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Up to 15 programmable rhythms for electronic organs

by A. Battaiotto and G. Ronzi *SGS-Ates Application Laboratory, Agrate, Italy*

Two m.o.s. integrated circuits designed to drive eight electronic musical instruments according to a programmed rhythm are described. With these i.cs, a rhythm section based on simulated percussion instruments can be incorporated into an electronic organ. Type M252 has 15 programmable rhythms. A general introduction to the rhythm generator is followed by device details and their principal electrical characteristics. A second article deals with the application of the devices and gives circuitry for inclusion of a rhythm section in an electronic organ.

The description rhythm generator is used to refer to a system which generates trigger or excitation pulses for oscillators, whose amplified, damped outputs simulate the acoustic sensation of the musical instruments in the rhythm section. The rhythm generator is not itself a source of sounds, but only a means of timing the switch-on of the oscillator circuits which constitute the sources.

To realize such a system each cycle of the complete rhythm must be divided into a number of "elementary times" using a counting technique. A fixed memory then determines whether or not a given instrument should be triggered during each of these elementary times. The elementary times or counter states, which constitute the smallest subdivisions of the rhythm can be grouped into bars or measures, usually 1, 2, 3 or 4. Within the complete rhythm, each of these bars can be programmed differently.

Each bar, then, consists of n elementary times in which the beats of each instrument will be programmed to occur. In musical notation the length of these beats is described as a fraction of a known reference period see Fig. 1. When the sum of the beats in any bar comes to 4/4, the rhythm is described as 4/4.

The number of elementary times in the bar fixes the minimum duration of each beat; in other words, the greater the number the elementary times the shorter will be the minimum length of the beats and the richer the resulting rhythm. For example, a 4/4 rhythm programmed in four bars over 32 elementary times, i.e. eight per bar, can only use musical beats of length 1, 1/2, 1/4 or 1/8 and not of 1/16, 1/32, 1/64. If the same rhythm is programmed in two bars of 16 elementary times each, musical beats of length 1, 1/2, 1/4, 1/8 and 1/16 can be used, 1/32 and 1/64 being still excluded. The basis of such a rhythm generator is illustrated by the block diagram of Fig. 2.

Table 1. Count requirement

1st case:	Rhythm: 4/4 Minimum duration of each beat: 1/16 Number of bars per rhythm: 2 ∴ Count is 16 elementary times × 2 bars = 32
2nd case:	Rhythm: 3/4 Minimum duration of each beat: 1/16 Number of bars per rhythm: 2 ∴ Count is 16 × 3/4 × 2 = 24.
3rd case:	Rhythm: 5/4 Minimum duration of each beat: 1/16 Number of bars per rhythm: 1 ∴ Count is 16 × 5/4 × 1 = 20.

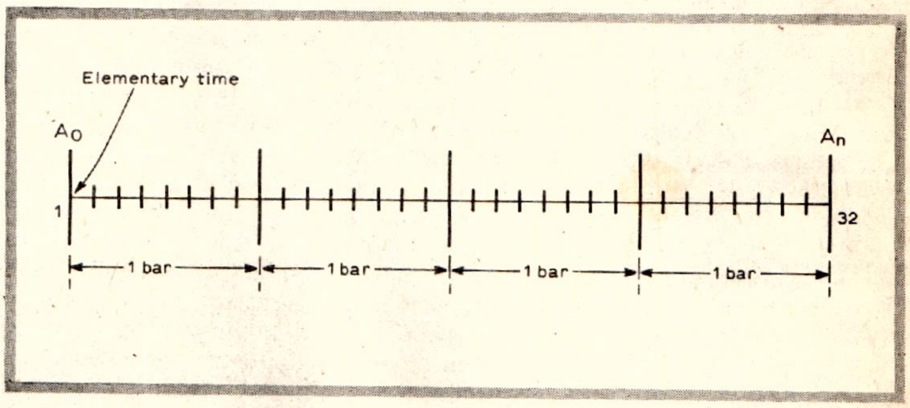
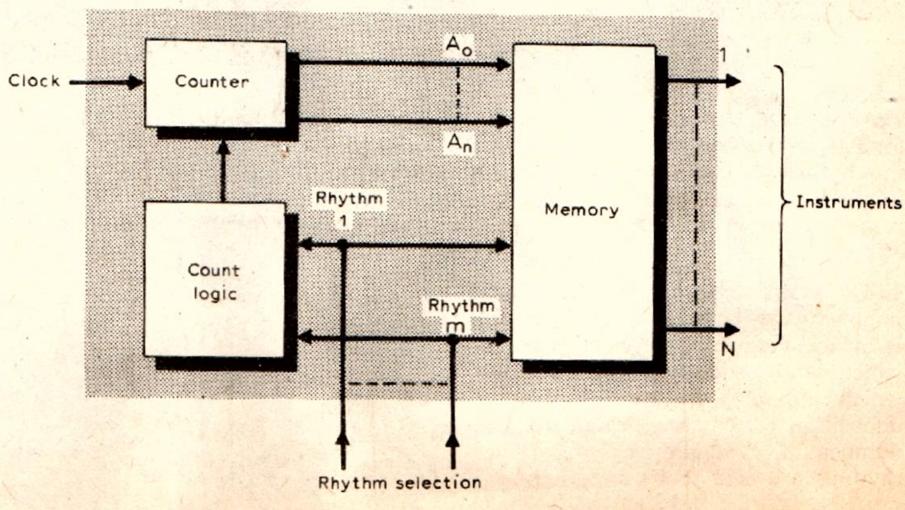


Fig. 1. Division of the rhythm into elementary times and bars.

Fig. 2. Block diagram of a trigger generation system for the oscillator circuits.



Counter

The counter must be able to count the number of elementary times corresponding to rhythms of 3/4, 4/4 and 5/4. This means that the counter must stop and reset to its initial position (to repeat the rhythm) after a certain number of counts which depends on the selected rhythm.

Two characteristics of the rhythm determine the count requirement i.e. the minimum beat of the rhythm, and the number of bars in the complete rhythm Table 1.

Making a practical rhythm generator

The system described in principle above can be realized with integrated circuits or discrete devices, illustrated in Fig. 3. If i.cs are used the counter can be produced in t.t.l. although due to the large amount of storage required, the memory will almost certainly have to be in m.o.s. Using a 4096-bit memory such as the M240, organized in 512 words of 8 bits, it is possible to program 16 rhythms selected by lines A5, A6, A7 and A8, each consisting of 32 elementary times (the counter drives lines A0, A1, A2, A3 and A4). As the r.o.m. outputs are not of the reset-to-zero type they must be reset by an external clock before being applied to the instrument oscillators. If the generator were to be built with discrete components both the memory and the count decoder could be realized with a diode matrix. The return to zero of the outputs can be achieved by resetting the decoder. But such a system would lead to the use of a very large number of diodes. As a result the reliability would be poor and the assembly cost very high.

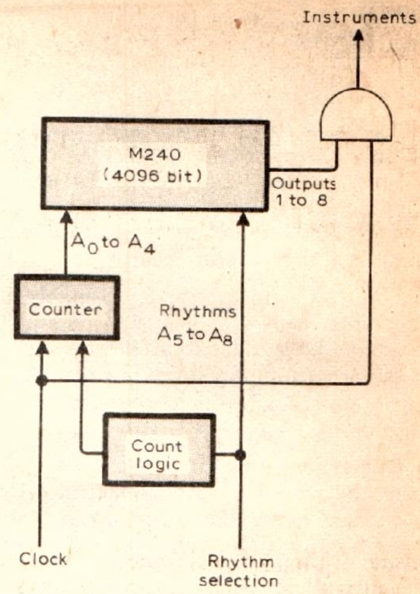
The ideal rhythm generator

The characteristics of an ideal rhythm generator can be summarized in the following points.

1 The entire system described above would be contained in a single device thereby achieving maximum reliability in the minimum space. The labour required for assembly is also reduced.

2. The counter should have the highest count possible. For a rhythm containing a fixed number of bars this means that the rhythm can be subdivided into shorter beats and will consequently be musically more interesting. Similarly for a given number of elementary times the rhythm can be made up of a greater number of bars, possibly different, resulting in a more interesting musical effect.

3. The system should provide a large number of rhythms. Here it is necessary to make a distinction between rhythms which can be superimposed and those which cannot, as the concept of superimposition is closely linked to the number of available rhythms. Two rhythms are said to be superimposed when, selecting both simultaneously at the system input, the output commands for each instrument correspond to a combination of the commands that would have been produced by the rhythms selected separately, see Figs 4 & 5. Technically, rhythms can only be superimposed if they are selected by means of separate lines and not by a coding technique. Superimposition, therefore, involves a greater number of input pins (one for each rhythm), but does not call for a very high number of rhythms because the organist can choose any combination of those available.



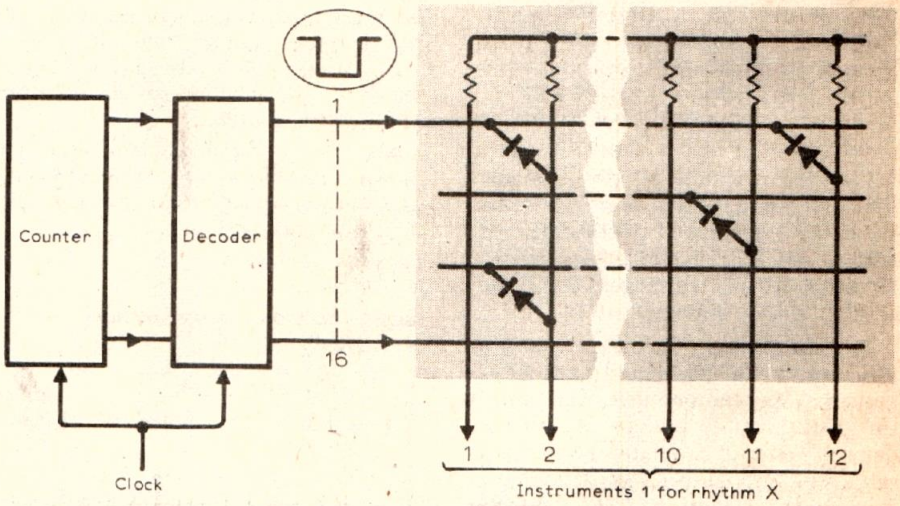


Fig. 3. System realized with i.cs (right) and with discrete devices (below).

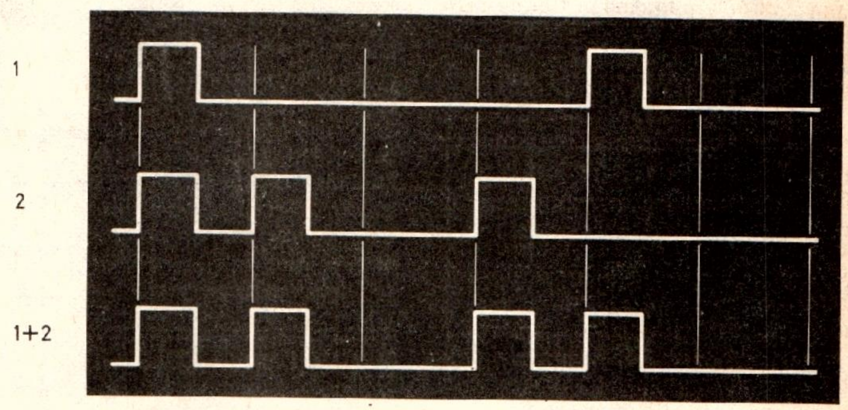


Fig. 4. Instrument trigger for combination of two rhythms.

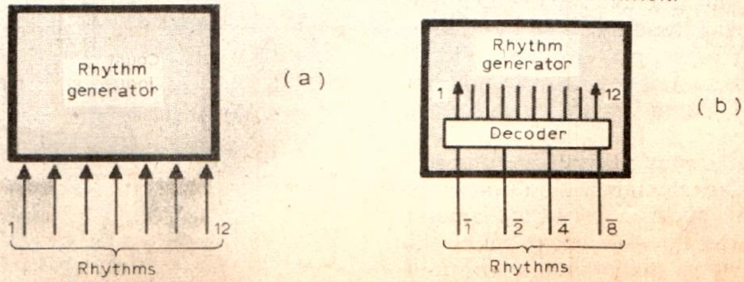


Fig. 5. Rhythms superimposed and not. At (a) 12 rhythms are available in combination, at (b) 2^4 rhythms not available in combination.

In general, 12 is a sufficient number of rhythms if they can be superimposed, but there have to be more if superimposition is not possible, usually 15 or 16.

4. The system must have a large number of outputs (instruments). The number of instruments programmed for each rhythm will generally vary between 3 and 6. Eight represents a maximum number which is rarely used.

5. The system must be programmable in any time, 3/4, 4/4, 5/4, 6/8. It must therefore be possible to intervene at the mask programming stage, on the reset of the elementary time counter for each rhythm.

6. The system must produce no spikes on the memory outputs caused by successive decoded counter states. This creates undesired triggering of the instrument oscillators.

7. The system must provide the possibility of externally resetting the elementary time counter, so that it restarts from the first elementary time of the first beat. This enables key or touch operation in which the rhythm generator remains reset until at least one key is played.

8. The system should supply a downbeat output signal corresponding to the first elementary time of the first beat of each rhythm. This signal allows synchronization between the organist and the device's internal counter.

9. The system must be realized with a static form of logic designed for the low frequency operation of a rhythm generator (20 Hz).

Table 2: Rhythm selections
The following binary code must be generated to select each rhythm (logic positive)

Rhythm	8	4	2	1		
1	1	1	1	0	Waltz	3/4
2	1	1	0	1	Jazz Waltz	3/4
3	1	1	0	0	Tango	2/4
4	1	0	1	1	March	2/4
5	1	0	1	0	Swing	4/4
6	1	0	0	1	Foxtrot	4/4
7	1	0	0	0	Slow Rock	6/8
8	0	1	1	1	Rock Pop	4/4
9	0	1	1	0	Shuffle	2/4
10	0	1	0	1	Mambo	4/4
11	0	1	0	0	Beguine	4/4
12	0	0	1	1	Cha Cha	4/4
13	0	0	1	0	Bajon	4/4
14	0	0	0	1	Samba	4/4
15	0	0	0	0	Bossa Nova	4/4
No selected rhythm	1	1	1	1		

10. The system must be input compatible with t.t.l. and d.t.l. level signals so that it can be interfaced with an oscillator realized with such devices.

11. The system must have low dissipation — 150 to 300 mW.

12. The system must have a single standardized supply.

Points 2, 3 and 4 together create a single requirement, namely that the system must have a maximum memory capacity in terms of the number of bits. The maximum number of bits is limited by the die-size of the device which in turn is determined by the cost of the device itself.

Once the memory capacity has been established by economic factors, it follows that a compromise between the number of rhythms, the number of instruments and the number of elementary times will be made. An effective solution is

— a maximum of 32 elementary times
— 8 instruments
— 15 rhythms

with a memory capacity of 3840 bits (32x8x15).

The SGS-ATES solution

Rhythm generators type M253 and M252 fulfil all the requirements of the ideal system, see Fig. 6.

● The M 253 has:

– 12 rhythms which can be superimposed
– 3 instruments for 3/4 or 4/4 tme or 7 instruments for any time
— a maximum of 32 elementary times
— external reset

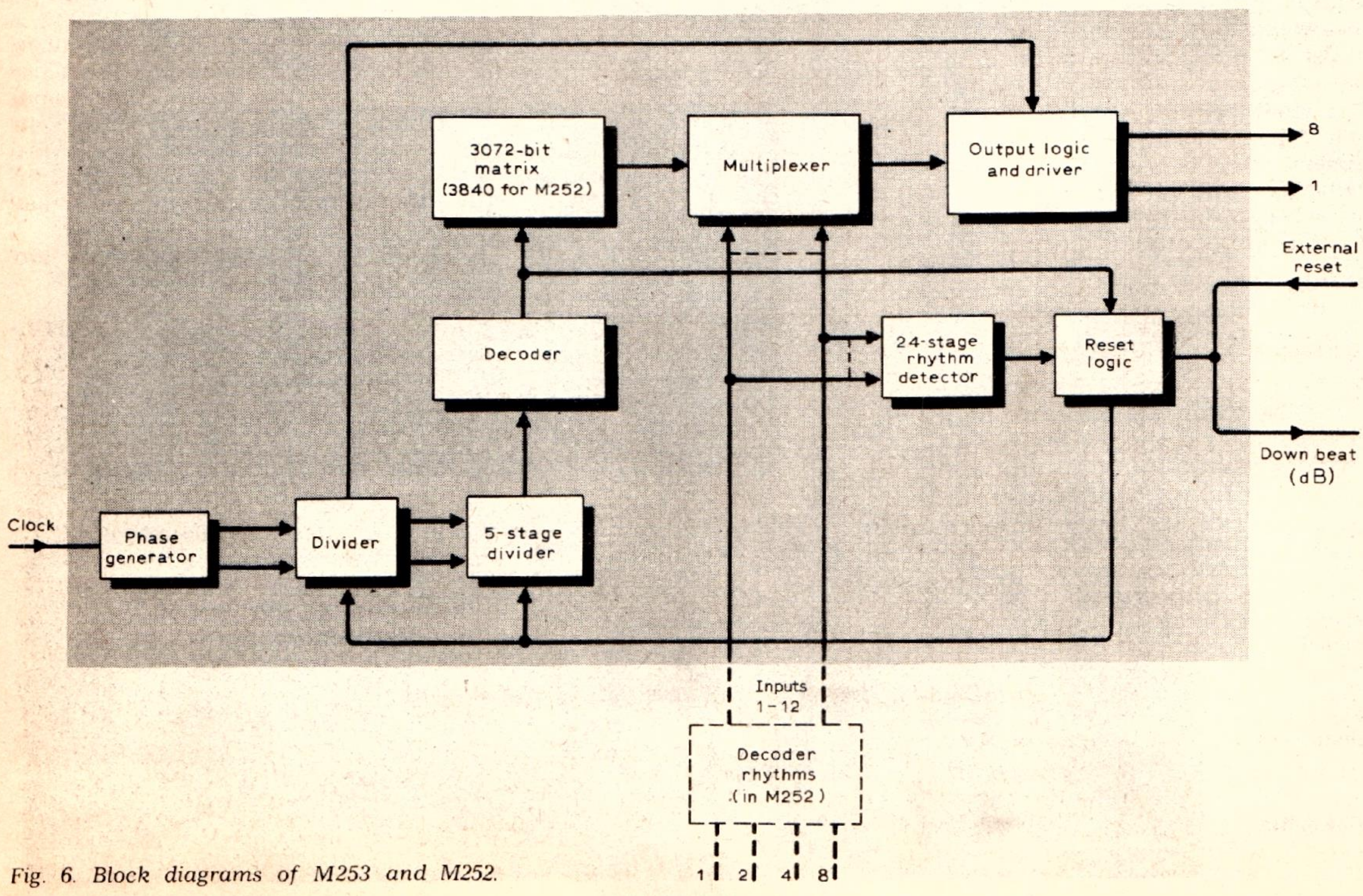


Fig. 6. Block diagrams of M253 and M252.

— down-beat output
— internal anti-spike circuit
— single supply
— low dissipation, typically 100 mW
— pin-to-pin compatible with the M250
— directly coupled
— 24-pin plastic or ceramic package

● The M 252 has:
– 15 rhythms which cannot be superimposed
– 8 instruments for 3/4 or 4/4 time or 7 instruments for any time
— maximum of 32 elementary times
— external reset
— down-beat output
— internal anti-spike circuit
— single supply
— low dissipation, typically 100 mW
– can be directly interfaced (input) with t.t.l, d.t.l.
— directly coupled
— 16-pin plastic or ceramic package.

Both of these devices are derived from the same chip which, during the processing stages, is provided with the memory pattern specified by the customer and the ancillary functions that distinguish the particular system.

How the M 253 works

The phase generator uses the incoming clock signal to produce the two non-over-lapping phases at regenerated levels which are required for driving the following divider.

This divider has to create a reset signal for the return to zero of the outputs. Width of this pulse is independent of the duty cycle of the incoming clock. The divider's outputs also serve as timing signals for the first stage of the five-stage counter, which uses master-slave static flip-flops.

The counter states are decoded to drive the rows of the memory matrix. The columns of the matrix are divided into 12 groups of 8, representing the 12 rhythms and the 8 instruments. One particular state, the 24th is decoded, logically combined with the rhythms in 3/4 time and is used as the counter's internal reset for rhythms programmed in this time. This device is therefore suitable for programming any rhythm in 4/4 time over 32 elementary times or in 3/4 time over 24 elementary times. This means that when a rhythm is programmed over a single bar the intervals can be as short as 1/32 allowing great musical flexibility.

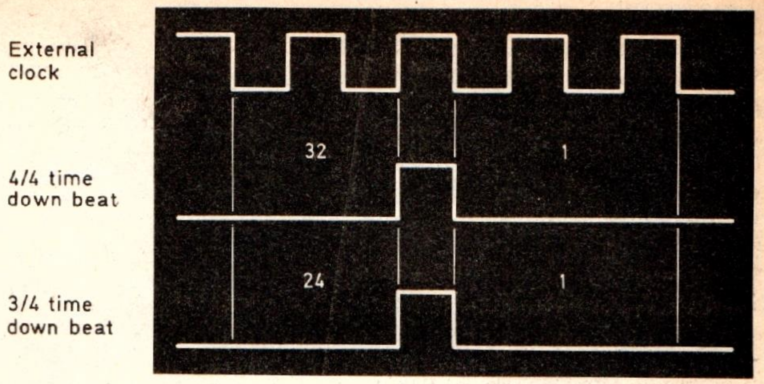


Fig. 7. Down-beat timing and duration.

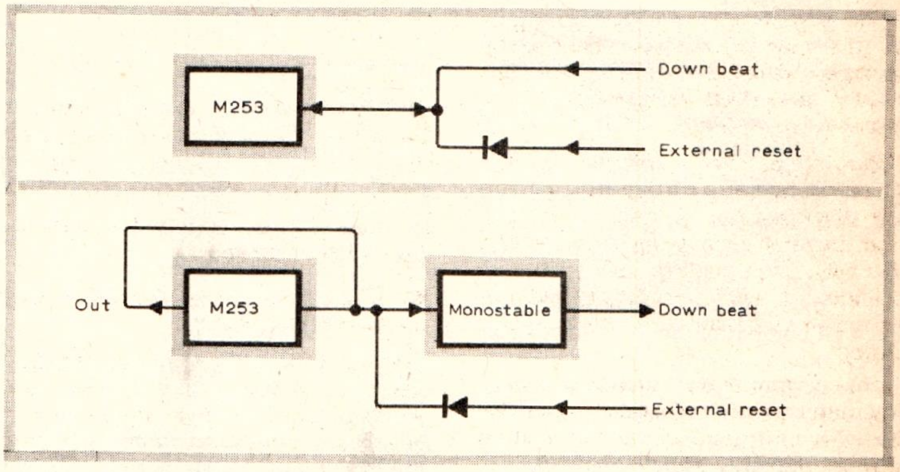


Fig. 8. Use of the down-beat signal.

The counter can also be reset by an external signal which, when driven directly by an output of the M253 itself, sacrificing one instrument, can be used to reset the counter to any position for times other than 3/4 or 4/4. If, for example, we want to reset at the state n for a rhythm X, a beat must be programmed at the elementary time $n + 1$ at the output of the rhythm to be used as reset. This output, connected at the input of the external reset, immediately zeroes the counter and therefore causes the disappearance of the reset signal; other than the $n+1$ beat there should be no program on the output used as the reset.

The columns of the matrix are

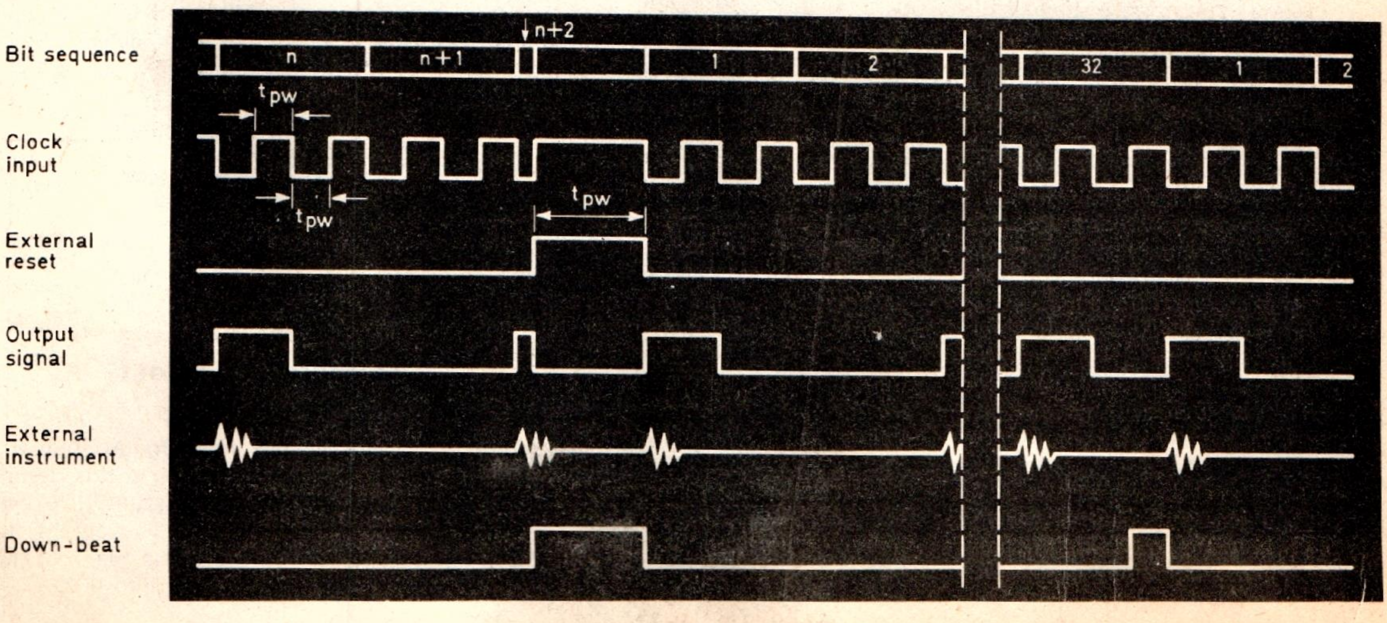


Fig. 9. Timing waveforms.

enabled, singly or in groups (the rhythms can be superimposed) via the buffer according to the rhythm or rhythms selected. The presence of one rhythm, therefore, does not exclude the possibility of another rhythm being selected contemporarily, and the result on the output of each instrument for each rhythm is the sum of the beats of the single rhythms, see Fig. 4. One particular case is when the rhythms are selected contemporarily with a different matrix, eg a 3/4 or 4/4 rhythm. In this case the count cycle will correspond to the rhythm with the lowest number of elementary times, in the example the cycle will be of 24 elementary times.

The delayed, decoded signal from the 24th state (3/4 rhythms) and the 32nd (4/4 rhythms) are used as down-beat signals, i.e. as starting signals to indicate the first beat of the first bar, see Fig. 7. This signal, whose usefulness will be seen in the application section, was brought out to a pin already used for an input signal — the external reset signal — since no supplementary pin was available in the package used. In reality, the presence of an external reset signal is compatible with a down-beat signal although the reverse is not true as a down-beat signal must not have the effect of an external reset. This can be achieved by using a diode to separate the two signals as shown in Fig. 8.

For rhythms other than 3/4 or 4/4 the pulse present at the output connected to the external reset can be used to trigger a monostable circuit, whose output will be the down-beat signal. When no rhythm is selected the down-beat signal is present and the counter counts to 32.

Operation of the M252

The phase generator, the counter, the matrix, the output and reset logic, and the 24th state decoder for the reset in 3/4 time, operate in the same way as in the M253. The difference is in the rhythm command inputs, which are in binary logic using the code shown in Table 2. Given that it is impossible to select two different codes at the same time, it follows that it will be impossible to superimpose these rhythms.

One code word has been used to indicate "no rhythm selected." In this state, there are no instrument output signals, the down-beat signal is present and the counter counts to 32.

For the dynamic characteristics note that a duty cycle of 50% is not required for the clock signal. The width of the "mark" of the clock waveform need only be as great as the width of the down-beat impulse internally generated.

Supplies and absolute maximum ratings

All the supplies and levels shown in Tables 3 and 4 are expressed as a function of V_{SS}. As V_{SS} can have any value, various power supply formats can be used, e.g. V_{GG} 0V, V_{SS} 17V; V_{GG} −12V, V_{SS} +5V, and so on as long as $V_{SS}-V_{GG}=17\pm1$V. This makes it very simple to solve the problem of interfacing with input and output devices. The user, however, must always respect the limits imposed by the absolute maximum ratings, Table 5. These voltages, temperatures or currents are values which must never be exceeded, not even momentarily, as the device can be permanently damaged should this occur.

It is of particular importance that a check is kept on the positive overshoot at all the pins with respect to V_{SS} (see Fig. 10). If the positive overshoot, which, on the oscilloscope will always appear limited to one V_{BE} when measured on an in-circuit device, exceeds the values quoted in the absolute maximum ratings it causes a parasitic which discharges the surrounding negative nodes, causing incorrect circuit operation. More seriously, a fixed positive level more than 300 mV above V_{SS} will probably damage the circuit.

(To be continued)

Table 3: Static electrical characteristics (positive logic, V_{GG} −11.4 to −12.6V, V_{SS} 4.75 to 5.25V, T_{amb} 0 to 70°C unless otherwise specified)

Quantity		Test conditions	Min.	Typ.	Max.	Unit
Clock input						
V_{IH}	Clock high voltage		$V_{SS}-1.5$		V_{SS}	V
V_{IL}	Clock low voltage		V_{GG}		$V_{SS}-4.1$	V
Data inputs ($\overline{IN1}$ ..... $\overline{IN12}$)						
V_{IH}	Input high voltage		$V_{SS}-1.5$		V_{SS}	V
V_{IL}	Input low voltage		V_{GG}		$V_{SS}-4.1$	V
I_{LI}	Input leakage current	$V_i=V_{SS}-10V$ $T_{amb}=25°C$			10	µA
External reset						
V_{IH}	Input high voltage		$V_{SS}-1.5$		V_{SS}	V
V_{IL}	Input low voltage		V_{GG}		$V_{SS}-4.1$	V
R_{IN}	Internal resistance to V_{GG}	$V_o=V_{SS}-5V$	400	600		kΩ
Data outputs						
R_{ON}	Output resistance	$V_o=V_{SS}-1$ to V_{SS}		250	500	Ω
V_{OH}	Output high voltage	$I_L=1mA$	$V_{SS}-0.5$		V_{SS}	V
I_{LO}	Output leakage current	$V=V_{IH}$ $V_o=V_{SS}-10V$ $T_{amb}=25°C$			10	µA
Consumption						
I_{GG}	Supply current	$T_{amb}=25°C$		7	15	mA

Table 4. Dynamic electrical characteristics (positive logic, V_{GG}, V_{SS} −16 to −18V, T_{amb} 0 70°C unless otherwise specified)

Quantity		Min.	Max.	Unit
Clock input				
f	clock repetition rate	0	100	kHz
t_{pw}°	pulse width	5		µs
t_r°°	rise time		100	µs
t_f°°	fall time		100	µs
External reset				
t_{pw}	pulse width	5		µs

° Measured at 50% of the swing
°° Measured between 10% and 90% of the swing

Table 5. Absolute maximum ratings

V_{GG}*	Source supply voltage	−20 to 0.3V
V_i*	Input voltage	−20 to 0.3V
I_o	Output current (at any pin)	3mA
T_{stg}	Storage temperature	−65 to 150°C
T_{op}	Operating temperature	0 to 70°C

*This voltage is with respect to V_{SS} pin voltage

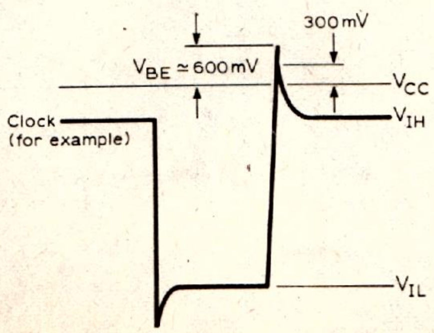


Fig. 10. Positive overshoot.

Low-noise, low-cost cassette deck

Several readers have found that the erase and bias oscillator in this design (May, June and August issues, 1976) can be reluctant to work. The cure is to reduce the value of C_{21} in Fig. 5 of the May 1976 issue from 2.2µF to 1µF.

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Interfacing the M252 and M253 circuits, described in the March issue

by A. Battaiotto and G. Ronzi, *SGS-Ates Application Laboratory, Agrate, Italy*

So that the rhythm section may be inserted into an electronic organ, a signal must be available which indicates whether one or more keys on the organ key board have been played. This signal, which we call the key played, starts the rhythm section. When a key is played the rhythm section can be arranged to start at the beginning of the bar (touch or key operation), i.e. the playing of a key removes the reset from the clock and from the M 252 or M 253.

Alternatively it can be arranged to start at any point in the bar (continuous or silent operation) i.e. the rhythm generator runs continuously, but its output is enabled by the "key played" signal. In continuous operation, therefore, the down-beat indicator is indispensable as it allows the first key to be played when the bar begins.

A third method (continuous free running) allows the unit to operate without playing any of the keys. This is done simply by selecting a rhythm on the push button array of the rhythm section. Neither the touch key nor the continous silent key must be on when this method is used.

Fig. 11 illustrates the insertion of the electronic rhythm section into an organ. The two parts within dashed lines are details of the rhythm section, of interest for the connections to the keyboard of the organ.

Rhythm section with 15 rhythms and 9 instruments

This rhythm section, realized with the M 252AA, is programmed with 15 different rhythms in such a way that each rhythm can use up to a maximum of eight of the nine instruments available, Fig. 12. The 15 rhythms programmed are the waltz, jazz, waltz, tango, march, swing, foxtrot, slow rock, pop rock, shuffle, mambo, beguine, cha cha, bajon, samba and bossa nova, and can be brought in one at a time by means of the key board. The instruments available are the bassdrum, snare drum, claves, high bongo, low bongo, conga drum, long cymbals, short cymbals and maracas.

The three controls are volume, tone and tempo. In addition, a switch allows the rhythm to be started at the beginning of the bar or stops the rhythm. The assembly is carried out on two printed circuits, one contains the sound generators and preamplifier, and the other contains the supply, the M 252AA, the variable clock generator and the monostable circuit for driving the down-beat lamp.

The circuit can be divided into four parts, the sound generators, the variable clock generator, the down-beat monostable and the encoder. Operation of the M 252AA has already been described in the first part, but some further details will be given toward the end of this description.

Sound generators

The generators are designed to reproduce as faithfully as possible the sounds made by percussion instruments. They can be divided into two broad groups, namely, sounds consisting of damped, sinusoidal waves, like drums, and those consisting of damped white noise, like cymbals.

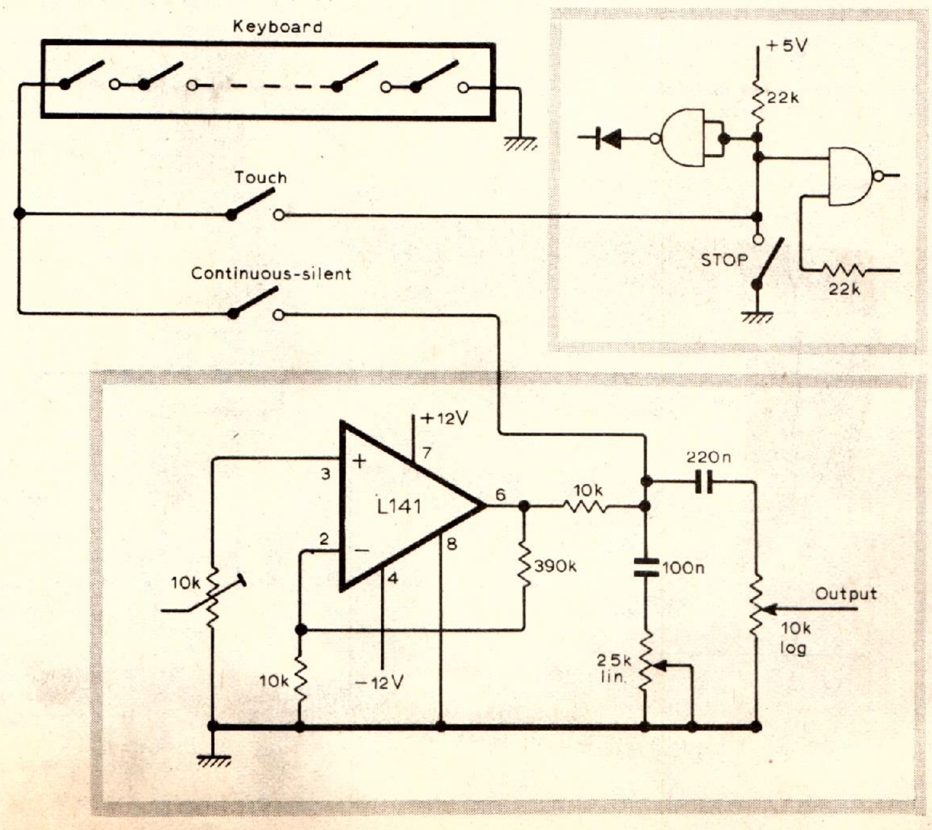
In the first category we can include the bass drum, high bongo, low bongo, conga drum and the claves, for which the basic circuit is shown around the twin-T parts of Fig. 13.

This circuit is a simple twin-T oscillator with active c.m.o.s.* element kept slightly below the point of oscillation by the pre-set resistor. To obtain the effect of different frequency instruments you only have to select the right values for the capacitors. The potentiometer also regulates the length of the damping, so that longer or shorter sounds can be obtained.

The command from the M252AA is applied at points BD, HB, etc. As the M252 produces a square wave, the RC

* A discrete-component oscillator circuit is available on request.

Fig. 11. Connections for incorporating into electronic organ. Rhythm unit parts are within shaded enclosures.



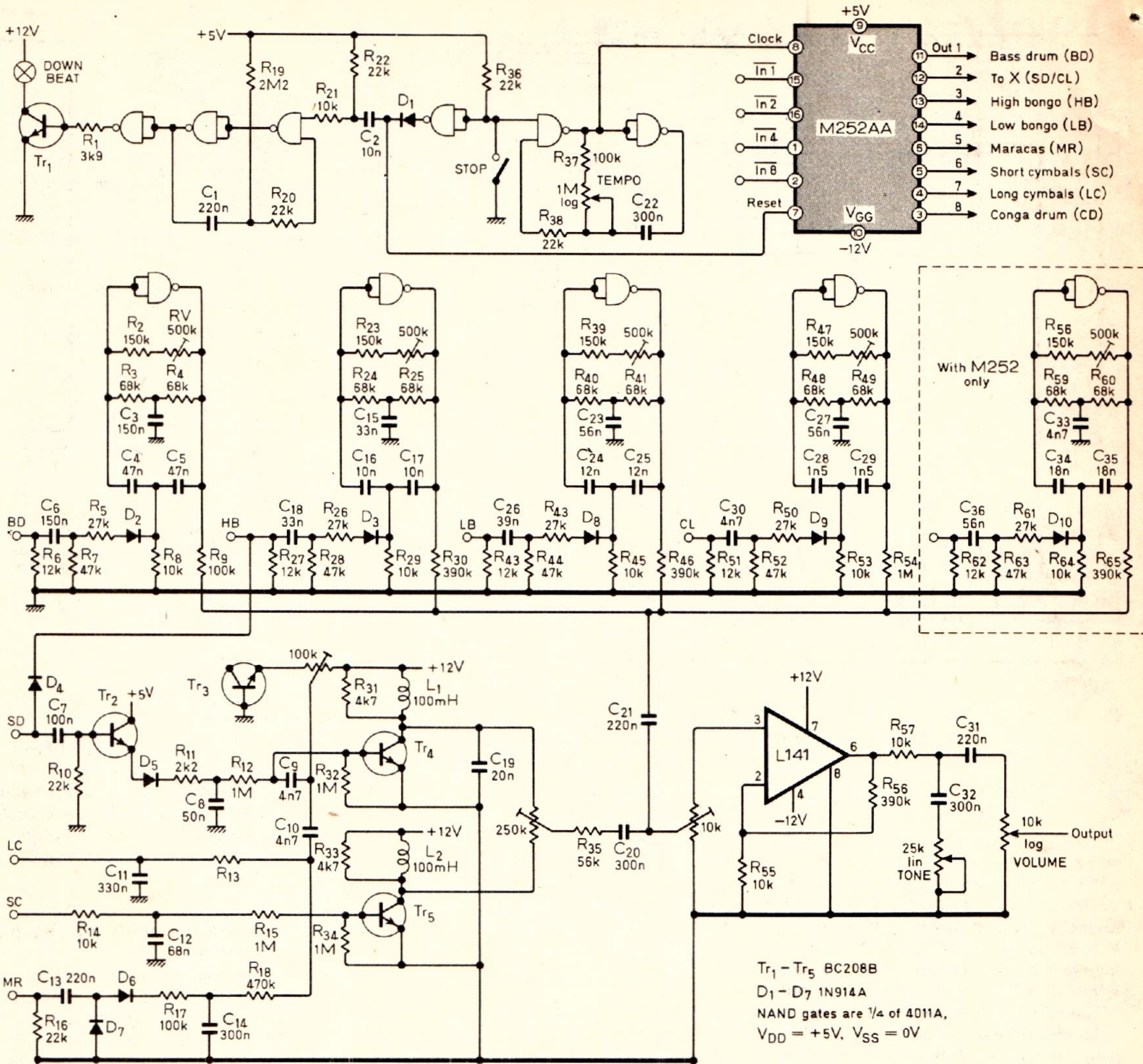
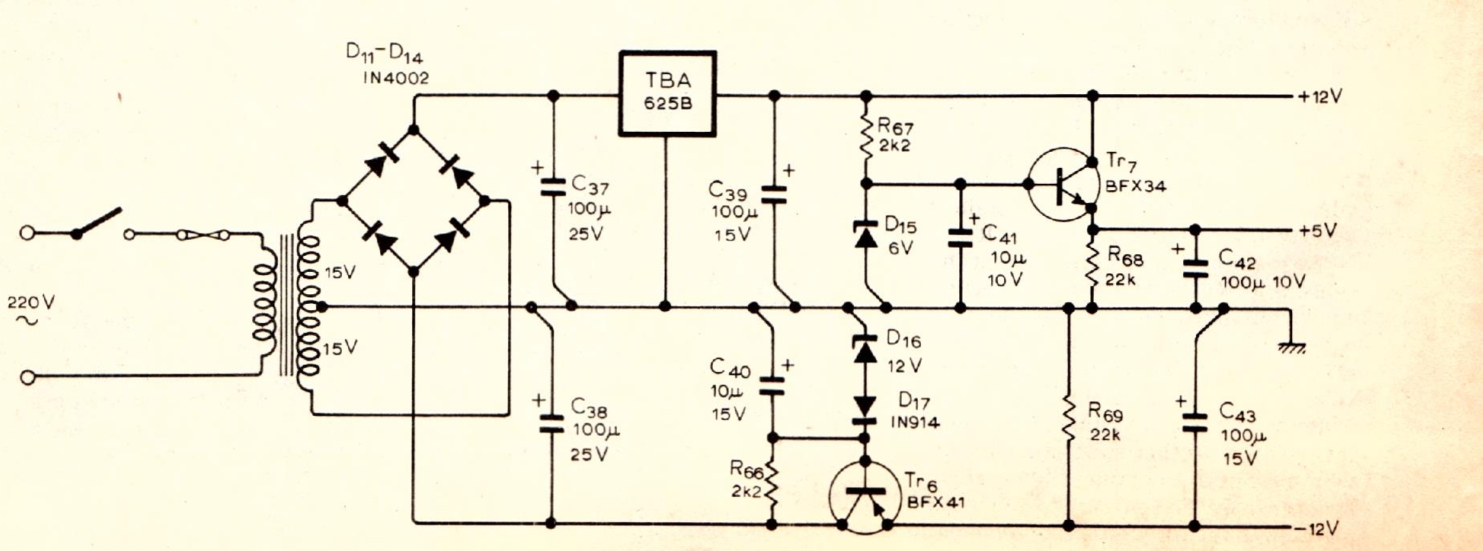


Fig. 12. Use encoder circuit of Fig. 13 with this M252 15-rhythm unit. (Rhythm selection details for M253 circuit will appear in part 3.) Circuit includes twin-T oscillators.

Below is show a conventional three-rail power supply circuit for rhythm generator.



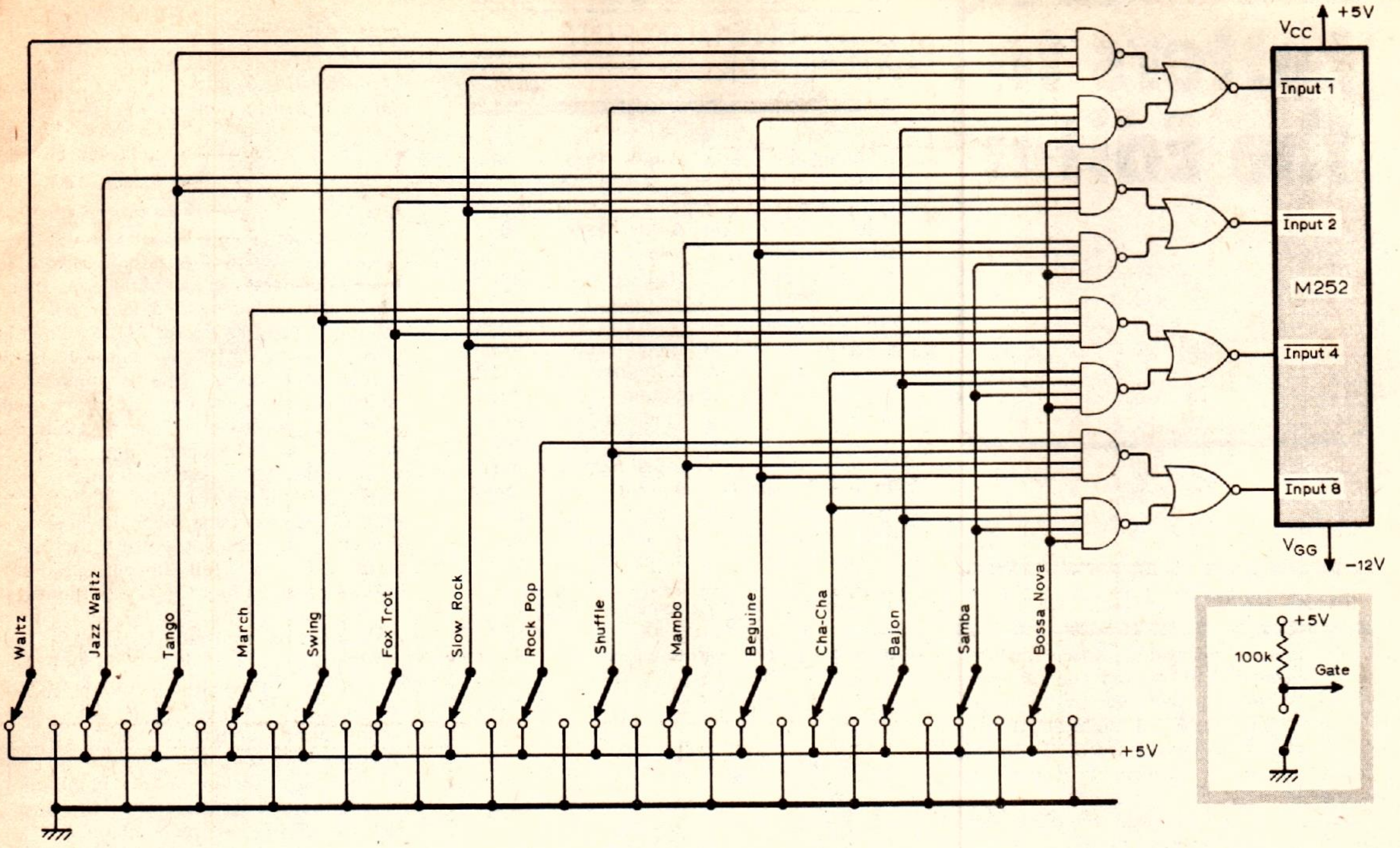


Fig. 13. In c.m.o.s. encoder for use with M252 rhythm unit single-pole switches can be used with resistors if desired. (See part 3 for M253 rhythm selection.)

differentiator (e.g. C_6, R_7) must be introduced so that a fairly short pulse arrives at the oscillator, which should not interfere with the damping of the oscillation but should be sufficient to activate the oscillator itself. Resistors R_{27}, etc, keeps the input at earth in the absence of a command, otherwise it would remain floating since the outputs of the M252AA are open-drain types.

In the second category are the long cymbals, short cymbals and maracas, for which the basic circuit is shown bottom left in Fig. 13. Transistor Tr_2 charges the capacitor C_8 during the short command pulse. This capacitor then discharges through R_{12} and the base of Tr_4.

The white noise produced by the zener effect of the base-emitter junction of a transistor is applied at the base of Tr_4. during the discharge of C_8, therefore, transistor Tr_4 can amplify this noise. The level of amplification, however, will follow the discharge curve of C_8 and therefore a damping effect of variable length will be obtained according to the values of C_8 and R_{12}.

The inductor and the capacitor at the collector of Tr_4 allow partially selective amplification to be obtained so that some harmonics can be boosted and an effect more similar to the instrument being simulated can be obtained.

Almost all the instruments used in this ryhthm section start immediately with maximum amplitude and decrease exponentially. The only exception is the maracas simulator,whose signal increases progressively and then decreases like the others. This effect was achieved by means of the integrator-differentiator circuit which allows controlled amplification of the white noise. The snare drum is obtained by adding a signal of the second type, i.e. a metellic sound, to a drum sound. Each sound starts on the positive edge of the control pulse.

Variable clock generator*

The clock generator is realized with two c.m.o.s. gates and the tempo regulated by means of a potentiometer. When closed, the switch sets the generator in such a way that the output remains at 1 and at the same time the M252AA is reset. By opening this switch the bar begins i.e. the output immediately goes to 0 so generating the negative edge necessary to cause the first command pulse or pulses to be produced by the M252AA, according to the rhythm selected.

Down-beat*

This too is made with two c.m.o.s. gates. The down-beat pulse supplied by the M252AA is too short to light a lamp. Also it occurs at the end of the bar whereas the lamp should be lit at the beginning. This monostable, Fig. 12 top, which starts on the negative edge i.e. at the beginning of the bar, operates with an auxiliary transistor in such a way that the lamp lights for a sufficient period of time to indicate the beginning of each bar.

* Alternative clock generator and downbeat circuits have been designed using t.t.l., h.l.l. and discrete components. Copies are available from editorial office.

Encoder†

Circuit, Fig. 13, uses HBF4012A four-input NAND gates, and HBF 4001A two-input NOR gates. If simple single-pole switches are to be used rather than an array of two-way switches, 15 resistors of 100kΩ must be inserted as indicated.

Rhythm section with 12 rhythms and 8 instruments

An alternative rhythm section was realized with the M253AA in which 12 different rhythms are programmed, each rhythm being able to drive simultaneously a maximum of seven out of the eight instruments available.

The 12 rhythms programmed are the tango, waltz, shuffle, march, slow rock, swing, pop rock, rumba, beguine, cha cha, samba and bossa nova. These rhythms can also be combined; two more can be selected simultaneously.

The instruments are the same as for the preceding unit with the exception of the conga. The adjustments too are equivalent, and the assembly is simply carried out on two printed circuit boards (£6 inclusive from M. R. Sagin, 23 Keyes Road, London NW2).

The sound generators, variable clock generator and monostable for the down-beat, are the same as for the M252 rhythm section.

The keyboard has the function of connecting the snare drum or the claves to the third output of the M253AA, according to the rhythm selected.

† Alternative encoder circuits are possible using mechanical switching, a diode matrix or t.t.l. gates. Copies of circuits may be obtained from the editorial office.

To be concluded

Rhythm unit — 3

Rhythm selection for M253

Switching circuit of Fig. 14 is for selection of the 12 rhythms of the M253AA i.c. Remaining circuitry of a 12-rhythm generator using this i.c. is shown on page 74 of the April issue, also the basis of a 15-rhythm unit using the M252* i.c. A suggested printed board pattern and component layout are available for the M253 i.c. and sound generators shown, and boards made to this SGS-Ates design are available (see April issue).

In the "keyboard" switching circuit, Fig. 14, inset diagram shows connections that are common to all 12 switches, one section serving to connect output three to the snare drum (SD) or claves (CL) circuits in Fig. 12, as determined by the rhythm selection. Output three can also be used to modulate a chord played on an organ.

In organ use, output one allows a "basso alternato" accompaniment using two chosen notes. Each time a beat of the bass drum occurs (output two) a note emerges from the basso alternato; output one serves only to establish which of two notes will be played. In Fig. 15 the tonic appears when output one is absent and output two is present. The other note, a fifth, appears when both outputs one and two are present.

Concluding note

- By resetting the clock generator to zero instead of to one (positive logic), a bar will begin half a clock period later than the release of the reset.
- By leaving the clock generator free and resetting only the M252 or 253, there are two possibilities at the release of reset
  - — if the clock is at '0' the rhythm starts immediately from the beginning of the bar
  - — if the clock is at '1', the bar begins as soon as the clock switches over, and there is therefore a random delay which varies from about zero to half a clock period.
- With no reset applied, the clock running and no rhythm selected, the down beat signal occurs every 32 elementary times, or every 64 clock pulses (for both i.cs).

* Keyboard/mechanical encoder for the M252 circuit is available on request.

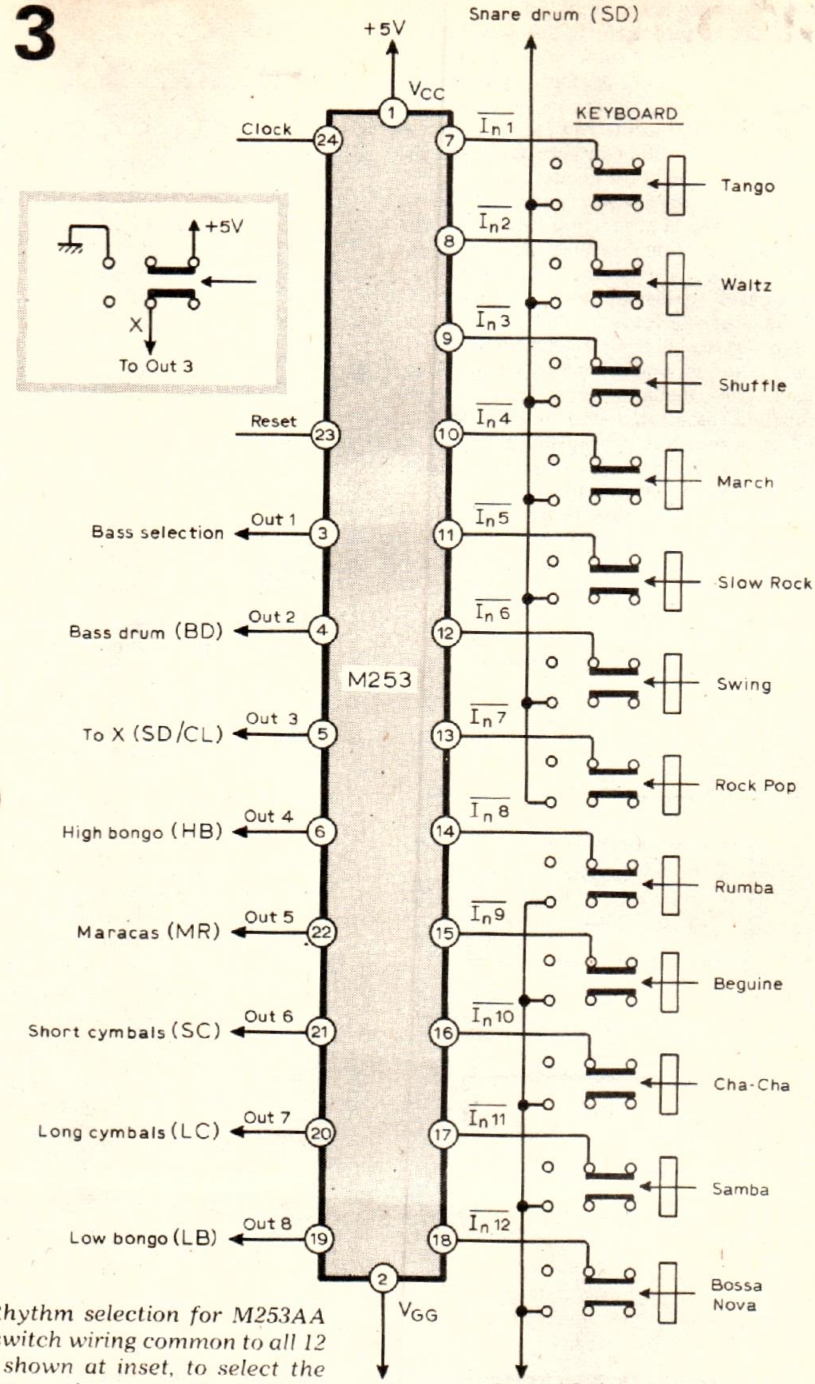


Fig. 14. Rhythm selection for M253AA includes switch wiring common to all 12 rhythms, shown at inset, to select the snare drum or claves circuits. Half the switch contacts can be eliminated if the snare/clave switching is not required.

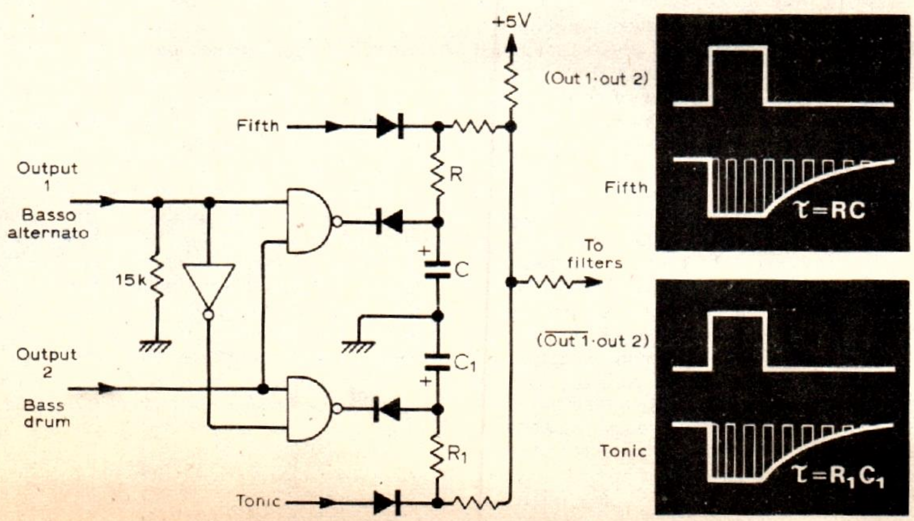
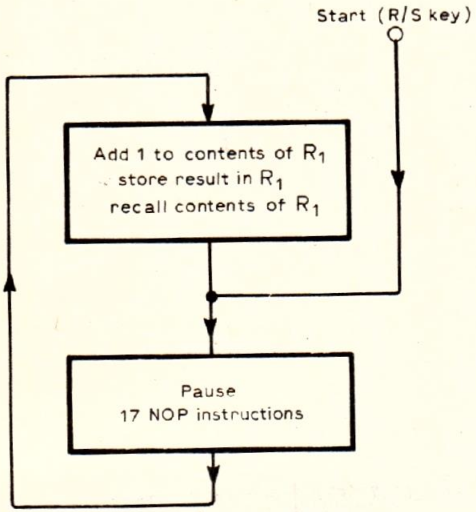


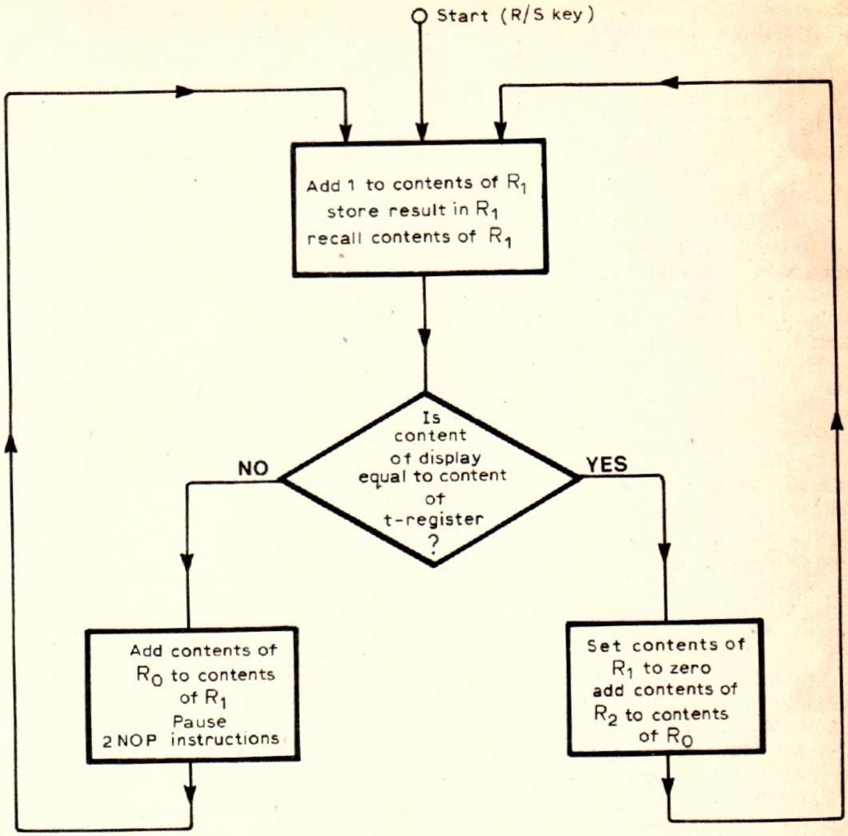
Fig. 15. For organ use, this circuit switches between two chosen notes for an alternating bass effect, and is driven from outputs one and two of M253.

ends when we press the R/S key. When we press this key at the end of the event which is being timed, the display may not hold the desired number of seconds, since we may press the key at any step in the programme which is being executed by the calculator; we therefore recall the contents of R1 and read off the duration of the event in seconds.

Before we give a flow chart, we have to refer to the "pause" and "no operation" instructions. When the programme comes to the "pause" instruction, the calculator is instructed to display the contents of the display register for about half a second. It is necessary to kill time so that the calculator may take just one second to run through a loop. The calculator has a "no operation" function, associated with a NOP key, the effect of which is to transfer control to the next step. The transfer of control takes a short time and we can use it as a means of killing time. We can vary the number of NOP instructions to regulate the time required for one loop. If we have too few, the calculator is "fast"; too many, and it is "slow". My calculator required 17 successive NOP instructions to keep time.

The flow chart is given below:





● **The calculator used as a digital clock, with display of minutes and seconds.** In this application, the display shows $M_1M_20000S_1S_2$; the digits at M_1, M_2 represent minutes; those at S_1, S_2 represent seconds. (Because the calculator suppresses leading zeros, in the first minute, digits corresponding only to S_1S_2 can be seen.) Register 0 (R0) holds the sum of the minutes. Register 1 (R1) holds the sum of the seconds. Register 2 (R2) holds 1000000. The t-register holds 61. R0 and R1 initially hold zero. The flow chart above should explain the way the programme works.

The effect of this programme is that, towards the end of the first minute, the display is 58, 59, 60, 1000001, 1000002, 1000003 . . . . We have not much scope for regulating the clock, with only two NOP instructions to play with; however, with the programme as given, my calculator loses only two seconds in ten minutes. Those who want a clock with the accuracy of a quartz crystal are not likely to be interested; those who want some fun writing a programme, may be.

Those who have calculators which permit "direct register arithmetic" will find that this facility shortens programmes slightly; I used it in the programmes given above.

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