A Solid State, Crystal Frequency Calibrator

A compact instrument which may be used to deliver any of thirteen accurately controlled and stable test frequency signals, all derived from a quartz crystal oscillator and having a fast-transition rectangular waveform of high harmonic content. It should be found invaluable for calibration of receivers and instruments, and would also be useful as an audio oscillator, square-wave generator, digital circuit tester or as the heart of a crystal-controlled chronometer.

By Jamieson Rowe

A source of accurately controlled and stable test frequency signals vastly simplifies and facilitates the frequency calibration of short-wave receivers, signal generators and other equipment, both during initial calibration following construction, and for "spot check" purposes during critical operation. Such a source can also serve as a marker generator for sweep-frequency alignment, and as a time-period reference for such applications as the calibration of an oscilloscope timebase.

The instrument to be described in this article delivers any one of thirteen quartz-crystal derived fundamental test frequencies, each of which is accompanied by a series of its harmonics extending well up into the VHF spectrum. It is therefore well suited for the above applications, as well as for more general use as an audio-video squarewave generator and as a digital "clock" generator. It might also form the basis of a quartz-crystal chronometer, or the timebase system of a digital counter.

Although functionally very flexible, the instrument is basically quite straightforward in design. It is also very compact, and will involve but a modest outlay. When built up in its complete form, for example, it should cost no more than about $50. However, if the full range of output frequencies is not required, this figure may be significantly reduced.

The key to the attractive high flexibility/low complexity ratio offered by the instrument lies in its use of integrated digital microcircuits to perform all the active functions. In fact, apart from the single quartz crystal and the power supply components, the instrument consists of nothing more than a handful of microcircuits and a few bypass capacitors.

The microcircuits used are all of the low-cost "RTL" (resistor-transistor logic) variety. Only two device types are used, both from the MC700P range manufactured by Motorola Semiconductors. One type MC799P dual buffer device is used in the crystal oscillator, while up to thirteen type MC790P dual J-K flip-flop devices are used in the cascaded divider chain used to derive the various output frequencies. All devices are in the 14-pin "DIL" (dual in-line) package. They are distributed in Australia by Cannon Electric (Aust.) Pty. Ltd.

All of the active circuitry of the instrument is mounted on a small single-sided printed wiring board, making assembly of the unit a simple and straightforward operation. The board measures only 3¼in x 5¼in, but provides adequate space for the quartz crystal and all fourteen microcircuits, together with minor components and wiring.

Heart of the instrument is the crystal oscillator, shown in figure 1. This uses an MC799P dual-buffer device connected basically as an astable multivibrator, with the quartz crystal in one feedback link. A capacitor/trimmer combination connected in series with the crystal allows vernier adjustment of the frequency of oscillation, and permits standardisation of the instrument against a reference such as the NBS standard transmissions of WWV or WWVH.

The crystal used in the oscillator is a "D-type" unit, having a nominal frequency of 2MHz (2,000KHz). This frequency was chosen in contrast with the more usual figures of 1MHz and 100KHz because it would appear that, where modern crystals are concerned, 2MHz represents a considerably more attractive performance/cost compromise.

Typically a modern 2MHz crystal costs slightly less than half that of a 1MHz crystal of comparable tolerance and frequency stability, and less than one third the cost of a comparable 100KHz crystal. Naturally, the use of a 2MHz crystal involves additional frequency division, and this tends to reduce the cost advantage. However, with the use of low cost microcircuits in the divider chain the additional division is provided very economically, so that the advantage of employing a 2MHz crystal is still quite significant.

The crystal used in the prototype instrument is a .003 per cent adjustment tolerance AT-cut type, specified for operation at ambient temperatures. It was kindly supplied by Pye Pty. Ltd., who advise that similar units can be supplied to readers on order, either direct or via normal parts suppliers. The Pye designation of the unit in terms of tolerance and stability is class "FEF," with the holder code "Q12A" and the nominal intended shunt capacitance 30pF.

Similar crystals of different manufacture may be used, and even a disposals crystal may be tried if available. The oscillator circuit is not critical, and will operate with a wide

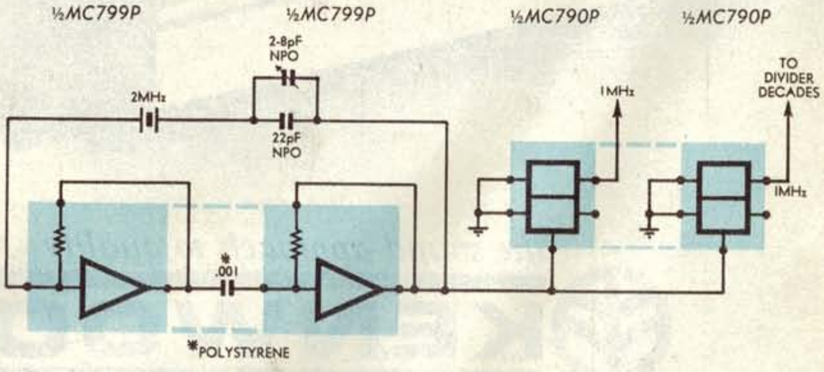


Figure 1 CRYSTAL OSCILLATOR/BUFFER DIVIDER

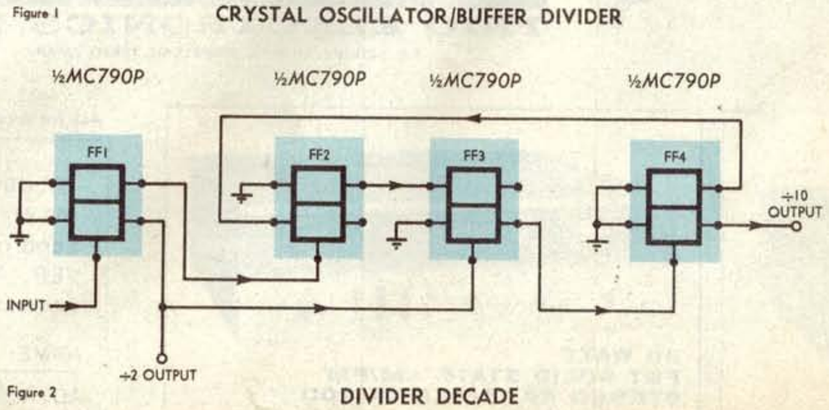


Figure 2 DIVIDER DECADE

variety of crystals. However, it should be borne in mind that the ultimate frequency stability of the instrument depends almost completely upon the crystal, so that a low-grade unit may seriously prejudice usefulness.

It may be noted that the capacitor and trimmer connected in series with the crystal are both NPO ceramic components, to ensure that the temperature stability of the oscillator is not significantly less than that of the crystal itself. It is for the same reason that the .001uF coupling capacitor is specified as a polystyrene type.

The 2MHz output from the crystal oscillator could be used directly as the highest fundamental output frequency of the instrument, although this would require the use of a third buffer element to ensure that output loading would not degrade the frequency stability. In the final design of the instrument we have not followed this course, but instead have settled upon 1MHz as the highest fundamental output frequency.

This has allowed the use of an MC790P dual J-K flip-flop both as an oscillator buffer and as the initial 2:1 divider. Both flip-flops of the device are connected in toggling mode and operated from the 2MHz oscillator output, as may be seen in figure 1, one effectively providing a buffered 1MHz output and the other providing an independent 1MHz signal for the following divider chain.

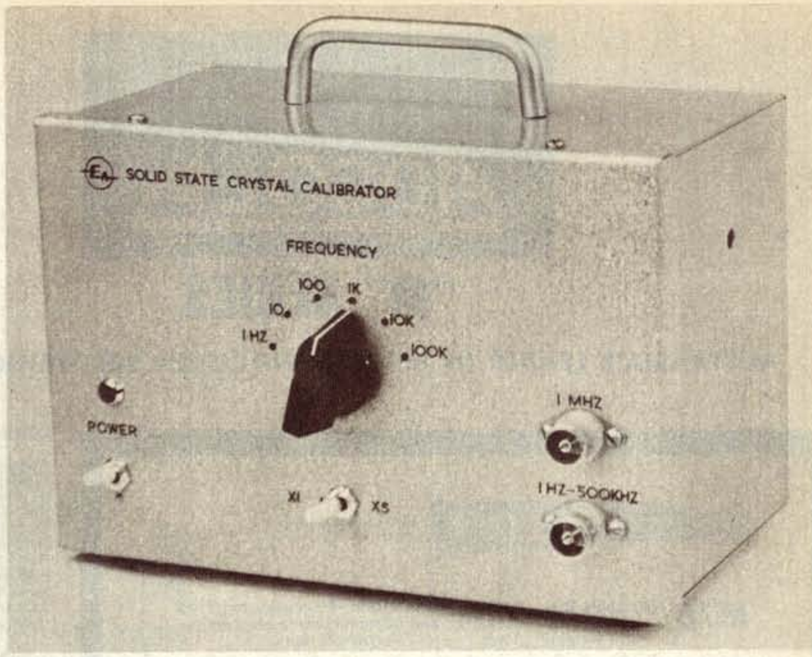
The divider chain of the instrument consists of a series of 10:1 divider decades, each using the configuration shown in figure 2. The configuration divides in what may be called a "quibinary" or (5 x 2) fashion, with the first element FF1 dividing the input by two, and the remaining three elements dividing by five.

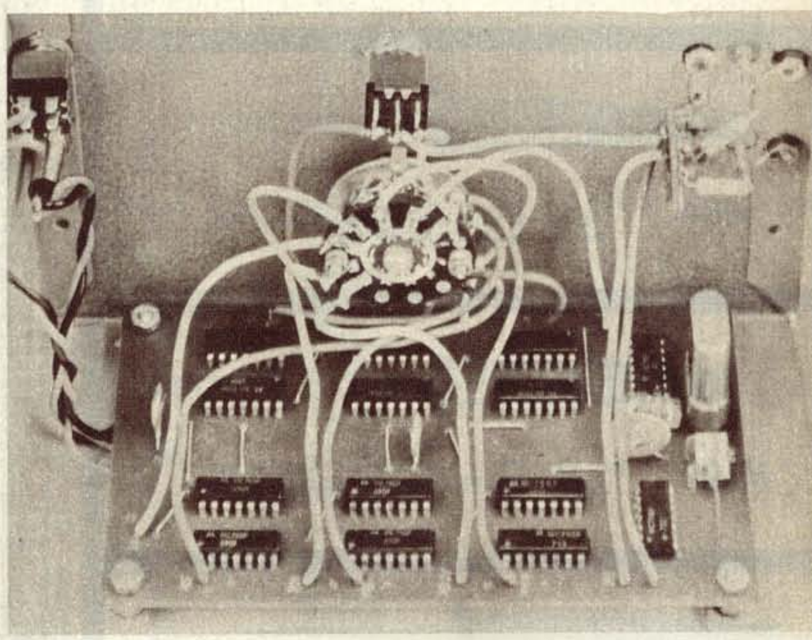
The actual configuration used is particularly attractive from the point of view of economy, for as may be seen it requires no separate gating elements to perform the required decade division. Only four J-K flip-flop elements are required, all gating being performed by the elements themselves. (The four elements used are provided by two MC790P dual flip-flop devices.)

Quite apart from its economical use of elements, the configuration has a further attraction. From the output of element FF1 may be taken a useful auxiliary output signal, representing a 2:1 division of the input signal. Thus in terms of frequency multiples, each decade of the divider can provide both a "X1" signal (FF4 output) and a "X5" signal (FF1 output).

Space is provided on the printed wiring board for up to six divider decades, in addition to the crystal oscillator and the initial buffer divider. Whether or not all of these decades are wired will depend solely upon the needs of the constructor concerning the available range of output frequencies.

If all decades are wired, the range of frequencies available extends from 1MHz down to 1Hz in a 10-5-1 sequence. However the sequence may be terminated at any desired point simply by omitting the redundant microcircuits. If both devices of any redundant decades are omitted, the lowest available frequency will be a multiple of 1 (or 10); however, it is entirely permissible to wire in only one device of the lowest decade involved, in order to provide the appropriate "X5" signal.





At top is a view of the completed calibrator, which will deliver any one of thirteen crystal-locked frequencies. Above is a view of the rear of the panel when inverted for inspection, showing the printed wiring board and its microcircuits.

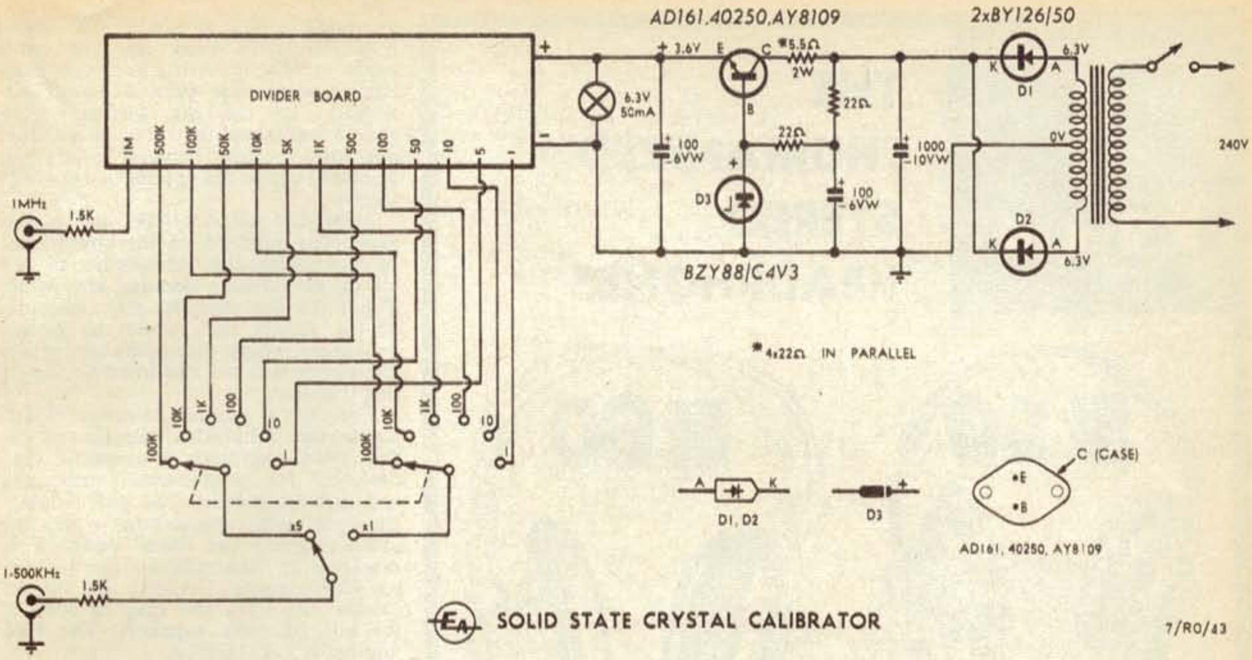
Hence if the constructor desires to provide only those frequencies extending down to 10KHz, he would wire in only the first two decades following the crystal oscillator and buffer divider. This would involve a total of only six microcircuits, and result in a considerable saving.

Another of the many possible variations would be where those frequencies down to 50Hz are required, but not those lower. This would require four full decades, together with the first device only from the fifth decade. In this case a total of eleven microcircuits would be involved.

Output voltage for all signals is approximately 2V peak to peak.

The design of the printed wiring board and circuitry is such that any or all of any decades or part-decades omitted when the instrument is first made could easily be added at a later time if the need arose for the provision of lower frequencies. It would also be feasible to add additional decades to the six allowed for on the board, in order to obtain still lower frequencies than 1Hz. However if this is contemplated it should be borne in mind that the power supply may have to be re-designed to cope with the additional current demands.

As may be seen from the main circuit diagram, the oscillator/divider board forms the heart of the instrument. The remainder of the circuitry consists of a simple regulated power supply delivering a nominal 3.6V DC



SOLID STATE CRYSTAL CALIBRATOR

The circuit of the calibrator, showing its essential simplicity. The number of microcircuits used on the divider board and the number of switch positions wired will depend upon the output frequencies required; the circuit shows the system as fully wired.

for the microcircuits, and a straightforward switching system to permit selection of the desired output signal.

The printed board pattern will be supplied to interested board manufacturers, so that boards should be available in the near future. The pattern is coded 69/c9.

The power supply consists of a conventional full-wave rectifier followed by a simple series-pass regulator using an NPN power transistor. Reference voltage for the transistor is obtained using a 4.3V zener diode. The transistor base supply is filtered to ensure that the transistor also acts as a dynamic filter.

As the current drain of the oscillator/divider board is approximately 500mA when all divider decades are wired, the quiescent power dissipated by the series-pass transistor can exceed one watt. In view of this it is desirable to employ in this position a device with a rated dissipation of 3W or more at 40 degrees C., to allow adequate safety margin.

The TO-66 type power devices specified on the circuit have adequate ratings for this purpose, and are thus quite suitable. However, a device with higher ratings could be used if on hand. Alternatively it would be possible to use medium-power silicon TO-5 devices such as the 40408 or AY8116, providing they were fitted with the appropriate clip-on heat radiator to limit case temperature.

The output signal selection circuitry has been arranged for simplicity and operating convenience. The 1MHz output signal has been taken directly to one output connector, both because it is in a sense "thirteenth man" and because this permits the instrument to be calibrated to greatest accuracy using this signal, even when one of the other signals is being used simultaneously for another purpose.

The selection of the remaining twelve output signals is performed by a two-pole six-position switch and a two-position toggle switch, the latter connecting to a second output connector. Isolating resistors (1.5K) are fitted in series with each of the output connect-

List of Components

1 Case, 7½in x 5in x 4in, with wrap-around front panel, board brackets.
1 Printed wiring board, 69/c9.
1 Stepdown transformer, 240V to 12.6V CT, at 1A.
1 2.000MHz quartz crystal (see text).
1 Two-pole six-position rotary switch.
2 SPDT miniature toggle switches.
1 Miniature pilot lamp, bezel, 6V at 50mA.
2 Co-axial connectors.

CAPACITORS

1 2-8pF NPO ceramic trimmer (see text).
1 22pF NPO ceramic.
1 .001uF polystyrene, 400V or lower if available.
3 .047uF 25VW ceramic.
2 100uF 6VW electrolytic.
1 1000uF 10VW electrolytic.

SEMICONDUCTORS

2 BY126/50 diodes or similar.
1 BZY88/C4V3 or similar 4.3V zener diode.
1 AD161, 40250, AY8109 or similar NPN power transistor.
1 MC799P dual buffer microcircuit.
13 MC790P dual J-K flip-flop microcircuits (see text).

RESISTORS

6 22 ohms ½watt.
2 1.5K ½watt.

MISCELLANEOUS

Mains cord and plug; grommet and cord clamp; 8-lug section of miniature resistor panel; 3-lug miniature tagstrip; case handle, rubber feet; screws, nuts, connecting wire, solder, etc.

NOTE: Motorola Semiconductor devices such as the MC700P microcircuit series are available in Australia from Cannon Electric (Aust.) Pty. Ltd., whose addresses for mail order are 58 Cluden Street, East Brighton, Vic. 3187; P.O. Box 25, Mascot, N.S.W., 2020; and Commonwealth Aerodrome, Parafield, S.A. 5106.

ors to prevent damage or malfunction due to severe loading or short-circuits.

The instrument is housed in a small rectangular instrument case similar to that used for many of our recent designs, and measuring 7½in x 5in x 4in. The front panel controls consist of the frequency selection switches, the output connectors and the mains switch and pilot bezel.

Inside the case, the printed wiring board is supported by two right-triangular brackets which are in turn clamped to the front panel by the input connector screws at one end, and the mains switch and bezel at the other. A hole in the bracket adjacent to the crystal end of the board and a similar hole in the appropriate end of the case permit the crystal oscillator trimmer to be adjusted for calibration once the instrument is fully assembled.

The two miniature toggle switches and miniature pilot bezel used in the instrument are available from I.R.H. Components Pty. Ltd. The switches are N.K.K. type S-2012, while the bezel is a Rodan 6V 50mA type. Both components may be ordered via the usual parts suppliers.

Using the wiring diagram provided, assembly of the components on the printed wiring board should be simple and straightforward. The main point to watch is that a small, well tinned iron should be used, and the joints made rapidly in order to avoid overheating either the printed board conductors, or the microcircuits. Care should be taken that the solder does not form bridges between conductors in places where the spacing is relatively narrow.

Note that all wire links and bypass capacitors mounted on the board must be fitted, regardless of whether or not all of the divider decades are wired. The links are essential for continuity of the supply line, while the bypass capacitors ensure that operation of the microcircuits is not disturbed by supply line transients.

The NPO ceramic trimmer which forms the calibration adjustment for the crystal oscillator is a special type designed for printed-board mounting and side adjustment. The unit employed in the prototype and for which the printed board has been designed is marketed in Australia by the Imported Components Division of Plessey Ducon Pty. Ltd., and may be ordered via normal parts suppliers. The type number is DV11-PR8A.

The power supply section of the instrument is mounted in the lower rear of the case, with the power transformer mounted toward the case end opposite to that of the quartz crystal, in order to reduce thermal drift effects. The mains cord terminations are mounted on one side of the transformer, while the rectifier and regulator components are mounted on the other side on an 8-lug section of miniature resistor panel.

The regulator series-pass transistor is mounted centrally on the rear of the case, being insulated electrically by means of the usual mica washer and plastic bushes. In this way the case itself acts as the heat radiator for the device.

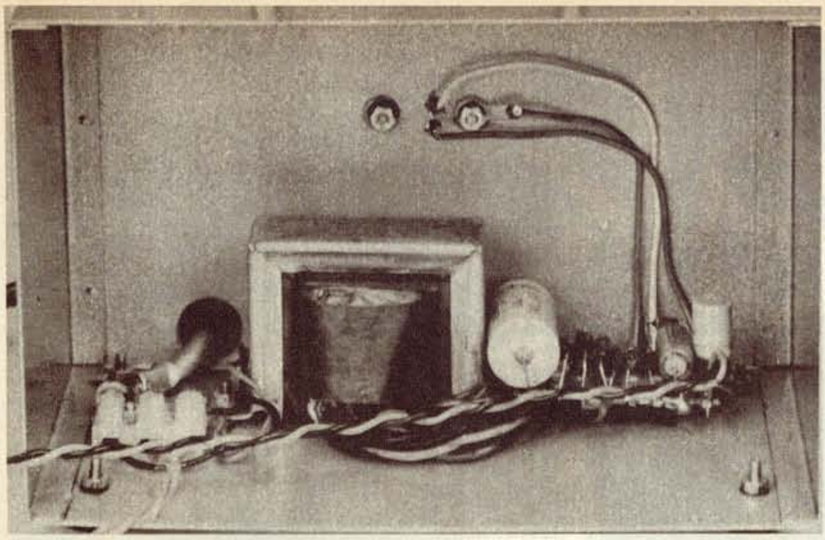
The power supply wiring is not critical, and the constructor may deviate from the layout of the prototype if desired. However, care should be taken to ensure that the power cord is clamped securely upon entry via the usual grommetted hole, to prevent strain on the connections. The cord earth conductors should be taken to a solder lug clamped under the adjacent transformer counting screw.

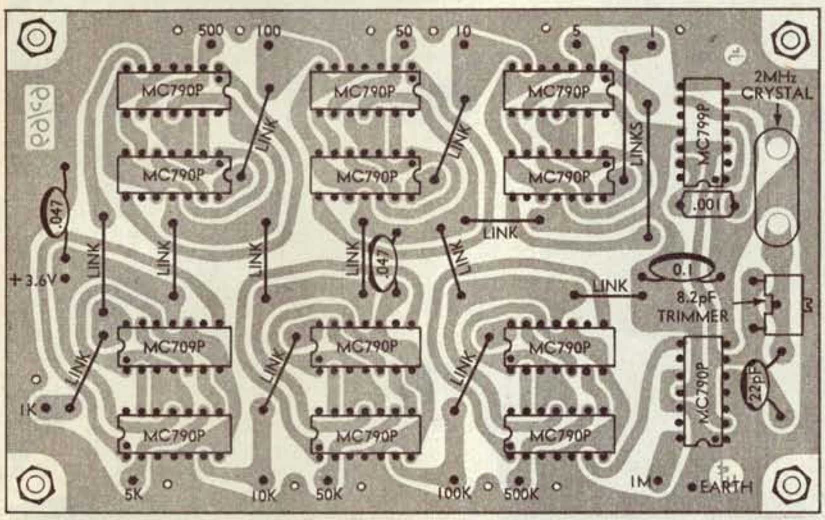
When the power supply section is completed, it would be wise to apply power and check its output voltage before the oscillator/divider board is connected. This will ensure that if an error has occurred, it can be rectified before damage could be caused to the relatively costly microcircuit array.

Without the microcircuits connected, the voltage delivered by the power supply should be between 3.8 and 4.5V DC; if it lies within this range, everything is probably in order and the microcircuits may be safely connected. However if the voltage is markedly higher than 4.5V with no load, switch off and look for a wiring or component fault.

As virtually all the functional wiring is provided by the printed wiring board, connection of the 3.6V supply to the completed board should result in full and correct operation. The only aspect of construction which will remain at this stage is calibration of the crystal oscillator against a known reference.

As explained earlier, this operation





At top is a view inside the rear of the calibrator case, showing the power supply circuitry. Above is a diagram of the printed wiring board, viewed from the component side. Actual size of the board is 5¼in x 3¼in.

is performed when the unit is completed and assembled, using the small ceramic trimmer. Adjustment of the trimmer is carried out using a small insulated alignment tool, introduced through the holes provided in the end of the case and the board support bracket.

Two methods of calibration may be used. One simply involves measurement of the 1MHz output of the instrument using a high-accuracy digital frequency meter. This is a very efficient technique, and will no doubt appeal to those with the appropriate facilities. However, it should be noted that the frequency meter used should be one having a timebase system whose accuracy and stability are at least within 1 part per million, otherwise the exercise will have little validity. The reason for this is that the calibrator itself is likely to have a performance approaching 10 parts per million, when set up.

The electrical setup for the alternative method of calibration is almost as simple, and may be more convenient. It involves only a conventional shortwave or communications receiver capable of receiving a standard frequency transmission such as those radiated by station WWV on 2.5, 5.0, 10.0, 15.0, 20.0 and 25.0MHz, or by station WWVH on 5.0, 10.0 and 15.0MHz. The 1MHz signal from the calibrator is simply fed into a rudimentary aerial near the receiver, and the calibrator trimmer adjusted for zero beat.

The procedure is to switch both the calibrator and the receiver on and let them run for about 15 minutes to allow the case temperatures to stabilise. At this stage no connection should be made to the output connectors of the calibrator, in order that radiation should be minimal. Then tune the receiver carefully to whichever of the standard frequency signals is currently available at a level adequate for convenient and reliable reception.

A foot or two of hookup wire may then be inserted into the 1MHz output connector, whereupon a beat note should become audible in the receiver output. It may in some cases be necessary to place the wire close to the receiver aerial lead-in, or perhaps even twist the two together, in order to obtain sufficient coupling.

Adjustment of the calibrator trimmer should allow the beat note to be reduced in frequency below audibility, although continued turning of the trimmer in the same direction should result in the note re-appearing and rising in pitch once again. The zero-beat condition lies in the centre of the inaudible-beat segment of adjustment, and with many receivers it may have to be estimated by interpolation. However, if the receiver is fitted with an "S" meter it should be possible to observe the beats on the meter when they are near zero, and a more accurate setting may be achieved.

Once set up in this fashion the calibrator should retain its calibration for a considerable period. The oscillator circuit is relatively insensitive to temperature, and is also free from many of the aging effects which are found with other circuits. However, before critical measurements are to be made using the instrument, it would be wise to re-check its calibration using the above techniques. ■