

A SIMPLE SSB TRANSCEIVER

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A dual-band transceiver with a crisp receiver and a clean SSB signal is described. It started its life as an investigation of the excellent S7C receiver described in EMRFD. This transceiver was specifically designed to use components that are easily available in TV and Radio spares shops. The receiver sports an above average dynamic range, very clean signal and noiseless performance. Although the components are easily available, and every detail about making it is covered here, this is not a weekend project. The design is elaborate and invites improvisation.

We decided to pursue the following rules in designing this transceiver:

- ▶ Use what is easily available. Very often, we find designs that look good but they use exotic parts like TUF-1 mixers that are simply impossible to get hold of in India and other countries. Instead, we have tried using those spares that are universally available.

- ▶ Keep impedances and gain low: Often, we try coaxing maximum gain out of a stage making it difficult to duplicate and stabilize. We chose to take only modest gain out of each stage, using extensive feedback to make the circuit stable. Most of the interconnections between modules are for 50 ohms termination. In fact, the rig was a number of discrete board connected using RCA audio cables and sockets before we hooked it all up together to work.

- ▶ No PCB. We directly solder the components over a plain copper clad board (un-etched PCB). It is an excellent way to experiment, physically robust and has a quick and dirty appeal. You can usually solder up a whole circuit as you think it out in a few minutes. See the pictures.

- ▶ Broadband. We wanted to be able to use broadband design where applicable. We have found that the television balun cores are an excellent and very cheap (about Rs. 2 per balun, that is 5 cents) way of making broadband transformers.

- ▶ Modest cost. While we didn't want to use very expensive components. We didn't want to compromise the performance either. You will see that we have used 2N3866 exclusively. This was because we found that the BF195/BF194/2N2222 series transistors available in the market were consistently inferior in the HF range and performed below their stated specs. The 2N3866 is commonly

used in cable TV equipment and has a good HF performance: both as a low noise small signal transistor as well as driver up to 1 watt level. 2N3866 is expensive (about Rs.20 each, but well worth the expense). It is used in a number of critical places.

- ▶ Measure what you have built. We used a 12 volt 1.5A power supply, a frequency counter, a test oscillator (to measure the crystals and coils) and a high impedance voltmeter with an RF probe to test and measure the design. All these test equipment were homemade. The transmitter design did require a PC-based oscilloscope. It helped us identify the spurs and harmonics using the in-built FFT functionality. But now that the design is complete, just an RF probe and a 14MHz receiver are enough to align the rig.

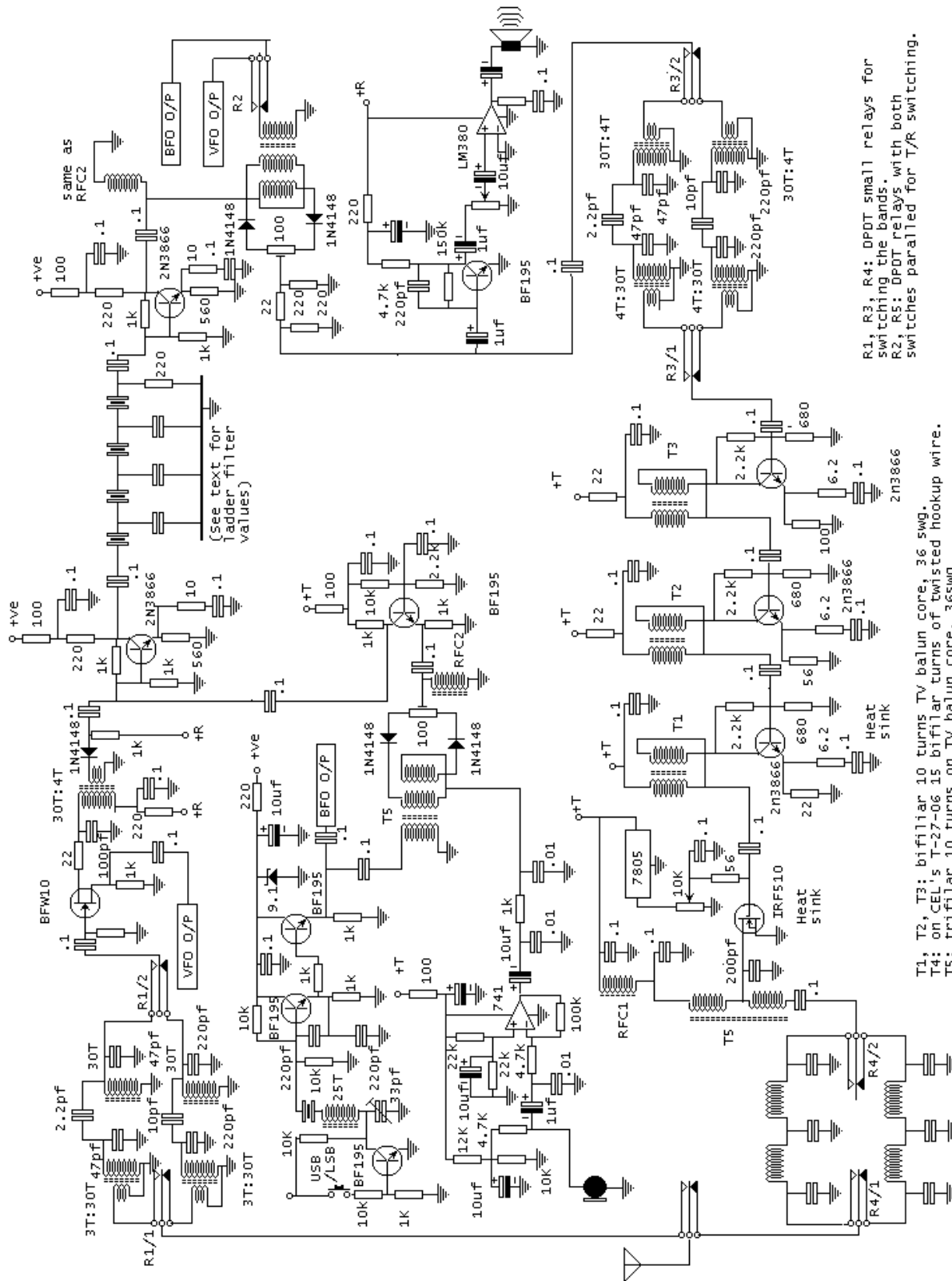
- ▶ Quality over quantity. A better signal is preferred to a bigger signal. This is a 6 watt design that will work off a simple 12V, 1.5A supply (using a single 7812).

The ladder crystal filter

A good filter is central to the crispness of a receiver and the quality of the transmitter. There are two types of crystal filters possible, the lattice filter and the ladder filter. The lattice filter requires ordering crystals with 1.5 KHz frequency difference between them. This was ruled out, also procuring readymade filters from BEL India and other sources was ruled out as it is too expensive to do that. Instead, a ladder filter was chosen. The ladder filter offers results as good if not better than a lattice filter. However, the design is crucially dependent upon internal parameters of the crystals used. It is not possible to suggest any generic values for the capacitors to be used in the ladder filter. Rather, a method to measure each of the crystals and calculate the capacitor values has been worked out. We present this here. This design procedure will work only for 10 MHz crystals. 10Mhz is the chosen IF of our filter as the crystals are easily available and it sits comfortably between 7 and 14 MHz amateur bands. We have followed the Butterworth design methodology given in the new ARRL book 'Experimental Methods in RF Design'.

The circuit centers around a four crystal ladder filter. Each lot of crystals from each manufacturer differs from the others. We will describe a way to experimentally calculate the values of the capacitors for the filter. You should probably buy 10 crystals and select 5 of them.

Circuit of the transceiver



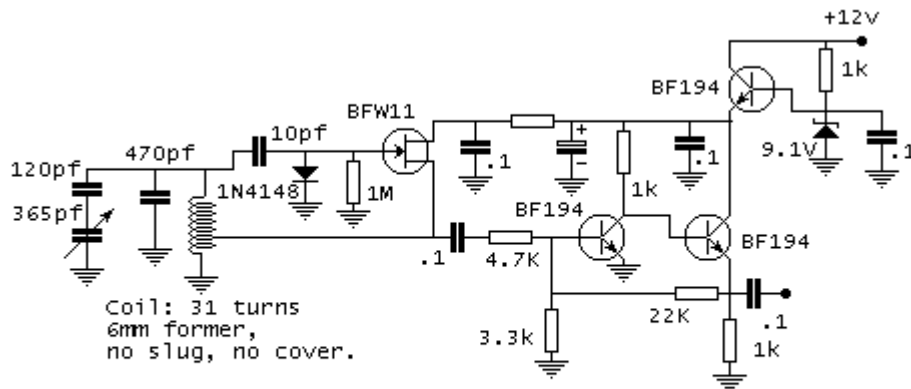
R1, R3, R4: DPDT small relays for switching the bands
 R2, R5: DPDT relays, with both switches paralalled for T/R switching.

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T1, T2, T3: bifilar 10 turns TV balun core, 36 swg.
 T4: on CEL's T-27-06 15 bifilar turns of twisted hookup wire.
 T5: trifilar 10 turns on TV balun core, 36swg
 RFC1: five turns of hookup wire through a PC SMPs toroid.
 RFC2: 25 turns on a 2 watt 100K resistor.

All other coils on 6mm former with ferrite core and shield using 36 swg. Dont forget the shield.

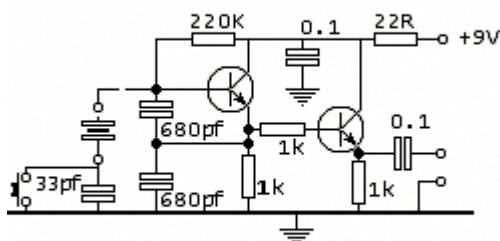
VFO of the transceiver



VFO: Use two identical VFOs using two sections of the broadcast gang, switch power supply for each VFO. The 470Pf should be a polystyrene or a 'Styroflex' cap. The 14 Mhz VFO tunes from 4 to 4.4Mzh.

For this purpose, construct the test circuit of **figure 1**. This is a simple Hartley-style crystal oscillator. You will require access to either a frequency counter or a general coverage receiver (ask a neighborhood ham to allow you to bring over your crystals to his shack and test them for few minutes). Mark each crystal with a number and solder it into the circuit (don't use a crystal socket). Connect the 9 volt battery and measure the frequency. If you are using a receiver, find out the frequency on which the crystal is absolutely zero. Note the frequencies with the 33 pf capacitor in series and shorted. You will have a pair of frequencies for each crystal. Select four crystals with pairs of frequencies that match within 50-40 Hz of each other. A fifth (for the carrier) oscillator crystal should be within 100 hz of the other four selected.

Fig1. Test Oscillator for Filtler Design



Note: Don't use a switch across the 33 pf, use a small component lead to short the capacitor.

Calculate the value of the capacitors of **Fig.2** like this:

1. Calculate the average frequency shift of the four chosen crystals as F (in KHz).

2. $C1 = 21 * F$, $C2 = 40 * F$. Choose the nearest available fixed capacitor. If you can't find a fixed capacitor within 10% of this value, then parallel two capacitors to achieve the capacitance.

For instance, in the case of the first prototype, we measure an average of 5KHz of shift. Thus, the capacitors calculated were 107pf and 200pf. We used 100pf and two parallel 100pfs as a substitute for 200pf capacitors. These calculations are for 200 Ohms termination. For a complete discussion of this design method, you are referred to the excellent paper by Craver in the Communications Quarterly of 1993, Winter.

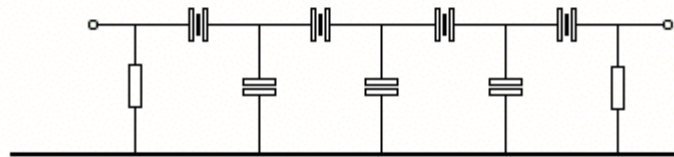
Broad-band design without Toroids

It was decided to use broad-band techniques where suitable and keep the circuit free of too many critically tuned circuits. We decided to investigate the TV baluns as cores for broadband transformers. The TV baluns as small ferrites as shown in the picture.

Almost all the broadband transformers are bifilar. Two (the modulator and the transmit mixer cum product detector) are trifilarly wound. They are simple to produce. Making a bifilar transformer:

- ▶ Take two lengths of 36 swg copper enameled wire.
- ▶ Hold them together. Tie one end to a nail.
- ▶ Twist the wires together so that they cleanly have about 8-10 turns per inch.
- ▶ Check that the wires are evenly twisted (although there will be more twists towards the ends).
- ▶ If the balun core is mounted on a PCB, cut it out with a cutter and remove all the original windings.

Designing a 10MHz SSB ladder filter.



Frequency shift in circuit of Fig 1 was 5KHz
 $C1, C3 = 5 * 21 = 105 \text{ pf}$
 $C2 = 5 * 40 = 200 \text{ pf}$.

We used 100 pf at c1, C3 and 200 pf at C2

- ▶ Pass the twisted pair through one hole to the other side, bend the wire back and pass it back through the other hole (like a U turn). This is one turn, like this, make similar 10 turns.
- ▶ Cut out the remaining ends of the windings leaving about half an inch of the twisted pair on each end.
- ▶ Scrap the enamel off to about quarter inch, and tin the leads.
- ▶ Using a VOM at low ohms setting, identify the two separate windings of the twisted pair. If we call the two wires X and Y, each will have two ends A and B. This you will have four ends AX, BX, AY and BY. Short AX and BY together and use this as the center point of the transformer in the circuits. Use AY and BX as the two opposite ends of the transformers.

Making a trifilar transformer is similar, except that you have to use three wires twisted together. Separate out the three wires as before, use the first two as described above, and the third winding as the secondary.

IF sub-system

The crystal filter and its associated IF circuitry is shared between the receiver and transmitter. Although the crystals are inexpensive enough to be able to afford separate filters for the transmitter and the receiver, we noted that each filter would have a different center frequency. This would make zero-tuning difficult for SSB operation. Therefore, it was decided to share the same crystal filter, carrier oscillator and the VFO between transmit and receive functions.

The crystal filter requires 200 ohms impedance matching at both ends to provide the correct bandwidth and low ripple. A regular practice among hams is to strap a resistor of approximately

the same value as the terminating filter impedance across the input and output ends of the filter. This is incorrect. This looks like a resistor that is paralleled with a reactive impedance of the rest of the circuitry attached to the filter. When the crystal filter is not properly terminated and sees reactive termination, ripple and ringing are introduced. This will spoil the crispness of the receiver and spoil your on-the-air quality.

The crystal filter is terminated on both sides by 'strong' RC coupled amplifiers based on 2N3866. This is slightly unusual. The 2N3866 is used mostly as a VHF power amplifier. It has excellent low-noise characteristics, good gain and using it as a small signal device is now an established practice. The 2N3866 is an expensive transistor. It costs about Rs.20 in the open market. We think it is a good investment.

Using RC coupled broadband amplifiers makes the IF system a 'no-tune' affair. The output of the post-filter amplifier is coupled to a two diode mixer. The two-diode mixer uses a broadband bifilar wound transformer. It is next to impossible to get toroids in India. We have evaluated using TV baluns as substitutes for toroids. These baluns are available at most TV spare shops.

Most designs we have studied couple the RF input to the diode detector through the transformer and inject the BFO at the center of the transformer. This is a wrong practice. The diode mixer requires a minimum of 5mW of energy from the transformer input to operate properly. There should be enough energy to switch on both the diodes. This means about 1.2 v peak voltage. The received signals are rarely this level. As a result, the product detector operates like a regular envelope detector and the diodes act as distortion devices to mix the BFO with the signal. The correct configuration is to inject the BFO across the transformer

An unusual approach is taken here. The IF amplification gain is just enough to maintain good noise figure and recover the losses in the ladder filter. We measured almost 10 dB loss in the filter.

The Receiver

The receiver is minimal. By keeping the number of active devices low (3 devices between the antenna and the audio amplifier), very good fidelity is achieved. The circuit is kept at a low impedance and broadband everywhere except the front-end. This helps in stability.

The front-end uses a low-noise FET. We have used a BFW11 (because the local component shop ran out of BFW10). They have slightly different characteristics. Almost any FET can be used if it is biased properly. The FET should be biased for exactly half the pinch-off voltage. Wes Hayward (W7ZOI) has described the proper way to bias a FET Mixer for proper operation:

- ▶ Short gate and source and measure the current that flows through a 560 ohms resistor connected to +12V through the drain. This gives the exact I_{dss} .
- ▶ Place a 10K resistor between the source and the ground. Keeping the gate grounded and the drain still connected through the 560 ohms resistor, measure the voltage between the source and the ground. This gives you the pinch-off voltage.
- ▶ The FET has to be biased such that the voltage on the source is exactly half the pinch-off voltage and there is half of I_{dss} current flowing through the FET. Such a scheme assures you that the FET is driven between pinch-off and maximum drain by the VFO injected at the source. This gives the proper switching action for the mixer to operate as well as maximum gain. We measured the pinch-off voltage for BFW11s as 2.1 volts and I_{dss} as 5mA. A standard 1K resistor at the source gives the proper bias.

It should be noted here that we first tried a double balanced diode ring mixer at the front-end. It has a number of spurious responses that literally made it impossible to use the receiver. We tried to properly terminate the diode ring mixer by inserting attenuators between the mixer and the Ladder filter's pre-amp. It didn't cure the problem. When we changed to the FET mixer, the noise figure improved, the receiver's dynamic range, while unmeasured, was never found lacking in the last one month of extensive usage at VU2PEP.

The output of the IF amplifier is detected in a balanced detector using just two diodes. Here gain, we break a common myth. You will see most of the HF receivers employing a two diode balanced detector with the BFO fed to the center tap and the incoming signal applied through the primary winding of the detector transformer. This is wrong. The signal applied through the primary winding should strong enough to switch the diodes on and off

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(requiring about 0.6 across each diode, that is, 1.2 volts across the winding). This roughly translates to about 5 mW power. The diodes switch the low level signal coupled at the center-tap of the coil to the detector output. Therefore, in our design we have applied the local oscillator through the primary of the transformer and the incoming signal from the IF stage to the center tap.

There is a 100 ohms preset used to null the local oscillator from appearing at the output. This is of importance during transmit where the balanced detector also doubles up as the transmitting mixer. An audio pre-amplifier follows the detector. The capacitor of 220 pf between the base and the collector ensures that the 'hiss' is kept down. The audio amplifier used is an LM380. Almost any audio amplifier can be used. We have tried everything from the PC's ampli-speakers to a Sony amplifier to a TBA810 amplifier. We would recommend using a high fidelity, low cost amplifier like the TBA810 if you plan using a speaker. If most of your work is with headphones (to save your companion from the late night QRM), we recommend the LM386.

The Transmitter

The transmitter starts with the modulator using a 741. There is a three resistor network that biases the electret microphones. We use a Phillips 'walkman' style headphone with built-in microphone for our work. The electret microphone requires a bias that provides 5V as given by the circuit.

The balanced modulator also had two 22pf trimming capacitors for nulling the carrier. They were later found unnecessary (as long as both the diodes are purchased from the same roll) and removed. If you do find balance a bother, feel free to add a 22 pf trimmer to one side and a 10 pf fixed to the other side as indicated in the schematic.

The output of the balanced modulator is routed to the common IF amplifier through a buffer amplifier using a BF195. This serves to keep the carrier leak from the modulator out of the IF string during the reception mode.

The balanced detector of the receiver also doubles up as a mixer during transmit. It is important to balance out the VFO energy at the output by setting the 100 ohms trimmer properly. We noticed a 50mW residual out-of-band output from the transmitter when the VFO is unbalanced. The power chain is an interesting broadband amplifier. You can use this in virtually any transmitter of up to 7 watts (and higher with more than 12 volts supply to the final stage). Three stages of broadband amplifiers feed an IRF510 PA. It is an interesting twist that the driver 2N3866 transistors cost more than the IRF510! The IRF510 should be biased for 80mA of standing current during transmit with the microphone disconnected (no modulation) and carrier nulled by the trimpot of the balanced modulator.

Construction

We heavily recommend constructing over pieces of un-etched PCBs. They are cheaply available everywhere. See the pictures as a guide to component layout. We recommend the following rules:

- ▶ Keep your leads short. Short connections are more important than components that are at right angles to each other. What might look neat to you might look unstable to the RF design.
- ▶ Keep the outputs and inputs isolated from each other. We have taken care to keep the high impedance points down to a minimum. But still, maintain design hygiene.
- ▶ Make one module at a time, test it completely, then move to the next one. Construct the transceiver in the following steps:
 - ▶ Make the VFO. Check the RF output using an RF probe. Check the stability on a regular receiver or a frequency counter. With the tuning capacitor fully closed (the plates inside each other), set the trimmer so that the VFO frequency is exactly 3.9995 MHz (keep 5 KHz margin at the band end)
 - ▶ Make the BFO. Check the output on the RF probe.
 - ▶ Calculate the ladder filter values and make the IF strip along with the audio preamplifier.
 - ▶ Connect the BFO, VFO, IF strip and an external audio amplifier together. When you power on and attach a piece of 2-3 meter long wire to the input of the IF amplifier you should be able to hear the atmospheric noise. Tune the BFO coil by fully screwing the slug in and then slowly tuning it out until the IF noise sounds right (not too shrill and not too muffled).
 - ▶ Wire up the receiver mixer, connect the VFO. Peak the mixer output and the RF input coils for maximum output. Then tune to a weak signal on the band and tune for the best signal. Be careful to tune for best quality of signal and not for maximum loudness. Take a break, spend a day or two listening to the band with your receiver. Nothing is more enjoyable than using a crisp receiver that you have homebrewed.
 - ▶ Wire up the modulator. If you have an oscilloscope, you can check the modulation. The modulated output will be too low for you to be able to measure on the RF probe.
 - ▶ Wire up the linear chain. DON'T solder the IRF510 yet.
 - ▶ Put the transceiver in transmit mode. Whistle into the microphone and peak the transmit mixer output coils for about 6 volts peak RF voltage on the probe at the 56 ohms resistor where the gate of the IRF510 would be.
 - ▶ Solder in the IRF510. ATTACH A DUMMY LOAD. We used four 220 ohms two watts resistors paralleled together.

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- ▶ Keep the bias trimmer totally down towards zero. Attach VOM in series with point X in the power amplifier. Apply power in transmit mode and slowly increase the bias until you have 80mA flowing through the IRF510.
- ▶ Connect the RF probe across the dummy load.
- ▶ As you whistle, you should get about 20-24volts of peak RF on the probe. When you pull out the microphone from the jack, the RF output should drop to complete zero. What if your transmitter is unstable?

- Don't curse your fate. All transmitters start out as unstable beasts. Relax.
- Start disconnecting power from the stages starting from final IRF510 and working backwards. When you have located the unstable stage, there are a number of things you can do to fix it.
- Try increasing the value of the 10 ohms resistor used in the emitter degeneration OR
- Strap a resistor of about 1K across the output transformer of the unstable stage to 'load' it.
- Move the linear amplifier away from the rest of the circuitry.
- Redo the board. This time spread the stages out. We guess that the linear chain should occupy about 6 inches of space, all laid out in one line.

Substitutions

The BF195 transistors can be substituted with any other HF transistor like 2N2222 etc. The 2N3866s are best not substituted. The circuit works with slight increase in the noise figure if BF195 or equivalents are used in place of 2N3866s in the IF stages. The output power on the transmitter absolutely needs the 2N3866s. Substituting them with other switching transistors didn't give good performance.

The IRF510 should not be substituted with any other transistor. The other IRFs, though rated higher, have higher input capacitance which makes them a bad choice for 14MHz operation.

The LM380/LM386 can be substituted with almost any other audio amplifier. Our first amplifier was Cambridge SoundWorks Sound System. If you turn down the bass, they are an excellent system for the shack. We have tried a TBA180, an LM386, an LM380 and even a glow-bug guitar amp. Feel free to experiment.

Final Notes

The first contact we made using this rig was DF6PW. He reported us 57. Within the first evening we had worked four continents. The rig is regularly used at VU2PEP. People are often surprised at how the transmitter quality is 'just like a commercial rig'. Many refused to believe that it is a seven watt rig.

72/73!