RADCOM TECHNICAL FEATURE

MSF Locked Frequency Reference

The first of a two part feature by Andy Talbot, G4JNT

WHEN OPERATING narrow-band on the microwave bands, frequency setting can become a problem. Typically, crystal oscillators used in transverters can, with a certain amount of care, achieve 0.5 parts per million (ppm) accuracy when temperature compensation is used. However, at 10GHz this still corresponds to 5kHz uncertainty, nearly two SSB bandwidths! Frequency counters are available that can give accuracies of 1 part in 10^8 but these are expensive and not usually available when wanted.

Some years ago a frequency source based on the 200kHz long wave transmission from Droitwich was published. This suffered from residual phase modulation on the carrier and a good 'note' was difficult to obtain when multiplied to 10GHz. Since then, the Droitwich transmission has moved to 198kHz and the carrier is phase shift keyed at 25Hz during some times of the day, making a reliable and clean frequency standard much more difficult to achieve.

It was decided to adopt a different approach. The MSF Standard Frequency Transmission from Rugby on 60kHz is well known for transmitting time and date information which is easily decoded. The carrier frequency is related to International Standards, and is accurate to better than 1 in 10^{10}. This corresponds to an error at 10GHz of just 1Hz! In fact accuracy can be degraded by the transmission path at dusk and dawn, due to Doppler shift caused by the height of the Ionosphere changing, but this is unlikely to be noticeable.

It was decided to produce a general purpose frequency standard that had sufficiently good short term stability to be multiplied to microwave frequencies. In addition, lower frequencies would be provided that could be used as the timebase for frequency counters and oscilloscopes if required.

Direct multiplication of the 60kHz signal would not serve any useful purpose. No useful frequency could be produced for timebases, and the concept of directly multiplying by 172800 to 10GHz is mind boggling! In any case, the carrier is pulsed at 1Hz and an intermittent output would result.

The solution was to employ a 12MHz voltage controlled crystal oscillator which is divided down to 60kHz and phase locked to the MSF transmission. 12MHz was chosen for several reasons. Firstly, a simple to achieve division ratio of 200 gives the 60kHz VCXO signal. Secondly, all frequencies in the narrow-band segments of the microwave bands are (currently) multiples of 12MHz, making calibration simple. Since the prime purpose of the frequency standard was for calibrating my 10GHz equipment, a times-9 multiplier section was added to give a 108MHz output which could be used to generate a comb of harmonics detectable up to 10GHz.

The frequency reference is built in four modules, each one of which could be used for other purposes. A block diagram of the Reference is shown in **Fig 1**. The MSF signal is received off air by a ferrite rod antenna and head amplifier, mounted remotely. Any attempt to place the antenna near to the divider circuits will lead to pick up of the VCXO signal and the loop locking to itself rather than MSF. An NE567 tone decoder provides a gating signal corresponding to the carrier on/off keying. The received signal is squared up in an LM393 comparator, and applied to an Exclusive OR gate used as the phase detector for the PLL.

A 12MHz crystal oscillator is voltage tuned over a limited range of approximately 5ppm by the varicap across the crystal. The 12MHz output is applied to two bipolar tripler stages to give the 108MHz signal, and a portion is squared up and divided by 200 in a TTL divider chain. The resulting 60kHz output is applied to the other input of the phase comparator.

The output of the phase comparator has a mean level corresponding to the phase difference between the two signals when the carrier is on but settles to half output when the carrier is keyed off every second. The gating output of the tone decoder is used to control a sample-and-hold circuit consisting of a 4066 analogue switch and capacitor.

The voltage at this point is an accurate measure of the phase relationship between the two signals, and is displayed on a front panel meter to show the loop lock state. A loop filter integrates this output and uses it to control the VCXO frequency. Since a second order loop is used, the mean phase relationship is exactly 90° and the meter clearly shows when the loop is in lock by sitting firmly at mid scale.

An analogous system to this reference is used in colour television receivers to regenerate the colour subcarrier, at 4.43MHz, from a burst reference transmitted just after the line synchronising pulse. In this case the gating signal is generated by delaying the line

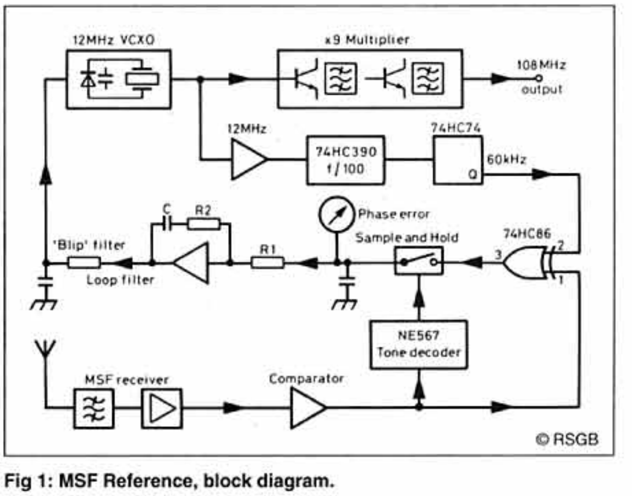

Fig 1: MSF Reference, block diagram.

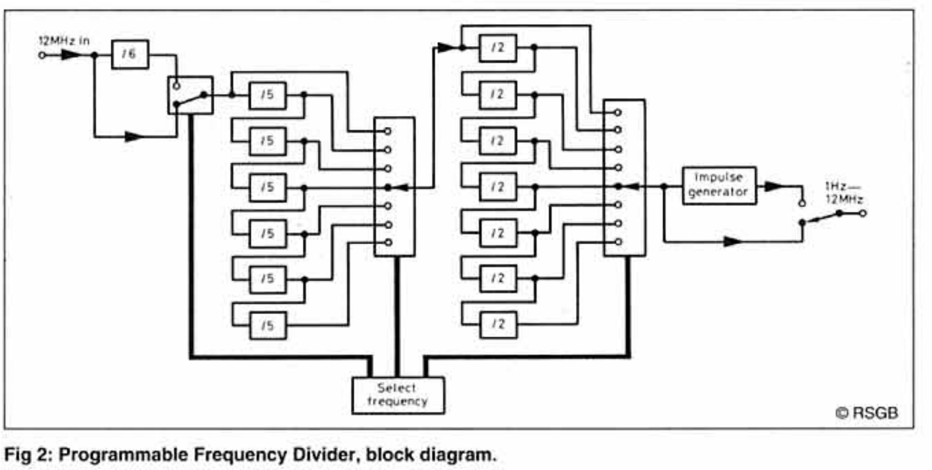

Fig 2: Programmable Frequency Divider, block diagram.

timebase flyback pulse.

To provide a range of other useful frequencies, a switchable, or programmable, divider is also included. The block diagram of this is shown in **Fig 2**. By selecting thumb-wheel switches, the 12MHz signal can be passed through between 0 to 7 divide-by-2 blocks, 0 to 6 divide-by-5 blocks and a possible divide-by-6. By this means 112 different frequencies down to 1Hz can be produced, by setting total division ratios from 1 to 12,000,000. All the 'useful' ones such as 1MHz, 25kHz etc can be obtained, as well as such frequencies as 93.75kHz and 375kHz. Who knows, they may be useful one day!

CONSTRUCTION

NO DETAILED CONSTRUCTION details are given as constructors will probably want to tailor the design to their own requirements. Separate units such as the times-9 multiplier and the programmable divider could be used on their own if desired.

The complete circuit diagram is given in **Figs 3, 4, 5 and 6**. The MSF head amplifier is built in a remote box and supplied with power via the coaxial cable. In spite of being at nearly audio frequencies, RF techniques need to be used here because of the low signal levels in this area. Input and output signals should be kept separate as the high gain in this block can easily cause oscillation. The ferrite rod antenna is a long wave unit, with extra capacitance added, and provides the only filtering needed. Bandwidth is around 1kHz, but depends to a large extent on the size of rod employed. The bigger the ferrite rod the larger the signal received.

The reference generator is made in three blocks. The VCXO and times-9 multiplier are on one board, which contains all the real RF circuitry. Layout should be suitable for the frequencies involved, and ideally a printed circuit board should be used. However, any other method of RF construction, such as the 'ugly' technique could be employed.

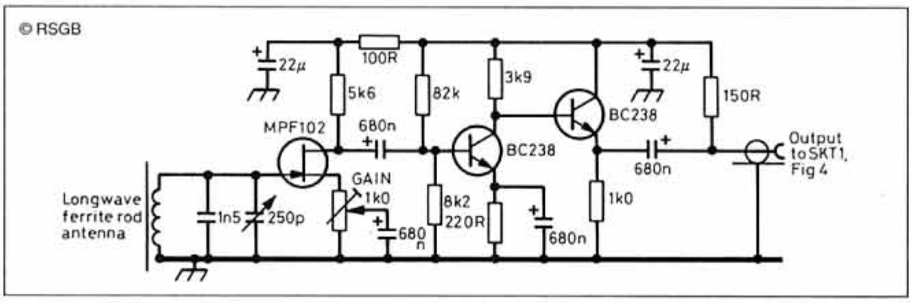

Fig 3: 60kHz Head Amplifier.

A second board contains all the sections needed for the PLL and the divide-by-200 circuitry, together with the MSF input comparator and tone decoder. Any 'logic' type construction such as point-to-point wiring is suitable. Care should be taken to keep the two 60kHz signals separate, as otherwise the loop will lock onto its own internally generated signal, and ignore MSF completely. Each integrated circuit should be by-passed with a 0.1µF capacitor at its pins, and ground connections should be as thick and direct as possible. If the 108MHz output is not required, the VCXO could also be incorporated on this board.

The same comments on decoupling and layout apply to the programmable divider; this should be kept away from the RF board as the low frequency signals could modulate the crystal oscillator in the event of any leakthrough.

ADJUSTMENTS

THERE ARE A NUMBER of adjustments to be set up and constructors are advised to follow the procedure given.

Firstly the VCXO is built and the 108MHz multiplier aligned. Monitor the voltage on the emitter of TR2 and peak L1 - L3 for a figure of 0.7V or higher. Then monitoring the emitter of TR3, peak L4 and L5. Finally, using a diode detector, peak L6 for maximum output. An output level of around 10dBm should be easily achieved, enough to drive a 1N23 type diode in a comb generator to 10mA.

The next stage is to bring the ferrite rod onto 60kHz. The use of an oscilloscope makes this a relatively straightforward job. With the head amplifier unpowered, connect the oscilloscope across the tuned circuit and, making sure the ferrite rod is at right angles to the direction of Rugby, adjust the preset capacitor until a 60kHz signal is seen which is pulsing on and off. Depending on the particular ferrite rod employed, it will probably be necessary to slide the coils along the rod to obtain resonance.

On the South Coast I am able to obtain a signal of 5 to 10mV peak-to-peak (p-p). If the head amplifier is now powered, a signal of more than 0.5V p-p sinewave should be present on the feeder. If a distorted signal much greater than this is present, the gain of the head amplifier should be reduced by adjusting the preset.

With the MSF signal applied to the Phase Locked Loop board, ensure that a 60kHz square-wave output from the LM393 comparator is present on pin 2 of the NE567. During breaks in carrier, noise should cause a random output at this point. Adjust the 10k preset until the LED flashes on and off with the received carrier. This completes the tone decoder setting up.

Set the lock / free switch so that the VCXO

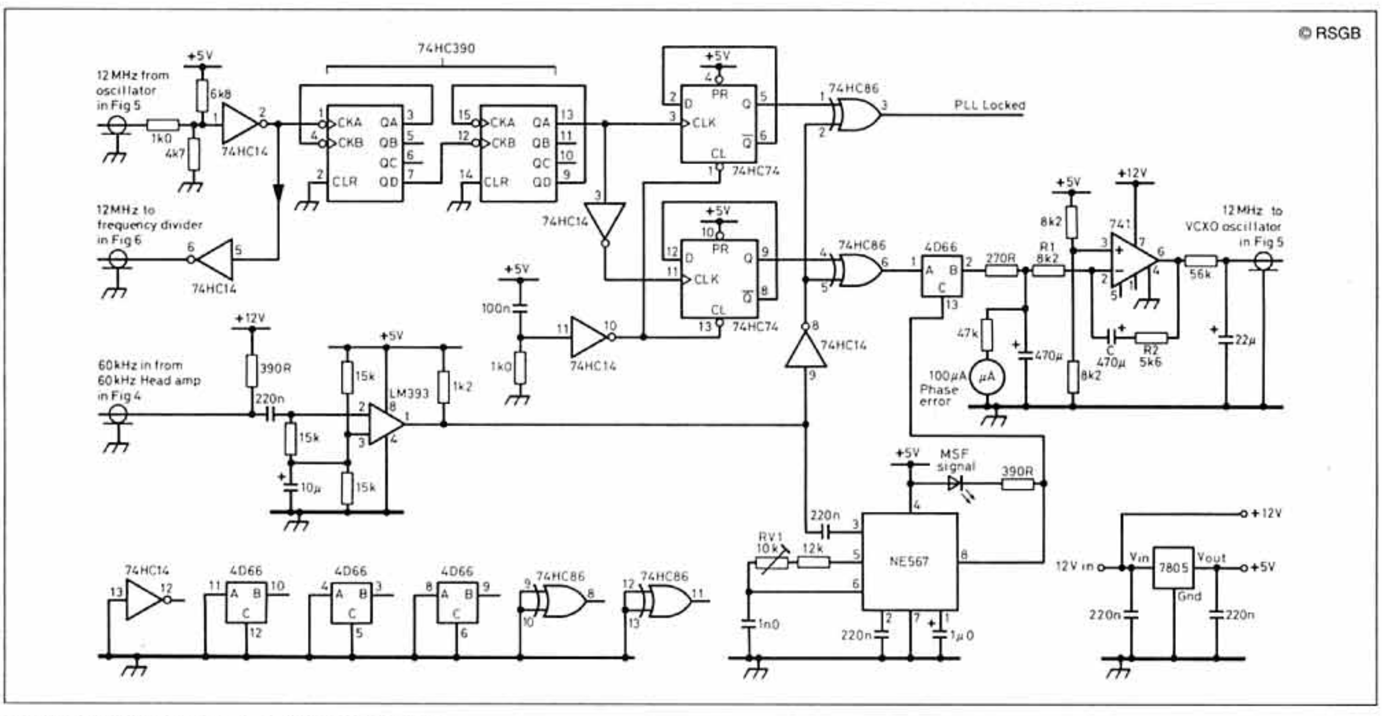

Fig 4: Comparator and part of Phase Locked Loop.

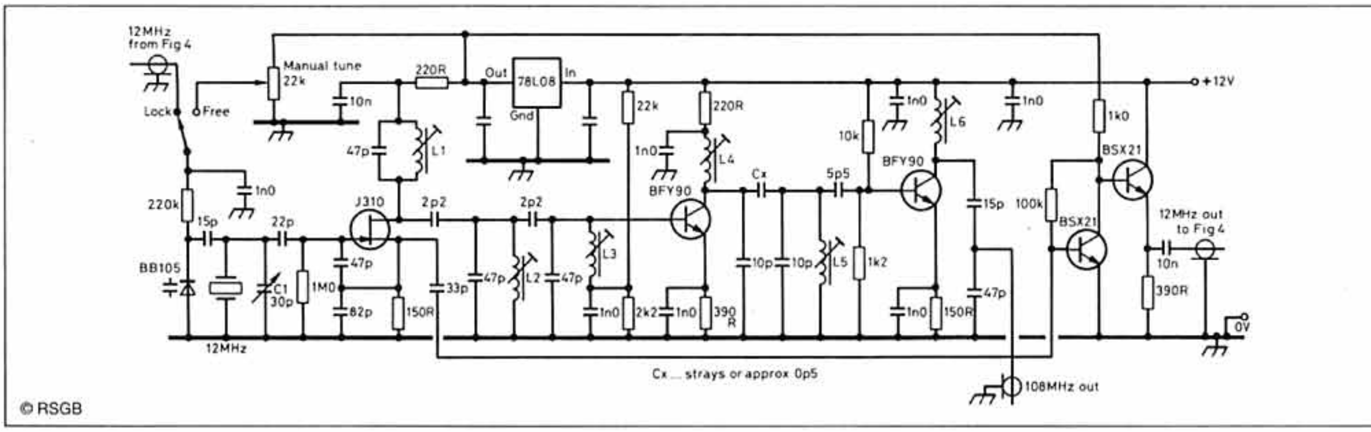

Fig 5: 12 MHz VCXO and Multiplier.

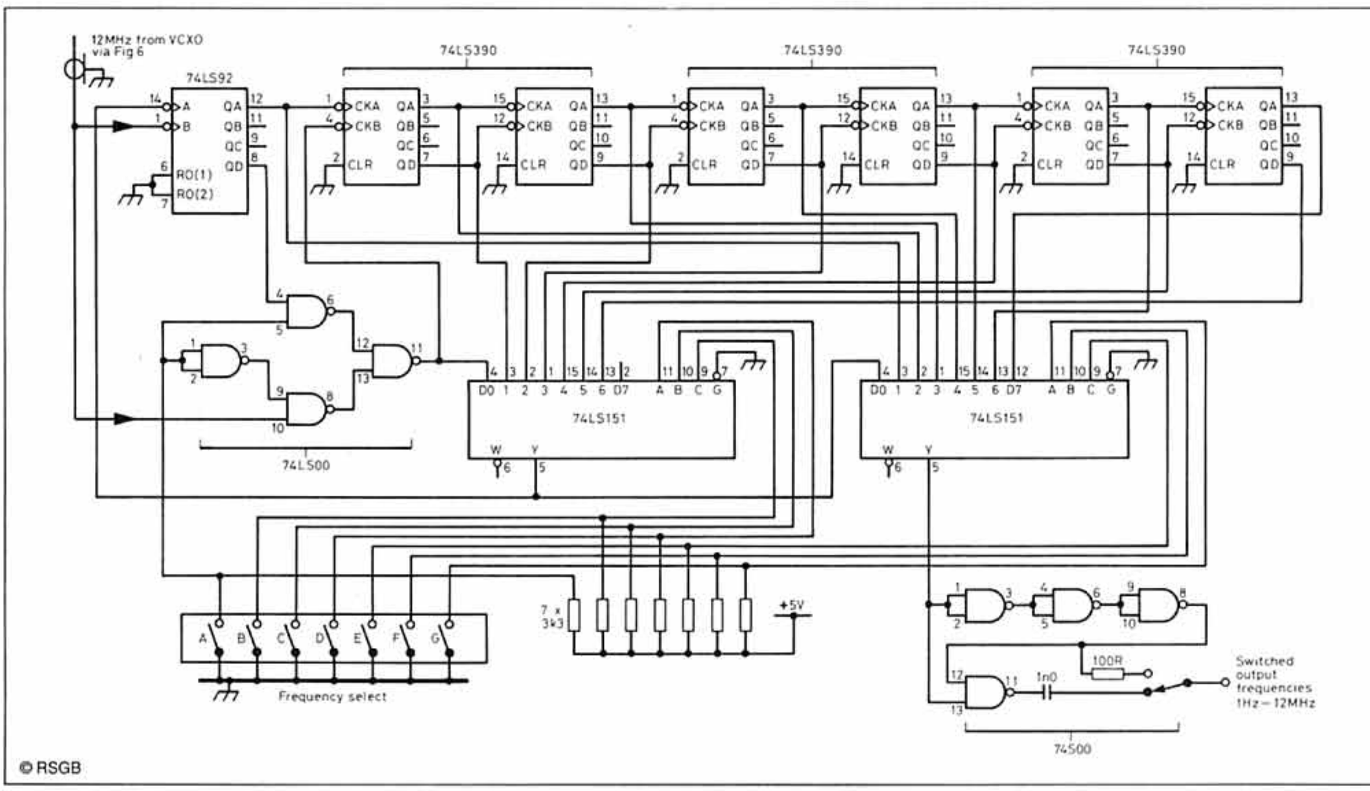

Fig 6: Switched Frequency Divider

free-runs and adjust VR1 for a VCXO tuning voltage of 3V. If the divide-by-200 circuitry is working correctly, the phase meter should now be swinging between 0 and FSD. If not, it is possible that the beat frequency between the VCXO and the received signal is too high for the meter to indicate.

Adjust the VCXO preset, C1, to bring this beat frequency as near as possible to zero. The error should be less than 0.1Hz, ie a complete cycle from zero to full scale and back to zero should take longer than ten seconds. Set the switch to Lock, discharge the 470μF capacitor, C1, by momentarily shorting it, and watch the meter. After three to four swings, the amplitude of the oscillation should have died away and the meter needle will be resting at mid scale, this is the 90° phase point and the loop is now locked.

If a digital voltmeter is available, monitor the tuning voltage over a period of one hour, it will drift due to the VCXO warming up, and if the voltage exceeds 3.5 Volts, C1 should be adjusted to achieve this value when locked. Harmonics of the VCXO can now be listened for on any band of choice and the calibration of receivers etc checked.

If at any point in the setting up, the MSF LED stays on, the receiver is picking up the internally generated 60kHz signal and the head unit should be moved further from the main unit. If all leads are sufficiently decoupled, a distance of 1 to 2 metres should be sufficient.

There is no setting up of the programmable divider, except by ensuring an output of the correct frequency is available for different settings of the programming switches.

. . . to be continued

NEXT MONTH

IN PART TWO, G4JNT will be detailing how to set up the receiver chain without using an oscilloscope.