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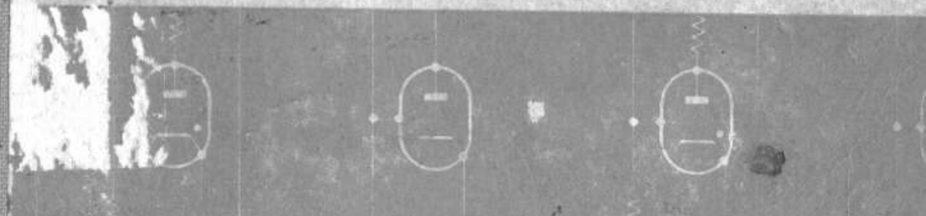

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CONTENTS

ILLUSTRATIONS

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INTRODUCTION

SINCE the advent of electronic music in 1935, the demand for some instrument which the amateur could make has grown. For a long time it was not possible to obtain satisfactory imitative tones; the minimum equipment was too bulky and costly; the rate of attack was unlike that of physical instruments; tones could not be properly mixed; stability of tuning was poor; and so on. With the increase in knowledge resulting from the production of many thousands of such instruments, it is now possible to design effective circuits in the simplest possible terms.

The author has been able to visit nearly all the plants producing electronic musical instruments in England and America, inspect their products both in the factory and under many conditions of installation; and acknowledgement is hereby made to the many companies who use some part or some similar circuit arrangement in their own production.

Now, the advent of television has promoted a new interest in music for the home, so we are going to describe some simple instruments to cater for various needs. For example, many have a piano; so some melodic attachments are described so that an orchestral solo can be played with piano accompaniment. Then some have no piano; here we provide a kind of electric accordion, which, with one of the melodic devices, makes a little orchestra—still playable by one person. Again, organ lovers often wish they had a pedal attachment for their pianos on which the long deep notes of the organ could be played, to help their practice. This is described, but by a simple attachment it can be made to sound like a string bass so that, with other instruments herein, a complete band is formed. Other ideas to suit further requirements are described, and it is hoped that there will be something within these covers for every music-lover; for in the course of over 30 years as an organist, the author has had ample opportunity to assess the value of every kind of musical sound and the reader may rest assured that all these instruments are *musical*.

And speaking of music, some readers may only have a hazy idea of how musical terms are expressed, and what the common nomenclature of the art means. So let us begin with a few comments on music in general.

Firstly, we know that all instruments have some range of pitch or frequency, and that they are tuned to a definite pitch. The pitch range of an organ is the widest of any single instrument, but then it is really a collection of instruments under the control of one player. The range is from 16c/s to perhaps 8,000c/s. The piano comes next, with a range of 27c/s to 4,186c/s. But the pitch range of any orchestral instrument is much less. Now, regardless of the range, there must be some standard of pitch to which everything can be referred. This is a single note chosen to lie inside the range of all the principal musical instruments, and is A = 440c/s. Most people have heard an orchestra tuning to this note sounded on an oboe. An oboe is chosen because it has a wooden reed, and so is less affected by temperature than any metal instrument. We cannot discuss orchestral instruments in detail here, but there is plenty of published literature for the interested reader.[1] Most libraries have these books.

Any exact doubling or halving of any pitch is called an octave interval, so that octaves go both up and down, as it were. The whole range of any instrument is called its compass, measured in numbers of notes.

Every octave is now divided into twelve equal parts, called semitones. These are the smallest intervals between adjacent notes used in the Western world and are of course the fixed intervals on any keyboard. A semitone is a multiplication of the pitch of one note by $\sqrt[12]{2}$ or 1·05946, resulting in a slightly imperfect tuning for all notes; but it is the only way in which it is possible to play (on a keyboard) in any key[2].

To revert to pitch. Basic or unison pitch as it is called is based on the organ pipe. An open pipe 8ft. long (from mouth to lip) gives out the lowest C on an organ keyboard, 65·406c/s, and so all sounds playable by that kind of pipe are called 8ft. pitch. This is also the pitch of a piano. One often hears of 4ft. or 16ft. pitch; this only means all notes are one octave above or below the 8ft. notes. The pedal bass of an organ or the string bass, is based on 16ft. pitch. The lowest note of the piccolo is very high, it is actually of 2ft. pitch—two octaves above most other instruments. An organ is the only instrument on which all these pitches can be found or sounded independently, but a *coupler* is fitted to many other instruments to play two adjacent octaves at the same time but not independently, for it is a mechanical device.

The word attack is constantly used. This means the rate at which a musical sound starts. It is very variable in orchestral instruments because the way in which they are manipulated determines this, but with the exception of the piano and harpsichord it is fixed in other instruments. The point is, only a limited variation in the attack characteristics is possible, otherwise the sound appears unreal.

We hear a lot about *vibrato*. This is the "wobble" which is an essential ingredient of vocal music and is often required of orchestral instruments. It is known as a tremulant on an organ and is electrically provided by a low-frequency oscillator which modulates the main tones at this rate. Its judicious use greatly enhances the

[1] *The Physics of Music* by A. Wood, Methuen. *The Acoustics of Orchestral Instruments and the Organ*, by E. G. Richardson, Arnold & Co.

[2] *Electrical Synthesis of Musical Sounds. Electronic Engineering*, July, August and September, 1953.

musical appeal of electrically-produced tones but again, it must be right or it causes an unpleasant bleating sound.

Another matter that we want to know a little about is harmonics and overtones. No musical sound consists of just the fundamental or pitch note; it has other notes superimposed on this as well. These are generally harmonics. A harmonic is any exact multiple of the pitch note. An overtone is some non-mathematically related interval; for example a church bell or a triangle has many overtones. They may be, and generally are, discordant, but their presence is essential to the realism of certain musical sounds. It is the presence of harmonics which gives the different quality of sound, or *timbre* as it is called, to any fundamental or pitch note. In most orchestral instruments and organ pipes, these harmonics often fall into well-defined groups of fixed frequencies and are then called formants. These groups are the essential tone-forming component of the characteristic tonecolour and are due to the material of which the instrument is made, the rate of travel for sound waves in this being different from that in air. The interesting part about formants is that the one fixed band of frequencies appears for every note in the range of the instrument regardless of the pitch. Thus, if we could make the formant band separately and add it to other pitch notes, we should expect a sound like that of the instrument in question. This is possible, and is naturally a most valuable factor in simplifying electrical tone-forming circuits. Fig. 1 shows the formant bands for certain orchestral instruments. The figure above each group indicates the relative intensity of the formant to the main tone.

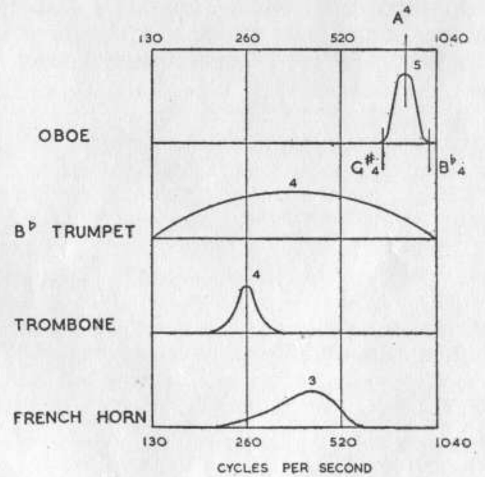


FIG. 1. FORMANTS OF SOME ORCHESTRAL INSTRUMENTS

But we do not need to synthesize the full formant group to give realism; quite a lot of harmonics can be omitted, yet the tone will still be satisfactory. Compare a cheap radio set with the tone control at "mellow" and consider how easy it still is to identify instruments, although some octaves of upper harmonics have undoubtedly been cut off.

So now we have a fair idea of the simpler musical terms as related to the kind of instruments to be described, and in conjunction with the keyboard shown in Fig. 2 and the frequency or pitch table (shown in the Appendix), this should be enough to let us get on with the construction of any of these instruments.

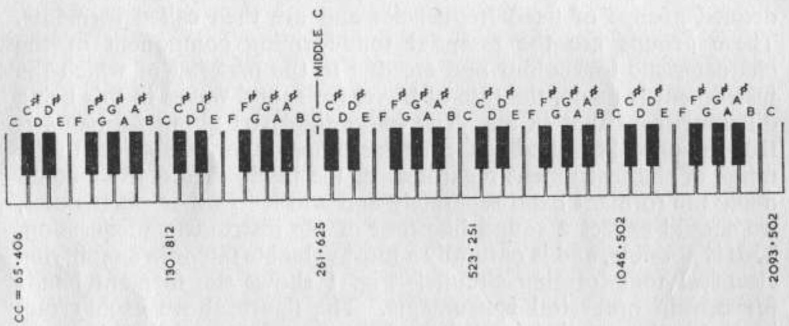


FIG. 2. FIVE OCTAVE KEYBOARD 8 FT. PITCH

I

GENERAL CHASSIS DETAILS, POWER SUPPLIES, AMPLIFIERS AND LOUDSPEAKERS

Most of the instruments described are compact and, in consequence, two sizes of chassis will suit any of the generators, amplifiers or power supply units in these chapters. It is not recommended that any power supply pack be on the same chassis as a generator.

Fig. 3 shows two generally useful chassis. Owing to the range of frequencies employed, it is rather risky to use steel. Each of these chassis should be 3" deep and this will contain all the components except valves, which should be external, and mains transformers, which should be slotted through. The 6SN7, 6SL7, 5Z4G, VR105 and 150; EF37A, EF39, 6SJ7, 6V6 valves all require an octal holder, hole diameter = $1\frac{1}{8}''$. The 12AU7, 6BR7, 12AX7 are on a B9A base, hole diameter = $\frac{3}{4}''$. The 6BA6 is on a B7G base, hole diameter = $\frac{5}{8}''$. Volume control potentiometers and variable wire-wound resistors in general have a $\frac{3}{8}''$ diameter fixing bush. Otherwise, there is little standardization of part sizes, depending on the method of manufacture, size and rating. The reader must judge for himself where best to attach tag strips, terminal blocks, etc., but if the layout is at all critical this is mentioned in the text; otherwise, any sensible layout can be used. Remember that *all* a.c. leads at mains frequency should be twisted pairs, but no screening is necessary.

Generator details are given under their respective headings, so here we confine ourselves to power supplies and amplifiers. All the circuits have been designed to make use of a main h.t. line voltage

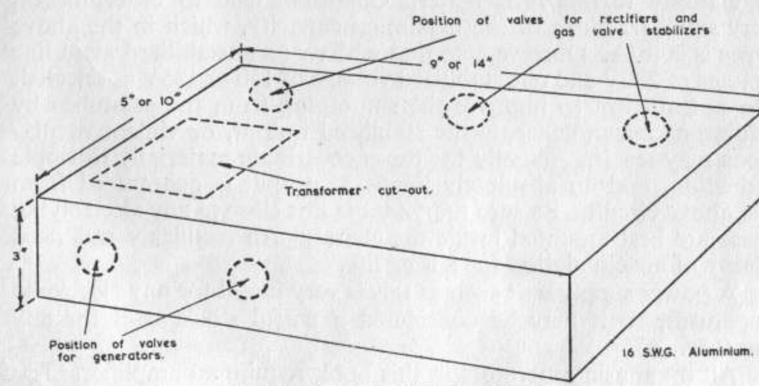


FIG. 3. GENERAL PURPOSE CHASSIS

of 280/300, and one stabilized line voltage of either 150 or 185. The a.c. heater voltages are, of course, 6/6·3 for all valves except rectifiers, which are 5V. A useful general purpose mains transformer should be selected, so that it will suit both generator and amplifier. This can be rated at 350.0.350V 150m/A, with two 6V windings of 2/4 amps and one 5V winding. The inexpensive but very well worthwhile provision of a mains fuse, 1 amp capacity, on the primary side should not be overlooked.

Now, smoothing of the h.t. line must be exceptionally good for music generators, because minute traces of 50 or 100c/s ripple will modulate the tones and cause an unpleasant rasping sound. As we will assume the amplifier to work class A, the load current will be almost constant so we can use a capacitor input filter.

It is really best, though more expensive, to use a paper dielectric capacitor across the rectifier valve; but if an indirectly heated 5Z4G is used, there will be only a small surge on switching on and an 8/450V electrolytic capacitor will serve. The chokes should be 10hy 150m/A and the remaining capacitors will be electrolytics, 16/450 and 32 or 40/450 respectively. The supply will then be approximately 280V at 150m/A, unless the smoothing chokes have an excessively high resistance; about 250 ohms or less is satisfactory.

Every tone generator described here requires a stabilized h.t. line voltage. The stability conferred by gas-tubes of the VR type is adequate, since, as the load is almost constant, the regulation is generally better than 1 volt. Fig. 4 shows a typical power unit and the use of either one VR150 for a line voltage of 150V or two VR105 in series for a line voltage of about 190. The series resistor in either case is 6·8K, 5 watts, wire-wound, for this transformer, which is a stock type. There will then be about 15/19m/A available for the generators, which is sufficient. Note that the standing current in these tubes should not be reduced below 10m/A for good regulation—15/18m/A is better. Gas-tubes tend to be erratic on very small fractions of the maximum capacity, which in the above types is 30m/A. Observe here that we have an unstabilized main line voltage of 280V and one stabilized voltage of 150 or 185V as selected. Do not attempt to improve the smoothing from the gas-tubes by adding a capacitor across the stabilized output, or violent oscillations may result. Actually the tubes contribute materially to ripple reduction, and an absolutely hum-free output is guaranteed from the above circuit. Be sure the 5Z4G is not close to any electrolytic; these are best mounted inside the chassis. All rectifier valves need plenty of air circulation for a long life.

A power supply unit such as this is very useful for any electronic apparatus, so it may be considered a useful stock asset for any purpose.

All the music generators in this book require an amplifier. The "best" circuit for this purpose does not exist; circumstances so

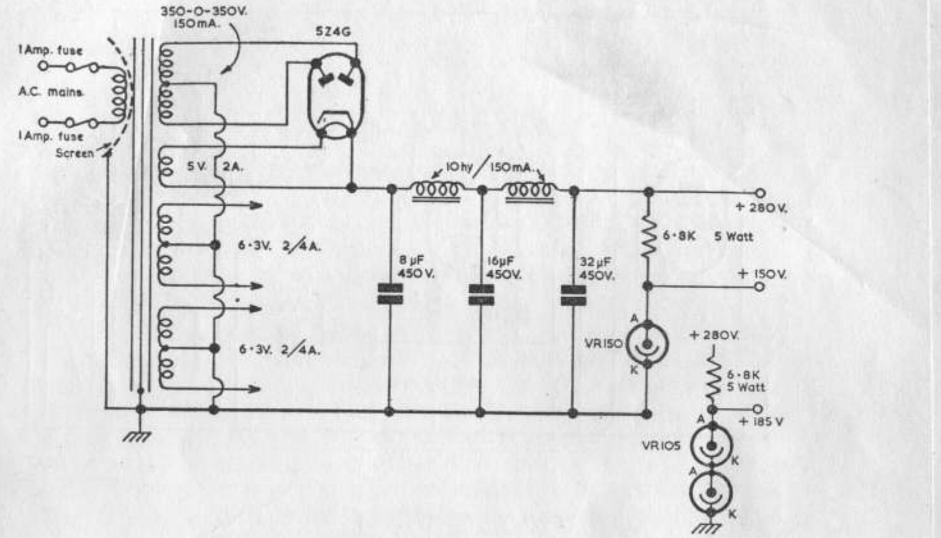


FIG. 4. MAINS UNIT

modify the final result that it has been decided to specify one universal circuit of extremely high quality and modest cost. This has been used in much more exacting instruments and fills every requirement for the home. Distortion is low, frequency response is wide, intermodulation is negligible and no special output transformer is required; outputs up to 10 watts are available, which is quite enough for the home. In addition, it is just the amplifier for record or radio reproduction, so it kills all the birds with one stone. The principles have been described in the press[1] so that only the circuit and output transformer details are reproduced here in Fig. 5. The h.t. load is nearly 90m/A so our power unit has plenty in hand for the stabilized output for the generators.

The output transformer is quite easy to wind, but be sure to reverse the direction of winding of all three coils on the right-hand half of the bobbin. No instrument in this book has a lower frequency than 32c/s, but the upper harmonics may extend to 12,000c/s. The response of this amplifier is only 1db down at 4c/s and 20,000c/s so it will be seen to be entirely suitable.

Then we have to consider the loudspeaker. For any of the keyboard instruments, the new W.B. 10″ cambric cone unit has an outstanding performance at the lowest possible price, and will respond down to 32c/s as well; but its power handling capacity at very low

[1] *Electronic Engineering*, August, 1952.

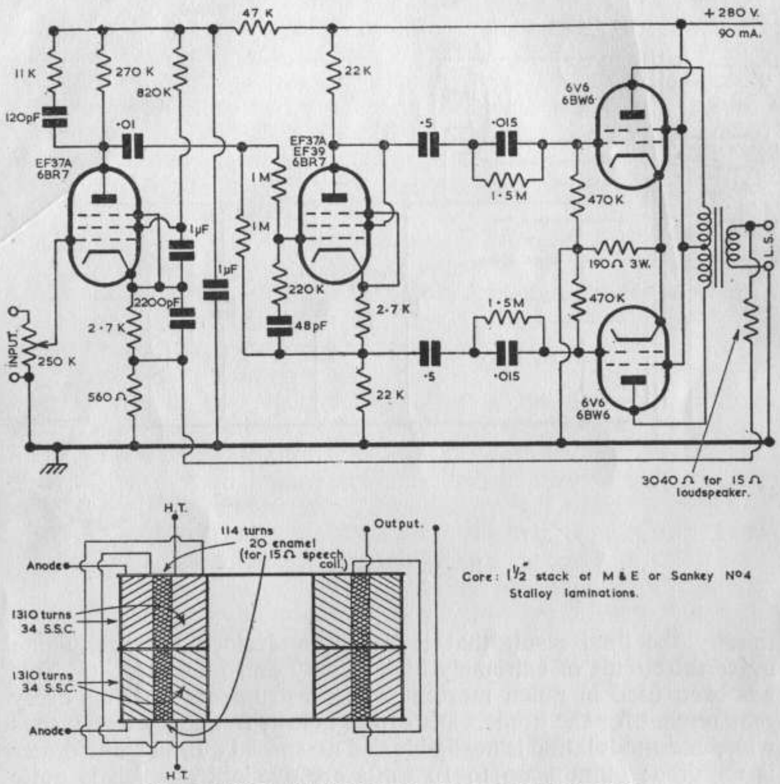


FIG. 5. MILLER AMPLIFIER AND OUTPUT TRANSFORMER

frequencies is limited, so that for larger outputs at very low notes a 12″ cone is to be preferred. It has been found to be all right up to six watts, and a 12″ cone to about 12 watts, at 32c/s. There is a choice of several of the larger units on the market.

Observe that if very low notes are being reproduced, the resistance of the leads from amplifier to loudspeaker is of great importance. They should not exceed 40ft. in length and a heavy cable such as 15amp twin flex should be used. In fact, the heavier the wire the better.

Naturally, the constructor can use any other high-quality amplifier and loudspeaker which may be to hand, including the pick-up input of a really good radio set; but for those starting from scratch, the circuit of Fig. 5 is, in the opinion of the author, by far the least costly and the most satisfactory arrangement.

2

AN INFINITELY-VARIABLE PITCH GENERATOR

PRIOR to the last war, a very simple and ingenius musical instrument called the *Trautonium* was developed in Germany. The especial merit of this device was that the tuning intervals were not exactly fixed, so that gliding tones and sub-divisions of the tempered semitone scale were possible. The instrument is again in production, and in fact concerts have been given using groups of four to 10 Trautoniums either alone or with an orchestra.

The tones available are numerous, and the keying device is so constructed that a note sign may be attached opposite the proper part of this element to produce that definite note. Thus, anyone can play the instrument in the ordinary way, as well as obtain many novel gliding tone effects; compare the Hawaiian guitar. It can be noted that the tuning element might also be a rotary potentiometer, and if this has a logarithmic construction, a scale attached can be calibrated in angular degrees per note.

A novel and useful way of employing this instrument is to make up 2, 3 or 4, each played by a different person, so that the effect is that of, say, a quartet. We require a triode gas-tube for the generator, and since this does not have to stop oscillating (or rather conducting), any of the smaller British thyratrons, such as the GT1C, will serve admirably.

The circuit is in Fig. 6 and this has been evolved from the trautonium with a superior method of keying. In the original instrument, a carbon microphone button was placed under the variable resistance strip, so that pressure on the strip compressed the button. Current then passed to the loudspeaker, causing it to sound. On releasing the resistor, springs made it lift, allowing the button to open, and the very high resistance thus placed in series with the loudspeaker coil prevented it from speaking. However, owing to the difficulties in obtaining suitable carbon buttons and the rather precise method of mounting required, we have introduced a resistance-capacitance network which performs the same function by the simple depression of a switch or push-button. Also, we have revised the somewhat arbitrary tone filters so that much more musical tones are formed.

If we look at Fig. 6 we see a gas-tube of the thyratron type having a fixed tuning capacitor of 0·1mfd and a variable tuning resistor of 1 megohm. There is also a fine tuning resistor of 20,000 ohms in the grid bias circuit and the part of the circuit which suppresses the key clicks consists of the 510,000 and 1,300,000 ohms resistors.

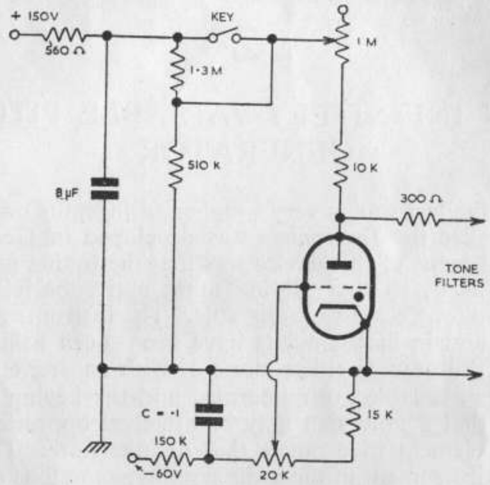


FIG. 6. GAS-TUBE GENERATOR

The only circuit element which is unusual is the 60V grid bias battery; but, since the drain on this is negligible, the life can be expected to be about two years. It will already have been noticed that many gas-tube circuits require a negative bias supply.

A most important feature of this and other gas-tube circuits is the current limiting resistor attached directly to the anode of the thyratron. Without such a resistor, the tube would pass almost unlimited current once it had ignited, leading to its rapid destruction. There is another reason for including this resistor which is that in conjunction with the 1 megohm variable resistor it fixes the range of pitch possible with C = 0·1mfd. The coverage in notes is equal to three octaves.

Another interesting feature is that by moving the tuning contact about the mean position for any particular note, a *vibrato* effect of any desired kind can be produced. Thus, a separate oscillator is not required. Of course, practice is necessary to obtain the best effect—quite a lot of practice. But, aided by the tone filters illustrated in Fig. 7 many delightful musical effects are possible. The tone filters are each intended to cover a limited range and not to be combined. If more mixed tones are required, then reference should be made to the overlapping resonant filters already described in Chapter 7.

No especial care is needed to lay out this circuit but in order to get the keying quite free from clicks or thumps, the voltages specified should be accurately set. The h.t. supply must be stabilized, and here one VR150 gas-tube will be exactly right for the main anode

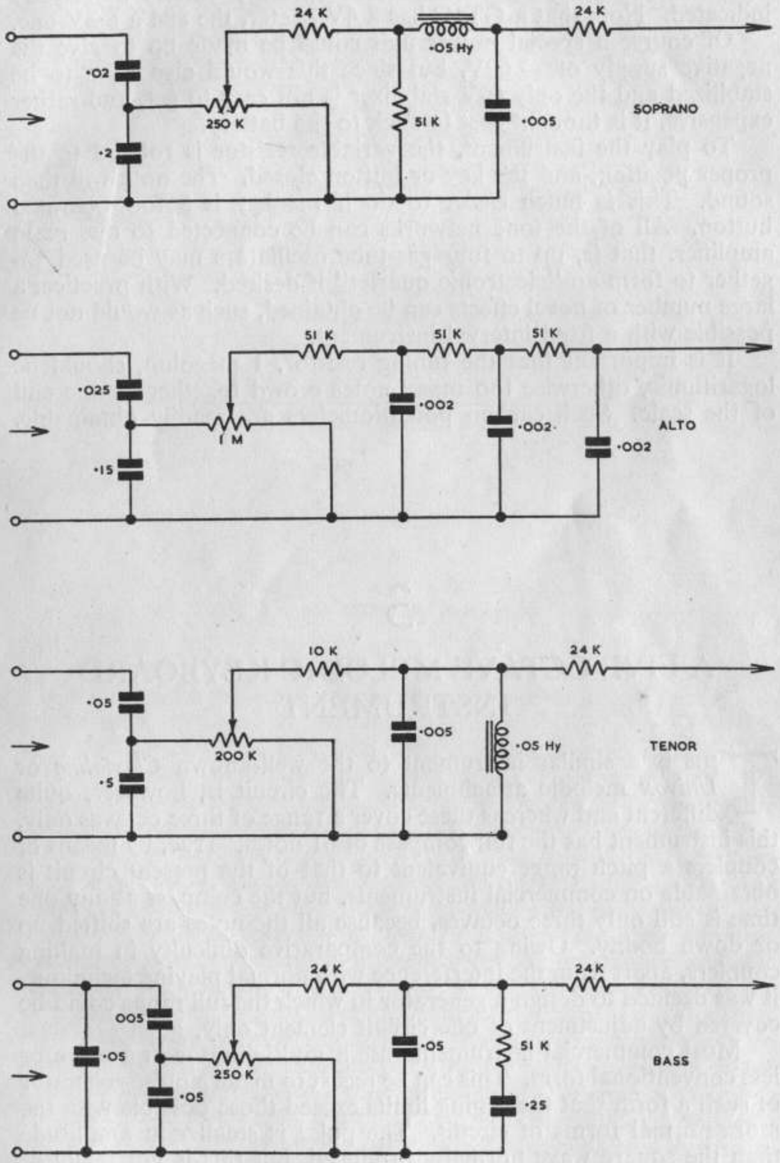


FIG. 7. TONE FILTERS FOR FIG. 6

feed, the — 60V being obtained from the dry battery as already indicated. Note that a GT1C has a 4V heater, the 884 a 6·3V one.

Of course a special power unit could be made up to give the negative supply of — 60V, but since this would also have to be stabilized and the only 60V stabilizer is not easy to get, and rather expensive, it is thought best to stick to the battery.

To play the instrument, the variable resistor is rotated to the proper position, and the key or button closed. The note will then sound. This is much easier to do if the key is a foot-operated button. All of the tone networks can be connected to one main amplifier, that is, up to four gas-tube oscillators may be used together to form an "electronic quartet" if desired. With practice, a large number of novel effects can be obtained, such as would not be possible with a fixed interval instrument.

It is important that the tuning resistor, 1 megohm, should be logarithmic, otherwise too many notes crowd together at one end of the scale. Such carbon potentiometers are readily obtainable.

3

A FIVE OCTAVE MELODIC KEYBOARD INSTRUMENT

THIS is a similar instrument to the well-known *Clavioline* or *Univox* melodic attachments. The circuit is, however, quite different and whereas these cover a range of three octaves only, this instrument has the full compass of 61 notes. True, by means of couplers a pitch range equivalent to that of the present circuit is obtainable on commercial instruments, but the compass at any one time is still only three octaves, because all the notes are shifted up or down bodily. Owing to the comparative difficulty in making couplers, apart from the interference with normal playing technique, it was decided to design a generator in which the full range could be covered by adjustment of one circuit element only.

Most commercial instruments use a multivibrator in a more or less conventional form. This can be recast to make a pulse generator of such a form that the tuning limits exceed those possible with the more normal forms of circuit. The pulse is smaller in amplitude than the square wave normally produced, but this is not really of any account since, if the tone-forming circuits are properly applied, a single stage of amplification will be ample to give the shaped pulse

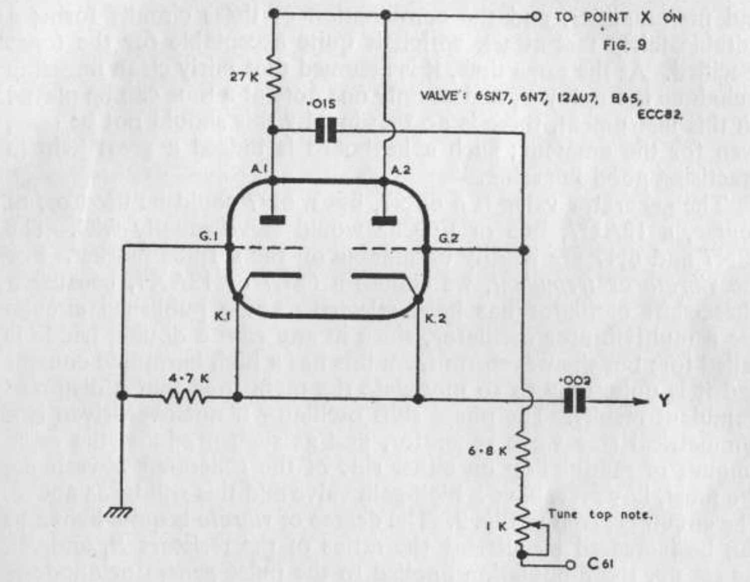


FIG. 8. PULSE GENERATOR

a usable value. Actually, the harmonic content of this kind of pulse is rather more useful for tone-forming than the usual type of wave generated.

A little research produced the very simple generator of Fig. 8. Not only are there few circuit elements, but the amplitude of the pulse appearing at the cathodes is fairly constant over our required range, namely 65 to 2093c/s, which is, of course, an advantage. A further advantage is that a pulse of this shape will trip a frequency divider, and although one is not fitted on this unit, the circuit is given later in the book. Such a divider will enable either lower pedal notes to be formed, or allow of a suboctave being simultaneously played; in this case, different tone colours can be applied to the filters if desired.

Suitable values for the components are indicated, and it will be seen that the normal frequency is that of the top note, C 61, 2093·004c/s. This is accurately set by the variable resistor of 1,000 ohms, which spreads out the tuning nicely so that it is not too critical. In the event of the tuning capacitor of 0·015mfd being out of tolerance, it is a simple matter to alter the 6·8K resistor leading to the variable tuner so that the correct pitch lies near the middle position of the rheostat.

It will be noted that no special attack circuit is shown for this unit; this is because it is integrated with the tone forming circuits and pre-amplifier, and the combination of these circuits forms a suitable fairly fast attack which is quite acceptable for the tones specified. At the same time, it is assumed that fairly clean fingering technique is employed, and as only one note at a time can be played on this instrument, there is no reason why this should not be easy, even for the amateur; such a keyboard is indeed a great help in practising good fingering.

The generator valve is a 6SN7, but a 6N7 could be used or, of course, a 12AU7, B65 or ECC82 would serve equally well. The 6SN7 and 6N7 are readily obtainable on the surplus market. For the *vibrato* or *tremulant*, we choose a 6SL7 or 12AX7, because a phase-shift oscillator has been selected. Some published circuits use a multivibrator oscillator, since in any case a double triode is called for; but the waveform from this has a high harmonic content and it is quite easy to so modulate the main tone that a distorted tremulant results. The phase shift oscillator if not overdriven is a symmetrical sine wave generator, and as such produces the same amount of modulation on either side of the generated waveshape. We must, however, have a high-gain valve and this will be as above. The circuit is given in Fig. 9. The degree of *vibrato* is quite light and can be increased by altering the ratios of the resistors R_1 and R_2. As set up, the modulation applied to the pulse generator anode is approximately one-fiftieth of the swing of A_2. To switch this *vibrato* circuit off it is only necessary to close the *vibrato* switch as shown.

Some instruments interpose their tone-forming networks between the generator and the amplifier, but since in this case we want them to assist in attack control we feed directly from the 0·002mfd capacitor on the generator cathodes into the grid of the 6BA6 amplifier. An EF50 or EF36 valve will also be suitable here, or a 6SJ7. This amplifier requires very few components and the signal outlet comes direct from the 0·01 capacitor to the tone-forming circuits.

In this instrument it has been thought best to provide fixed imitative tonecolours rather than a series of harmonic switches to allow of arbitrary tone-forming. At the same time, the tone filter network is split in such a way that certain stops can be combined, in which case their tones add. Examination of the published details of the simpler tone-forming circuits shows that these are usually connected in shunt between the output signal line and earth. Some designs, however, use series networks; in this case it is easier to equalize the loading if different stops are combined. Since we have a dual case here, we use a part of both circuits and a series-parallel network as in Fig. 10.

When the *Horn* switch is operated, all switches marked A make connection between the lower contact and the arm.

When the *Kinura* switch is operated, all switches marked B make connection between the lower contact and the arm.

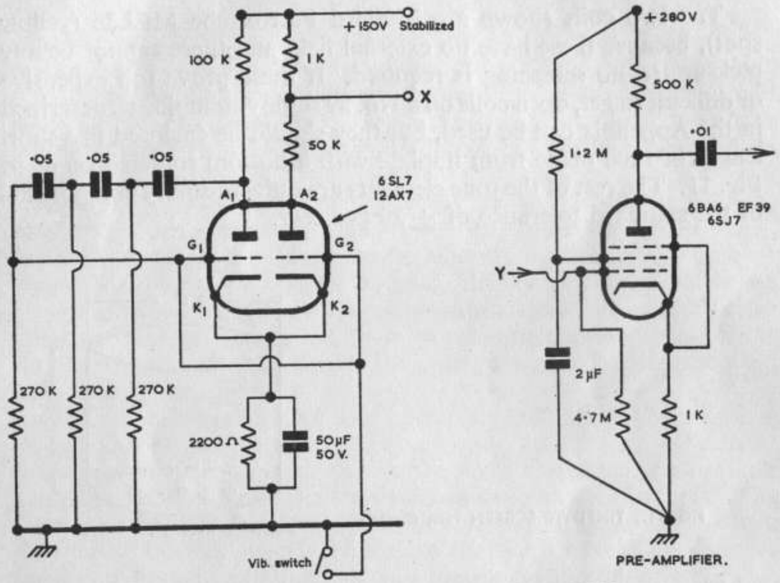


FIG. 9. VIBRATO GENERATOR AND PRE-AMPLIFIER

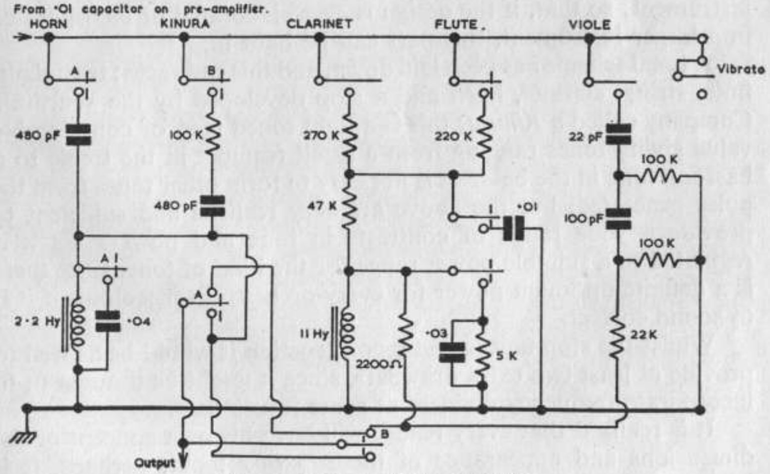


FIG. 10. TONE FORMING CIRCUITS

The two coils shown are Mullard Ferroxcube MEL26 (yellow spot), because these have no external field and there cannot be any pick-up, so no screening is required. If these prove too expensive or difficult to get, open coils on a No. 39 stalloy stamping as described in the Appendix can be used, but they should be enclosed in a short length of tube made from tinplate with a bottom soldered on as in Fig. 11. The rest of the tone elements are quite ordinary components of the standard tolerance of $\pm$ 20 per cent.

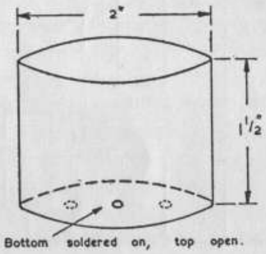


FIG. 11. TINPLATE SCREEN FOR CHOKES

Now we come to the stop control mechanism. It will be obvious that this can be done in a variety of ways, and many such have been published; but experience has shown that simple wires and contacts which do not wipe sufficiently are a constant source of trouble. It is, therefore, much better to make up a more difficult kind of assembly which will not only last, but can be adapted to any kind of keyboard instrument; so that, if the design is ever elaborated or incorporated in a larger instrument, this part can be built in.

A tonal scheme has been laid down, and this embraces: tremulant, flute, string, clarinet, horn and a stop developed by the Wurlitzer Company called a *Kinura;* this is a tight toned reed of considerable value giving tones ranging from a small trumpet in the treble to a bassoon tone in the bass. It is not easy to form other tones from the pulse generated, but the above are very realistic and sufficient to provide a wide range of contrasts in tone and power. Each is regulated to a suitable power range for the kind of tone, since there is a definite optimum power for every orchestral tonecolour, if it is to sound correct.

Whilst the stop unit is under construction it would be as well to provide at least two extra drawbars, since it might be thought fit to incorporate frequency dividers at some future date.

It is realized that every reader will have his own concept of the dimensions and appearance of these "stops"; but, perhaps, it is best to make them of the standards laid down for regular modern

pipe organs, since they are just as nice looking and very easy to manipulate. Accordingly we allow 8″ length for the eight positions required (six active and two prepared for). These will need a base of ¼″ thick bakelite (or perspex, often more readily obtainable and just as good), 10″ long by 7″ deep. We also need two strips of the same thickness each 1½″ high by 10″ long, but hardwood would do here.

The stop drawbars are made from ¼″ by ¼″ bakelite or perspex, easily cut from sheet with a hacksaw. Eight are required, each 8″ long. The edges should be made smooth by filing in a vice or vigorous rubbing on a sheet of fairly fine emery cloth. Now we require 24 contact springs and these should have silver alloy tips; they are readily obtainable from surplus telephone type relays, very cheap at many dealers. Two relays with 12 spring sets on each will do the lot.

Fig. 12 shows most of the construction. The 1½″ strips are slotted as shown to let the drawbars slide and a strip of billiard cloth or thin felt is glued on continuously to reduce friction and make the action regular, as we shall not have any spring bias. The slots must be carefully filed until, with the felt in position, the bars slide easily but not loosely. Some of the relay springs are bent as shown so that the contact tips rub lightly on the baseplate. This keeps them clean and prevents oxidization. The travel required is ¼″ from the "off" to the "on" positions.

The tremulant needs one travelling spring; the flute three; the viola one; clarinet two; the horn two; and the kinura two. The diagram, Fig. 13, shows how some contacts are on and others off in the back position, that is, with the stop "off". Each spring is secured with a ½″ by 4BA screw tapped through the drawbar. A 1½″ by 6BA screw is tapped into the baseplate adjacent to each 4BA screw in its "off" position and a little loop connection is made between the two by a strand of thin copper wire extracted from flex.

The contact pieces on the base are cut from the other end of the springs used for the travelling parts, and must be radiused with a fine file on the side which the contact will meet; some, as will be seen, require radiusing on opposite faces because they are change-over switches. If a 4BA by ¼″ screw is used to attach each fixed contact, the large holes in the pieces will allow them to be moved enough to get a very exact setting for the "on" and "off" positions. Fig. 14 should be consulted for the disposition of the tone-forming elements; this is marked to correspond with Fig. 10.

The part of this assembly which holds the stop key facings themselves is quite simple. The whole assembly is carried on aluminium or brass brackets screwed thereto and these are drilled to take a piece of screwed brass rod by 4BA. Eight pieces of hardwood or bakelite are cut as in Fig. 12 and drilled with a 4BA clearing drill (No. 37). Each is again drilled near the top end with a

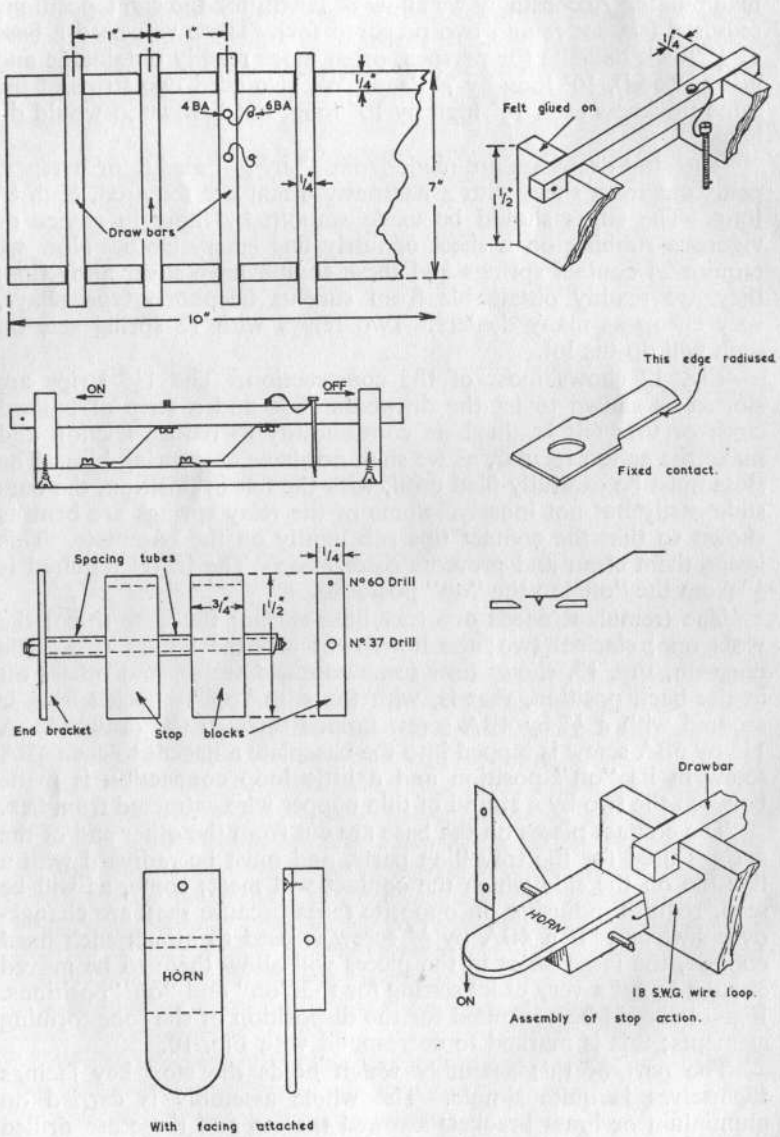


FIG. 12. STOP CONTROL MECHANISM

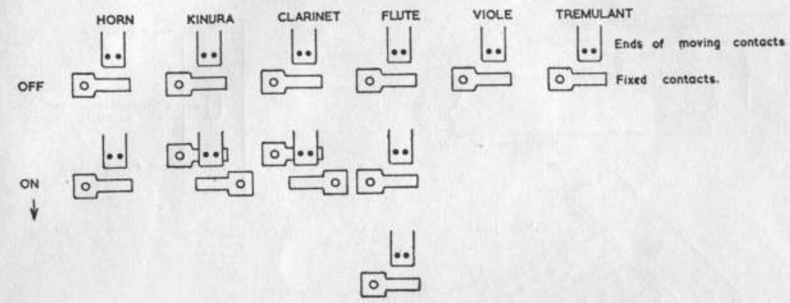


FIG. 13. STOP CONTACT DISPOSITION

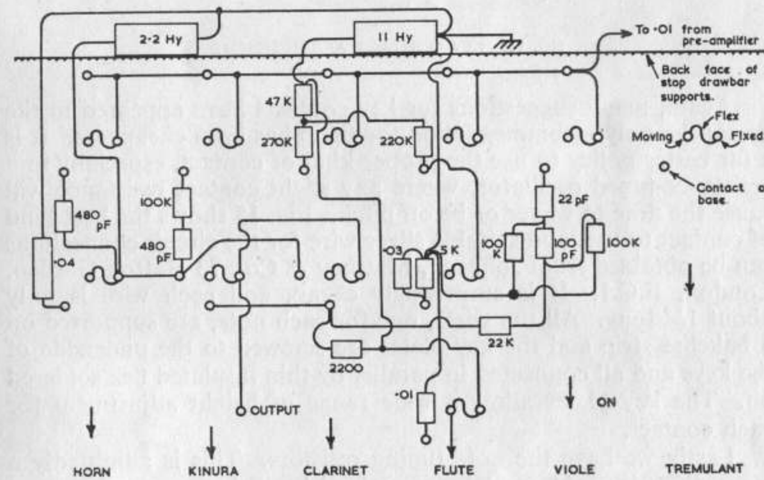


FIG. 14. ARRANGEMENT OF TONE ELEMENTS

No. 60 drill and the drawbars are also so drilled, so that if stiff 18 s.w.g. wire is bent into a loop, it can be passed through the stop mount and the bar end, thus coupling them together. A suitably engraved facing is then cemented or screwed to the block, and on depression of this, the bar is pulled forward into the contact position. To prevent it from rising out of the slots, strips of $\frac{1}{4}''$ by $\frac{1}{4}''$ hardwood or bakelite are screwed to the top face of the bar guides, and to some extent these can be used to alter the pressure on the bars, so controlling the force required to move the stops. The blocks are spaced from each other by small pieces of thin brass tube threaded onto the long 4BA support rod, which in its turn is secured at each end by a 4BA nut outside each end bracket.

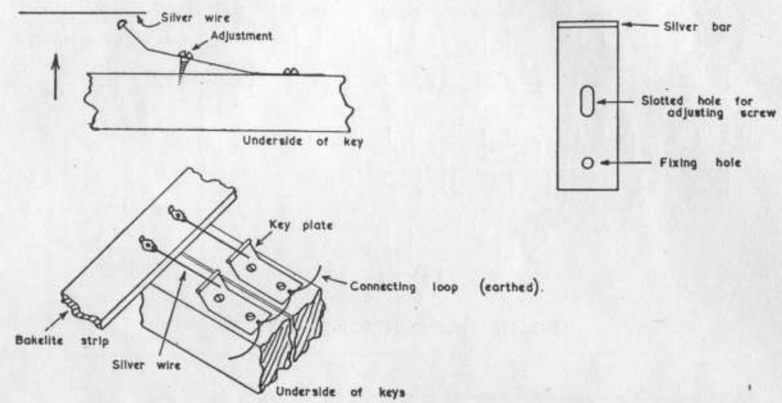


FIG. 15. KEY CONTACT ARRANGEMENT

Again, many suggestions for key contacts have appeared in the press; the only recommendation for these has been cheapness. It is a far better policy to use the proper kind of contact, especially in a resistance-tuned oscillator, where any slight contact resistance will cause the note to waver or be off pitch. Fig. 15 shows the best kind of contact to use, and suitable silver wire for the circuit connections can be obtained from Johnson, Matthey & Co., 73 Hatton Garden, London, E.C.1. It is surprisingly cheap, and each wire is only about $1\frac{1}{4}''$ long. All the wires, one for each note, are supported on a bakelite strip and the key plates are screwed to the underside of the keys and all connected in parallel by thin insulated flex soldered on. The key plates allow a wide range of height adjustment for each contact.

Lastly we have the note tuning resistors. This is admittedly a more difficult problem. We can only risk a 0·1 per cent. tolerance on these, whilst the best available commercially is 5 per cent. Therefore a selection must be made, or the more expensive Egen type 104 variable resistors used. Probably a local radio dealer could be interested in this project, and help by allowing a choice from his stock; however, it will be found that for many notes, a standard value will be exactly right, and experimental experience shows that about 50 per cent. of the notes fall into this category; on the other hand, some notes always prove "difficult", and it may be necessary to parallel one or two extra ones to get the tuning dead right. Of course, cheap parcels of assorted resistors are still available at very low prices from dealers in radio gear.

For the anode load resistors shown, Fig. 16 is a table giving the correct tuning resistor values. Tuning is best done against a piano

NOTE	No.	VALUE		NOTE	No.	VALUE	
C	61	1 K Variable resistor		D♯	28	2800	OHMS
B	60	210	OHMS	D	27	3100	"
A♯	59	250	"	C♯	26	3200	"
A	58	280	"	C	25	3410	"
G♯	57	310	"	B	24	3700	"
G	56	360	"	A♯	23	3900	"
F♯	55	400	"	A	22	4170	"
F	54	420	"	G♯	21	4400	"
E	53	450	"	G	20	4600	"
D♯	52	480	"	F♯	19	4820	"
D	51	500	"	F	18	5150	"
C♯	50	520	"	E	17	5390	"
C	49	550	"	D♯	16	5600	"
B	48	580	"	D	15	6200	"
A♯	47	600	"	C♯	14	6400	"
A	46	650	"	C	13	6820	"
G♯	45	700	"	B	12	7400	"
G	44	750	"	A♯	11	7800	"
F♯	43	800	"	A	10	8340	"
F	42	875	"	G♯	9	8800	"
E	41	920	"	G	8	9200	"
D♯	40	1000	"	F♯	7	9640	"
D	39	1100	"	F	6	10300	"
C♯	38	1200	"	E	5	10780	"
C	37	1300	"	D♯	4	11200	"
B	36	1450	"	D	3	12000	"
A♯	35	1600	"	C♯	2	12740	"
A	34	1800	"	C	1	13560	"
G♯	33	1970	"				
G	32	2100	"				
F♯	31	2250	"				
F	30	2400	"				
E	29	2650	"				

FIG. 16. TABLE OF RESISTOR VALUES FOR TUNING GENERATOR

and the top note should be referred to quite often to make sure it is still on pitch; sometimes, when valves are new, they take a long time to settle down to exact pitch. Note that the top pitch is fixed by the 1K variable resistor, so that we start with B60, and work downwards.

It will be understood that if, on the score of expense or for any other reason, it is not required to cover the whole five octaves at once, a start can be made on, say, the first three; but always working down from the top note. The remainder can always be added at any time.

No expression control is shown for this unit, since it must always work into an amplifier such as that of Fig. 5, which has its own volume control; and it must not be forgotten that the h.t. supply has to come from the + 150V line of Fig. 4. The load is roughly 10m/A. A stop unit similar to that described in this section can be used for any of the other musical instruments described in this book.

4

A GAS-TUBE KEYBOARD INSTRUMENT WITH FREQUENCY DIVIDER

THE advantage of a generator using gas-tubes is that a practically perfect sawtooth wave can readily be obtained. From this, a very high degree of tonal realism can be extracted[1]. It also has the advantage that, as a frequency divider, such a circuit locks perfectly with a frequency multiple and will, moreover, remain locked over four or five notes, thus simplifying the tuning and giving the advantage of being able to sound two octaves of any one note simultaneously without shortening the overall range; and, in this case, with different tone-colours for each pitch if desired. This feature is not to be found in any commercial melodic instrument.

There are not many suitable gas-tubes on the British market, and the American 884 is not readily obtainable; but experiments have proved that the 2D21 (Standard Telephones) strapped as a triode, is satisfactory and is in current production. Only two are required and although a range of only three octaves is proposed, there is no real limit to this and the full five or even six octaves can easily be covered if the tuning capacitors are sufficiently extended. This is left to the discretion of the constructor, since, having covered three octaves, he will see at once how to proceed to extend the compass.

The circuit is shown in Fig. 17. It can be seen that there are two gas-tubes; one is the oscillator and the other is the divider; each is

[1]Jeans *Science and Music*, C.U.P.

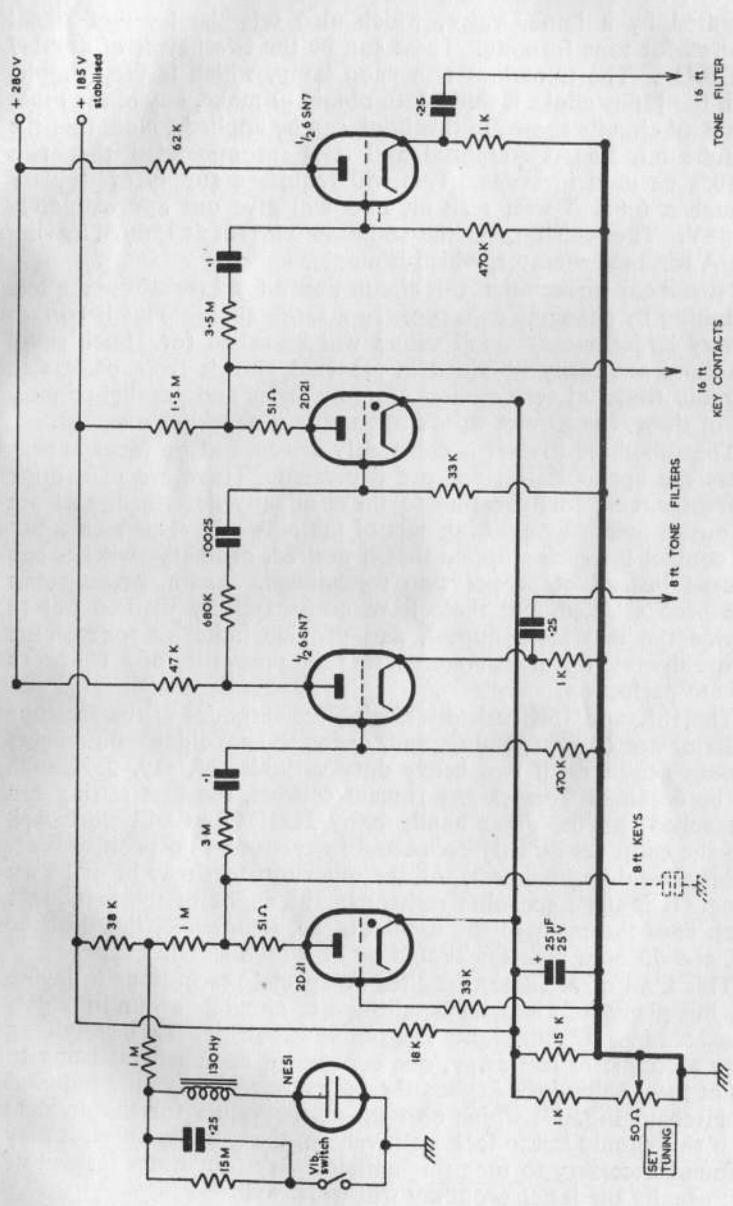


FIG. 17. GAS-TUBE GENERATOR AND DIVIDER

separated by a buffer valve, which also sets the level of signal required for tone forming. These can be the two halves of a 6SN7 or 12AU7. The tremulant is a neon lamp, which is very simple, but if the 130hy choke is difficult to obtain or make, any of the other tremulant circuits shown in this book can be applied. Note that the gas-tube h.t. line is stabilized and it is recommended that two VR105s be used in series. This will require a supply of + 350V through a 6·8K 5 watt resistor, and will give out approximately + 185V. The resistor sets the stabilizer current at 15m/A, leaving 15m/A for the generator, which is ample.

Now it can be seen that this circuit uses a fixed resistor and alters the tuning by changing capacitors in a series chain. This is so that no very large or very small values will be called for. Such small capacitors are easily obtained in assorted parcels from dealers in the radio trade, at very modest cost; by series and parallel connection of these, the correct values for tuning is quickly arrived at.

The suboctave divider is constantly driven, but no tones appear unless the appropriate stops are depressed. These are of a quite different circuit configuration to those already described, and are put out of action by earthing part of the network. This means but one contact for each stop, so that if desired, ordinary switches can be used instead of proper stop mechanism. Again, preset tones have been selected, but these have been carefully worked out to provide the maximum appeal, and provide imitative tonecolours of considerable fidelity, demonstrating the properties of a sawtooth wave to perfection.

The 18K and 15K resistors biasing the cathodes of the gas-tube oscillator are 10 watts rating, and, owing to unavoidable differences between gas-tubes, if two heavy duty variables of, say, 25K each can be obtained from ex-government sources, the best setting can be reached; on the other hand, many 2D21 tubes will work well with the cathodes directly connected to earth and no positive bias; so this should be tried first. All the other resistors may be of 1 watt rating. It is the 1 megohm resistor in the anode of the first 2D21 which fixes the pitch of the oscillator, so, if possible, this and the 38K and 75 ohm resistors should be of a high stability type.

This kind of oscillator requires no special precautions in laying out, but plenty of air must be allowed to circulate around the gas-tubes as they get rather hot. The tuning capacitors can be anything up to a couple of feet away, one convenient arrangement being to mount them behind the keyboard on tag strips. The values required are given in Fig. 18, which also shows the values for the divider; but if this should fail to lock positively on the extreme notes, it may be found necessary to tune this unit to every four notes instead of five; usually the latter economy will work well.

The tone filter circuits are shown in Fig. 19 and are interesting; they are of the series-parallel type, and the point at which they are

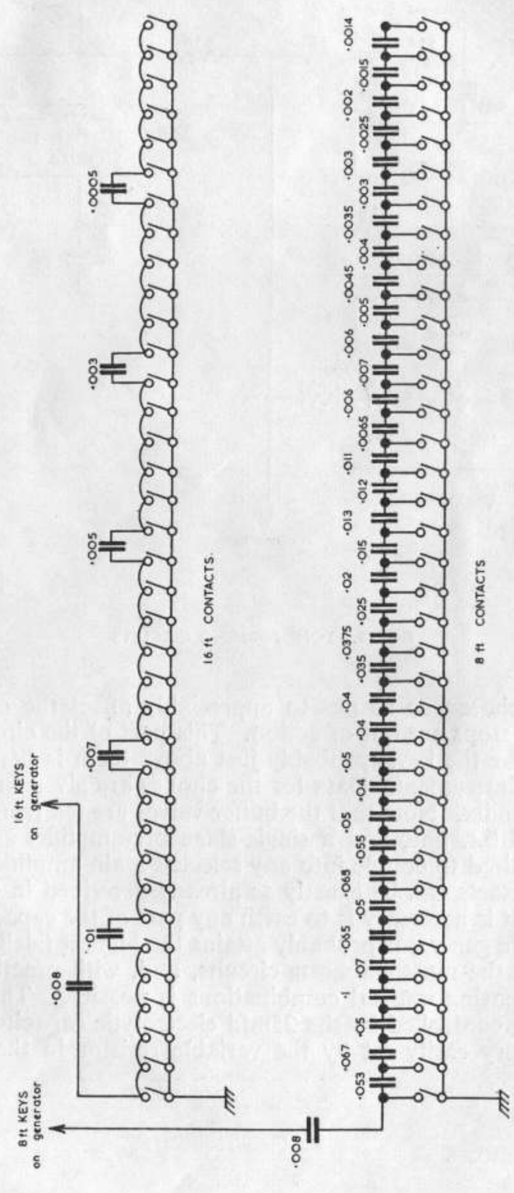


FIG. 18. TUNING CAPACITORS

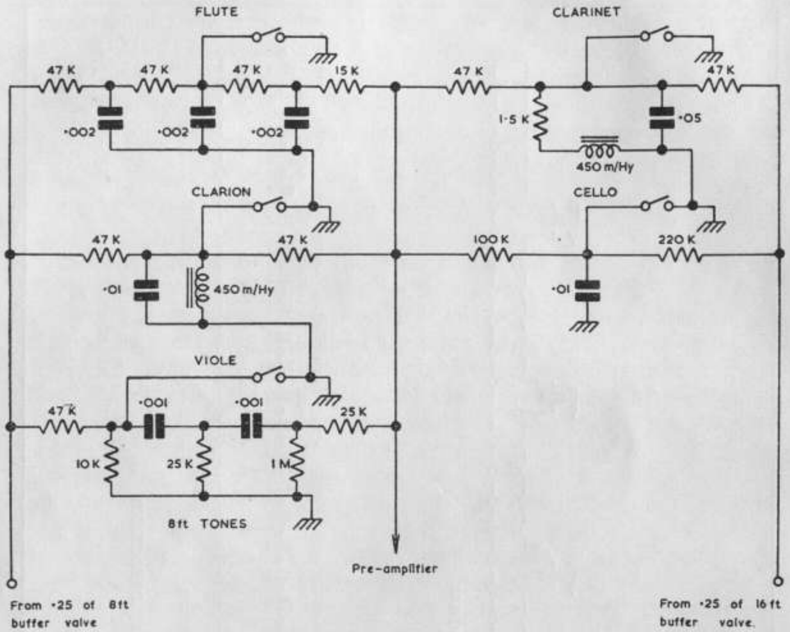


FIG. 19. TONE-FORMING CIRCUITS

earthed is chosen so as not to appreciably affect the other tones when some stops are out of action. This part of the circuit should be fairly near the keys, probably just above them is best as in the five octave instrument. Data for the chokes are given in the tables in the Appendix. Note that the buffer valves are fed from the main unstabilized h.t. line, and a single-stage pre-amplifier as in Fig. 9 will be required to couple into any selected main amplifier.

Key contacts can be exactly as already described in Chapter 2, since all that is necessary is to earth any part of the capacitor stack.

This little generator probably attains the highest fidelity possible except with the most elaborate circuits, and, with practice, a wide range of pleasing musical combinations is possible. The attack is good, being controlled by the 25mfd electrolytic capacitor, and the tuning is very easily set by the variable resistor in the oscillator circuit.

5

AN ELECTRIC ACCORDION

(By pressing the appropriate button, a complete and ready-made chord sounds in any selected key)

UNDOUBTEDLY the most difficult part of amateur music is the "left hand". This implies the provision of suitable chords and harmonies to accompany a tune or melody, though, of course, the harmonies are often shared between both hands.

This instrument is a little more complicated than the others described in this book, yet it only requires six valves and six coils: the complication comes in the switching. However, it solves a major problem, for, even if the amateur can play in some keys, it is almost certain that he fights shy of others. But now it is as easy to play in B as in C.

The principle is that a desired chord is selected by pressing the appropriate button. A bar is then depressed by the wrist, when that chord sounds. It is as easy as that. Firstly, let us examine the musical side. There are 96 buttons giving eight different chords in any one key. Some of these are in the minor of the key. A diagram of the available buttons is given in Fig. 20. To make it easier to understand, all the chords likely to be required for the key of C are shown in a frame. The actual composition of the chords, in the notes supplied by the oscillators, is given in Fig. 21. A circuit of one oscillator is given in Fig. 22 (they are all the same). It is possible to obtain all the required notes from only six oscillators because no chord needs more than five notes and no chord needs two immediately adjacent notes. Thus the oscillators can easily be retuned.

The control bar could, of course, be a foot pedal if required; it removes a paralysing bias from the 6J5 control valve and allows the note to sound through a delay network. It can be seen that no skill whatever is required to play really acceptable harmonies, equal to those of the trained musician. By means of a foot-operated volume control on the amplifier, the rapid dynamic changes of the accordion can be imitated.

In making this instrument we depart from the usual rule of laying out the parts in any convenient way on any convenient chassis. This is largely because we want to support the chord button mechanism off the same chassis and it should therefore be 14″ by 10″ by 3″. The six coils will probably present the most difficult part of the construction and should be put in hand first. They are fortunately all the same and can be made with the aid of a hand drill held in a vice. The frequency range of these coils is 170c/s to 330c/s.

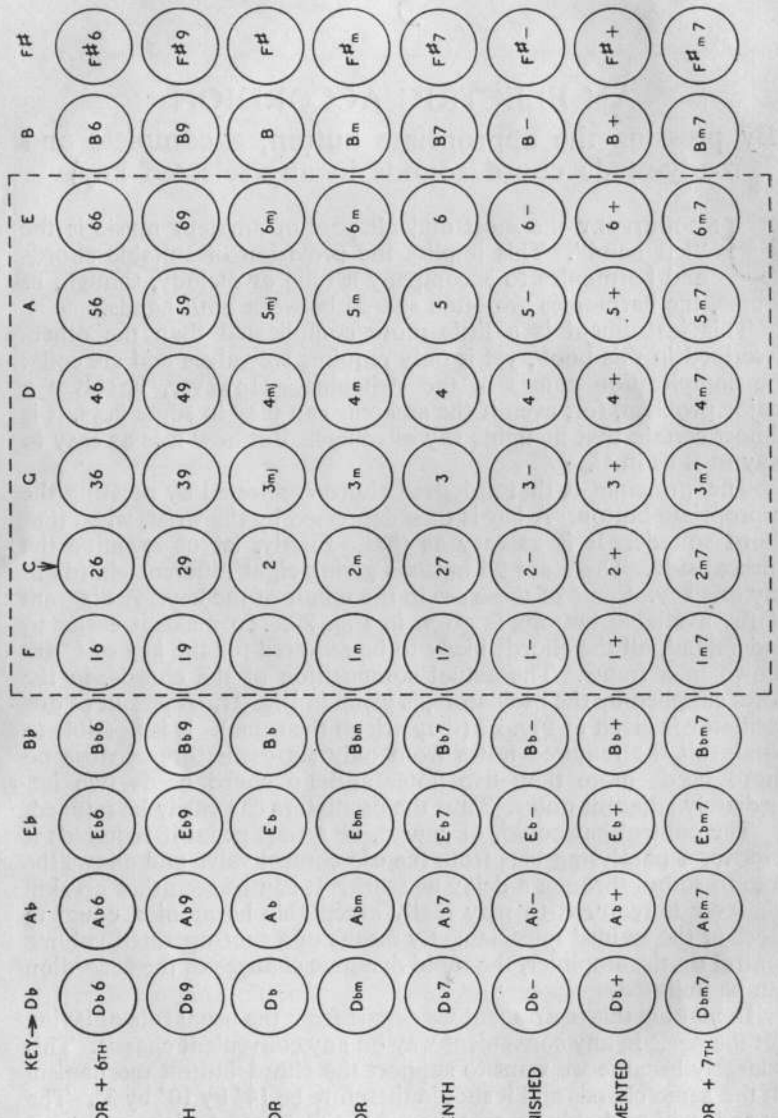


FIG. 20. LAYOUT OF CHORD BUTTONS

BUTTON	NOTES IN CHORD				BUTTON	NOTES IN CHORD			
KEY $G^{\#}$					KEY B				
Ab6	F^{K}	$G^{\#}$	C	$D^{\#K}$	B6	$F^{\#}$	$G^{\#}$	B^{K}	$D^{\#K}$
Ab9	$F^{\#}$	$A^{\#}$	C	$D^{\#K}$	B9	$F^{\#}$	A^{K}	$C^{\#K}$	$D^{\#K}$
Abmj	$G^{\#}$	C	$D^{\#K}$		Bmj	$F^{\#}$	B^{K}	$D^{\#K}$	
Abm	$G^{\#}$	B^{K}	$D^{\#K}$		Bm	$F^{\#}$	B^{K}	D	
Ab7	$F^{\#}$	$G^{\#}$	C	$D^{\#K}$	B7	$F^{\#}$	A^{K}	B^{K}	$D^{\#K}$
Ab–	$F^{\#}$	$G^{\#}$	B^{K}	D	B–	F^{K}	$G^{\#}$	B^{K}	D
Ab+	$G^{\#}$	C	E		B+	G^{K}	B^{K}	$D^{\#K}$	
Abm7	$F^{\#}$	$G^{\#}$	B^{K}	$D^{\#K}$	Bm7	$F^{\#}$	A^{K}	B^{K}	D
KEY A					KEY C				
A6	$F^{\#}$	A^{K}	$C^{\#}$	E	C6	G^{K}	A^{K}	C	E
A9	G	B	$C^{\#K}$	E	C9	G^{K}	$A^{\#}$	D	E
Amj	A^{K}	$C^{\#K}$	E		Cmj	G^{K}	C	E	
Am	A^{K}	C	E		Cm	G^{K}	C	$D^{\#K}$	
A7	G^{K}	A^{K}	$C^{\#K}$	E	C7	G^{K}	$A^{\#}$	C	E
A–	$F^{\#}$	A^{K}	C	$D^{\#K}$	C–	$F^{\#}$	A^{K}	C	$D^{\#K}$
A+	F^{K}	A^{K}	$C^{\#K}$		C+	$G^{\#}$	C	E	
Am7	G^{K}	A^{K}	C	E	Cm7	G^{K}	$A^{\#}$	C	$D^{\#K}$
KEY $A^{\#}$					KEY $C^{\#}$				
Bb6	F^{K}	G^{K}	$A^{\#}$	D	Db6	F^{K}	$G^{\#}$	$A^{\#}$	$C^{\#K}$
Bb9	F^{K}	$G^{\#}$	C	D	Db9	F^{K}	$G^{\#}$	B^{K}	$D^{\#K}$
Bbmj	F^{K}	$A^{\#}$	D		Dbmj	F^{K}	$G^{\#}$	$C^{\#K}$	
Bbm	F^{K}	$A^{\#}$	$C^{\#}$		Dbm	$G^{\#}$	$C^{\#K}$	E	
Bb7	F^{K}	$G^{\#}$	$A^{\#}$	D	Db7	F^{K}	$G^{\#}$	B^{K}	$C^{\#K}$
Bb–	G^{K}	$A^{\#}$	$C^{\#K}$	E	Db–	G	$A^{\#}$	$C^{\#K}$	E
Bb+	$F^{\#}$	$A^{\#}$	D		Db+	F^{K}	A^{K}	$C^{\#K}$	
Bbm7	F^{K}	$G^{\#}$	$A^{\#}$	$C^{\#K}$	Dbm7	$G^{\#}$	B^{K}	$C^{\#K}$	E

See text for meaning of "K".

FIG. 21. COMPOSITION OF CHORDS (1)

We shall require 190 laminations Stalloy type 70 and six strips of soft iron or mild steel each $2\frac{1}{4}''$ by $\frac{1}{2}''$ by $\frac{1}{8}''$ thick. For winding, we need nearly a pound of 39 or 40 s.w.g. enamel copper wire.

BUTTON	NOTES IN CHORD				BUTTON	NOTES IN CHORD			
KEY D					KEY F				
D6	$F^{\#}$	A^{K}	B^{K}	D	F6	F	A^{K}	C	D
D9	$F^{\#}$	A^{K}	C	E	F9	G	A^{K}	C	$D^{\#K}$
Dmj	$F^{\#}$	A^{K}	D		Fmj	F	A^{K}	C	
Dm	F	A^{K}	D		Fm	F	$G^{\#}$	C	
D7	$F^{\#}$	A^{K}	C	D	F7	F	A	C	$D^{\#K}$
D–	F^{K}	$G^{\#}$	B^{K}	D	F–	F	$G^{\#}$	B^{K}	D
D+	$F^{\#}$	$A^{\#}$	D		F+	F	A^{K}	$C^{\#K}$	
Dm7	F^{K}	A^{K}	C	D	Fm7	F	$G^{\#}$	C	$D^{\#K}$
KEY D#					KEY F#				
Eb6	G^{K}	$A^{\#}$	C	$D^{\#K}$	F#6	$F^{\#}$	$A^{\#}$	$C^{\#K}$	$D^{\#K}$
Eb9	F^{K}	G^{K}	$A^{\#}$	$C^{\#K}$	F#9	$G^{\#}$	$A^{\#}$	$C^{\#K}$	E
Ebmj	G^{K}	$A^{\#}$	$D^{\#K}$		F#mj	$F^{\#}$	$A^{\#}$	$C^{\#K}$	
Ebm	$F^{\#}$	$A^{\#}$	$D^{\#K}$		F#m	$F^{\#}$	A^{K}	$C^{\#K}$	
Eb7	G^{K}	$A^{\#}$	$C^{\#K}$	$D^{\#K}$	F#7	$F^{\#}$	$A^{\#}$	$C^{\#K}$	E
Eb–	$F^{\#}$	A^{K}	C	$D^{\#K}$	F#–	$F^{\#}$	A^{K}	C	$D^{\#K}$
Eb+	G^{K}	B^{K}	$D^{\#K}$		F#+	$F^{\#}$	$A^{\#}$	D	
Ebm7	$F^{\#}$	$A^{\#}$	$C^{\#K}$	$D^{\#K}$	F#m7	$F^{\#}$	A^{K}	$C^{\#K}$	E
KEY E					KEY G				
E6	$G^{\#}$	B^{K}	$C^{\#K}$	E	G6	G^{K}	B^{K}	D	E
E9	$F^{\#}$	$G^{\#}$	B^{K}	D	G9	F^{K}	A^{K}	B^{K}	D
Emj	$G^{\#}$	B^{K}	E		Gmj	G^{K}	B^{K}	D	
Em	G	B^{K}	E		Gm	G^{K}	$A^{\#}$	D	
E7	$G^{\#}$	B^{K}	D	E	G7	F^{K}	G^{K}	B^{K}	D
E–	G	$A^{\#}$	$C^{\#K}$	E	G–	G^{K}	$A^{\#}$	$C^{\#K}$	E
E+	$G^{\#}$	C	E		G+	G^{K}	B^{K}	$D^{\#K}$	
Em7	G	B^{K}	D	E	Gm7	F^{K}	G^{K}	$A^{\#}$	D

FIG. 21. COMPOSITION OF CHORDS (2)

Fig. 23 shows the wooden formers on which the bobbins are made, together with other details of the bobbins. These are made from card (like a postcard) glued together; notice the strips running through and glued to the end cheeks; these prevent the cheeks from being forced off by the pressure of winding successive layers.

Three small solder tags should be inserted in one end cheek

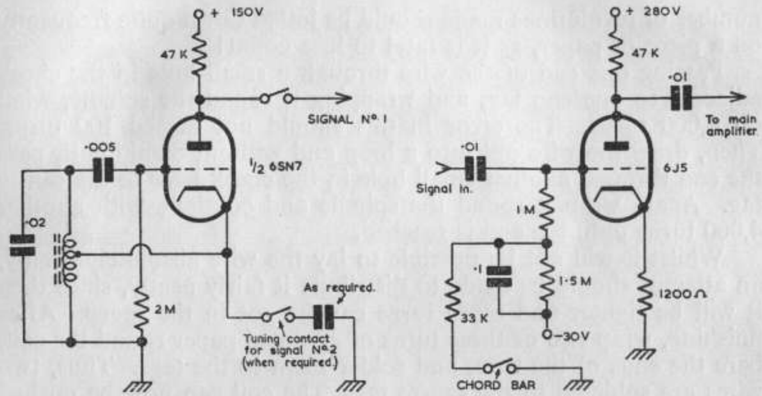


FIG. 22. OSCILLATOR AND CONTROL VALVE

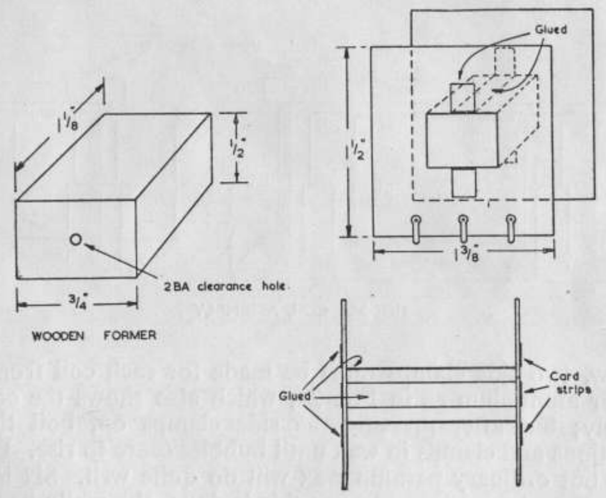


FIG. 23. BOBBIN DETAILS

before winding, and a strip of gummed paper stuck over their backs (inside the cheek) so that the enamel will not be damaged by successive layers rubbing on the bare tags. Two squares of wood are cut to restrain the end cheeks when winding and a 2BA threaded rod is passed through the whole assembly, bolted up and inserted in the jaws of a hand drill held horizontally in a vice. Now for the winding. One can work out the gear ratio of the drill so that each revolution of the handle will mean, say, 4½ turns of wire. The number of revolutions made should be jotted down quite frequently on a piece of paper, as it is fatal to lose count!

Passing one end of the wire through a small hole in the cheek adjacent to one end tag, and wrapping it round the spindle, wind on 4,000 turns. The error in this should not exceed 100 turns. Then, draw the wire out into a loop and without breaking it, pass the end through another small hole in the cheek near to the centre tag. Again wrap it round the spindle and continue with another 4,000 turns until the end is reached.

Whilst it will not be possible to lay the wire absolutely evenly, an attempt should be made to distribute it fairly neatly, since then it will be tighter and more turns can be got in the space. After finishing, wrap two or three turns of gummed paper round the coil, bare the ends of the wire, and solder them to the tags. Thus, two wires are soldered to the centre tag. The coil can now be pushed into the centre limb of a ½″ stack of laminations, *i.e.* 30 or 31 stampings. Try to press in as many as possible, but be very careful not to cut the cardboard centre of the coil.

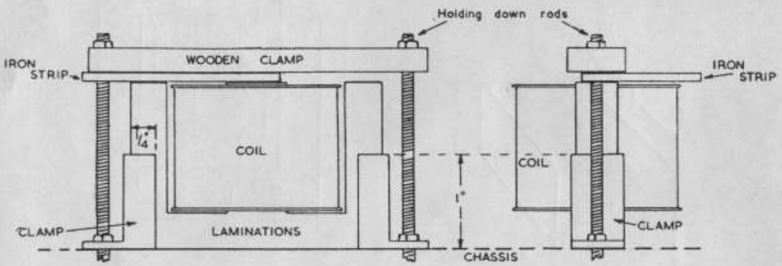


FIG. 24. COIL ASSEMBLY

Now, two side clamps must be made for each coil from scrap brass or aluminium as in Fig. 24, which also shows the complete assembly; but after pressing the side clamps on, boil the coil, laminations and clamps in wax until bubbles cease to rise. Beeswax is best but ordinary paraffin wax will do quite well. Six identical coils have to be made, and once this is done, the really hard work is over!

It can be seen that the iron strips are clamped under the top wood bar by nuts on the holding-down bolts, and it is by these strips that the coil is fine-tuned to a definite pitch after rough tuning by the shunt capacitor. The nuts are loosened and the strip moved about until the pitch is correct. The nuts are then carefully tightened, although this may have to be done more than once in the final tuning.

To refer again to Fig. 22, the circuit of any one oscillator, it will be noticed that one signal is taken from the anode line, and that

is pitch No. 1; by keying the anode line again but, at the same time, inserting a capacitor between the cathode and earth, a second note, pitch No. 2 is formed. Thus, 12 notes are available from the six oscillators, and these, in various combinations selected by the switches, are all that is required to cover all our chords. Note that these oscillators run all the time; but no signal is heard until the chord control bar is pressed, since the amplifier valve is cut off by the excess bias. This greatly simplifies the switching.

Examination of Fig. 25 shows how all the chords are formed

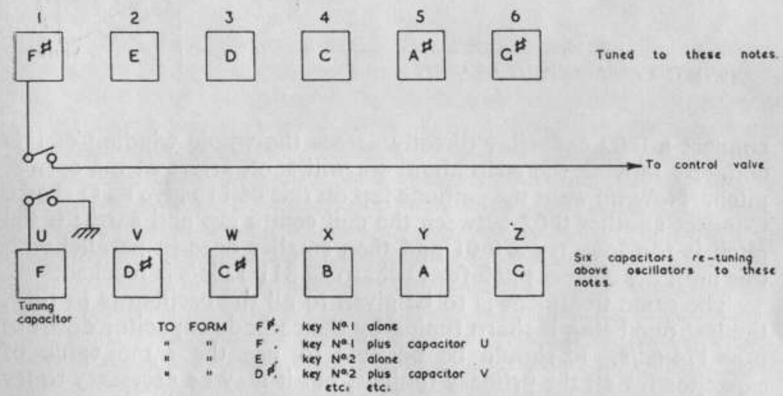


FIG. 25. DERIVATION OF NOTES FROM OSCILLATORS

without ever using the same oscillator twice in any one chord. This looks much more complicated than it really is, and, of course, if the reader decides that he will never want to play in B or F sharp, these or any other switchings could be omitted. Study the chord formation carefully, taking first a key with which one is familiar, such as C or F major, and examining all the chords therein. Each set of eight chords covers virtually every reasonable musical possibility. It might be noted that keying the cathode capacitor into circuit always produces a note *lower* than the primary tuning of that oscillator.

The six coils can be arranged symmetrically on the chassis as in Fig. 26, but it is best for the valves to be at the sides so that heat from them does not reach the coils. Three 6SN7 or 12AU7 are recommended. The circuit elements shown are arranged on any convenient kind of tag strips inside the chassis, and here there is no need for any special layout; there is no interaction or pick-up whatever. We now have to consider the tuning.

Taking the top note first, E = 329·627c/s, we connect this oscillator only through a 0·01 capacitor to any handy amplifier—a radio set will do. Applying a stabilized voltage of + 150 d.c. we

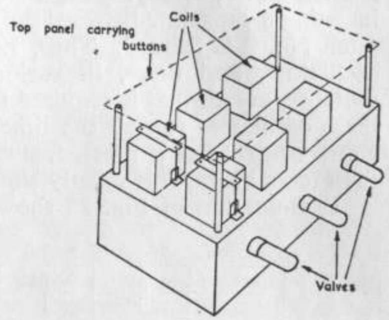


FIG. 26.
SUGGESTED ARRANGEMENT OF UNITS

connect a 0·02 capacitor directly across the whole winding of this coil. By moving the strip about we will soon arrive at the correct pitch. Now we want the cathode tap on this coil to give us D sharp. Connect another 0·02 between the coil centre tap and earth; if the pitch is too low, try a 0·01 and then smaller ones in parallel with this until the correct pitch for D sharp = 311·126c/s is reached.

The same treatment is to be given to all the oscillators in turn, the last one being F sharp tuning by the cathode capacitor down to F = 174·6c/s. It should be possible to use the same value of capacitor for all the primary tunings, but it may be necessary to try different values for the cathode capacitors owing to the regrettably wide tolerances on such elements. However, this has only to be done six times.

We should now have the 12 notes of the octave, in turn of course, and we can turn to the switching. The maximum number of keyings for any chord is four. The ideal mechanism for this is a radio push-button tuning strip, with four "makes". Often these can be picked up at the popular dealers. If unobtainable, the best thing to do is to use G.P.O. relay contacts, which are readily available on the surplus market, and these are easily stacked as in Fig. 27. To draw these down, fibre washers can be threaded on to 6BA screwed brass rod so as to engage the ends of the springs. The top end of the rod can be inserted in a push-button (available in a number of colours) and the bottom can pass through a hole in a paxolin guide strip. The spring sets will return the button, which should slide in a hole in the wooden top panel lined with billiard cloth glued on inside the holes. Small card discs with the name of the chord can be stuck to the tops of the buttons with "Bostik" cement and, if varnished over, the legend will not be rubbed off. It is a good plan to have all the buttons for the key of C white, the F ones blue and so on. The grouping is then clear even to a stranger.

If it is required to have the buttons closer together than the spring sets will allow, then alternate switches can be mounted at a

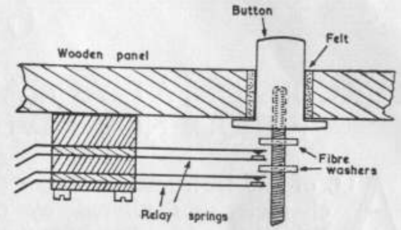


FIG. 27.
PUSH-BUTTON ARRANGEMENT

lower level and the actuating rods extended to suit. In this way, the lower layer of spring sets can be made to lie under the spaces between the upper spring sets. It should be carefully noted that when any note is *cathode tuned*, four springs per oscillator are required instead of two. Where these are required will be clear from the chord analysis; each oscillator denoted by a number needs two contacts, whereas one with K requires four.

Some care is required to set up these contacts and their buttons, but this is amply repaid by the ease of manipulation.

The control bar can take any convenient form. Some favour an upstanding strip in front of the buttons which can be depressed by the wrist after pressing a button; in other cases, a foot-operated button may be thought better; but in either case, only one contact has to be actuated and this as can be seen is a d.c. circuit removing the paralysing bias from the 6J5 grid so can be run for several feet without screening. No drawing is given for this item, since it is almost certain to take some form dictated by individual preference, but it must have a good strong spring so that the contact operates in a positive manner on the release of the bar or press button.

The 6J5 control valve can be built into the same chassis and calls for no comment; the − 30V bias cell is an Ever Ready "Batrymax" deaf aid battery and will last for several years; it can be held in with a little clip.

The output from this oscillator group, which is of a quite pleasant natural tone quality, is taken to any ordinary amplifier; but in fact some tonal changes can be made by means of the circuits shown in Chapter 7. This is left to individual tastes.

6

PERCUSSION, ATTACK AND DECAY CIRCUITS, FREQUENCY DIVIDING CIRCUITS

ALL of the instruments herein described can have their attack characteristics altered by one of the following circuits. Whilst some fixed rate for the onset of the tone must of course be provided, many novelty effects can be obtained by varying this in some way. It is not well appreciated how the *shape* of the envelope containing a certain group of notes affects the nature of the resultant sound. For instance, a typical piano note is shown in Fig. 28. Notice the steep wavefront, which gives it its percussive

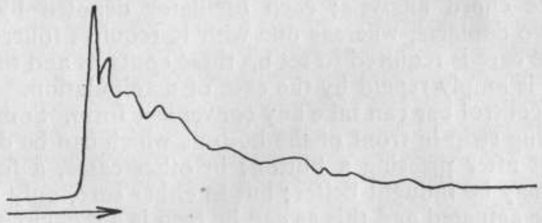


FIG. 28. TYPICAL PIANO WAVEFORM

sound, and the gradual dying away of the tone with its many phase changes. Now, such a note can, of course, be recorded, and when played will reproduce the original sound exactly. But, suppose it to be played backwards, what then? The sound is totally different. It begins slowly and swells out like an accordion, ending abruptly: the last thing it resembles is a piano. Yet the same waves with the same harmonics are present, and the pitch is unaltered; only the time/frequency characteristic is changed.

So, by "holding up" a note and releasing it quickly, or the reverse, we can obtain a variety of effects from exactly the same original tone. Those readers who are familiar with the *Novachord* will know that it can produce steady tones like the organ or sharply percussive ones like the harpsichord—all from the same waveform, for only one is generated for each note. It was mentioned earlier that the bass generator for the piano could be made to imitate a string bass by such a circuit, but it would be wasteful to limit the circuit to this effect only when others are possible with the necessary components.

Fig. 29 illustrates an arrangement which produces a fast attack, a slow attack, and a true percussive effect. The input and output

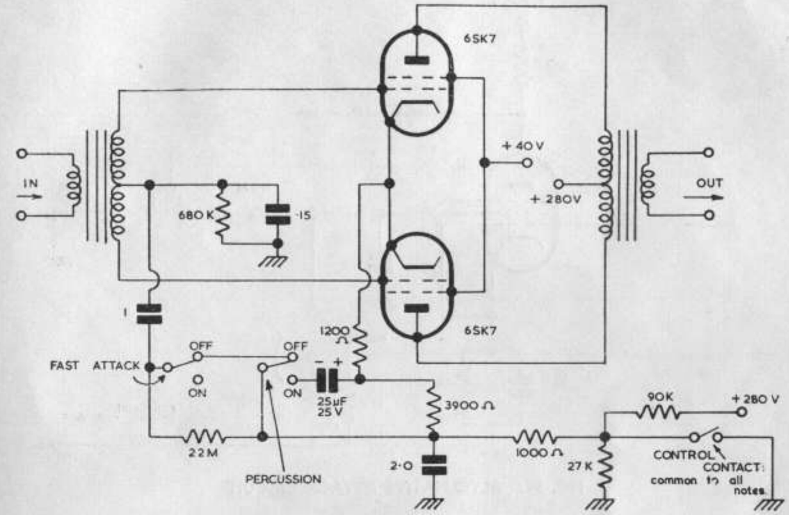


FIG. 29. ATTACK CONTROL CIRCUIT

transformers must, of course, respond to the frequency range required. There is little gain in this circuit, so its insertion will not seriously affect any existing arrangement, but it must come *after* any tone-forming circuits or the time constants will be upset. The 6SK7 valves should be matched or a slight thump may be heard on the percussive setting; however, this is perhaps not out of place for a string bass effect.

An advantage of this circuit is that it does not require a negative supply, but the + 40V tap for the screen voltage must be set carefully. A wire-wound potentiometer of 50,000 ohms at 5 watts across the + 280V line will allow of this. The diagram is self-explanatory, but be sure to use good quality capacitors.

Another way to obtain a wide range of attack control is by altering the screen potential of a suitable valve. Examine Fig. 30. The screen of the 6SJ7 is connected to a capacitor which is charged from two sources; one being a 105V dry battery *via* a 2·2 megohm resistor. This cuts off the anode current. A contact common to all keys of the music generator applies the second source of about + 170V to the attack resistors. The time required for the screen capacitor to charge positively now depends on the value of the resistor. With a capacitor of ·25mfd and 10,000 ohms, the time is about ·0025 sec. The capacitor does not fully charge in that time, but after about ·01 sec. the voltage rises enough to give full gain. Now, with a $\frac{1}{4}$ megohm resistor the time is increased to ·25 sec. and with a 4 megohm resistor, it reaches 4 seconds. So, by having a

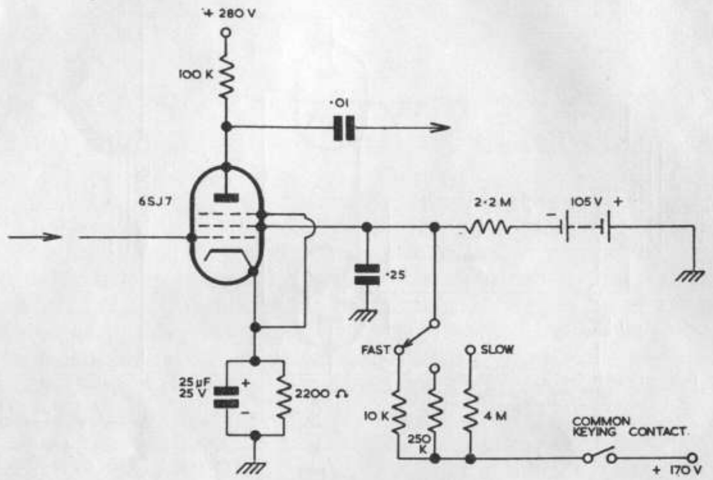


FIG. 30. ALTERNATIVE ATTACK CIRCUIT

variable resistor of, say, 2 megohms, a very wide range of attack times is possible. There is, of course, very little current drain on the 105V battery, the life of which should be almost equal to its shelf-life.

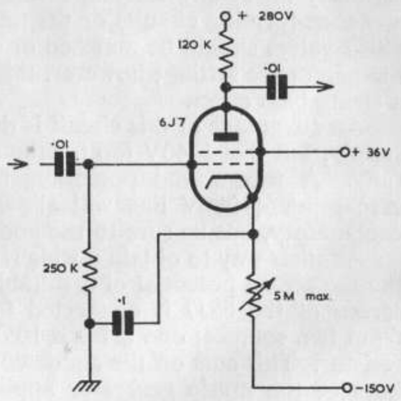


FIG. 31. PERCUSSION CIRCUIT

The maximum possible percussive effect is obtained with the circuit of Fig. 31. This can be set by alteration of the cut-off bias to give an almost explosive sound, but care must be taken not to cut off less than one-half cycle of the waveform fed in. Short attack and decay times are required for simulation of the banjo and in some circumstances, the guitar. This circuit has been used for this

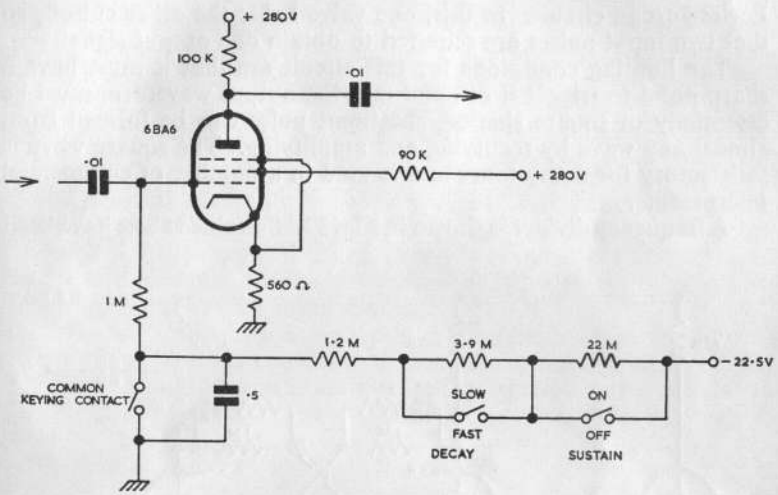


FIG. 32. DECAY CIRCUIT

purpose with marked success. The negative potentials called for do not really constitute a problem, for in no case do they mean any real current flow and so can always be obtained from a small dry battery.

At the other end of the scale, delays in the sound stopping are best achieved by the circuit of Fig. 44, redrawn here as Fig. 32, to contain the delay elements only. Some uncanny effects are possible with a circuit of this kind. As shown, the maximum delay is about ·5 sec., but by increasing the 22 megohm resistor, the times can be increased.

It will be apparent from the foregoing that the only way to apply attack and decay effects is by control of d.c. potentials. There is no easy way by which these effects can be applied to the signal line, although, of course, variants of magnetic recording techniques are now quite widely used for this purpose in the more elaborate equipments.

The appeal of any instrument on which only one note at a time can be played is greatly enhanced if octaves can be sounded simultaneously. This is possible if a frequency divider is used; in fact, one commercial instrument uses up to four in cascade, to provide successive divisions downwards from the generated pitch. All such dividers, with the exception of the locked relaxation oscillator as described in Chapter 3 require an aperiodic circuit, *i.e.* one which is not dependent on the frequency of the signal fed in but only on the magnitude or sign of the input pulse. The only circuit which fulfils this condition with the necessary simplicity is the well-known

Eccles-Jordan circuit. In this, one valve holds the other cut-off, so that two input pulses are required to obtain one output signal.

The limiting conditions for this circuit are that it must have a sharp pulse to trigger it off, and that the output waveform must be essentially of square shape. The input pulse can be formed from almost any wave by rectifying and amplifying. The square wave is satisfactory for many tones and is used in a number of commercial instruments.

A frequency divider is shown in Fig. 33. Suitable values have been

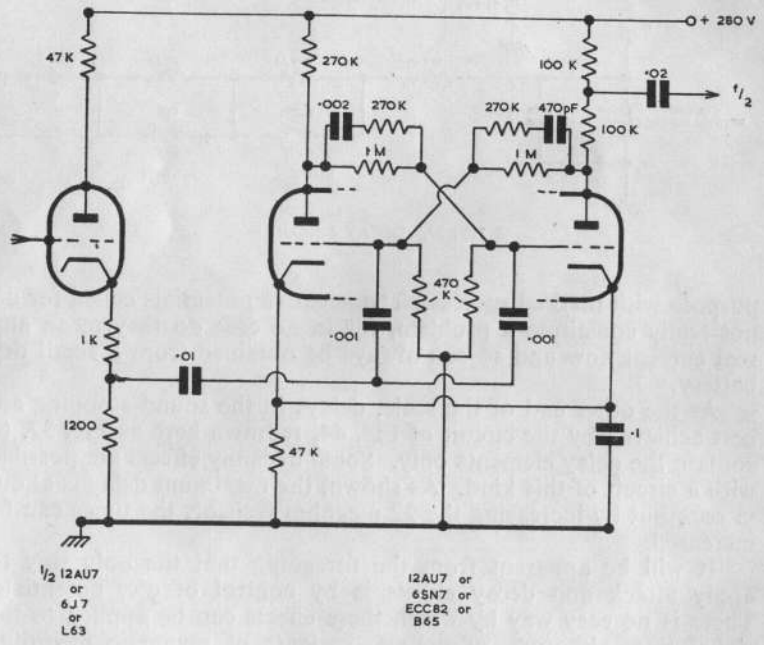


FIG. 33. MODIFIED ECCLES-JORDAN FREQUENCY DIVIDER 8FT. TO 16FT.

given for dividing from 8ft. pitch to 16ft. pitch. These dividers may be cascaded, *i.e.* used in series to form progressively lower notes. In practice, division from 4ft. to 8ft., and then to 16ft., is ample for all musical contexts. Since the output from any divider is substantially square, it will not trip a succeeding divider and must be shaped each time. This is in fact an advantage, as the sharpened pulse can also be taken out to a tone-forming valve to enrich the tone from the square wave, or even to form new tones. It must, of course, be clearly understood that frequency dividers can only

be used on a melodic instrument—they cannot divide a chord fed into them.

Many other circuits have been devised for frequency division (see the author's *Electronic Musical Instrument Manual*, Pitman), but in general they are rather touchy and sometimes fail to divide or do by some other integer, say 3 or 5. Consequently circuits depending on some such property as the rate of leakage across a capacitor for a long period of time have been avoided. Such circuits are often advocated because of their simplicity; but one often ends up by requiring a dividing value for every two notes or so; the small extra complication of the Eccles-Jordan divider is fully justified from an economic standpoint alone.

We are sometimes faced with the problem of mixing signals from more than one generator so that, whilst the combined outputs are fed into a common main amplifier, each source can be independently controlled in volume. If not more than two such sources are used, this mixing can be carried out by a 1/1 ratio transformer and the simple circuit of Fig. 34 is very useful. The

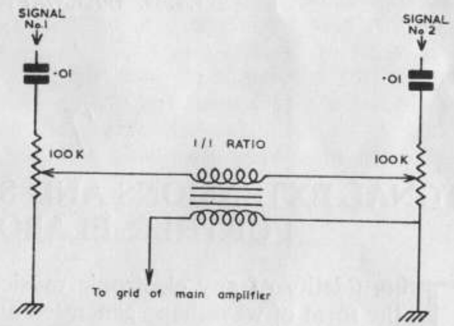


FIG. 34. TWO-WAY MIXER

transformer has 5,000 turns of 42 s.w.g. enamel wire on each winding, the core being a No. 39 stamping, requiring a $\frac{1}{2}''$ by $\frac{3}{8}''$ stack of Mumetal stampings. If, however, more than two inputs are to be combined, then they should be mixed through pentode valves as shown in Fig. 35. In this circuit, one signal cannot react on any other. Wire-wound potentiometers of 100,000 ohms should be used in these mixing applications. A great many other circuits can be used for signal mixing, many of which are illustrated and described in the *Radio Designers' Handbook*, 4th edition, Iliffe.

It is sometimes found that when a foot pedal is used, it does not give a sufficient number of angular degrees travel of the potentiometer spindle. In this case, a simple gear drive can be made up from Meccano parts. A suitable ratio would be 3 to 1, and standard wheels are available at any stockists. All other parts to complete such a gear drive can be made from the same source.

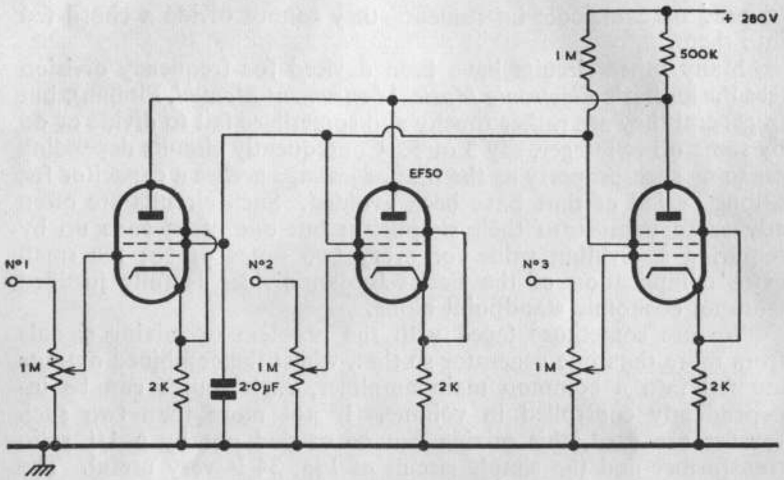


FIG. 35. MULTI-WAY MIXER

7

TONAL EXTENSIONS AND SUGGESTIONS FOR FURTHER ELABORATION

THE fidelity of any electronic musical instrument is related to the form of waveshape generated and its subsequent treatment by the tone-forming filters. This is true even where only one tone at a time is being formed.

Since every filter must have characteristics which are only exact or definite when it is terminated by the correct load, it follows that if several filters are combined, they will lose part of their individual characteristics and give rise to a new set. Whilst this will, of course, lead to a change of tone (and it may be a quite acceptable one), it will not be and cannot be the tones of these filters which have been combined. It is partly for this reason that few commercial melodic keyboard instruments are supplied with fixed tonecolours, but rather with a set of switch tablets so arranged that all the filter elements may be arranged to provide continuous variation in tone.

The arbitrary tones often so formed can readily be identified if an instrument of this kind is playing in an orchestra, just because they are not truly imitative. It is fully appreciated that this kind of tone is in many cases desired, indeed one obvious use for this kind

of music generator is to form "new" tonecolours. But, if truly imitative tones are required, then several matters arise. Firstly, the waveform generated must contain a sufficiency of the right kind of harmonics. Secondly, the tone filters must be separately worked out and only used singly, unless considerable elaboration is permissible.

To deal with the waveform first. For a long time, commercial instruments of the melodic type used a square wave. If this is symmetrical, it cannot contain any even harmonics. In this case, accurate imitations of flute and string tones are impossible, although over a limited range and by certain subterfuges, tones conforming broadly to these classes may be produced. They will however be "harder" and inclined to have an edge on them. On the other hand, the square wave is very useful for all "hollow" sounding tones, like the clarinet, bassoon, French horn (under certain conditions), etc.

Now, a sawtooth wave contains both odd and even harmonics evenly distributed. So that a high degree of tonal realism is possible from this kind of generator. Clearly, to really imitate a range of orchestral instruments (if that is the object), both waveforms ought to be available, and independently. Fortunately, a very simple and ingenious circuit due to W. E. Kock is available to provide this requirement; but it can only be used in a melodic instrument if frequency division is employed, for the reason that it needs not only the note required, but also, its octave above.

Fig. 36 is the circuit and if a sawtooth wave is injected at the

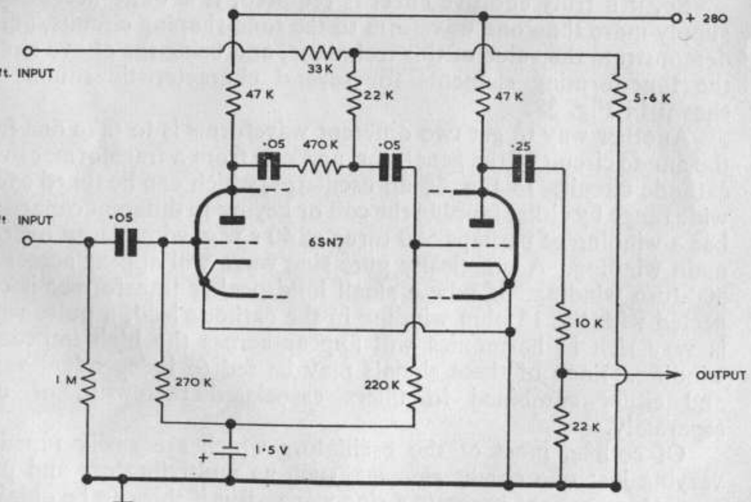


FIG. 36. PHASE REVERSING AMPLIFIER

input, the phase is reversed by means of the second valve and added to a sawtooth an octave below. If this is suitably arranged, the two waves combine as in Fig. 37 with the result that a substantially square wave is formed. Both these waveshapes can then

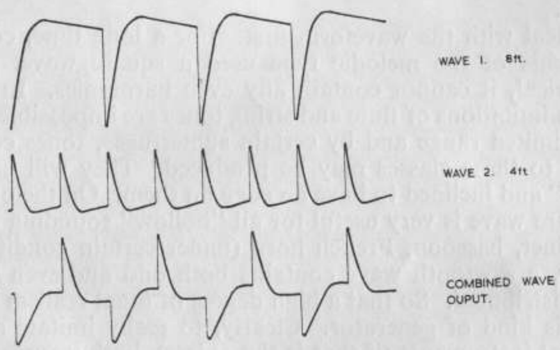


FIG. 37. COMBINATION OF INPUT WAVES TO PRODUCE PHASE-REVERSED SQUARE WAVE

be fed to independent tone filters to form two quite different tone-colours. Now these two tones will add, if a high impedance is in series with the output, and this arrangement is used in the well-known Baldwin organ.

So, if a truly additive effect is required, it is quite necessary to supply more than one waveform to the tone-shaping circuits, and to demonstrate the value of this technique, and using the above circuit, the tone-forming elements for several characteristic sounds are shown in Fig. 38.

Another way to get two different waveforms is to take one from the anode circuit of the generator, and one from a transformer in the cathode circuit. In Fig. 39 an oscillator, which can be tuned over a wide range by either tapping the coil or keying-in different capacitors, has a winding of perhaps 500 turns of 40 s.w.g. wire placed over the main winding. A practically pure sine wave will appear across the 500-turn winding. If now a small loudspeaker transformer is connected with the 15 ohm winding in the cathode lead, a pulse which is very rich in harmonics will appear across the high impedance winding. Each of these signals may be fed to independent valves and either combined in filters associated therewith, or used separately.

Of course, most of the oscillators which are easily tuned by varying just one circuit element, such as multivibrators and pulse generators, cannot generate a sine wave. But if this can be obtained from a melodic instrument, over a sufficient range of notes, then the wave-shaping circuit of Fig. 40 is very useful, for not only can

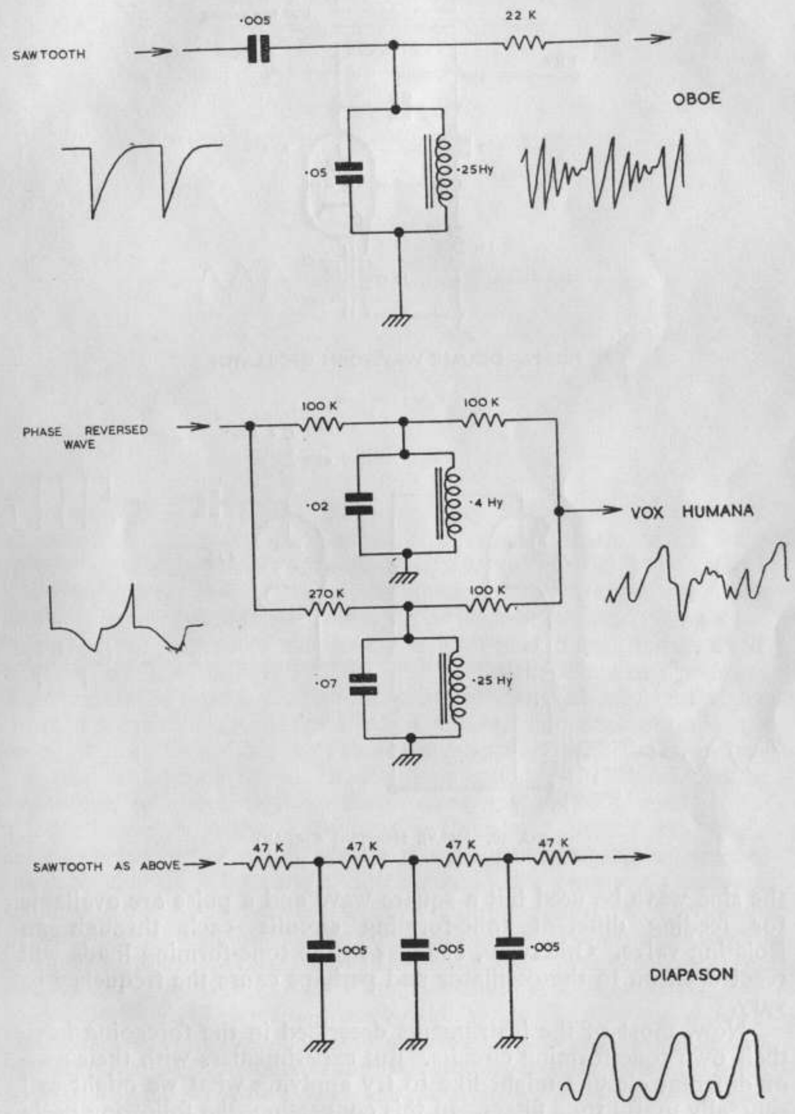


FIG. 38. TONEFORMING FROM FIG. 36

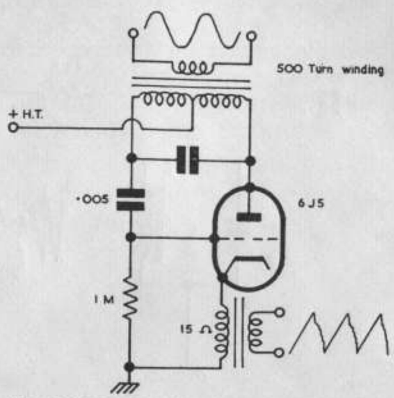


FIG. 39. DOUBLE WAVEFORM OSCILLATOR

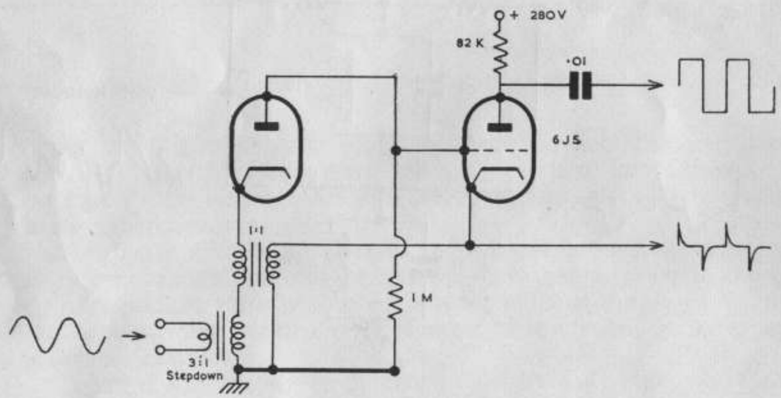


FIG. 40. WAVE SHAPING CIRCUIT

the sine wave be used but a square wave and a pulse are available for feeding different tone-forming circuits—each through an isolating valve. Otherwise, changes in the tone-forming loads will react back on to the oscillator and perhaps cause the frequency to vary.

Now, most of the instruments described in the foregoing have their own tone-forming circuits. But experimenters with their own or different circuits might like to try applying what we might call generally useful tone filters. In this connection, the following basic design points should be noted. Firstly, a sine wave cannot be treated in a tone circuit except to cut down the response at the upper or lower ends. This is rarely of value. Then, circuits really useful

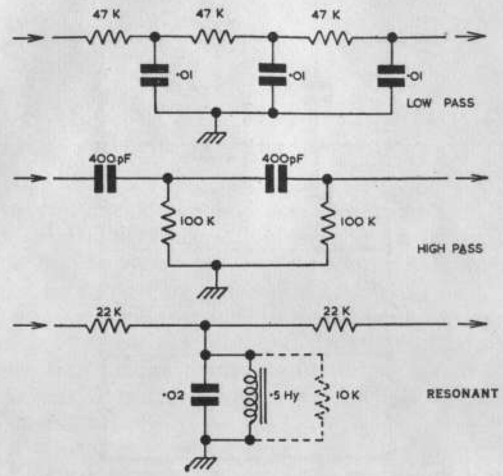


FIG. 41. BASIC FILTER TYPES

for tone-forming presume an input wave containing a series of harmonics. There are three kinds of circuit to which such a wave can be applied, which are shown basically in Fig. 41. The first is a low-pass filter. This rejects all frequencies above a certain figure and is generally used to form smooth or flute-like tones. The second circuit is the reverse of this and is a high-pass filter. It rejects all notes below a certain value and is of value for tones in which the fundamental is weak, such as all string tones. The last type is the most important, the resonant filter. These are, in practice, equivalent to band pass filters and accentuate a group of frequencies around the resonant point to which they are tuned. The band can be broadened by shunting them by resistors, say 10,000 ohms.

We know from the discussion in Chapter 1 that if we have a set of such filters we can obtain the main characteristic tones of many instruments by tuning our filters to the required frequency bands. Now we must also have the fundamental or pitch note present and so we make the *Q* or magnifying power of the resonant circuit quite low, perhaps between 1 and 5, so that the pitch note can be heard as well as the resonant band. It is then possible to join these filters in series to cover a wide range of notes and a useful layout is shown in Fig. 42. Here we have circuits resonating at 450, 900 and 2,500c/s. Such a grouping provides a wide range of tones for, as can be seen, any filter can be used independently as well. Included also is a simple top-cut capacitor, giving a mellow kind of tone from a sawtooth oscillator, and the same, with a slight "edge" to it, from a square wave. Observe that this series group of filters is connected between any amplifier grid circuit, and earth.

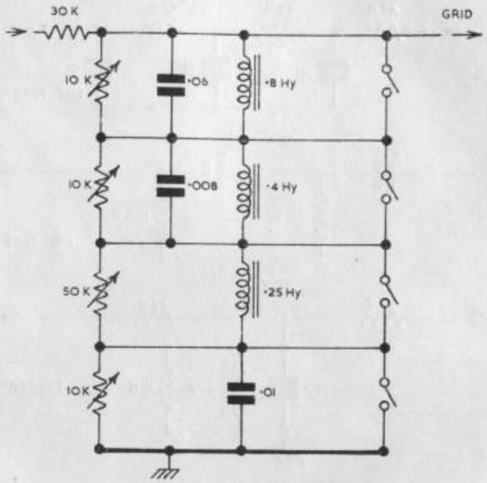


FIG. 42. UNIVERSAL FILTER

There is in fact an infinite variety of tone-forming circuits[1] depending on many factors, but in this book we have tried to reduce such circuits to the bare minimum consistent with really musical results; consequently the reader interested in other methods should consult some of the references given if he wishes to try extensive variations.

[1] See the author's *Electronic Musical Instrument Manual*, Pitman.

8

A PEDAL BASS ATTACHMENT FOR ORGAN PRACTICE WITH A PIANO

ALL organists require the means to play pedal parts at home, and whilst pedal attachments which operate on the existing keys are available, they are not able to produce sustained notes, a different tone, or be subject to expression control.

This device fills the need for such an instrument, at the same time providing a range of rates of attack and decay, a sustaining device, and by a simple attachment being convertible into an instrument on which the percussive notes of the string bass can be played. It is thus suitable for all tastes.

Essentially it is an unsymmetrical multivibrator of a kind slightly different from that previously described, since a good waveform of large amplitude is required. The reason for this is that it is almost impossible to form deep pedal notes of true organ character from a pulse as ordinarily understood. Fig. 43 shows the resistance-tuned generator. This requires + 150V from a high tension line stabilized by a VR150 gas-tube. The tuning is set for the top note by the 25K variable resistor, and this will be correct if a 30-note pedalboard is

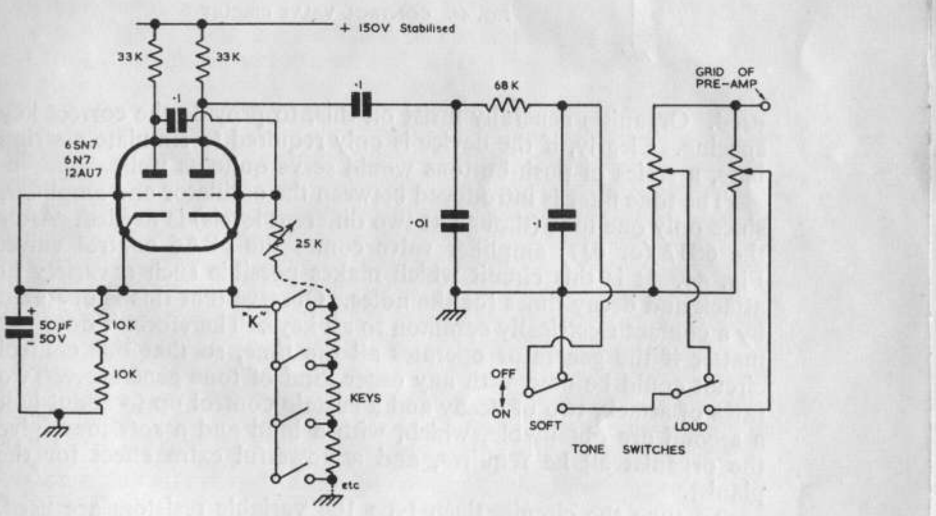


FIG. 43. BASS TONE GENERATOR

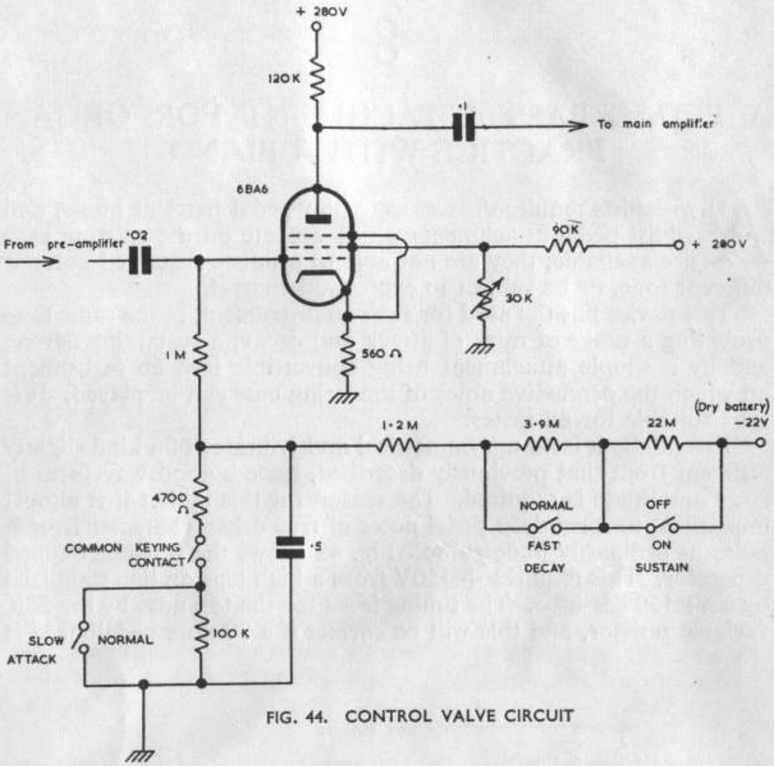


FIG. 44. CONTROL VALVE CIRCUIT

used. Organists generally insist on this, to provide the correct key spacing. Clearly, if the device is only required to simulate a string bass, a series of push-buttons would serve quite as well.

The tone filter is introduced between the oscillator and amplifier, since only one tone (though at two different levels) is needed. After the 6SJ7 (or 6J7) amplifier valve comes the 6BA6 control valve, Fig. 44. It is this circuit which makes possible such a variety of attack and decay times for the notes. Observe that this is operated by a contact electrically common to all keys. Therefore, it does not matter if the generator operates all the time, so that this control circuit could be used with any other kind of tone generator. Two rates of attack, two of decay and a sustain control up to about half a second are obtainable, which, with a loud and a soft tone, give the organist all he requires, and a powerful extra effect for the pianist.

To tune the circuit, Egen type 104 variable resistors are used. It would be very difficult to select fixed resistors of sufficiently exact

values, since although it might be thought that very exact tuning is not required, in fact the small beats produced by a slight degree of off-tune are most objectionable at these very low pitches; we shall require 14 of 5,000 ohms and 15 of 10,000 ohms. The pitch of the lowest note CCC is 32·7c/s. If the compactness of the Egen flat resistors is not necessary, then many wire-wound potentiometers are still available ex-government surplus.

The two tone switches or stops each need a change-over single pole contact; these could be tumbler switches if desired, and this pattern will serve for the attack and decay controls as well. The level of each tone can be independently set by the two potentiometers and this will, of course, depend on personal tastes, the room, amplifier and loudspeaker, etc. For such low notes, a really good amplifier is necessary, and those who find the Williamson type too expensive are recommended to use the circuit described in Chapter I. This has been employed most successfully in this unit as well as on full-scale organs. The low-frequency response is more than adequate.

Now, to play this unit with the proper technique, it is of course necessary to have a pedalboard. This might appear a formidable requirement, but actually it is simplicity itself to make. The design shown here has been made by many amateurs and a really professional job can be put together for under £4. Of course, a visit to an organ builder may secure an old one quite cheaply, but it would probably be under size, short compass or with parallel keys. This design conforms with the standards of the Royal College of Organists and the American Guild of Organists, so is much better for practice if that is essential.

Fig. 45 is the plan and elevation of the frame and the front and rear ends (known as the toe and heel ends). Fig. 46 gives details of the plain keys (naturals) and the black keys (sharps). Only the lengths of the projecting part of the sharps alters over the whole compass. These dimensions are also given. Suitable felt, springs and kid can be obtained. To ensure smooth working, the exposed end of the keys where they pass through the dowels should be bound with thin leather glued on. Such scrap pieces are easily obtained from any leather merchant or glove maker. The rest of the details should be clear from the figures.

Generally in any organ the pedals themselves do not carry any contacts; but, if these are to be attached to a piano, the exposed fixed contacts would readily be damaged apart from collecting dust and so on, therefore we have fitted the necessary contacts underneath the keys where they are well protected. These include the common attack control contact, which of course closes last. A similar scheme to that already described with two contacts back to back on a bakelite strip is used, but owing to the long span a piece of $\frac{1}{2}''$ by $\frac{1}{2}''$ aluminium angle should be attached to the bakelite to stiffen it. This can be fixed by brackets to the side pieces of the

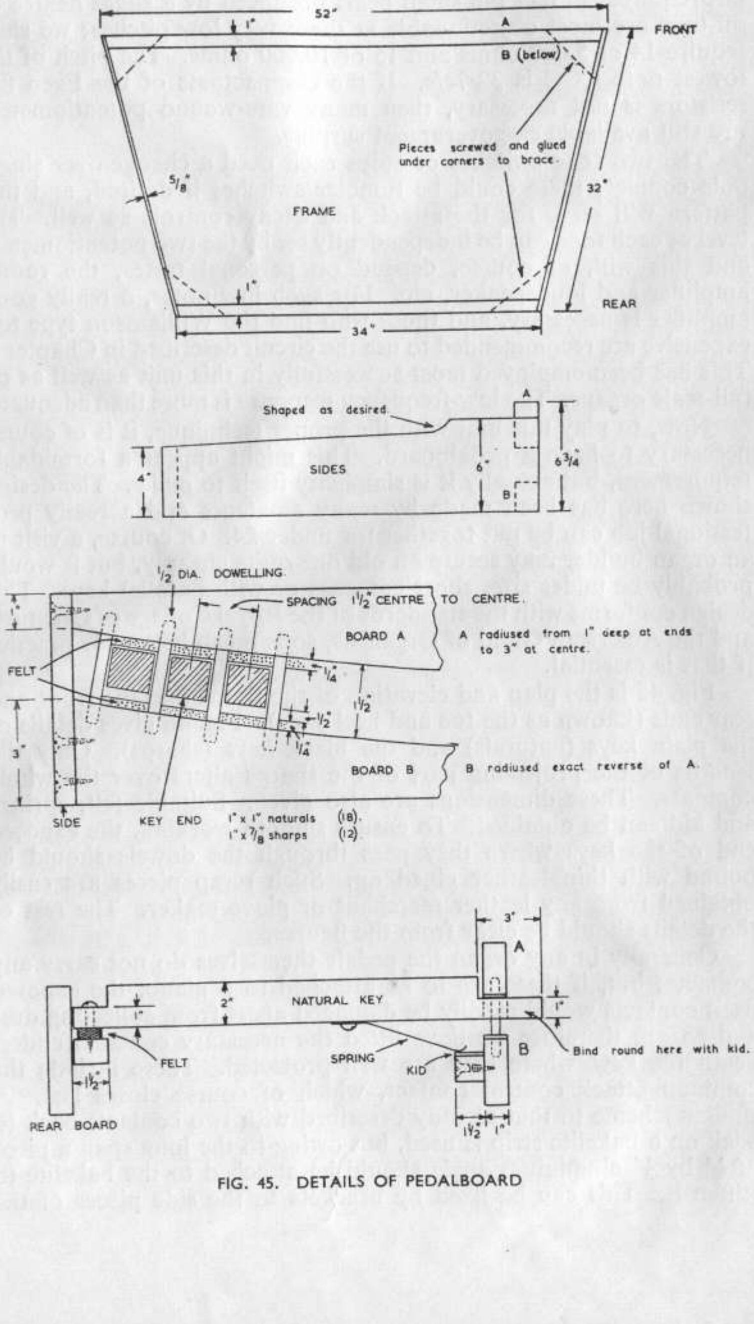


FIG. 45. DETAILS OF PEDALBOARD

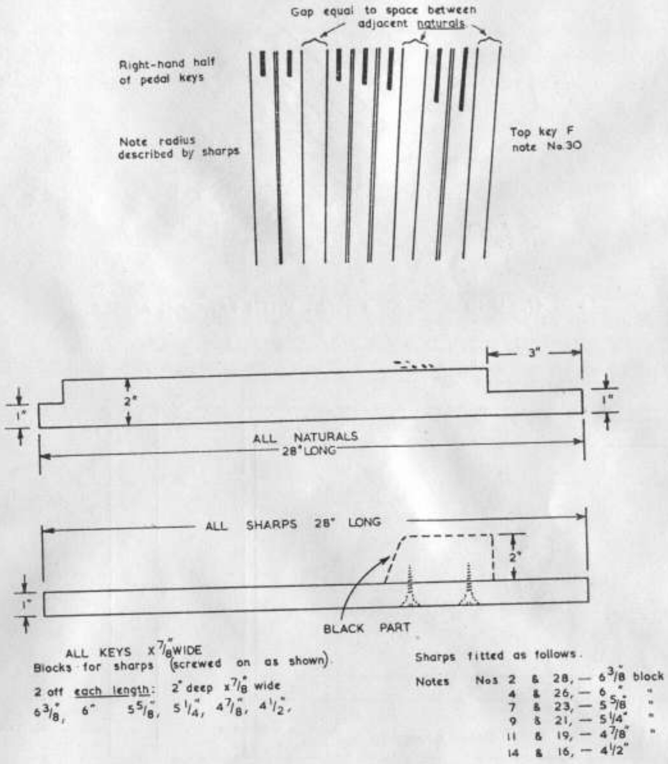


FIG. 46. CONSTRUCTION OF PEDAL KEYS

pedalboard frame inside. Make the bakelite strip wide enough to accommodate the angle. Fig. 47 shows the idea. Ordinary manual key plates will work well, but, owing to the increased depth of touch, the contact wires should be 3″ long. Thirty-three wires then run out from the pedalboard if the resistors are external, and can be cabled up and go to some form of plug on the piano or generator if desired to remove the pedalboard. At least 6ft. of cable can be run and no screening whatever is required. The pedalboard should remain stationary by its own weight, but should there be any tendency to creep on the floor, small squares of rubber cemented to the corners will stop this.

Naturally, no ordinary piano stool will span a pedal board and a bench is needed. A design for a very simple one which is also cheap is given in Fig. 48. Quite probably the reader may be encouraged to make a complete electronic organ at some future date, in which

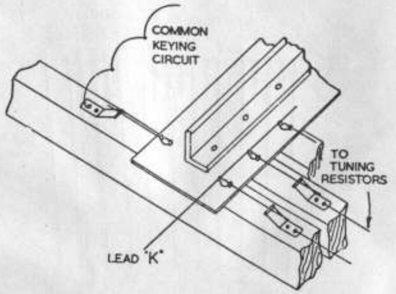


FIG. 47. UNDERSIDE OF PEDALS WITH BRACING ANGLE

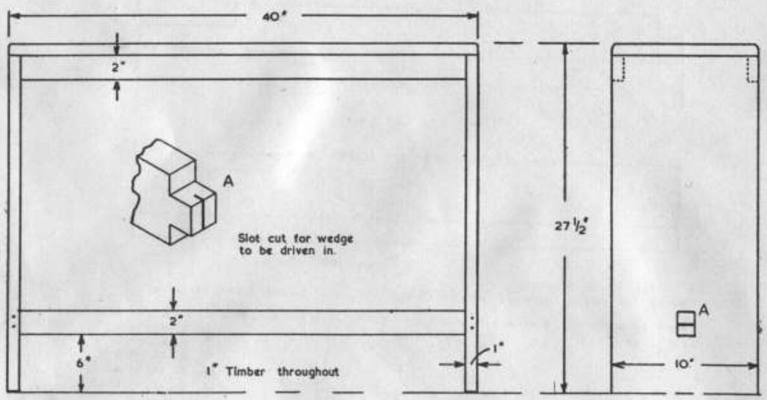


FIG. 48. ORGAN BENCH

case the bench will be required; in any event it enables piano duets to be played with greater ease and is also more comfortable if a melodic generator is attached to the piano.

Other designs of foreshortened pedal have appeared in the press, but it is always desirable to develop the correct playing technique and it is no harder to make the proper pedalboard in the first place.

It was mentioned that this generator could easily be converted into an instrument simulating the percussive attack of the string bass; the circuit for this is to be found in Chapter 6, which contains a variety of auxiliary devices to extend the resourcefulness of some of these instruments. With this circuit, any time between a few milliseconds and a constant tone level can be set up, and in this way a large number of novel effects can be obtained, none of which interfere with the original purpose of the generator. It will be realized that, with one of the solo instruments, the electric accordion

of Chapter 5, a percussion circuit and the pedal unit, a complete small dance band is available—which with sufficient skill can all be manipulated by one person. Truly a good example of electronics as applied to music!

9

AN ELECTRIC GUITAR

ONE of the most popular kinds of electrical tone producers is the guitar with a suitable form of pick-up. Strictly, this is not a tone generator but a tone converter; however, owing to its simplicity, some details of an inexpensive pick-up attachment may be helpful.

Fig. 49 shows two alternative methods of applying the pick-up.

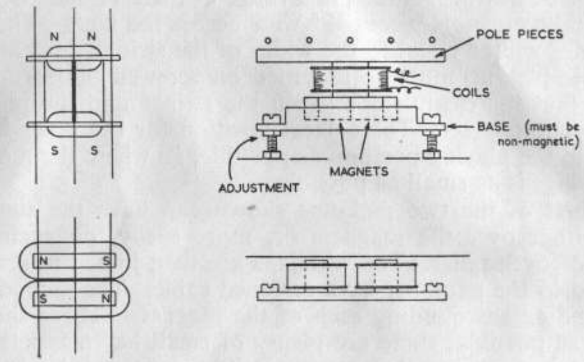


FIG. 49. MAGNETIC PICK-UPS

As can be seen, this consists of a simple permanent magnet system, and in one case the magnets are at right angles to the "strings" whereas in the other case, the magnets are transverse. Now, the pick-up can be used with any instrument having steel strings, and this also includes the zither, banjo and mandolin; for, since the tone is now dependent only on the relationship between the pick-up area and the vibrating length of the string, the resonating body of the instrument does nothing except act as a tank for the storage of energy passed from the strings to the bridge, controlling the rate of decay of the sound. It will be realized, no doubt, that if there is no resonator or sounding board at all, there will be nothing to stop the strings from vibrating for some time after they have been struck; but the tone will remain unaltered. Further, the player would be unable to hear anything except through his loudspeaker, but at the same time this kind of instrument has great virtues for special effects and the strings can always be damped by the wrist or hand if necessary.

The movement of a steel wire or plate to and from the poles of a magnet will change the flux density in the air-gap; hence, if a coil of wire surrounds the magnet, a voltage will be induced in this coil in proportion to the change in the magnetic flux. Also, as the wire vibrates above the magnet poles, a signal is induced in the coil below and when coupled into an amplifier, gives rise to a tone corresponding to the kind of vibrations executed by the string at the joint above the magnet poles. For this reason there will be a difference in the tone with differing areas of the pole piece on the pick-up. This is because the overtones or harmonics in the string become higher and higher in pitch, as they become shorter in length. Thus, a time might come when more than one harmonic is present in the length of pick-up pole. The resolving power of the pick-up would then be lost, and the higher of the two harmonics would not be heard. As the pitch range of a steel guitar is limited, we can make our pole pieces $\frac{1}{16}''$ wide across the faces. The length of the poles will be equal to the width of the strings, plus about $\frac{1}{4}''$. The whole pick-up must be mounted on screwed brass rod about 2BA, so that the clearance between the strings and the pole faces can be accurately set. The correct position for the poles is as far away from the playing position as possible, *i.e* where the movement of the strings is as small as possible.

The first of the two pick-ups shown can have the signal coil wound either over the magnets or, more easily, on each of the north and south poles. The windings are then joined in series and connected to the amplifier by a screened cable. The second design has a winding surrounding each of the magnets. These should be as small as possible; there are plenty of small bar magnets on the market at present, but they must not be too powerful. A suitable winding for either arrangement is 4,000 turns of 46 s.w.g. enamel copper wire per coil. In some circumstances, a small tinplate shield over the coils may be necessary to reduce hum pick-up, especially if very long leads are used.

As already stated, any other similar instrument can be re-strung with steel wires to permit the application of this kind of pick-up. An alternative device which is independent of the string material is shown in Fig. 50. Here a piezo-electric gramophone pick-up crystal is mounted inside the belly of the instrument, which does not vibrate in phase with the upper board. Contact is made under the bridge, near to the post which drives the back board, and with a well-adjusted pick-up of this kind, a very high degree of realism is possible.

It should be noted in connection with all the foregoing, that no great force is required in playing, so that unwanted sounds such as

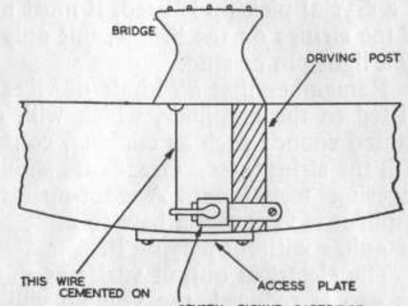


FIG. 50. CONTACT PICK-UPS

plucking transients, scraping of wires due to fingering, etc., need not be audible.

A very wide pole piece is obviously required for an instrument like a zither, but this is by no means impossible. However in this case it is best to connect one end of the pole system rigidly to one end of the strings, so as better to define the magnetic circuit. This will be clear from Fig. 51. The electrical output will be less, so that

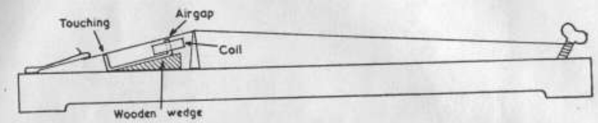


FIG. 51. PICK-UP FOR ZITHER OR SIMILAR DEVICE

more amplification must be provided. It can be noted that even an instrument with gut strings can have an electrical pick-up applied to it, either of the crystal type outlined, or by wrapping very fine iron wire round the strings for about $\frac{1}{2}''$ close to the bridge; a magnetic pick-up such as in Fig. 49 can be used.

In all these cases, the effect is to increase the amount of fundamental in the tone, and the general sense is of a fuller, smoother sound. The reader may think that further adjustment to the tone quality could be made by electrical circuits of the ordinary bass or treble lifting types, and this is, of course, possible; but the realism of the actual physical tone will be less as the electrical correction becomes greater; so that care is needed in applying this kind of electrical tone correction.

The important points to remember are: If a magnetic pick-up is used, the poles should be placed at some point where the movement of the vibrating string is very small; this will enable a close adjustment of the air-gap with improved volume and frequency response.

If a crystal pick-up is used, it must not be strained by the pressure of the strings on the bridge, but only be in contact with the bridge by a light pin or stud.

Remember that *all* kinds of vibrations of the strings are transmitted to the amplifier, which will, of course, include all the unwanted sounds such as clicking, contact of the player's finger nails with the strings, etc. Great care should be taken to acquire a clean fingering technique. A foot-operated volume control for the amplifier is very useful here to mute the loudspeaker when handling the guitar without playing it.

The electrical output varies as the square of the air-gap; so, as the gap is reduced, the volume will rapidly increase. Some care should be given to finding the most effective pick-up position.

APPENDIX

FREQUENCY TABLE

C	$C^\sharp$	D	$D^\sharp$
16·353 = CCCC 32 ft pitch	17·323	18·354	19·445
32·703 = CCC 16 ft pitch	34·647	36·708	38·890
65·406 = CC 8 ft pitch	69·295	73·416	77·781
130·812 Tenor C	138·591	146·832	155·563
261·625 Middle C	277·122	293·664	311·126
523·251	554·365	587·329	622·253
1046·502	1108·730	1174·059	1244·507
2093·004	2217·460	2344·318	2489·014
4186·004 Top note of piano	4434·920	4698·636	4978·028
8372·016 Top note of organ	8869·840	9397·272	9956·056
16744·032 Extreme limit of audibility			

E	F	$F^\sharp$	G
20·601	21·826	23·124	24·499
41·203	43·653	46·249	48·999
82·406	87·307	92·498	97·998
164·813	174·614	184·997	195·997
329·627	349·228	369·994	391·995
659·255	698·456	739·988	783·991
1318·510	1396·912	1479·976	1567·982
2637·040	2793·824	2959·952	3135·964
5274·040	5587·648	5919·904	6270·928
10548·080	11175·296	11839·808	12541·856

$G^\sharp$	A	$A^\sharp$	B
25·956	27·500	29·135	30·867
51·913	55·000	58·270	61·735
103·826	110·000	116·540	123·470
207·652	220·000	233·081	246·941
415·304	440·000	466·163	493·883
830·609	880·000	932·327	987·766
1661·218	1760·000	1864·654	1957·532
3322·436	3520·000	3729·308	3951·064
6644·872	7040·000	7558·616	7902·128
13289·742	14080·000	15117·232	15804·256

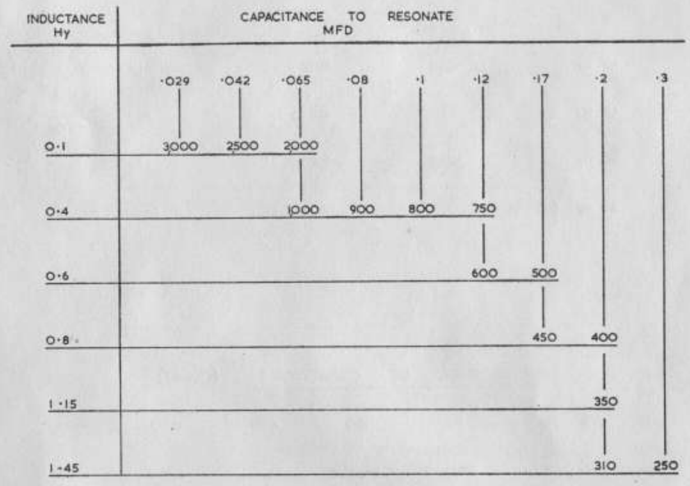
HARMONIC TABLE (FOR A = 55 c/s)

HARMONIC	EQUALLY TEMPERED SCALE DEVIATION FROM TRUE FREQUENCY	% ERROR
1	0	0
2	0	0
3	− 0·19	0·115
4	0	0
5	+ 1·82	0·662
6	− 0·37	0·112
7	+ 7	1·820
8	0	0
9	− 1·12	0·226
10	+ 4·37	0·795
11	+17·75	2·935
12	− 0·74	0·112
13	−16·54	2·320
14	+13·99	1·820
15	+ 5·61	0·680
16	0	0
17	− 2·67	0·286
18	− 2·23	0·226
19	+ 1·50	0·147
20	+ 8·73	0·793
21	+19·66	1·700
22	+34·51	2·850
23	−20·49	1·620
24	− 1·49	0·113

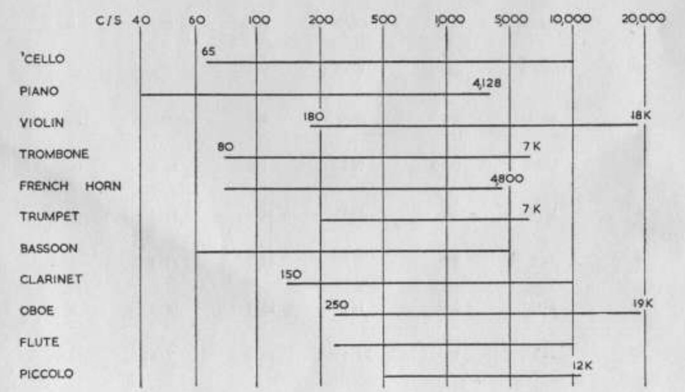
FREQUENCY RATIOS WITHIN AN OCTAVE (C = 1)

C	1·000	D#	1·189	F#	1·414	A	1·681
C#	1·059	E	1·259	G	1·498	A#	1·781
D	1·122	F	1·334	G#	1·587	B	1·887
						C'	2·000

USEFUL RESONANT FREQUENCIES FOR TONE-FORMING CHOKES



APPROXIMATE FREQUENCY RANGE OF MUSICAL INSTRUMENTS



USEFUL SMOOTHING CHOKES

$\frac{3}{4}$" x $\frac{3}{4}$" stack of No 60A Stalloy laminations.
38 s.w.g. enamelled copper wire

	AIR GAP	TURNS	D.C. RESISTANCE
10 Hy	·030"	5,000	418 Ohms
15 Hy	·035"	6,300	544 "
20 Hy	·044"	7,600	689 "
50 Hy (40 s.w.g. wire)	·010"	14,000	2,400 "

REACTANCE OF CAPACITORS (OHMS)

MFD \ C/S	30	50	100	400	1000	5000
·005	1,060,000	637,000	318,000	79,600	31,800	6370
·01	531,000	318,000	159,000	39,800	15,900	3,180
·02	263,000	159,000	79,600	19,900	7,960	1,590
·05	106,000	63,700	31,800	7,960	3,180	637
·1	53,100	31,800	15,900	3,980	1,590	318
·25	21,200	12,700	6,370	1,590	637	127
·5	10,600	6,370	3,180	796	318	63·7
1	5,310	3,180	1,590	389	159	31·8
2	2,650	1,590	796	199	79·6	15·9
4	1,310	796	398	99·5	39·8	7·96
8	663	398	199	49·7	19·9	3·98
10	531	318	159	38·9	15·9	3·18
20	265	159	79·6	19·9	7·96	1·59
50	106	63·7	31·8	7·96	3·18	0·637

FREQUENCY / WAVELENGTH

FREQUENCY C/S	30	50	100	200	400	1000	4000	
WAVELENGTH	452	271	136	67·7	33·9	13·6	3·39	INCHES
	37·7	22·6	11·3	5·65	2·82	1·13	0·282	FEET

VELOCITY OF SOUND IN NORMAL AIR :—

$f \times \lambda$ = 1129 Ft PER SECOND

f = C/S

λ = WAVELENGTH IN FEET

LOUDSREAKER ACCOMMODATION

Volume of typical loudspeakers : to be deducted from cabinet calculations.

LOUDSPEAKER DIAMETER	8"	10"	12"	15"	18"
VOLUME (cubic inches)	250	400	650	1300	2300

LOUDSPEAKER CABINET DIMENSIONS

Assume cone resonant at 35 C/S

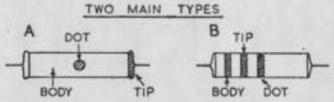
FOR 8" UNIT	6 CUBIC FEET minimum
12"	9 " " "
15"	24 " " "

Triangular corner form most effective, two slots at bottom of sides, total slot area equal to cone area.

RESISTOR COLOUR CODING

COLOURS	
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GREY	8
WHITE	9
GOLD	± 5% Tolerance
SILVER	± 10% Tolerance
PINK	High stability

TWO MAIN TYPES



Always read – BODY, TIP, DOT, in that order.

EXAMPLES :–

BODY	TIP	DOT	
GREEN	BLACK	RED	
5	0	2	$= 50^{\times 2\ \text{zeros}}$ = 5,000 Ω
YELLOW	VIOLET	ORANGE	
4	7	3	$= 47^{\times 3\ \text{zeros}}$ = 47,000 Ω
BROWN	BLACK	GREEN	
1	0	5	$= 10^{\times 5\ \text{zeros}}$ = 1,000,000