Standard Frequency Receiver Conversions

Dr P. Stewart, G7EAH, shows how to convert 200kHz standard frequency receivers to 198kHz operation.

Employing the modification described here reduces the cost and complication of building a completely new system for 198kHz and eliminates expensive coil construction and difficult tuning. Further, it is not necessary to change internally in any way an existing 200kHz off-air standard receiver. Many will already have constructed a 200kHz off-air receiver based, for example, on circuits given the chapter 'Frequency Measurement' in the RSGB book *'Test Equipment for Radio Amateurs'*.

FREQUENCY STANDARDS

Before describing the circuit it might be useful for those not familiar with off-air frequency standards to explain why and how they are used.

An ordinary quartz crystal oscillator operating at a frequency of 5MHz performs, without special precautions, with a stability of about 2 parts in a million over a second. If the crystal is cut in a special way and placed in an oven with a temperature sensor to maintain a constant temperature, an improvement in the stability to 5 parts in 10^{12} can be achieved over one second. A rubidium gas cell oscillator of the kind used in the Droitwich transmitter system for Radio 4 has a similar short-term stability. Whereas a high quality quartz oscillator of the kind referred to above will have a systematic drift over a day of about 5 parts in 10^{12}, the rubidium oscillator typically drifts only 2 parts in 10^{11} in a month.

Another system is the caesium beam tube — as used in the MSF 60kHz transmissions from Rugby. Caesium is described as a primary reference, while rubidium is a secondary standard. The reason for the adoption of caesium as a primary standard is that, while the short-term stability of caesium over one second is not significantly better than that of a good quartz oscillator and is in fact inferior to a rubidium system, the long-term drift of caesium is about an order of magnitude better than rubidium. The best system for long-term stability commercially available is the hydrogen maser but this is not currently used to provide stable carrier transmissions for off-air standards nor has it been adopted as a primary frequency standard. These primary and secondary standards are well beyond the means of even a small commercial laboratory costing between £10,000 and £40,000.

It is possible for the amateur to exploit the accuracy of primary and secondary standards without the expense by using what is known as an off-air standard receiver. Droitwich is just one of a number of radio stations emitting a carrier whose frequency is maintained to a very close tolerance. This transmitter does not have a quartz oscillator but a synthesizer based on a rubidium gas lamp whose frequency can be maintained to an accuracy of about 1 part in 10^{11} in any 24 hour period and constantly compared by the National Physical Laboratories with their caesium long beam primary standard. Another standard is MSF Rugby transmitting on a frequency of 60kHz, this is an even more accurate carrier based on caesium; here the carrier is maintained to an absolute accuracy of about 2 parts in 10^{12}.

Further up the bands into the HF spectrum various countries transmit accurate carriers on 2·5, 5·0 and 10·0MHz. The problem with HF transmissions is that they are much more affected by, for example, ionospheric doppler shift and refractive index changes than those in the VLF and LF bands. MSF and Droitwich are also affected but to a much lesser degree. The Droitwich transmissions (particularly at night) are affected by interference from Eastern European stations. It is particularly advantageous therefore to use a frequency for which the principal mode of a transmission at the time of measurement is the ground wave.

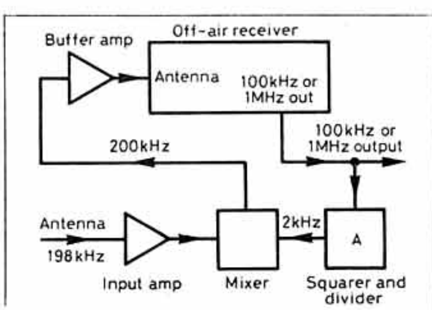


Fig 1. (above) Conversion block diagram.
Fig 2. Add-on squarer and divider circuit.

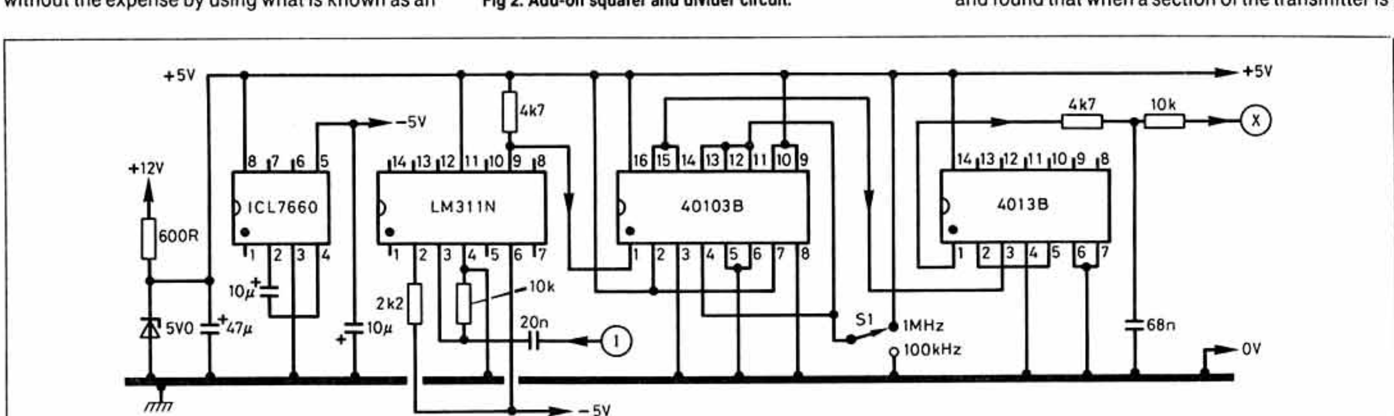
For many years the Droitwich transmitter has provided a reasonably accurate carrier for normal industrial and amateur reference. Most amateurs will be well satisfied if they are able to adjust their frequency counters to about 1 cycle at 10MHz — remember, if your counter is out by 10 cycles at 100kHz it will be out by 1kHz at 10MHz! The more enthusiastic amateur could well be looking for greater accuracy and so the question arises just how accurate is Droitwich?

The frequency as measured at your off-air receiver is the combined effect of the drift in the rubidium standard, changes in the conditions in the transmitter, the ionosphere, the electrical conductivity of the intervening terrain, local interference and the phase stability of your receiving system. The wave received can take two principal routes from the transmitter one is the ground wave the other the sky wave, with one interfering with the other because of the phase difference; the magnitude of the interference between these waves is constantly changing.

The ionosphere is one of the most significant factors determining the phase stability and hence the apparent frequency of the received signal. For example, during the day at a time of moderate ionospheric disturbance, the short-term stability — on a time scale of seconds — of Droitwich might be 1 part in 10^9 if your receiver is only 50 miles from Droitwich but this figure is a factor of 10 worse 500 miles away.

At night when the interaction between the ground and sky waves is more significant the above figures can be expected to deteriorate by another factor of 10. This means that at night within about 200 miles of the transmitter you could not expect to obtain a reference frequency from Droitwich of much better than 1Hz in 10MHz. Of course, should there be a solar storm then none of the above applies.

Experiments performed in Manchester in the Summer of 1988 reveal that the best time to use Droitwich is during a five hour period starting from about 2 hours after sunrise. Outside of these items more noise is encountered. There is, however, one caveat — namely that during a working day at Droitwich, sections of the transmitter are switched in and out for maintenance purposes. I have checked the behaviour at the Manchester location and found that when a section of the transmitter is



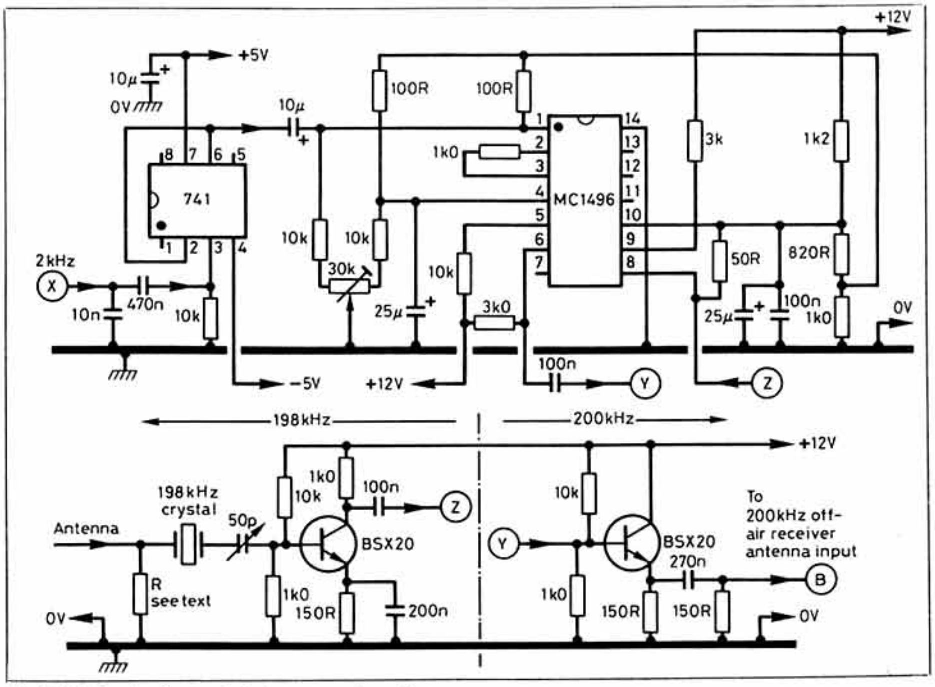


Fig 3. RF input, mixer and buffer amp schematic.

taken out of service there followed a sudden step in the phase of the received signal and, usually about an hour later a section of transmitter is put back into the main feed; there then follows a slow change in phase for about an hour amounting to a frequency error of worse than 1 part in 10^{11} (presumably as the reinserted section of the transmitter warms up). These measurements were made by comparing the Droitwich transmission with a rubidium standard while the latter was compared against MSF Rugby to ensure that the rubidium standard was not itself the source of the phase difference. The times of the observed phase changes were checked with the Droitwich engineers and seem to agree with the changes at the transmitter.

There is a further possible complication with Droitwich, ie. the phase modulation at about 25 cycles — at present used for what is called 'teleswitching' enabling the electricity generating board to switch domestic storage heaters on and off according to varying requirements and is achieved by phase modulating the carrier + and — 23 degrees each phase swing lasting about 20msec. Discussions with BBC engineers reveals however that the telemetry in this code stream gives an average a zero phase shift relative to the carrier which if frequency measurements are made over a time scale in excess of a second (as is normal) should not cause any problems, this being because most off-air standards contain a quartz crystal oscillator 'flywheel' with time constants in excess of a second implying receiver bandwidths of better than 1Hz.

All of this seems rather complicated but, provided that accuracies of order 1 part in 10^8 are required day and night there should be few problems.

MODIFICATIONS FOR 198kHz

Turning now to the circuit which is to be used to modify a 200kHz off-air receiver. **Fig. 1** shows the block diagram: simply take a nominal 100kHz or 1MHz signal output from the off-air receiver at about 0·3-5v and apply to the circuit block marked 'A'. The block firstly divides by either 50 or 500 depending on whether the signal from the receiver is 100kHz or 1MHz, respectively. The output from the divider (2kHz) is then filtered from a 5V square wave to produce a 0·3v sine wave with negligible harmonic content and then to a buffer and balanced modulator. Here the 2kHz sine wave is mixed with a signal from the aerial at 198kHz to produce at the output two frequencies one at 196kHz and the other at 200kHz; these signals then pass through an emitter follower with a low output impedance of less than 50ohms to the off-air receiver. It is the 200kHz signal to which the phase-locked-loop within the off-air receiver will lock.

Referring to **Figs. 2 & 3:** the points marked 'X' are connected together similarly with pairs 'Y' and 'Z'. The circuit is designed to operate from a 12V DC supply; the chip ICL7660 and the zener diode provide +/-5V which together with the 12V supplies the circuit with power. The 100kHz or 1MHz signal is fed into the comparator LM311N which simply squares the sine wave to a 0-5v square wave. This is then fed into a presettable counter (40103B) the voltages on whose pins are held at 0 or 5V according to whether 100kHz or 1MHz signals are being taken from the off-air receiver. This produces a short pulse every 25 or 250 periods (of the input signal) — depending on the setting of the switch SW1 (Figure 2). This then passes into a 4013B divide-by-2 circuit, the 2kHz output of which goes to a low-pass filter, the output of which is fed into a unity gain buffer amplifier 741 which has the low output impedance necessary to drive the modulator (MC1496P). The C-R chain at point 'X' serves to filter the square wave to an almost pure sine wave so that no spurious sidebands are produced by the balanced modulator. Into this modulator is also fed the 198kHz Droitwich signal which passes through a buffer amplifier and 198kHz crystal filter (bottom left of Figure 3) via point 'Z' to the carrier input of the mixer (pin 8 of MC1496 also marked 'Z').

The 198kHz signal is now converted into two side-bands one at 196 the other at the required 200kHz. These signals pass from the modulator with a high output impedance through an emitter-follower to the antenna input terminal of the off-air receiver. The 198kHz crystal filter is inserted between the antenna and the buffer amplifier and serves to prevent the 202kHz sideband of the amplitude modulated carrier mixing with the 2kHz and producing 200kHz at the receiver input. The 30kΩ trimmer potentiometer on the modulator should be adjusted to give zero output at point 'B' (Figure 3) when a 198kHz signal is inject at 'Z' with no 0·1/1MHz signal into the comparator at point 'I' (Figure 2). A 150R resistor is placed across the output to the off-air receiver because some models may require a D.C. path.

Two types of antenna may be used — either a long wire, in which case a resistor of 1k — marked R in Figure 3 — should be placed across the 198kHz input terminals to protect the circuit, or a long wave ferrite rod aerial with a 150pF trimmer capacitor in parallel for tuning.

SETTING UP PROCEDURE

On completion of the circuit, connect an antenna to the input (Figure 3 bottom left). Connect also the off-air receiver antenna input to the output of the circuit (Figure 3 bottom right). Connect the 100kHz/1MHz output from the off-air receiver to point 'I' (Figure 2) and switch SW1 (Figure 2) to the appropriate frequency. All receivers have some form of signal strength indicator — adjust the 50pF trimmer capacitor in series with the crystal (Figure 3) to give a maximum signal strength indication. Where a ferrite rod is used, position it at right angles to the direction of Droitwich and tune the 150pF trimmer for maximum signal. You will probably find that the signal strength indicator will oscillate but this should eventually stabilize on a maximum value as the crystal in the off-air standard locks onto 200kHz. Should this not happen, there are several possible causes, eg. the long wire antenna needs re-positioning or lengthening or the internal crystal of the off-air standard is outside the capture range. If the receiver is a few years old it is possible that the crystal has aged — over 20 years this could be in excess of 10 cycles. If the crystal is too far out the phase-locked-loop may not lock and the remedy is to adjust the variable capacitor associated with the crystal oscillator in the receiver to bring the 100kHz output to its nominal value. Stabilization of the output indicator will then be seen.

When this procedure has been successfully completed the 100kHz and 1MHz outputs from the off-air standard will be locked to Droitwich.

CONSTRUCTION

At the low frequencies involved in the above circuitry, VEROBOARD construction is quite sufficient so that no elaborate PCB layout is needed. The BSX20 lead connections as seen looking at the bottom of the transistor with the protruding lip on the left are emitter-base-collector taken clockwise.

TRIALS

Four different types of 200kHz off-air standard receiver were tested and found to function reliably with this conversion: — Hewlett Packard's 5090A and 5090B models, RCS Electronics 103 and Advance OS1.

SUPPLIERS

The 198kHz crystal may be obtained from Golledge Electronics, Merriott, Somerset TA16 5NS and the semiconductors and ICs from among others Maplin, Electrovalue and the Chip Shop (Semicons) Ltd., 6, Beanleach Dr, Stockport, Cheshire. □