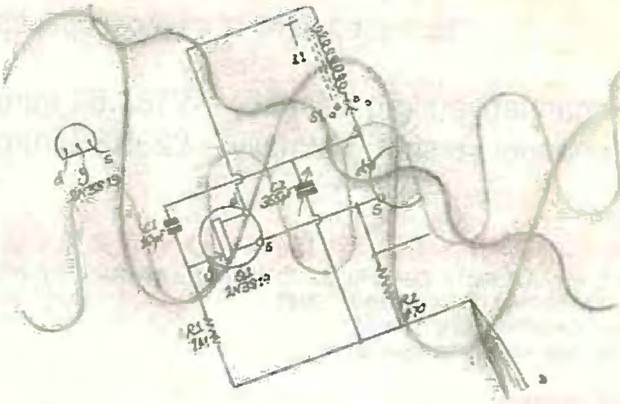
Special Series

# PRACTICAL OSCILLATOR DESIGNS



## RAYMOND HAIGH

*Most text books deal with oscillators in a theoretical way. This series, prepared with the electronics enthusiast and experimenter very much in mind, is intensely practical. Tried and tested circuits are fleshed out with component values, and their vices and virtues are exposed.*

## PART FIVE – CRYSTAL AND CRYSTAL CONTROLLED OSCILLATORS

PREVIOUS articles have described oscillators which rely upon tuned circuits formed by inductors and capacitors (*L/C*) to determine the operating frequency. Oscillators of this kind can be tuned over a wide frequency range and, with appropriate circuitry, deliver a sinusoidal waveform of good purity. Their only drawback is frequency drift, which becomes an increasing problem above 5MHz or so.

This month crystal and crystal controlled oscillators (XOs), which display a very high degree of frequency stability will be considered. Although some circuits permit the operating frequency to be "pulled" over a very narrow bandwidth (VXOs – variable crystal oscillators), crystal oscillators cannot be tuned as broadly as *L/C* oscillators: they are essentially spot-frequency signal generators.

### BRIEF HISTORY

Many types of crystal, but particularly Rochelle salt and quartz, develop an electrical charge across opposite faces when they are distorted by mechanical stress. Changing the stress from pressure to tension reverses the polarity of the charge.

The phenomenon was called *piezoelectricity* (electricity through pressure) by Jacques and Pierre Curie who discovered it in 1880. A year later they demonstrated the converse: that stress could be set up in certain crystals by applying an electrical potential.

The effect remained a scientific curiosity until the First World War when a French scientist, Langevin, used it to detect acoustic waves produced by submarines. Spurred on by the developing radio industry, research was also taking place into the use of crystals for frequency control. In 1921, Professor W. G. Cady of the American Wesleyan University applied two pairs of terminals to a quartz crystal, connected it in the feedback path of a three valve amplifier, and discovered its remarkable frequency stabilising action.

He demonstrated his circuits to Professor G. W. Pierce of Harvard University in January 1923. Within a few months Pierce had developed an improved version, simplified by the use of a two terminal crystal, and his oscillator is still widely used today.

### FREQUENCY RANGE

Crystal units can be produced to resonate at fundamental frequencies from 1kHz to above 100MHz, but range extremes are expensive and not readily available. Most retailers usually stock fundamental mode crystals with frequencies from 1MHz to 20MHz, and some carry a range extending from 32kHz to 30MHz.

Frequencies in excess of 20MHz are often generated by a crystal designed to resonate at an overtone frequency, usually the third or fifth harmonic of its fundamental: e.g., a crystal for 27MHz would have a fundamental of 9MHz. (Accuracy, particularly at frequencies in excess of 30MHz or so, is easier and cheaper to achieve in this way).

### FREQUENCY OF OSCILLATION

Appropriate circuitry must be used or the frequency of an oscillator may differ slightly from that stamped by the manufacturer on the crystal case. It will, however, always be quite close, and where stability rather than absolute precision is the overriding consideration, this aspect of the technology can be ignored.

Departures from the quoted frequency of the crystal are caused by two factors. First, a crystal unit has two natural resonances. Second, its frequency can be shifted, or "pulled", by external reactances (inductance, *L*, or capacitance, *C*).

The lower of the two natural resonances occurs when the crystal is operating as a *series* tuned circuit. Its impedance is then at its lowest. The higher resonant frequency, also called the anti-resonance, is caused by the tuning effect of the "capacitor" formed by the crystal's electrodes, plus any stray circuit capacitance. Together with the inductive reactance of the crystal, this forms a *parallel* tuned circuit with a very high impedance.

The spacing between these two resonances, sometimes called the crystal bandwidth, being dependant upon electrode and stray capacitances, is subject to variation. Usually, however, it is between 0·05 per cent and 0·1 per cent of the stated frequency.

### LOADING UP

Most crystals are intended for operation in the parallel mode, and the manufacturers quote a loading capacitor value (usually 30pF) which must be connected to ensure oscillation at the stated frequency. In practice, this loading capacitor, or part of it, often comprises a trimmer capacitor which can be adjusted to compensate for stray circuit capacitance and set the frequency of oscillation very precisely. Crystals cut to give the specified frequency when connected in the series mode, i.e., used as series tuned circuits, do not require a loading capacitor.

It should be noted that the mode of operation is determined by the external circuitry. Any crystal unit will oscillate at its resonant and at its slightly higher anti-resonant frequency.

### CRYSTAL MANUFACTURE

Quartz is a crystalline form of silicon dioxide ($SiO_2$). When the technology was in its infancy, resonators were cut from naturally occurring crystals, but the use of synthetic quartz is now almost universal.

Unique characteristics, coupled with low manufacturing costs, have brought about the widespread use of quartz crystals in clocks, watches, computers, navigation systems, and every item of equipment where a precise, drift-free, spot-frequency generator is required.

Demand for crystal units is so great that the world-wide manufacture of synthetic quartz now exceeds 2000 tons per year.

We come now to the second factor influencing the frequency of oscillation: external reactances. Capacitance placed in series with the crystal will raise its frequency of oscillation; capacitance wired in parallel will lower it. Series resonant crystals (where there is no external parallel capacitor) can have their frequency lowered by means of a series connected inductor.

## PULLING POWER

Just as external reactances can be connected to set the crystal to its correct operating frequency, they can also be used to "pull" it over a narrow band of frequencies. An oscillator configured in this way is known as a variable crystal oscillator (VXO).

How much the crystal can be "pulled" is determined by its mechanical springiness. Although crystals can be manufactured with a high degree of "springiness", it should be noted that the amount of pulling is, at best, limited to a very small percentage (around 0·15) of the crystal's resonant frequency, and this percentage tends to reduce as the operating frequency decreases.

Units designed to resonate at an overtone resist "pulling" at the overtone frequency because stiffness increases rapidly with overtone number. They are, however, often particularly responsive at their fundamental frequency.

## FREQUENCY DRIFT

Simple oscillators in which resistors and capacitors (*R/C*) are used as the frequency determining components can achieve a frequency stability of around one part per thousand. When tuned circuits comprising inductors and capacitors (*L/C*) fix the frequency, stability is usually of the order of one part per ten thousand.

## QUARTZ CRYSTAL UNITS

Mechanical stresses are induced in a slice of quartz when a voltage is applied across its opposite faces. An alternating voltage of the correct frequency will make it vibrate or resonate in the same way that a violin string resonates. Resonant frequency is determined by the mass of the crystal and its connecting electrodes. Fundamental resonances can range from 1kHz to more than 250MHz, although 100kHz to 30MHz is common.

In use, the crystal simulates an *L/C* tuned circuit with a *Q* factor which can, theoretically, exceed a million. (The very best inductor-capacitor combinations seldom achieve *Q* factors in excess of 300).

A near zero coefficient over a fairly wide temperature range can be obtained by cutting the slice from the bulk crystal at a particular angle. This feature, together with the remarkable *Q* factor, enables crystal units to impart a high degree of frequency stability to oscillatory circuits.

Basic crystal controlled oscillators can have a stability better than five parts per million, even when no special precautions are taken to minimise drift. When temperature control measures are incorporated, a stability of one part per million is achievable, and, if special care is taken, this can be further improved by a factor of ten.

Clearly, therefore, when a spot frequency has to be generated, and when freedom from drift is of paramount importance, there is no practical substitute for a quartz crystal oscillator. Crystal oscillators must, however, be buffered, and regard must be had to all of the other drift reducing measures outlined in Part Two, if the highest levels of stability are to be achieved.

## PIERCE OSCILLATOR

One of the earliest crystal oscillators, still widely used, is the Pierce oscillator. In an updated version, the crystal is connected between collector and base of a transistor or drain and gate of a f.e.t. (field effect transistor).

A bipolar transistor version of Pierce's early valve circuit is given in Fig.1, where a quartz crystal, X1, is connected between the collector (c) and base (b) of TR1. The transistor is biased by resistor R1, and the output is developed across the r.f. choke L1.

The crystal is operated in the parallel mode and its loading capacitor is formed by C1 and trimmer capacitor VC1, which are effectively connected in series across it. The frequency of oscillation can be adjusted, within narrow limits, by VC1, which is usually a miniature film-dielectric trimmer. (An air-spaced component should be used if maximum freedom from drift is required).

The values of C1 and VC1 should prove suitable between 4MHz and 15MHz, but they may need increasing for lower and reducing for higher frequencies. With this version, oscillation is usually at its most vigorous when the capacitance provided by VC1 is approximately twice that of C1.

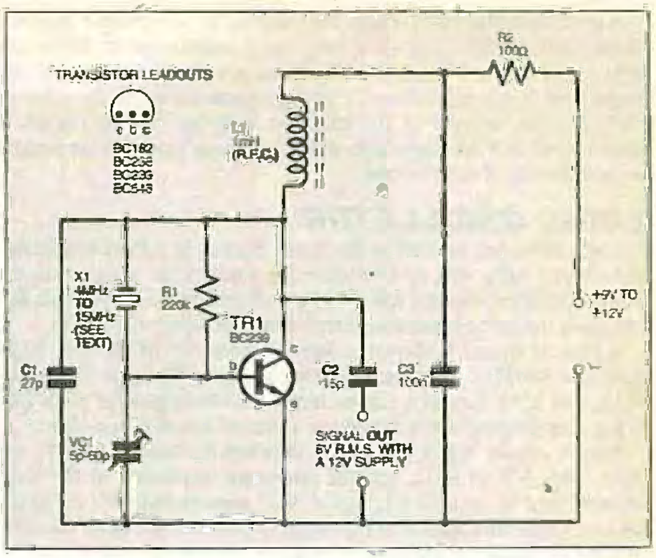


*Fig.1. An updated bipolar transistor version of Pierce's valve-based crystal oscillator*

Some low frequency (1MHz and below) crystals can be "sluggish" and if difficulty is encountered, a 4·7mH choke as a collector load should make the circuit oscillate.

Output is taken from the collector via d.c. blocking capacitor C2. The value of this component should be kept as low as possible consistent with sufficient signal being delivered to the accepting circuit. The oscillator is decoupled from the power supply by means of resistor R2 and capacitor C3.

## F.E.T. Version

A Pierce oscillator maintained by a f.e.t. is shown in Fig.2, and the circuit is very similar to the bipolar version. The gate (g) of TR1 is grounded via resistor R1 in order to ensure correct operation, and source (s) biasing is provided by resistor R2 with its bypass capacitor C2.

The source bias components must be provided when a J310 transistor is used, but they can be omitted with a 2N3819 and the source directly grounded. This modification will increase output to around 5V r.m.s.

It is customary with f.e.t. oscillators to connect a silicon signal diode (a 1N4148 with cathode grounded) between gate and the negative rail in order to limit oscillation amplitude and prevent forward conduction of the f.e.t.'s gate. With this circuit the measure can result in erratic and uncertain operation above 10MHz, and for this reason a diode has not been shown.

Amplitude limitation is, however, desirable in the interests of minimising drift and optimising waveform quality, and it is good practice to connect a diode whenever other aspects of performance are not compromised.

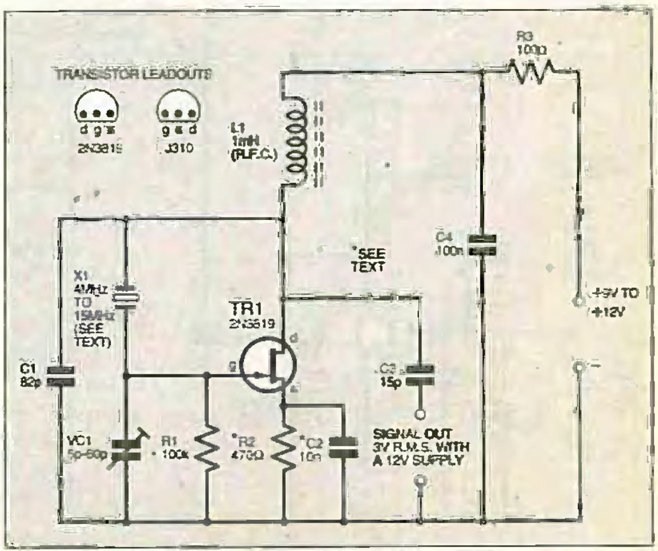


*Fig.2. Field effect transistor (f.e.t.) version of the Pierce crystal oscillator.*

Again, the values of C1 and VC1 should prove suitable between 4MHz and 15MHz, but they may need increasing at lower and reducing at higher frequencies. Oscillation is usually at its most vigorous with this circuit when C1 is approximately twice the value of VC1; i.e., the reverse of the situation with the bipolar circuit. It would seem that the capacitors and crystal are acting as an impedance-matching $\pi$ tank circuit.

## LOGIC OSCILLATOR

Logic gates can be used as the active devices in a Pierce oscillator, and circuits using one or two gates are common in digital systems. Stability is inferior to that afforded by well constructed crystal oscillators using discrete components, but it is still of a very high order.

A typical circuit is shown in Fig.3, where two of the four NOR gates in a 4001B i.c. are used. The maintaining device is formed by IC1a, and IC1b acts as a buffer stage, the two inputs of each gate being strapped together to produce a pair of inverting amplifiers.

Quartz crystal X1 is connected between the output (pin 3) and input (pins 1/2) of IC1a, and the operating conditions of the stage are stabilised by resistor R1. Again, VC1 together with C1 act as the loading capacitors, and the frequency of oscillation can be adjusted slightly by means of VC1.

The output from IC1b (pin 4) is in the form of a square wave with a peak-to-peak value almost equal to the supply voltage. A tolerable sinewave output can be taken, via a low value capacitor, from pin 1 and pin 2 of IC1a. Supply line decoupling capacitor C2 should be mounted close to pin 14 of the chip.

With CMOS (complimentary metal oxide semiconductor) devices, propagation delay (the time taken for the output to change in response to a change of state at the input) is particularly dependant upon supply voltage. The circuit will oscillate readily at 3MHz or 4MHz with a 5V supply, but 12V has to be applied to ensure reliable oscillation at 8MHz. The maximum "safe" voltage is 15V.

Some versions of the circuit include a 10 kilohm or 100 kilohm resistor in the feedback path (between the output of IC1a and the junction between X1 and C1). This resistor reduces the drive to the crystal and, together with C1, acts as a low-pass filter, inhibiting oscillation at other than the fundamental crystal frequency.

Reducing feedback levels is always desirable in order to minimise drift, but the circuit will be less ready to oscillate at its upper frequency limit, or with "sluggish" crystals. Moreover, no problems with spurious frequencies were encountered with the circuit as shown in Fig.3.

## CLAPP OSCILLATOR
### – Bipolar Transistor Version

A bipolar transistor Clapp crystal oscillator is shown in Fig.4. Transistor TR1 is biased by resistors R1 and R2, and feedback, developed across emitter resistor R4, is applied to the capacitive tapping formed by C1 and C2. These components swamp the voltage and temperature variable internal capacitances of TR1, and in this way the feedback circuitry helps to combat drift.

The output signal is often taken from the emitter terminal of TR1, but, in this version of the circuit, the output is developed across the collector load resistor R3, thereby affording a small measure of isolation from the frequency determining components. Notwithstanding this, the d.c. blocking capacitor C3 should be as small as possible consistent with the delivery of sufficient signal voltage. Collector load resistor R3 must not have a greater value than emitter resistor R4 or oscillation will be inhibited. The circuit is decoupled from the power supply by capacitor C4 and resistor R5.

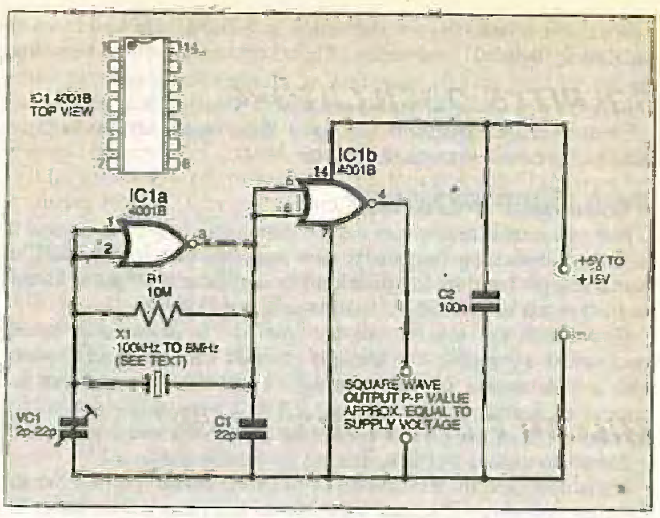


*Fig.3. Circuit for a CMOS logic gate version of the Pierce crystal oscillator.*

Trimming capacitor VC1 is connected in series with the crystal X1, thereby forming the Clapp variant of the Colpitts circuit. It enables the frequency to be adjusted over the usual narrow limits. If the greatest possible freedom from drift is required, the bulk of this series capacitance should be made up of fixed components selected by trial and error to produce an optimum combination of temperature coefficients.

Feedback capacitors C1 and C2 are not excessively critical and the quoted values should ensure reliable oscillation. Making capacitor C2 larger than C1 will reduce feedback, minimise drift, and may improve output waveform. Again, the trial and error selection of capacitors with the most favourable temperature coefficients will help to ensure a high degree of stability.

### – F.E.T. Version

A field effect transistor version of the circuit is given in Fig.5. These devices are less active than their bipolar counterparts, and an r.f. choke has to be used as a source load in order to ensure sufficient feedback. Signal output is taken from the source (s) via d.c. blocking capacitor C3.

Feedback capacitors C1 and C2 have a lower value with this circuit, but the comments made earlier regarding selection apply equally here. If a J310 f.e.t. is substituted for the 2N3819, a 470

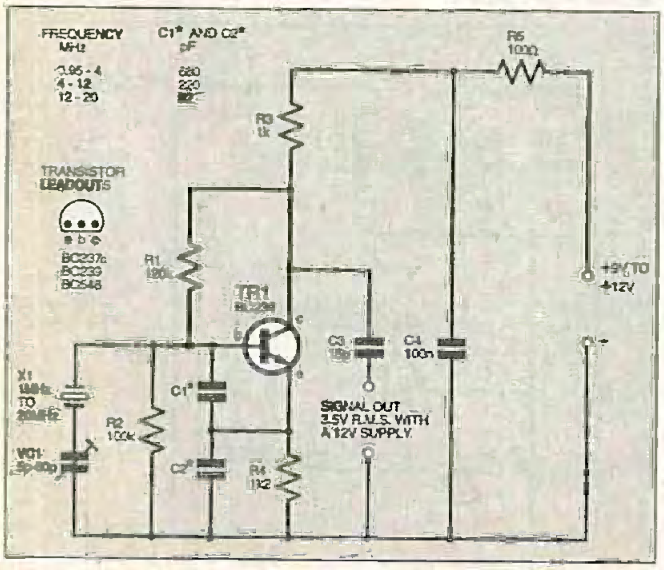


*Fig.4. Circuit for a bipolar transistor version of the Clapp crystal oscillator.*

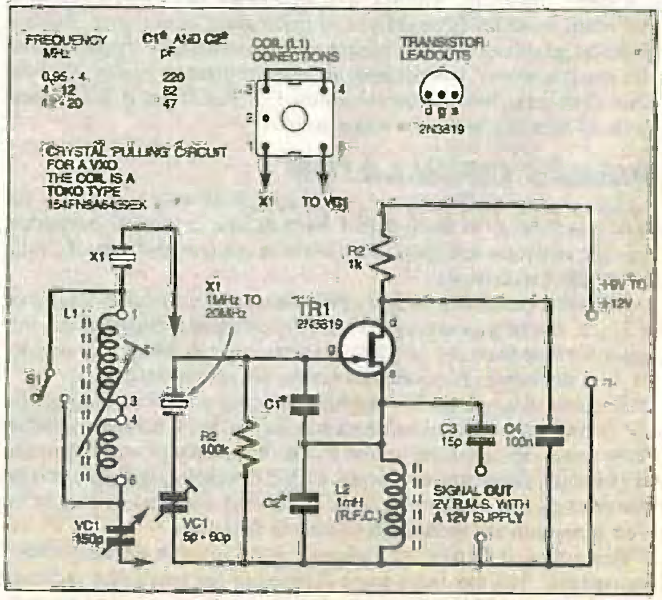


*Fig.5. Field effect transistor version of Clapp crystal oscillator.*

ohm resistor, bypassed by a 10nF capacitor, must be placed in series with the "grounded" end of the r.f. choke to ensure correct biasing.

## COLPITTS OSCILLATORS

By omitting series trimmer VC1 in the circuits shown in Fig.4 and Fig.5, and connecting the crystal directly between base or gate and ground (0V), a Colpitts oscillator is formed. Frequency adjustment can then be provided by including a small trimmer capacitor as part of C1 or C2.

With so much capacitance in parallel with the crystal, it is likely that adjustment of the trimmer will fail to lift the frequency of oscillation up to the figure quoted by the manufacturer. If precise operating frequency is important, the values of capacitors C1 and C2 should, therefore, be reduced, consistent with reliable oscillation. (The series connected capacitor, VC1, in the Clapp circuit avoids this problem).

## MILLER F.E.T. OSCILLATOR

A f.e.t. version of Miller's early valve oscillator is shown in Fig.6. Miller's circuit has much in common with Armstrong's tuned grid/tuned anode arrangement, but here a quartz crystal replaces the *L/C* tuning connected between grid (now gate) and negative rail or ground.

The *L/C* circuit, which acts as TR1 drain (d) load, is tuned to the crystal frequency (or a harmonic) and a high level, high impedance output can be taken from the drain. A coupling winding on the coil can be used to provide a low impedance output, and the connections for inductors in the Toko range are also shown.

The frequency coverage afforded by Toko and hand-wound coils has been tabulated in earlier articles. Below 2MHz, this oscillator starts more readily if there is a relatively high ratio of capacitance to inductance in the tuned circuit (approximately 500pF and 50mH at 1MHz).

Limiting diode D1 and the source (s) bias components, R2 and C2, improve the operation of this circuit, and the output waveform is of good quality.

## CRYSTAL CONTROLLED

In the circuits considered so far, the crystal unit has replaced an *L/C* tuned circuit and oscillation would not occur without it. These circuits should, therefore, be regarded as crystal oscillators.

A crystal unit can be inserted in the feedback path of an *L/C* oscillator so that sufficient feedback can only occur at the crystal's resonant frequency. Circuits of this kind are known as crystal *controlled* oscillators.

A crystal controlled f.e.t. version of Armstrong's tuned anode oscillator (now tuned drain) is given in Fig.7. Drain tuning is accomplished by coil L1 and capacitor C1, and coil L2 is a coupling winding supplying feedback to the gate.

Crystal X1, placed in series with L2, offers very little opposition to the feedback at its series resonant frequency, and a very high reactance at all other frequencies. In this way, the crystal controls the oscillator. The tuned circuit formed by L1 and C1 must, of course, resonate at the crystal frequency or a harmonic.

Signal output is taken from the drain and the impedance at this point is very high. Unless the accepting circuit has a matching high impedance, the signal voltage delivered to it will be much less than the stated 4V r.m.s.

Connection details for Toko coils are also given in Fig.7. The circuit will oscillate even when the feedback winding is wrongly connected (it then functions as a tuned-drain-tuned-gate oscillator). Oscillation is weaker, however, and harmonics of the fundamental crystal frequency will only be generated when the feedback winding L2 is connected as shown.

## BUTLER OSCILLATOR

A crystal controlled Butler oscillator is shown in Fig.8. Butler's circuit was described in its *L/C* form in Part Three, and it will be recalled that it ingeniously matches the impedances of two source coupled f.e.t.s and the tuned circuit formed by coil L1 and capacitor C1.

In this version, crystal X1 is placed in the feedback path between the drain (d) of TR1 and the gate (g) of TR2, where it inhibits feedback at all but its series resonant frequency.

A more conventional arrangement is to use separate 1 kilohm source resistors and to couple the sources via the controlling crystal. A feedback capacitor of between 10pF and 100pF, depending on frequency, then links the drain of TR1 to the gate of TR2.

Sluggish low frequency crystals may, however, be unable to initiate oscillation when connected in the low impedance path between the sources. Success is, therefore, more certain with the arrangement shown in Fig.8.

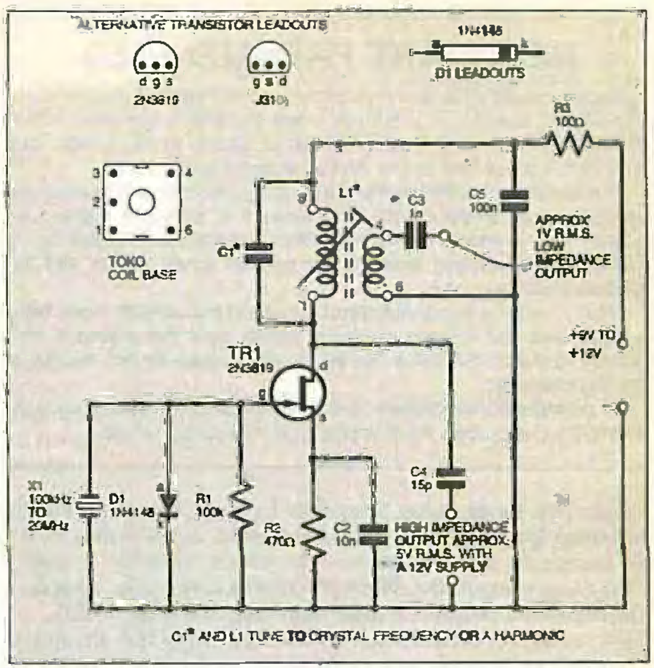


Fig.6. Circuit for a field effect transistor version of the Miller crystal oscillator.

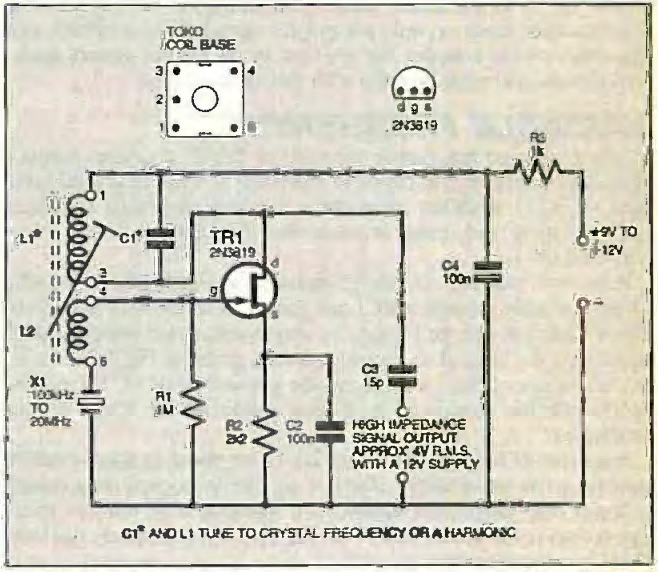


Fig.7. Crystal controlled version of Armstrong's tuned anode (now drain) oscillator.

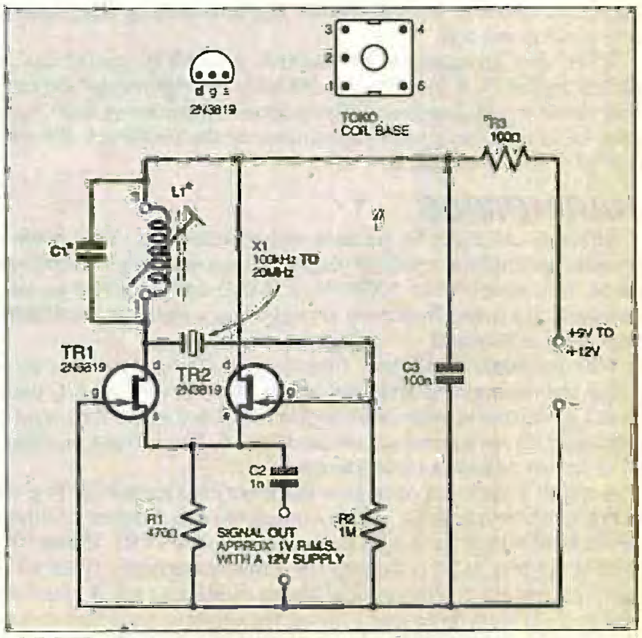


Fig.8. Crystal controlled Butler oscillator.

## RESONANT FREQUENCIES

Quartz crystal units resonate at two, closely spaced frequencies. The lower frequency is produced when the unit is operated in the series mode, simulating a series tuned circuit. In this mode, the impedance presented by the crystal at resonance is low.

The capacitor formed by the connecting electrodes deposited on opposite faces of the crystal slice tunes it to a slightly higher frequency. This is known as the parallel or anti-resonant frequency. In this mode the crystal simulates a parallel tuned circuit and its impedance is very high.

Most crystals are manufactured for use in the parallel mode with a small external loading capacitor which sets the resonant frequency to the stated value. Series mode crystals do not require a loading capacitor.

All crystals will resonate in both modes, and the frequency can be slightly low or high if the wrong type of crystal is used.

Again, the tuned circuit formed by L1 and C1 must resonate at the crystal frequency or a desired harmonic. Signal output is at a low impedance and isolated, to some extent, from the frequency determining components. When the crystal couples the sources, a high impedance output is usually taken from the drain of TR1.

The crystals in the circuits shown in Fig.7 and Fig.8 are operating in their series mode and, in theory, series mode devices should be used or the frequency of oscillation will be slightly lower than the figure stated by the manufacturer. In practice, the frequency can usually be set to the stated value by adjusting the core of L1, even when parallel mode crystals control the circuit. This is not the case when the crystal couples the sources in the Butler circuit, and a series mode unit *must* be used with this arrangement.

## VARIABLE FREQUENCY

When external reactances are used to "pull" a crystal across a band of frequencies, the circuit is known as a *variable* crystal oscillator, or VXO. Stability deteriorates as frequency shift increases, and oscillation may cease, or the crystal lose control, if the process is carried too far.

A typical "pulling" circuit is included in Fig.5, where inductor L1 and variable capacitor VC1 are placed in series with the crystal X1. A VXO can also be formed by connecting these components in series with the crystal in Pierce's circuit, given in Fig.3. However, this arrangement does not permit the grounding of VC1's moving vanes, and the modification is best made to the Clapp crystal oscillator.

Inductors of between 5μH and 20μH are usual in these circuits: increasing the value above 20μH in an attempt to pull the frequency lower may inhibit oscillation. The specified coil, with its windings connected in series, can be set between approximately 6μH and 12μH by adjusting its cup core.

When the widest possible "pulling" range is required, provision must be made for shorting out this inductor. Shorting switch S1 should be operated by a miniature signal-switching relay located very close to the coil.

When this arrangement is adopted, a 14MHz crystal can be shifted around 0·15 per cent (i.e. 20kHz). The percentage increases with rising crystal frequency. Stray circuit capacitances must, however, be kept to an absolute minimum or the frequency coverage will be seriously curtailed.

## HARMONICS

Although advances in manufacturing techniques have made it possible to produce crystals which will oscillate, in fundamental mode, well in excess of 100MHz, it is still commonplace to use a harmonic of a lower frequency crystal when a signal above 20MHz or 30MHz is required.

With harmonic oscillators, frequency multiplication takes place within the maintaining amplifier and is controlled by an *L/C* tuned circuit in the output stage. Almost any oscillator where the output is developed across a tuned circuit (see Figs. 6, 7 and 8) can be adjusted to deliver at least a close harmonic.

A circuit which will operate at higher crystal harmonics is given in Fig.9, where transistor TR1 is configured as a Colpitts oscillator and its base bias is fixed by resistor R1 and preset VR1. Preset VR1 enables the bias to be optimised for different transistor types when operation becomes more critical above 50MHz or so. A transistor with an $f_T$ at least three times higher than the required harmonic is necessary for the reliable operation of the circuit.

Feedback is developed across r.f. choke L2 and applied to TR1 base via the capacitance tapping formed by capacitor C1 and trimmer capacitor VC1. The feedback capacitors C1 and VC1 also act as the loading for the crystal X1, and the inclusion of trimmer VC1 permits the fundamental to be set to the correct frequency. Emitter bias is provided by resistor R2, which is bypassed by capacitor C3.

A high impedance output is developed across the collector load formed by tuned circuit L1/C2. This tuned circuit must, of course, be adjusted to resonate at the desired harmonic of the crystal frequency. An alternative low impedance output could be provided by using a coupling winding on the coil, as shown in Fig.6.

As the output frequency increases above, say, 50MHz, capacitor C1 can be reduced or even omitted (the internal base/emitter capacitance of TR1 can be sufficient to maintain oscillation). Substituting an r.f. choke of lower inductance may also be of benefit. Whatever the frequency, optimum performance is usually realised when VC1 has an in-circuit value of around twice that of C1.

## OVERTONES

Overtone oscillators use specially cut crystals which resonate at an odd harmonic, usually the third or fifth, of their fundamental. Whilst crystals of this kind can be made to oscillate at their fundamental frequency, they are designed to resonate, or vibrate, at a stated overtone.

This represents the crucial difference between overtone and harmonic oscillators. In an overtone oscillator, the crystal itself is vibrating at the higher frequency: in a harmonic oscillator, the crystal vibrates at its fundamental frequency and multiplication takes place within the transistor.

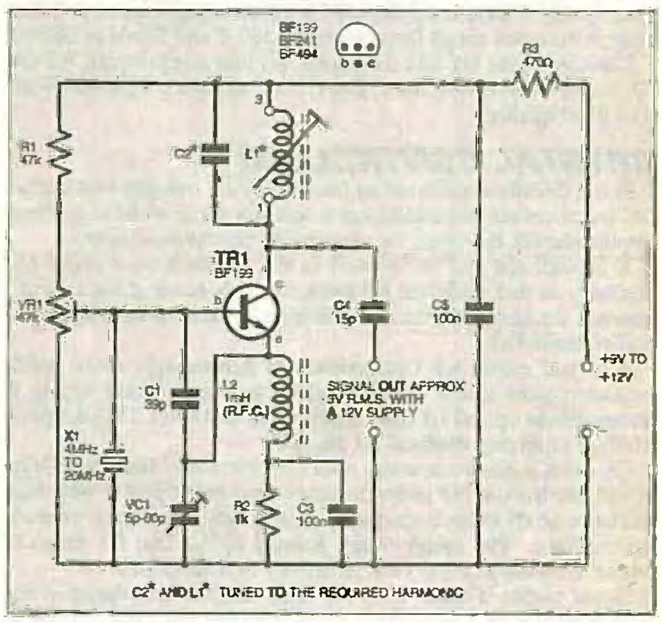


*Fig.9. Circuit diagram for a harmonic and overtone crystal oscillator.*

Sometimes measures are taken to suppress any tendency of an overtone circuit to oscillate at the crystal fundamental. Arranging for the feedback to reduce at the lower frequency is a common method.

In Fig.9, feedback is developed across r.f. choke L2. If this component is replaced by an inductor of much lower value, feedback will be insufficient to maintain oscillation at a fundamental of, say, 9MHz, but will be capable of doing so at the third overtone of 27MHz.

Inductors from the Toko S18 range are ideal for this purpose, and a 5·5 turn ferrite slug tuned coil (nominal value 0·23μH) should prove suitable for crystals with fundamentals in the 6MHz to 12MHz range. Temporarily substituting a tuned circuit which resonates at the fundamental for L1 and C2, will enable activity in this mode to be checked.

If the oscillator is producing an output at the crystal's fundamental, withdraw the core of the S18 coil until it stops. The relative values of capacitors C1 and VC1, and the gain and $f_T$ of TR1, also influence the feedback level, and some experimentation may be necessary to eliminate unwanted oscillations. The circuit is, however, quite easy to set up.

## DIVIDING DOWN

Crystals cut to resonate below 1MHz become more expensive and less readily available as the frequency is lowered. If a square wave output can be tolerated, bistable flip-flop (divide by two) and decimal counter (divide by ten) i.c.s can be used to produce submultiples of a higher frequency.

There is some additional complication, but the CMOS i.c.s are inexpensive and require no external components other than a supply decoupling capacitor.

If a sinewave output of good quality is the priority, an *L/C* oscillator will usually be more than sufficiently drift free at frequencies below 100kHz, especially if the precautions detailed in Part Two are observed.

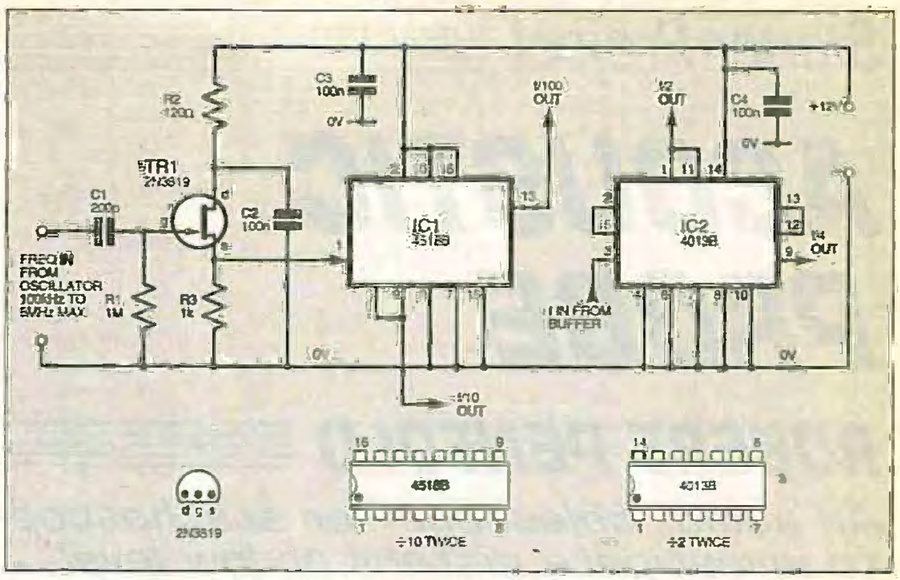


Fig.10. Circuit diagram for dividing the frequency down using a CMOS dual decimal counter i.c. plus a dual bistable flip-flop i.c.

### *DIVIDING DOWN*

Crystals which resonate below 1MHz tend to be more expensive and less easy to obtain. If a square wave output can be tolerated, highly stable low frequency signals can be obtained, at lower cost, by using integrated circuits (i.c.s) to divide down the output from a higher frequency crystal.

A divider circuit using a dual decimal counter, IC1, that can be used to divide a frequency by 10 or 100, is shown in Fig.10. By this means, a 2MHz crystal would provide outputs at 200kHz and 20kHz. Alternatively, IC2, a dual bistable flip-flop, will divide by 2 or 4, and the two devices can be connected in tandem to produce various submultiples of the input frequency.

A source follower buffer stage, TR1, is necessary to ensure reliable operation of the i.c.s. Direct connections must be made between the buffer and the i.c.s and between any i.c.s in a dividing chain: a d.c. blocking capacitor is not required. The f.e.t. buffer stage is not needed when the dividers are used with the CMOS logic gate oscillator shown in Fig.3.

Output is a near perfect square wave with a peak-to-peak value almost equal to the supply voltage. The maximum input frequency for the i.c.s is around 8MHz when the supply voltage is 12V or 15V.

**Next month:** Oscillators which use *R/C* (resistor and capacitor) networks to fix the operating frequency will be considered.