NO TUNE MICROWAVE TRANSCEIVERS

Rick Campbell
Department of Electrical Engineering
Michigan Technological University
Houghton, MI 49931

Most amateur SSB CW microwave operators use a commercial HF or VHF transceiver with a transverter. The most expensive part of the station is often a multimode VHF transceiver, and the greatest technical difficulty is often modifying the transceiver to drive the transverter. If amateur microwave activity is to continue to grow, we must explore options for complete stand alone microwave stations that can be easily reproduced at moderate cost. This paper discusses one approach to high performance weak signal microwave transceivers, and describes a prototype single conversion no tune SSB CW transceiver that can be built for any band from 432 through 3456 MHz.

INTRODUCTION

Figure 1 is the block diagram of a SSB CW transceiver. It has a SSB CW generator and IF receiver, a pair of mixers and an LO to perform the IF to RF frequency conversion, and RF amplifiers to set the receiver noise figure and increase the transmitter power. The same block diagram may be used for signal frequencies from a few kHz to hundreds of GHz.

In practice, the IF is often set to about 10% of the signal frequency (for example, FM broadcast radios use a 10.7 MHz IF). There are several reasons for this. One important reason is that it is possible to discriminate against the image frequency with relatively simple filtering.

The success of no tune microwave transverters depends on using printed filters with bandwidths much larger than the expected construction and material tolerances. The 8 to 10% bandwidth printed filters used in the 432, 902 and 1296 MHz filters work very well on FR-4 or G-10 board. The narrower filters used in the 2304 and 3456 transverters require much closer manufacturing tolerances, and high quality teflon board.

The "10% IF" rule of thumb suggests the following IFs for the various microwave amateur bands: 43 MHz IF for 432; 90 MHz IF for 902; 130 MHz IF for 1296; 230 MHz IF for 2304; 350 MHz IF for 3456; 576 MHz IF for 5760; and 1040 MHz IF for 10368 MHz. Examination of the spurious output levels of the various no-tune transverters shows that transverters with an IF near 10% have acceptable spurious performance.

The 10% IF rule of thumb appears to be a useful guideline for superheterodyne systems up through at least the lower microwave region. Of course, if the engineer is willing to use precision machining and tuning into a microwave network analyzer, then much lower IFs may be used. For no tune systems, we should stay close to 10%.

Now that we have "ballpark" IFs for each of the amateur microwave bands, all we need is a no tune SSB and CW generator, and a no tune IF receiver that will work at the appropriate frequency.

Unfortunately, the highest frequency for which we can obtain SSB bandwidth crystal filters is about 16 MHz. It takes at least one more stage of frequency conversion to reach the crystal filter IF from the 10% IF of the microwave front end. Each additional frequency conversion requires more mixers, another LO and extensive filtering (a no tune 1296 transverter has 18 printed tuned circuits to achieve -45 dB spurs), and it becomes difficult to obtain acceptable performance without numerous tuning adjustments.

But wait! Back in the old days before meteor scatter, when our forefathers bounced six meter signals off high altitude pterodactyls, there were no crystal filters. Clever hams generated six meter SSB signals right at 50 MHz, with no frequency conversions at all. Is this a technique that could still be applied today, or was 50's technology so superior that we should stick to our ICOMs and not rock the boat?

Phasing techniques have a reputation in the U.S. based on the performance of a few inexpensive radios using primitive components that needed continuous adjustment. Inevitably they were used on crowded bands without proper tuneup, and the mean spirited occupants of the amateur HF phone bands told the unfortunate owners to get off the air until they could afford a decent radio. Sad to say, the current occupants of the HF amateur phone bands should not, in general, be exposed to anything of technological interest.

Outside of amateur radio in the U.S., phasing techniques are all pervasive. Everything from police radar to Drake's new shortwave receiver has in-phase and quadrature detectors. The receiver at one end of the first 10 GHz EME contact used an image reject mixer. A number of phasing SSB receiver articles have appeared recently in the E.C. (European Community) amateur radio press. The fine print in the new Kenwood TS-950 advertisement attributes the outstanding transmitter performance to the use of phasing techniques. A phasing receiver in QST a few years ago [1] was designed and built by the editor of RF Design. In other words, lots of smart people are using phasing techniques, and a lot of appliance operators are not.

To microwave radio engineers, phasing SSB generation and reception techniques offer two advantages over the filter method: they work at any frequency, and by eliminating one or more frequency conversions, they have fewer spurious outputs and responses.

In principle, we could generate SSB at the microwave signal frequency and use a phasing direct conversion receiver to eliminate frequency conversions altogether. There are a number of practical difficulties inherent in the direct conversion approach, but they may be overcome with careful engineering.

Our goal, however, is to build a no tune transceiver. Since we already have no tune transverters for the various microwave bands, it will be easier to concentrate our efforts on a no tune IF than to start from scratch with direct conversion transceivers for all the different bands.

Suppose we want a 130 MHz SSB CW generator and IF receiver. For the SSB CW generator, we need a 130 MHz carrier oscillator, a pair of double balanced mixers, a microphone amp and audio phase shift network, a phase shift network for the 130 MHz carrier, and an RF combiner. For the IF receiver, we need an RF splitter, two double balanced mixers, a 130 MHz BFO, a BFO phase shift network, an audio phase shift network, an audio combiner, and an audio amplifier. All of these functions may be implemented using modern components to obtain better performance than the phasing rigs of the 50's. As a fringe benefit, the use of modern components eliminates most of the adjustments.

The only transmitter spurious outputs (aside from the suppressed carrier and opposite sideband) are the harmonics. Since there is only one oscillator in the IF receiver, it will not have any birdies, and the only spurious responses are at the odd harmonics of the BFO. Phasing receivers and transmitters will work nicely with only a lowpass filter on the RF port.

We now have a technique for building a complete "no tune" single conversion microwave transceiver for any frequency from 432 MHz through mm waves. The next step is to build one and see how it stacks up next to a more conventional rig.

PHASING SSB RECEIVER

We need three blocks to build an IF transceiver: an LO, an SSB CW generator, and an SSB CW receiver. Since the SSB phasing receiver was the biggest challenge, it was started first. An SSB phasing receiver is just a direct conversion receiver with an additional mixer and two phase shift networks. The first step was to build a high performance direct conversion receiver. After that worked, the additional parts would be added to eliminate one sideband. A review of the literature revealed that most of the amateur engineering talent was directed toward simple, low cost receivers for QRP CW operation on the lower HF bands. There were a few good designs, but nothing that fit the requirements exactly. Almost a year was spent developing a no tune, easily reproduced high performance direct conversion receiver circuit board. The only problem was that the resulting circuit worked so well that it demanded publication, and many months were spent working on the article for QST [2]. The key performance features of the basic QST direct conversion receiver are wide frequency range (1 to 500 MHz with SBL-1 mixer), excellent selectivity, very high dynamic range and exceptionally low audio distortion. Since the basic receiver circuitry was intended to be used as part of an SSB phasing receiver, it also has excellent gain and phase stability.

As soon as the basic receiver design was completed, a single signal version was constructed using a pair of identical mixer-diplexer-preamp boards, an audio phase shift network designed with the help of several references [1,3,4], an op amp summer and the basic receiver audio filtering and output stage.

An RF phase shift network for 7 MHz, a 40 m VFO and a full sized outdoor dipole were connected to evaluate the receiver performance in a noisy environment with lots of signals. I won't try to impress you with expletives describing how well this receiver works. Two comments sum it up: I haven't turned on the commercial gear for about six months; and (blasphemy!) this receiver is too good for microwaves!

For a technical discussion of basic receiver performance, see the August '92 QST article. The only area not covered there is the opposite sideband suppression of the phasing version. Worst case opposite sideband suppression across the 300 to 3000 Hz band is 41 dB. That is better than the small monolithic filters typically used in 2 m multimodes, and comparable to the typical SSB filters used in under $1000 HF radios.

The schematic of the phasing receiver board is shown in figure 2. The board is 3 1/2" by 5", and the parts are as high as 0.7", so the receiver board fits inside a 3 1/2" x 5" x 1" box. There is an audio balance control on the pc board, and a pot to set the idling current of the low distortion audio power amplifier. Not quite "no tune," but the adjustments may be made with a VOM (idling current) and by ear (balance) and then glued in place with nail polish.

There is some question of the need for opposite sideband suppression in a microwave receiver. The probability of an interfering signal in the opposite sideband is very low. There will be noise in the opposite sideband, and if it is not suppressed, it will add 3 dB to the receiver noise figure. For some applications, a 3 dB higher noise figure may be acceptable, and the simpler circuit in the QST article may be used. For more demanding applications like EME and tropospheric DX, the opposite sideband noise needs to be suppressed.

PHASING SSB CW GENERATOR

The transmitter board was a little easier to design than the receiver, because the signal levels are all greater than a millivolt. A standard op amp speech amplifier drives an LC audio bandpass filter, followed by an audio phase shift network identical to the one in the receiver. The I and Q audio signals drive the IF ports of the SBL-1s through emitter followers. The RF ports of the mixers are summed with a combiner circuit. I used a Mini Circuits PSC2-1 in the prototype. To keep the distortion low, the output level at the summer is only about -10 dBm. An MMIC amplifier brings the output level up to +3 dBm to drive the transmit IF port of any of the no tune transverters. The MMIC amplifier also presents a constant impedance to the combiner, so that SWR variations won't upset phase or amplitude balance. Once adjusted, the phase and balance trimmers may be locked in place with nail polish.

The transmitter board also has a sine wave sidetone generator and switching and delay for semi break-in CW. There are two ways to generate CW with this board. One way is to inject a little of the sine wave into the transmit audio. This is very useful, because it provides a tone to adjust the SSB generator. The other way is to upset the balance of one of the SBL-1s by running a little DC current into the IF port. Each method has advantages and disadvantages.

The problem with injecting a sine wave into the audio section of the SSB generator is that there are always low level spurious outputs from the transmitter at the carrier and opposite sideband frequencies. Any non-linearities later in the transmitter will produce distortion products, so that the transmit output will have the desired tone, and then a bunch of spurious outputs 30 or 40 dB down at multiples of the tone frequency on either side of the desired output.

The problem with upsetting the balance of an SBL-1 to provide CW is that the CW is then at zero beat to the SSB signal. In a transceiver, some means must be provided to offset the LO just the right amount to put the CW signal at the appropriate frequency in the passband. Offset circuitry is not too difficult to build, but it can degrade the stability of a VFO, and may be hard to add to an overtone crystal oscillator.

One requirement for a successful phasing transmitter is very low distortion in all the circuitry from the input of the audio phase shift network to the RF combiner. Distortion products have different phase relationships, and will appear in the opposite sideband. The practical result is that successful phasing SSB generators sound really good on the air. This one is no exception. I used a stereo cassette player into the microphone port and a locked LO to eliminate frequency error, and transmitted a little music into the dummy load while picking up the signal with the companion SSB receiver across the workbench on 1296 MHz. The audio quality was a little better than broadcast AM. Clean signals may not win more contests, but they sure are nice to listen to.

When the audio balance and RF trimmers are adjusted, the opposite sideband suppression is 41 dB and the carrier is about 35 dB down. This is a little worse than my ICOM 202 and a little better than my ICOM 502.

The schematic of the SSB-CW generator board is shown in figure 3. The prototype board is 1 1/2" by 3 1/2", but doesn't include the CW switching or sidetone circuitry. The next version will be about 2 1/2" by 3 1/2".

BUILDING A SYSTEM

The SSB-CW generator board and SSB receiver board will interface directly with the T and R IF ports of the no tune transverters. The block diagram of my 1296 transceiver is shown in figure 4. The IF receiver board noise figure is about 17 dB without an amplifier stage, so it may be useful to add an MMIC if the transverter gain is low. The IF receiver will hear signals at reduced sensitivity at odd harmonics of the LO frequency, so the IF receiver input needs a simple low pass filter. My prototype no tune transceiver uses a 1296 no tune transverter board, with plenty of RF gain and a low pass coupler out of the mixer, so a piece of RG-174 was connected straight from the transverter receive IF port to the input of the receiver input splitter.

The transmitter has an MMIC and low pass filter already on the board, so a direct connection will work with any of the no tune transverters.

The IF transceiver may be built for any frequency between 1 and 500 MHz by changing the LO and its phase shift network, and the IF low pass filter components. There are no other frequency sensitive components on either the SSB-CW generator or SSB receiver board. In order to do a side by side comparison of the no tune transceiver with one using an ICOM 202 IF, the no tune IF was built for 144 MHz.

Since the crystal oscillator in my no tune transverter is fixed, a 144 MHz VFO was needed. The premixed one in the appendix works well, but it is not an easily reproduced design, and it isn't no tune. A simpler approach would be to use a crystal controlled IF transceiver, and add a VXO adjustment to the crystal oscillator in the transverter.

The 1296 no tune transceiver was built with a single RF phase shifter on the LO output, switched between the receiver and transmitter LO ports with a tiny relay. That was a mistake. When the phase shifter is adjusted for 41 dB of opposite sideband rejection in the receiver, the transmitter opposite sideband suppression degrades to less than 30 dB. Apparently there are a few degrees difference in the phase shift in the RF circuitry of the two boards. The solution is easy--split the LO and use separate phase shifters for transmit and receive. Then the transmit phase shifter can be adjusted for best transmitter performance, and the receiver phase shifter can be adjusted for best receiver performance.

Much of the receiver circuitry is duplicated on the transmitter board--the audio filtering, audio phase shift network, two SBL-1 mixers and splitter-combiner. It would be possible to save money and space by adding some switching and sharing the common circuitry. The receiver and transmitter were kept separate for two reasons. One is that I just haven't gotten around to combining them yet. It was easier to build and optimize the receiver and transmitter separately. The other reason is more important. There are many applications that need only a receiver, or only a transmitter. A few that immediately come to mind are:

1. Companion transmitters for multimode scanners, like the FRG-9600 and R-7000

2. Dedicated beacon receivers

3. Propagation measurement systems

4. Independent transmit and receive stations.

CONCLUSIONS

Figure 5 is the measured output spectrum of the no tune 1296 transceiver. It is a little cleaner than the no tune 1296 transverter driven by an ICOM 202. It is much cleaner than the no tune 1296 transverter slightly overdriven by a badly aligned FT290R. It is not as clean as an ICOM 1271, but it sounds much better, on both transmit and receive. There are no birdies over the entire receiver tuning range.

On transmit, the carrier and opposite sideband suppression are comparable to VHF multimode radios, and the audio quality is far superior. On receive, the combination of high fidelity, low distortion audio, decent opposite sideband suppression, and no AGC is a real eye opener. Loud, clear signals 40 dB above the noise simply disappear on the other side of zero beat. Weak signals at the noise level may be heard without the distractions of audio distortion and an AGC system that resets the gain on every noise peak.

The 1296 transceiver described here is an ambitious construction project. It is easier to scrounge an old 2 m multimode rig for an IF. For someone who wants to push the state of the art a little and build an entire transceiver, I would highly recommend the phasing approach. Phasing rigs with modern parts work much better than the old vacuum tube and paper capacitor rigs of the dinosaur age. The single conversion microwave transceiver with phasing transmit and receive IF is a practical approach for the most demanding weak signal microwave amateur SSB CW applications.

REFERENCES

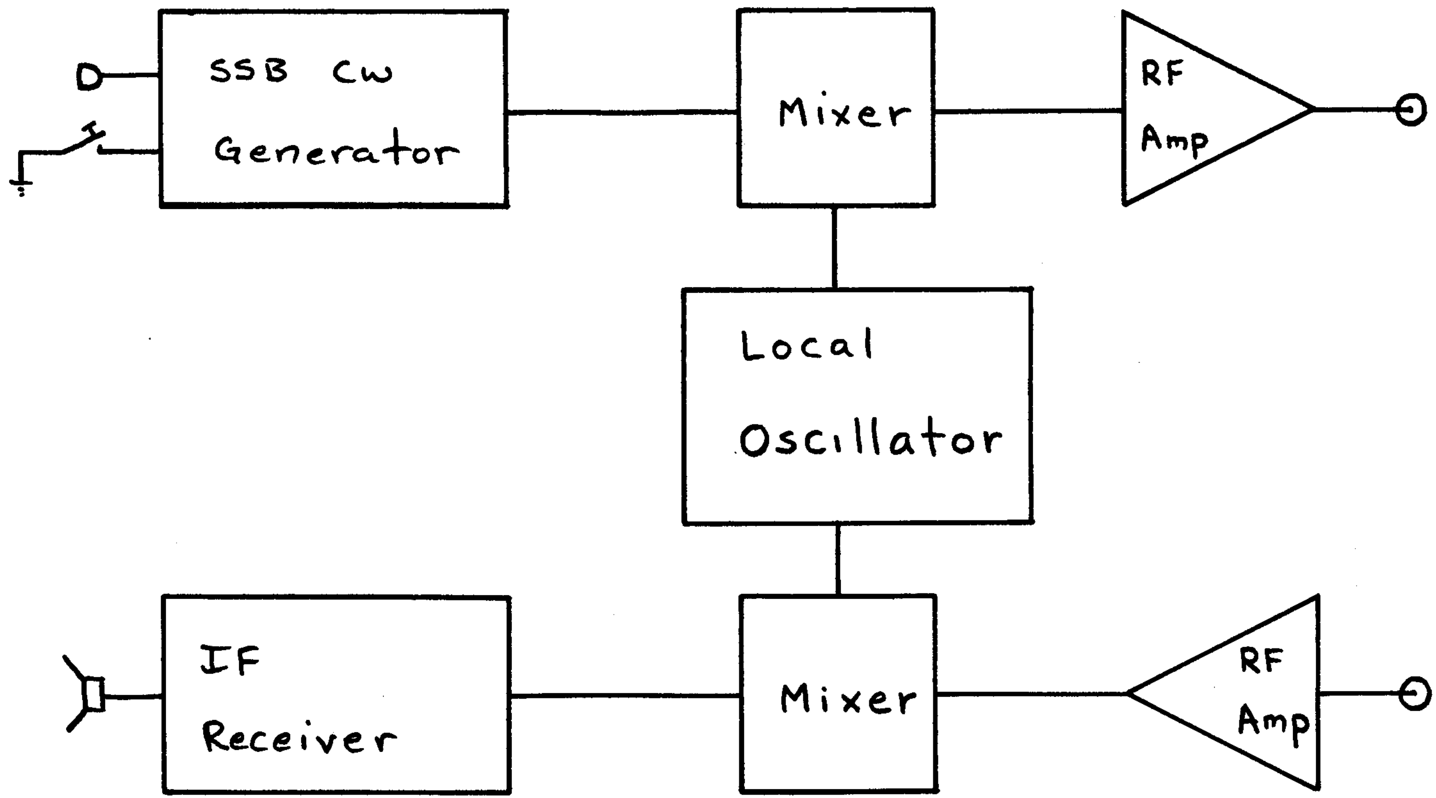
1. Breed, Gary, "A New Breed of Receiver," in QST, volume LXIII number 1, January 1988, pp 16-23.

2. Campbell, Rick, "High Performance Direct Conversion Receivers," in QST, volume LXXVI number 8, August 1992, pp 19-28.

3. Oppelt, Ralph, "The Generation and Demodulation of SSB Signals using the Phasing Method Part 1: Basic Theory," in VHF Communications, volume 19, edition 2, Summer, 1987, pp 66-72.

4. Oppelt, Ralph, "The Generation and Demodulation of SSB signals using the Phasing Method Part 2: Signal Processing for a SSB/DSB/AM Transceiver without using Crystal Filters," in VHF Communications, volume 19, edition 3, Fall, 1987, pp 130-140.

FIGURES



SSB CW Transceiver

Figure 1

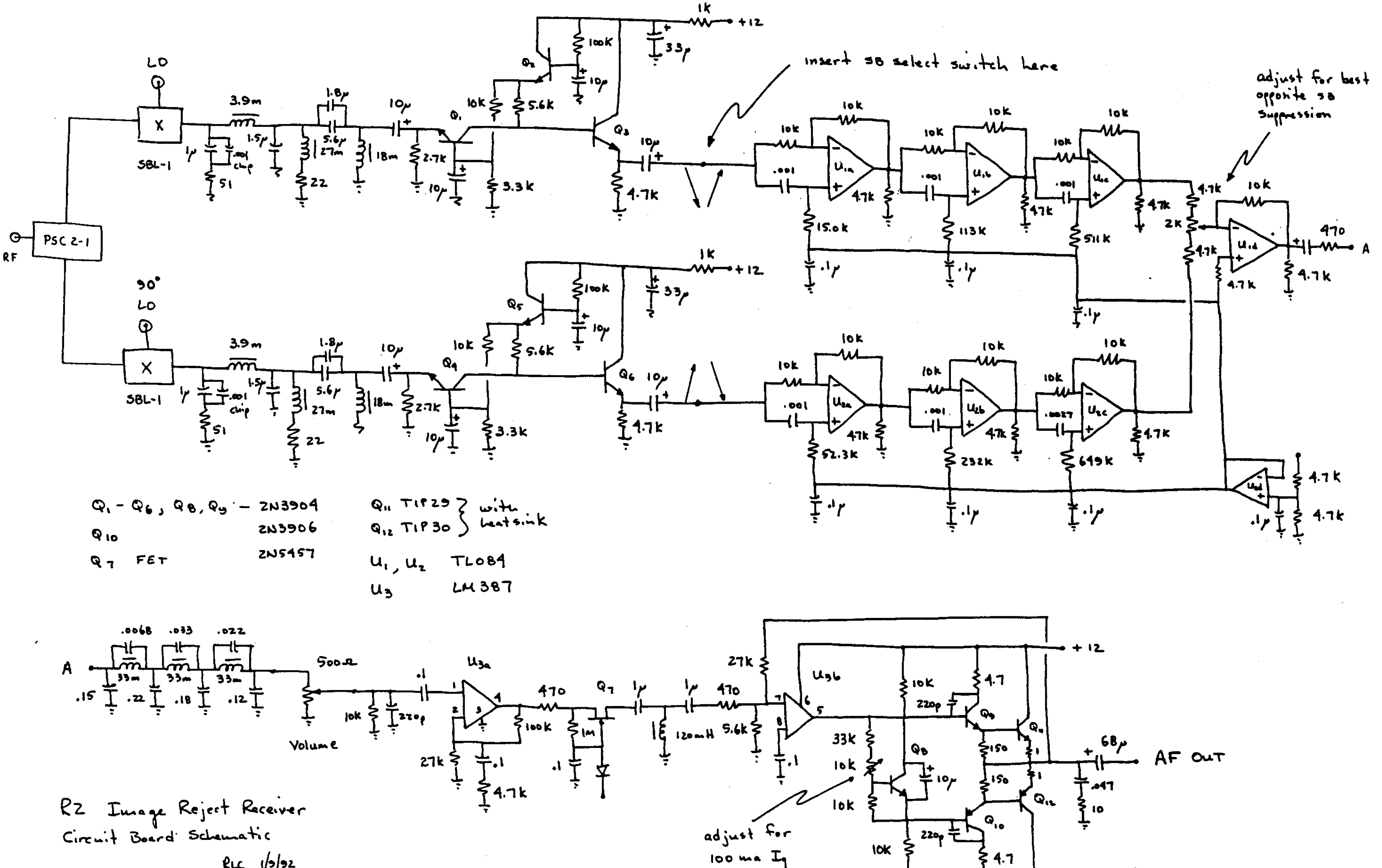
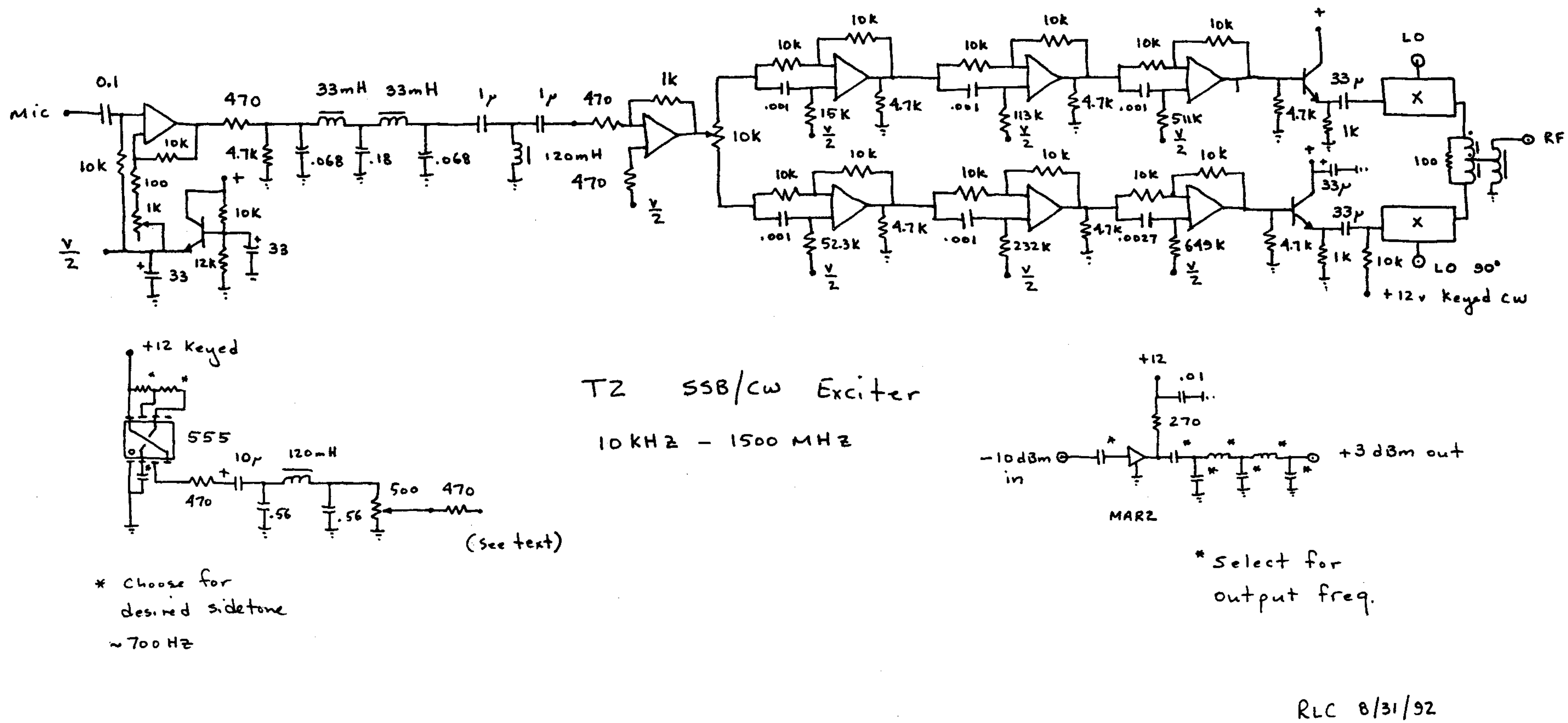
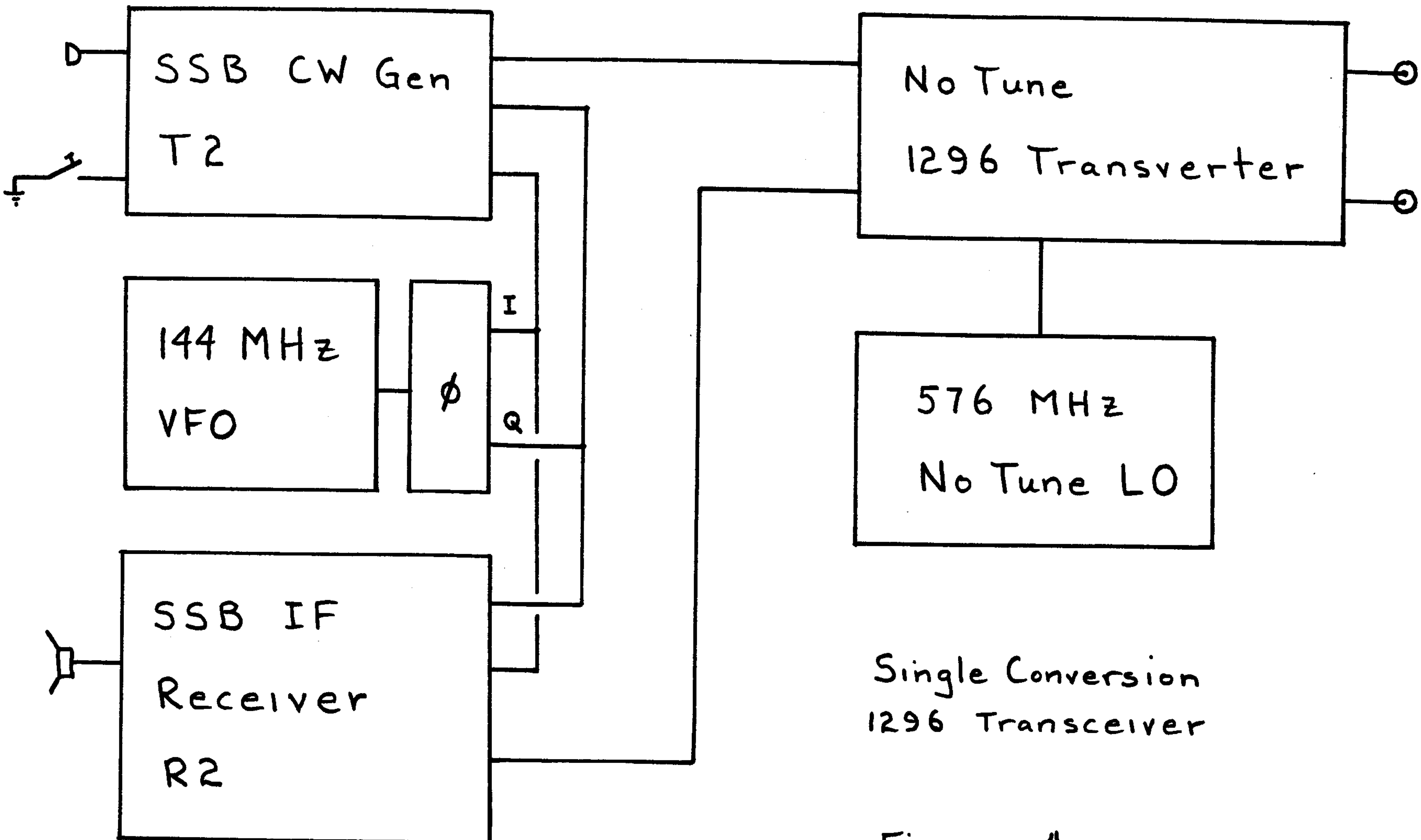

insert SB select switch here
adjust for best opposite SB suppression
adjust for 100 ma Iq
RF
PSC 2-1
LO
90° LO
SBL-1
AF OUT
+12
- Supply
Volume
Q1 - Q6, Q8, Q9 - 2N3904
Q10 2N3906
Q7 FET 2N5457
Q11 TIP29 } with
Q12 TIP30 } heatsink
U1, U2 TL084
U3 LM387
R2 Image Reject Receiver
Circuit Board Schematic
RLC 1/5/92

Figure 2



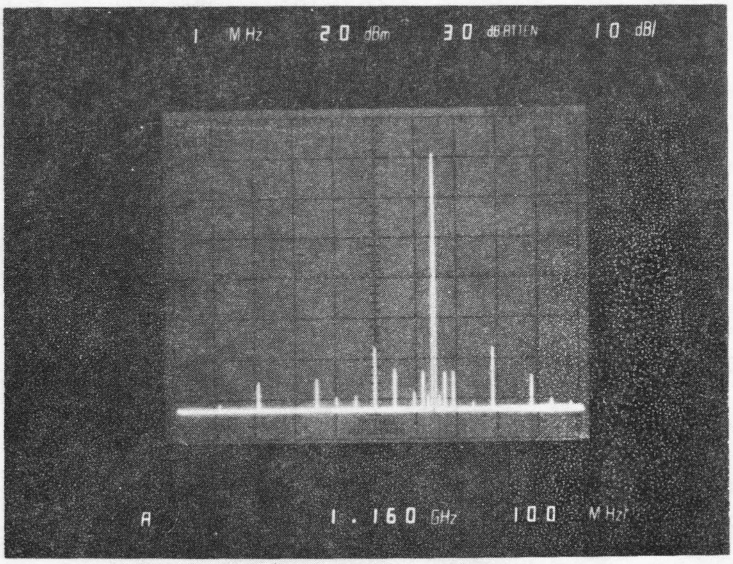
Mic
0.1
10k
100
1K
470
4.7k
33mH
33mH
.068
.18
.068
1μ
1μ
120mH
470
1k
V/2
10k
.001
15K
52.3k
4.7k
113k
232k
511k
649k
.0027
33μ
LO
X
100
RF
LO 90°
+12v keyed cw
+12 Keyed
555
10μ
120mH
.56
500
(See text)
* Choose for
desired sidetone
~700 HZ
T2 SSB/CW Exciter
10KHZ - 1500 MHZ
+12
.01
270
-10dBm
in
MAR2
+3 dBm out
* Select for
output freq.
RLC 8/31/92

Figure 3



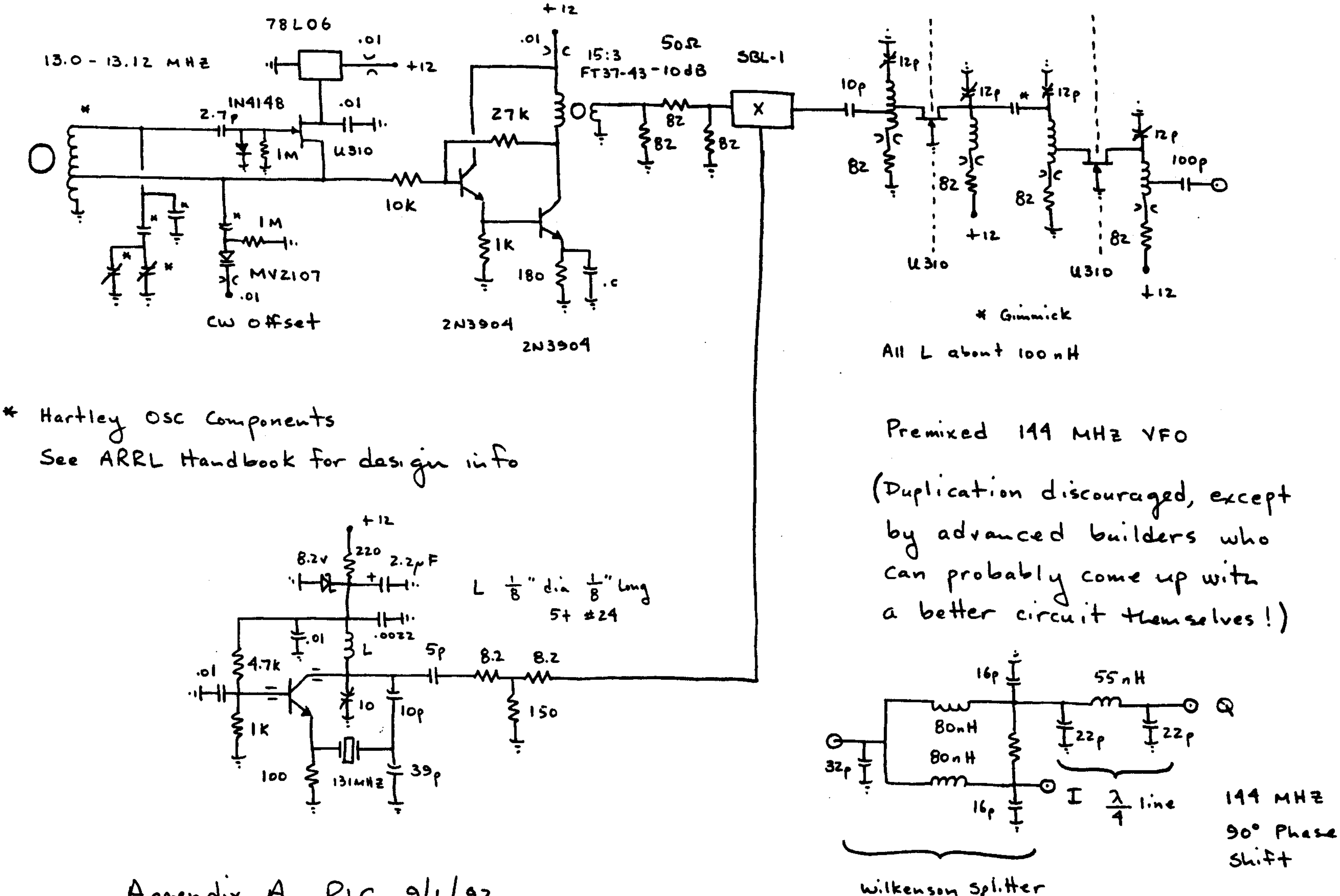
Single Conversion
1296 Transceiver

Figure 4



Output Spectrum
of No Tune 1296
Transceiver

Figure 5



Appendix A RLC 9/1/92