FRIDAY 7 MARCH 1975

SESSION: Studio Equipment II

CHAIRMAN: P. J. Walker

Starboard Room Morning

L-55

MUSICAL INSTRUMENT R-C TUNING OSCILLATOR EMPLOYING AUTO-TRANSFORMER TAPPINGS TO GIVE ± 0.005% INTERVAL ACCURACY

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1. INTRODUCTION

In recent years much attention has been given to digital techniques for generating a series of semitones in equal-temperament frequency ratios (1),(2),(3),(4),(5).

The present contribution is concerned with a non-digital solution to the problem, which is both economical and capable of very high ratio accuracy and long-term stability. The new circuit* is basically an R-C oscillator of the double-integrator-loop variety(6), but the frequency intervals are determined by varying the gain of one of the integrators by means of tappings on a small and quite cheap auto-transformer. Only the ratios of this transformer are of first-order significance, not the inductance values as such.

2. CIRCUIT EXPLANATION

The operation of the practical oscillator circuit may best be explained by considering first the simpler circuit shown in Fig. 1. In this circuit, operational amplifier 2, with its associated parallel tuned circuit, constitutes a selective stage giving maximum response at the tuned circuit resonant frequency, accompanied by 180° phase inversion. Operational amplifier 1 functions as an aperiodic phase-inverter stage, and positive feedback is applied round the two stages via a silicon diode limiter, to promote oscillation. If the tuned-circuit Q-value is high, a low-distortion sine-wave output of stabilized amplitude is obtained, even though the input waveform fed to the phase-inverter stage is approximately a square-wave.

The use of a physical inductor leads to practical difficulties if highly-accurate variation of frequency is required, especially if a ferromagnetic core is employed. However, the inductor may readily be replaced by an active circuit, since the fundamental function performed by it is to feed to the virtual earth of operational amplifier 2 a current which lags by 90° on the output voltage and which has an amplitude inversely proportional to frequency if the output voltage amplitude is assumed constant.

Referring now to Fig. 2, and assuming initially that the switch is on the top contact, it will be seen that the integrator involving operational amplifier 3, in combination with the phase-inverting stage 1, also causes a current component to be fed to the virtual earth of operational amplifier 2, this current having the same frequency characteristics of amplitude and phase as the inductor current of Fig. 1. The circuit thus functions as an

* Patent applied for.

oscillator just as does that of Fig. 1.

On moving the switch arm downwards, the inductor-simulating current fed to operational amplifier 2 virtual earth is reduced. This is exactly equivalent to increasing the value of the inductor in Fig. 1, and therefore reduces the oscillator frequency. The amount of the frequency change is determined almost entirely by the tapping ratio and not by the transformer inductance as such. The frequency is proportional to the square root of the number of turns between the bottom end of the transformer winding and the tapping point in use.

3. SMALL ERRORS AND THEIR REDUCTION

The following very small second-order effects prevent the actual frequency changes from being quite perfectly in accordance with the above-mentioned square-root law:-

(a) Imperfections in the operational amplifiers.

(b) Inequality of the flux linkage with turns at different parts of the transformer winding.

(c) Series resistance and reactance of C_2 in combination with the transformer impedance.

(d) Variation in Q-value of the simulated tuned circuit with frequency - with a square-wave limiter, the oscillation frequency differs slightly from the true resonance frequency by an amount dependent on the Q-value.

(e) Variation with frequency of the exact shape of the approximate square-wave produced by the limiter.

(f) Effect of the copper resistance of the transformer winding, in association with the shunt core-loss resistance and inductance, on the effective ratio and phase angle of the transformer.

(g) Effect of the copper resistance in adding extra resistance in series with R_4, thus lowering the frequency.

A further source of error, of a quite different kind, arises from the fact that, when the appropriate numbers of turns for the various tappings are calculated, it is naturally found that these do not, in general, come to exact multiples of a half-turn, which is the smallest increment possible when using ordinary E and I, or T and U, laminations. Small corrections to the frequencies may readily be produced, however, by connecting low-value resistors in series with some or all of the tappings. Nevertheless, using a 2000-turn winding on a small transformer, frequency errors from this cause not exceeding ±0.02% (about 0.3 cent) may be achieved without recourse to such correction resistors.

If correction resistors are used, their values may be modified to compensate also for effect (g) above.

By using µA 741 i.c. amplifiers, suitable transformer design, a sufficiently high Q-value (about 50) and a large enough value for C_2, all the above errors may be made extremely small.

It will be seen that the damping is provided by two components, shown in broken-line in Fig. 2. These give equal amounts of damping in the middle of the tuning range and thus minimise the variation of Q-value with frequency.

4. THE PRACTICAL DESIGN

The practical design covers one octave, from middle C upwards. Two potentiometers, not shown in Fig. 2, are provided to give (i) a calibrated fine frequency adjustment, covering ± 35 cents and (ii) a preset frequency adjustment enabling the oscillator to be set up to produce an accurate A = 440 Hz, as radiated, for example, by the BBC. Long-term frequency variations are determined almost solely by the stability of the two metal-oxide resistors and the two polystyrene capacitors in the integrators, and have been found not to exceed about ± 2 cents over a period of months in normal use. No adjustment for the accuracy of the intervals is provided, it being quite practicable to hold the errors within ± 0.005% (i.e. ± 0.1 cent) without such individual adjustment.

The unit includes a timbre control, enabling a variable amount of even-harmonic content to be introduced into the audible output. With the control fully clockwise, no fundamental is left, thus raising the pitch by an octave.

Lastly, attention has been directed to economical techniques for giving a visual indication of the magnitude and sense of mistuning of a musical instrument(7). The availability of quadrature outputs from the oscillator lends itself to this.

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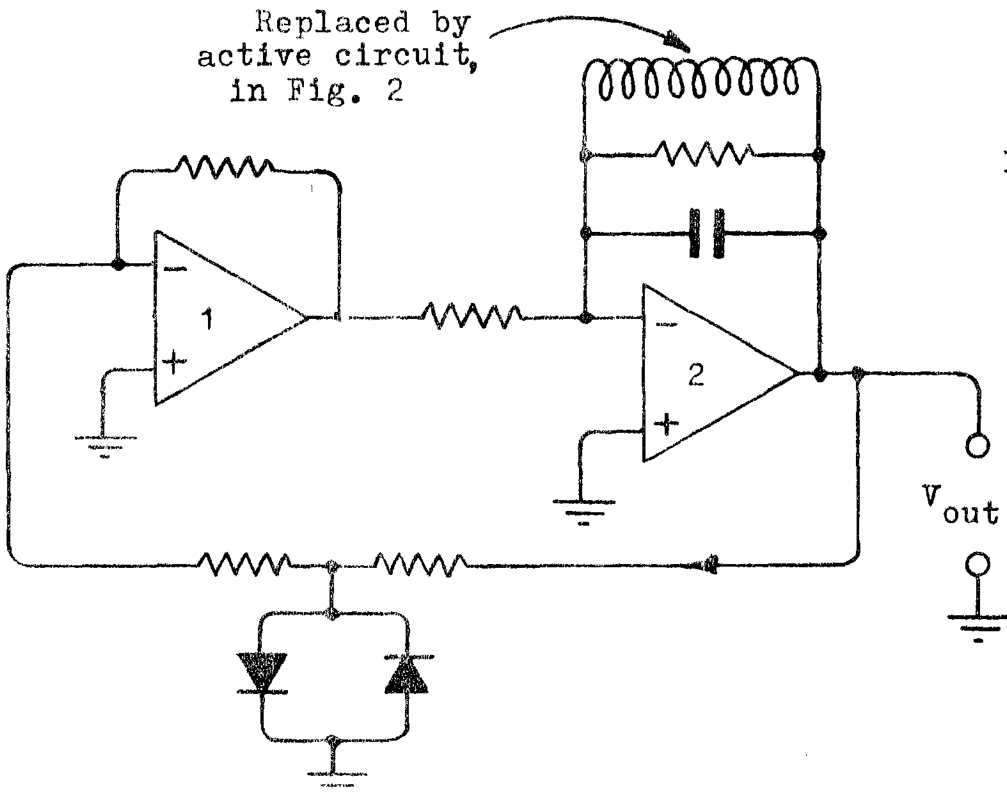
Replaced by
active circuit,
in Fig. 2
1
2
Vout

Fig. 1

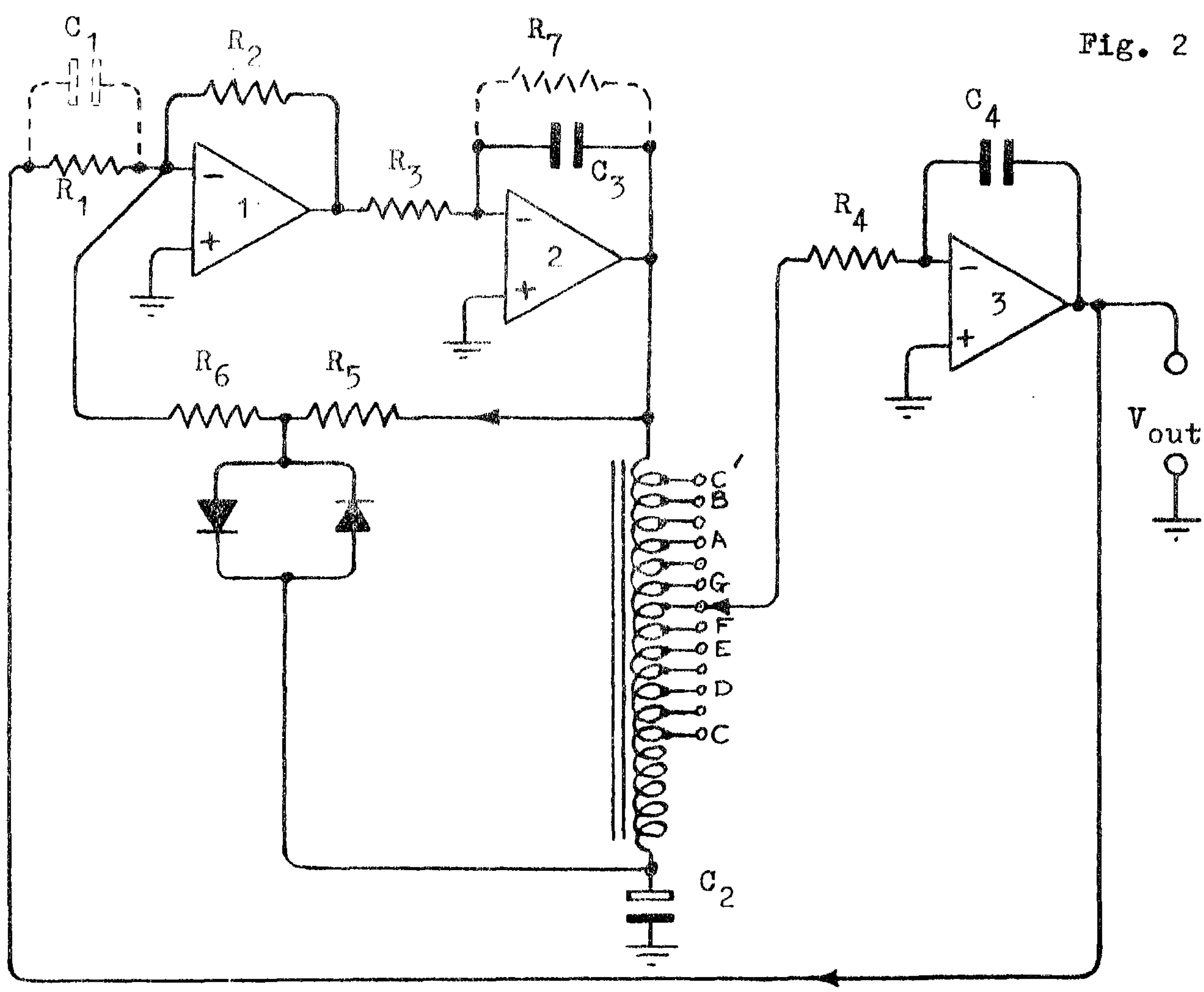
C1
R2
R7
C4
R1
R3
C3
R4
1
2
3
R6
R5
Vout
C'
B
A
G
F
E
D
C
C2

Fig. 2