MARCONI INSTRUMENTS

NEW DESIGN

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A.F. Oscillator . . . . . TYPE TF 2100

by L. M. SARGENT

This small transistorized audio frequency oscillator provides over 8 V unloaded, or 4 V in a matched 600 Ω load over the range 20 c/s to 20 kc/s. The distortion factor does not exceed 0·05% from 63 c/s to 6·3 kc/s, or 0·1% elsewhere. Frequency accuracy and stability are high. The output voltage can be adjusted conveniently over a range of 100 : 1.

THE NEW Audio Frequency Oscillator TF 2100 is an instrument of conveniently small size, which develops a sine-wave of very low distortion in the audio frequency range. Its main applications lie in checking the performance of transmission apparatus concerned with the handling of high-fidelity entertainment programmes, and in assisting the design and testing of other low distortion equipment. Its good output frequency characteristic assists in response checking, and its high stability makes it useful for measurements involving bridges and filters.

The oscillator covers the range of 20 c/s to 20 kc/s in six bands. It will be seen from the photograph that the frequency scales are nearly linear, this being achieved by the use of non-linear tuning potentiometers. Thanks to the linearity and the relatively small frequency cover, a better discrimination than on most small oscillators is achieved, a change of ±1% frequency being easily discernible; total scale length is about 36 in. It is necessary to use potentiometers for tuning, instead of the conventional variable capacitors, because of the reduced impedances of transistorized circuits. Allowance is made for the very slight frequency steps which are occasioned by the wire-wound potentiometers, by providing a FINE TUNING control giving some ±0·2% frequency variation at the low end of a band, and ±0·6% at the high end. The rated output is +15 dBm, which provides 4·36 V in a 600 Ω load, or some 8·5 V unloaded. The output voltage is a fraction of the fixed output of the oscillator, adjusted

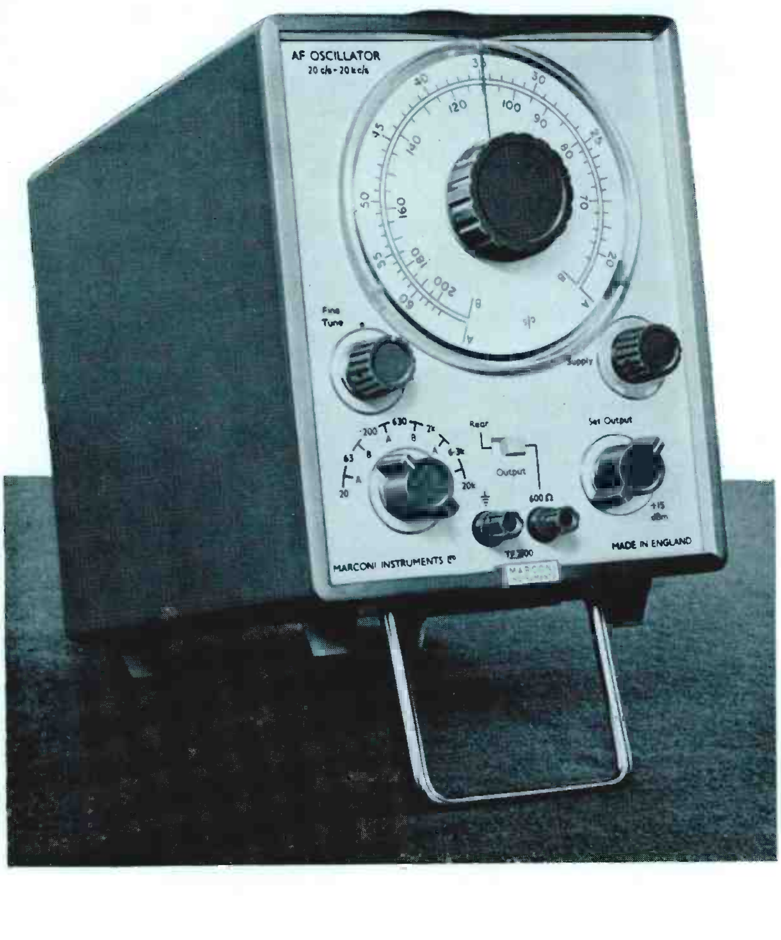

Fig. 1.
Very low distortion is a feature of this small transistorized A.F. Oscillator, shown here with its tilting stand in use

SOME TYPICAL CHARACTERISTICS OF INTEREST

A.F. Oscillator Type TF 2100

Fig. 2.

FREQUENCY	
Long Term Stability:	0.015% in 7 hours, 1 hour from cold.*
Short Term Stability:	0·003% in any 10 min as above.*
Variation with Supply Volts:	+0·0005% for shift 200 to 250 V at 20 kc/s.
Temperature Coefficient:	−0·01% per °C, from 10° to 35°C.
Reaction to Application of Matched Load:	+0·03% at 1 kc/s. +0·25% +0·1 c/s at frequency extremes.
AMPLITUDE	
Distortion Factor:	0·02% from 200 c/s to 10 kc/s. 0·06% at 20 c/s, 0·04% at 20 kc/s.
Supply Hum:	0·002% at maximum output.
Long Term Stability:	2% in 7 hours, 1 hour from cold.*
Short Term Stability:	0.3% in any 10 min as above.*
Variation with Supply Volts:	+0·005% for shift 200 to 250 V.
Temperature Coefficient:	−0·4% per °C, from 10° to 35°C.
Supply Frequency Beat:	0·01% modulation close to 50 c/s.
Time to settle within 1% after switching:	7 sec at 20 c/s, less elsewhere.

* *Brit.I.R.E. standard definitions, except that oscillators were subjected to unstabilized temperature and power supply.*

by an uncalibrated variable T-pad, so that the distortion of the signal across the load does not vary with output level. Output impedance lies within some ±20% of 600 Ω at any level, and is very much closer at full output; d.c. resistance at the output is 100 kΩ, and up to ±25 V d.c. can be applied without damage. The law of the output T-pad is such that the change of level in decibels is approximately linear with respect to the angle of rotation over some 40 dB range, so that signals down to about 50 mV can be set up by monitoring with a millivoltmeter, without the necessity for an external attenuator.

The r.m.s. distortion factor of the output signal is less than 0·1% (−60 dB) over the whole range of 20 c/s to 20 kc/s, and over the middle range of 63 c/s to 6·3 kc/s it is less than 0·05%. Supply hum is also very low, of the order of 80 dB below the signal. Being designed primarily for very low distortion, the circuit is not economical in the use of battery supplies, but the facility of switching over to an external d.c. supply is provided, since it can be very useful for occasional field tests, or especially for the odd test involving an audio source completely free from supply frequency hum. A heavy negative feedback loop, which is largely responsible for the low distortion, also provides exceptional frequency stability. This is also assisted by the power supply stabilization, applicable to both a.c. and d.c. supplies. A panel switch allows the output to appear either at the front panel, or at the rear of the instrument to facilitate racking interconnections, and the switch is also convenient for temporary removal of the signal without upsetting any parameter, as often required during tests.

The simplified circuit diagram of Fig. 3 shows that the system consists essentially of:

(*a*) a sustaining amplifier,
(*b*) a feedback system containing narrow-band positive feedback of adjustable frequency, and wide-band negative feedback which is level-conscious,
(*c*) an output attenuator of simple form.

Problems of Obtaining Low Distortion

The majority of commercial general-purpose resistance-capacitance oscillators employ a sustaining amplifier having a bandwidth roughly equal to the required band of output frequencies, and incorporating both positive and negative feedback paths, one of these paths being frequency-conscious in such a sense as to cause the net feedback to be negative except at some particular frequency. At this frequency the feedback causes oscillation. The control of level is provided by a power—or voltage—sensitive device which modifies the wide-range feedback, so rendering the net feedback less positive as the output level increases. The total feedback system reduces to a bridge, the output of which is the difference between the output from (*a*) a pair of arms having inverse reactance/resistance arrangements, and (*b*) a pair of resistive arms. Henceforward, the complex arms will be referred to as the reactive network.

The reactive networks used give an output in phase with the input, the output reaching either a maximum or minimum at the so-called 'tuned' frequency. Such outputs are used in oscillators as frequency-conscious positive or negative feedback respectively. The most popular networks so used are the two complex arms of a Wien bridge[1], and the capacitance bridged-T network[2]. Wide-range feedback (the second of the two required paths) is invariably derived from a resistive potentiometer, one of the two elements being modified in value by the output level. An amplifier with differential inputs must be used, and the number of phase reversals which the two signals undergo decides which of them promotes positive feedback and which one promotes negative feedback.

This differential effect is usually obtained by feeding to grid and cathode, or base and emitter, of an amplifier; and in either case the stage has reduced gain due to the unwanted current feedback caused by the load resistor in the circuit of the cathode or emitter. At the same time, this electrode presents a fairly heavy load, which ultimately demands a substantial alternating current from the output of the amplifier. Now, low gain and heavy loads are barriers in the way of achieving a pure output signal. The reactive network tends to cause a gain greater than unity at the 'tuned' frequency round the feedback system, either by providing a peak in the positive feedback, or by providing a trough in the negative feedback. The level-conscious device adjusts this gain to unity. At the output point, non-linearity in the amplifier will produce distortion of the sine-wave, but at the second and third harmonic frequencies, due to the frequency response of the reactive network, there will be net negative feedback, the effect of which will be to reduce the distortion. The magnitude of this negative feedback depends on the amount of gain available in excess of the transmission loss through the reactive network at resonance, and also on the change in the magnitude and phase of the transmission loss through the reactive network at the harmonic frequencies with respect to the fundamental frequency.

There are two very important points to consider if heavy negative feedback is to be achieved. The first concerns spurious oscillation in amplifiers with negative feedback. To avoid such oscillation, it is necessary to keep the phase shift low over the range of frequencies in which the loop gain is high. The more amplifying stages there are, the greater the risk of spurious oscillation, and for the degree of distortion correction intended, it is highly desirable to have only a single time-constant involved. The roll-off of response will then occur at the rate of 6 dB per octave, with an ultimate phase angle of 90 degrees. This requirement indicates that a single stage of high gain must be employed. It should be noted, incidentally, that this problem and the one to follow can be dealt with more easily in oscillators providing a selection of fixed frequencies, rather than in those that are fully tunable. The second important point concerns the bridge. If the components in the reactive network have the exact values required, there will be a maximum or minimum output (as applicable) at the theoretical frequency, and in phase with the input. Thus, the complete bridge would be able to come to a perfect balance with zero output, which would be the value of input required by an ideal amplifier with infinite gain. However, if in practice the bridge, due to imperfections in the matching of components, is unable to provide a minimum small enough to equal the reciprocal of the actual gain of the amplifier, there will be

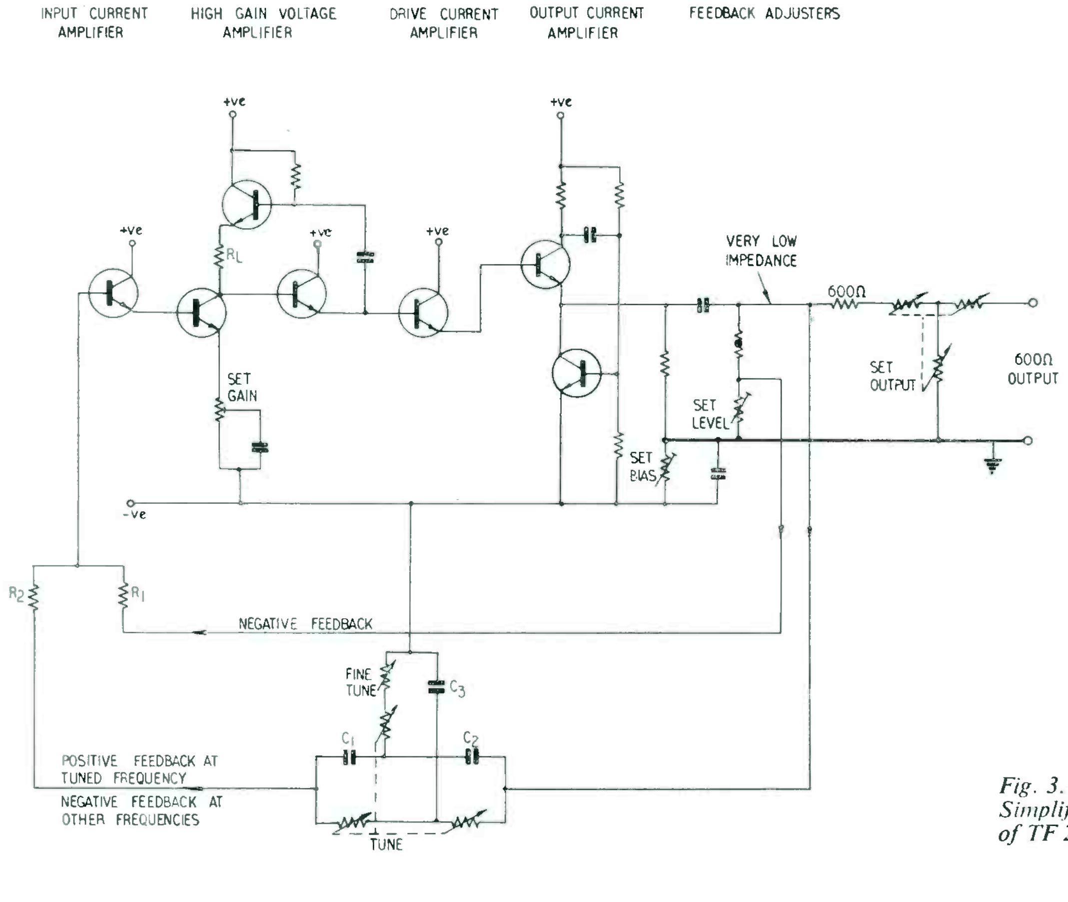

Fig. 3.
Simplified circuit diagram of TF 2100

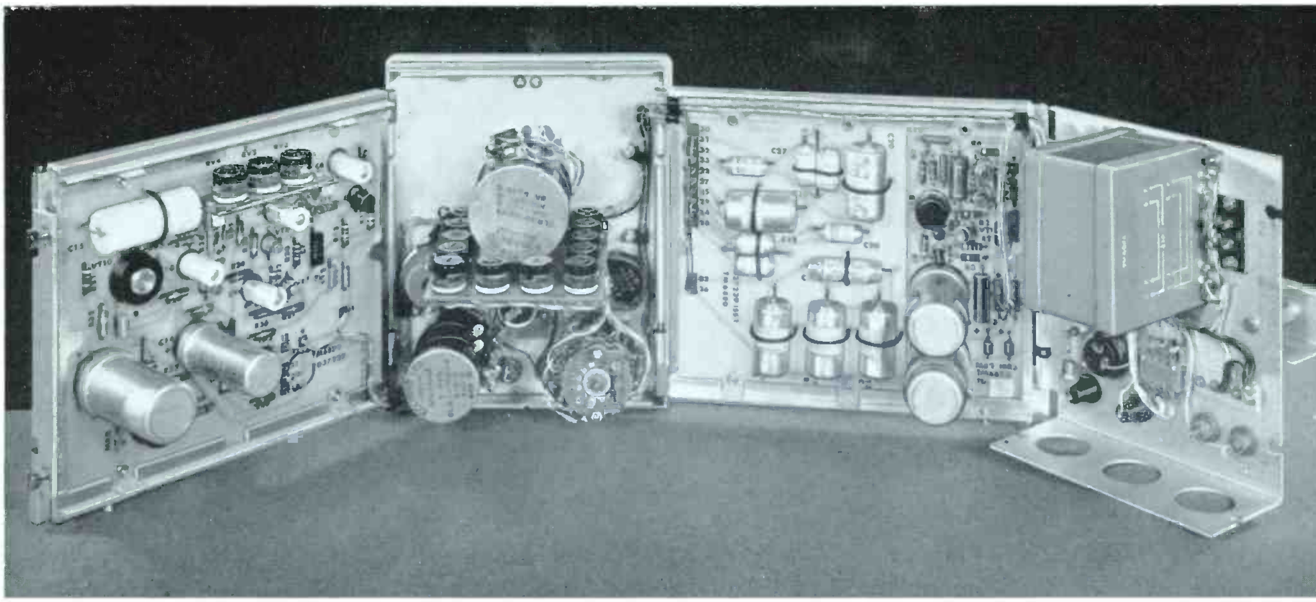

Fig. 4. Instruments in the modular range are hinged to open flat without disconnecting circuits or interrupting the output. This ensures maximum component access during servicing despite the high component density

a loss of performance. The oscillator will operate at a frequency near to the correct one, such that the real component of the net input signal to the differential amplifier has the value and phase angle required, whilst the modulus of the signal is larger and at some considerable phase angle. This situation fails to make use of any gain in the amplifier exceeding the reciprocal of the transmission loss, through the complete bridge, of the real component of the signal. The theoretical situation required is the reverse, i.e. that the gain should be smaller than the reciprocal of the loss, so that any variations in the loss, such as may be occasioned by tuning the network over a range of frequencies, will not vary the distortion in the signal. Now, this is impossible to achieve in a commercial instrument with reasonably priced components, using bridges of the general types described. For instance, a Wien bridge requires a transmission loss as great as 50 dB if it is to reduce the inherent distortion of the amplifier by a factor of 30 dB, such as might be sought for the purpose of obtaining a signal with 0·03% distortion from an amplifier with 1% distortion. The required matching of bridge components is closely similar to the required transmission loss measured in percent; and the maintenance of a match of 0·3% over various ranges and between ranges, especially with the variable resistance tuning which transistors demand, is an uneconomic requirement. Also, there would be anxiety, as already mentioned, concerning the stability of the required two-stage amplifier with so much negative feedback.

Parallel-T Network

Parallel-T networks and their use in oscillators are discussed extensively in the literature. They have remained without much attraction until several authors have recently pointed out various advantages of deliberate 'unbalance' of the normal relationship between the shunt legs of the two T-pads involved. Instead of a null at the tuned frequency, appropriate unbalance can be arranged to produce merely a trough in which the output signal phase, over a narrow range near the tuned frequency, passes through the condition of being in antiphase with respect to the input. In an oscillator circuit, this can be made to produce positive feedback at the tuned frequency to promote oscillation, and also to produce considerable negative feedback at the harmonics to reduce distortion. Bailey[3] provides level control by applying to the amplifier in parallel with the output of the network, a small amount of feedback at the fundamental frequency, obtained from the usual level-conscious potentiometer. The parallel feed dispenses with the need for the amplifier to have a differential input arrangement. His single amplifying stage is equipped with a bootstrap circuit to provide the maximum possible gain.

Looking back at the problems of obtaining low distortion, the important points noted were:

(1) Inherent distortion in amplifier at rated output,
(2) Amplifier gain (reduced by a differential input),
(3) Parasitic oscillation promoted by multiple stages of gain,
(4) Transmission loss of fundamental through the reactive network,
(5) Transmission of harmonics by reactive network, relative to fundamental,
(6) Quality of bridge balance, limited by component matching.

It will be seen that the system described above is very helpful with regard to items 2 and 3. The choice of net-work has little effect on the non-linearity of the transmission characteristics of the amplifier, item 1, which will not be considered further here. However, items 4 and 5 are considerably affected by the use of an unbalanced parallel-T. By using a slight degree of unbalance, the transmission of harmonics relative to the fundamental (item 5) can be made very good at the expense of a heavy loss of the fundamental (item 4). A compromise situation causes items 4 and 5 to be considerably better in this circuit than in a Wien bridge, or in a capacitance bridged-T, which lies between the two. The final item, 6, bridge balance, can be less troublesome when using the unbalanced parallel-T, a factor which is of great importance. Since the network produces a fairly shallow minimum, rather than a null, it is not surprising that imperfections of component matching do not have such a marked effect on the magnitude and phase of the output as they do in balanced networks. This minimum output is balanced in the complete bridge against the control feedback returning via the level-conscious potentiometer, which comprises a thermistor and SET LEVEL adjuster, as seen in Fig. 3. Due to the high gain available, the resultant output is very small, and slightly in favour of the output from the network, providing a little positive feedback at the fundamental. The system is highly sensitive to the phase angle of this resultant, promoting high stability of frequency, and it is also highly sensitive to the level of the control voltage. Hence, supply variations have a reduced effect on frequency and output level.

In using any reactive network the thermistor will maintain a constant output by readjusting the negative feedback to allow for changes in transmission of positive feedback. Tuning by ganged wire-wound potentiometers will give rapid variations in the output from the reactive network as the sliders traverse the individual turns of wire on the tracks. The thermal time-constant of the thermistor will not allow it to restore the level instantaneously, so that the variations will be impressed on the output signal as a rapid flutter of amplitude whilst the frequency control is being rotated. Since the transmission through the unbalanced parallel-T varies less with component unbalance than does the transmission through balanced networks such as the Wien bridge, this undesirable jitter is considerably reduced. The thermistor in the present oscillator is already chosen to operate as quickly as possible. The speed is limited by consideration of the distortion which will follow any adjustment of the output level during the time of one cycle of the lowest output frequency of 20 c/s.

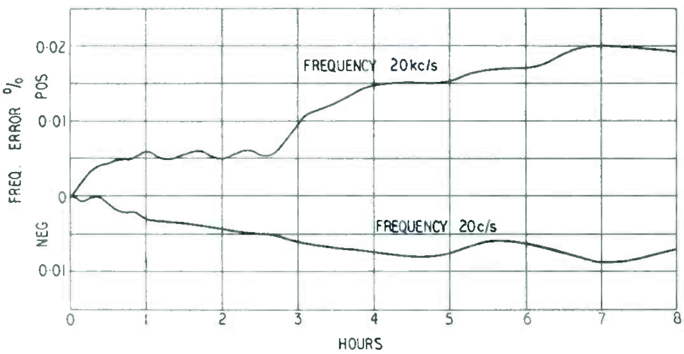

Fig. 5.
Typical frequency stability

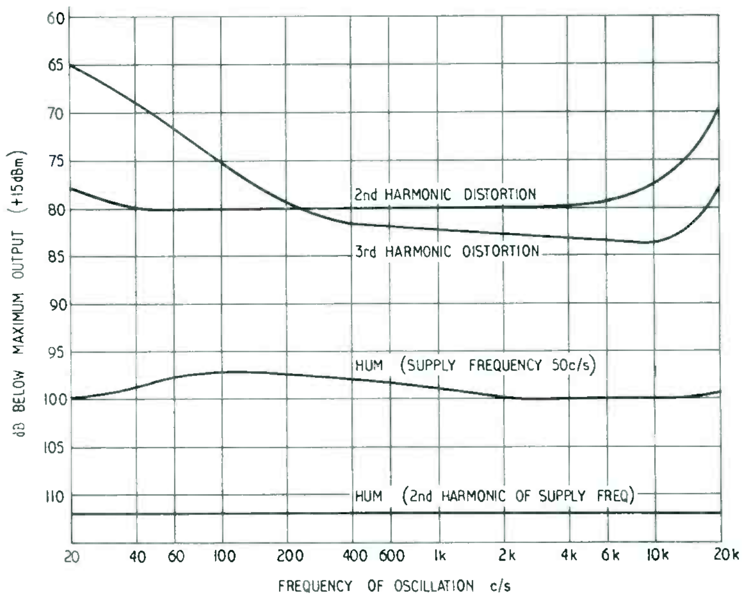

Fig. 6.
Typical harmonic content and supply hum

Returning to the six important items, it will be seen that this system has advantages with regard to each applicable item. However, it has its drawbacks, one of which is the need for three ganged potentiometers instead of two. Another concerns the amount of control feedback which, as shown in Fig. 3, is applied by the thermistor through a resistor R_1 on to the input base; this base being shunted by a second resistor R_2 in series with the output impedance of the parallel-T, so that any variation of the impedance with frequency will tend to alter the feedback fraction, and hence the output voltage.

Basic Circuit

Although the junction R_1/R_2 is a point of low impedance, distortion is improved if the amplifier presents a high impedance to it. Accordingly, the first stage is an input current amplifier providing an input impedance of some 50 kΩ. The voltage amplifier following this has a gain of 50 dB as a result of the two emitter-followers which pass the majority of the collector signal upwards to the top end of the collector load R_L, so rendering its apparent resistance very large. Stability is preserved by arranging that all other stages have a frequency response much wider than that of this stage. This amplifier feeds a current amplifier and thence the output stage, which consists of a pair of transistors arranged as a shunt-compensated emitter-follower, to provide the required current with low distortion at a very low impedance. This impedance is then padded up to 600 Ω, and the signal is passed through a variable 600 Ω T-pad to the output points. The circuit is well isolated from the effects of varying the conditions of output and load: even if the output is short-circuited, distortion only rises a little and the effect on the frequency is very slight. The normal frequency drift is very small, as shown in Fig. 5. The T-pad is a necessary evil because, if the output stage were fed via a potentiometer, it would be necessary to provide two feedback loops, one each for the oscillator and the output stage, and it would be found more difficult to achieve the required low distortion content.

Fig. 3 shows that the output stage feeds back to the input via two paths, the right-hand path constituting the narrow-band positive feedback via the unbalanced parallel-T network. The left-hand path constitutes the wide-band negative feedback via the level-conscious potentiometer including the thermistor and the SET LEVEL preset control: it will also be found to contain d.c. negative feedback, preset by the SET BIAS control to a different value from the a.c. feedback. The d.c. feedback serves two purposes—it stabilizes the working points of the transistors against changes due to temperature, and also holds the d.c. value of the output point constant so that the relative h.t. across the two output transistors does not shift and cause changes in the amount of distortion. The control is normally set to provide identical h.t. across each transistor: however, with slight off-setting, the instrument can be made to provide temporarily an exceptionally low quantity of second harmonic distortion at any given frequency. A typical record of distortion performance with normal adjustment is shown in Fig. 6.

REFERENCES

1. Hickman, D. E. D. 'Wien Bridge Oscillators.' *Wireless World*. December 1959, 65, p. 550.
2. Sulzer, P. G. 'A Note on a Bridged-T Network.' *Proc. I.R.E.* July 1951, 39, p. 819.
3. Bailey, A. R. 'Low Distortion Sine-Wave Generator.' *Electronic Technology*. February 1960, 37, p. 64.

ABRIDGED SPECIFICATION

Frequency

RANGE: 20 c/s to 20 kc/s, in six bands.
ACCURACY: ±1% ±0·2 c/s.

Output

POWER: + 15 dBm (31·6 mW) into 600Ω; over 8·5 V open circuit.

CONTROL: At least 40 dB range of attenuation.
IMPEDANCE: 600 Ω unbalanced.

Frequency response

±0·4 dB.

Distortion

Less than 0·05% from 63 c/s to 6·3 kc/s; less than 0·1% elsewhere.

Hum

Less than 0·01% (−80 dB) of output signal, or −100 dBm, whichever is the greater.

OUR CENTRE PAGE ILLUSTRATION shows all the instruments featured in this issue plus the TF 2700 Universal Bridge described in the last issue. The accessories in the top row are the terminal-to-coaxial adaptors for use with the Oscillators and Attenuators, and the isolating transformer for TF 2700. At bottom left is a rack mounting case fitted with one blank panel. A strong family resemblance is apparent from the standardized instrument sizes, case construction, knobs, drives and dials. The picture also demonstrates the relationship between the composite signal sources in the centre row and the individual instruments directly above them.