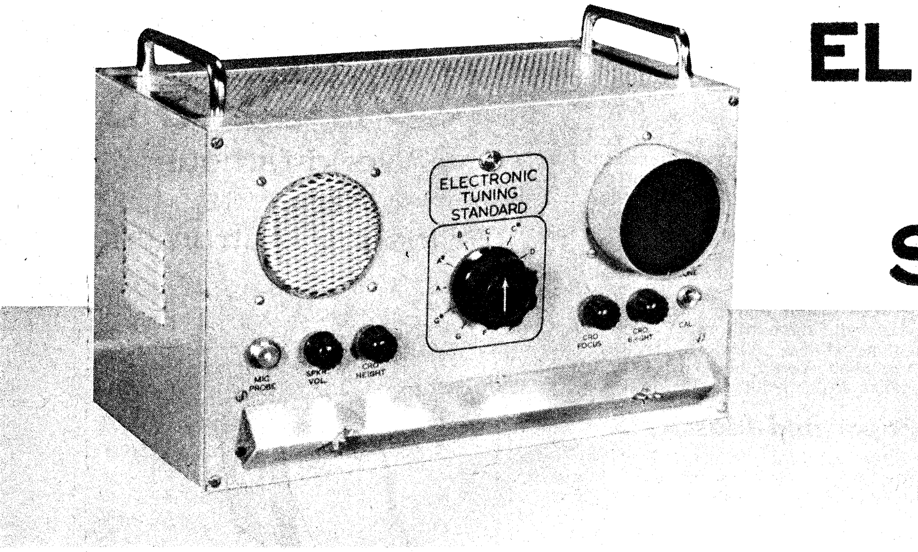


ELECTRONIC TUNING STANDARD

Last month, we carried an article on musical tuning, but expressed in the terminology of electronics. In this article, we suggest a design for an electronic tuning standard, which can be built around components and techniques borrowed from electronic organ practice. It could be a valuable asset to readers working with electronic organs or other electronic musical instruments.

By Neville Williams and John Davidson

THE idea of building some kind of electronic tuning aid came out of work we were doing at the time with the electronic organs. In turn, the article featured last month, on the principles of tuning itself, grew out of our thinking about a tuning aid.

In examining the whole question, we read many articles and considered many ideas, our reactions being more or less as set out in the last issue. As far as we could discover, there is no such thing as an accurate and unambiguous electronic tuning aid which, from the constructor's point of view, could also qualify for the description of "simple."

One commercial instrument, which did take our fancy, uses an L/C oscillator to produce a basic octave, individual semitones being obtained by switching to appropriate tappings along the resonant inductor. Output from the oscillator is used to drive an amplifier, thence synchronous motor and strobe wheel.

The signal for comparison and adjustment is passed through a separate internal amplifier, to operate a strobe light. When the incoming signal is in tune with the reference semitone, the strobe pattern appears to be stationary. The instrument can be checked during use by strobing a particular semitone against a fork or other reference frequency and varying a small capacitor across the oscillator. It is assumed that the adjustment will be effective for all other semitones.

To duplicate this instrument in the home workshop might not be easy, however.

While the strobe system could doubtless be replaced by a relatively simple oscillographic display, the job of designing a suitably tapped inductor, and duplicating it precisely in production, appeared to be a formidable one. Misplaced tappings would emerge as built-in frequency errors, which could only be discovered and compensated by cross-reference to another accurately adjusted tone source.

A couple of transformer production people, with whom we discussed the matter, were not at all optimistic about the prospects.

Faced with this problem, we began to wonder about an oscillator system adapted from the Stromberg/Playmaster organ. After a "settling in" period, these oscillators stay in tune for months, or even years on end, though admittedly in the relatively stable environment of an organ console. They might be less tolerant of the conditions inside a portable instrument case.

On the other hand, even a somewhat unstable octave of semitones would still be a lot more accurate and convenient to somebody working with electronic instruments than any conventional audio generator. If it turned out to be stable, by musical standards, so much the better. There was one way to find out—which is the precise reason for the instrument as pictured coming into being!

During the 18 months or so that the instrument has been on hand, in home and laboratory, it has proved invaluable when working with basic tone generators and it is quite stable enough to serve as a tuning standard, if kept in adjustment. With its aid, an organ in a home or church can be tuned in a few minutes and almost in silence.

A valuable feature is that the instrument can be set against a C-523 fork and then adjusted against itself by the beat method for exact tempered scale intervals, thus by-passing problems due to tolerance errors in the components.

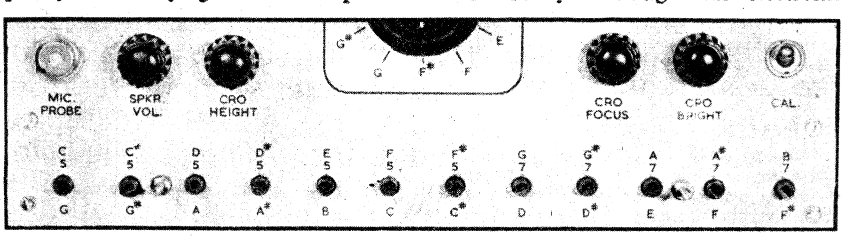
It may logically be asked what advantage such an instrument could have when it relies for its setting up on the very procedure which it is designed to render unnecessary!

The answer to this lies simply in the fact that the instrument can be set and checked out, from time to time, at leisure on the service bench, using its in-built indicator system to simplify the job. This is a great deal easier than following the same procedure on individual and strange instruments in equally strange environments. At least, that is how the author has found it!

At first glance, it might appear that such an instrument, with the facility for cross checking semitones, would need four shared oscillators, as in the Stromberg/Playmaster and early Thomas organs, to provide the requisite twelve semitones of the reference octave.

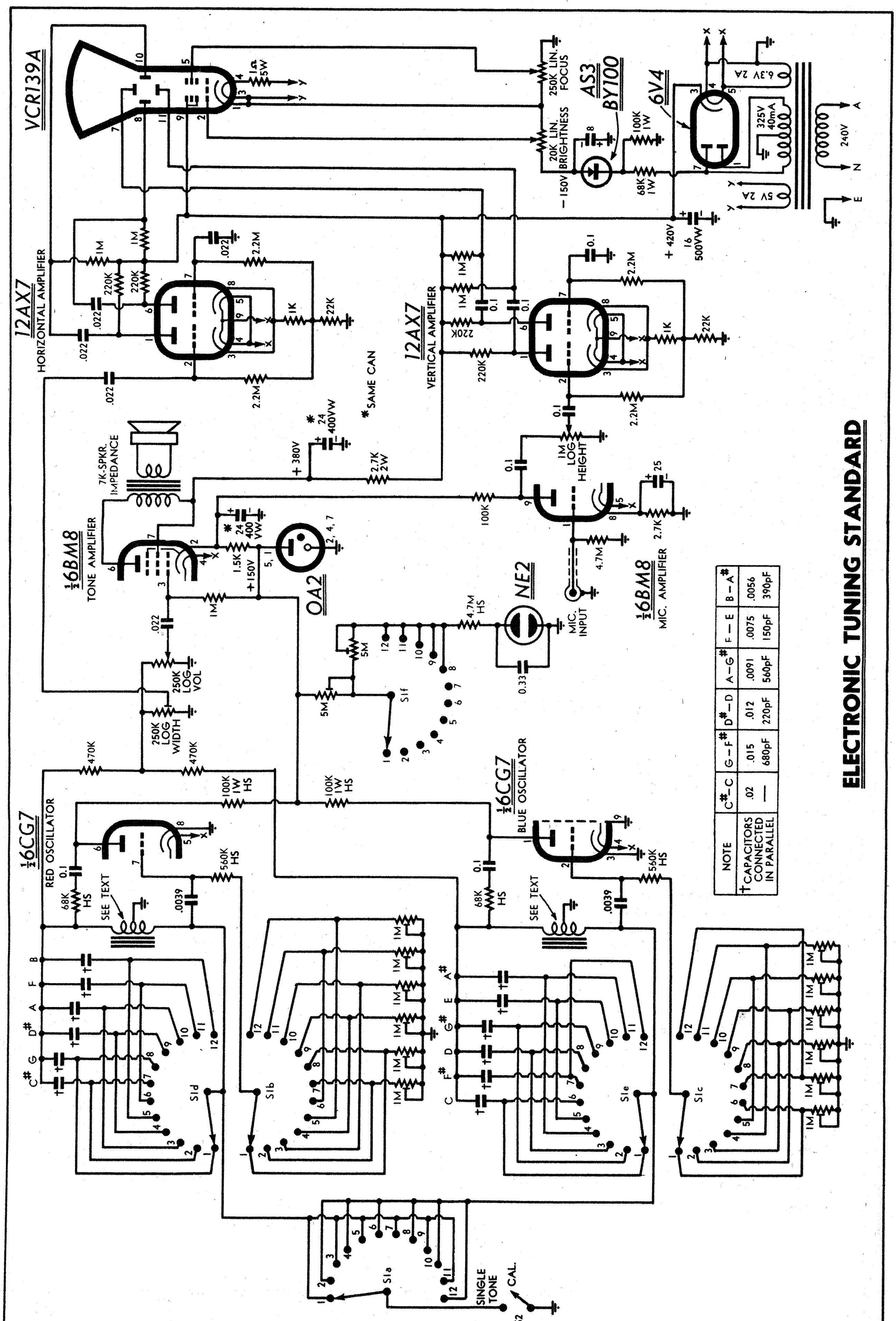
A little figuring, however, showed that only two basic oscillators will be required, each providing six tone intervals.

The first must provide middle C, D, E, F-sharp, G-sharp and A-sharp.



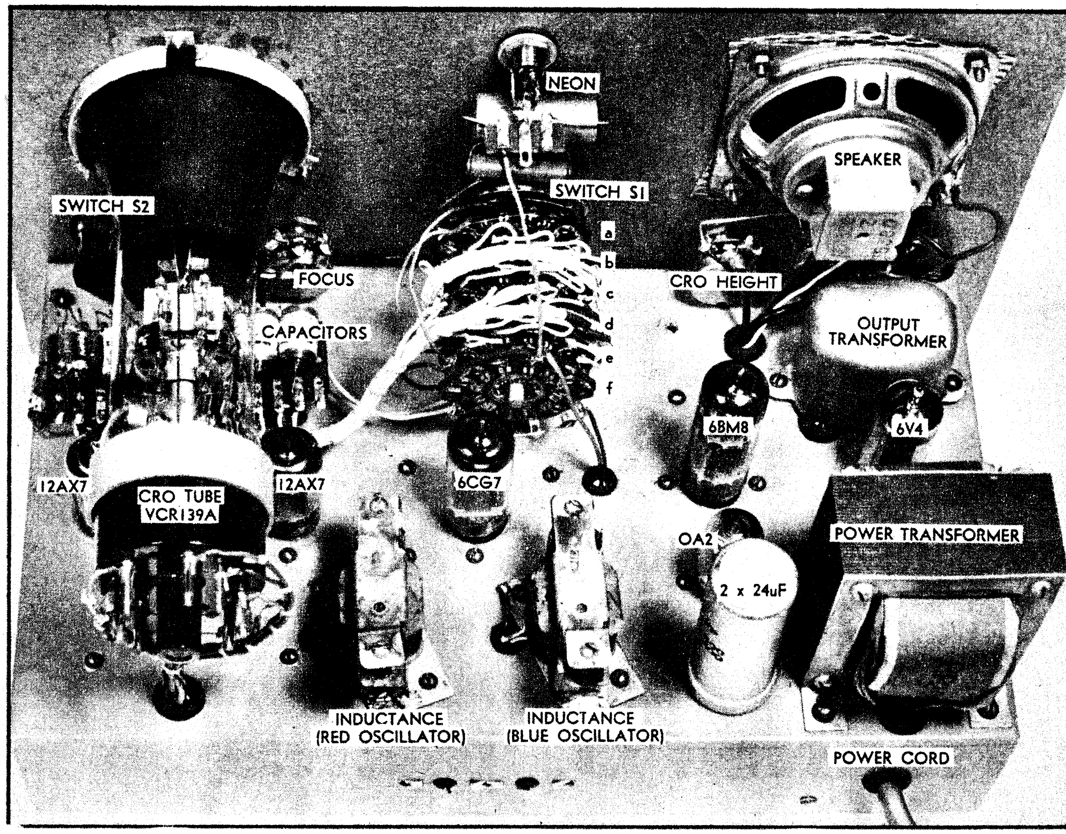
The picture at top left shows the complete prototype tuning standard, with the individual semitone tuning pots covered by a piece of aluminium angle. The picture above shows the controls, close-up, with the cover removed. The top of the case is perforated to minimise heat rise.

At right is the circuit of the tuning standard. The respective semitones are produced by two oscillators which are symmetrical but staggered in tuning by one semitone. The CRO circuitry provides visual indication of beat effects, both within the instrument for self-tuning and between the instrument and external signals.



ELECTRONIC TUNING STANDARD

NOTE	C#–C	G–F#	D#–D	A–G#	F–E	B–A#
†CAPACITORS CONNECTED IN PARALLEL	.02	.015	.012	.0091	.0075	.0056
	—	680pF	220pF	560pF	150pF	390pF



A top view of the instrument, with most of the components visible and marked for identification. To minimise hum fields from the transformer, the CRO tube neck was wrapped with nu-metal but this was not in place when the picture was taken. The two tab pots for adjusting the pulse rate indicator are just visible on the rear lip of the chassis.

The second must provide C-sharp, D-sharp, F, G, A and B.

If these combinations are checked against the tuning procedure set out last month, it will be found that it does not simultaneously involve any two notes in the one group.

The prospect thus emerged of designing the instrument around a twin triode, with each section providing six-tone intervals, as outlined. It remained to be discovered whether the oscillator would function reliably over a near-octave range, whether the tuning capacitors required would be practical values and whether the original scheme of varying the grid resistor as a frequency vernier would still work out.

To cut short a rather long story, practical tests indicated that, with slight amendments to the original organ generator circuit, it could be made to cover the required frequency range. It involved using the same inductor as for the original middle-C triplet in the organ (code, yellow leads) and tuning capacitors ranging downward in value from .02uF—fortunately in practical values.

Figures already published for the inductor indicate that it involves 5300 turns of 40B&S enamelled wire, bobbin wound and centre-tapped. Inductance is adjustable, by means of the core, from 32 to 8 Henries.

We should stress here that the tuning capacitors are quite critical, as indeed they are in the original organ or any other such instrument. They must be Styroseal or equivalent components, stabilised and to close tolerance, preferably better than 5 per cent. The tolerance is all the more important in this case because the one setting of the adjustable choke must serve six notes—not three as in the original design. There is therefore less opportunity for compensating stray capacitance values with counter adjustment to the inductor core.

The most practical set of values is as shown on the circuit. This involves six main tuning capacitors ranging in value from .02uF to .0056uF and of the type as mentioned. Five of these capacitors have to be shunted with smaller but standard capacitors to give the requisite total value. While the figures specified will probably be right, the shunt values do give opportunity for easy manipulation of all but the lowest semitone to keep it within range of the appropriate fine frequency adjustment potentiometer.

The potentiometers, by the way, are 1M A-taper (linear) tab types with knurled, slotted shafts, capable of being turned either with fingers or a screwdriver.

While the small shunt capacitors must also exhibit good stability (preferably Styroseal but NOT high-K ceramic) they are not as critical as the larger value across which they are shunted. Obviously enough, percentage variations in a low value shunt component diminish to a much smaller percentage when related to the total parallel capacitance.

The two oscillators required can use identical capacitor networks since they require to deliver a similar sequence of tones, but displaced by a semitone. A mere touch on the inductor core adjustment is sufficient to shift one oscillator by this amount.

The selection of individual notes obviously calls for switching to bring into circuit the appropriate tuning capacitor combination and a pre-set potentiometer by which the particular note is tuned. A variety of switching arrangements is obviously possible and we spent a good deal of time debating the possibilities.

However, having respect to the purpose of the instrument, we decided to concentrate the entire switching function around a multi-band 12-position rotary switch. What appears on the panel looks quite logical, therefore; what goes on inside is more subtle.

On the front panel, the 12 positions of the switch are simply marked in progressive semi-tones, from middle-C at the top, clockwise through to B above middle-C. Setting the switch to any selected position makes available that particular semi-tone for external reference.

What goes on in the switching is perhaps best indicated by considering specific examples. Consider position 1, for middle-C.

On this position, switch section S1e connects an .02uF capacitor across the inductor of the lower oscillator, while S1c brings into circuit the pre-set potentiometer for exact middle-C tuning.

At the same time, S1a shorts the grid side of the upper oscillator to earth when the "Cal.-Single Tone" switch S2 is closed.

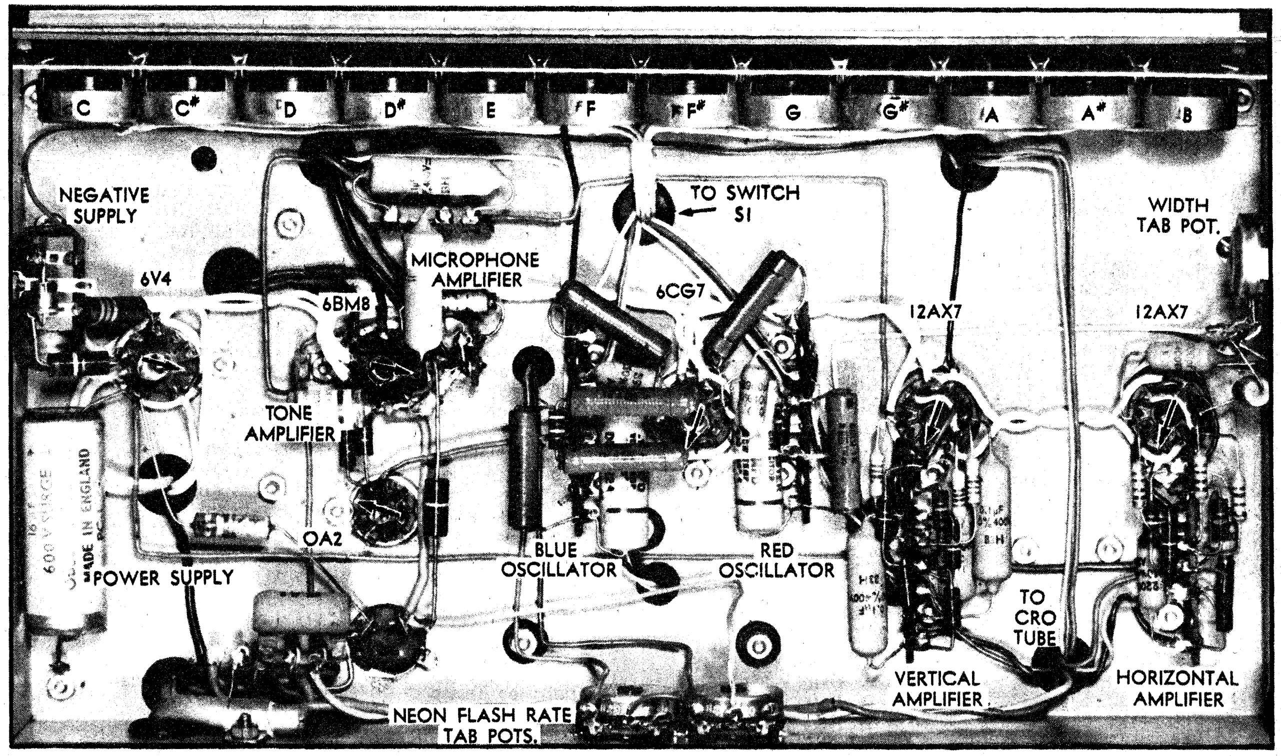
On the next switch position, representing C-sharp, the short is transferred to the lower oscillator, while the upper one is connected to the .02uF capacitor and pre-set pot necessary to produce this particular note.

So the sequence is followed, through to B, involving the upper oscillator, its .0056uF capacitor and the relevant potentiometer.

On the circuit, by the way, the upper and lower oscillators have been respectively marked "Red" and "Blue." This coding, if carried through the wiring, switching, etc., even to appropriate ink or paint spots, makes it somewhat easier to keep track of things when building the unit.

However, don't confuse it with the coloured leads by which the original organ inductors were identified. For this instrument, you need two identical inductors, intended for the middle C triplet and identified in the original organ by yellow leads.

It will be obvious enough that the



An underneath view of the instrument, again with the major component groups marked. The design calls for high stability resistors in certain positions, while the oscillator tuning capacitors must be as specified in the article. Advertisers may or may not make metalwork for this project available, depending on demand.

switching is designed to accomplish more than has thus far been explained.

Returning to the earlier example, when the switch is in position 1 for middle-C, the lower oscillator is set up to produce this particular note and this is the only one which will be produced as long as S2 is closed.

However, cross-connections in S1d and S1b connect the upper oscillator to its components to produce the note G.

If S2 is now opened, both oscillators will function and the two notes will be available simultaneously in the output circuitry, producing the characteristic C-G beat.

Again, with the selector switch in position 2 for C-sharp, the upper oscillator produces this note, but the lower one is switched to produce G-sharp—and so on through the octave.

In short, the switching performs two major functions:

(1) It ensures that a reference tone is always available corresponding with the switch positions as marked, from middle-C to the B above.

(2) It simultaneously switches the alternative oscillator to the appropriate note in the beat tuning sequence, this second note being suppressed or otherwise according to the setting of S2.

Thus, in the "Calibrate" position of S2, the switching performs the function of playing pairs of notes together, ready for the constructor to adjust the frequency of the second note in each case, according to the appropriate beat rate. More will be said about this later in the article.

Since the switch has to be a 12-position type, separate decks are necessary for each pole, or function.

Function S1f has nothing to do with the basic oscillator circuit and will be mentioned elsewhere.

Output from the two oscillators is combined by a simple mixing circuit and made available to two separate 250k potentiometers. This mixing circuit, by the way, serves the additional purpose of isolating the two oscillators from each other to prevent "pulling" effects as harmonics approach coincidence.

One of the potentiometers is a panel control, feeding the signal to the grid of a 6BM8 pentode which, in turn, drives a small loudspeaker on the panel.

From this loudspeaker, the individual semitones are available directly for acoustic reference while, for setting up and subsequent checking, the pairs of notes and their beats can also be heard.

To economise in current drain and help keep down heat dissipation in the case, the 6BM8 pentode operates in DC cascade with a 150-volt regulator tube, from which is supplied the two oscillators.

As a result of this, the voltage available for the 6BM8 and the power output is limited, though the sound level from the loudspeaker is still ample for the purpose.

In fact, the instrument would be quite useful if this were the limit of its facilities.

However, while experienced musicians have no trouble in transferring pitch from octave to octave it is not always so easy for the untrained person, particularly when adjusting notes in the extreme treble register or from the pedal bass.

The job is greatly simplified if an oscilloscope is available, the reference note being fed to one set of deflection plates and the note to be tuned to the other deflection plates. When the resulting Lissajou figure is stationary, or substantially so, the notes are in harmonic relationship, while the exact frequency ratio can be determined by counting the number of loops.

While many electronic workers will have an oscilloscope available, there is obvious advantage in having the facilities built into the instrument. The idea is rendered more attractive by the fact that the CRO facilities can be of an elementary nature, with a couple of 12AX7 valves as deflection amplifiers, but with no special requirements in regard to frequency response and no time base.

One 12AX7 takes a signal from the same source as the 6BM8 pentode, through a 250K preset potentiometer. This is simply adjusted to produce a suitable horizontal deflection, which remains at all times within the limits of the screen.

The 12AX7 operates as a push-pull "long-tailed pair" with 220K plate loads to secure maximum swing and sensitivity, with frequency response of no great import. The plate load resistors run back to the rectifier cathode — the highest available positive potential. Hum is no problem, because the direct sensitivity of the deflector plate circuits to hum content is quite low.

The second 12AX7 is used in a generally similar circuit arrangement, except that larger coupling capacitors are used, to maintain response at the very low frequencies which it may be called upon to handle.

It takes its signal from a preamplifier stage using the triode portion of the 6BM8, and with an interposed 1M pot., panel mounted and serving as a "height" control.

Input to the preamplifier is through a standard microphone screw connection on the front panel. There is enough gain from this terminal to operate in conjunction with an ordinary high output crystal microphone, if acoustic pickup is required. Here again, purity of waveform or equality of frequency response is of no special significance, since interest centres on movement in Lissajou figures, not on actual waveform or frequency response.

DIRECT PICK UP

In practice, it is more satisfactory to feed the instrument with a direct electrical signal derived from the organ loudspeaker voice coil or from a suitable point in the amplifier; signal may be available, for example, from an "external" amplifier" socket.

The one important requirement is that the signal not overload the 6BM8 triode; this is unlikely to happen with microphone input but it can happen with direct pickup, requiring careful setting of the organ volume pedal or the use of a signal connector with attached divider network.

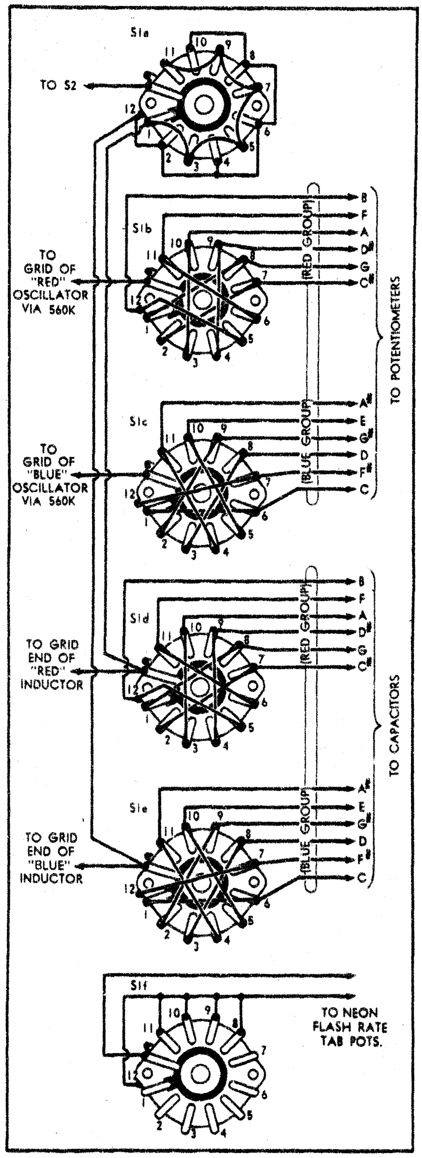
It will be noted that all four deflector plates of the CRO tube return directly to the high voltage supply point, without provision for spot centering. This would have added considerably to the complexity of the unit, without much benefit except in those cases where the tube is badly misaligned.

If you do strike trouble along these lines, it is suggested that one or more very high value resistors—10M or so—be shunted between particular deflector plates and earth, to centre the beam.

The cathode of the tube, along with its brightness and focus control circuitry, runs back to a negative source supplied by a supplementary rectifier diode and filter. The voltage available here is about minus 150 which, together with the 400 volts positive from the main supply, adds up to about 550 volts for the CRO tube.

The tube itself is a 2½-inch dia. ex-disposals VCR-139A. Large numbers of these have been in circulation and may be on hand or obtainable from a friend on a "swap" basis. If not, the circuit provisions are sufficiently representative and non-critical to hold good for other tubes of the same general class.

Coming to the constructional side, our prototype instrument was built up to fit our large instrument case measuring 13 inches wide x 6¾ deep x 8¼ high. The particular version of the case chosen has a top panel of perforated metal, the purpose being to limit, as far as possible, temperature rise.



This diagram shows the sequence of switch banks, drawn as viewed from the rear of the instrument. The top bank in the drawing is the one in the instrument nearest the panel.

The various photographs show fairly clearly the layout adopted for the prototype instrument and should allow an experienced constructor to duplicate it without too much effort. Whether advertisers produce metalwork for the unit will probably depend on demand but, as we said last month, we regard the instrument more as a contribution to thinking on the subject, than as an item which a lot of people will want to build for themselves.

With no precedent to go by, time alone will tell.

Looking at the front panel, the large knob in the centre is the note selector, beginning with "C" at the top and rotating clockwise, semitone by semitone, through to B. This is the primary function of the knob; its secondary function, related to the tuning procedure, has already been described.

To the left of the main selector knob is the in-built loudspeaker, while to the right, is the face of the CRO tube.

The two knobs beneath the loudspeaker control loudspeaker volume and CRO pattern height, while those below the CRO tube control focus and brightness.

To the extreme left of the panel is the input connector, while on the right is the toggle switch which selects single tone or mixed tones for self-tuning of the instrument.

The "on-off" indicator bezel at the top of the panel warrants some comment. Originally, we planned to put a simple lamp behind this. Then came the idea of substituting a neon flasher circuit which could be adjusted to flash at the rates of 5 or 7 beats per 5 seconds, being the rates set out for tuning the original Stromberg/Playmaster organ.

Accordingly, a flasher circuit was wired in, using a miniature neon lamp (type NE2) selected to have a low ignition voltage (80 VDC approx.) and therefore capable of operating reliably from the 150-volt regulated source. Preset pots were installed to allow the two beat rates to be set up, with interconnection to the main selector switch so that the lamp always flashes at the appropriate rate for the semitone pair then in circuit. This is function S1f, referred to earlier in the article.

The idea of a visual beat rate indicator is novel enough but its value is somewhat diminished by a tendency for the beat rate to change slightly with temperature and, perhaps, other less obvious factors. Perhaps a stabilised type of neon tube would be better, although it may then have to be operated from a higher and therefore unregulated voltage.

However, while we do not attach any great importance to the idea, we left it in the circuit and in the instrument for the sake of those who may care to experiment further.

Who knows? Someone may even think of cross-connecting it to the CR tube grid to produce an intensity modulation and therefore have to the tube display both a Lissajou pattern and a reference beat rate!

Along the bottom of the front panel is a line of tab-pots for tuning the individuals semitones, starting with C on the extreme left and progressing to B on the right.

The tab pots are mounted on a back plate, with just enough of the shaft coming through the panel to allow for either finger or screwdriver adjustment. To prevent the adjustments from being bumped accidentally, we arranged for a piece of 1-inch aluminium angle to cover them, being held in place with a long bolt and wing nut at each end.

The tab pots used in the original were IRC type D7, obtained from clearance sources, for a fraction of their original price. Whatever type is chosen, they must be small enough to mount on 15/16-inch centres, so that 12 of them will fit in a row within the limits of the internal chassis. Those used in the original just made it, after we cleaned off odd metal burrs to allow them to sit snugly side by side.

The pot. shafts are marked, above, in terms of semitones, from C on the left through to B on the right.

However, other semitone markings appear below the knobs, with a figure 5 or 7 in between.

In order, left to right, the markings are: C 5 G; C-sharp 5 G-sharp; D 5 A; D-sharp 5 A-sharp; E 5 B; F 5 C, F-sharp 5 C-sharp; G 7 D; G-sharp 7 D-sharp; A 7 E; A-sharp 7 F; B 7 F-sharp.

As you will probably have guessed, the markings are a code to the tuning sequence given last month, obviating the necessity of referring to a separate table.

After first tuning C, the code would be read as follows: "C, tune G 5 beats flat"; "switch to G and tune D 7 beats flat"; "switch to D, tune A 5 beats flat" . . . and so on.

Whether or not you code the instrument in this exact fashion is a matter for individual constructors but at least mark each semitone adjustment prominently. In use, it is all too easy to reach for the wrong knob, when tuning up, and upset a tuning sequence half-way through.

Incidentally, when wiring the pots use the pair of terminals such that rotating the pots in the clockwise direction will reduce the amount of resistance in the grid return circuit and therefore increase the oscillator frequency. This will produce the logical control function of clockwise to increase frequency, anticlockwise to reduce it.

The coded rear view of the instrument shows the placement of all major components and valves.

The CRO tube is supported at the front by a sleeve which passes right through the front panel. The sleeve is held in place by a couple of flaps bent over and screwed to the rear of the panel. A separate support is provided for the rear of the CRO tube.

If stray magnetic fields from the power transformer cause residual deflection or thickening of the trace, the tube can be enclosed in a mu-metal or mild steel shell to minimise the effect.

The two inductors, as pictured, are originals from the Stromberg/Playmaster organ. These items have since been advertised by Messrs. O'Donnell Griffin (Television Services) Pty. Ltd., of 184 George Street, Concord West, N.S.W.

In an effort to secure maximum stability from this pattern of choke, we stiffened the assembly bracket adjacent to the adjusting nut. Small chips of tinplate were fitted across the corners and solder flowed over the tinplate filling the corners and securing the nut in place at the same time.

Some resilience was also provided in the inductor mounting arrangements to isolate them from possible stresses, the mounting bolts being passed through grommetted holes in the chassis. Because this also isolated the inductors electrically, a flexible earth lead was added.

As distinct from the chokes mentioned above, a different pattern of choke is available from Syntronics Pty. Ltd. of 680A New Canterbury Road, Hurlstone Park, N.S.W. These were as used in the Australian Julius organ and, judged on finish and appearance, they should be eminently suitable as they are.

The remaining major item above the chassis is the rotary selector switch. Because there are twelve semitones in the octave to be selected, there is no option but to use 12-position switch banks, which differ from the more usual 11-position types by having a supplement-

PARTS LIST

1 Large standard instrument case (well ventilated), chassis, panel, sub-bracket.
1 Power transformer 325-0-325V, 6.3V 2.5A, 5V 2A.
1 Speaker, 4 or 5-inch.
1 Speaker transformer 7K to speaker impedance.
2 Organ inductors (see text).
1 12-position, 6-wafer switch.

VALVES

6BM8, 6V4, OA2, 6CG7, 2x 12AX7, 1 CRO tube, disposals type VCR139A or similar.
1 NE2 neon indicator.
1 Silicon power diode type AS3 or BY100.
1 DPST switch.
1 Microphone socket and plug.
1 Cheap crystal microphone or insert.
1 Bezel.
4 Small knobs.
1 Pointer knob.
5 9-pin and 1 7-pin miniature valve sockets.

CAPACITORS

1 2 x 24uF 400VW electrolytic.
1 16uF 500VW electrolytic.
1 8uF 350VW electrolytic.
1 25uF 12VW electrolytic.
1 0.33uF 200VW.
7 0.1uF 400VW.
5 0.022uF 400VW.
2 0.0039uF 200VW

2 sets of the following values preferably within 2% tolerance:— 0.02; 0.015; 0.012; 0.0091; 0.0075; 0.0056uF; 680, 560, 390, 220, 150pF.

POTENTIOMETERS.

1 20K lin.
1 250K lin.
1 250K log.
1 1M log.
1 250K log. tab.
12 1M lin. tab.
2 5M lin. tab.

RESISTORS. (All ½W unless stated).

1 4.7M
4 2.2M
5 1M
2 470K
4 220K
1 100K
1 100K 1W
1 68K 1W
2 22K
1 2700
1 2700 1W
1 1500
2 1000
1 1-ohm 5W

High stability resistors.

1 4.7M
2 560K
2 100K
2 68K

Miniature tagstrip.

4 8-lug.
1 5-lug.
1 4-lug.
2 3-lug.
2 2-lug.

Resistor strip 14 tags long.
Grommets 8⅜in, 7¼in.
Power cord and plug, various coloured hookup wire, nuts, bolts, washers, clamp for power cord, brackets for CRO tube and tab pots, protection strip for tab pot controls, wing nuts, instrument case handles.

aray contact and ring on the front face to provide the twelfth active position.

For convenience in use, the stop can be removed from the clicker plate to allow continuous rotation in any direction.

Wiring a multi-position, multi-bank switch is always a tricky and tedious procedure and this one is no exception. However, we have provided a diagram which shows, from top to bottom, the sequence of switch banks and positions, progressing from front to rear of the instrument. The job of sorting out leads will be simplified by use of differently coloured wires and, as mentioned before, identification of the two oscillator systems by the use of red and blue coding.

The two sets of tuning capacitors attach to a length of tagstrip seen mounted underneath the CRO tube. The capacitor banks are mounted on opposite sides of the strip using alternate pairs of contacts. This assembly can normally be pre-wired, though it is wise to leave the mounting nuts accessible in case the values have to be modified in any way.

Underneath the chassis, there is plenty of room for everything, but the main component groups are identified in the photograph for the guidance of prospective constructors.

POT. MOUNTING

Note the row of tuning potentiometers mounted on a sub-bracket behind the front panel. Some reasonably accurate metalwork is necessary here so that the shafts will pass through the sub-bracket, the front of the chassis and the front panel, without binding. The holes in the bracket and chassis can be oversize, of course, but those in the panel should be of clearance size only, for the shafts, and accurately located.

Mark the semitone designation on each pot. body to simplify identification later.

So much for construction of the Tuning Standard.

If you have decided to put in the beat rate indicator neon, the logical first step in setting up the instrument is to adjust this, as necessary.

Begin by setting the main switch to any position 8-12, which will short out the lower potentiometer in the circuit. Now adjust the upper potentiometer to produce a pulse rate of 7 flashes in 5 seconds.

Leaving this potentiometer set, turn the main switch to any position 1-7 and adjust the second potentiometer for a pulse rate of 5 flashes in 5 seconds.

Note that the potentiometers must always be adjusted in this sequence.

The indicator light can now be used as a guide for tuning the individual semitones.

In setting up the instrument, a lot of time can be saved by "cheating" and tuning it initially to any instrument that might happen to be available — mouth organ, melodica, accordeon, piano or, best of all, an electronic organ. Try to arrange matters so that the semitone tuning pots, are, as far as possible, within the centre of their travel, the inductor cores being set to produce the sequence of tones.

For more accurate self-tuning, set the main switch to C and check that the C fine tune pot. is at about the centre of its travel. Connect a mic. to the input and hold a tuning fork near it, adjusting the height to produce a trace on the screen at least ¼-inch high. Now very carefully adjust the core of the "blue" oscillator inductor until a stationary pattern is obtained on the screen, looking like an elongated figure 8 on its side.

If the "red" oscillator has not already been roughly set by "cheating" as above, switch to C-sharp, adjust the inductor for the figure 8 pattern against the fork, then release the screw slightly to sharpen the note by what sounds like a semitone to C-sharp.

Now switch back to C, make sure that the note still checks with the fork, then turn the height control right down.

Set S2 to the "Cal" position, which will bring in a nominal G from the "red" oscillator. See that the "G" potentiometer is at centre travel, then very carefully adjust the core of the "red" oscillator inductor to produce a stationary beat pattern on the CRO face. Now screw the core in ever so slightly to make the G flat in relationship to C for a beat rate of 5 beats in 5 seconds.

Once the core is within a touch of being right, you can probably leave it set and adjust the beat rate critically by a touch of the "G" tuning pot.

At this point, the constructor is allowed to hope fervently that the inductor cores will not need to be touched and that the remaining procedure can be followed through using the potentiometers only .

Having thus set G, the rest of the procedure can be followed through as explained earlier.

Switch to semitone G and adjust semitone D, using the pot only, for 7 beats flat in 5 seconds.

This done, switch to D and tune A for 5 beats flat in 5 seconds.

And so on through the procedure until all semitones are in tune.

If you run into trouble with one or more of the semitones, it may be necessary to re-set an inductor slightly and start again, or pad a capacitor, or something!

This is where ability to set the instrument against a properly tuned organ can save a lot of worry.

As in the case of the organ, the oscillators may tend to drift a little until the inductors "settle down" and this process should not be interrupted by unnecessary tampering with the core adjustment. No more than the merest touch should be necessary after the initial adjustment, most of the tuning being done with the potentiometers.

SENSITIVE DISPLAY

One point should be stressed about this instrument or, in fact, any instrument whose beat rates are displayed by visual means: Beat rates which would not be evident to the ear look most obvious to the eye and can cause one to judge as quite bad, orders of frequency drift which are of little consequence acoustically.

By way of example, if the instrument is operating stably on C and compared with the reference fork, the CRO will readily show the difference in fork frequency as the fork comes up to the temperature of the hand holding it.

Yet tuners rarely stop to argue with their forks!

Such then is the story of our Electronic Tuning Standard. You may or may not feel inclined to build it but we trust that it has provided interesting food for thought.