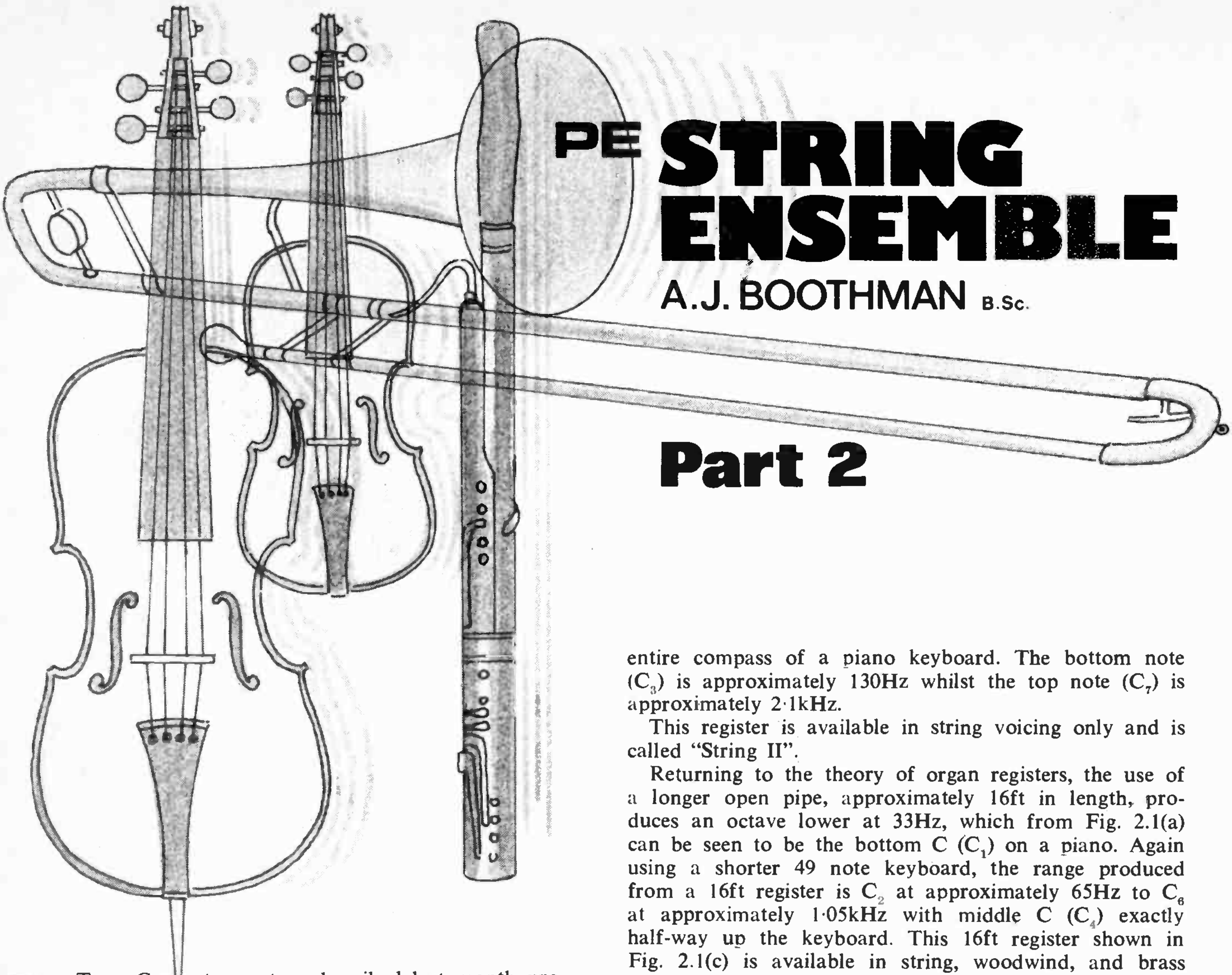


PE STRING ENSEMBLE

A.J. BOOTHMAN B.Sc.

Part 2

THE Tone Generator system described last month provides up to 96 square wave frequencies, 85 of which are used in the String Ensemble to facilitate a number of combinations of register for both hands, and up to three even harmonics above the fundamental over the entire keyboard range.

For simple reference in playing the instrument I, II and III indicate the register of the fundamental range of each control, and equate to the organ terminology of 16ft, 8ft and 4ft respectively.

FOOTAGES

The use of the term "footage" arose in organ parlance due to the length of pipe required to produce a particular fundamental frequency. An open pipe approximately eight feet long produces 65Hz, which is two octaves below middle C on a piano, and on a classical organ with a 61 note manual the range would extend for five octaves to three octaves above middle C (261Hz) up to approximately 2·1kHz, and this would be known as the 8ft pitch, normal pitch, or 8ft register. A spinet type of organ, which is the format normally employed in entertainment type organs uses either 49 note or 44 note keyboards, and in the 8ft register of the upper manual maintains the same number of octaves above middle C, with a reduced number of notes below middle C.

The String Ensemble follows the recognised practice for the latter type of organ and it can be seen from Figs. 2.1(a) and 2.1(b) how the 8ft register relates to the entire compass of a piano keyboard. The bottom note (C_3) is approximately 130Hz whilst the top note (C_7) is approximately 2·1kHz.

This register is available in string voicing only and is called "String II".

Returning to the theory of organ registers, the use of a longer open pipe, approximately 16ft in length, produces an octave lower at 33Hz, which from Fig. 2.1(a) can be seen to be the bottom C (C_1) on a piano. Again using a shorter 49 note keyboard, the range produced from a 16ft register is C_2 at approximately 65Hz to C_6 at approximately 1·05kHz with middle C (C_4) exactly half-way up the keyboard. This 16ft register shown in Fig. 2.1(c) is available in string, woodwind, and brass voicing and is the fundamental orchestral register (I) used in the String Ensemble.

LOWER KEYBOARD SPLIT

With the "Couple" push button control depressed all 49 notes give a continuous range, at either 16ft (I) or 8ft (II), for the voices selected on the Upper Voice sliders. However three further push puttons allow the keyboard to be split such that the lower 16 notes are independent of the upper 33 notes.

Fig. 2.1(d) indicates the "String I" button depressed, and under these conditions the upper 33 notes remain under the control of the sliders, whilst the lower 16 notes convert to 16ft (I) strings only.

The lower range is C_2 to E^b_3 at approximate frequencies between 65Hz and 156Hz. Depression of "String" (II) converts the lower section to 8ft, ranging from approximately 130Hz to 311Hz (C_3 to E^b_4), Fig. 2.1(e), now converting middle C (C_4) into the left hand, in addition to remaining within the compass of the 16ft (I) setting, Fig. 2.1(c), of the upper section of the keyboard which is played by the right hand.

The "String III" push button converts the lower section to 4ft pitch (C_4 to E^b_5), which as shown in Fig. 2.1(f) commences at middle C on the piano compass and it can now be seen that the lower section clearly rises in register above the middle of the upper keyboard section, with a fundamental range of approximately 261Hz to 622Hz.

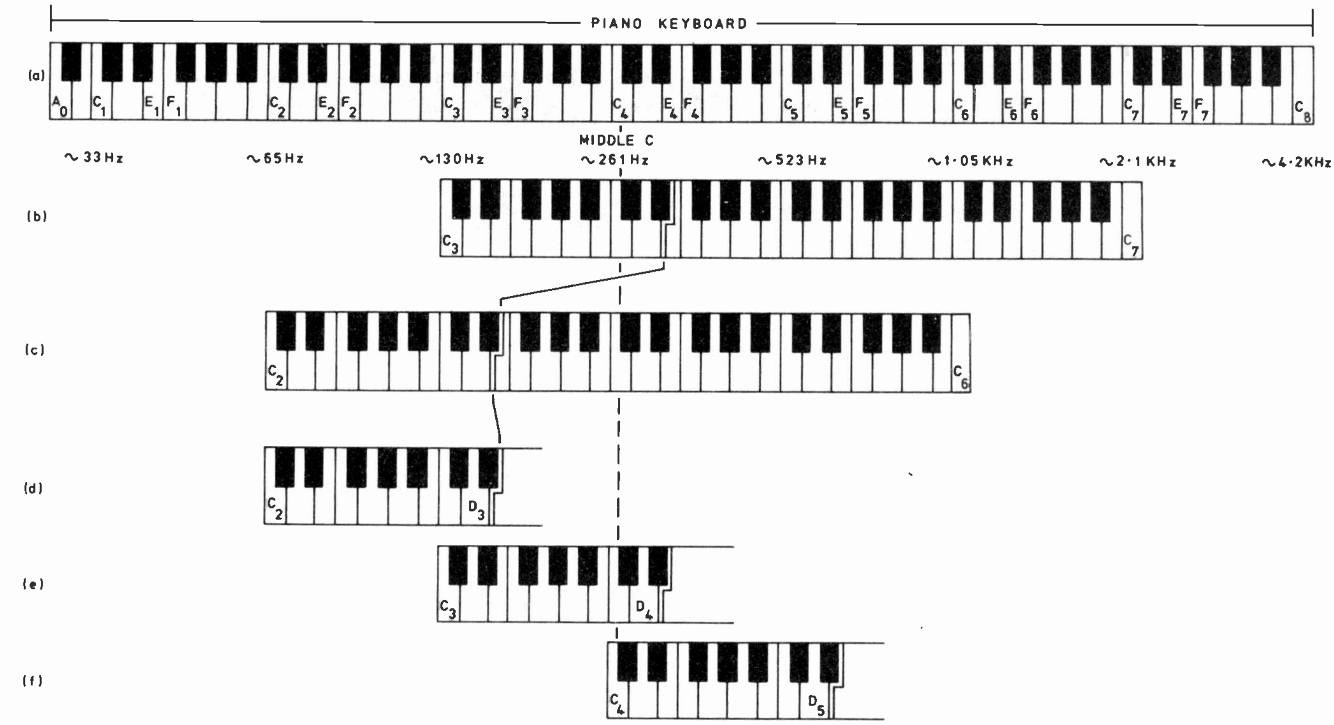


Fig. 2.1. Keyboard registers of the String Ensemble relative to a piano compass (a) Piano compass (b) Ensemble 8ft register—"String II" (c) 16ft register (String I, woodwind and brass) (d) Lower keyboard split—16ft "String I" depressed (e) Lower keyboard split 8ft String II depressed

ADDITIONAL FREQUENCIES

The highest fundamental frequency shown for the instrument is indicated in Fig. 2.1(b) as approximately 2.1kHz (C_7). Frequencies up to approximately 8·4kHz are available from the Tone Generator system and these are used to give additional even harmonics to be described later in association with the voice circuitry.

FREQUENCY SWITCHING

The switching of the large number of frequencies, including harmonics, described above is complex by traditional means in which direct signal keying by multi-mechanical contacts has been used. Many modern electronic organs simplify this problem by the use of electronic keying utilising diode, transistor, or integrated circuit elements with single mechanical contacts.

Diode keyswitching has been adopted in the String Ensemble.

COMPONENTS . . .

DIODE GATES (49 required)

Resistors
R5 3·3k Ω (49 off)
R6–R13 120k Ω (392 off)
R14 10k Ω (49 off)
¼W 5% carbon film

Capacitors
C13 4·7μF elect. 25V (49 off)

Potentiometers
VR6 10k Ω linear slider
VR7 4·7k Ω log slider

Diodes
D14–D22 1N4148 (441 off)
D23–D30 1N4148 (8 off)

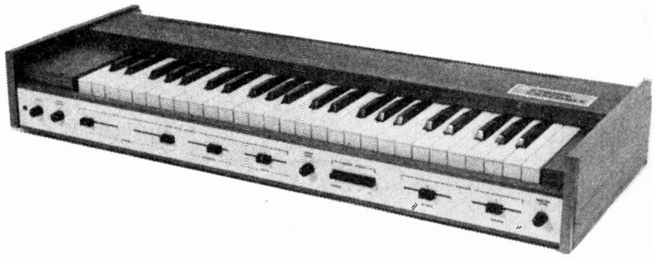
Miscellaneous
3 printed circuit boards
49 note keyboard (Italian style) with set of keyswitch components—(Clef Products)

DIODE KEYING

Switching of the Tone Generator frequencies through to the voice circuits is accomplished by diode gating circuits shown in Fig. 2.2. One circuit within the shaded area is required for each note of the keyboard such that whilst that key is down four octave related square waves corresponding to the note concerned, are switched independently onto busbars identified as 16ft, 8ft, 4ft and 2ft.

SHAPING FOR ATTACK

On depression of the key the moving keyswitch makes contact with a keyswitch rod which is at a positive potential thus charging C13 via R5 with a relatively slow time constant to simulate the slow attack of a string section. The keyswitch rod receives its potential via a slider potentiometer VR6 which further slows the charging rate of C13, and the optimum string attack rate is chosen to coincide with VR6 in its mid position.



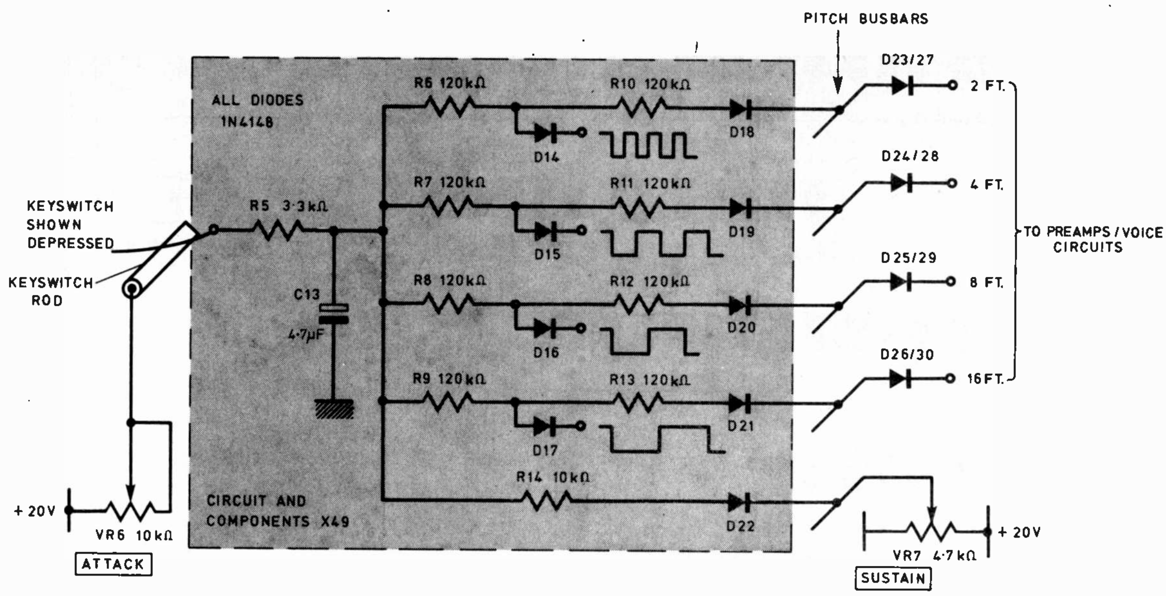


Fig. 2.2. Diode gating circuits

This simple "Attack Control" produces a degree of automatic levelling of the overall output as the number of notes depressed changes which is useful in simulating the smooth flow of the string section, but the slowest attack position can introduce the effect to an excessive degree, whilst in the fastest attack position the keyboard section is fully additive.

SUSTAIN

When the key is released the capacitor C13 is discharged at a rate dependent on the time constant of C13 coupled with the combined effect of resistors R6–13, which are eventually grounded via terminating resistors on the busbars, but modified by the effect of R14 which is returned via D22 to a potential set on slider potentiometer VR7. When the potential is high it is isolated from C13 by D22, but when VR7 is at minimum potential (0V) the low value of R14 dominates over the R6–13 combination to produce a short sustain. As the potential from VR7 is set at an increased level, the domination of R14 ceases when the falling potential on C13 approaches that on VR7 such that the longer time constant associated with R6–13 comes in earlier giving an overall increased length of sustain.

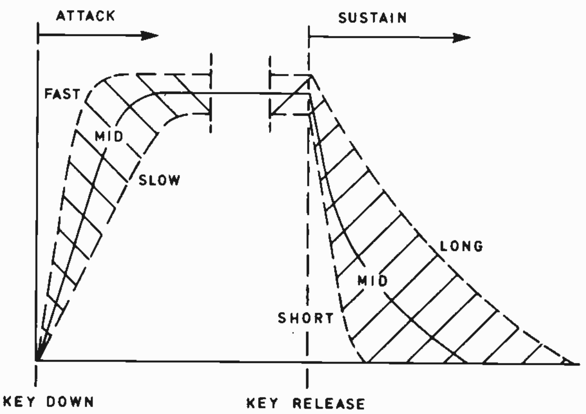


Fig. 2.3. Envelope shapes produced by the Diode Gate circuits

The resulting envelope shapes available are shown in Fig. 2.3, indicating the variations possible from the mid position each of the slider potentiometer controls.

TONE SWITCHING

The required octave related square waves for a particular note are connected to the cathodes of D14–17, and have amplitudes of approximately 14 volts. Assuming the key is at rest with the keyswitch in the open circuit condition then C13 will be discharged and the junction of R5 and C13 at zero potential. Thus the anodes of D14–17 will also be at zero potential and the reverse characteristics of the diodes will block the Tone Generator signals.

Whilst a positive potential is present on C13 during the envelope generation process, the signals will pull down the voltages on R6–9 via D14–17 allowing signals to pass through R10–13 which are proportional to the envelope amplitude.

BEEHIVE REDUCTION

"Beehive" is the term used to describe the effect of all frequencies in the Tone Generator breaking through into the amplifier circuits in chorus, producing a background level of sound which gives considerable annoyance. There are many routes in a polyphonic instrument by which this can occur, related to screening, cable looming and earthing of the various sub-assemblies, but the first route to consider is the direct transmission of low level tones through the keyswitch system when it is supposedly in its quiescent state.

Diodes D18–22 first isolate each gate from the other 48 such that from the point of view of one signal it does not see the 120 kilohm resistors in all other notes of the same pitch, only considering the terminating resistor at the end of the busbar in determining its final level at the preamplifier. Secondly the diodes block the sum total of signals from the keys depressed feeding back to C13 and providing a small positive potential for the signal to modulate in a supposedly quiescent note. The diodes also

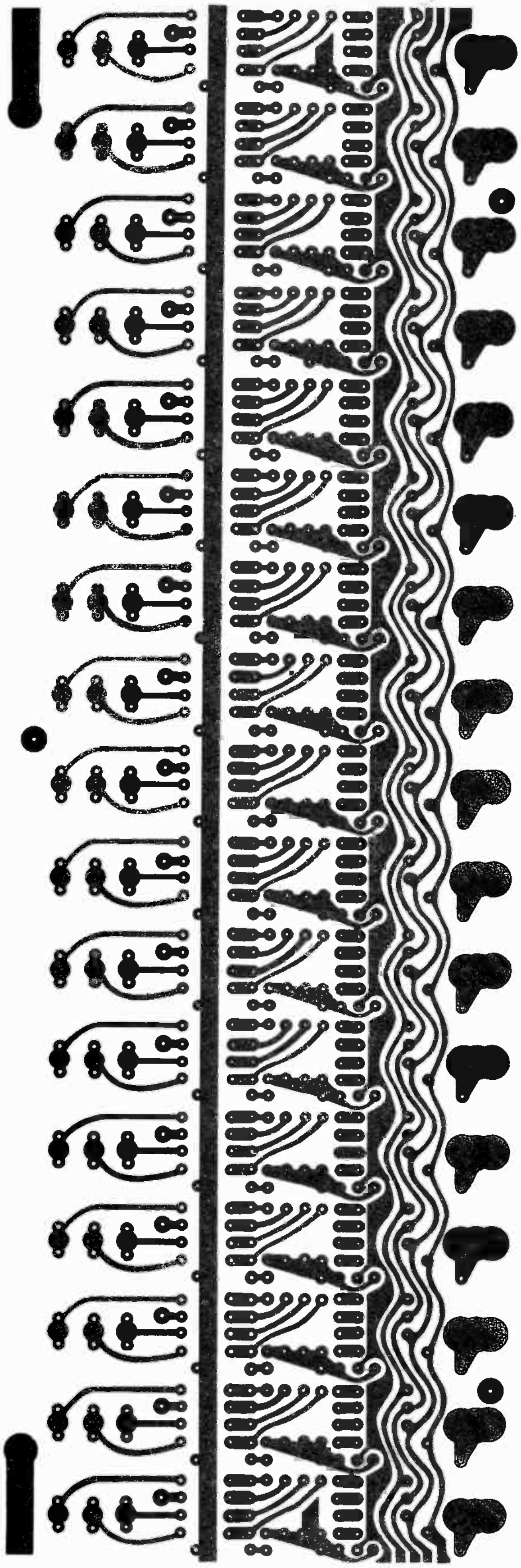


Fig. 2.4. Track layout of Diode Gate p.c.b.

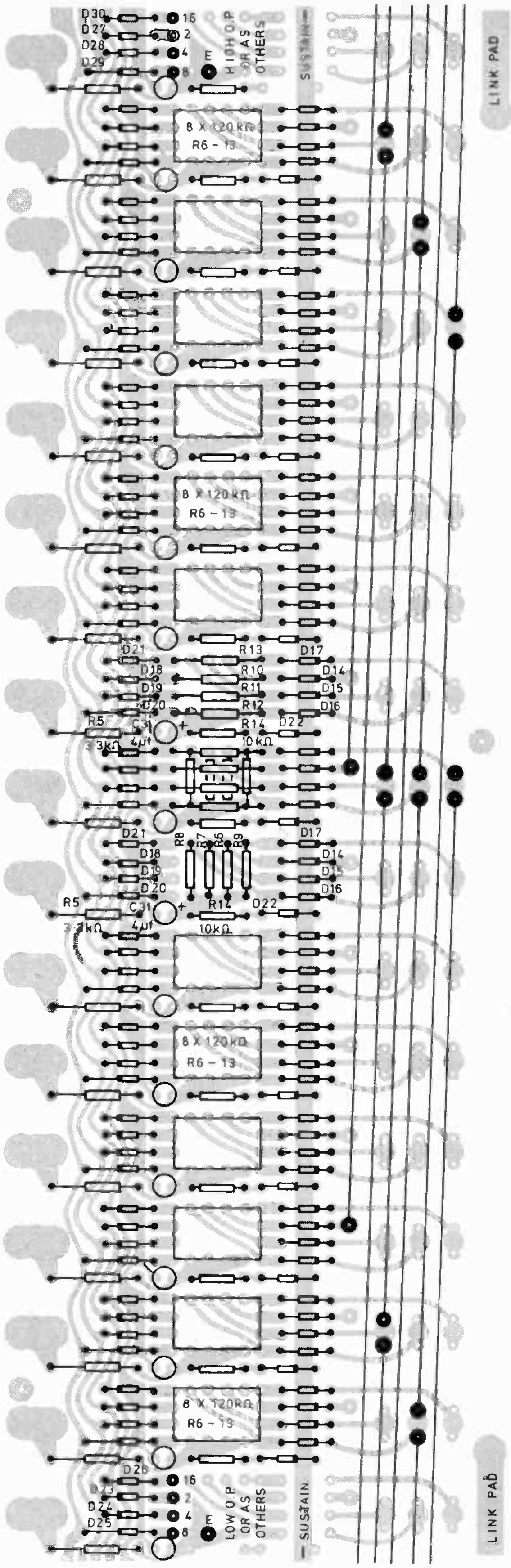
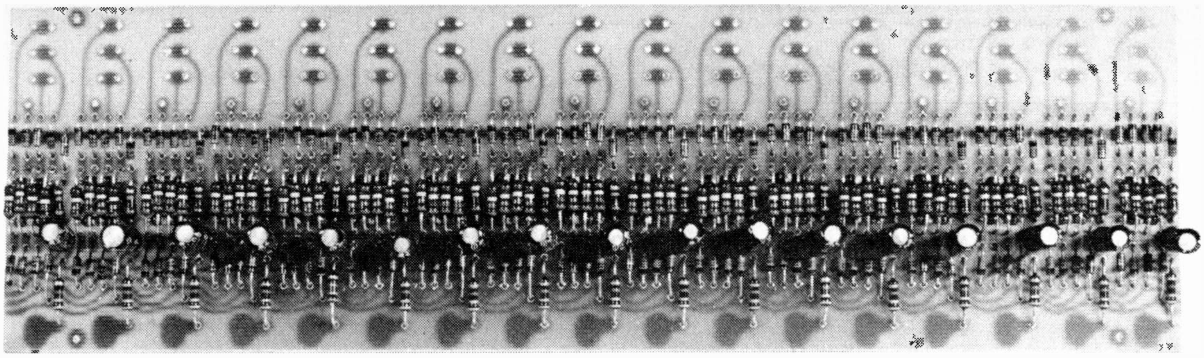


Fig. 2.5. P.c.b. component layout



have a high impedance in the forward direction at low voltages to assist the blocking of any small residual voltage on C13, and effectively increase the values of D18–22 in this condition.

Finally it has to be accepted that even when reversed biased D14–17 allow low level spike signals to pass due to internal capacitance, and the small finite stray capacitance of D18–22 further reduces to a small degree the onward transmission of signals from this source.

THRESHOLD DIODES

Even at this stage beehive signals are present on the pitch busbars in the quiescent state and diodes D23–30 are used to further block the breakthrough from reaching the preamplifiers. Since the keyboard is split with two independent sets of outputs from the keyswitch circuits, two sets of threshold diodes are required, D23–26 for the lower section of the keyboard and D27–30 for the upper end of the keyboard.

The overall result is negligible beehive due to transmission through the Diode Gate circuits, and since all signals are in square wave form, with a common baseline potential, the signal harmonic content or distortion level is not modified.

DIODE GATE P.C.B. CONSTRUCTION

All Diode Gate circuits are mounted on three printed circuit boards, the etching and drilling details of which are given in Fig. 2.4, with the component assembly details in Fig. 2.5. The boards are designed to accommodate 49 identical circuits of the type previously described within the shaded area of Fig. 2.2. Since each board has a pattern to cover 17 notes, two are omitted, one at each end of the final three board assembly, and the remaining spaces are used to accommodate the threshold diodes D23–30. Thus in Fig. 2.6 it can be seen that PCB1 is at the lower end of the keyboard and contains 16 notes plus threshold diodes D23–26 on the left hand end, PCB2 contains 17 notes, whilst PCB3 contains 16 notes plus threshold diodes D27–30 at its right hand end at the upper end of the keyboard.

To assemble the Diode Gate p.c.b.s resistors R5, R14 and R6–9 should first be fitted to the board, omitting R10–13 at this stage. All diodes, including D23–30, should then be soldered followed by R10–13, and finally C13. Care should be taken when fitting R10–13, which are mounted across R6–9, that none of the resistor lead ends are positioned such that shorting can occur.

CLOSE INSPECTION

Experience has shown that whilst repetitive soldering of the type involved in this project is easy, ninety percent of problems occurring in similar projects can be eliminated by *close* physical inspection of the completed p.c.b. The most common fault is to completely miss a solder connection, such that after cropping the waste leads a superficial check on the board indicates that all connections are made. On closer more careful inspection it can then be seen that a component wire is simply passing through a hole without any solder present.

A second possible fault is the creation of a solder bridge

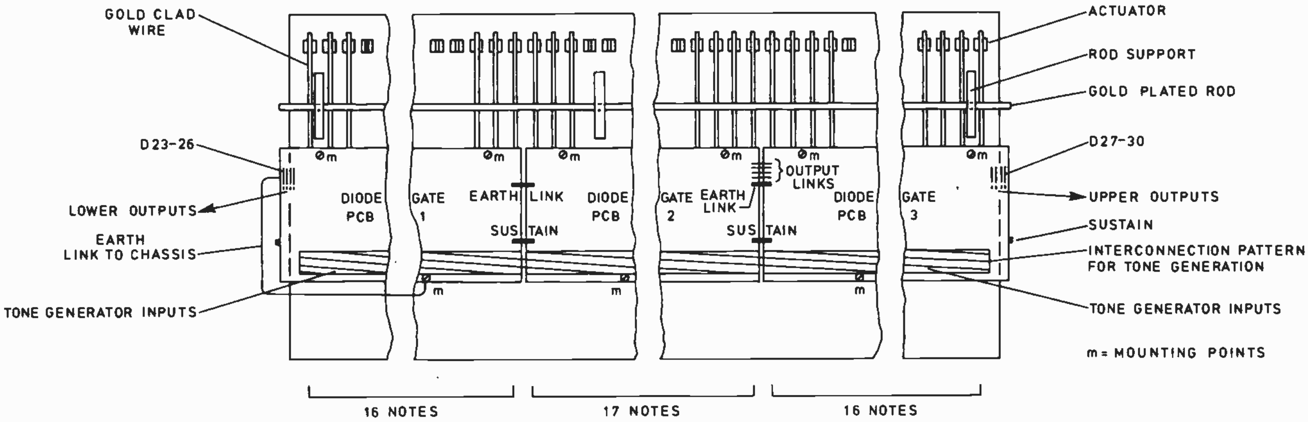


Fig. 2.6. Assembly of Diode Gate p.c.b.s under Veroboard

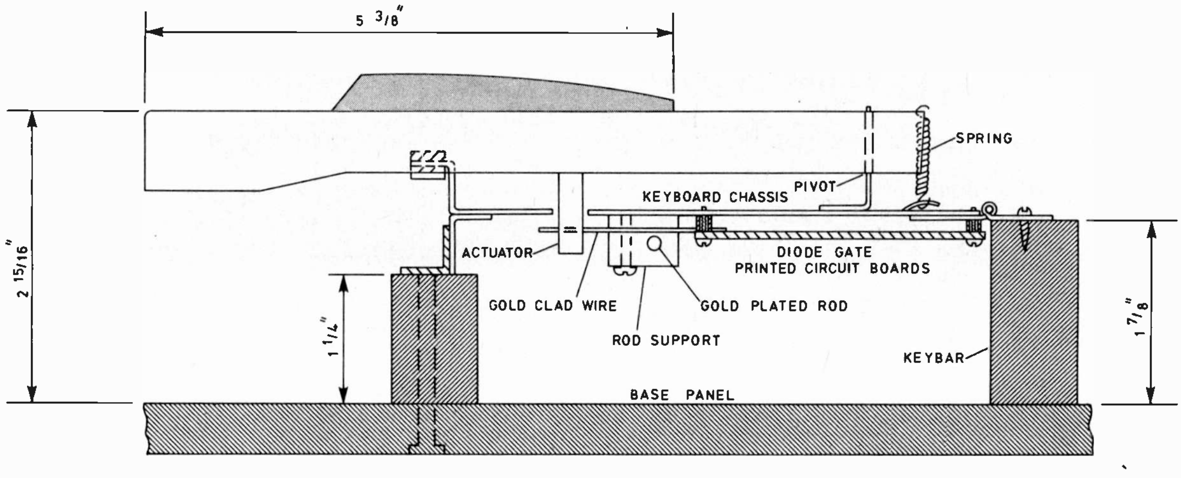


Fig. 2.7. Keyswitch and Diode Gate p.c.b. mounting detail

between two adjacent lands or tracks which again requires careful inspection to detect.

Whilst on the subject of faults the one other error which does occur is the incorrect reading of resistor or capacitor values by factors of ten. Careful attention to these three points in a positive manner leads to a very high degree of complete project success first time when using modern reliable components.

GATE CONTROLS AND P.C.B. MOUNTING

The "Attack" and "Sustain" controls, VR6 and VR7 respectively, are mounted on the front panel at a later stage, and are unnecessary in any tests carried out after assembly of the Diode Gate p.c.b.s and keyswitch.

Referring back to Fig. 2.6 the position of the Gate p.c.b.'s can be seen and before any interwiring is carried out the mounting points (m) for the p.c.b.s can be marked on the keyboard chassis using both Figs. 2.6 and 2.7. Fig. 2.6 also indicates connections between each of the diode gate p.c.b.s.

The interconnection pattern to distribute the signals from the Tone Generator is given in detail later, but it should be noted that earth and sustain links are required both between PCB1 and 2 and between PCB2 and 3. A link should also be made from an earth track to the keyboard chassis to provide an additional screening effect. A further four output links are required between PCBs 2 and 3 which together constitute the 33 notes of the upper section of the keyboard. Outputs for this section are taken from diodes D27–30 and for the lower section from diodes D23–26.

Output footages are marked in Fig. 2.5, with a point E for connecting the four-core cable screen.

KEYBOARD AND KEYSWITCH

The keyswitch action is integrated with the Diode Gate p.c.b.s and consists of gold clad springy wires approximately 2 inches long soldered onto lands provided on the p.c.b.s. Details are shown in **Fig. 2.7.**

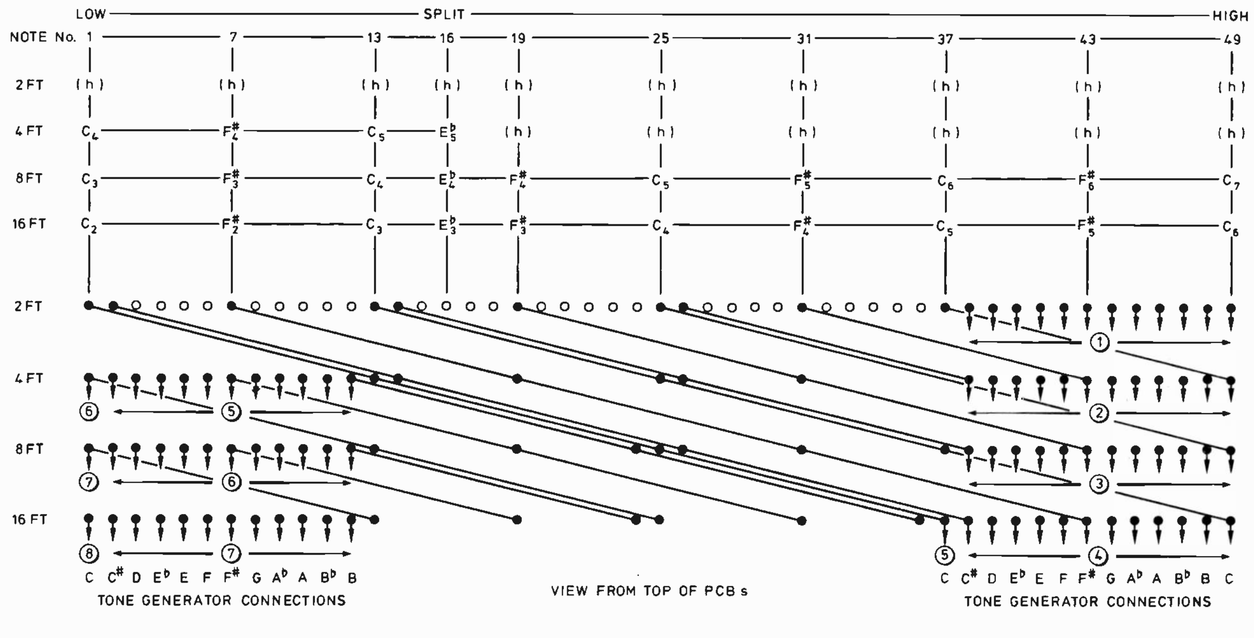
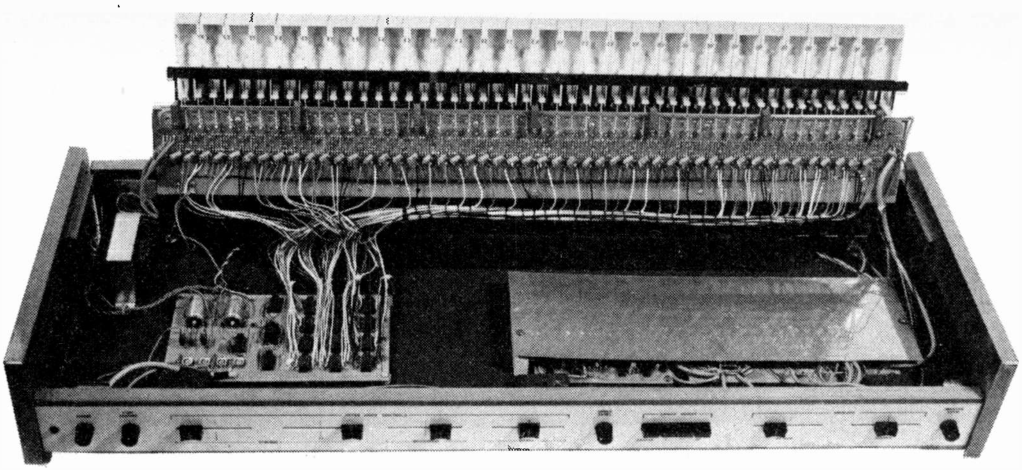


Fig. 2.8. Interconnection pattern for Diode Gate p.c.b. and connections to Tone Generator



The Diode Gate p.c.b.s are shown fixed to the underside of the keyboard with stand off insulated washers.

INTERCONNECTION PATTERN

In order to distribute signals at the four pitches 16ft, 8ft, 4ft and 2ft from the Tone Generator to each note on the keyboard an interconnection process to the pattern shown in Fig. 2.8 is required. This is carried out on the Diode Gate p.c.b.s, a continuous wire linking for example the 2ft gate input for note No. 7 with the 4ft gate input for note No. 19, the 8ft gate input for note No. 31, and the 16ft gate input for note No. 43, then continuing as the interconnecting lead to the Tone Generator board output F♯(4).

All notes in this example are F♯'s and it can be seen from Fig. 2.8 how the same F♯(4) tone generator frequency acts as the fundamental where F♯5 in the piano keyboard, shown in Fig. 2.1(a), occurs, i.e. at 16ft and 8ft in notes 43 and 31 respectively, whilst in note 19 it acts as the fourth harmonic for F♯3 at 16ft and the second harmonic for F♯4 at 8ft, and in note 7 as the eighth harmonic for F♯2 at 16ft, the fourth harmonic for F♯3 at 8ft and the second harmonic for F♯4 at 4ft.

This pattern is repeated for every pitch of every note until a complete matrix is made up with 85 interconnecting leads to the Tone Generator board.

MATRIX CONSTRUCTION

The three Diode Gate board assembly is constructed before it is fixed to the keyboard. The three boards should be temporarily clamped in line using nuts, bolts and washers at the front and rear of each junction, or in a temporary timber frame which allows the boards to sit in slots during assembly.

The first process is to solder the earth and output linkages previously described and shown in Fig. 2.6. Two extra link pads are also provided on the p.c.b.

Copper wire of approximately 28 s.w.g. with a solderable insulated coating is used to build the matrix. A few guidelines for the pattern are given on the p.c.b. component identification diagram in Fig. 2.5. A continuous wire both interconnects the relevant pitch on each note and acts as a lead between the Diode Gate p.c.b.s and the Tone Generator. A solder land is provided on the Gate board for each pitch of each note and has two holes one on each side of the land.

The copper wire is threaded through one hole from the top of the board and then returned through the remaining hole. All interconnect wires can be "knitted" in this way prior to soldering and then as a final process a hot iron is used to melt the insulation providing the solder connection to each land. A cross section of the joint is shown in Fig. 2.9.

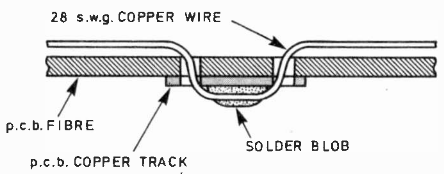


Fig. 2.9. Cross section of solder joint and method of threading copper wire through Diode Gate p.c.b.s

TONE GENERATOR CONNECTION

The points at which interconnect wires are taken from the Diode Gate boards to the Tone Generator are shown in Fig. 2.8. The corresponding Tone Generator frequency reference numbers are also given in this diagram, i.e. C(1) to C(8).

When threading the wires to construct the matrix, an extra length should be allowed to reach the Tone Generator. For connections taken from the left hand group in Fig. 2.8 an extra 16 inches should be allowed, and for connections taken from the right hand group an extra 30 inches should be allowed.

As each wire is fitted to the matrix, labels can be attached to the tone generator end of the lead identifying the tone generator reference numbers, or alternatively identification can be ignorsd whilst interwiring and a multi-meter used to locate the leads at a later stage.

TESTING THE GATE/KEYSWITCH ASSEMBLY

A test of the system can be carried out at this stage by terminating each of the output busbars with 10 kilohm resistors to ground giving simple square wave outputs at 16ft, 8ft, 4ft and 2ft, from lower and upper parts of the keyboard. The Keyswitch rod should be fed direct from the +20 Volt supply on the Tone Generator board, and the sustain line may be fed from either +20 Volts or ground to give maximum and minimum sustain respectively.

Note: In Fig. 1.6 the copper track between pins 1 and 14 should be broken.

Next Month: Cabinet assembly and Chorus System description.