Homebrew

We look at the phasing method for SSB and CW.

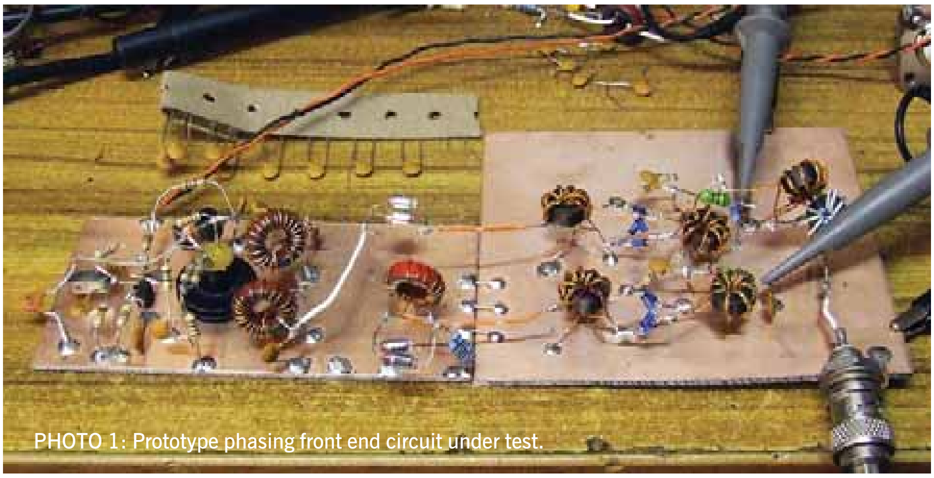


PHOTO 1: Prototype phasing front end circuit under test.

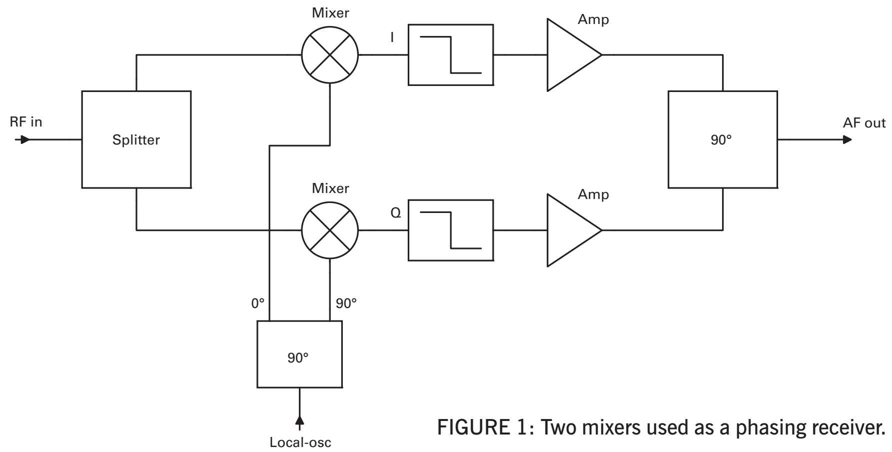


FIGURE 1: Two mixers used as a phasing receiver.

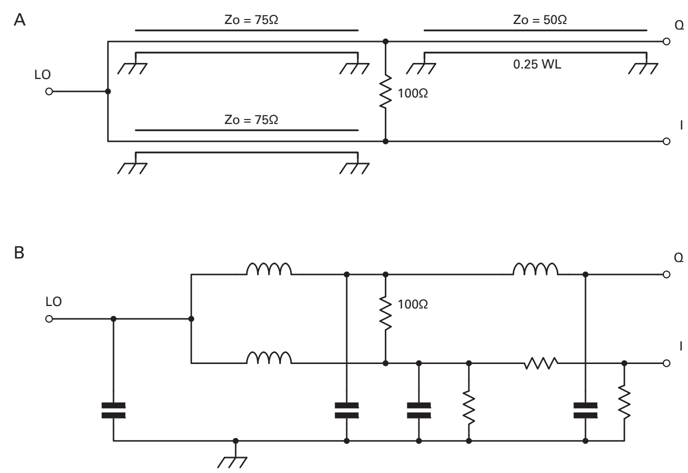


FIGURE 2: Generating a quadrature signal by (a) a coaxial delay line at or above VHF and (b) using lumped components at lower frequencies.

CHEAP & EASY. The phasing method offers a simple and inexpensive way of achieving true single-signal CW and SSB reception. In the early days of SSB voice transmission, phasing SSB transceivers were widely used on the amateur bands. When crystal and mechanical SSB IF filters became available at a reasonable cost, the phasing method fell out of favour with many amateurs. Pre-packaged SSB filters offered single-signal selectivity in a convenient and well screened tin can. In more recent times, phasing methods of SSB generation and reception have seen something of a revival. The tight tolerances and good long term stability of modern components make them well suited for use in phase shift networks. Some of the more tricky circuits, like wide bandwidth AF phase quadrature circuits, can be implemented numerically using digital signal processing (DSP).

The simple direct conversion receiver is capable of excellent performance. It is not too difficult to build a direct conversion rig that has excellent sensitivity, good selectivity and a high dynamic range. The biggest and perhaps the only major problem with a simple direct conversion receiver is its total lack of image rejection. If we are willing to trade extra complexity for greatly improved performance, it is possible to build a single signal direct conversion receiver.

Rejection of the unwanted image signal is achieved by using an 'image rejection mixer' (IRM) that is usually made from a pair of conventional balanced mixers or double balanced mixers and a pair of 90° hybrid circuits. There are a number of reasons why we might want to suppress the unwanted image signal. On the busy short wave bands, there are obvious advantages to removing the image signal. Signals on the image frequency are very likely to interfere with the wanted signal. Even on a quiet band, removing the image also halves the effective bandwidth of the receiver. This can improve the receiver noise figure by up to 3dB, which is a significant improvement for a VHF/UHF receiver.

METHODS. The two most commonly used methods of SSB reception are known as the 'filter method' and the 'phasing method'. There are several different variations of each method and it is quite common practice to use a combination of the two. The filter method uses a frequency mixer to convert the RF signal to an intermediate frequency (IF) and a very selective band pass filter to remove the image signal. The IF filter is usually a high Q crystal, ceramic or electro-mechanical filter. The phasing method uses phase cancellation to suppress the unwanted image signal. **Figure 1** shows the configuration of the most common type of phasing receiver. A pair of mixers are used instead of the single mixer that would be used in a filter method receiver. The RF signal is split into two separate paths using a splitter/divider circuit. Phase-quadrature local oscillator signals are fed to the LO ports of the mixers. Phase-quadrature means that there is a 90° phase difference between the two LO signals. The output from the mixers can be an intermediate frequency as with the filter method, or an AF baseband signal in the case of a direct conversion receiver. The two mixer outputs are referred to as the in-phase (I) and quadrature (Q) signals. The two LO signals should have equal amplitude and accurate phase quadrature. The two RF signals should be in phase and of equal amplitude. If the two frequency mixers are absolutely identical, the AF baseband signals at the IF ports will also be in phase quadrature. If the I/Q baseband signals are fed to a 90° shift network and the two outputs of the phase shift network are added together in a summing circuit, the wanted signal will be reinforced and the image signal will be eliminated by phase cancellation. By swapping the I and Q outputs, it is also possible to reinforce the image and cancel the wanted signal. This provides a convenient method of USB/LSB mode switching in a direct conversion receiver.

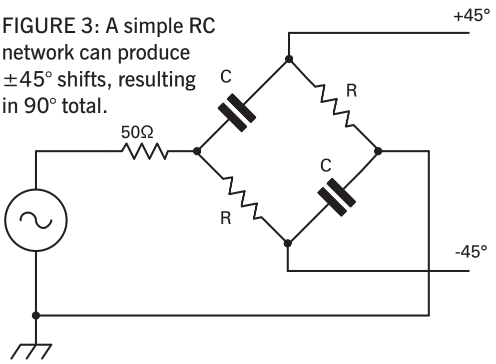


FIGURE 3: A simple RC network can produce ±45° shifts, resulting in 90° total.

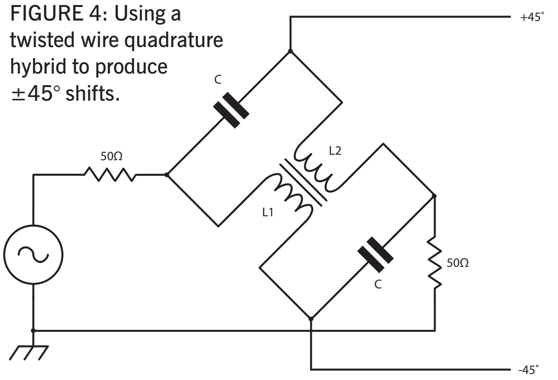


FIGURE 4: Using a twisted wire quadrature hybrid to produce ±45° shifts.

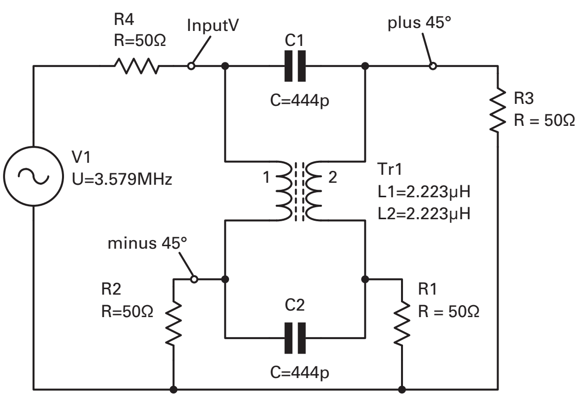


FIGURE 5: Simulating the 90° hybrid using QUCS.

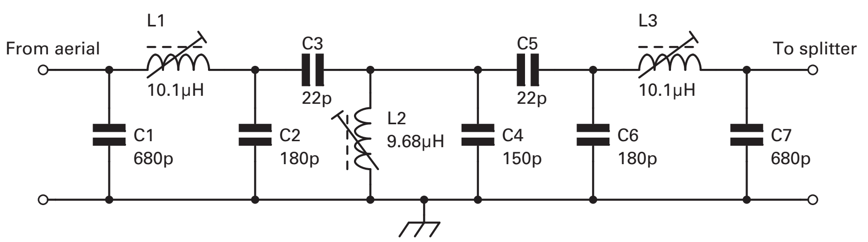


FIGURE 6: RF bandpass filter for the 80m phasing front end.

The mixers in Figure 1 are quite conventional and of the same type that would be used in a filter method superhet receiver. Balanced or double balanced mixers (DBM) are recommended because the improved port to port isolation of the DBM reduces the possibility of AM breakthrough in a DC RX. DBMs also give better isolation between the I and Q channels of the receiver.

There are many ways of generating a phase quadrature signal. A combination of a power splitter and a quarter wave transmission line is one possible solution. One port of the splitter provides the 0° signal, the signal from the other port is sent (delayed) through a quarter wavelength of transmission line to provide the 90° signal. **Figure 2a** shows how a Wilkinson divider can be used to split the LO signal and a quarter wavelength of coaxial line or PCB microstrip can be used to provide a 90° phase shift, a method popular at VHF/UHF. **Figure 2b** shows the lumped component equivalent of this circuit, suitable for use at HF. This version uses an LC Pi network to provide the 90° phase shift. The resistive attenuator on the I port has loss that is equivalent to the losses in the LC network so that perfect amplitude balance is maintained. It is relatively easy to make a phase shift network for the LO of a single band receiver. Perfect phase quadrature will only be achieved on a single frequency, but reasonable results can usually be achieved over an entire amateur band.

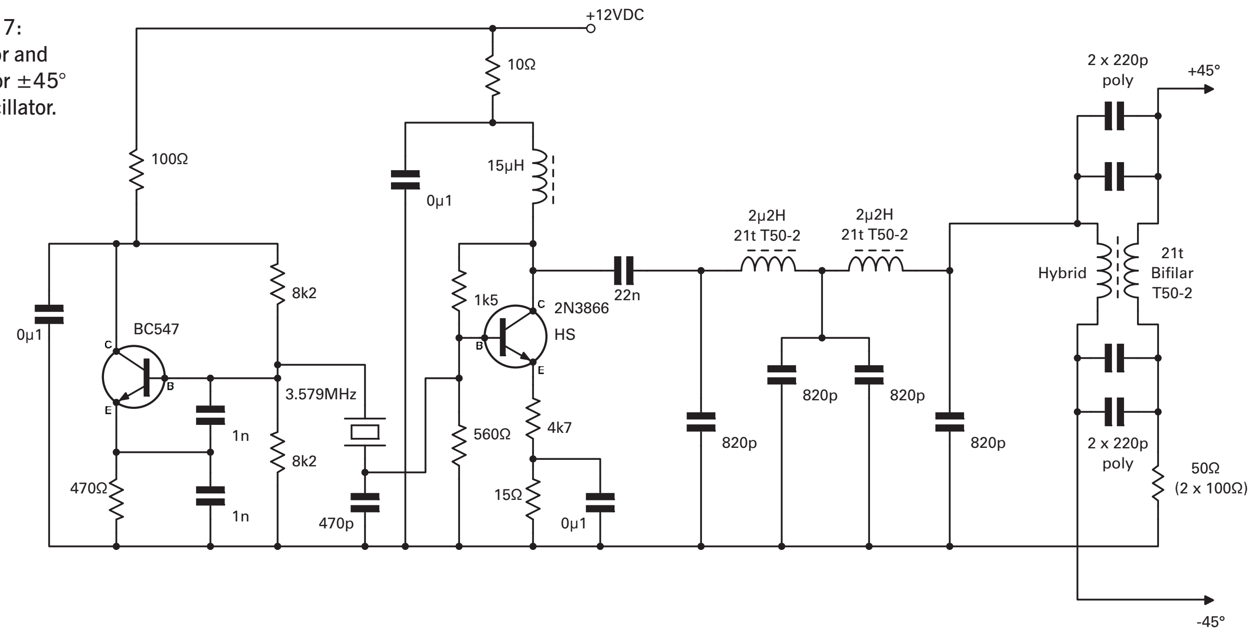
The design of audio phase shift networks is a lot more difficult. A simple RC or LC network may produce acceptable results for use in a CW receiver with very narrow bandwidth but for SSB and other relatively wide bandwidth modes a different approach is required. **Figure 3** shows one of the most popular types of RF phase shift network. To achieve a 90° phase difference between the outputs, the reactance of C should be equal to R. The outputs should be terminated in an impedance that is much greater than R. Any loading of the outputs will result in phase and amplitude errors.

The twisted wire quadrature hybrid **[1]** provides a very simple and elegant method of generating phase quadrature signals. This 90° 3dB hybrid combines the functions of the power splitter and quadrature circuit using just five components. **Figure 4** shows the hybrid circuit. L1 and L2 have a reactance of 50Ω (XL=50Ω), C has a reactance of 100Ω (XC=100Ω). The plus and minus 45° outputs must have a 50Ω termination. The remaining port must be terminated by a 50Ω resistor. This terminating resistor will not dissipate any of the input power when the other three ports are correctly terminated. **Figure 5** shows a QUCS simulation of the 90° hybrid. The component values are chosen for a LO frequency of 3.579MHz so that C = 444.7pF and L = 2.223μH.

The capacitors should be polystyrene or other high stability types. L1 and L2 form a transformer. Both wires are twisted together and wound on a powdered iron or ferrite core. This ensures tight coupling between the two windings. It is possible to make an audio frequency version of this hybrid circuit, but you would need to use a large ferrite pot core for L1/L2. Large transformers with a good low frequency response are not desirable in the front end of a direct conversion receiver because they can cause instability in the very high gain AF amplifiers or act as a microphonic pickup for mechanical vibration. For a hybrid that is optimised for a frequency of 700Hz (typical for a CW receiver), the required value of L would be 11.37mH.

A PHASING RECEIVER FRONT END. This month's construction project is a phasing receiver front end that can be used in a conventional analogue phasing receiver or as an RF front end for a computer based SDR (software defined radio). I have been planning to build some SDR projects for several years. My interest in SDR was renewed recently when I received a gift of a

FIGURE 7: Oscillator and hybrid for ±45° local oscillator.



SoftRock-40 SDR receiver kit (thanks Jerry). The SoftRock-40 is a small and relatively simple 40m phasing receiver. The image rejection mixer used in this receiver is a quadrature sampling detector known as a Tayloe Detector (after its inventor Dan Tayloe, N7VE). The SoftRock version of the Tayloe detector uses a high speed bus switch as the detector and digital logic ICs to provide square wave quadrature LO signals.

Despite its small size and apparent simplicity, the SoftRock is capable of excellent RF performance. Used in combination with a good quality sound card and SDR software, the SoftRock offers advanced features like variable bandwidth DSP filters, automatic notch filtering, noise blanker, second receiver and as many modes as are supported by the software. As the software is constantly under development, there is no limit to the potential for future improvements. New modes, improved features and bug fixes can be added without modifying the hardware.

The phasing receiver described here uses a pair of diode DBMs as an image rejection mixer. I would probably have used a Tayloe circuit if suitable components were available. I used a pair of home made mixers of the type described in January 2009 Homebrew. A pair of pre-packaged DBMs can also be used in this circuit. The RF ports of the mixers are fed with in-phase RF signals using a broadband power splitter. A pair of common-base transistor amplifiers are used for post mixer amplification.

CONSTRUCTION. This project uses some of the modules from previous Homebrew projects. The RF BPF is lifted from the DC RX project in February 2006. The BPF circuit is shown in **Figure 6**. The three inductors are 25 turns on a Toko 10K type former. If 10K formers are not available, you can use 45 turns on T50-2 toroids for L1, L2 and L3. Trimmer capacitors in parallel with C2, C4 and C6 can be used for tuning the filter.

All stages of this project were built dead-bug style on copper PCB laminate. The local oscillator is based on the test oscillator from January 2009. I used a BC547 in the oscillator and a 2N3866 transistor as the buffer amplifier. This stage requires a heatsink. The LO and quadrature hybrid circuits are shown in **Figure 7**. The quadrature hybrid is made from a twisted pair of enamelled copper wires wound on a T50-2 core. I used 0.15mm wire, but the exact size shouldn't be too critical. The 50Ω terminating resistor is made from a parallel pair of 100Ω 1% tolerance resistors (Maplin M100R or similar). L1/L2 is 21 turns bifilar wound. I used a pair of 220pF polystyrene capacitors connected in parallel to make the 444pF capacitors for the hybrid circuit. This is close enough to the required value, especially if the SDR software has automatic phase/amplitude calibration. The mixers are two rings of 1N5711 diodes. The transformers used in the mixers are each 7 turns, trifilar wound on an FT37-43 ferrite core.

It is essential that the two mixers are absolutely identical. You can use a pair of commercially made DBMs instead of building your own. The local oscillator drive to each mixer is about 4V p-p, which is 40mW (or +16dBm). If you use level-7 (+7dBm drive) mixers like the SBL-1, you may need to reduce the LO level by using fixed attenuators at the mixer LO ports. Each mixer is followed by a simple diplexer. The 47Ω resistor provides something resembling a 50Ω termination at the RF and LO frequencies. The 100μH choke and associated capacitor form a low pass filter. The cutoff frequency of this LPF is 100kHz, which is higher than usual for a phasing RX. This allows us to use this circuit with PC sound cards that have sampling rates of 96ksps or even192ksps.

The BC547 transistors were chosen because they were readily available rather than for optimum performance, but they seem to perform well in this circuit. The RF splitter transformer T2 is 10 turns bifilar wound on a FT37-43 core. This splitter is designed for 50Ω termination of both output ports. The input of the splitter should be driven from a 25Ω source. T1 is a 50Ω to 25Ω transformer. The winding of T1 is 10 turns of insulated hookup wire with the 25Ω tap three turns from the top. The circuit of the IRM including mixers, post mixer amps and RF power splitter is shown in **Figure 8**.

TESTING. The local oscillator and phase quadrature units were tested first. I used four 100Ω resistors to make a pair of 50Ω terminations for terminating the ±45° outputs during the tests. If you have a well-calibrated dual trace oscilloscope, you can use it in XY mode to check the phase accuracy of the quadrature outputs. When the circuit is working properly, the scope will display a perfect circle. **Photo 1** shows the prototype circuit under test. There is no provision for adjusting the phase of the output signals in my prototype circuit. The SDR software I will be using has a clever phase/amplitude calibration routine that can be used to tune out small phase and amplitude errors. If you will be using this circuit with an analogue back-end, it would be possible to use a pair of trimmer capacitors in the quadrature hybrid to fine-tune the phase quadrature accuracy. You can simplify this trimming circuit by using a handy tip from K0JD: “Eliminate C2 and make your C1 twice the value (ie 50Ω reactance at the chosen frequency). This is what I'm using lately to save variable capacitors!” **[1]**.

There are no adjustments to be made on the image rejection mixer unit. If an oscilloscope is available, you can check the

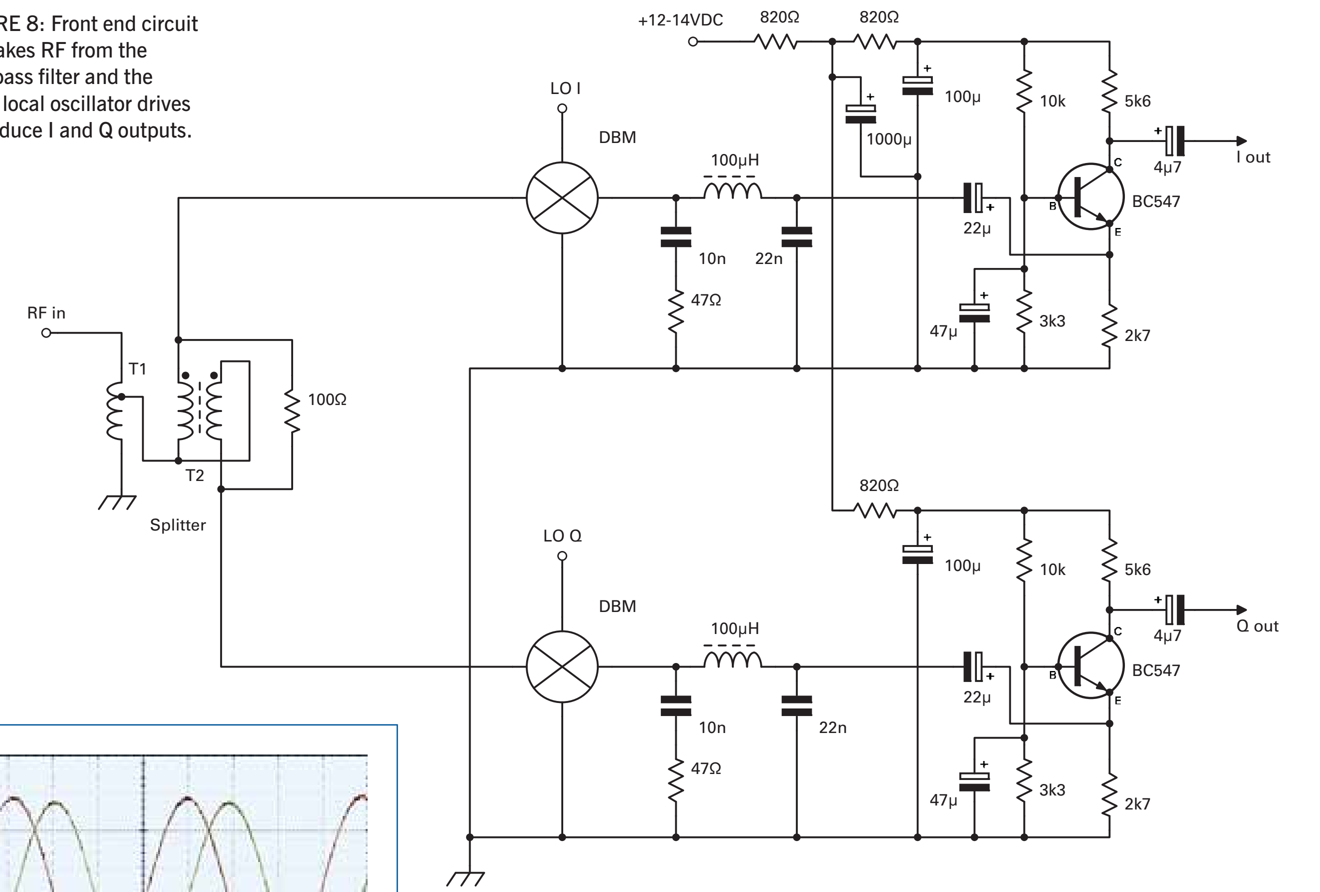


FIGURE 8: Front end circuit that takes RF from the bandpass filter and the ±45° local oscillator drives to produce I and Q outputs.

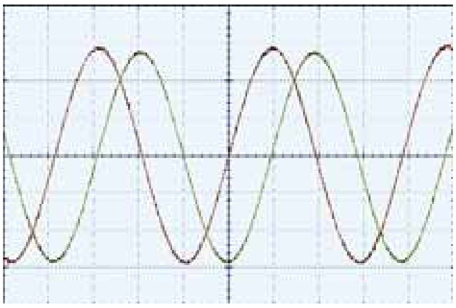


FIGURE 9: The I and Q audio outputs at 500Hz. Note how one sine peaks as the other crosses zero – a perfect 90° phase relationship.

LO level on the RF and IF ports of the mixers to make sure that they are correctly balanced. I see more than 45dB LO to RF and LO to IF isolation on both mixers. When the RF BPF, IRM and LO/quadrature modules were all wired together, I connected a signal generator to the RF input and used a dual-trace oscilloscope to monitor the outputs from the I and Q post mixer amplifiers. Figure 9 shows the oscilloscope traces.

The signal generator was set to 3.579500MHz, which results in a 500Hz audio output from the I/Q outputs. The phase accuracy seems very good. There is a small amplitude imbalance that is indicated by a slightly lower peak voltage on the yellow trace. As the amplitude difference is only 0.3dB, I didn't bother trying to correct it at this stage.

When I was satisfied that all of the modules were working correctly, I connected the I/Q outputs from the post mixer amplifiers to the line-input of my PC sound card using a pair of screened audio cables and a 3.5mm stereo jack plug. A word of warning is in order at this point: take care that you don't damage the sound input of your PC by accidentally putting excessive voltage into it. Damaging a plug-in PCI or USB sound device would be a bit unfortunate; damaging the built-in sound chip on your PC or laptop mainboard would be much worse. Use screened cables to keep high levels of RF out of the input circuits. Last year, I destroyed the line-in circuit on one of my motherboards while transmitting at high power on 40m. You have been warned!

I have two reasonably good quality sound devices. A Creative Soundblaster Audigy that claims to have a dynamic range of 100dB and the built-in 24 bit HDA sound chip on my PC motherboard. Both of these devices offer reasonably good performance when used with SDR software.

I connected my HF doublet and ATU to the input of the RF BPF and tried recording a few seconds of audio using Audacity sound editing software. So far, so good: the recorded sound has at least one recognisable Morse signal and a lot of indistinct high pitched noises. The level of audio on the left and right channels seems to be quite well balanced. Next, I ran the Linrad [2] software and was quite surprised to see that the spectrum display was full of signals. Linrad is currently configured for a sampling rate of 48kHz, which gives a total tuning range of 3.579MHz ±24kHz. This covers the upper part of the CW section and the very bottom of the phone section of the 80m band. It should be possible to cover a bigger slice of the band by using a higher audio sampling rate. Several CW and SSB stations were copied without any difficulty. You can find audio samples of my first tests at http://homepage.eircom.net/~ei9gq/phasing.html.

Testing the uncalibrated system showed that the image rejection was about 30dB. This is hardly state-of-the-art, but it is still a lot better than a simple direct conversion receiver. Software calibration improved the image rejection to better than 75dB. Swapping the I/Q wires at the output of the post mixer amplifiers while listening to a strong signal was quite interesting. The strong signal always disappeared to be replaced by any signals that happened to be on the image frequency. The receiver never showed any sign of overloading or AM breakthrough.

The DSP filtering offers 'brick wall' selectivity for SSB and CW. Sensitivity is good enough to hear the local band noise at midday. Several trans-Atlantic signals were heard without any difficulty. As I don't have a good stock of crystals for other parts of the 80m band, I disconnected the crystal oscillator and replaced it with the November 2008 Homebrew DDS. This allowed coverage of the entire band.

The test system used open-source Linrad software by SM5BSZ running on a Linux PC with a dual-core AMD Athlon 64 CPU. Windows users should try PowerSDR, WinRAD or Rocky.

REFERENCES:

[1] www.seboldt.net/k0jd/phase_notes.html
[2] www.sm5bsz.com/linuxdsp/linrad.htm