

Fig. 41 Complex-wave oscillators

Generally speaking the inductances for such circuits are found to give a near approximation to the required frequency with some standard value of capacitor, then the fine tuning to obtain exact pitch is done by moving part of the iron core of the coil assembly. This is done in one of the ways shown in Fig. 43 (or if a pot core, by the screwed slug). The foregoing represent the really useful valve oscillators for organs, but since the valve is now almost obsolete as a prime tone source, we do not show the many other possible circuits; that of Fig. 42 is the most useful and stable of those described.

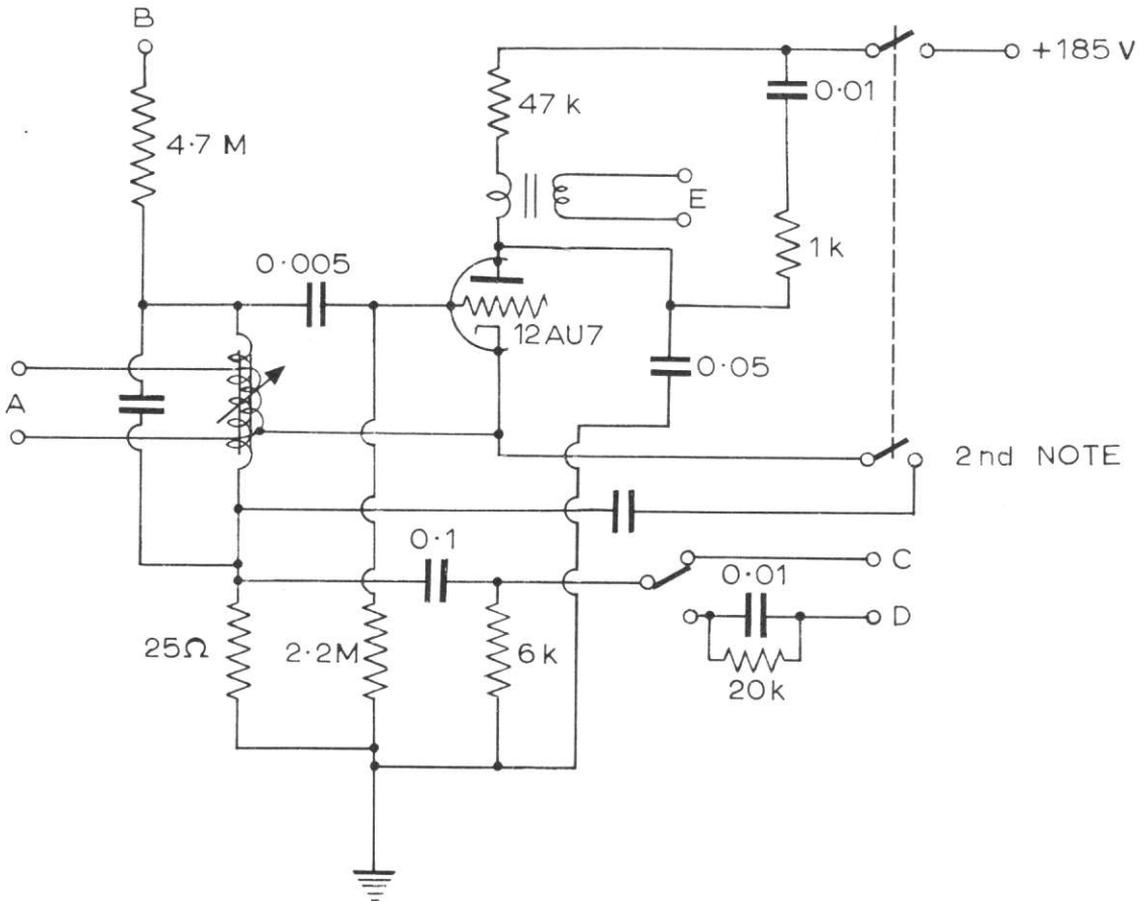


Fig. 42 Multiple wave-form oscillator

A = sine wave; B = square wave; C = sawtooth wave;
D = modified sawtooth wave; E = triangular wave

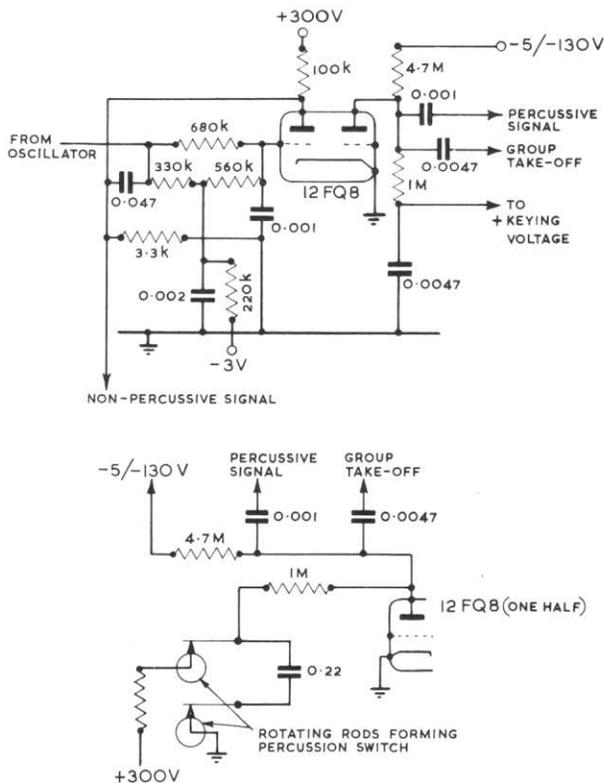


Fig. 66 Wurlitzer frequency divider and percussion circuit

does not affect the frequency. The two tubes have a high impedance to earth. Capacitors C_3 and C_4 in another divider are $1/100$ th of the values of C_1 and C_2 . As their midpoint is connected to that of V_3 and V_4 , the proportion of the output of the first stage at the second stage is nearly proportional to the values of the two capacitors.

Assuming that the negative flyback pulse of the first stage appears before the charge on C_5 and C_6 is high enough to ionize V_3 and V_4 and is applied to the junction of V_3 and V_4 , the lower electrode of V_3 then becomes sufficiently negative to ignite it. A higher positive potential then appears on the upper electrode of V_4 and that tube ignites. Capacitors C_5 and C_6 quickly discharge and extinguish V_3 and V_4 . Capacitors C_5 and C_6 begin to recharge to produce the rising portion of the second stage output wave. So the first stage triggers the second. Any divided signal fed back to the output of the first stage (a common failing with single tube dividers) must pass through the high-impedance

voltage divider (C_3 and C_1 in series) and the low-impedance shunt divider C_2 . Very great attenuation of the fed-back signal is achieved.

Notwithstanding these precautions, a good deal of artificial ageing of cheap neon tubes is necessary to stabilize their performance. Thereafter their behaviour depends to a great extent on how often they are used. Long periods of dis-use frequently result in inability to start and means must be provided to adjust the free-running frequency of such oscillators.

To equal the long-term stability of valve oscillators, it is really necessary to use high-quality gas tubes, which increase the cost. Even so, there remain certain difficulties which can be overcome by replacing the lower gas tube by a silicon diode, e.g. Philips type BA100.* This provides a very low resistance path when the gas tube is conducting, so that the capacitor discharges extremely rapidly. But when the tube is not conducting, there will be a very high resistance path so that with the small coupling capacitors a high synchronizing voltage can be injected to the cathode of the gas tube. Germanium diodes are unsuitable because of their high leakage. This causes a reduction of the pulse duration so that synchronization may be lost due to 'jitter', that is, fluctuation of the discharge voltage.

Despite the prevalence of other forms of saw-tooth oscillator or frequency divider, the gas tube remains an inexpensive and accurate method of generating this form of wave, which is so useful for synthesizing imitative tone qualities in organ generators. We will note one or two features of the tube itself which determine whether or not the result will be effective.

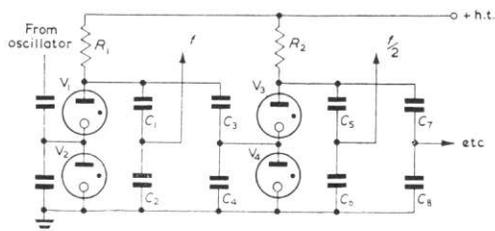


Fig. 67 Gas tubes in series with capacitive voltage dividers

* H. van de Kerckhoff, N. V. Philips Gloeilampenfabrieken.

When the supply voltage to the tube is raised to the point of ignition, the gas is ionized and a current flows. The voltage then drops to the maintaining voltage, which is less than the voltage needed to cause ignition. In this condition the tube has a negative resistance and thanks to this property oscillation can take place when a capacitor is connected in parallel with the diode.

For some small increase in current now, the discharge will spread farther over the cathode whilst the voltage will remain nearly constant; the resistance is very low. If this process continues, so that the whole cathode is covered by the glow, the voltage across the electrodes will rise. The correct maintaining voltage is of the utmost importance because the frequency depends on it.

Also, the ignition delay must be short in relation to the period of the sawtooth; a high value of delay will lead to jitter, so that the amplitude of the sawtooth will vary statistically with time. The delay can be made short by treatment of the electrode and gas filling or by applying a strong synchronizing pulse—one exceeding the ignition voltage.

Then the highest frequency of which the tube is capable depends on the de-ionization time of the charge carriers in the gas. It is difficult to provide equal recombination times over a very wide frequency range, so the gas is further treated to have a slow time at low frequencies, thus avoiding jitter. Also, there must be a relationship between the supply voltage and timing resistor for various values of capacitor. Some of these points are shown in Fig. 68 (A), (B) and (C).

Thus, unless good-quality gas tubes are used, there will be a high percentage of tubes which will not synchronize or will fall out of synchronism with time. But, given tubes with suitable gas filling and electrodes of good purity, this circuit is an excellent example of a sawtooth frequency divider.

Another device, the silicon unilateral switch, can be used to produce a good sawtooth wave as in Fig. 69. These elements require a stabilized supply line, but give excellent wave forms with no interference. An oscillator is of course required to drive the chain; here we show one consisting of a field effect transistor, which is very simple; but any other circuit would do as well.

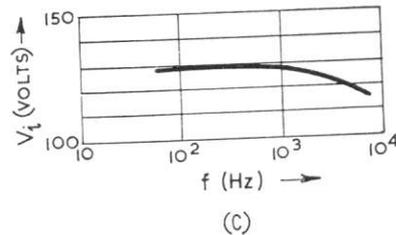
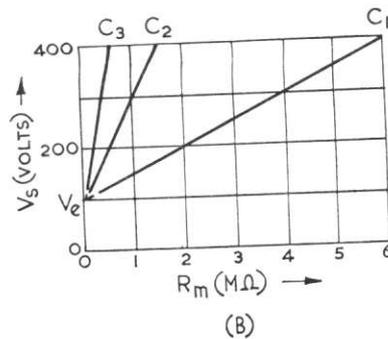
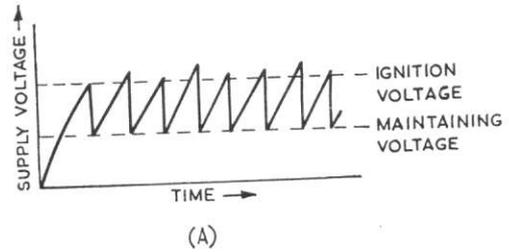


Fig. 68 (A) The phenomenon of jitter in which the amplitude of the sawtooth signal fluctuates regularly; (B) The relationship between the minimum resistance R_m and the supply voltage V_s at a certain value of the capacitance: $C_1 = 100$ pF; (C) The dynamic ignition voltage V_i as a function of frequency

If, however, a true square wave is required, then to form accurate tone colours there must be sharp edges to the wave; this is also true of square waves as triggers; to ensure that there is no loss of time, the coupling resistors must be shunted by small capacitors as shown in Fig. 71, where the effect is illustrated.

It will be clear from the previous few pages that to form a good square wave by frequency division is very easy; but to form a good sawtooth, there is

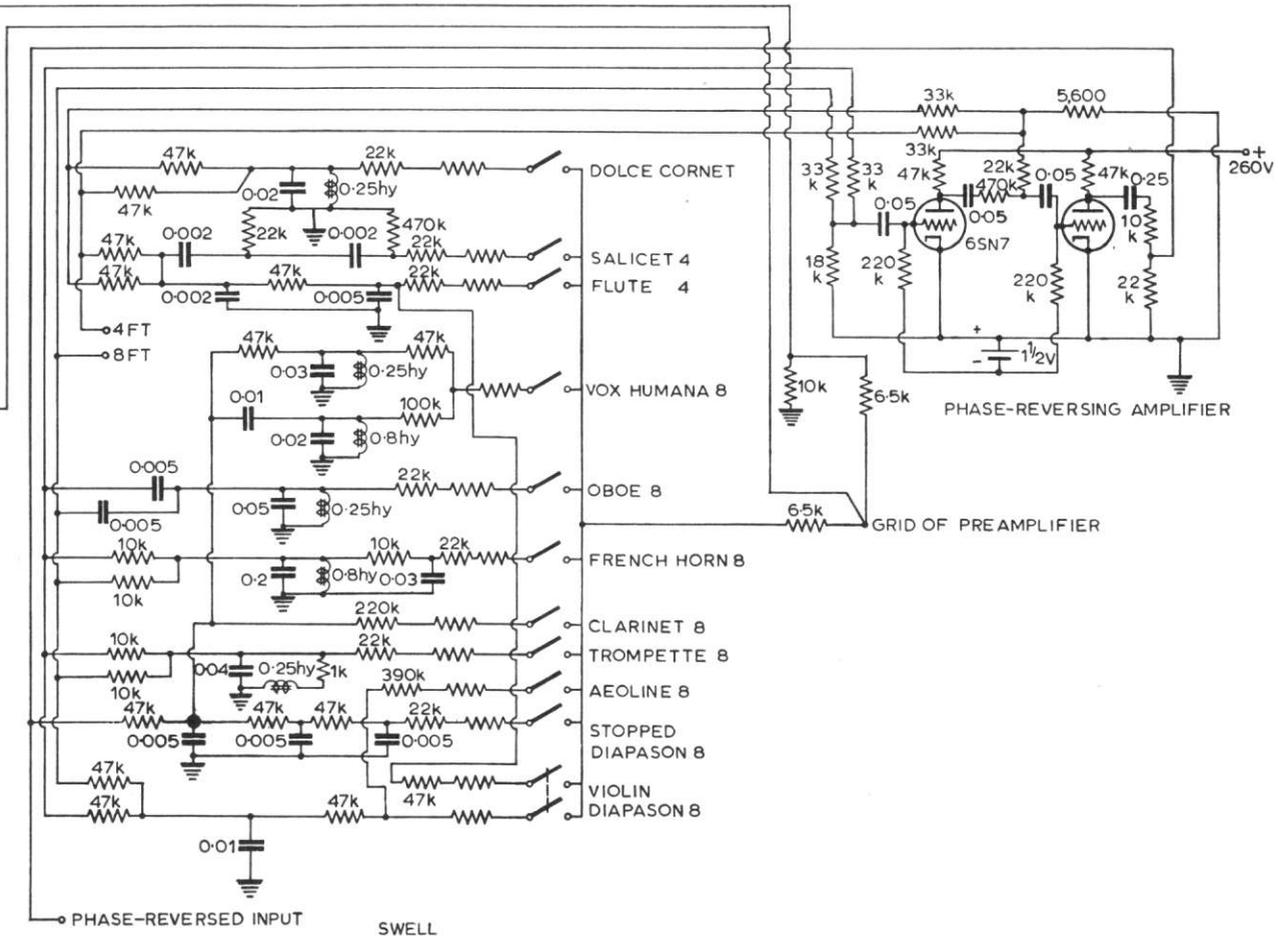


Fig. 113 Complete tone-forming circuits, Baldwin Model 5 organ

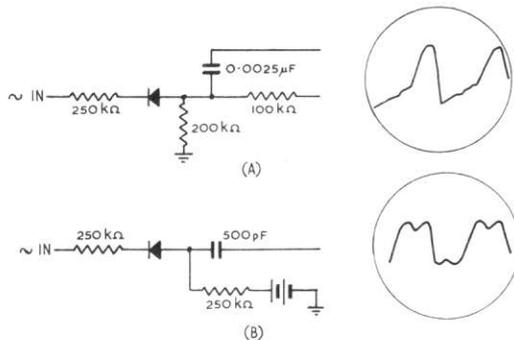


Fig. 115 Wave-form modifiers

simple contact of sufficient cross-section to carry the current. In any normal design this current will not exceed 2 mA per oscillator, often much less; the wire which has become almost a universal standard is hard silver. This contains 4 per cent copper, which makes it springy and the usual gauge is 0.016 in. We will not at the moment look at the mechanical aspects of construction but in any case, standard contact blocks can be bought with from 2 to 20 wires in each.

Both valves and transistors start oscillating very quickly, with the result that a click or some other objectionable transient can be heard at the start of the tone. This will be of very short duration and therefore of high frequency, and is quite easily

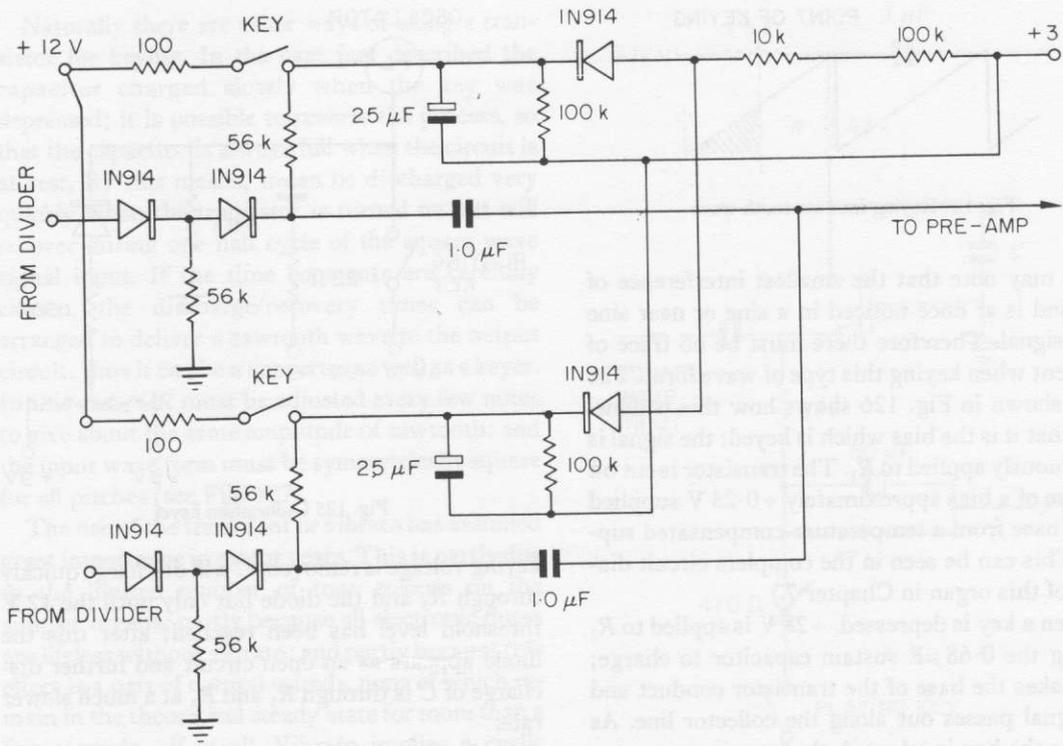


Fig. 121 Diode keying for pedal notes

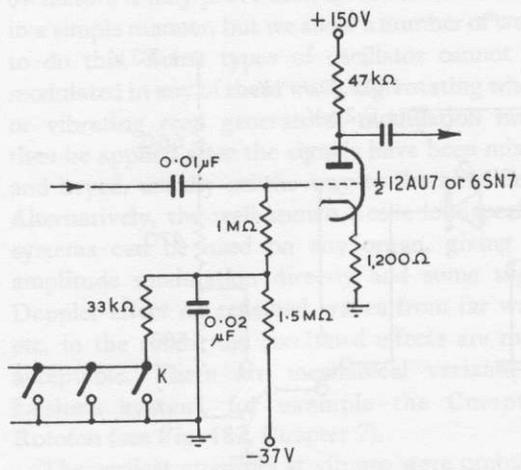


Fig. 122 Valve keying delays

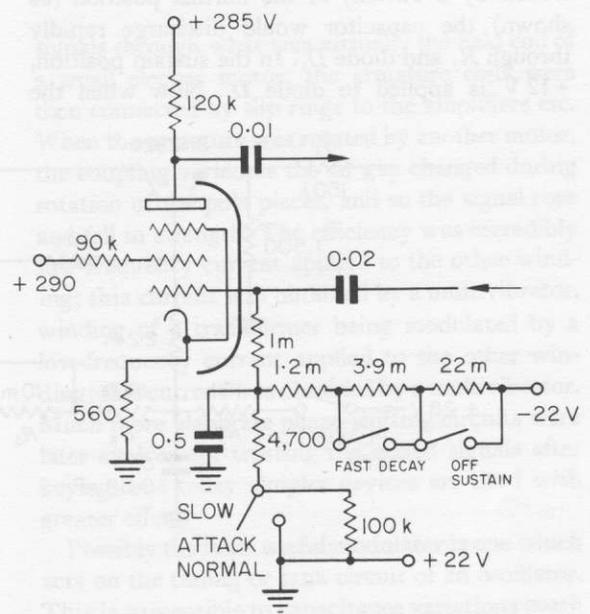


Fig. 123

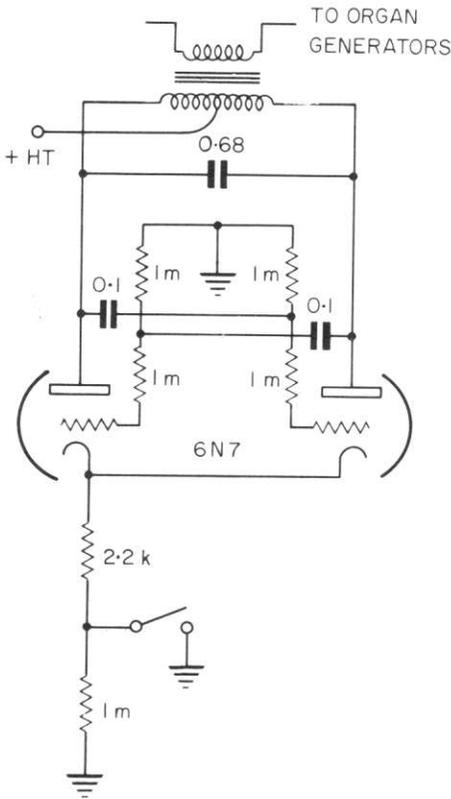


Fig. 129 Multivibrator modulator

an illusion of both frequency and amplitude modulation; though on examination by an oscilloscope the change in level is nearly all amplitude. The shape of the side of the cup has a great bearing on the effect of the tremulant, also on wind noise and the power required to drive the device. One advantage is that owing to the length of the sound waves at low frequencies, they leak round the sides of the rotor and are cut off; thus there is an automatic cancellation of the vibrato at low frequencies, e.g. on pedal notes, which is a musical advantage. The total depth is not very great, but is quite adequate for all but extreme effects.

Some further reference to experimental methods of vibrato or tremolo will be found in the last two chapters of this book.

This section is concluded with some references to reverberation circuits and devices. Everyone

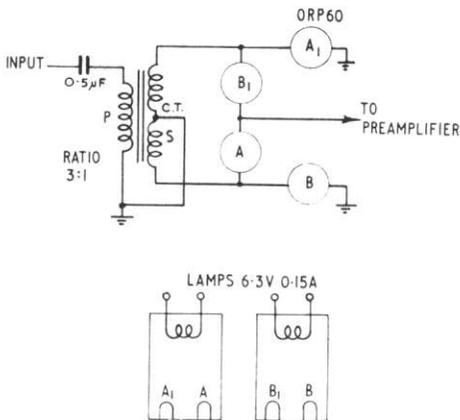


Fig. 130 Simple external modulator

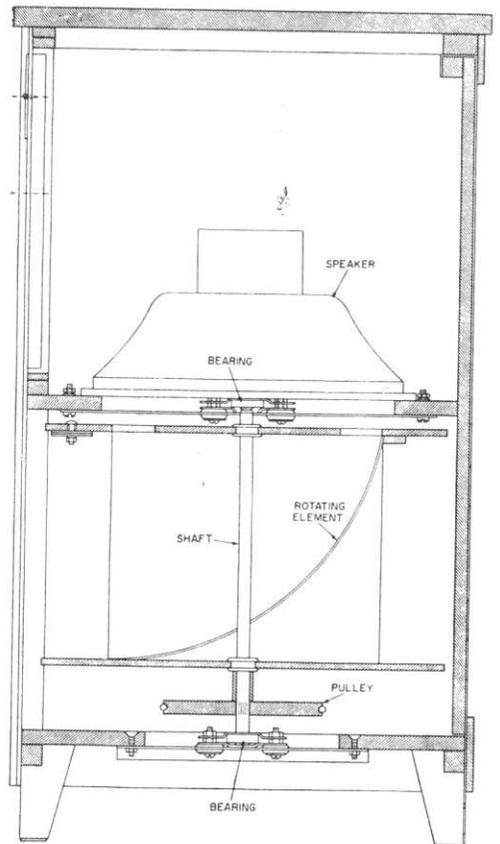
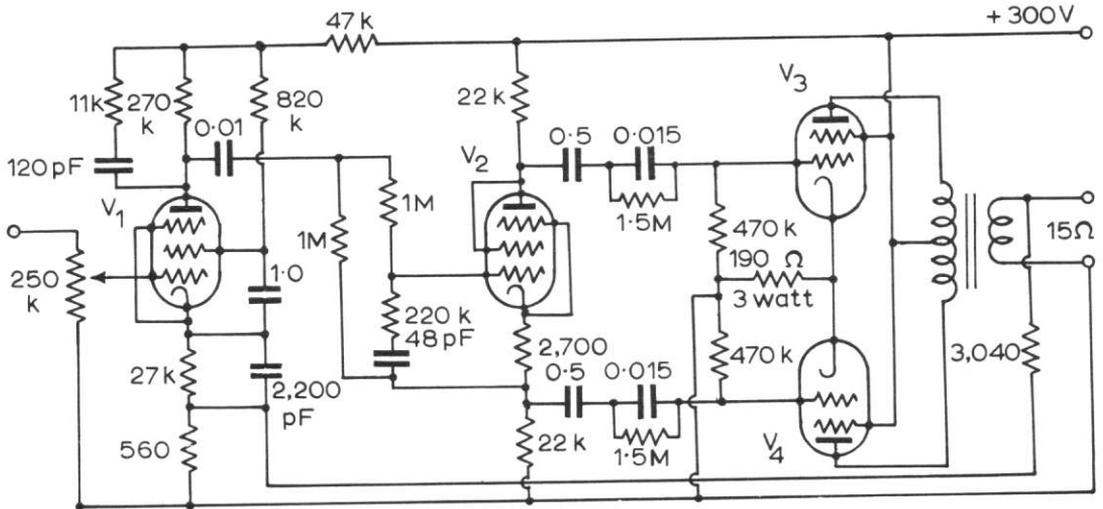


Fig. 131 Leslie Tremulant

reader may be unable to lay his hands on a suitable power supply unit, so one is shown in Fig. 138. There is no need for any stabilization, but it is desirable to fit the interference suppression

capacitors across the primary of the mains transformer. Twisting the a.c. leads to the heaters will reduce pickup from these to adjacent equipment. Be sure to use the maker's recommended



V1. V2. EF 37A. EF86. 6BR7
 V3. V4. 6V6. 6BW6.

± 1dB 10Hz - 20 kHz
 ± 3dB 4 Hz - 100 kHz

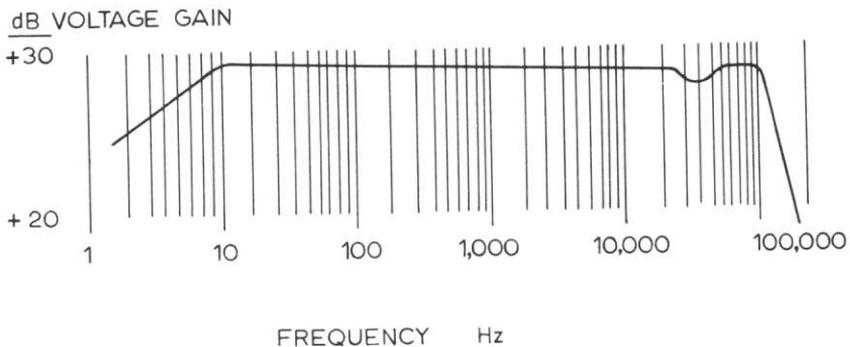
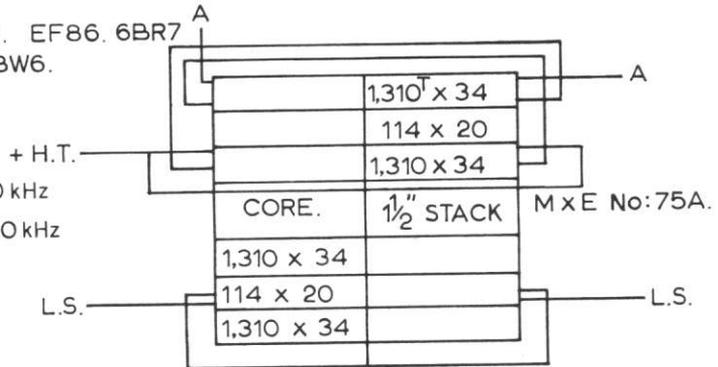


Fig. 137 Amplifier designed for the Post Office

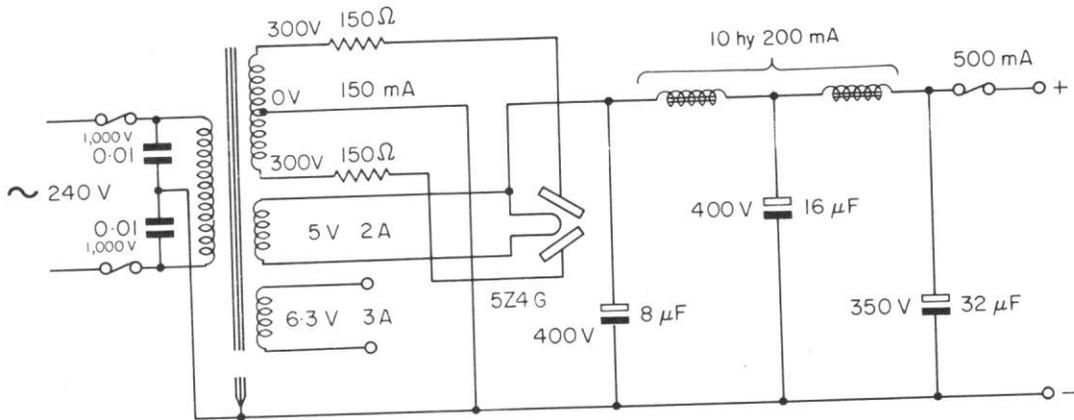


Fig. 138 Power supply unit for Fig. 137

limiting resistors in series with each anode of the rectifier valve; if in doubt, this is—

$$R_a = R_s + n^2 R_p$$

where R_s = resistance of half secondary
 R_p = resistance of total primary winding
 n = ratio of number of turns on half secondary to number of turns on whole primary.

In general, these values lie between 100 and 200 ohms, a little higher with cheap transformers. Filtering should be good if pre-amplifiers are also to be fed from the same power supply, and this means thorough decoupling (see page 35). Finally we show a stabilized power supply unit (Fig. 139), perhaps for oscillators etc.; it will not give more than about 100 mA at 185 V; of course the supply of 350 V should be well smoothed, but just as with

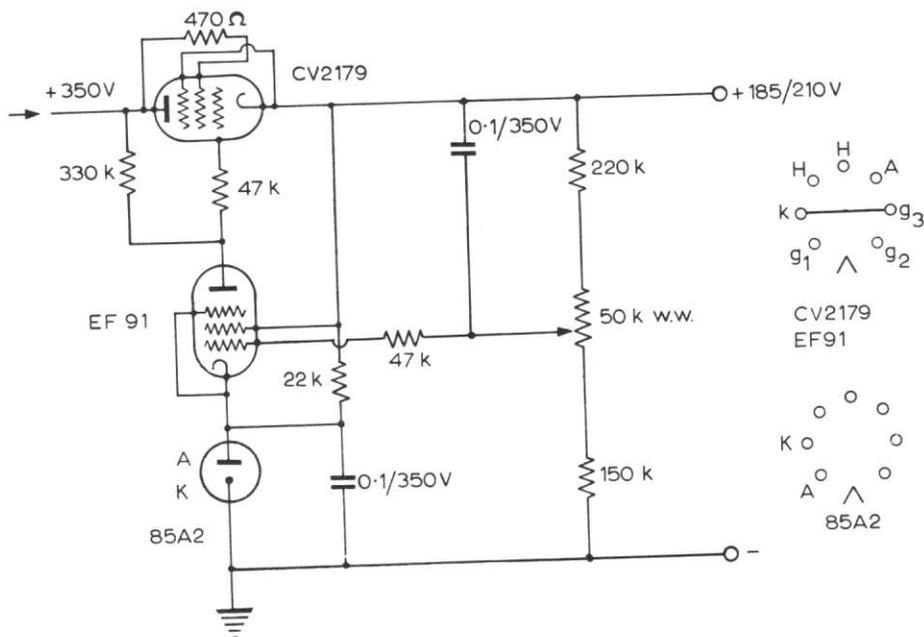


Fig. 139 Circuit for H.T. stabilizer

tion in Germany, and a number of investigators had adopted them in preference to vacuum valves for oscillation generators. Apart from the greater circuit simplicity, the wave form is always rich in harmonics, and thus the sound is readily modified to give musical tonalities which are not, perhaps, the same as those of conventional instruments, but which are quite pleasing. With this object in view, a simple single keyboard instrument was evolved in which one neon tube was coupled with a resistor and tuning capacitor so as to oscillate continuously.

This performed very satisfactorily but since such a tube must work into a very high impedance as any appreciable load will alter the action of the circuit, the modern instrument makes use of a gas triode (Fig. 165). This is more stable, easier to control, and can deliver appreciable power.

The variable resistor marked 'manual' in Fig. 165, together with capacitor C , adjusts the frequency range as required over about three octaves. To facilitate playing, the manual resistor is in flexible form, so proportioned that the frequency of oscillation is proportional to the length of strip in use. Dummy keys are mounted above the strip to indicate the approximate position of the main intervals, but it will be realized that the frequency can be made *continuously variable* and thus gliding tones may be played. Manipulation of the 'keyboard' simply consists of pressing the tubular

cover enclosing the resistance contact strip at the point selected to produce the correct pitch note.

The generator oscillates instantly; to control the attack or rate of build-up for the sound, an auxiliary resistance element is placed below the manual resistor and is so contrived that pressure on the playing strip also compresses the attack resistor, so causing the note to sound. Thus various modes of attack are possible, depending on the rate at which contact is made, and the pressure exerted at that time.

In simple models, there are formant circuits of an elementary nature, from which sounds approximating to reed (Fig. 166 (A)), string (Fig. 166 (B)) and flute tones (Fig. 166 (C)) can be obtained. The sounds are somewhat arbitrary, but the extreme simplicity of the device led to its wide adoption in schools abroad, where many pupils could practice simultaneously by wearing headphones, without interference. The circuit shown was used for this purpose, but by further amplification the usefulness was extended.

More recent models have grown up somewhat, and are fitted with two keyboards. The considerable length of wire required to develop enough resistance for variation of the grid bias over a range of three octaves made the physical intervals too large to be comfortably manipulated on the model described above. By winding the wire round a drum it has been possible to bring the intervals

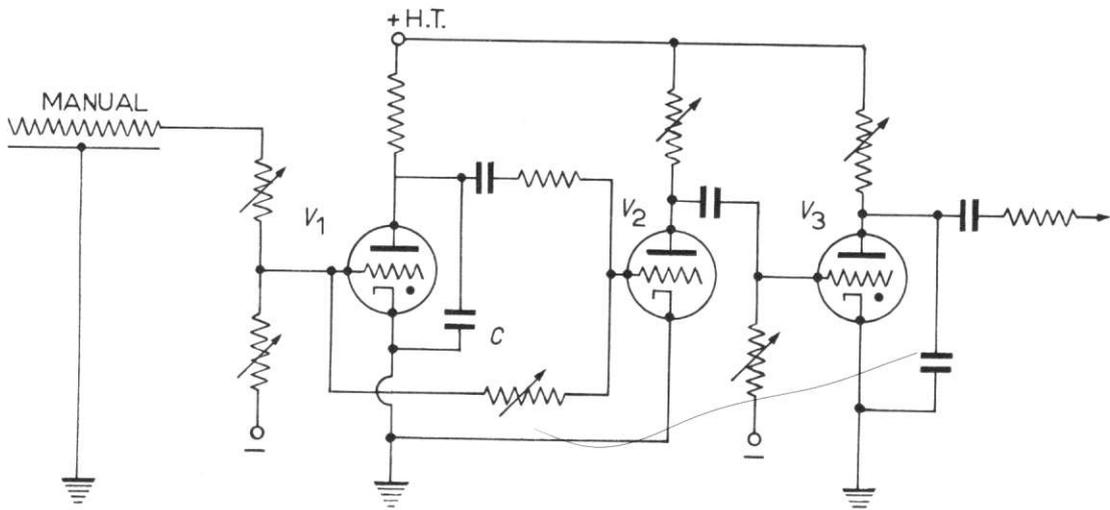
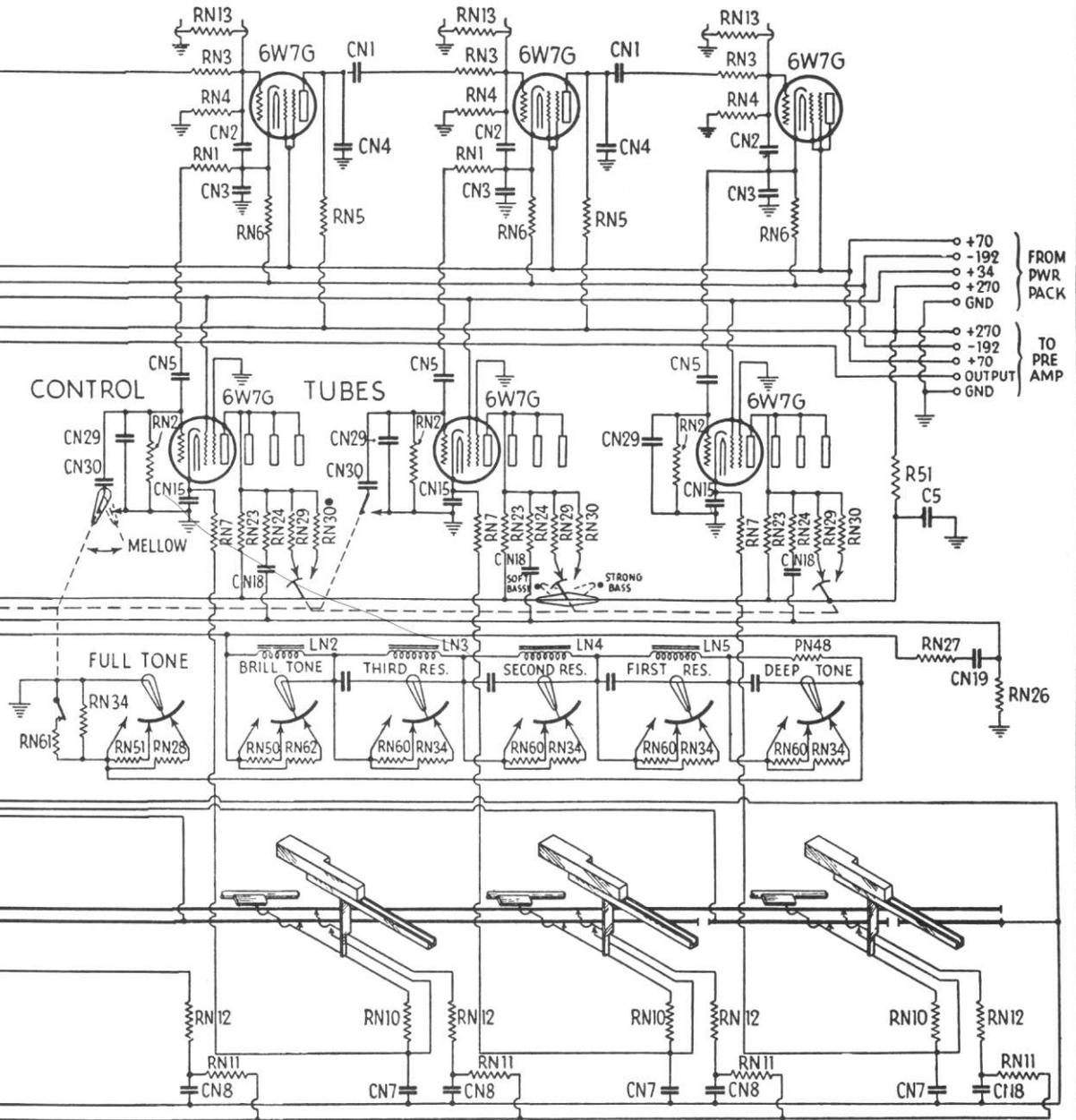
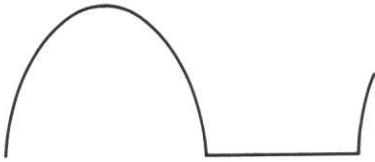


Fig. 165 Circuit of Trautonium with frequency divider

FREQUENCY DIVIDERS





PERCENTAGE OF FUNDAMENTAL				
Harmonic No.	2	4	6	8
%	42	8.4	3.6	2.0

Fig. 235 Harmonic content of rectified sine wave

is uninteresting, if it is rectified we get Fig. 235, the harmonic content of which is given below; so this wave is more suitable for flutes etc. which are near to sine waves, but certainly not exactly so.

Earlier it was said that generators having a mechanical origin (i.e. tone wheels, reeds etc.) are not susceptible to electronic vibrato circuits; in such cases there must be a modulator of some other form. An early circuit is shown in Fig. 236 and is for valves only. The small transformer is any step-up type, the primary being the lowest impedance winding. There is provision here to reduce the vibrato towards the bass end of the compass, for it is a general rule that when the vibrato frequency approaches that of the tone frequency it

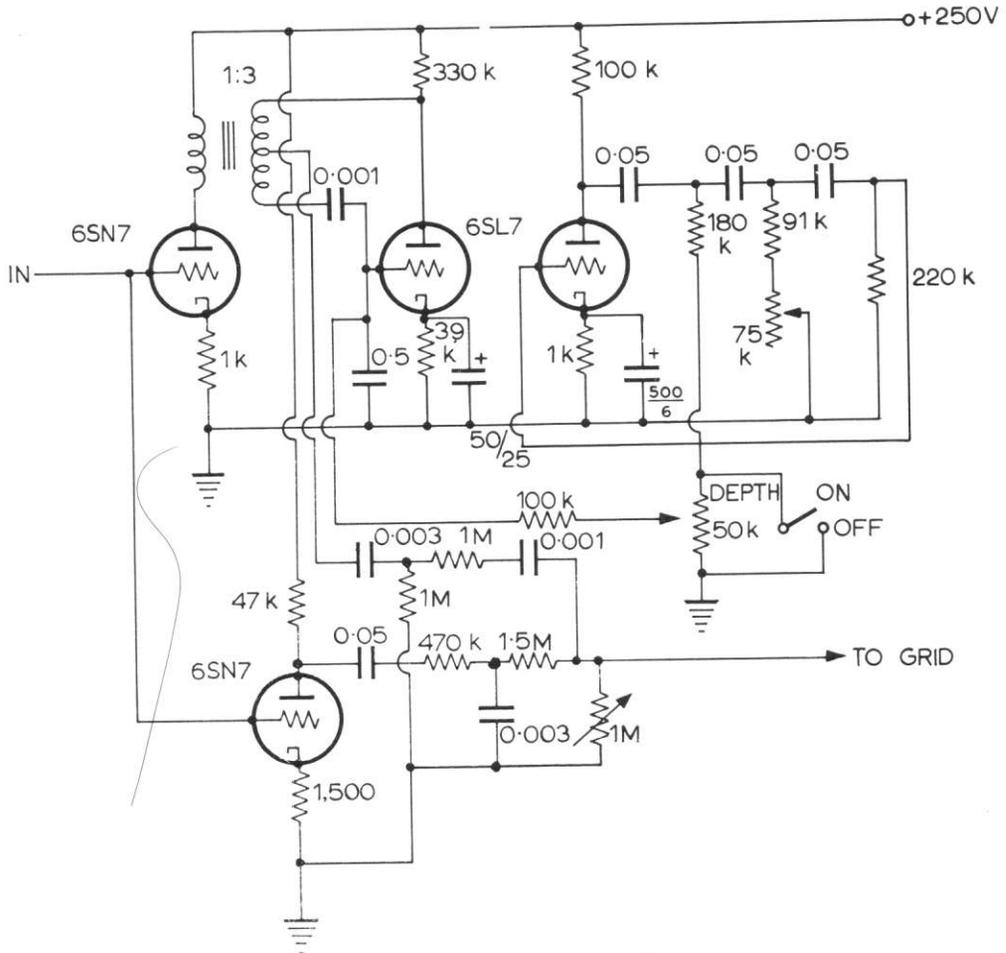


Fig. 236 Phase-shift vibrato circuit

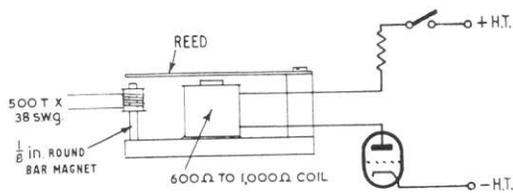


Fig. 242 Mechanical reed sustain device

it is possible to have a mechanical sustain as in Fig. 242; it is only applicable to organs having an independent oscillator for each note. The small steel reed is tuned to the oscillator frequency and when the anode current flows through the coil, the reed is caused to oscillate at that frequency. When the key is released, the inertia of the tongue allows it to vibrate for a time, so that if a pickup coil is placed near to it, the tone can be heard. It can either be added to the main tone or used on its own with separate tone-forming networks; this permits reeds of different harmonic content to be tried. Since there is no soundboard or cavity there is no acoustic output and the reed drive causes no audible sound. The reeds can be made from clock spring and carefully filed until they are in tune with the oscillator; though they will pull in if close to that frequency. It has also been suggested that they might be of twice the designed frequency so that when the valve is silenced they tend to revert to

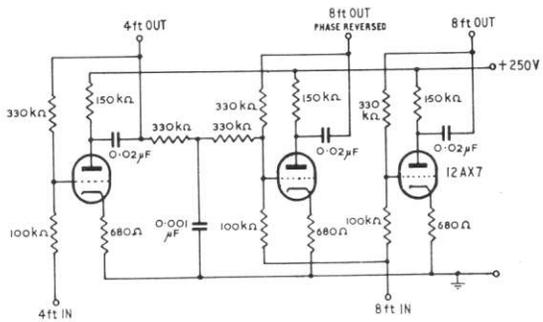


Fig. 243 Phase-reversing circuit

their true frequency; this could give an 'Hawaiian guitar' effect.

It is in the field of experiment that we find people still using valves to some extent, so we give a phase-reversing circuit here which operates in the same way as the transistor device on page 50. Fig. 243 has the correct values of resistor to attenuate the 4-ft signal and the best valves for this circuit are 12AX7 as shown. Applied sawtooth waves appear as 8-ft square waves.

A method evolved some years ago to control overloading of amplifiers in a simple way is reproduced again in Fig. 244; of course it can be applied equally well to transistor circuits. The small lamp is connected, through a regulating resistor, across a loudspeaker speech coil. It is associated with a cadmium sulphide photo-cell

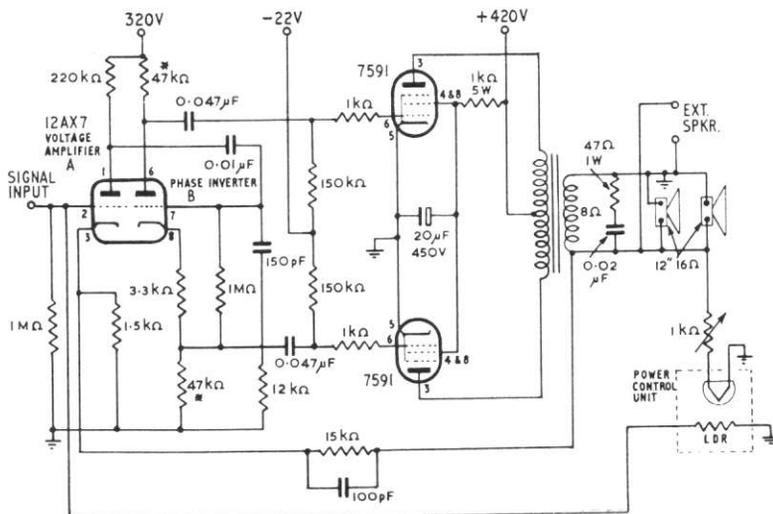


Fig. 244 Method to control overloading of amplifiers

piston with the switch it is to control. This is because this switch sets the operating states for the circuit; for instance, if the stop switch is 'off', C4 will not be charged. When the stop is 'on', C4 will be charged to -17 V . These are the reference parameters which must be set up before the circuit can operate.

In the quiescent state Q23 is not conducting and the emitters of Q21 and Q22 are at approximately -17 V . None of the transistors now conduct and C4 is at 0 V . Q23 is cut off, and until the piston is pressed we assume C4 to be discharged. On closing the contact, the base of Q23 is grounded through C5 and R10, causing Q23 to conduct. This places the emitters of Q21 and Q22 near ground potential. As C5 charges, a point is reached where Q23 will stop conducting, allowing the emitters of Q21 and Q22 to return to -17 V . When the piston is released, C5 discharges through R6 and R9.

For the short time that the emitters of Q21 and Q22 are near ground potential, one of these two transistors will conduct. If C4 has -17 V on it (stop switch 'on'), Q21 will conduct, holding Q22 off because of the low collector potential of Q21. This low potential also goes through R13 to the base of Q25, turning it on; the current from this passes through the 'off' coil L2, causing the tab to rise to the off position. This makes the switch contact of this coil position close and so cut off the -17 V supply to C4. Before C4 becomes discharged to the point where Q21 would stop conducting, and cause Q22 to come on, Q23 cuts off and this prevents Q24 or Q25 from becoming active.

So with the tab switch up (off), C4 discharges to zero. Now if the piston is closed and Q23 conducts, Q21 will remain cut off. Q22, however, is biased on through R5, R7 and the -17 V supply. Q24 is next biased on through R12 and Q22, with Q24 current flowing through the 'on' coil, L1, so moving the tab to the 'on' position. The switchback contact opens and C4 is again allowed to discharge through R2, R3 and D3, and the system is now ready for the next reversal pulse from the toe piston switch. Perhaps we might note in passing that by using thyristors in place of small current transistors, the large action magnets found in pipe organs are controlled by transistor keying nowadays and small

primary chest magnets can be controlled with the kind of transistor shown above. So the trend affects design in many fields and simplifies servicing, apart from the advantages of silence and long life.

A very simple little instrument from which a great deal of satisfaction can be obtained is shown below. Many may also want to make a similar device if only as an introduction to the techniques of organ building. Accordingly a useful circuit is given in Fig. 270, and this produces a square wave just like many frequency dividers; therefore, any of the tone-forming circuits described for these can be applied. In this particular circuit, some three octaves can easily be covered. It would be possible to add a frequency divider if desired. The circuit is a simple multivibrator, tuned by variation of the resistance chain. The initial pitch is set by the rheostat R¹ and each subsequent semitone downwards is adjusted in value until correct. The next interval is then tackled, and so on to the end of the range. The resistor values follow a logarithmic law, being small for high notes and large for low notes. Unfortunately, there is no accurate way of predicting their exact values—and they must be exact; the values must be found by experiment. The pitch can be shifted up or down an octave with the same key resistors by switching the fixed capacitors shown; these will of course have to be trimmed exactly by means of small variables of about 500–1000 pF.

Keying transients are reduced by the simple bias circuit shown. This requires no additional supplies. A continuously variable vibrato is supplied by the second multivibrator. The oscillator must work into a buffer valve, such as the 12AU7 or ECC82.

Of course, transistors have proved very suitable for this kind of instrument and indeed are much easier to use as multivibrators than valves. In Fig. 271 a useful circuit is shown; this is divided into two parts, the vibrato oscillator on the left and the tone circuits next. Just as with the valve circuits, initial tuning is set by the 25 k Ω variable resistor, and other variables are connected as shown to form lower notes. The circuit is suitable for three octaves. It is best to make up a Zener stabilized power supply as suggested on page 91.

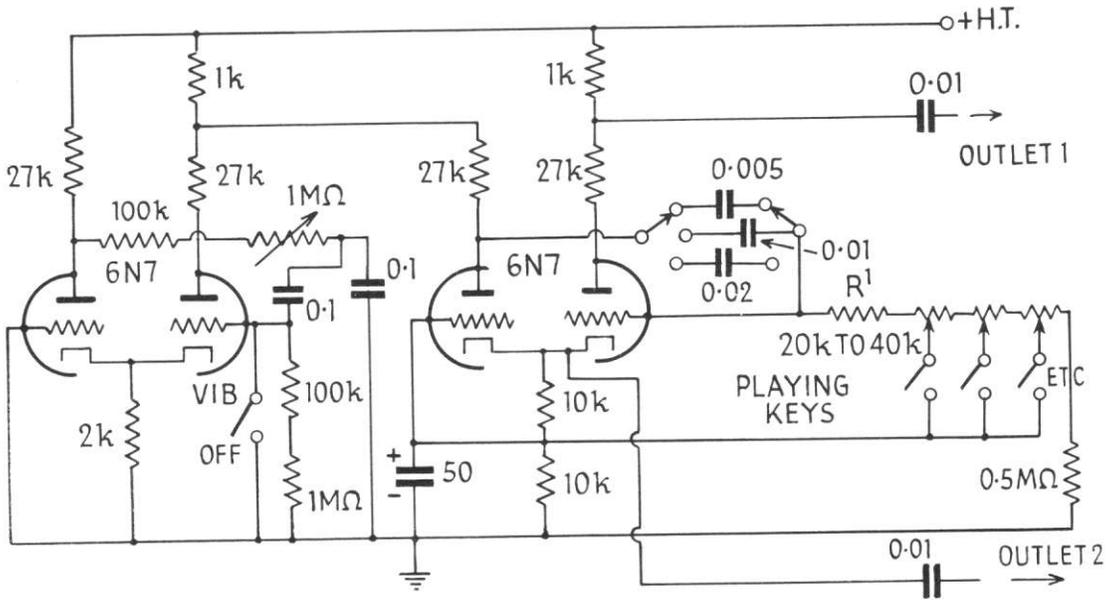


Fig. 270 Simple melodic instrument

As an alternative to the multivibrator, one can use a simple blocking oscillator with a single transistor, as in Fig. 272. Here we show not only the tunable oscillator, but two stages of frequency division. All transistors may be of the same type and an emitter-follower stage isolates the second divider from the first to prevent intermodulation. The transformer can be wound on a core $\frac{3}{8}$ in. by $\frac{3}{8}$ in., simple stalloy or 3.4 to 3.9 per cent silicon iron. Primary 500 turns of 38 swg, secondary 800 turns of the same wire. It may be necessary to adjust the value of the $0.01 \mu\text{F}$ tuning capacitor and it is difficult to cover more than $2\frac{1}{2}$ octaves

with this circuit. However, it can be made so small that it could be contained in a toy piano, for example. Fine tuning is by the $2\text{k}\Omega$ variable resistor shown, and the pitch is not so liable to drift as a multivibrator, so that it could be run from a dry battery.

A useful way to obtain harmonically rich wave forms of more than one kind from an oscillator is shown in Fig. 273. Because the base of the transistor is supplied from a fixed source, it can be so biased that it can be somewhat overdriven. In this case, a square wave appears at the collector and if we then apply a network as previously described in Chapter 4 for conversion to a sawtooth, we can have both types available from the one circuit, so enabling many more experiments in tone forming. It should be pointed out that any bias applied in the manner shown must be stabilized, since variations in the voltage would result in variations in the frequency; this is made use of in Conn organs, where some of the base resistors are so connected (when this effect is required) that alternate notes become slightly sharpened, the others being slightly flattened. This improves the chorus effect when many notes are played at the same time.

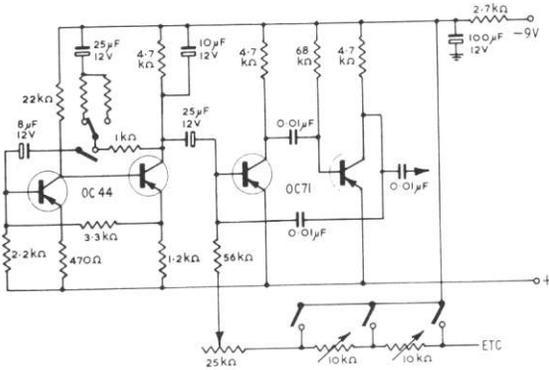


Fig. 271 Transistor multivibrator