it attenuates the signal that appears between U1 pins 1 and 2. Since this is a hi-Z point, the PCB traces to R1 must be very short.

C3's function is pretty clear: it puts pin 2 of the NE602 at AC ground, which is necessary since the input signal to U1 is single-ended, not differential. But what about D1 and D2? A little background will help.

Since the SST uses transmit monitoring at the I.F. rather than sidetone, I had to find a way to completely kill any RF signal coming in from U1 on transmit. Otherwise, the monitor tone would be too loud and would vary with power output. But smooth transmit monitoring is not as easy as it may seem: you have to protect both the receiver and transmitter on key-down, while muting the receiver and attenuating the input signal. It's a tall order.

Here's how it works in the SST. Switching diode D1 and PIN diode D2 are both reverse-biased during receive, so neither has an effect an effect on the received signal. As soon as the rig is keyed, D1's cathode is pulled down to ground, which causes three things to happen: (1) the positive half-cycles from the final amp output are shunted to ground, making C1 appear as part of the low-pass filter and effectively removing RFC1 from the circuit; (2) the DC bias on pin 2 of U1 goes well below 1.4V, unbalancing the mixer and cutting off the received signal; (3) D2 becomes forward biased, removing any remnant of the transmit signal seen on pin 1 of U1. Whew! The net result is very fast QSK using only two transmit/receive switching components (D1/D2).

Next we get to what is perhaps the strangest use of an LED that you'll ever encounter. D3, an ordinary red LED, is almost the entire fixed-calibration AGC circuit. The AGC circuit activates slightly on transmit, too, eliminating the need for a muting circuit between the product detector and the AF amp.

Stick with me, folks—this is really interesting. Product detector U2 normally has a 1.2 to 1.4VDC bias on pins 1 and 2; this is set by an internal voltage divider in the NE602. Like most standard red LEDs, D3 requires about 1.7 volts across it to become forward biased. With no signal at the AF output, D3's cathode is at zero volts, so it is reverse-biased and has no effect on the product detector.

But at an AF output level of around 0.6Vp-p, D3 starts to conduct on the negative half-cycles of audio. D3 is visible through a hole on the front panel, so as it conducts you can observe it charging up AGC filter capacitor C39. I could have used three silicon diodes instead of an LED to get over the 1.4V forward-bias threshold, but why not use a single part that doubles as a received-signal indicator? (Note that a "high-efficiency red" LED has a higher forward-bias voltage, typically over 2 volts. You could use this kind of LED if you wanted to increase the AGC threshold.)

D3's brightness is directly proportional to the instantaneous change in signal strength—not the absolute signal strength—so it doesn't really function like an S-meter. Still, you can easily tell a strong signal from a weak one, and as Bob Dyer told me, with practice you can visually copy strong signals just by watching the LED!

Unlike most AGC circuits, there's no high-impedance buffer amp in the SST, so C39 has to be very large in value to both remove the rectified audio signal from the LED and set the AGC time-constant. But C39 is still physically small because its voltage rating can be very low.

The only other component involved in the AGC circuit is RFC2. It has a very low DC resistance, which holds pin 1 at the same DC voltage as pin 2, thus keeping the mixer balanced. This reduces distortion on strong signals and greatly extends the AGC range.

Some of you may be wondering what happens to an audio signal when you use the NE602 as an AGC-controlled product detector. As it turns out, by the time the signal gets large enough to cause distortion, the '602 is already in compression (i.e., hitting its limit). At the same time, the bias voltage on pins 1 and 2 is pulled down to as low as 0.6V when signals are very strong, so the NE602's input stage is nearly cut off. Distortion is nearly imperceptible under these circumstances. I haven't measured the AGC range, but I haven't yet encountered a signal it couldn't handle. Even if this happened you could turn down the RF gain (R1). The RF gain control is well isolated from C1/RFC1 by C2, so it has little effect on the Q of this filter.

In actual use, there is bit of a "thump" the first time C39 charges up, as with most AF-derived AGC circuits. Still, overall AGC action is quite good considering the simplicity of the circuit. In fact I'm now using it as a secondary AGC loop for the NorCal 40A, extending that rig's AGC range.

VXO and Transmitter Circuits

Since the receive mixer (U1) becomes unbalanced during transmit, I could not use U1's built-in oscillator as the VXO. A transmit signal tends to upset the NE602's built-in oscillator when the '602 is also being used as the receive mixer, and this can cause instability or chirp. Here, Q1 is the VXO, which is varactor tuned as in the 38-special. As Ori pointed out, RFC3 must be low-Q for best range; the value of RFC3 is also fairly critical.

The schematic shows an MVAM108 varactor at D4, which provides an operating range of about 7.032 to 7.042Mhz. However, you can add an SPDT switch to select either an MVAM108 or an MV209. The MV209 will provide a range of about 7.038 to 7.046MHz. I'm still experimenting with other varactors to see which single varactor will provide the best range. R7 sets the VXO output level, and is selected to provide around 0.6 to 0.8Vp-p at pin 6 of U1.

In most of my other designs, including the NorCal 40A and Sierra, I've used a JFET buffer and 2N2222A driver. I wanted to try something different this time. The LT1252, U5, is an inexpensive video amplifier IC, with nearly flat frequency response up to 50MHz in low-gain configurations. With its high input impedance and low output impedance it is perfect for this application, replacing the JFET, the 2N2222A, and the driver-to-final transformer, too. Its output impedance is under 10 ohms. R10/R11 form a gain-setting divider, just as in an op-amp. For example, if you need to increase the gain, you can decrease the size of R10. Be careful not to increase the gain too much, as this can cause instability and distortion. The LT1252 can swing about 8V peak-to-peak when running on 12V.

I eliminated the usual PNP keying transistor, instead simply keyingthe ground pins of the transmit mixer and the video amp. The slow start-up of the transmit mixer oscillator makes for a clean rising edge, and if you want a slow fall time as well you can add an electrolytic cap in parallel with C23. Even without a slow fall time, the keying sounds quite good. Not a hint of chirp.

The final itself can be any of the usual suspects, including a 2N3553 or 2SC799 (or even a 2N4427 if you keep power under 2W). R12 does triple duty as the load for the LT1252, protection for Q2 on negative half-cycles, and the drive level control.

Construction

A very high-quality, double-sided, silk-screened and plated-through PC board is supplied with the SST kit. However, there's no reason why you couldn't build it using dead-bug, sickly-starfish, scraggly-cacti or other "ugly" techniques. Just remember to keep all RF signal leads short, and use good grounding, especially around the crystal filter and the video amplifier chip.

Some builders may want to try using a variable capacitor—rather than the varactor circuit shown—to increase VXO range. Just remember to ground the tuning capacitor well and keep all leads short. If you modify the VXO circuit in any way, check the output voltage of the VXO using a DMM (digital multimeter) and an RF probe. The voltage at the source lead of Q1 should be about 500 mV (rms).

I have not included RIT in the SST because it didn't fit my "ultra-compact, no-frills" definition. That said, it should be fairly easy to add. You'll need an LM393 dual comparator, an RIT on/off switch, an RIT pot, and two resistors. I'm leaving this one to QRPp readers as a design exercise, with one hint: look at the NorCal 40A or Sierra schematic!

There are provisions for a keyer and frequency counter; the relevant connection points are all labeled on the schematic. For example, note the "K" label near the key jack, J3. This is where you'd connect a keyer's keyline. Other points include "8V" (8 volts), "V+" (DC input), "A" (for the KC1 audio signal), "counter" (for the freq. counter), and "GND."

The SST will also work with the BuzzNot noiseblanker (Wilderness). I built one into the 20-meter version, and it killed all of the annoying impulse noise from my nearby power poles. The BuzzNot is so small (about 0.6 x 1.1") that it can nestle down directly on top of the receive mixer. The input to the BuzzNot should come from the anode of D1, and the output of the BuzzNot must be connected through a .01uF capacitor to the point marked "B" on the schematic. You can use a miniature potentiometer as a noiseblanker gain control as described in the BuzzNot manual. I used a SPDT switch instead, with one position connecting the full 12V supply to the noiseblanker, and the other placing a 2.2K resistor in series. I recommend at least two positions to give you some flexibility in different noise situations.

The custom enclosure's front and rear panels are secured to the PC board using the control nuts on the headphone jack, VFO pot, key jack, and antenna jack. PEM nuts are provided on these panels so that the top and bottom covers can each be secured using four 4-40 screws.

9 Volt Battery Option

Running a miniature transceiver from an internal, ultra-light, 9V lithium battery gives you an amazing sense of freedom. These batteries, available from many vendors, have over 1 Amp-hour of life, which translates to several days of casual backpack operation at 1/2 to 1 watt output. It's the ultimate for lightweight back-packing or the Spartan Sprint.

To use an internal 9V battery:

1. Replace the 8V regulator (LM78L08) with a 6V or 6.2V regulator. A low-dropout regulator is recommended.
2. Since the regulated voltage will be re-

duced, the varactor tuning range will decrease somewhat. You may want to use the MV209 rather than the MVAM108 to keep the upper portion of the tuning range, which usually is closer to the QRP frequency.

3. Adjust the transmit power level so that the maximum current drain on transmit is 100 to 120mA (or less), the recommended maximum for a 9V lithium battery. You can use other 9V battery types, but you'll need to adjust the power level for the desired battery life.

4. If you use a KC1, you must power it directly from the 9V battery, not the regulated supply, since 6V is too low for proper operation of the KC1's own 5V regulator.

Tune-up

This may be the world's easiest-to-align superhet. First, connect a suitable antenna and peak C1 on receive. Then plug in a hand key and peak C28 on transmit, preferably into a 50ohm dummy load. You can use a wattmeter, SWR bridge, or a DMM and RF probe as a signal indicator. The drive level control, R12, should be set for the desired power level.

You can slightly alter the value of C24 if you want to change the TX offset pitch. The pitch is usually around 650Hz with the indicated value of C24. Also note that the TX monitor tone will change if you alter the BFO frequency, which is controlled by C10.

Operation

You must use stereo headphones with the SST, or a stereo-to-mono adapter. For best results, use light-weight but efficient stereo headphones, such as Sony model MDR-W08. These phones have relatively poor bass response, which is easier on the ears over time. They also fold up and stow easily. The AF amp will drive a speaker, but only to moderate volume, since the peak voltage is limited by the AGC circuit.

NOTE: The headphone jack is on the FRONT panel on the SST, not on the rear panel! Don't plug your headphones into the key jack, which is on the back.

The RF gain control (R1) is mounted on the rear panel of the SST because it is rarely used. It should only be turned down when necessary to prevent mixer overload by gargantuan signals. Normally R1 is left all the way up (clockwise, viewed from the rear panel), and the audio level is controlled using R3, at the AF amp output. The AGC circuit does the rest.

The VXO control covers about 10 to 20 kHz with any particular varactor diode. This may not seem like much range, but you'll find that most QRP activity happens in the covered ranges, providing plenty of QSOs. You can add a switch and a second varactor to increase range if desired.

Conclusion

For an unknown reason, I set my sights years ago on small, efficient radio design, and it has been an interesting path to follow. But for every rig that has been successful, there is one no one will ever see, one that has in some way been a personal learning experience for me. For example, I built a hand-held NorCal 40A w/KC1 called the "Koala" which convinced me that you really CAN make a rig too small!

The SST is in some ways the end of a particular branch of the path. It began in 1993 with our first club project, the NorCal 40. Ever since I have wondered whether certain portions of that design—such as the AGC and muting circuits—could be reduced in complexity. I also wanted a truly compact superhet that would fit in a fanny pack pocket and still leave room for a wire antenna, headphones, and key.

The SST fulfilled both of these goals for me, and is much more stable and buildable than the experimental Koala. I hope builders find it an easy kit to build and operate, and I welcome your suggestions for improvement.

SST KIT INFORMATION

The SST will be supplied only as a complete kit. It includes a high-quality double-sided and silk-screened PC board; a custom, unfinished .050 aluminum enclosure with hardware; all controls, connectors, knobs, rubber feet, etc.; detailed manual; and all parts for the band(s) of your choice. Painting and silk-screening are up to you.

The club price for each SST is $69. TO GET THIS PRICE, orders must be received by May 1st, 1997. After May 1st, the SST will be available as a Wilderness Radio kit for $85. I will be updating the design at that time based on results from the field test. The target shipping date is late May.

ORDERING INSTRUCTIONS

PLEASE DO NOT CALL DOUG HENDRICKS or JIM CATES. Hard as this may be to believe, they are NOT doing the kits! If you have questions, call Bob Dyer at (415) 494-3806 (9AM to 6PM Pacific time, M-F). Or, send e-mail to my HOME e-mail address only, which is svecbrdk@well.com.

1. Please enclose $69 per kit ordered before May 1st, and $85 thereafter.
2. For each kit ordered, you must specify the band: 40m, 40m/novice, 30m, or 20m. (Remember, this is a VXO-based transceiver, so the rig does not cover the entire CW band. Approximate coverage is: 40m, 7.032-7.042; 40m/novice: 7.105 - 7.115; 30m, 10.105-10.120; 20m, 14.046-14.064. Other ranges are possible with small modifications.)
3. California residents must add 7.75% sales tax PER KIT.
4. Shipping charges are extra: $3 U.S., $5 Canada/Mexico, $15 DX (other). This is a PER-KIT shipping charge.
5. Please make out checks to Wilderness Radio, NOT NORCAL. Wilderness will also need your name, call, address, phone number, and (optional) e-mail address with your order.
6. Send U.S. funds only (checks drawn on US banks, or an international money order) to:

Wilderness Radio,
P.O. Box 734
Los Altos, California 94023-0734,
USA

SST/40M PARTS LIST

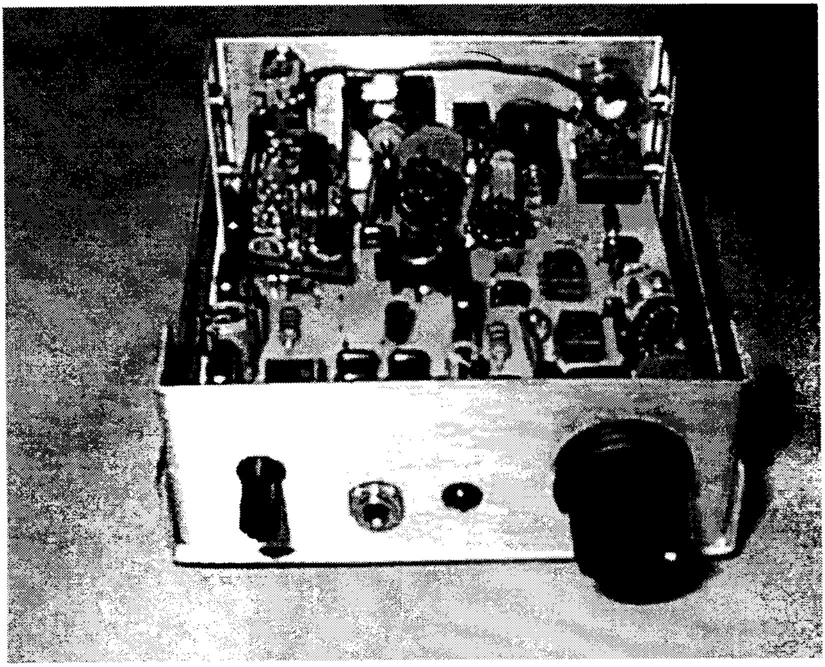
N6KR

Rev. A. (Preliminary)

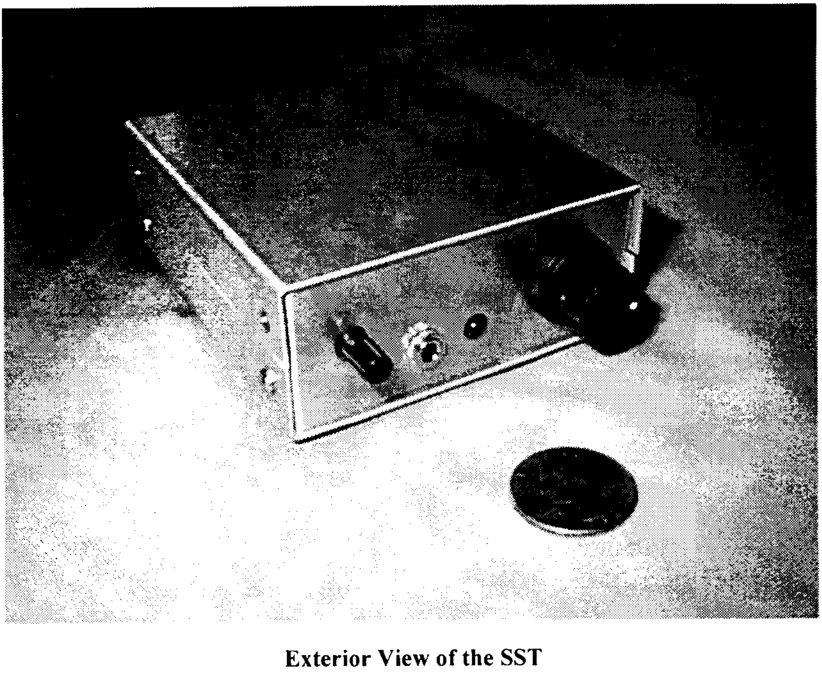
Note: All disc caps have 0.2" lead spacing

C21	1pF, 5% NPO disc
C2,C26,C29	5pF, 5% NPO disc
C10,C24	33pF, 5% NPO disc
C4	47pF, 5% NPO disc
C6,C9,C19,C20	82pF, 5% NPO disc
C27	100pF, 5% NPO disc
C7,C8	180pF, 5% NPO disc
C11,C25	270pF, 5% NPO disc
C34,C36	330pF, 5% NPO disc
C30,C35	820pF, 5% NPO disc
C3,C5,C16,C22,C38	.01¦F, 20% disc, Digikey #P4437-ND
C14,C23,C31,C32,C33,C37	.022¦F, 20% disc, Digikey #P4439-ND
C12,C13	0.1¦F, 5% film, Digikey #P4525-ND

C15	2.2uF, 25V elec, Mouser #140-XRL25V2.2
C17,C18	100uF, 25V elec, Mouser #140-XRL25V100
C39	470uF, 10V elec, Mouser #140-XRL10V470
C1,C28	8-50pF trim, Mouser #242-8050
D1	1N4148
D2	PIN diode, MPN3700
D3	Red LED, R.A. mount, Mouser #512-MV60539.MP7
D4	MVAM108
D4 Alternate	MV209 (see text)
D5	Shottky diode, Digikey #1N5817GICT-ND
D6	1N4755 (43V zener)
J1	DC barrel, Mouser #16PJ031
J2	BNC, PC mount, Mouser #177-3138
J3,J4	Jack, 1/8" stereo
L1	3.2uH, 28t #28, T37-2
L2,L3	0.6uH, 12T #26, T37-2
Q1	J309
Q2	2SC799 (alt: 2N3553, 2N4427)
R10	220 ohm, 1/8 watt
R7	330 ohm, 1/8 watt
R11	620 ohm, 1/8 watt
R2	1.8K, 1/8 watt
R8,R9	10K, 1/8 watt
R5,R6	100K, 1/8 watt
R12	100 ohm trimmer (P/N TBD)
R3	1K right angle trim w/shaft, Mouser #317-2091-1K
R4	10K panel mount, Mouser #31CW401
R1	50K right angle trim w/shaft, Mouser #317-2091-50K
RFC1,RFC3	15uH, Mouser #43LS155
RFC4	22uH, Mouser #43LS225
RFC2	1mH, Mouser #43LS103
RFC5	10 turns #26 on FT37-43 toroid (black)
S1	SPDT slide switch, Mouser #102-1271
U1,U2,U4	NE602 mixer/oscillator IC
U3	LM386N-1
U5	LT1252CN8-ND, Digikey
U6	78L08
X1,X2,X3,X4,X5	Xtal, 4.000MHz, matched, Digikey #CTX006-ND
X6	Xtal, 11.046MHz, Digikey #X025-ND
MISC.	Cabinet
MISC.	PC Board, double-sided, plated through
MISC.	Knob, 0.5" dia, Mouser #450-2034
MISC.	Knob, 0.6" dia, Mouser #450-2035
MISC.	Rubber foot, Mouser #517-SJ-5012BK
MISC.	Heatsink, star, 0.75" diameter
MISC.	3/8" x 4-40 Panhead phillips machine screw
MISC.	Manual
MISC.	Mating conn. for J1, Mouser #1710-2131



Interior View of the SST



Exterior View of the SST