# PE STRING ENSEMBLE

PART 1

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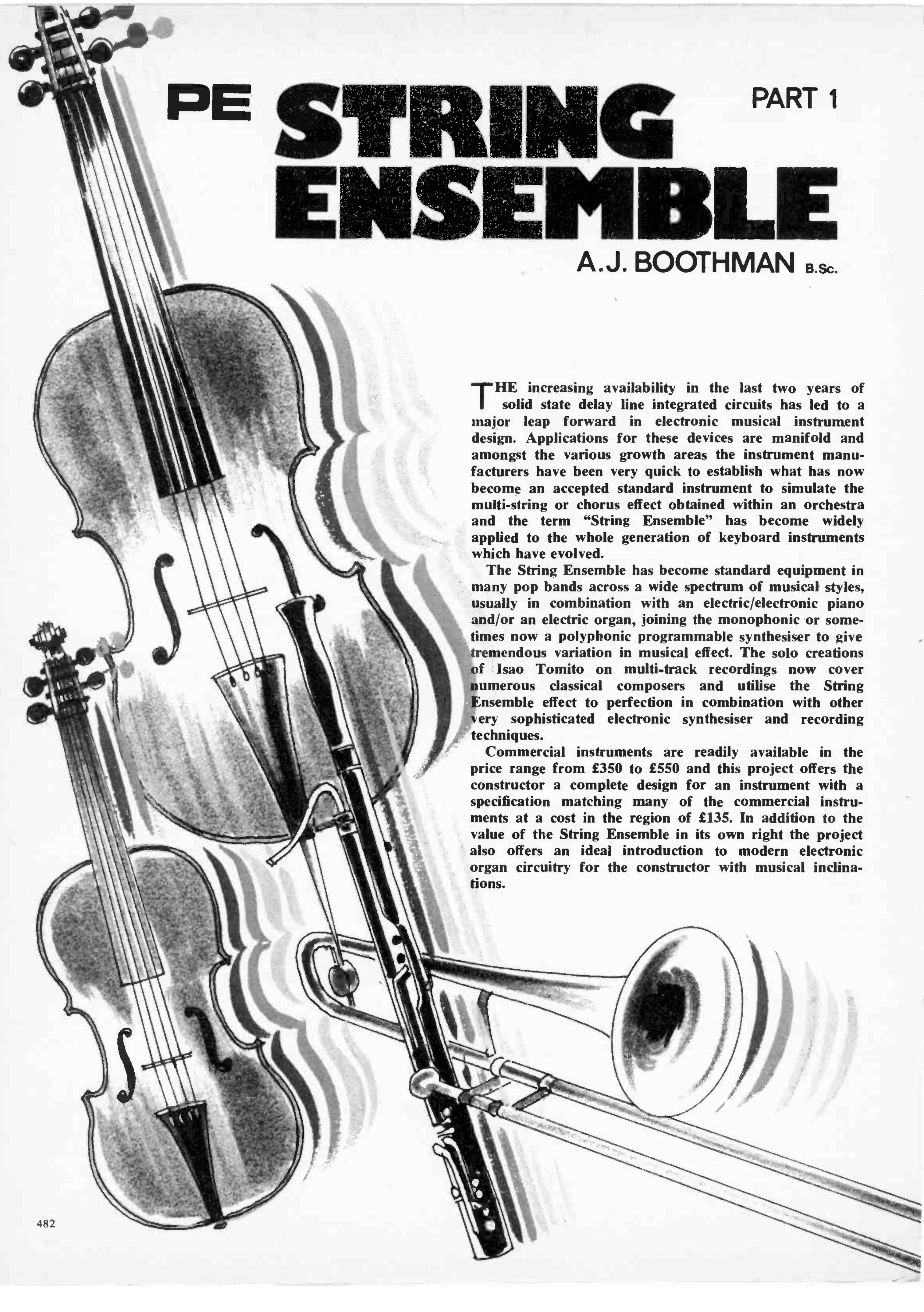


THE increasing availability in the last two years of solid state delay line integrated circuits has led to a major leap forward in electronic musical instrument design. Applications for these devices are manifold and amongst the various growth areas the instrument manufacturers have been very quick to establish what has now become an accepted standard instrument to simulate the multi-string or chorus effect obtained within an orchestra and the term "String Ensemble" has become widely applied to the whole generation of keyboard instruments which have evolved.

The String Ensemble has become standard equipment in many pop bands across a wide spectrum of musical styles, usually in combination with an electric/electronic piano and/or an electric organ, joining the monophonic or sometimes now a polyphonic programmable synthesiser to give tremendous variation in musical effect. The solo creations of Isao Tomito on multi-track recordings now cover numerous classical composers and utilise the String Ensemble effect to perfection in combination with other very sophisticated electronic synthesiser and recording techniques.

Commercial instruments are readily available in the price range from £350 to £550 and this project offers the constructor a complete design for an instrument with a specification matching many of the commercial instruments at a cost in the region of £135. In addition to the value of the String Ensemble in its own right the project also offers an ideal introduction to modern electronic organ circuitry for the constructor with musical inclinations.

## SCOPE OF THE INSTRUMENT

The prime object of the instrument is to simulate the multiple source situation present in the string section of an orchestra, but a number of playing features have been introduced into the String Ensemble which add to its enjoyment and have practical advantages during a performance.

The split keyboard facility which operates on the bottom 16 notes commencing at $E^b$ below middle C (See Fig. 1.1) allows the musician to select a register in the left hand which is either below or above the general compass of the right hand. The effect thus obtained of a moving string section in the right hand passing through a chord in the left hand is impressive. An inverse situation is the use of a single bass note in the left hand against moving chords in the right hand. Many combinations of this sort are possible giving effectively two manual capability.

A Pitch Transposition Control is available primarily for $B^b$ and $E^b$ instrumentalists who would like to use the Ensemble as a rest from playing saxophone or trumpet using their existing music pad, while the B transposition makes it easy to play with those determined guitarists who insist on playing everything in E major. For the home entertainer the apparent increase in the musical capability can bring forth admiration.

The alternative voices are not designed to achieve the same degree of simulation as the strings, but by using these voices in combination with the attack and sustain controls a wide range of sounds can be obtained from trumpet against strings, through piano accordion to the proverbial "Mighty Wurlitzer".

Due to the non-percussive nature of the String Ensemble it is safe to use with a normal hi-fi system although some care should be exercised in the use of heavy bass at full volume! Use with an existing organ speaker system is an alternative solution.

## OVERALL SYSTEM

The block diagram shown in Fig. 1.1 contains the complete system and illustrates the inter-relationship of the various sub-assemblies within the system.

A single printed circuit board assembly contains regulated power supplies and a complete 96 pitch tone generator of which 85 pitches are used in the Ensemble. An oscillator running at approximately 2MHz, controlled by the transposer switch and Fine Tuning potentiometer, feeds into a 12 note master tone generator integrated circuit. Each M.T.G. output is followed by a seven stage divider giving a total of 96 available different frequency square waves, including the top octave.

Diode gating circuit boards are attached to the back of the keyboard with solder bands to anchor the contact wires which travel from the open circuit condition to a positive rail on depression of a key. The envelope available from the gates is controlled by attack and sustain sliders, and each keyer switches four octave related square waves, obtained from the tone generator, onto busbars at 16ft, 8ft, 4ft and 2ft pitch. The gating boards are arranged such that the lower 16 notes are transferred separately from the upper 33 notes, each section having for "footage" busbars as described feeding into the voice circuitry.

On the Voice Circuits Board the square waves are mixed and filtered to produce the required instrumental voices as controlled from the front panel. Balance, Expression Pedal and Master Level control are also connected to the Voice Board.

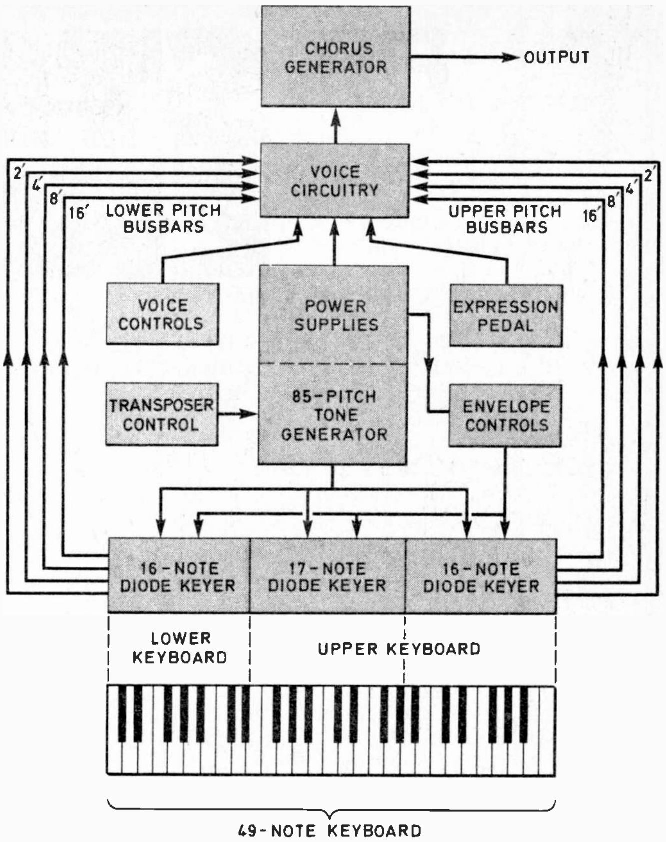


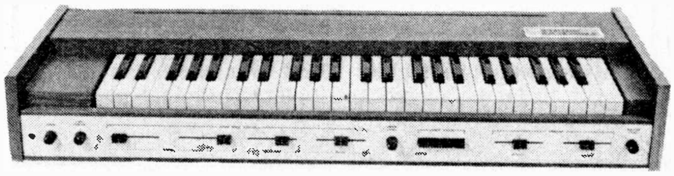

**Fig. 1.1. Block diagram of complete system**

The description to this stage follows one of the most popular methods employed in electronic organ design, and is easily adaptable to the conventional two manual type of instrument based on square wave tone generation. The circuitry used throughout is of CMOS type and the result is a very economic and easily constructed system.

## CHORUS GENERATION

The fundamental difference between the String Ensemble and a conventional electronic organ comes from the chorus generation technique coupled with suitable voice circuitry.

Chorus generation will be covered in depth later in the series, but for readers not familiar with the term in this context, it can be defined as the creation of an apparent multiplicity of sound sources from a single generator, each source producing on average the same note. Within a string section the score will dictate that a group of instruments play the same note but due to changing variations in the phase relationship of each sound the ear detects the fact that more than one instrument is playing.



## SPECIFICATION . . .

**MUSICAL COMPASS**

Four Octaves C to C—49 Notes
Keyboard Split—16 Notes Lower Section/33 Notes Upper Section
Strings available at 16ft and 8ft
Transposable Pitches C-B-$B^b$-$E^b$

**FREQUENCY COMPASS (Concert Pitch)**

Fundamental Range (16ft) 60Hz to 1kHz approx
Fundamental Range (8ft) 120Hz to 2kHz approx
Even Harmonic Generation up to 8·2kHz
Master Oscillator Frequency 2MHz approx

**NOMINAL OUTPUT LEVELS**

| | |
|---|---|
| High Level | 1V |
| Low Level | 100mV |

**MAINS INPUT**

240 Volts, 10 Watts

**SIZE AND WEIGHT**

Dimensions 33½in × 12¾in × 5in
Weight 20lb approx

**CONTROLS**

Power Indicator (l.e.d.)
Transposition Switch
Fine Tuning
Upper Voice Sliders
*String I (16ft)*
*String II (8ft)*
*Woodwind (16ft)*
*Brass (16ft)*
Upper Level Balance
Lower Voice Push Buttons
*Couple Strings*
*String I (16ft)*
*String II (8ft)*
*String III (4ft)*
Master Level
Expression Pedal
Envelope Sliders
*Attack Rate*
*Sustain Length*

**REAR PANEL TERMINATIONS**

Mains Supply Socket and Switch
Mains Fuse
Pedal Socket
High and Low Level Output Sockets

## COMPONENTS . . .

### POWER SUPPLY/TONE GENERATOR

**Resistors**

R1 1.8kΩ
R2 3.9kΩ
R3 470Ω
R4 1.5kΩ
All ¼W 5% carbon

**Capacitors**

C1-C2 1000μF elect. 25V (2 off)
C3-C4 10μF ceramic (2 off)
C5 4.7μF elect. 16V

**Potentiometers**

VR1-VR4 1kΩ presets (100 mW sub miniature)
VR5 500Ω linear

**Semiconductors**

D1-D9 1N4002
D10-D12 1N4148
D13 TIL209
IC1 LM341-15 + ve regulator
IC2 LM320-15 — ve regulator
IC3 4069
IC4 AY-1-0212
IC5-6 4069 (2 off)
IC7-18 4024 (12 off)

**Miscellaneous**

FS1 315mA slow blow fuse and holder. S1 Mains on-off switch. S2 4-way rotary switch. T1 Mains transformer with two secondaries each 15V 10VA. SK1 Mains input socket. 15 off 14 lead d.i.l. sockets. 1 off 16 lead d.i.l. socket. 114 off terminal pins. 1 printed circuit board.

The changing phase difference is caused by many factors associated with physical variations in the instruments, for example string tension, mass and length, body resonance and bridge design, bow characteristics, in addition to the effects introduced by the instrumentalist through bowing technique and small changes from absolute pitch. The controlled addition of vibrato introduces a further major variation in phase relationships, which are very noticeable, particularly when it is realised that the ear is extremely sensitive to small changes in phase relationships between two sound waves.

In the String Ensemble the effective length of electronic delay lives are controlled in a continually changing manner such that the phase relationship between similarly pitched notes coming out of the lives is continuously changing thus simulating a multiple source.

### ENSEMBLE LAYOUT

All the circuitry of the string ensemble is laid out on printed circuit boards which are mounted either on the underside of the keyboard or flat on the chipboard base panel. The simplicity of the concept can be seen in the photograph. Three p.c.b.s contain all the diode gating circuits and contact wires which are pressed onto the keyswitch rest when a note is played. The transformer, P.S.U. Tone Generator, Chorus and Voice p.c.b.s are mounted on the base. An earthed screen covers the chorus and voice circuitry to prevent pick-up from the tone generator harness. All controls are fixed to a front panel and input/output sockets are mounted within apertures in the rear panel.

### BUILDING SEQUENCE

The cabinet has been designed to give a convenient construction sequence for the whole project. The base panel of the cabinet is cut to 32in × 11in × ½in chipboard

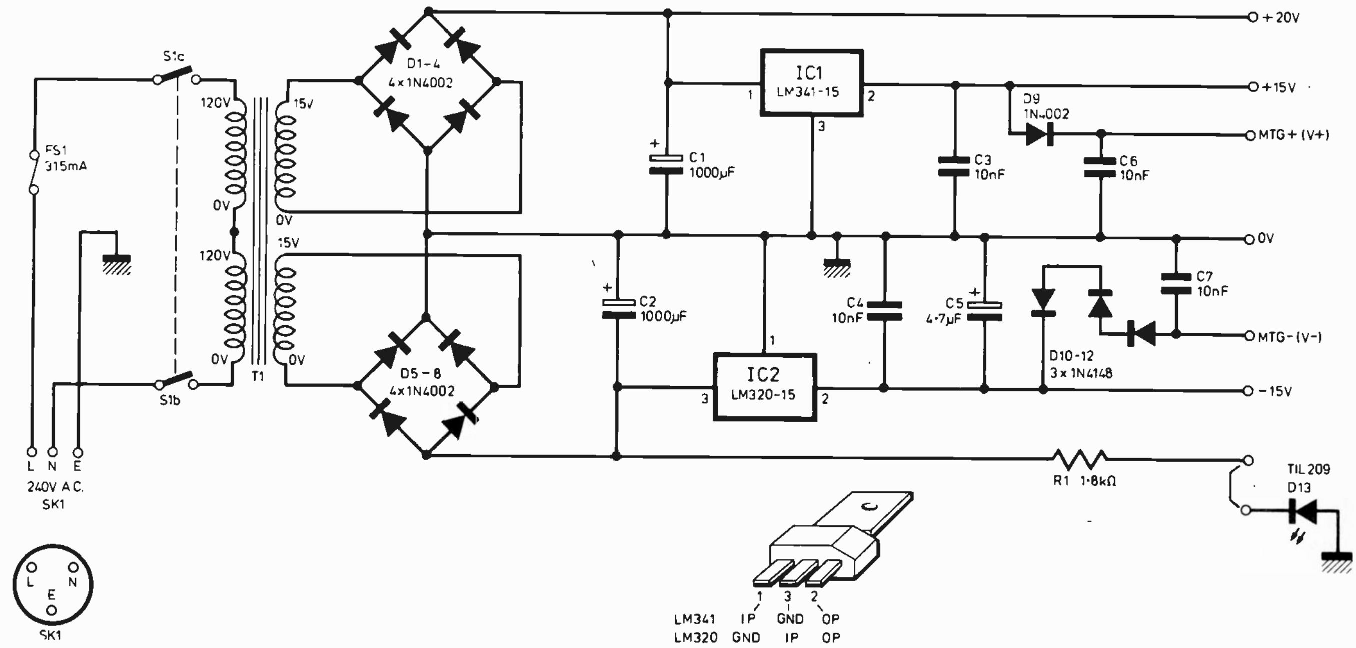



**Fig. 1.2. Circuit of power supply**

and used as the test bed throughout the project. Veneered sections of the cabinet may be assembled towards the end of the sequence to avoid damage to the surfaces.

The first sub-assembly described is the P.S.U./Tone Generator consisting of the transformer and one printed circuit board. These units can be fixed to the base panel, interwired and tested. The keyboard is then mounted onto the base panel from a timber key-bar supporting the rear of the keyboard via hinges. The Diode Gating p.c.b.s will be described, followed by the method of fixing to the keyboard and setting up the keyswitch action. After interwiring of the diode gate inputs to the tone generator, square wave tests may be carried out from the keyer output busbars. The Chorus printed circuit board will be described and may be initially tested using the square waves available at that stage. Finally, the Voice p.c.b. is constructed, and after interwiring to the front panel controls, and construction of rear ad side panels, the instrument is complete.

## POWER SUPPLY

The circuit of the power supply is shown in Fig. 1.2, and consists of a transformer with two 15 volt secondary windings, followed by two bridge rectifiers, which give an efficient running condition for the transformer, producing unregulated supplies of approximately plus and minus 20 volts. The positive rail provides the supply to the keyswitch busbar via the attack potentiometer, whilst the negative rail supplies the l.e.d. front panel power indicator (D13) via R1.

After capacitive smoothing integrated circuit voltage regulators produce plus and minus 15 volts which are used to supply the Voice and Chorus boards. Diodes D9–D12 reduce the supply levels to conform with the requirements of the AY-1-0212 master tone generator, taking into account the tolerance spread which can be obtained from the 15 volt regulators and the voltage supply envelope given in the AY-1-0212 data sheet. In the prototype instrument +14·8 and −15·0 volts were obtained from the regulators giving +14·0 volts and −12·5 volts at the AY-1-0212. This is equivalent of the General Instruments Microelectronics data sheet definition of $V_{DD} = -14$ volts and $V_{GG} = 26·5$ volts which is the best condition for use at its highest operating frequency as required in the String Ensemble.

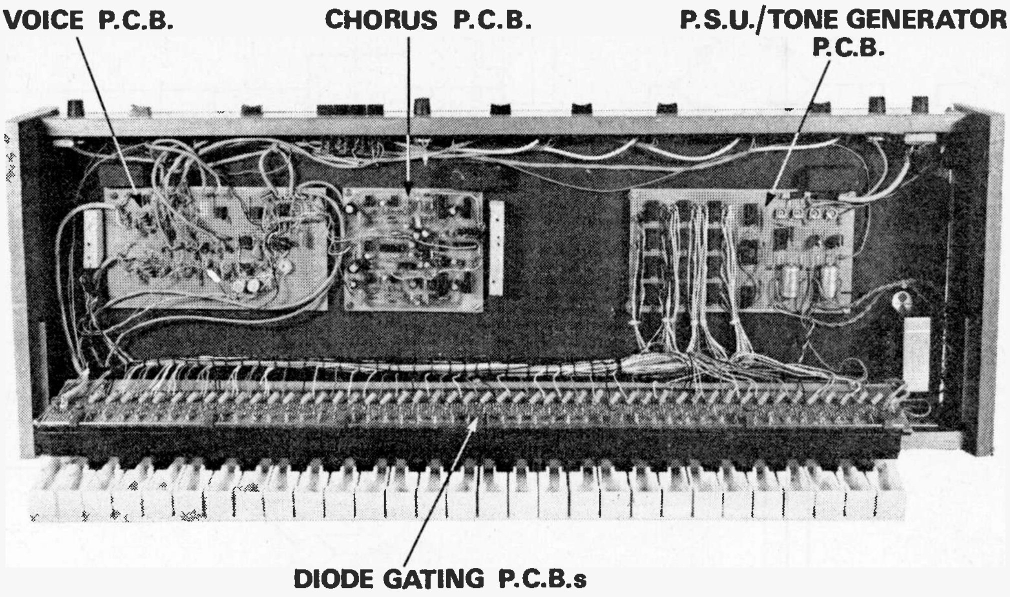
The integrated circuit dividers are also supplied from the voltage derived after D9 and were operating at 14·0 volts in the prototype. Whilst the mains current taken by the power supply is only 40mA, the surge at switch-on created by the inductance in the transformer can be many times greater and it is therefore recommended that a slow blow fuse be used; the 315mA version being a convenient standard type which gives ample protection to the instrument.

## TONE GENERATOR SYSTEM

Frequency generation is centred on the use of the G.I. integrated circuit type AY-1-0212. The remainder of the tone generation circuitry is entirely dependent on CMOS integrated logic circuits producing a system which is very economic, easy to construct and reliable in operation.

A single integrated circuit is used to produce the starting frequency of approximately 2MHz. Many application notes produced by CMOS manufacturers give the simple oscillator shown in Fig. 1.3 which consists of two inverting gates, which in themselves are high gain amplifiers.

Gates connected this way are inherently unstable such that if one considers the input to Inverter 1 to be low, its output and hence the input to Inverter 2 to be high, and the output to Inverter 2 to be low, then capacitor C will charge through resistor R until the voltage at point (A) rises sufficiently to change the state of Inverter 1 such




**Internal layout of String Ensemble**

that its output becomes low. Inverter 2 then also changes its state to become high at the output. The low state of the output of Inverter 1 then provides a low impedance to ground for C to discharge through R thus reversing the cycle.

The CMOS oscillator shown in Fig. 1.4 has considerable advantages over that previously described, the first of which is that it must oscillate. Some polyphonic instruments have been manufactured which when switched on do not always operate due to the fact that the oscillator does not start. Usually this can be cured by switching off and on again quickly but it can be disconcerting to the non-electronically minded musician.

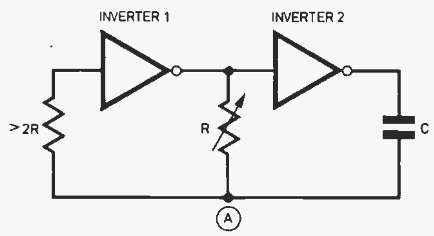



**Fig. 1.3. Two inverter CMOS oscillator**

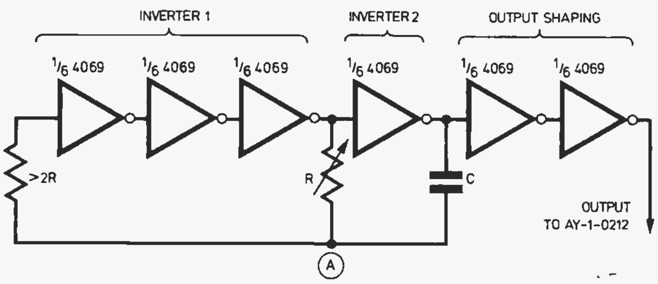



**Fig. 1.4. Multi-inverter CMOS oscillator**

In Fig. 1.4 the first inverter comprises three gates, and it is a fact that any odd number of gates connected from the final output back to the input will oscillate at a frequency determined by the total delay through the chain obtained by running the propagation delay time of each gate. The three gate circuit in the String Ensemble has a natural oscillating frequency of approximately 10MHz.

Inverter 2 consists of one gate and, by the process described for the simple oscillator, the C and R now slow down and determine the frequency of oscillation.

Two extra gates (inverters) finally shape the driving signal to a good square wave swinging over the full power supply range and not degrading as the frequency is changed.

## MASTER TONE GENERATOR

The very clean driving wave form produced by the last two gates in the multi-inverter oscillator allow the AY-1-0212 to be used reliably over its full operating frequency range, and although the G.I.M. specification gives a 1·5MHz maximum for the standard device, out of twenty or so samples tried all worked in excess of 2MHz, many over 3·5MHz.

The slightly more expensive AY-1-0212A is guaranteed to work up to 2·5MHz and this could be used instead of the standard device.

Since its initial introduction the specifications associated with the AY-1-0212 have varied, particularly in respect of operating voltage. As described earlier the power supply has been designed to meet the latest recommendations, particularly for high frequency operation, but it should be noted that circuit descriptions in the String Ensemble adopt the convention of $V_{DD}$ = Ground, $V_{SS}$ is positive, and $V_{GG}$ is negative for the AY-1-0212.

## TONE GENERATOR CIRCUIT

The complete Tone Generator circuit is shown in Fig. 1.5 and is capable of producing 96 tones of which 85 are used. A single 4069 CMOS integrated circuit, IC3, provides the

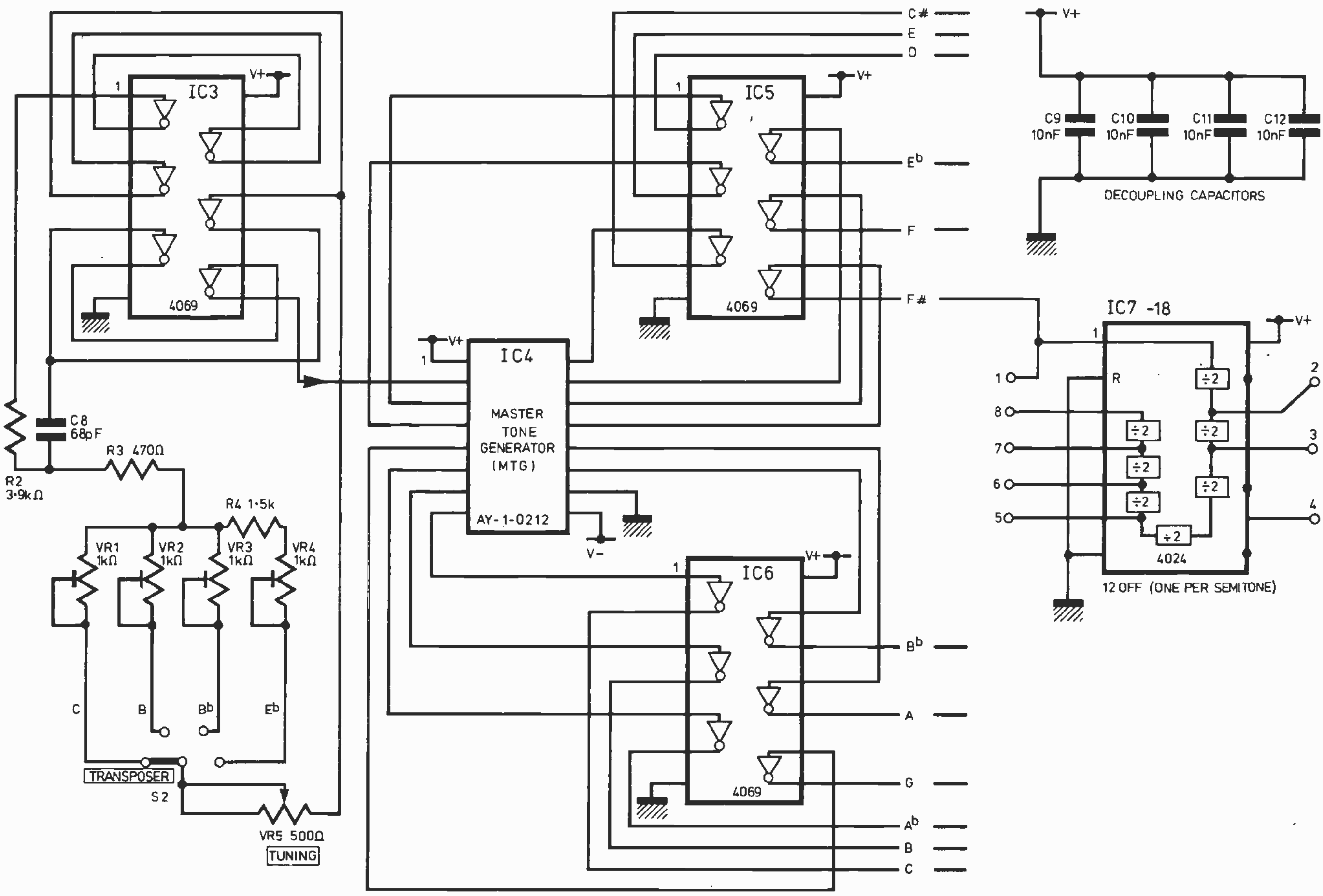



**Fig. 1.5. Circuit of 96 Tone Generator**

six inverters required for the oscillator, the frequency determining network consisting of C8 and the resistive combination of R3 in series with VR5 and VR1, VR2, VR3 or R4 plus VR4.

The alternative resistor combinations are switched by S2.

Following IC4, two hex inverters, IC5 and IC6, are used as buffers to ensure reliable operation of the 4024 seven stage dividers.

Twelve dividers are required, one for each semitone produced by the master tone generator.

The mains input socket, fuse holder and switch feeding the P.S.U./Tone Generator p.c.b. are mounted on a subpanel at the rear of the cabinet, details of which will be given later.

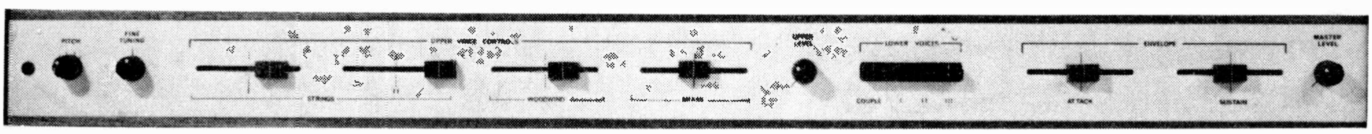
The transformer T1 is mounted on the base panel which it is suggested is used for all construction work as the project proceeds.

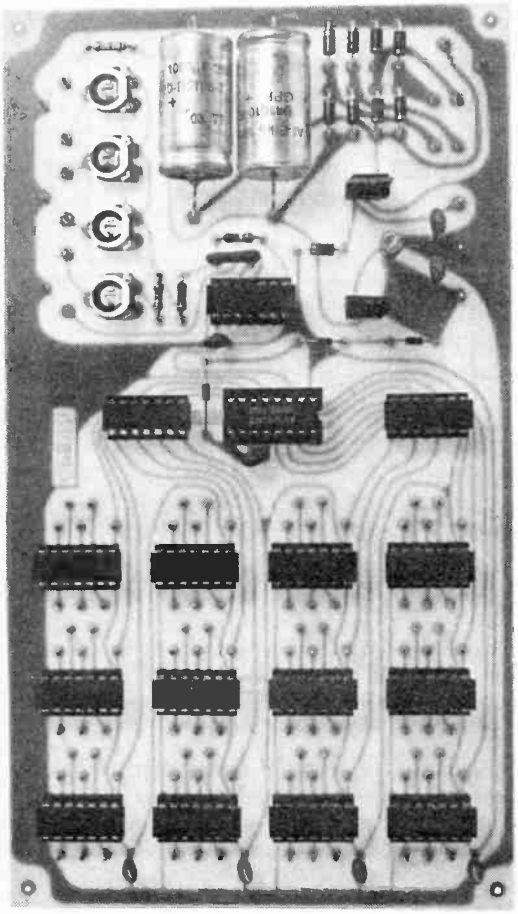
All other power supply and tone generator components are mounted on a single printed circuit board, the etching and drilling details of which are given in Fig. 1.6 with the component assembly details in Fig. 1.7.

To assemble the board the terminal pins should be fitted, followed by resistors, diodes, i.c. sockets, preset potentiometers, small capacitors and finally the large capacitors C1 and C2 and the voltage regulators IC1 and IC2. Sockets have been recommended for all dual in line integrated circuits on this board, partly due to the relative cost of the i.c.s and for easy fault tracing, and also to minimise handling of the i.c.s.

## HANDLING PRECAUTIONS

The AY-1-0212 and CMOS integrated circuits are susceptible to damage by static electricity. All contain internal protection networks designed in by the manufacturers, and after handling considerable quantities of CMOS the author is convinced that he has never damaged a device through static even though handling of the devices has been careless. Nevertheless it is wise to take the precaution of minimising device handling, and carry out the advice of touching an earthed lead before proceeding to insert the integrated circuits into their sockets. *Damage will occur if the devices are reversed.*





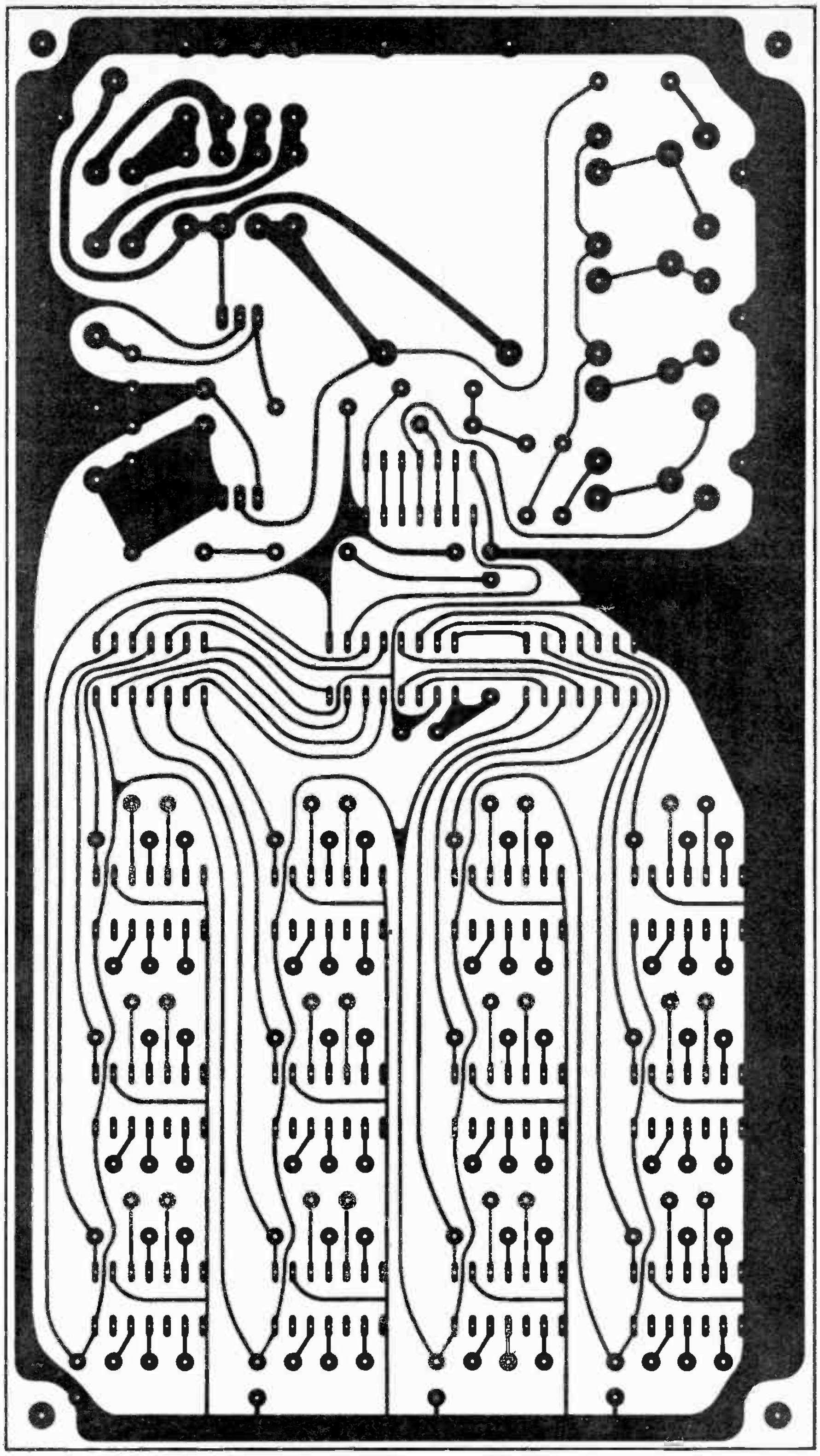


Fig. 1.6. Printed circuit layout of P.S.U./Tone Generator p.c.b.

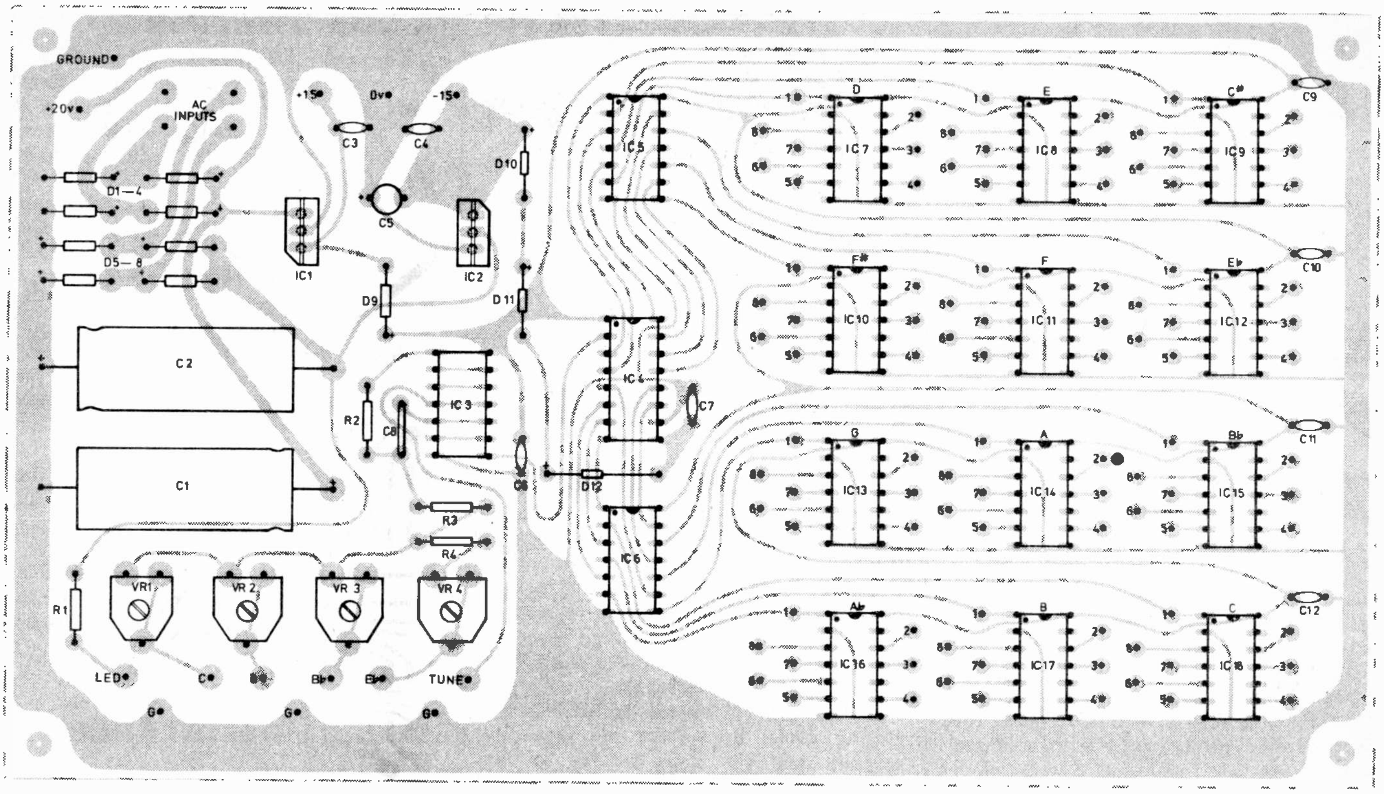



**Fig. 1.7. Component layout of P.S.U./Tone Generator p.c.b.**

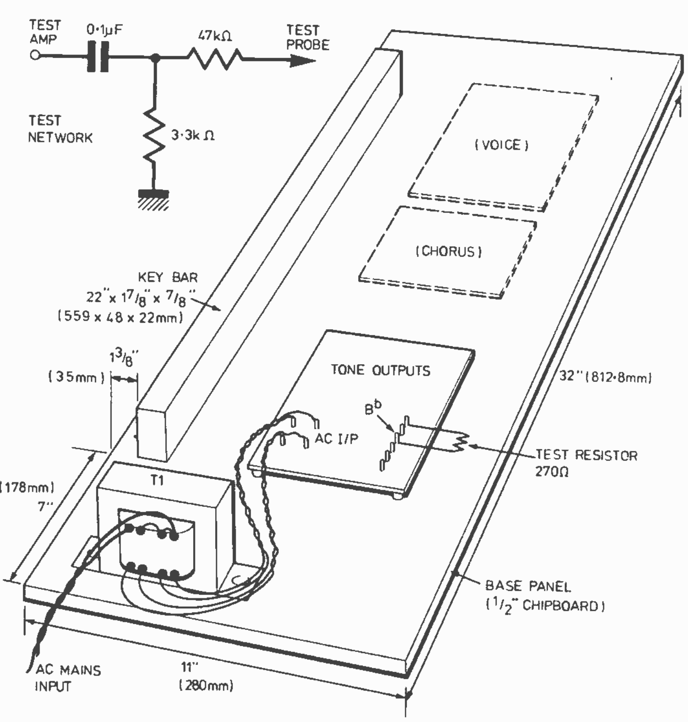



**Fig. 1.8. Mounting of P.S.U./Tone Generator components on base panel for initial test**

The danger of incorrect insertion could arise on the voltage regulators IC1 and IC2. A clearly identified p.c.b. is recommended to avoid this, but for those constructors who may not be using p.c.b.s your attention is drawn to Fig. 3 and to the point that IC1 and IC2 pin connections are different.

## INTERWIRING AND TESTING

Wiring at this stage is limited to connecting the T1 secondaries to the printed circuit board AC input pins as shown in Fig. 1.8. The sketch also shows how the base panel can be prepared by fitting the key bar, and after mounting T1 and the P.S.U./Tone Generator printed circuit board a sub-assembly test can be performed.

To simulate the Transposer and Tuning controls a test resistor of 270 ohms should be soldered between the pins marked "B♭" and "Tune". On connecting the mains, signals should be present at all the output pins grouped around each of the twelve 4024 integrated circuits, and the frequency should be variable by adjusting VR3.

To check the operation the probe network shown in Fig. 1.8 could be used which reduces the signal to approximately 300mV to feed a test amplifier. It is important to note that the 47 kilohm resistor is necessary in order not to overload the dividers. The 14 volt peak-to-peak voltage available from these is far too high for the average amplifier without the 3·3 kilohm attenuation resistor shown.

This test should be carried out *very carefully* since shorting the output pins to each other or ground could cause damage to the divider integrated circuits.

**Next Month: Keyboard, keyswitch and diode gating assemblies.**