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XEE...INSIDE

• AUTO BATTERY CHARGER • RADIO ASTRONOMY TECHNIQUES - PART 1

XEE HERE!

An animal approximation utilising integrated circuits to process optical and tactile sensing together with a random control to give reasonably lifelike responses

By G. Brown

THERE has been a considerable amount of correspondence relating to "electronic animals" following the earlier series on Bionics and the articles about EMMA last year. Readers' letters, in the main, have emphasised the need for less expensive drive systems in these "animals" and, among other things, pointed to the shortcomings of the noise cell arrangement used in EMMA.

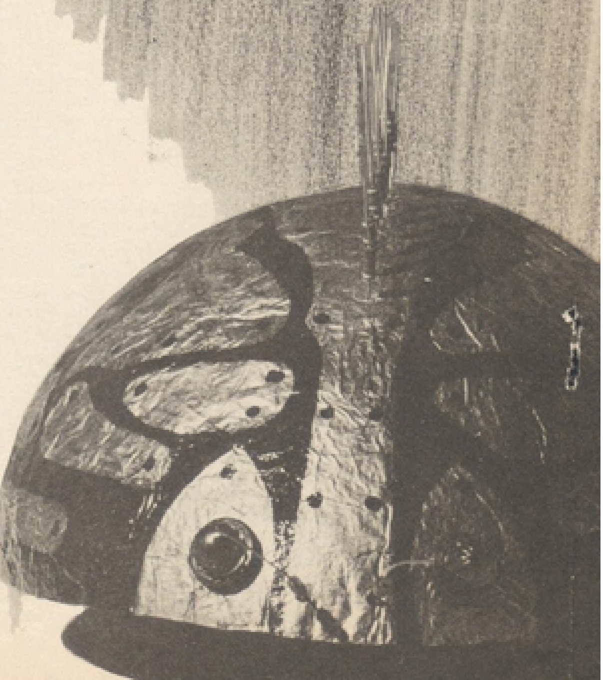
Unlike the earlier models, XEE employs integrated-circuitry for all its control logic, using discrete components only where it is more simple and cheaper to do so. Further differences include the embodiment of relays in the muscle control circuitry, rather than transistors which only afford a modicum of isolation between logic and drive systems, and which, because of their relatively high V_{ce} lose volts that could be usefully driving motors.

Related to EMMA, XEE is mechanically a sort of "middi" version; indeed, this new animal represents just the beginning of others which, physically, will tend towards the "mini". We will examine the anatomy of this latest "bug" which, not inappropriately, got its name from a computer that had been programmed to generate random letter and word sequences.

SYSTEM CONCEPT

Basically, XEE has two senses; one, an electro-optical sense provided by a pair of photo-sensitive resistors; and the other, a load monitoring arrangement associated with the muscle control circuitry. How XEE ultimately decides to respond as a result of inputs to these senses is determined by a subsystem employing a clock and random generator.

Several degrees of freedom are provided permitting turning to the right, turning to the left, driving forward, driving in reverse, and stopping. These functions, over which there is a fair amount of random control, thus provide XEE with a reasonably lifelike repertoire of responses. The response to optical inputs is additionally in part controlled by a random function, but more about this later on.



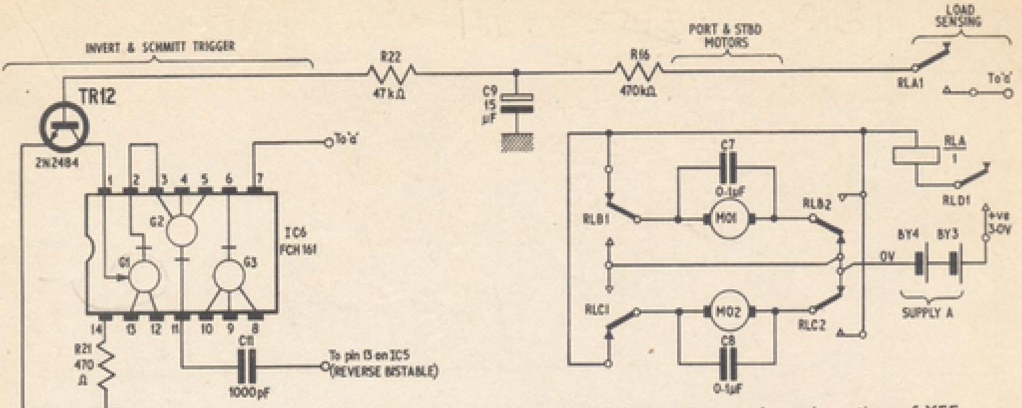


Fig. 1. Circuit diagram of the load sensing, delay and Schmitt trigger and muscle sections of XEE

CIRCUIT DESCRIPTION—LOAD SENSING

The circuit description will have as a basis only those areas which involve either totally, or in part, discrete components. This will be so since it is the *function* of the i.c.s that we will be concerned with rather than their internal circuitry. As a consequence, once the "loose ends" have been tied together, we shall consider in detail the system in an entirely logical form.

In order that XEE can sense both direct loads applied to its "body" and be aware of the presence of objects in its path, some means of tactile sensing is necessary. An extremely positive response can be obtained using a "feeler" and microswitch arrangement, but this scheme has the unfortunate disadvantage that the probe, or whatever, is all too easily snapped off!

A better idea, albeit one which displays a somewhat intractable sensitivity, is motor current sensing. No extra "appendages" are required when the latter set-up is embodied, but it does mean the need for a little more electronics.

The sensor itself is the humble reed-switch. Around its circumference are wrapped a few turns of relatively heavy-gauge wire which serve as the operating coil and pass the total motor current.

If, during operation of XEE, some maximum current level is exceeded, the reed switch will close to indicate that the motor load has increased. The switch is shown as RLA in Fig. 1 and its construction will be discussed later in the article.

DELAY AND SCHMITT TRIGGER

Although the load sensing system works well, it might almost be said that it works too well because whenever there is a rise in current, as when the motors change direction (stall current), the reed switch operates. We thus require some way of permitting the load sense to differentiate between transient loads and continuous loads. This can be met quite simply by way of a time-constant circuit (R16/C9) included after the reed switch, providing just long enough a delay to determine a real load. If such a load is present the switch will be closed for a longer time and hence C9 will receive a greater charge. This capacitor is connected across the input of a buffer amplifier controlling a Schmitt trigger. The latter switches whenever the input voltage to the buffer rises above about 0·6 volts. At such times the output of the Schmitt will go towards earth, the required condition for triggering the reversing bistable—mentioned in the section under logical operation.

The Schmitt is formed by coupling a pair of gates within a Mullard FCH161 integrated circuit and connecting a 470 ohm resistor (R21) in the negative supply lead. Since the FCH161 is a "triple-gate," this treatment does have the disadvantage that one of the gates will remain unused. The gates also have a very low input impedance which means that in order to get a delay with the sort of time-constant required, the capacitor used has either got to be very large, or a buffer must separate the delay from the Schmitt. As we have seen, XEE employs a buffer.

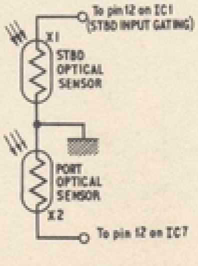


Fig. 2. Connection of the two l.d.r.'s to the logic circuitry

OPTICAL SENSE

XEE has a bilateral optical system; one starboard and one port sensor. The sensors, which are light dependent resistors (l.d.r.'s), are each connected to their respective logical invertors which serve both to amplify and establish the correct logic levels into the remainder of the system (Fig. 2).

NOISE SOURCE

In an earlier article, randomness was generated by the use of an electrochemical noise cell; this, as I feel sure many readers will appreciate, proved to be a very unreliable source of noise after it had been in service for only a short time. It was therefore imperative that some other scheme be adopted;

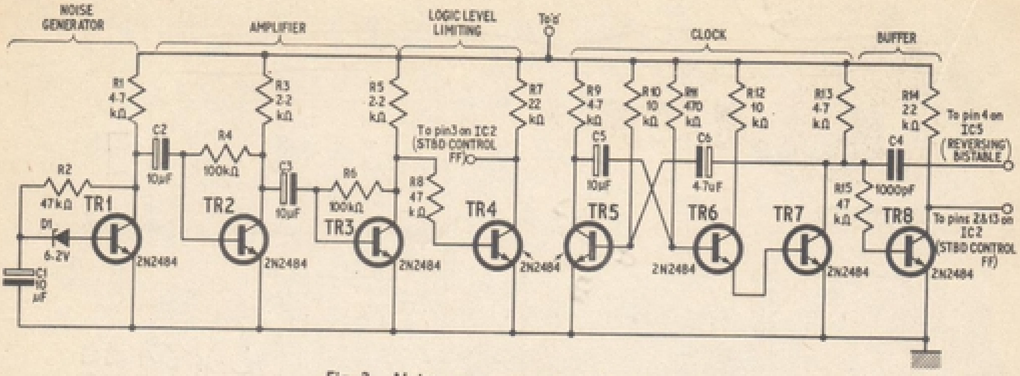


Fig. 3. Noise generator and clock circuitry

the result is shown in Fig. 3. Here, a Zener diode has been enlisted to generate the required noise.

Zener diodes are inherently noisy, particularly when run at very low currents, and it is this characteristic that is exploited here. The amplitude of the noise current, however, is fairly small and so requires some amplification. This is provided by transistors TR1, TR2 and TR3. The resultant noise spikes appearing at the collector of TR3 are taken to a further stage, TR4, which ensures that they are limited, both top and bottom, to levels required by the logic which they will be driving. Thus the spikes will either be there, or not be there; a logical 1 or a 0 is thus made available.

The noise pulses, although having quite a random time relationship, cannot be employed directly because their occurrence rate is far too high, typically 2×10^3 to 5×10^4 pulses per second. Their further processing is described in the functioning of the system logic.

CLOCK

Certain areas of the system logic are controlled by a clock or astable. Strictly, this is not performing a true clock function, but it is convenient to refer to it as such, since a number of actions occur which must either have given durations, or which must be initiated at particular times.

The clock, Fig. 3, is, in essence, a kind of "heartbeat" for XEE and comprises a slow-running astable. This circuit is highly asymmetrical; that is to say its output waveform has a large mark to space ratio. The reason for this is that one of the time periods (the random mode) is comparatively short, about 20ms, while another (the action mode) occupies a period of a little greater than one second. The circuit employs TR5, TR6 and TR7.

Transistor TR6 forms a super-alpha pair with TR7 and permits large time constants to be achieved without the need for large capacitors. In this way TR7 can effectively tolerate quite a sizeable base resistor whilst in no way jeopardising the long time requirement. A further buffer stage has been added after the clock to prevent it being overloaded. This is formed by TR8.

MUSCLE CONTROL

Control over XEE's motors, or "muscles", is under the direction of three transistor-controlled relays; these are RLB, RLC, and RLD shown in Fig. 4. The relays employed here, in fact, decided the choice of supply voltage, which, although a trifle on the high side, was considered justified in view of the relatively low price of the relays (available on ex-computer circuit boards).

Each relay is connected as the collector load of its associated transistor and incorporates a parallel, reverse-connected diode to minimise the chances of back e.m.f. damaging the transistor. In the energised state, RLD1 contacts ensure that the supply is fed to the motors. At these times, if relays RLB and RLC are not energised, their contacts connect both the motors to run forward. It will be noticed that double pole changeover contacts are employed on

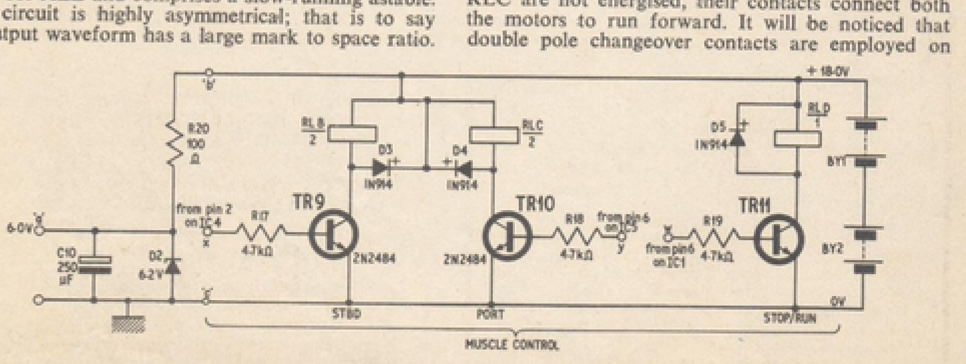
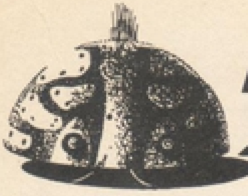


Fig. 4. Muscle control and power supply stabilisation circuitry



INSIDE XEE!

COMPONENTS . . .

Resistors

R1	4·7kΩ	R12	10kΩ
R2	47kΩ	R13	4·7kΩ
R3	2·2kΩ	R14	22kΩ
R4	100kΩ	R15	47kΩ
R5	2·2kΩ	R16	470kΩ
R6	100kΩ	R17	4·7kΩ
R7	22kΩ	R18	4·7kΩ
R8	47kΩ	R19	4·7kΩ
R9	4·7kΩ	R20	100Ω 5W ±10% w.w.
R10	10kΩ	R21	470Ω
R11	470kΩ	R22	47kΩ

All $\frac{1}{16}$W, ±10% except where stated

Capacitors

C1	10μF elect. 10V
C2	10μF elect. 10V
C3	10μF elect. 10V
C4	1,000pF
C5	10μF elect. 10V
C6	4·7μF elect. 10V
C7	0·1μF
C8	0·μ1F
C9	15μF elect. 10V
C10	250μF elect. 10V
C11	1,000pF

Diodes

D1	6·2V Zener SZ62A or OAZ202
D2	6·2V Zener SZ62A or OAZ202
D3	IN914
D4	IN914
D5	IN914

Transistors

TR1 to TR12	2N2484 (12 off)

Relays

RLA	see text
RLB to RLD	Claire, 700 ohm, DPDT (ex-computer type—3 off)

Motors

MO1 and MO2	Johnson 150 Type, available from Ripmax Ltd (2 off)

Integrated Circuits

IC1, 4–7	FCH161 Mullard (5 off)
IC2, 3	FCJ101 Mullard (2 off)

Miscellaneous

X1 and X2	SSP5, or ORP12 (2 off)
BY1 and BY2	PP6 (2 off)
BY3 and BY4	HP11 (2 off)

Veroboard 2½in × 4⅞in × 0·1in matrix
Veroboard ⅜in × ⅜in × 0·1in matrix (2 off)

Hardware

26 s.w.g. d.c.c. wire for RLA
Brass rod, two lengths of $\frac{3}{32}$in diameter
Gear pinions, 10 tooth, Ripmax Ltd (2 off)
Gear pinions, 30 tooth, Ripmax Ltd (2 off)
Worm and wormwheel, Ripmax Ltd (2 off)
Plastic tubing, approx. $\frac{3}{32}$in internal diam
Aircraft wheels, 1½in, rubber tyred, Ripmax Ltd
Aluminium sheet, see text
4B.A. and 6B.A. screws, nuts and washers.

the relays to obviate the need for a larger, centre-tapped, battery supply.

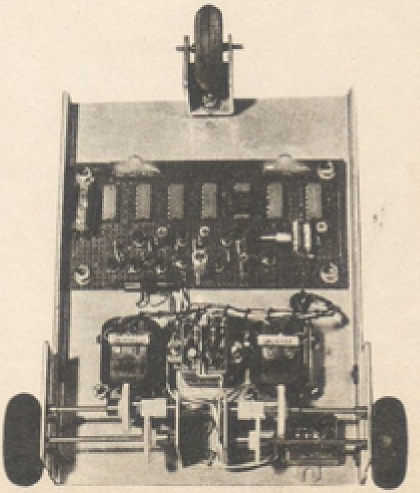
If either RLB or RLC only are energised, the starboard or port motors respectively will be caused to reverse, thus allowing XEE to turn right or left. When the relays are energised together, the model reverses. The remaining relay RLD provides a stop function only when de-energised. In this mode the system logic is arranged to inhibit any existing inputs to TR9 or TR10, thus RLB and RLC are de-energised and so unnecessary current drain, due to the relays, is avoided.

Both motors are of the fairly inexpensive Japanese variety and each has a nominal stall current of 450mA. Under running conditions the current drawn is in the region of 700mA for the pair. Since the motors are run from a separate power supply to the rest of the circuit, most of the electrical noise is isolated to the motor circuit and hence has little chance to interfere elsewhere. However, to prevent any trouble from radiated noise affecting i.c.s which, incidentally, are easily triggered in this way, each motor is equipped with its own suppression capacitor (C7 and C8).

POWER SUPPLIES

Quite a number of factors helped to govern the ultimate choice of power supplies; indeed, the final outcome is more compromise than choice! Since, economically, the model's cost must be kept as low as possible, such luxuries as expensive gear-boxes and small-current motors cannot be permitted. And yet the motors used must be capable of developing sufficient drive-torque to carry an all-up weight of approximately 1lb 10oz for, at least, long enough to allow satisfactory observation of the animal's characteristics. The batteries employed give fairly tolerable operation for about 20 minutes of intermittent use.

Motor supplies are provided by a pair of series-connected HP11 type batteries, while the electronics derive their various needs from two series-connected PP6 batteries. The respective voltages available from this set-up are 3·0V and 18·0V. The latter supplies the muscle control circuitry direct, but is taken to a suitable level (nominally 6·0V) for operation of the



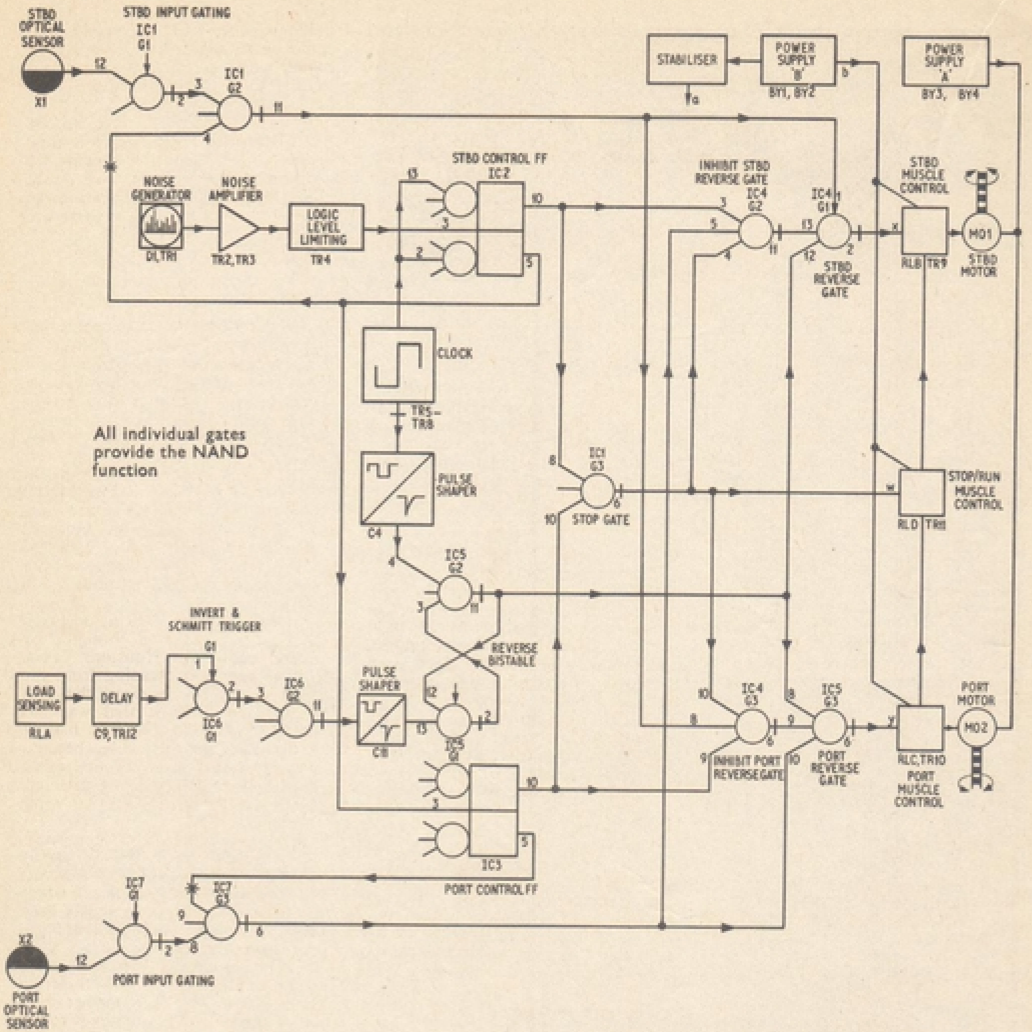
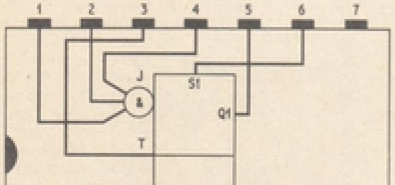


Fig. 5. Logic diagram of XEE. This shows the complete system and indicates the positions of the various gates and i.c.s. Also shown are the JK flip-flop connections for the FCJ101 i.c.s.



i.c.s and remaining electronics. This last supply is maintained by the Zener diode, D2, and its attendant components, R20 and C10.

LOGIC OPERATION

For an overall understanding of the system logic, the reader is referred to Fig. 5. From this it will be noticed that the sensory and control sub-systems have a hierarchy which is ordered effectively from the load-sensing, which takes priority over all except the clock. The random function is the next down the list of priorities, and finally, at the bottom of the list comes the optical sense.

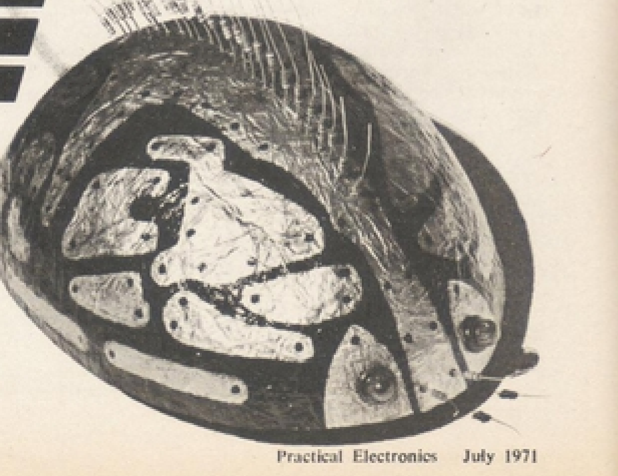
Next month: logic system explanation and constructional details

XEE

PART 2

An animal approximation utilising integrated circuits to process optical and tactile sensing together with a random control to give reasonably lifelike responses

By G. Brown



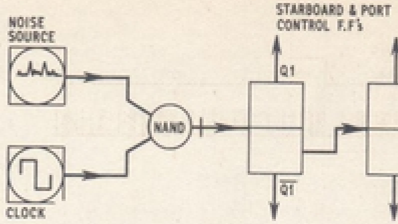


Fig. 6. Basic principle of the noise processing

In Part I we considered the theoretical aspects of XEE's operational characteristics. This month, in the second and final part, we look at the system logic, construct the animal and perform the various tests.

RANDOM CONTROL SYSTEM

Since our noise source produces spikes having a high occurrence rate, it is necessary to perform some processing before they can be usefully employed. The concept behind the scheme used here is quite a simple one (see, Fig. 6) which shows the basic principle). Noise pulses are fed continuously to the NAND gate, and the clock periodically "lets a few through" to operate the counter.

In the durations between clock pulses, the counter remains in the state previously set by the pulses occurring during the last clock period. It is at such times the counter can be "read" and so provide the required control information for the rest of the animal. It will be seen now that the occurrence rate of the noise pulses in no way affects the rate at which the random control data appears.

The principle is thus one of "throw the dice—look at the result—use the information", and so on. Indeed, a set-up of this type might usefully be employed in a dice throwing machine or, perhaps, a reaction-analyser.

NOISE PROCESSING

The general idea is shown in Fig. 6, but in practice the system is a little different. In Fig. 5 we see that because JK flip-flops are used we are able to take advantage of the JK function for gating purposes. Hence the effect of the noise pulses at the clock input to the starboard control flip-flop will only be valid at times when the clock applies a logical 1 at both the J and K inputs.

A clearer picture of what happens can be seen from the waveforms given in Fig. 7. From these waveforms it can be seen that during every clock pulse, or "window", the counter represented by the starboard and port flip-flops can be cycled many times before it finally comes to a stop. However, the important point to note is that this operation occurs quite randomly and hence the counter, following a clock period, can be set to any one of its several possible states.

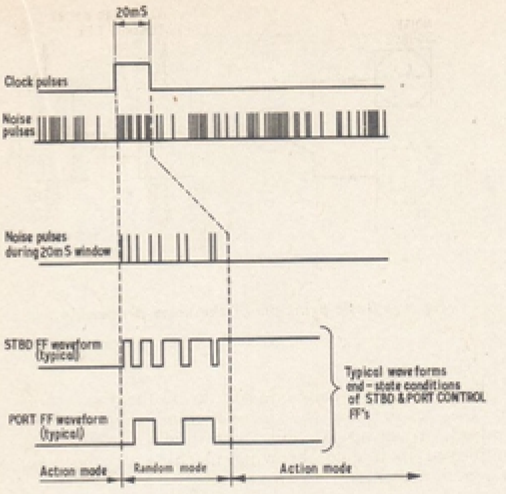


Fig. 7. Waveforms associated with random control system

The random control system has control, either directly or indirectly, over all gating functions within XEE. Since this information is derived from the Q and $\bar{Q}$ terminals of the flip-flops, the control is complimentary.

REVERSE GATING

The direction of rotation of the motors is dependent on the outputs at the starboard and port reverse gates. For forward rotation, the inputs to the particular gate must all be at logical 1 (output goes to 0). If both gates are in this condition, the animal will drive forward; if only one gate is producing a 0, the animal will turn either right or left.

If any input to the gates is taken to logical 0, the output will change to a 1, with the result that the corresponding motor will reverse. Both gates in this condition result in reverse drive of the animal.

INHIBIT REVERSE GATING

Inhibit reverse gating is provided by gates G2 and G3 (IC4); it is part of the stop function and serves to inhibit any reverse command given by the control flip-flops at such times. It is also included to ensure that correct homing on to light sources is provided when the optical sensors are stimulated (this only applies under conditions which will be mentioned later).

STOP GATING

The stop function, overriding all other functions, is available through the agency of gate G3 (IC1). If both its inputs are at logical 1 then the output is at 0, with the result that all motor supplies are disconnected and the animal stops. If, on the other hand, either or both inputs are at 0, then the output will be 1, permitting resumption of motor operation. The stop gate also controls the inputs to the inhibit gates to ensure that under stop conditions all muscle control relays are de-energised and consequently current in this area is reduced to a minimum.

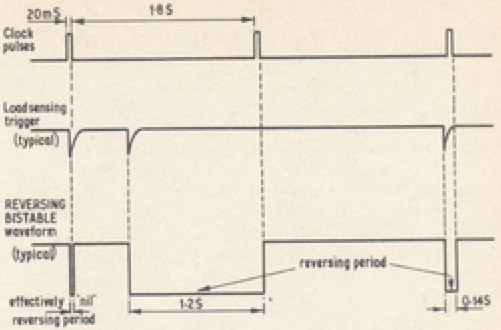


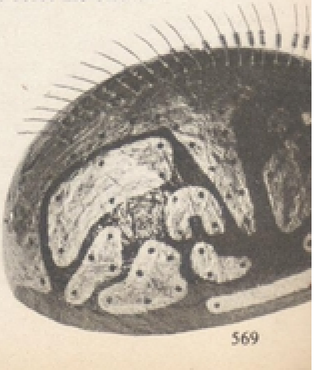
Fig. 8. Waveforms associated with load sensing and reversing bistable

AVOIDANCE FUNCTION

Application of any load exceeding a given period of time or amplitude will result in the avoidance routine being elicited. This amounts to the animal reversing for a short while then reverting to whatever the random system has currently set. The routine might thus be: reverse and turn left, or right, or stop. Whenever the Schmitt trigger is fired, a negative-going pulse sets the reversing bistable which simultaneously applies a 0 to one input of the reverse gates. Both gates thus return a 1 to the muscle control circuits, and XEE moves backwards.

The duration of the reversing mode is determined by the time interval from when it began, to when the clock pulse arrives to reset the reversing bistable. This will always be random, and can never exceed a complete clock period; take a look at Fig 8, which indicates the type of relationships that can occur between clock and load sensing pulses.

For operation of the reversing bistable it is convenient to think of it being first reset by the clock. Since, at the clock pulse, a 0 is fed to G2 (IC5) its output will go to logical 1. As a result, G1 (IC5) will have one input at the same level, and because its other input is connected to a capacitor (C11), this too is effectively at 1; the output from this gate is thus 0. Due to the cross-coupling between the gates, G2 (IC5) will have one input held at 0 by the output from G1 (IC5). The bistable will remain in this state unless a pulse arrives from the Schmitt; if this occurs, a 0 will be effectively applied to one input of G1 (IC5) whose output will go to 1. As a consequence, both the inputs of G2 (IC5) will then be at logical 1 and its output will go to 0. Again, due to the cross-coupling, this state will exist until the clock pulse arrives to reset the bistable.



OPTICAL SENSE AND RANDOM FUNCTION

For simplicity, the optical sensors do not boast any lens system, although, of course, there is absolutely no reason why this kind of sophistication should not be included if the constructor wishes.

The way in which the optical sense operates will depend on whether direct sensing is used, or whether the constructor chooses to permit some degree of random control. Since operation of this section of XEE is more easily understood by reference to the direct sensing arrangement, we will consider this first.

DIRECT SENSING

For this form of sensing, the connections to the input gating marked with an asterisk in Fig. 5, are disconnected. The gates, however, must be left connected in all other aspects otherwise the logic will be affected.

Under dark conditions, when neither of the sensors are illuminated, the animal will be under the control of the random system; it will be either turning in one direction or another, or driving forward. If, say, the starboard sensor is illuminated, a logical 0 will appear at the output of the starboard input gateing which will be applied to the inputs of the starboard reverse gate and the inhibit port reverse gate. The former gate will thus show an output of 1 and so cause motor MO1 to go into reverse drive. At the same time, the inhibit port reverse gate's output will be 1, and, provided the remaining inputs to the port reverse gate are also at 1, the additional input will ensure that a 0, and hence forward drive, is established for MO2.

This complementary control over both channels is necessary because, ostensibly, there could be a counter command from the random control system to the opposite channel, when, in fact, no optical input was present on that side.

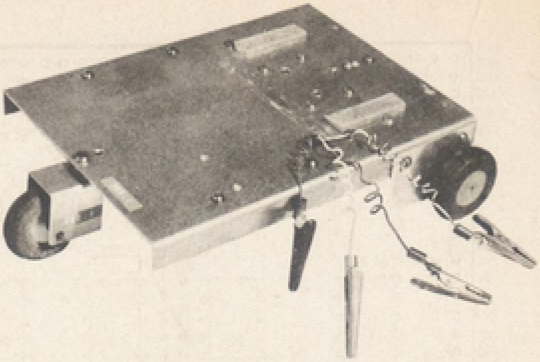
A similar regime will be operative if only the other sensor is stimulated. If both channels are active, though, the effects of the inhibit gates will be nullified, since the reverse gates will each have a 0 on at least one of their inputs, causing them to both return outputs of 1 resulting in XEE driving backwards.

Simultaneous illumination of both sensors is fairly rare, but can be an obvious embarrassment because when it happens XEE will continue its backing routine (up walls, if need be!) until the source of light is removed. A way of overcoming this difficulty is discussed later.

An important aspect of the optical sense is that a form of homing function is permitted. Take the case where light has fallen on the starboard sensor; this will cause a turn to the right. In doing so, the machine will move this sensor away from the source of illumination, but this will also result in the port sensor being brought in to line with the source. If this occurs, the animal will turn left, and so on. Under these conditions XEE thus performs a kind of "serpentine" movement until it is fairly close to the light, when it will suddenly veer off to the left or right.

RANDOM CONTROL

If the inputs to G2 (IC1) and G3 (IC7) are left connected to the starboard and port control flip-flops, the optical sense displays quite different characteristics. One interesting point is that XEE no longer shows quite the same zest for mounting walls when in the reverse mode!



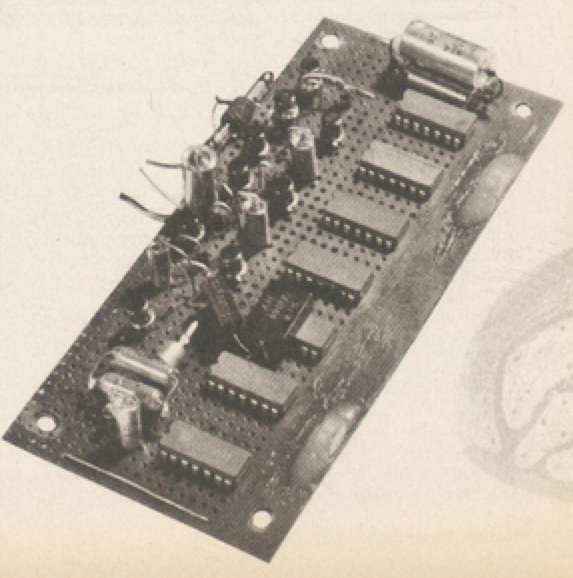
Optical sensing under random control permits XEE to extricate itself from powerful light sources. This is achieved by means of the control over the input gates. As a consequence, even though an input may be present at either of the sensors, unless the relevant gate is in receipt of a 1 from its associated flip-flop, the input will be ineffective.

XEE can therefore (apparently) make up its own mind about what it does, and does not, wish to look at! This does of course mean that in this mode of operation XEE is now free of the fetters that most moths seem unable to shake off.

CONSTRUCTION

An illustration of the general wiring scheme for the main circuit board is given in Fig. 9. This shows the wiring and layout on Veroboard. Additional, simpler boards which are involved with the muscle control circuits are shown in Fig. 10.

The main board must be drilled in accordance with the chassis holes shown in Fig. 11. The two smaller boards must be cut to the sizes given in the



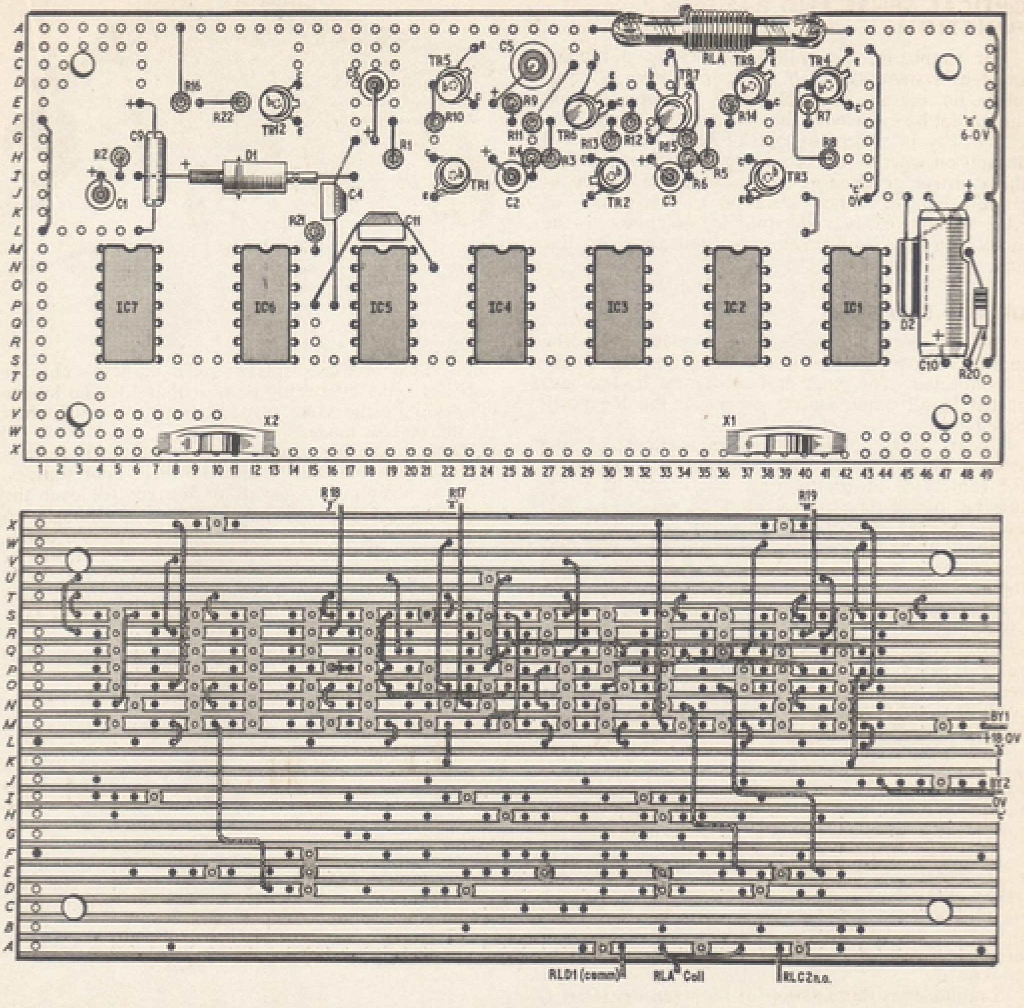


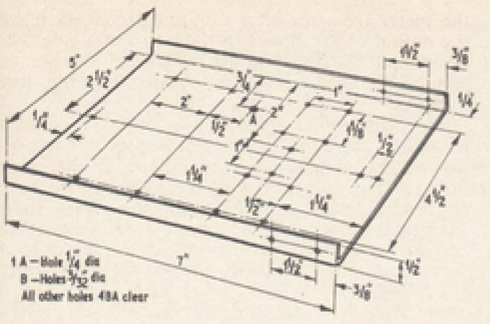
Fig. 9. Layout and wiring of the circuit board

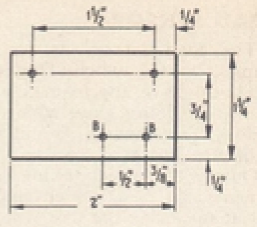
components list. All components are mounted by means of their leads; breaks in the copper strips must be made before the associated components are fitted. It is most important to make sure that the complete width of the relevant copper strip is cut through.

Do not fix the photo-sensors until last since they, almost always, are blessed with thin leads which with little doubt will break off if "man-handled" too frequently!

Mounting of the integrated circuits is best done first; the job is not a particularly difficult one, but it is essential that care be taken to ensure that every one of the 14 leads in each I.C. go through the holes in the circuit board. Attention is drawn to this fact because it is easy to think that all the leads are poking through the board, when in reality they are not. The trick, if there is one, in fitting the I.C.'s is to ease the seven leads on one side through first, then, with the aid of the three fingers of one hand placed in-line against the edge of the remaining pins, gently locate and press them through the relevant holes. As each I.C. is fitted in this way it is advisable to solder it in place, lest it falls out as the next one is being attached.

Wiring of the circuit boards, and interconnections between them, should be done with thin plastic covered wire. Since the pitch of the holes in the boards is small, the copper lands are necessarily close together and without care it is extremely easy to make accidental bridge-overs. Such errors should be looked for prior to connecting any supplies.





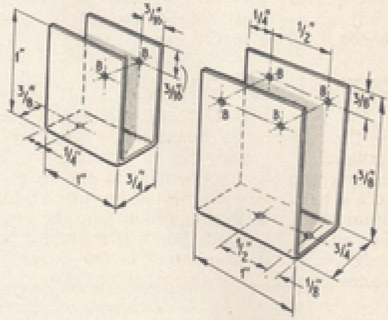


Fig. 11. Chassis details

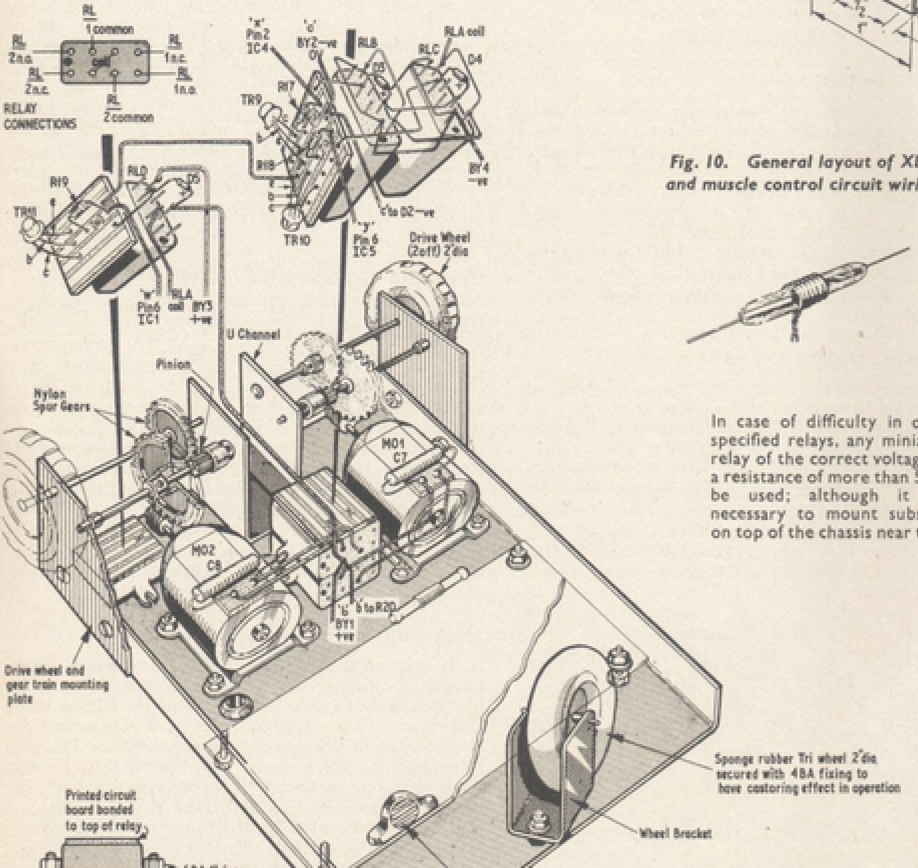


Fig. 10. General layout of XEE and muscle control circuit wiring

In case of difficulty in obtaining the specified relays, any miniature d.p.d.t. relay of the correct voltage, and having a resistance of more than 500 ohm, may be used; although it may prove necessary to mount substitute types on top of the chassis near the batteries.

LOAD SENSOR

The load sensor, as we previously discussed, employs a reed switch. This is of the 1 inch variety and must have approximately 16 turns of 26 s.w.g. enamel or cotton covered wire wrapped around its middle. The winding should take the form of two eight-turn layers.

During the initial testing the coil will be firmly cemented to the glass envelope of the reed switch, but at this stage the free wire ends to the coil need only be gently twisted together to keep everything from unravelling. An illustration of the complete sensor is shown in Fig. 10.

OPTICAL SENSORS

The two l.d.r.'s (X1 and X2) should be mounted so that when the board is in position they face forward. If a "body" is to be made for XEE these sensors can be incorporated in the front. Once the l.d.r.'s have been connected-up, an Araldite "fillet" should be made between them and the circuit-board. To ensure a good bond, the board should be roughened with a piece of emery paper just at the places of contact with the epoxy resin.

INITIAL TESTING

Just before testing, give the boards a visual inspection to make absolutely certain that no dry joints, bridge-overs, or wiring errors exist. The muscle control boards will not need to be checked out now, but will be tested in conjunction with the relays later. Connect points "b" and "c" on the main circuit-board to an 18·0 volt d.c. source; "b" must go to positive, and "c" to the negative. While performing the tests make sure to keep the optical sensors clear from any direct sunlight which could cause ambiguous results.

RANDOM CONTROL SYSTEM

Connect a voltmeter (set to a range which will measure 6·0V) between earth and pin 13 of the starboard control flip-flop (IC2), and check that approximately every second or so there is a brief flicker shown by the meter. This will be the indication if the clock is functioning correctly. Now disconnect the lead from pin 13 and connect it to pin 10 (IC2). The meter reading should be either a steady 6·0V (logical 1), or very nearly zero (logical 0); this indication should be interrupted about every second by the effect of the clock and noise pulses. It is important that this last reading changes in a random fashion periodically. Next, disconnect the lead from pin 10 and reconnect it to pin 10 on the port flip-flop (IC3). The reading should be similar to the last, to wit, it must change randomly from 1 to 0 every now and then. If no change is observed, then connect the meter between earth and pin 3 of the starboard flip-flop (IC2). In this position it should indicate a regular flickering due to the noise source. If this is not so, the Zener diode D1 should be disconnected and replaced by another one. Sometimes one comes across a particularly "un-noisy" diode, these "good ones" are however no good to us!

STOP AND REVERSE GATING

Connect the meter between earth and the output of the stop gate. This should periodically change its logical state from 1 to 0, or from 0 to 1. Disconnect the meter from the stop gate and reconnect it with the output of the inhibit starboard reverse gate. Now disconnect the leads going to pins 5 on the two control flip-flops, and apply the light from a torch to the port optical sensor.

The meter should indicate a logical 1 condition as long as the light remains on. Repeat this test with the meter connected to the output of the inhibit port reverse gate, but with the light applied to the starboard optical sensor. Again the meter should indicate the 1 state all the time that the light remains on. With the light still on, connect the meter to the output of the starboard reverse gate. The meter should again show the logical 1 state. Reconnect the meter with the output of the port reverse gate. This too should be at 1 when the light is transferred to the port sensor. Leave the meter connected for the next test.

REVERSING FUNCTION

With no light applied to the optical sensors, trigger the reversing bistable by momentarily touching an earth connection on either one of the inputs of G1, IC5 (pins 12 and 13). The meter should immediately indicate a logical 1 condition (if it is not already). This reading should eventually change once the reversing bistable has been reset by the clock pulse and the system returns to the control of the random control section. Connect the meter to the output of the starboard reverse gate. Again trigger the reversing bistable and ensure that the results are the same. Disconnect the meter and the 18·0 volt supply. Reconnect the leads to pins 5 of the control flip-flops.

CHASSIS CONSTRUCTION

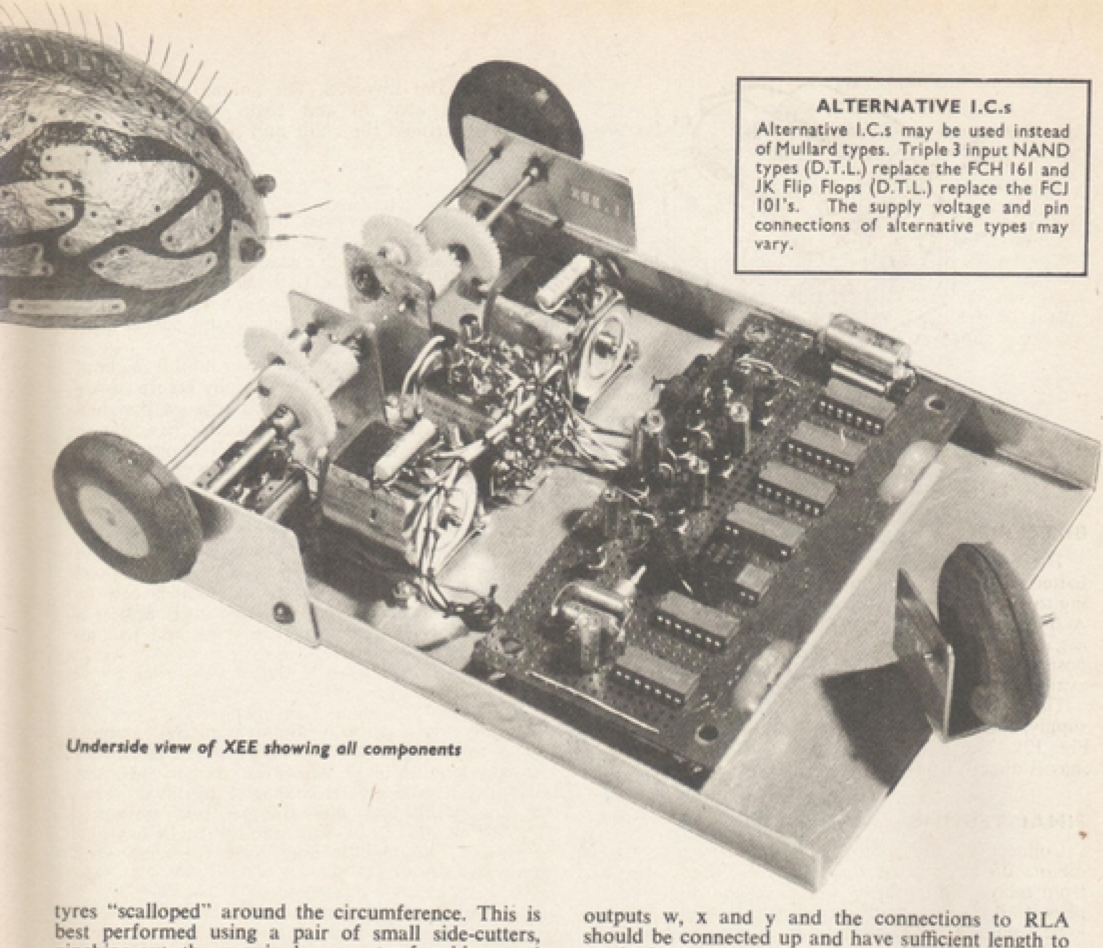
The type of material from which the chassis is fabricated is not particularly critical; for the prototype, 16 gauge aluminium was used. The chassis takes the form of a single piece of material having two ½ inch right-angle sections folded down the length of its sides. The rear side plates carrying the gear shafts and wheels are mounted on this chassis.

A "U" bracket, situated on the chassis midway between the two side plates, serves to support the inner ends of the gear shafts. A further "U" bracket is utilised for the frontally located castor wheel. All metalwork should be constructed according to Fig. 11. Any bending which is required can be done with the aid of two small pieces of tough wooden plank and a vice.

MOTORS, GEARS AND WHEELS

As Fig. 10 shows, both motors are situated side-by-side towards the rear of the chassis. Each motor has a friction-fit worm attached to its output shaft, and this is arranged to drive a further shaft at right-angles to it by way of a wormwheel. The gear ratio thus provided is 40 : 1. This lay-shaft is also fitted with a pinion which, in conjunction with another pinion, on the final drive shaft, results in a further reduction of 3 : 1. In this way an overall ratio of 120 : 1 is achieved.

The rear wheels, one attached to each final-drive shaft, are 1½ inch diameter soft rubber aircraft type. These should have their centres drilled out a little to accommodate $\frac{3}{16}$ inch shafting, and be secured in position with epoxy resin. In order to achieve improved traction, the rear wheels should have their



Underside view of XEE showing all components

ALTERNATIVE I.C.s

Alternative I.C.s may be used instead of Mullard types. Triple 3 input NAND types (D.T.L.) replace the FCH 161 and JK Flip Flops (D.T.L.) replace the FCJ 101's. The supply voltage and pin connections of alternative types may vary.

tyres "scalloped" around the circumference. This is best performed using a pair of small side-cutters, pinching-out the required amount of rubber and nipping it off. The resulting tread is fairly coarse, but serves its purpose, since, on nylon carpet, the wheels would undoubtedly slip.

The castor wheel is the same as the type used at the rear but, naturally, without the tread. The wheel is fitted to a shaft going through offset holes in the "U" bracket which swivels on a 4B.A. screw at the front of the animal.

Shaft retention is obtained either through the use of plastic tubing, or by means of washers soldered to the ends of the shafting. Sometimes the nylon gear-pinions have casting flashes still attached to them; this is particularly noticeable on teeth. The flashes must be removed with a sharp knife, or razor-blade, before the pinions can mesh properly.

MOUNTINGS

Four 4B.A. screws secure the main board to the chassis. The screws are initially bolted to the chassis, their nuts serving as spacers to separate the board from the metal body. Once the screws and nuts have been fitted, a layer of insulation tape, approximately the same size as the main board, should be placed directly beneath where the board will be located. This will ensure that no exposed wiring gets shorted out on the chassis. At this stage the supply leads, outputs w, x and y and the connections to RLA should be connected up and have sufficient length to reach the other areas of the animal to which they will be later connected. The main board can now be fitted.

Relays RLB and RLC are mounted one above the other, secured on a pair of long 6B.A. screws. The Veroboard associated with these relays is mounted on RLB. The board is fixed in place with an impact adhesive.

The remaining relay, RLD, is kept in position with this adhesive, as is its associated component board.

SYSTEM INTERCONNECTIONS

The various interconnecting wires are shown in Fig. 10. Once the relays have been connected to their respective boards, the inter-circuit wiring can be completed. The latter, when finished, should be neatly laced up or cleated so that all leads are formed into one common cable-loom. The free ends of the leads going to the batteries should be passed through the grommet in the chassis and terminated in crocodile clips. Constructors may, at this point, choose to include a switch for isolation of the batteries from the rest of the circuit; for both simplicity and minimum cost, however, it was considered sufficient to employ crocodile clips for the purpose at the time.

Before connecting any batteries, do make absolutely certain that there are no wiring mistakes.

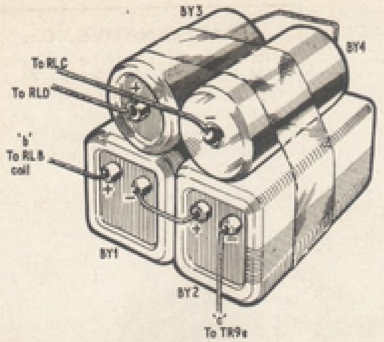


Fig. 12. Battery fixing and wiring details

BATTERIES

The motors are powered by a pair of type HP11 batteries. These should be strapped together according to Fig. 12 using masking tape or similar material. A link between the positive of one battery and the negative of the other should next be soldered into position. The free ends of the batteries will be available for connection to the motors.

The two PP6 batteries, that provide the circuit supply, should undergo a similar process (see Fig. 12). The batteries are mounted on top of the chassis directly above the motors.

FINAL TESTING

Connect up the motor supplies first; note that motors do not run. If this is not so, check wiring from relays. Temporarily disconnect the motor supplies if all is satisfactory. Connect the supplies to the logic and muscle control electronics; note that a regular ticking sound is evident from the RLB, RLC and RLD. If this is the case, then reconnect the motor supplies.

With both supplies connected the rear wheels should be either rotating so as to give forward motion of the animal if placed on the floor, or rotating in opposite directions. On no account should the rotation be that which would result in reverse motion. If, occasionally, this reverse action does occur, then disconnect the outer end of RLA operating coil and remove one turn. Reconnect the coil and try again. Repeat the process until conditions are just stable, i.e. motors not going into the reverse state when unloaded.

Apply a load to the rear wheels by attempting to stop them with the fingers; this should be done for a period of at least 1 second, or at least until reverse motion of the wheels occur. If no reverse action is noted short out the contacts of RLA and ensure that reverse action occurs. If this is not so, then check the Schmitt trigger or reversing bistable. Assuming that XEE reverses when RLA contacts are shorted out, then add one turn to the coil and test the function again. Once this function is satisfactory, the coil can be cemented in place. Shine a torch on to the optical sensors, whilst XEE is moving forward, and establish that the motors respond by reversing for the opposite side to that stimulated; this need not happen straight away since the random function is also involved. The animal can now be placed right way up and begin its life proper, journeying around the chair and table legs in your living room.

BODY

The constructor may wish to construct a shell for XEE to give it a more animal like appearance. The shell shown on last month's cover and in the various photographs was constructed by inflating a balloon to the required size and covering it with tissue paper or newspaper torn in small pieces and pasted with polycell glue.

The shell is built up layer by layer until it is about $\frac{1}{16}$ inch thick; it is then left to dry fully before slowly deflating the balloon. The bottom edge of the shell is then trimmed and a thick cardboard base cut to shape so that it fits inside the shell about 1 inch away from the bottom edge. This base is then fixed to the shell using more paper and paste and finally a hole is cut from the centre to accommodate the batteries and XEE is secured to the base.

Decoration can be painted on the shell as desired and eyes made from the plastic lamp covers glued on over holes in the shell behind which can be mounted X1 and X2. The prototype XEE utilises a selection of resistors to form a spine and has an on-off switch as a tail!

CONCLUSION

XEE is only a partially non-deterministic animal. That is to say it does not always respond to stimuli with any predictability. However, despite this, the beast does stand a greater chance of "survival" than, say, one which acts with 100 per cent certainty. Nevertheless, this in no way implies that it has any intelligence, although it does have the chance of reacting as if it did. ★

ACKNOWLEDGEMENT

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