A SINGLE BOARD NO TUNE TRANSCEIVER FOR 1296?

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ABSTRACT

All of the circuitry for a 1296 MHz multimode transmitter and SSB CW receiver is presented. The emphasis is on basic circuitry that may be aligned using simple, inexpensive test equipment. The transmitter is realized as a variable crystal oscillator and frequency multiplier, with a complex modulator operating at the signal frequency. The receiver is a single conversion superhet with a crystal controlled front end and a tunable VHF image reject IF. The merits of a single board versus independent transmit, receive front end and receive IF are discussed.

INTRODUCTION

This paper presents all of the circuitry developed for a complete 1296 MHz station on three double-sided circuit boards. As of this writing, in July 1993, the circuitry has been tested but the final circuit board layouts have not been completed.

The original plan was to have all of the circuitry for a complete 1296 station on a single 5" X 7" circuit board. That plan was abandoned for several reasons. The first is that it is simply easier to divide a large project up into smaller pieces that may be purchased, built and tested independently and then, if desired, assembled into a unit. Purchasing, assembling and then troubleshooting a complete microwave transceiver may be too much expense, time, and frustration for a weekend radio engineer to handle.

The second reason is more fundamental. The introduction and widespread acceptance of transceivers into amateur radio in the 50's and 60's heralded the era of the appliance operator. Prior to that time it was common for amateurs to purchase some components of their station, typically the receiver, and build other components. The station receiver served as the test equipment for transmitter, SSB generator and keyer construction. The VFO in the transmitter served as an alignment oscillator for receiver projects. A few crystals provided accurate dial calibration. An amateur with a separate transmitter and receiver could transmit into a light bulb dummy load and listen to his own signal.

The transceiver deprives an amateur of the opportunity for performing the most basic radio experiment--generating a signal and listening to it. Some transceiver owners spend thousands of dollars on accessory appliances--huge amplifiers and antennas--just so they can hear their own signals returning from the moon.

By designing the 1296 station as a separate transmitter and receiver, I hope to encourage the kind of experimentation that used to be the heart of amateur radio. An amateur with no other test equipment than a 1296 MHz CW transmitter, a 1296 MHz SSB receiver and an audio voltmeter or "calibrated ears" can evaluate antennas, amplifiers, transmission lines and filters; listen to Doppler shifted echoes from cars and airplanes; and operate on hilltops during the contests.
Anyone who has ever operated microwaves from a remote location will appreciate the ability to turn on the transmitter, listen to the signal on the receiver, and verify that they are both still working.

Transceivers are more convenient and easier to operate--idiot proof. In my opinion, it is time to take a giant step backward and start building radio receivers and transmitters again, and leave the appliances to their appropriate operators on the low bands.

The three circuit boards described here are a multimode 1296 MHz transmitter; a 1296 to 144 MHz receive converter; and a 144 MHz SSB-CW tunable IF. Each board is completely independent of the other two boards. The application notes at the end of the paper suggest a few possible stations, but the reader's imagination will no doubt provide many more.

The transmitter consists of a stable VXO and clean frequency multiplier chain, a complex modulator and speech amplifier, a CW keying circuit, and a low level output amplifier. The output level is about +7 dBm. USB, LSB, AM, DSB suppressed carrier, NBFM and CW may all be selected with an on board DIP switch.

The receive converter is a straight forward "almost no-tune" design. New features are the use of a packaged CMOS clock oscillator, CMOS frequency multiplier, shielded printed filters for improved stability and spurious rejection, and a single VOM test point for tuning up the frequency multiplier inductors.

The 144 MHz SSB-CW tunable IF has a VXO and clean CMOS frequency multiplier, switched input attenuator, tuned RF amplifier, image reject product detector and bandpass audio amplifier. It is based on the "R2" receiver published in January 1993 QST, with refinements and simplifications appropriate for microwave IF use.

All three boards are a standard size, 3.5" X 5", small enough to mount directly at the feedpoint of simple antennas or package together in a tiny microwave backpack station.

Some readers may wonder why the receiver is a single conversion superhet instead of a direct conversion microwave image reject receiver. It is certainly possible to build an excellent 1296 direct conversion receiver. The trouble with direct conversion receivers is that they have to be carefully engineered and packaged to overcome some very non-intuitive problems. I can build a good one, but I wouldn't encourage a microwave beginner to experiment with the circuit or packaging. The single conversion superhet, on the other hand, is probably the most "user friendly" receiver topology.

THE TX1296 TRANSMITTER

A number of significant changes and additions were made in the T2 circuit published in April 1993 QST to build a 23 cm multimode transmitter. The changes will be discussed first, followed by a detailed description of the additional circuitry. The first change is in the mixers. In a direct phasing transmitter, the modulation occurs at the signal output frequency. The balanced modulators (mixers) must have RF and LO ports that operate at 1296 MHz and IF ports that operate down to DC. TUF-5 mixers are relatively inexpensive, and smaller than the SBL-1 mixers used on the T2 board. TUF packaged mixers are available for frequencies from 150 kHz through 1500 MHz.

The carrier suppression in a phasing transmitter is determined by the LO to RF isolation of the balanced modulators. At 1296 MHz, the isolation between the RF and LO ports in commercial packaged double balanced mixers is considerably less than in commercial packaged mixers for HF and VHF. This limits the carrier suppression to about 20 dB in a direct phasing transmitter for 1296 MHz using packaged commercial mixers. To obtain better carrier suppression, it is necessary to either heterodyne from a lower IF frequency, or use printed double balanced mixers optimized for LO to RF isolation. Either approach adds size and complexity.

An audible carrier is an annoyance at HF and VHF, but may be useful at microwaves. Non-amateur microwave SSB systems all use some type of partially suppressed carrier or pilot tone to automatically lock in the receiver tuning. The next generation of shortwave broadcast stations will have SSB modulation with a partially suppressed carrier, and advanced shortwave receivers are already incorporating synchronous SSB detectors. A low level carrier is also introduced sometimes to "RF bias" non-linear amplifiers or provide a minimum signal level for advanced signal processing techniques. Trading carrier suppression for circuit simplicity was considered a good compromise in a small multimode transmitter intended for portable operation.

The T2 circuit published in April 1993 QST uses a 10k amplitude balance pot on the input to the audio phase shift network. This provides a high impedance drive level to the audio phase shifters that offsets the phase shift, makes adjustment more difficult, and limits the ultimate opposite sideband suppression to about 40 dB. Replacing the 10k pot with a 500 ohm pot, and adding a 2.7 k resistor from each end of the 500 ohm pot to the +6 v supply line makes adjustment easier and allows the ultimate opposite sideband suppression to be achieved.

The T2 board was designed as a high performance SSB and CW generator for use at HF and VHF. The amplitude balance and LO phase shift need to be tweaked on the T2 board when changing sidebands, to obtain optimum performance. The TX1296 board is designed for multimode experimenting on microwaves. Tweaking when changing modes is an inconvenience. By relaxing the opposite sideband suppression specification, it is possible to eliminate the amplitude balance pot and make the LO phase shift adjustment optional or "set and forget".

To facilitate experimenting with different modes, a DIP switch is included on the circuit board. By selecting different connections of the outputs of the two phase shifters and bias resistors to the I and Q mixer IF ports, it is possible to generate USB, LSB, AM, DSB suppressed carrier, NBPM and CW. The modulator on the T2 and TX1296 boards is called a "complex modulator," and is theoretically capable of generating any mode, within the limitations of the audio phase shift network bandwidth. For digital modes, the I and Q bit streams may be connected to the I and Q mixer IF ports through an appropriate current limiting resistor.

A particularly useful feature of the TX1296 board is progressive construction. It is not necessary to build all of the circuitry available on the board. The VXO, frequency multipliers, CW keying, complex modulator, speech amplifier, audio phase shift network, and output amplifier are all independent, and may be left off the board without affecting any other circuitry.

There is no sidetone generator on the TX1296 board, as the actual transmitter output is monitored on the receiver during transmissions.

The new circuitry not on the original T2 board includes the VXO, frequency multipliers, 1296 amplifier and LO phase shift network.

The VXO circuit is a frequency scaled version of an oscillator circuit published by Joe Reisert in 1984 [1] as part of a secondary frequency standard. Reisert used the circuit to drive a step recovery diode comb generator for receiver testing and calibration. I built a 4 MHz version to test Reisert's claims of superior frequency stability almost ten years ago and still use it as a calibration marker on all bands up through 1296. It is an order of magnitude more stable than the 5th overtone oscillators commonly used in no tune transverters. With the values shown, it will tune over about 40 kHz at 1296 MHz, with outstanding frequency stability. The Reisert article describes a method for component selection to achieve even better stability. Decreasing the values of the 10 pF NPO and N750 capacitors will increase the tuning range, with some loss in frequency stability. Up to about 400 kHz of reasonably stable tuning range should be available without resorting to series inductors.

This circuit isolates the transistor parameters from the frequency determining elements with resistors and big capacitors. The frequency is determined primarily by the crystal and the three capacitors from the high impedance end of the crystal to ground. The circuit board artwork does not include locations for these parts. They may be located off the board at a panel mounted variable capacitor with a short wire (the crystal lead is fine) to point C on the board, or just connected together in air above the board. Mechanical stability is critical here. This construction method should be almost as good as building the entire VXO circuit "dead bug" style over a ground plane.

The disadvantage of using a fundamental crystal oscillator instead of a VHF overtone oscillator is the large multiplier needed to arrive at 1296 MHz. Commercial radios use phase locked loops. The goal for the TX1296 board was to have all spurious outputs 60 dB down with all tune up done using only a tuning wand and inexpensive VOM. The first multiplier stage is a X5 using a 74HC04 or 74AC04 CMOS hex inverter IC. The first stage is biased as a high gain non-linear amplifier to turn the incoming sine wave into a square wave. The other five inverters on the IC are connected in parallel to provide low impedance square wave drive to the output filter. The third semester electric circuits course tells us that a square wave is composed of a fundamental, a 3rd harmonic down 9.5 dB, a 5th harmonic down 14 dB, a 7th harmonic down 17 dB, a 9th harmonic down 19 dB, an 11th harmonic down 21 dB etc. Measurements of the circuit shown indicate that the textbook values hold well up to about 160 MHz with the 74HC04 and 200 MHz with the 74AC04. The even harmonics are about 20 dB lower than the odd harmonics. Even harmonic levels depend on input signal symmetry.

The output filter is a 3 resonator Chebychev with 50 ohm in-band input and output impedance. The input impedance is high for the fundamental and undesired components of the square wave. The output impedance is low outside the passband, to aid in stability.

A conventional MSA1104 amplifier drives a second 3 resonator filter. The combination of even harmonic suppression in the multiplier and selectivity in the two filters is enough to reduce the undesired harmonic output levels to more than 80 dB below the desired output. Undesired signals coupled through the power supply lines and through the air from the input to the output of the filters will be higher than this. To achieve the desired clean output signal requires careful layout, grounding of all inductor shield cans to both the top and bottom of the circuit board, and some shielding.

The output of the odd harmonic multiplier at 108 MHz is applied to a balanced diode doubler. The balanced diode doubler was studied extensively in Solid State Design for the Radio Amateur [2] and provides excellent performance at VHF. A minor variation from previous designs in the amateur radio literature is the bias resistor. The primary function of the bias resistor is to provide a test point so that a VOM may be used to tune up the 108 MHz filters. It may be possible to achieve a little more output from the balanced doubler by experimenting with different values of bias resistor. The balanced doubler needs good sine wave drive to suppress odd harmonics. If a different source of 108 MHz drive is used it should pass through at least a low pass filter before entering the diode drive transformer.

The output of the balanced doubler output is filtered by a pair of 216 MHz resonators, amplified by another MSA1104 and then applied to a conventional "no tune" multiplier (it wasn't conventional when I built my first one 9 years ago!). Since the board already has a number of Toko shielded inductors, a few more were used in the multiplier stage instead of the more common hand wound inductors. Another bias resistor is used in the diode multiplier stage. This one does provide a little more output from the multiplier, as well as acting as the VOM test point for tuning up the 216 MHz filter and tweaking the multiplier inductors.

The rest of the multiplier chain is conventional "no tune" with one important exception--the hairpin filters are shielded. The ultimate rejection of a 1296 MHz amplifier stage using multiple 3 resonator hairpin filters on .0625" G-10 board is about 50 dB. The limitation is radiation coupling into the air from the first filter element and then pickup from the air by the last element. Radiation coupling is worse for narrow band filters than wider filters. In one experiment, an 850 MHz local oscillator with a X8 multiplier had spurs 30 dB down before shielding the hairpin filters, and more than 60 dB down after shielding.

To shield a hairpin filter, draw a rectangle on the hairpin side of the circuit board, about 0.1" away from the edges and ends of the filter elements, all the way around the three resonators of the filter. Then drill a bunch of small holes about 0.25" apart on the rectangle all the way around the filter, avoiding the input and output connections. Solder wires into all the holes (resistor leads work fine) and then make up an "EZ Solder Tin Sheet" or tin can shield cover that will sit about 0.1" off the board over the filter and solder it to all the wires. Of course with plated through holes all the little wires can be eliminated.

A fringe benefit of shielding the filters is that the major cause of instability in amateur microwave work--radiation coupling of signals into a resonant metal box containing lots of gain--is eliminated. In other words, the TX1296 should be unconditionally stable in any sized box.

The output of the last hairpin filter is amplified by yet another MSA1104 with a simple quarter wave resonator to ground on the LO output. An identical stage serves as the transmitter output.

The only remaining component on the circuit board is the LO phase shift network. A 90 degree splitter is easy at 1296 MHz--a quarter wave length of Sage Wireline works great. For avid homebrewers, a few inches of two different colors of wire wrap wire passed through a two inch length of tiny hobby brass tubing will work. I think Bill Olson wrote an article on this a few years back but I can't find the reference.

To tweak the LO phase shift network, you can either cut a hundred different lengths of Sage Wireline and pick the best one, or solder a tiny (.25" of twisted wire wrap wire) gimmick capacitor to ground from each mixer LO port and then clip for best opposite sideband suppression. Which method to use depends on whether you want to build just one, or a whole bunch.

Progressive construction allows the TX1296 board to be built as just a signal source, a keyed CW transmitter, an FM transmitter, an AM or DSB-SC transmitter, or as a complete multimode board with USB, LSB, AM, DSB-SC and NBPM selectable with the dip switch. NBPM (narrow band phase modulation) may be copied on a narrow band FM receiver or an SSB receiver. AM may be copied on an AM receiver or an SSB receiver. To generate true FM with wider deviation, the output of the speech amplifier may be connected to a varicap diode in the VXO circuit.

THE RCX1296 BOARD

The RCX1296 board was designed with a single purpose in mind: to get a set of ears on 1296 as quickly as possible. Any complete receiver for 1296 MHz will be a fairly ambitious project, but a receive converter can be quite simple. Many hams have a way to listen on 144 MHz SSB, and according to the surveys, most have a way to listen on 144 MHz FM. Since the TX1296 board will generate any mode, including NBPM, a TX1296 board, RCX1296 board and a 2 m HT will put a station on 1296, with the capability of upgrading to SSB. Connecting a receive converter to a 2 m rig is as easy as connecting an antenna.

The only variations from the no-tune transverter theme are the use of a 64 MHz CMOS clock oscillator and CMOS tripler to 192 MHz; the use of a TUF-5 mixer instead of the printed mixer; and the shields on the hairpin filters in the LO multiplier and RF amplifier stages.

The 64 MHz clock oscillator is an outgrowth of the circuitry developed for the TX1296 transmitter. It is simple, clean, starts every time and cheaper than buying a custom ground crystal. On the down side, the tripler inductors have to be adjusted for maximum indication on a VOM connected to the test point, so it's not "no tune." But it certainly is easy to tune. A piece of non-conducting packing foam should be scotch taped over the clock oscillator to reduce drift. Purists, and some not-so-purists, will find the frequency stability lacking. There is room to build a 64 MHz Butler overtone oscillator on the back of the board, or even better, a Reisert fundamental oscillator followed by a CMOS odd-harmonic multiplier.

The strategy is to get on the band first, and then make improvements. Having to adjust the receiver tuning occasionally while copying SSB is a small price to pay for getting on a new band, and is an activity as old as radio. Receiver drift is not as annoying when the transmitter is independent and stable, another fact as old as radio. Few Hallicrafters and Hammarlunds had the stability that some microwavers are expecting at 10 GHz!

The TUF-5 mixer is used because two of them are used in the TX1296 transmitter, and it is smaller than a printed mixer. It does not provide a performance advantage over the printed mixer, other than allowing the entire receive converter to fit on a 3.5" by 5" G-10 board.

The shields over the 4 hairpin filters clean up the LO chain; discriminate against brutally strong out of band signals; and most importantly, improve the overall stability of the converter and allow it to be mounted in a metal box without oscillating. They may be left off at the builders discretion.

An alternative to the 64 MHz clock oscillator followed by a tripler and sextupler (X18 overall) is a 46 MHz clock oscillator followed by two quintuplers (X25 overall) with the output at 1150 MHz. The output of the first quintupler is at 230 MHz, which is at the ragged edge of 74AC04 operation and requires some changes in the filter components. An 1150 MHz LO puts 1296 MHz at 146 MHz, which is a pretty bad choice, but it puts 1294 MHz, in the novice portion of the band, at 144 MHz, which is interesting to those of us with an old HT laying around and a novice in the family.

THE RX144 BOARD

The RX144 board is a complete image reject SSB-CW receiver on a single 3.5" by 5" double sided circuit board. The circuit is a refinement of the R2 receiver board described in January 1993 QST, with an on board VXO, LO phase shift network, switched attenuator and preamp. The components in the schematic diagram are for operation on 144 MHz, but advanced experimenters may select different component values for any frequency between about 14 and 200 MHz.

A number of changes have been made in the original circuit published in January '93 QST. These changes were generally made to ease component tolerances and make the receiver smaller--not to improve performance. The first change is the use of TUF-1 mixers instead of SBL-1s. The TUF-1 is smaller, has better RF to LO isolation in the HF range, and is less expensive than the SBL-1.

The most significant change in the circuit is the diplexer networks between the mixer IF ports and the preamps. The original diplexer provides outstanding close-in dynamic range, good skirt selectivity and a textbook termination of the mixer IF ports from DC to VHF. On the down side, the diplexer components are expensive, and are not available in the required tolerances off-the-shelf. The only reasonable way to obtain a set of diplexer components matched to the required tolerances is to buy lots of 10 from Digi-Key and hand match them using an LC meter. The simple diplexer shown in the schematic was designed to be used with off-the-shelf 10% components. The loss in close-in dynamic range and skirt selectivity are probably acceptable on the microwave bands.

There is some evidence [3] that the noise figure of the original R2 circuit is compromised by the noise of the op-amps in the audio phase shift networks. The gain distribution of the R2 was engineered for maximum dynamic range and appropriate audio output levels when the RF input is connected to a full size 40 m dipole, with no RF gain. On microwaves the internal receiver noise needs to be amplified to a comfortable audio level so that noise level signals may be copied. Adding a low noise op amp stage between the grounded base preamp stage and the audio phase shift network provides some additional audio gain, and assures that the audio phase shift network ICs do not contribute to the receiver noise figure. This change reduces the close-in dynamic range a little.

The audio phase shift networks were changed to a "low pass" topology from the original "high pass" version. This simplifies the op-amp bias network and should not have any measurable effect on performance.

It can be successfully argued that 40 dB of opposite sideband rejection is not needed in a receiver intended as a microwave IF. After all, the probability of an interfering signal appearing in the opposite sideband is small (and if an interfering microwave signal is present, it may be more than 40 dB stronger than the desired signal). The only real reason that opposite sideband rejection is needed in a microwave receiver is to get rid of the opposite sideband noise. 20 dB of opposite sideband rejection is enough to make the opposite sideband noise contribution insignificant. It is easy to obtain 20 dB of opposite sideband rejection with second order audio phase shift networks and no amplitude or RF phase adjustments. The decision not to relax the opposite sideband suppression on the RX144 was a purely subjective one--it is delightful to tune a received signal through zero beat on a properly tweaked phasing receiver and have it simply disappear on the opposite sideband. Maybe that's something only a receiver engineer can appreciate--if so, please feel free to alter the circuitry!

The combination of high pass-low pass diplexers, a seventh order LC low pass filter and a third order LC high pass filter in the original R2 circuit provides the high skirt selectivity needed in the crowded high frequency bands. At microwaves, the desired signal is most likely buried in noise, with no other signals present. The ear is probably more comfortable digging for weak signals through a nice rounded Butterworth shape than a steep skirted, ripply Chebychev shape. In a conventional superhet, the steep skirts are needed to get rid of the opposite sideband. Since the opposite sideband is removed by phasing in the R2 receiver and its derivatives, a more graceful filter response may actually improve the receiver performance for the "weak signal buried in noise" case. The filter shown in the schematic is a 3 kHz Butterworth low pass followed by a 300 Hz Butterworth high pass. It has nicely rounded corners, no ripple, and sounds very good on all modes. Advanced experimenters may want to add a switched CW bandwidth filter--just be careful to observe the input and output impedances.

The final change from the original R2 circuit is in the audio amplifier. The original circuit works well, but it draws a fair amount of current and uses the old LM387/NE542 stereo preamp IC. While the current drain is less than any "modern" SSB radio using a microprocessor, and both the LM387 and equivalent NE542 are readily available, a design using an NE5532 dual op amp was substituted. The NE5532 has enough output capability to directly drive personal stereo type headphones. The NE5532 is unity gain stable, so simple low pass capacitors are added across the feedback capacitors to reduce high frequency hiss while using headphones. The NE5532 will not directly drive a speaker. For very quiet locations, a speaker may be driven through a 1K:8 ohm audio transformer. The speaker should not be located in the same enclosure as the receiver board, since the time varying magnetic field of the speaker (and its leads) can be picked up by the inductors in the diplexer networks and amplified by all of the audio gain, resulting in regenerative, peaky audio or oscillation. Since the speaker needs to be remotely located anyway, a battery powered speaker-amplifier sold for use with personal stereos is the ideal solution.

There are some additions to the circuit board that were intentionally left off the general purpose R2 board described in January 1993 QST. Since the RX144 receiver is intended for use as a microwave IF, some input selectivity is needed, and the noise figure needs to be low. These requirements are met with the narrow band preamp using Toko slug tuned inductors, chip capacitors, and an MMIC. The bandwidth of the preamp is about 20 MHz, and it will tune from about 130 to 160 MHz with the components shown.

An input attenuator is needed to help the receiver deal with strong signals, as when monitoring the transmitter output. The circuit shown automatically switches in when the transmit line is grounded, and may also be switched from the front panel. Grounding the mute line silences the receiver. A 1 M trimpot in series with the mute line allows a variable amount of signal to leak through the muted receiver, so that the transmitter may be monitored.

Another addition is the LO phase shift network. This network provides the required phase shift over a relatively narrow band, about half a MHz at 144 MHz, but its phase is adjustable over a wide range without affecting the amplitude of the two output signals very much. This makes it very easy to adjust the two opposite sideband rejection trimmers on the board--just tweak the amplitude balance pot, touch up the phase shift inductor, and it's done.

The last addition to the receiver board is the VXO-multiplier. The circuit details were already covered in the transmitter section. The tuning range is about 50 kHz with the components shown. Experimenters may increase the range by adding the optional inductor, but frequency stability will suffer. The spurious outputs of the LO multiplier are about 60 dB down. Spurious levels are strongly dependent on proper grounding of the shield cans over the inductors.

The component values in the schematic provide an awful lot of audio gain for a small circuit board. After the final layout is completed, the feedback resistors in the op-amp gain stages will be changed if necessary to obtain a stable gain distribution.

APPLICATION NOTES

The possible applications of the circuits presented here are limited only by the imaginations of the readers. This audience is well known for its creativity, so I won't pretend to forsee all the possible uses for these boards. I can imagine dozens of different applications with no creative effort at all. I will present a few notes just to start the process, and leave the rest to the reader.

A basic complete station is shown in figure 1. The transmitter is enclosed in a small box with a front panel mike connector, key jack, transmit switch and VXO tuning control. The back panel has an SMA output connector, a receiver mute connector, and a 12 volt power cord. USB and CW are available by keying the mike button or closing the key. Other modes may be generated by opening the top cover and changing the DIP switch positions.

The receive converter is also enclosed in a small box, with an SMA input connector, BNC IF output connector, and 12 volt power cord.

The IF receiver is enclosed in a third box, with a front panel VXO tuning control, headphone jack, volume control, mute switch and attenuator switch. The rear panel has a BNC input connector, 12 volt power line, and mute connector.

This basic station may be used for hilltopping, as an independent beacon transmitter and receiver, as a source and receiver for antenna testing etc. Since the receiver does not have AGC, an audio output meter will respond linearly to changes in input signal strength. Direct signal-to-noise measurements, antenna gain comparisons and preamp gain measurements may be made. By measuring the increase in noise floor and the increase in the level of a weak signal, preamp noise figure measurements may be made with the preamp installed in the system, which may yield different numbers than a noise figure meter.

Another application is shown in figure 2. This is a very simple way to put a station on 1296, and takes advantage of the fact that almost everyone has access to a 2 m HT. The speech amplifier and local oscillator portions of the TX1296 board are built, with the output of the speech amplifier connected to a varicap diode in the VXO circuit. The transmitter board is fastened with tape to the side of an empty 3 lb coffee can, with a 2.5" piece of wire extending from the local oscillator output of the TX1296 board through a small hole in the side of the can. There is an optimum position and length for the wire, which should be experimentally determined. The receive converter is mounted on the side of a second coffee can antenna with a similar wire probe. The two cans may be mounted on a wooden cross bar, with 12 volt power supply lines and a BNC cable to the 2 m HT. 1296 operation doesn't get much easier than this, and it is upgradable to CW or SSB by just adding a few more parts to the transmitter board and switching the IF cable to a 2 m multimode.

The third application is shown in figure 3. The 10 GHz receive system is conventional. The TX1296 board drives a X8 multiplier to obtain a signal on 10.368 GHz. CW and FM are available just by manipulating the DIP switch. It is theoretically possible to generate a signal that, when multiplied by 8 in a non-saturated multiplier with stable characteristics, sounds like SSB. The Europeans have been playing with this technique for years.

Now that gain is readily available at 10 GHz, a more practical approach that generates excellent quality SSB is shown in figure 4. The output of the 1296 multiplier goes to a X8 multiplier to obtain a 10.368 GHz signal that is split to two 10 GHz balanced mixers. The I and Q audio outputs from the TX1296 board go to the IF ports of the mixers, and the RF outputs are combined and amplified. The resulting "TX10368" transmitter has all the characteristics of the TX1296, with frequency stability limited only by the thermal and mechanical design of the VXO. An off-board 5 MHz range temperature stabilized crystal with X3 or X4 multiplier might be used to obtain superb 10 GHz stability.

The RX144 local oscillator has enough output to drive a T2 board for a 144 MHz transceive IF as shown in May 1993 QST. This could be used with any of the no tune transverters to build a high performance transceiver. A high performance single conversion superhet transmitter could be built by using a T2 board on 144 MHz to drive an RCX1296 converter board with the RF gain stages reversed.

CONCLUSION

This paper demonstrates that building a complete 1296 weak signal station is now within the realm of possibility for the weekend engineer. The circuitry is simple and easy to get running, and provides a level of performance that will make it a welcome addition to the activity currently on the band. The combination of VXO tuning, printed filters and phasing techniques makes an ideal combination for simple weak signal microwave work.

ACKNOWLEDGMENTS

Since the publication of the R1, R2 and T2 articles in QST, I have received hundreds of letters with critical and constructive comments on the circuitry. Three contributors have been particularly helpful, and some of the refinements in the circuitry presented here are the results of our correspondence. Byron Blanchard did a computer simulation of the effect of driving point impedance on the audio phase shift network in the transmitter, and has studied the merits of various LO phase shift networks in considerable detail. While he may not agree with all of my design choices in the TX1296, I am far more comfortable with them as a result of our continuing discussions. Rodger Rosenbaum also questioned the driving point impedance, and provided an extensive bibliography of early and obscure references on phase shift network design. Wes Hayward built a copy of the R1 receiver and has been studying the gain and noise distribution. He also suggested the use of "low pass" topology audio phase shift networks as a way of simplifying the op-amp biasing.

Finally, I would like to acknowledge all of the negative correspondence I have received from amateurs who wouldn't waste their time building a phasing rig because it can't perform as well as a rig with a good crystal filter. It is easy to show, on paper or with a computer simulation, that a phasing transmitter or receiver will have disappointing performance. The theory that shows why real phasing rigs work very well is beyond the scope of most EE textbooks. It is also easy to show, using elementary electromagnetics, that a dipole strung between two trees is an inferior antenna. It takes a lot more theory to show that a dipole strung between two trees is really pretty good. I would encourage the phasing skeptics to lighten up a little on the theory and warm up the soldering iron. My experiments with phasing rigs have been more fun than anything else I have done recently in amateur radio, and all the crystal and mechanical filters I carefully hoarded over the years will just have to keep collecting dust.

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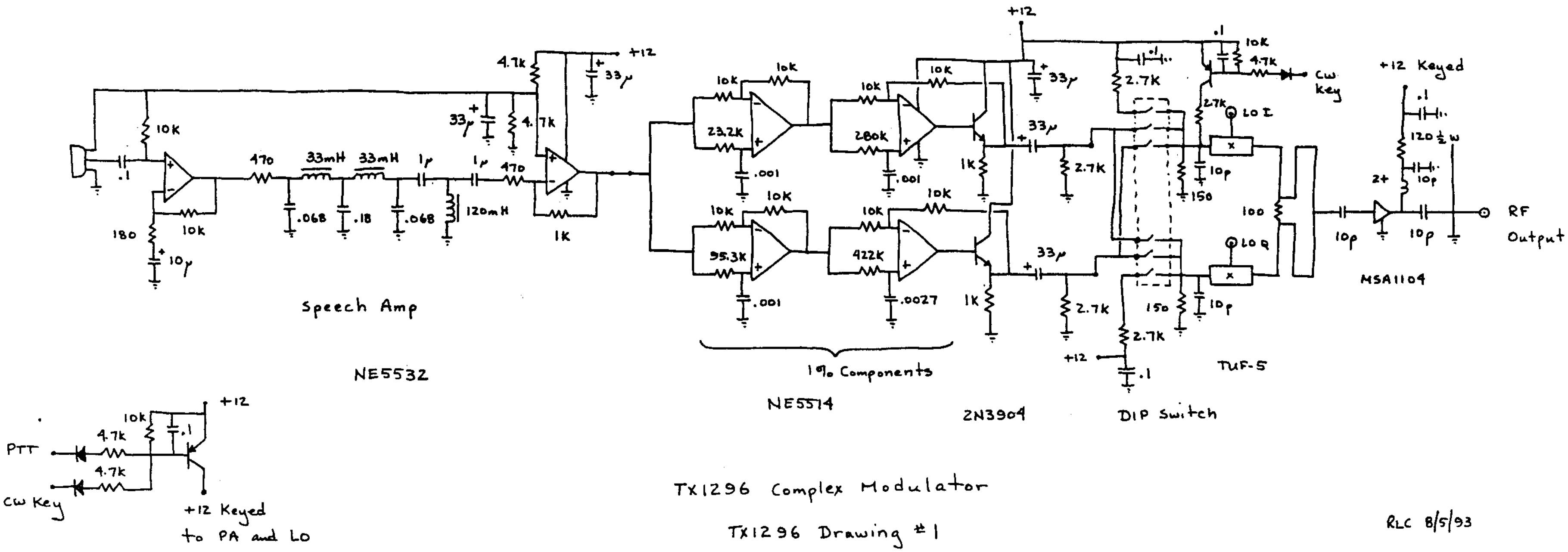

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NE5514
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DIP Switch
TUF-5
MSA1104
LO I
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CW key
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RF Output
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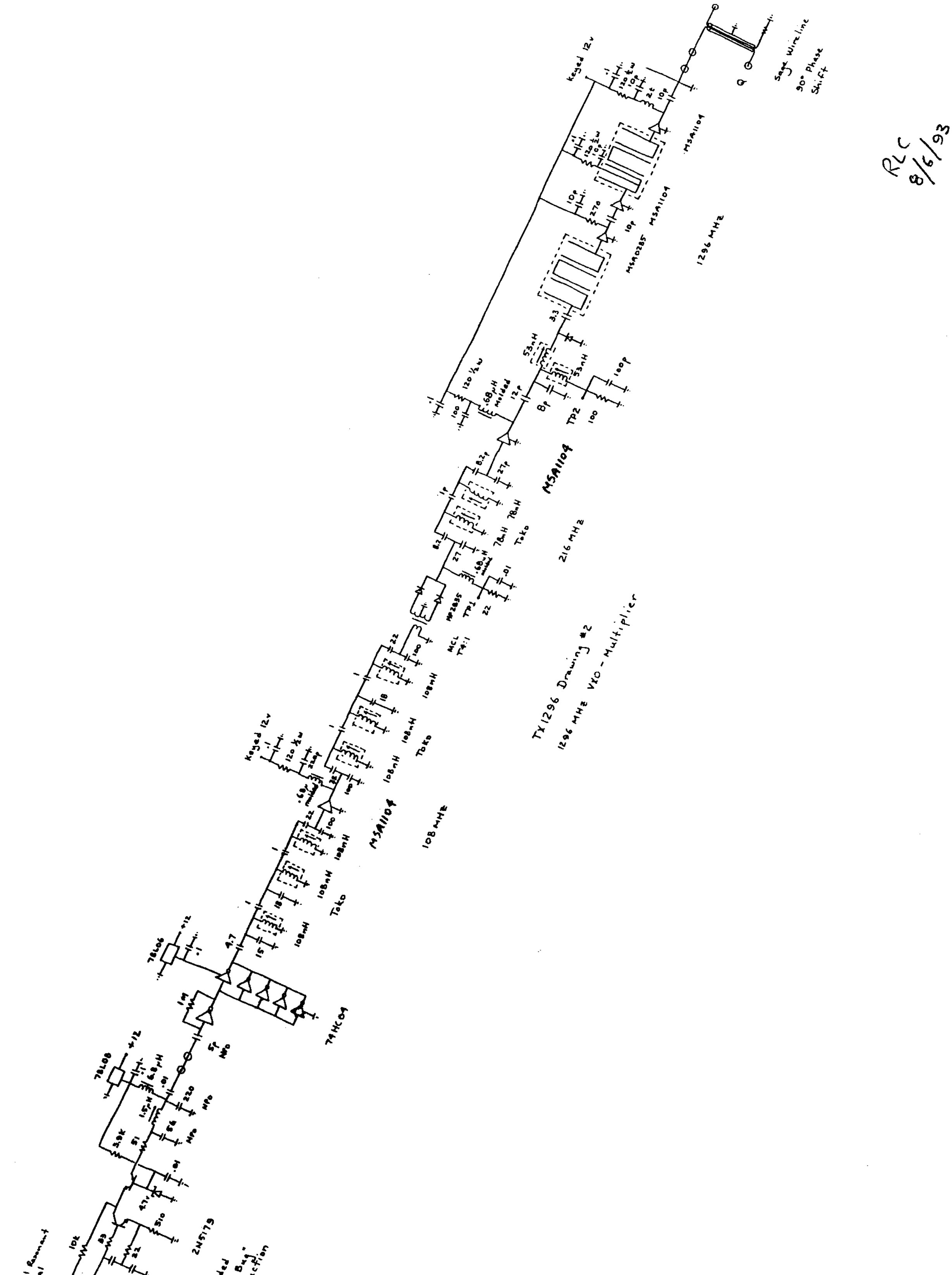
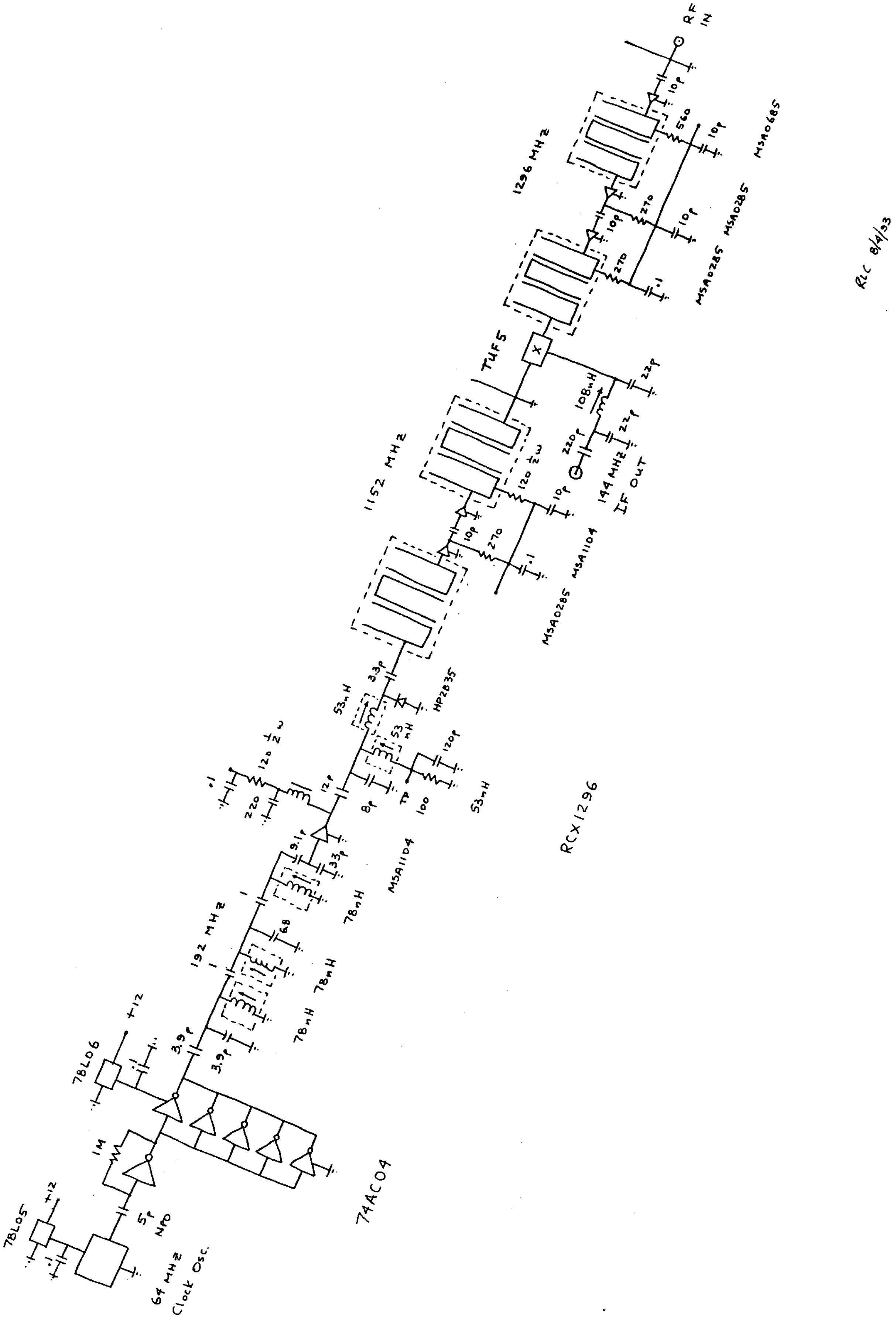
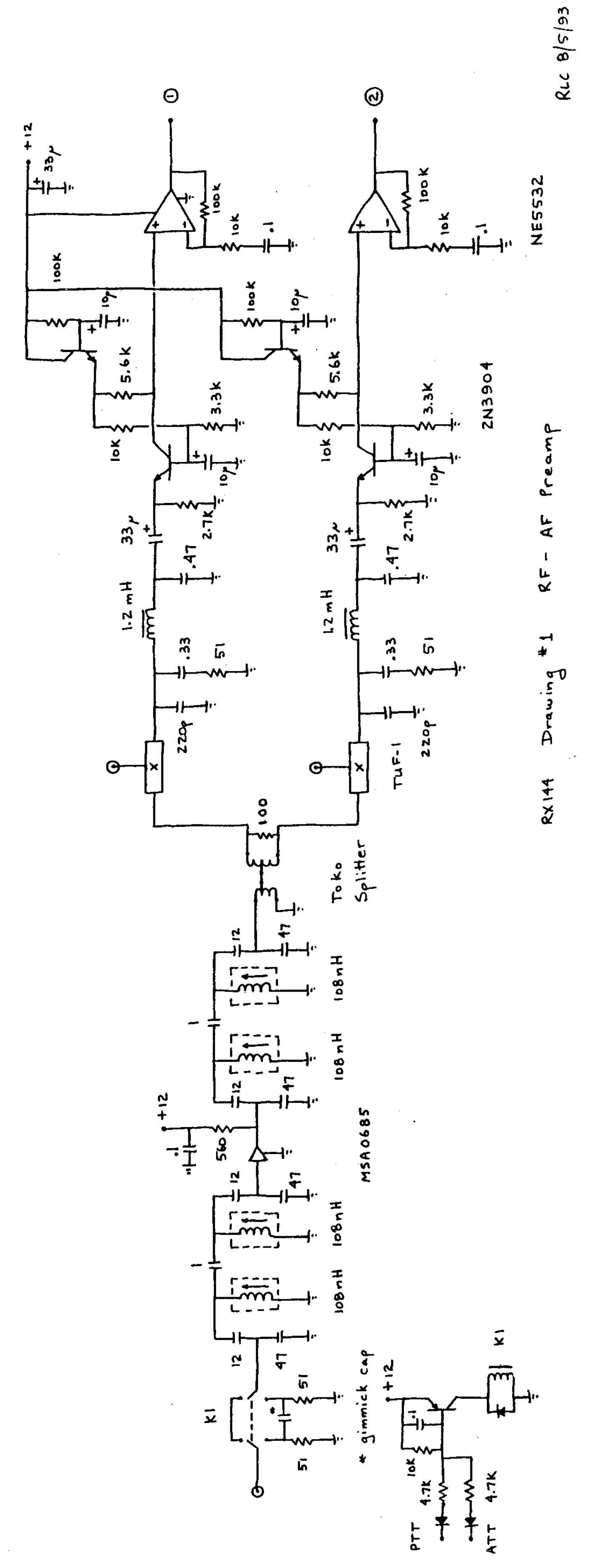
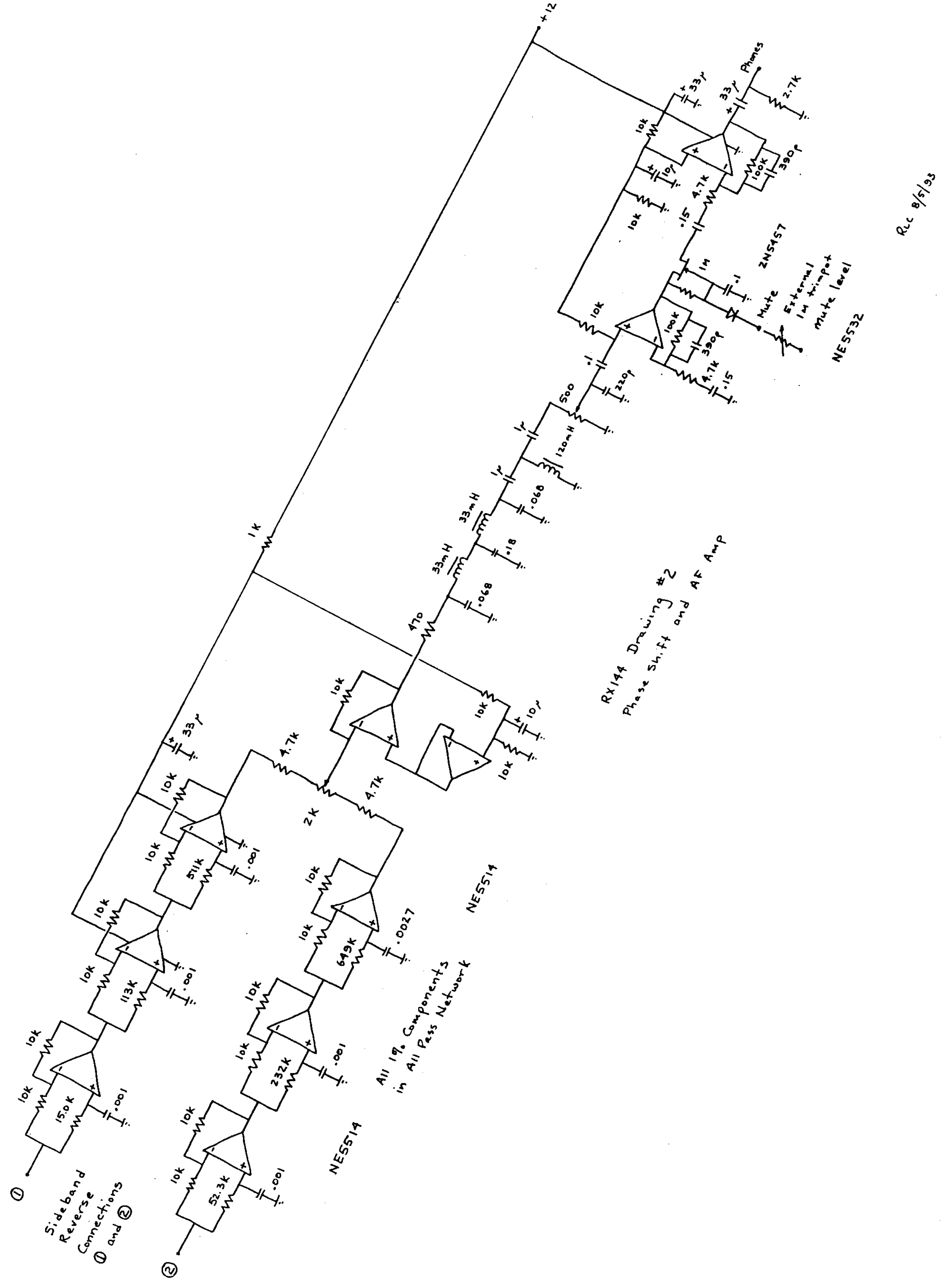
TX1296 Complex Modulator
TX1296 Drawing #1
RLC 8/5/93

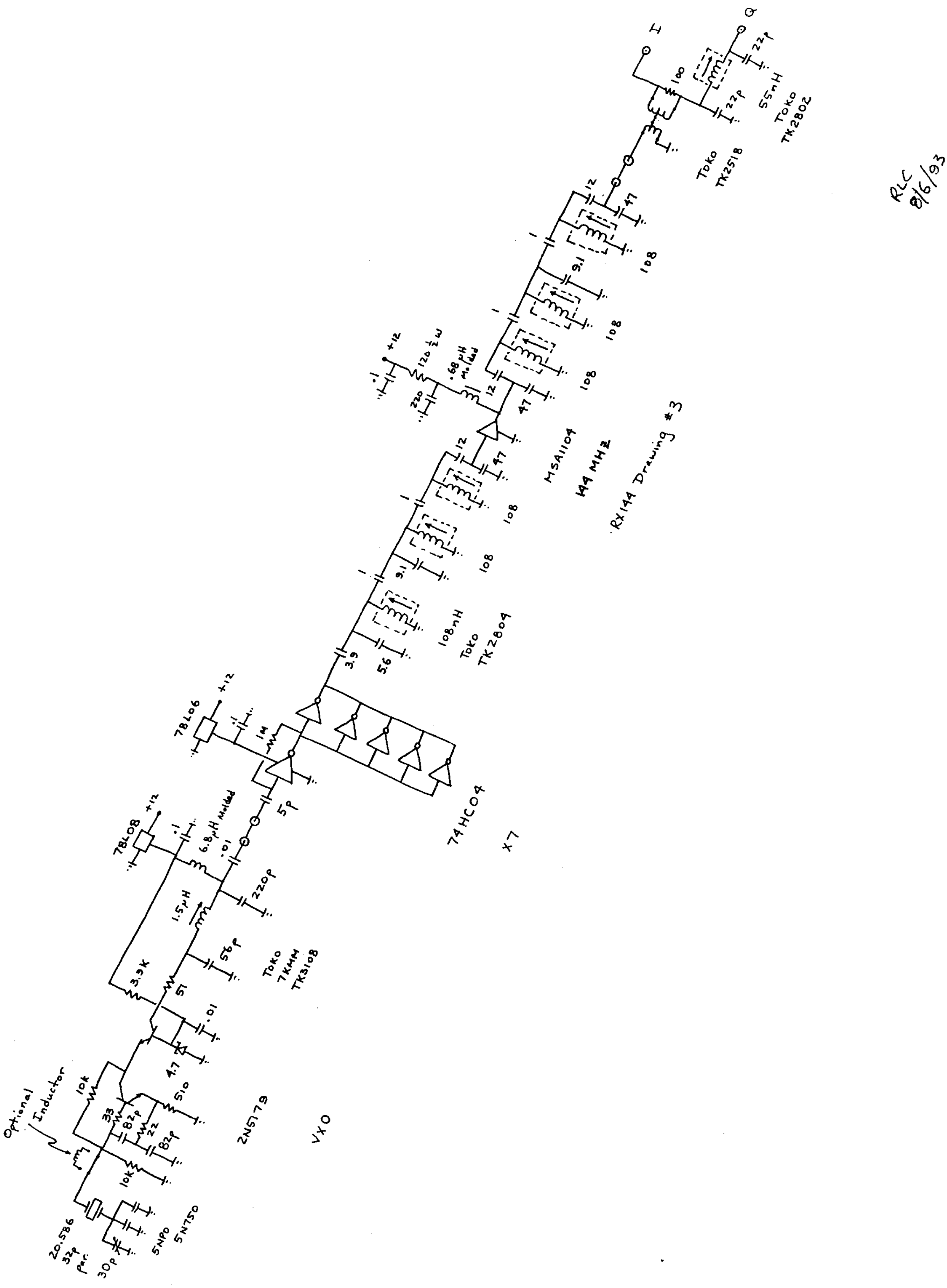

TX1296 Drawing #2
1296 MHz VXO - Multiplier
RLC
8/6/93
108 MHz
216 MHz
1296 MHz
MSA1104
74HC04
2N5179
78L06
78L08
Toko
Keyed 12v
90° Phase Shift
Shielded
"Dead Bug"
Construction
I
Q


RF IN
10p
560
10p
MSA0685
1296 MHz
270
10p
10p
270
.1
MSA0285 MSA0285
RLC 8/4/93
TUF5
X
22p
108nH
22p
220p
144 MHz IF OUT
1152 MHz
120 ½W
10p
270
10p
.1
MSA0285 MSA1104
3.3p
53nH
HP2835
53 nH
120p
TP
100
53nH
8p
12p
120 ½W
.1
220
RCX1296
MSA1104
9.1p
3.3p
78nH
192 MHz
68
78nH 78nH
3.9p
3.9p
+12
78L06
1M
74AC04
5p NPO
78L05
+12
64 MHz Clock Osc.


RX144 Drawing #1 RF - AF Preamp
RLC 8/5/93
NE5532
2N3904
TUF-1
Toko Splitter
MSA0685
108nH
1.2mH
100K
10K
5.6K
3.3K
2.7K
33µ
10µ
220p
.33
.47
51
12
47
560
100
+12
K1
* gimmick cap
PTT
ATT
4.7K
①
②



+12
Phones
2N5457
Mute
External
1M trimpot
mute level
NE5532
RLC 8/5/93
RX144 Drawing #2
Phase Shift and AF Amp
NE5514
All 1% Components
in All Pass Network
NE5514
Sideband
Reverse
Connections
① and ②
①
②


RX144 Drawing #3
RLC 8/6/93
144 MHz
MSA1104
74HC04
X7
VXO
2N5179
Optional Inductor
20.586
32p
Par.
30p
5NPO
5N750
10k
33
82p
22
510
4.7
.01
51
3.9K
56p
Toko
7KMM
TK3108
1.5μH
220p
.01
6.8μH Molded
.1
78L08
+12
5p
78L06
1M
3.9
5.6
108nH
Toko
TK2804
9.1
108
12
47
.68μH Molded
120 ½W
220
TK2518
100
22p
55nH
TK2802
I
Q

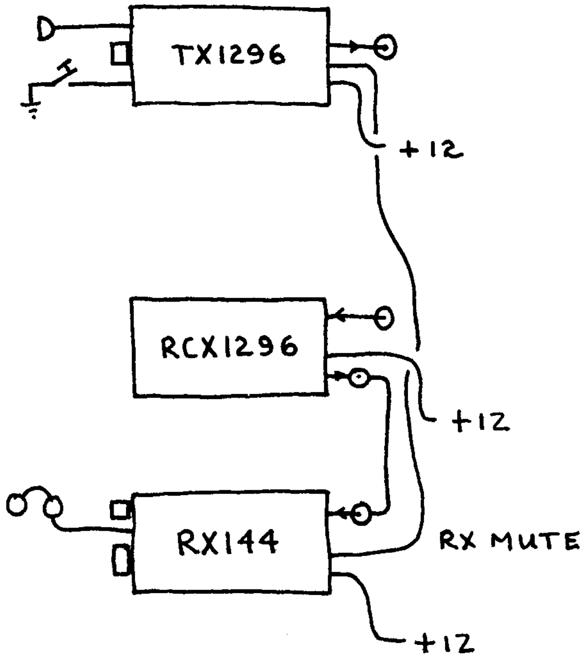


Figure 1
Basic System

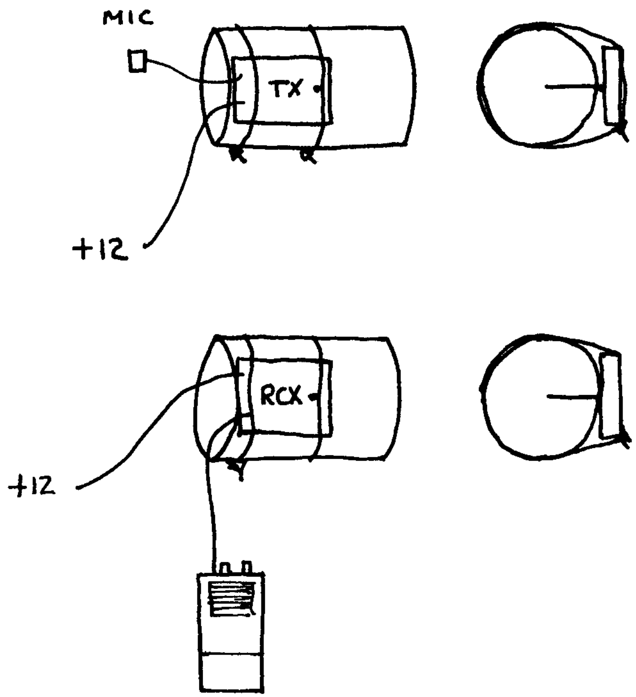
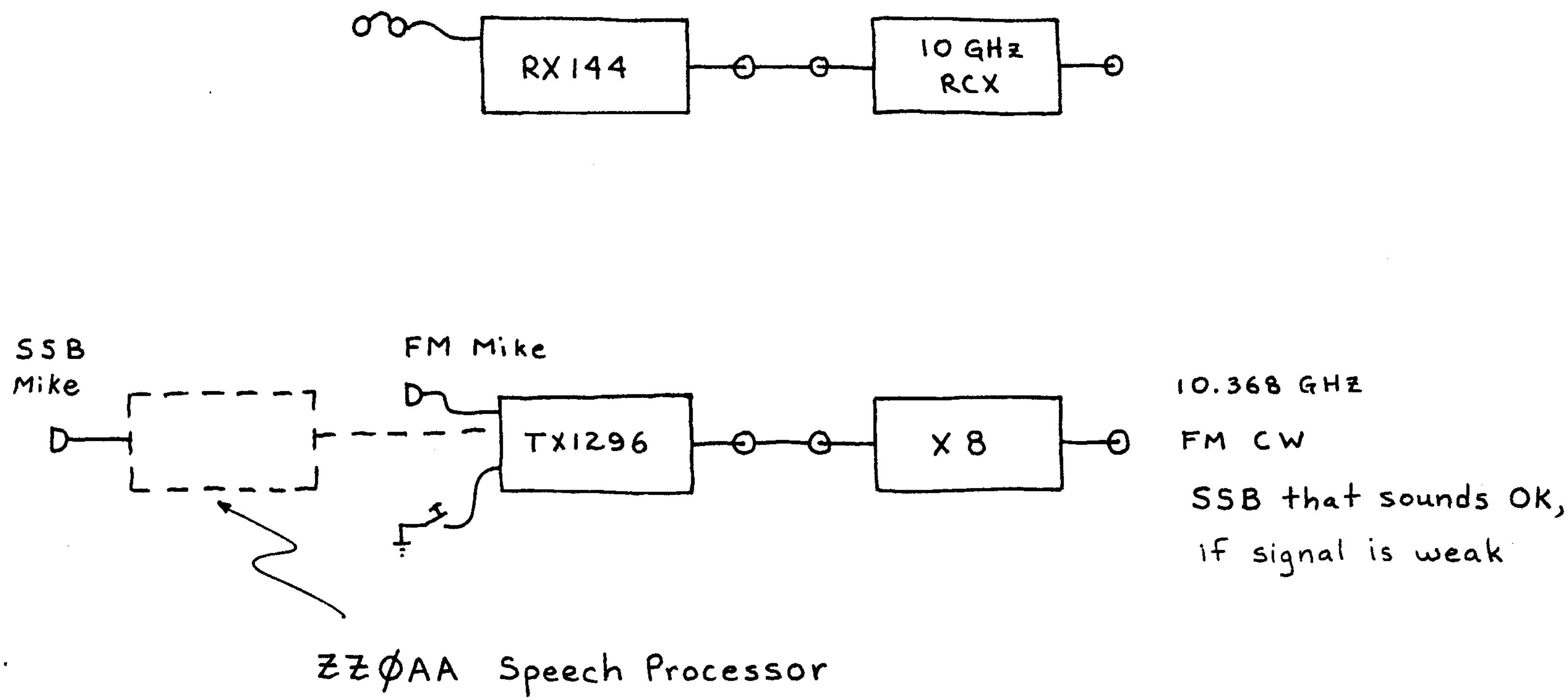


Figure 2
Simple Coffee Can System



10 GHz Station

Figure 3

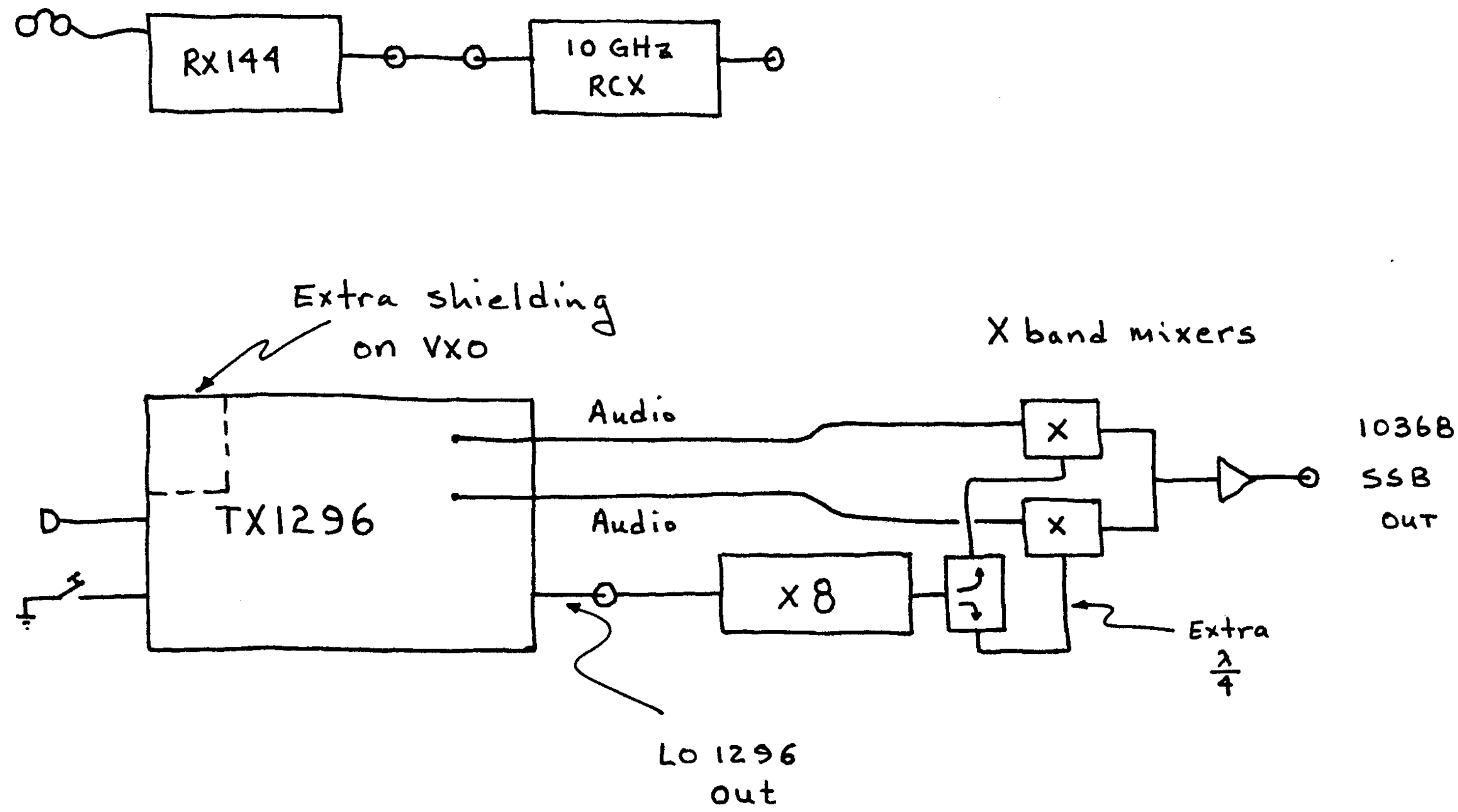

RX144
10 GHz
RCX
Extra shielding
on VXO
X band mixers
TX1296
Audio
Audio
X
X
x8
10368
SSB
OUT
Extra
λ/4
Lo 1296
out

Figure 4