Operationalising the direct conversion HF SSB transceiver

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1. Introduction

This third document describes how the direct conversion transceiver was made into an operational Ham station.

The challenges were to increase the power output to some 50 or 100 W in a controlled way, reduce harmonics on transmit and couple efficiently to the installed attic end-fed wire antenna.

The decision was made to rely on purchased modules where possible and to focus on three bands initially, being 80, 40 and 20 m.

2. Increasing the power

To increase power, two wide band RF amplifiers were initially selected, the first being an RF Driver with an output of about 3 W and the second a MOSFET RF Power Amp with a maximum output of 100 W. Both were purchased from the Chinese firm Lusya via AliExpress.

Several restrictions exist with these. The RF Power Amp cannot tolerate a VSWR of higher than 2:1 and its power gain is fixed at some 14dB. The RF Driver has a fixed gain of 37 dB. Neither is well documented.

The RF Power Amp has a PTT input, which means that the output can be blanked during Rx by using one transceiver change-over relay contact.

The maximum power the above setup could deliver, was about 50W. Thus, the RF Driver was replaced by one that could deliver 30W with a gain of 40 dB but would be restricted to some 4W. This allowed the full 100W output from the RF Power Amp. Unfortunately, it does not function well in the 80 m band where the signal is clipped and thus the initial RF Driver is used in that band with the resultant reduced output.

In dBm, the RF Power Amp has an output of 50 dBm (100 W) from an input of 36 dBm (4 W), i.e. a 14 dB power gain. The RF Driver just needs -4 dBm (0.4 mW) input to produce its output of 36 dBm.

3. Being able to vary the output power

The transceiver output level is about 13 dBm or 20 mW into 50 ohm.

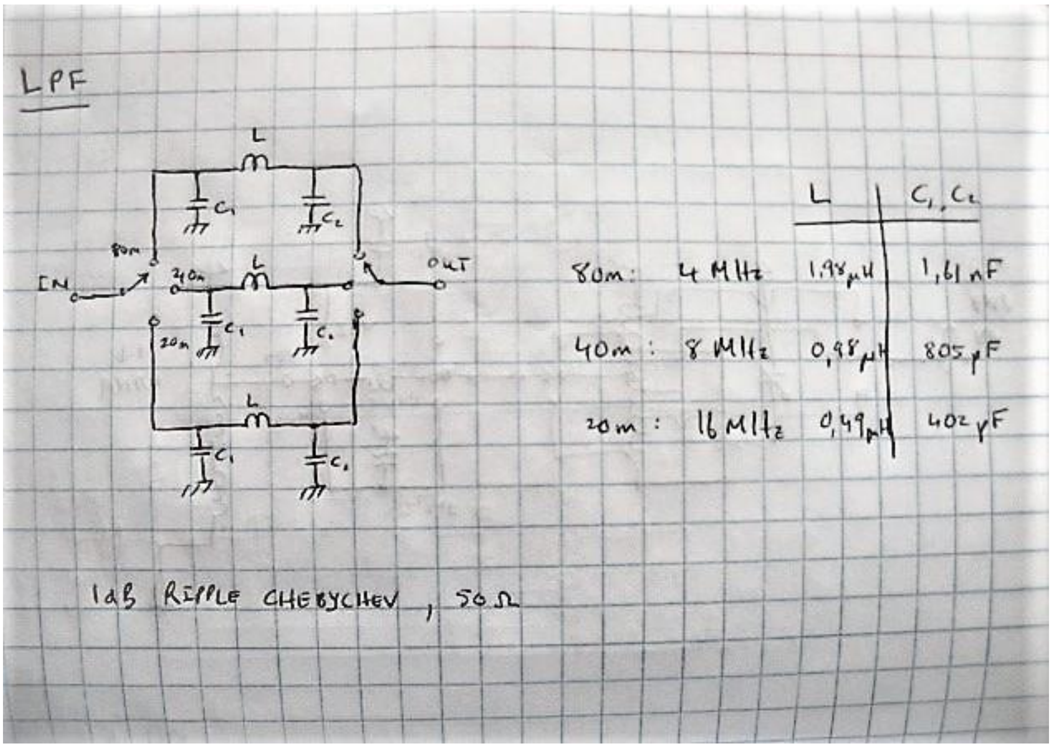
The transceiver output signal level is somewhat different for every band. Combined with the fixed 37 or 40 dB gain of the RF Drivers, which either needs a 0 dBm or a -4 dBm signal to produce required output; and the need to be able to increase or decrease power, a 60 dB pushbutton step attenuator is inserted between the transceiver and the RF Driver. This means that the signal level can be tightly controlled and predetermined and -selected for every band.

The output power into the antenna is determined as described in 9.2 (ii) below.

4. Reducing harmonics

The transceiver output is not free of harmonics and both the driver and the power amp create some harmonics. Thus, the power amp is followed by a band-switched 3 pole low pass filter (LPF1), home designed, using the York university website [*https://www-users.cs.york.ac.uk/~fischer/lcfilter]*. It is a 50-ohm Chebyshev 1 dB ripple design and has cut-off frequencies of 4, 8 and 16 MHz for the three bands respectively.

The coils were hand wound, empirically achieving the required inductance using the author's L-C meter. The conductor and switch need to be able to carry several amp. Initially ferrite cores were used but they were not rated adequately, causing saturation and overheating.



LPF2 has a cut-off frequency of 16 MHz and is the same design as LPF1.

Check the VSWR of each filter at each band using the SARK100 (see below) with the output connected to a 50-ohm dummy load. This is to ensure that component tolerances have not changed the impedance outside the acceptable VSWR limit.

5. Coupling to the antenna

Following LPF1 is a home-built reflectometer (from the 1968 ARRL Radio Amateur's Handbook) since the limit of 2 on the VSWR is very important.

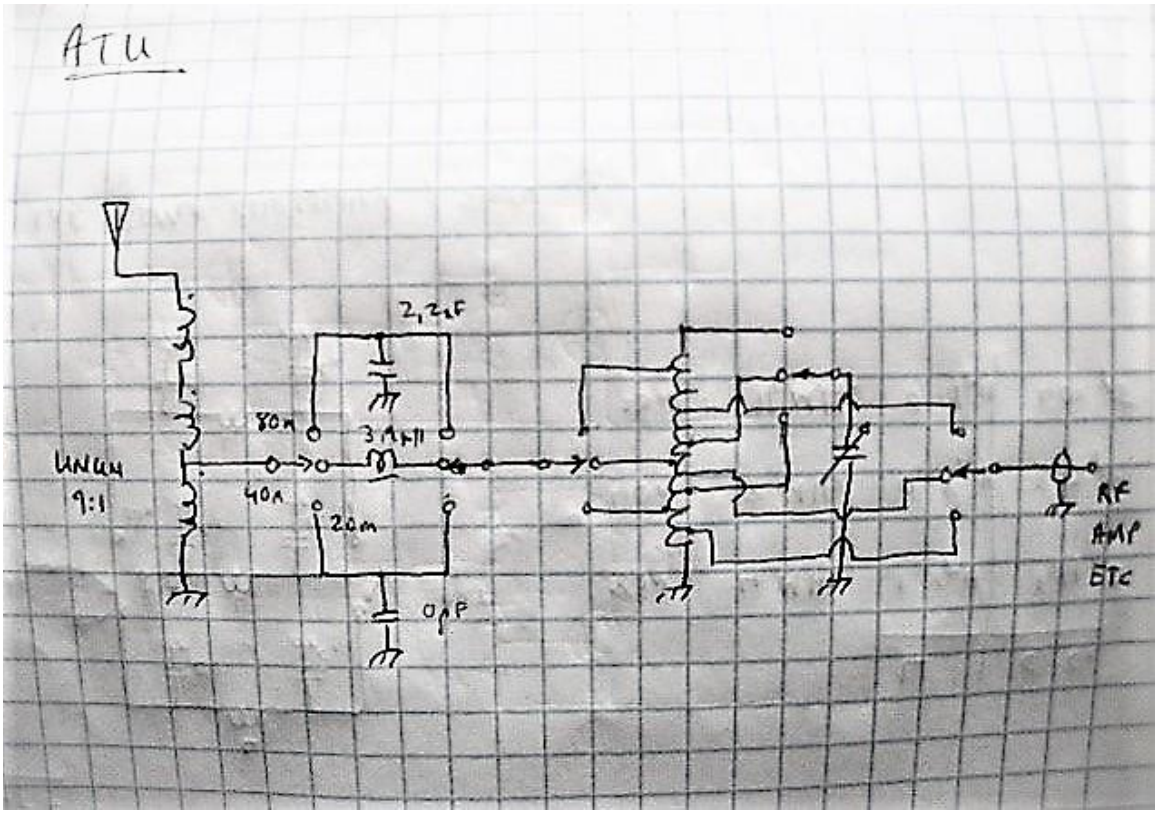
There are restrictions on outside antennas as the author lives in a security complex, thus an attic antenna is just about the only option. Three core 15 A power cable was used with the 3 conductors soldered together at the ends.

An attic end-fed wire antenna (respectable radio amateurs will flinch at the mere thought of calling it an antenna and may settle for "a piece of wire" if they are in a particularly good mood) was decided on as a starting point and was the biggest challenge. Its length of some 16.75 m, the length in the attic plus the down feed, means that it is much shorter than half wave on 80 m, shorter at 40 m and longer at 20 m.

Practical centre-fed half-wave dipole antennas have an almost purely resistive impedance of some 50 ohm, thus coupling to rf amplifiers of the same (industry standard) output impedance is easy. If the antenna is shorter or longer, the impedance becomes inductive or capacitive respectively and the resistive component also changes. To ensure maximum power transfer to the antenna, the reactive components must be cancelled out and the resistive component matched.

To accurately compensate for the reactive components of the attic antenna impedance on the different bands; and to be able to match the resistive component to the 50-ohm power amp output, it was decided to purchase a budget antenna impedance meter and SWR bridge with an internal frequency source (SARK100, again from China).

The ATU is home designed as follows. The coil forms a tuned circuit with the variable capacitor and can compensate for small reactive components. It also acts as a transformer for matching the RF Amp and antenna impedances. Connections to the coil are by means of a selector switch, crocodile clips or banana plugs, with pre-set connections determined for the different bands.



Since the antenna is end-fed, impedances tend to be high as half and full wavelengths are approached. The measured antenna impedances are (Z = R + jX):

Band (centre freq.)	R (ohm)	X (ohm)
80 m (3.65 MHz)	21	j21
40 m (7.1 MHz)	90	-j174
20 m (14.17 MHz)	58	j24

To measure the above at 40 an 20 m with the SARK100, a 9:1 UnUn had to be inserted between the meter and the antenna, since the impedances and SWR are so high. All the values in the table above need to be multiplied by 9 to get the true impedance.

At 40 m the reactive component is capacitive, as indicated by the negative sign in the table above, so to cancel it out a coil of equal reactance can be put in series with the antenna. At 80 and 20 m the reactance is inductive, so a shunt capacitor of equal reactance can be used. Or reactances can be inserted at the amplifier end.

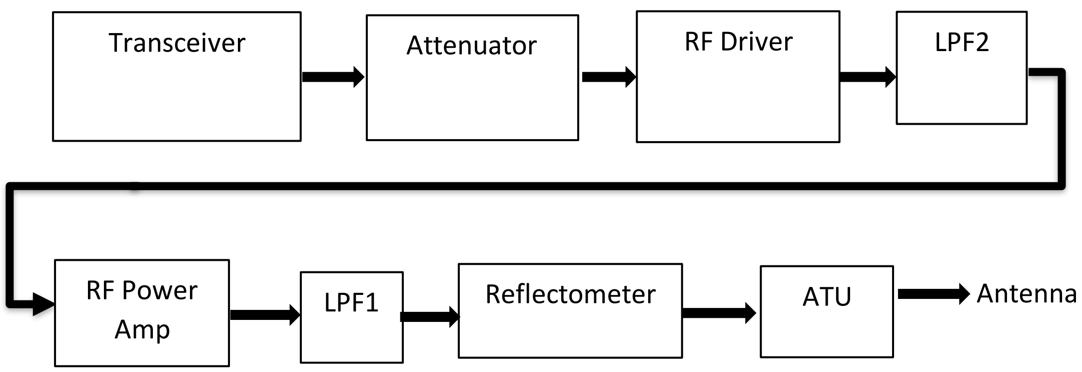
6. Power supply

All the above active modules are powered by an efficient switching power supply capable of delivering a continuous 20 A between 12 and 14 V.

7. Tx / Rx switching

The ATU plus antenna is switched between Tx and Rx by a changeover relay using the Tx / Rx signal from the transceiver.

8. Simplified block diagram (transmit)



9. Setting up

9.1 Matching the impedances

It was decided to keep the 9:1 UnUn in the antenna circuits for simplicity of switching and to bring the impedances closer to 50 ohm.

Calculate the required inductance or capacitance to balance out the measured reactance, L = X / 2*π*f and C = 1 / 2*π*f*X.

The correct tap for the resonating frequency of the ATU tuned circuit is determined per band.

Remember that transformer impedance varies as the square of the turns ratio. In simplified form, Z1 / Z2 = n1*n1 / n2*n2. After some mathematical manipulation, n2 = n1*SQRT (Z2/Z1). For the single winding auto trfr of this ATU, n1 will be the number of turns on the coil where the antenna connects, n2 the required tap position, Z1 the impedance of the tuned circuit, Z2 the amp impedance.

If the measured impedance of the antenna is e.g. 100 ohm and n1 is 20, then a 10-ohm tap will be at 20*SQRT (10/100) or at turn 6.3. Or a 50-ohm tap will be at turn 14.1.

In this case there are three "windings": the tuned circuit, the antenna, and the amp. Very little power will flow in the tuned circuit and most of the power will flow from the amp to the antenna. So the tuned circuit is ignored for these calculations.

Start off with an antenna tap of some 50% of the winding for that band and calculate the amplifier tap per band.

9.2 Testing

(i) Minimizing VSWR.

Per band tune the ATU to the resonant frequency.

Since the impedance measurement and calculations will not be exact, for example because in the author's case the ATU coil winding spacing is not even and the measured impedances would be influenced by the test conductor length etc, the optimal configuration needs to be determined empirically for minimum SWR. Tap positions, tuning capacitor setting, and compensating reactance value can be changed; adjusting the tuning capacitor in a small band around the resonant frequency compensates for residual inductive or inductive impedances. The optimum combination of the above is first checked with the SARK100 (for minimum SWR) and then at low power with the amplifiers and the reflectometer, with the SARK100 being the signal source instead of the transceiver. "Low power" is relative, the reflectometer requires a few watt to register. Initially only the RF Driver was connected to the ATU for setting up, then the RF Power Amp was inserted after checking that nobody was using that frequency.

The initial testing was bedevilled by the RF Driver seemingly oscillating at some VHF/UHF frequency which showed spurious and large deflections on the reflectometer (by design it is frequency sensitive and thus even small UHF signals can cause large deflections). Unfortunately, the available oscilloscope has a bandwidth of only 25 MHz so none of this could be accurately measured or seen. The oscillations started or stopped when the RF Driver or the attenuator were touched by hand and putting them on a metal ground plate controlled the situation. (The RF Driver has a bandwidth of 60 MHz so the guess is that it oscillated around there.)

In addition, the RF Driver was a class A linear amplifier, it clipped the signal for larger outputs and could not supply the 4 W required by the RF Power Amp. Thus the decision to replace it with a 30 W class AB driver, limited to 4 W.

The end-fed antenna of course has the (unforeseen by the author) characteristic that it radiates not only in the attic but actually from where it is connected to the ATU, inside the room / shack, in proximity to all the other equipment. This means that unwanted feedback can occur (probably causing the spurious oscillations mentioned above) and that testing and measurement becomes difficult because all the equipment needs to be screened. The speaker leads had to be bypassed at the chassis with 1 nF capacitors.

Initial testing showed that the VSWR increased with output power, which was probably caused by increased harmonics. The solution was to put another LPF, LPF2 in the chain.

Finally testing from the transceiver took place after carefully checking all connections and the Tx/Rx change-over controls.

(ii) Attenuator settings.

To find the appropriate attenuator settings per band, to ensure consistent output across the bands and that the PEP (Peak Envelope Power) does not exceed the rating of the amp, connect a 50-ohm dummy load to the RF Power Amp. If a peak-reading wattmeter is not available, connect an oscilloscope across the dummy load, set the time base to say 1 ms per division, speak a test message into the microphone and use the highest (RMS) voltage to calculate the PEP. The transceiver AGC will ensure a limit to the voice volume which means that even sharp sounds will not cause the PEP to be exceeded. Note that the y-axis of the oscilloscope probably reads peak voltage, the value must be divided by 1.4 to find RMS.

Start off with maximum attenuation and then reduce to obtain maximum rated output (PEP). Note the attenuator setting for that band.

The following table could be useful:

Vrms	Vpeak	Power (watt) into 50 ohm
7.1	10	1
10	14.1	2
15.8	22.4	5
22.4	31.6	10
31.6	44.7	20
50	70.7	50
61.2	86.6	75
70.7	100	100

Safety warning: Note the potentially lethal (>50V) voltages at the higher outputs! With the 9:1 UNUN before the antenna, this translates into voltages three times the above at the antenna. Ensure that all metal chassis are properly earthed.

The output power can be confirmed again when the RF Power Amp is connected to the ATU and antenna by measuring the voltage where the amp connects to the ATU.

10. Replacing the transceiver VCO with an external oscillator

Direct Digital Synthesis (DDS) signal generators, with dual output channels and where these two outputs can be synchronized with a selected phase angle (90 degrees of course in this case) have become available at a very reasonable cost from China, approx. US $ 80.

It was difficult to screen the internal VCO from self-interference when transmitting at 100 W, which manifested itself as the frequency jumping around at times.

Thus, the decision was made to replace the internal VCO of the transceiver, with its quirky tuning, with such an external DDS signal gen. The frequency adjustment is remarkably simple, stability and accuracy are excellent and the output levels of the oscillator signals that go into the balanced mixers can be easily adjusted for optimal signal detection performance.

Setting the signal generator to a sine wave between 0.7 and 2.6 Vp-p was found to be the best, with the lower value actually producing the clearest signals in Receive but also the lowest output power in Transmit, which can fortunately be compensated for by reducing attenuation.

See the photograph below for the complete ham station.

11. Conclusion

First of all, an indication of cost. The expensive items, being the attenuator, driver, power amp, power supply and impedance meter, cost about US $ 550, which is considered reasonable. In addition, the DDS signal gen cost about US $ 80.

Performance is acceptable and exciting!