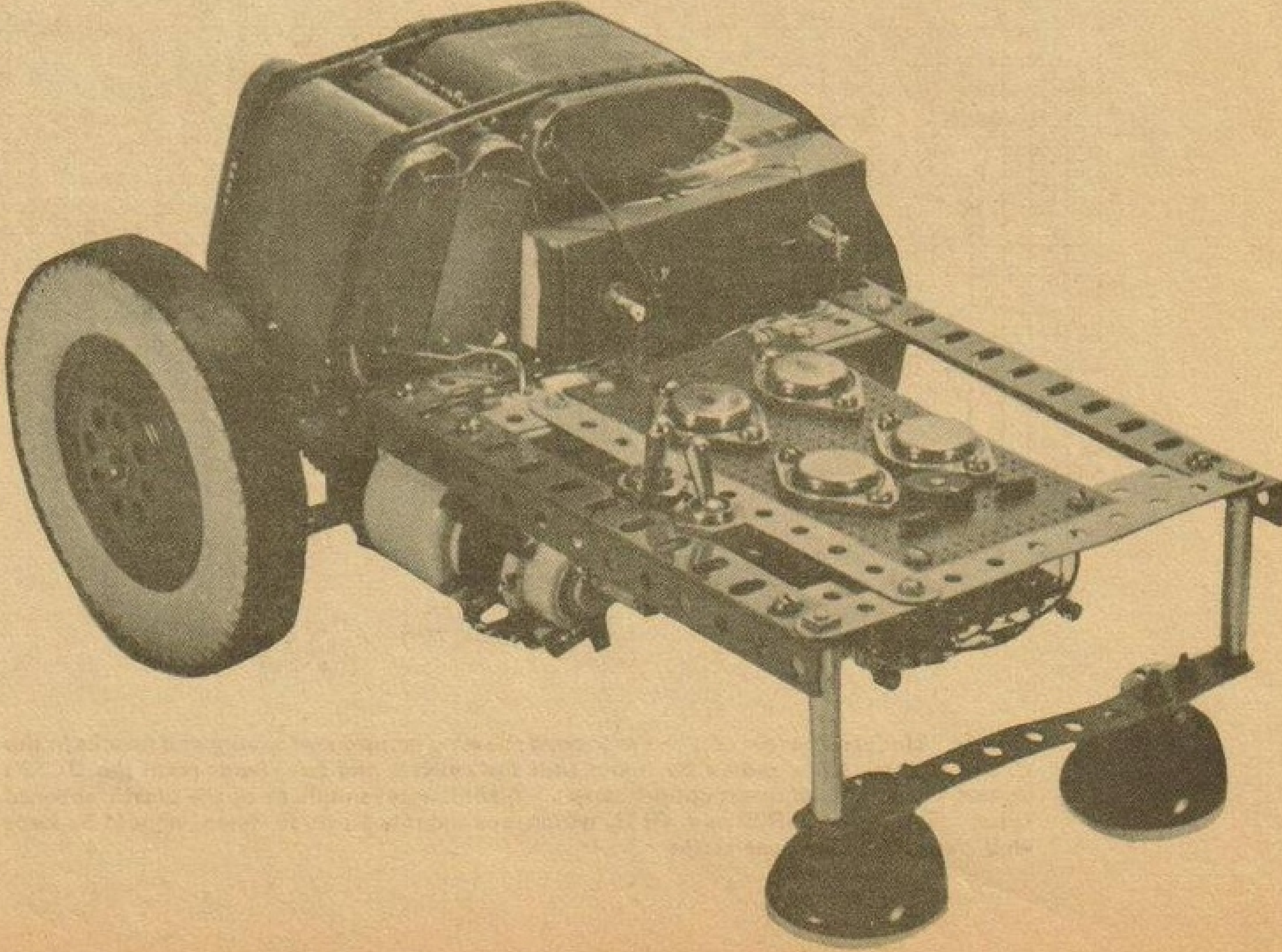


EMMA

THIS article deals with the construction and operation of an electronic "animal" (or robot) and is consistent with the subject matter given in the current P.E. series BIONICS. The design concept has been based largely on data relating to the habits of "real live" animals called *planaria*. These animals, which represent a species of flatworm, are commonly found lurking beneath small rocks and boulders in many of Britain's streams.

Whilst planaria demonstrate a crude form of learning, our synthetic version (which we have called EMMA) will exhibit only certain in-born or innate characteristics. This project should therefore be considered an open-ended affair, in that it can later form the basis for an even more sophisticated "animal". But, while keeping in mind such limitations, it must be emphasised that the model EMMA as described in detail in this article is a complete design and will provide a practical demonstration of this rather unusual application of electronics. In a more general sense, purely as a novelty, EMMA is likely to arouse interest amongst even those who have no electronic knowledge.

The electronic circuit boards, power supplies and the two electric motors which provide EMMA's muscle power are all mounted on a simple chassis. The constructional details for all these items, except the main circuit board, will be given next month in part two of this article. Final setting up and testing procedure will also be detailed in part two. In this opening article, we deal with the reflex circuits, which constitute the main circuit board (No.1)—and the major portion of the electronics involved in EMMA.

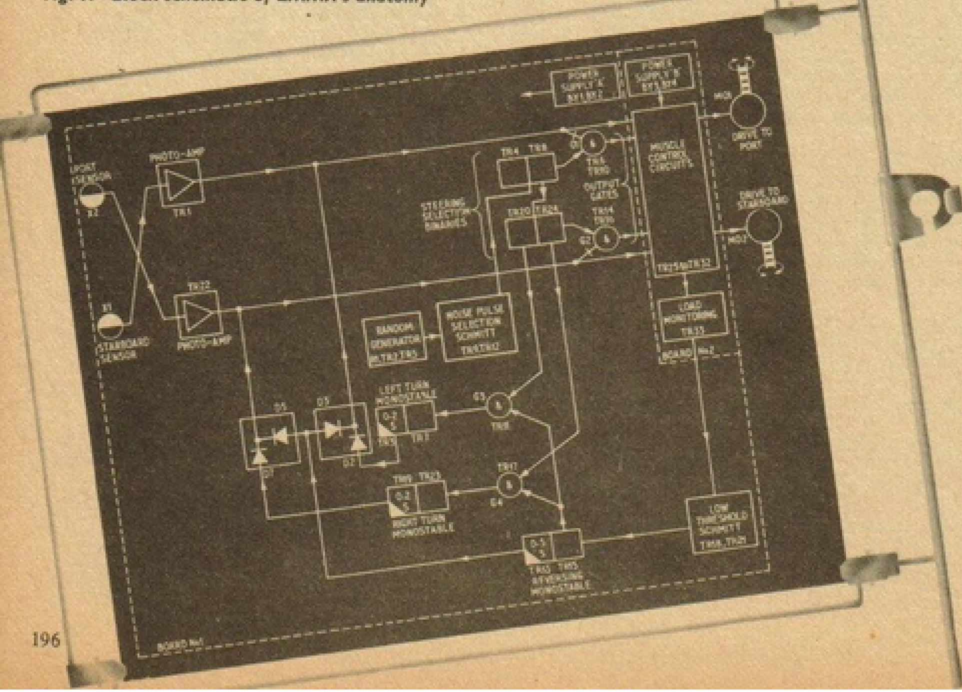
THE ANATOMY

An understanding of EMMA is best obtained by initially referring to Fig. 1 which is a block schematic of her anatomy. Like many real animals, particularly young ones, EMMA responds to stimuli in a rather negative fashion. By acting in such a way a fair degree of self preservation is thus afforded.

NORMAL FUNCTIONS

Under normal conditions the model will be capable of performing any one of four possible actions. These are

Fig. 1. Block schematic of EMMA's anatomy



ELECTRONIC MIME MOBILE ANIMAL

By G.C.BROWN
M.S.H.A.A. A.M.R.S.H.

determined quite randomly through a noise generator and drive selector. The responses available in this mode are as follows:

(a) Moving straight ahead—both motors driving forward.
(b) Moving forward to the right—one motor stopped (starboard) and the other (port) driving forward.
(c) Moving forward to the left—one motor stopped (port) and the other (starboard) driving forward.
(d) Stationary—both motors stopped.

The bracketed port and starboard refer to the respective physical locations on the "animal's" chassis, not to the direction of turn.

When the model is able to adopt this mode of operation its behaviour is very much like that displayed by a living animal finding itself in a strange environment. This design concept is intentional, since under these conditions a creature endowed with a learning faculty would gradually behave in a progressively less random way as it became familiar with its immediate environs. The normal functions are, however, overridden at times when EMMA interacts with photic and tactile (touch) stimuli.

REFLEX FUNCTIONS—PHOTO-SENSE

The sensing of light is bilateral; two quite separate channels exist—left and right. Each channel derives its input from a photo-sensor and, following suitable amplification, has direct control over the forward mode of operation of the opposite channel. Hence if a strong light stimulates one of the sensors the animal will make a reflex movement away from the source of illumination (i.e. the creature is negatively phototropic).

The photo-responses are thus:

(a) Reversing in a straight line away from frontal illumination—both motors running in reverse.
(b) Turning left and away from illumination on the right—one motor (starboard) driving forward and the other (port) driving in reverse.
(c) Turning right and away from illumination on the left—one motor (port) driving forward and the other (starboard) driving in reverse.

LOAD-SENSING

A form of tactile sense, reliant upon "muscle" loading, is built into the model and is an improvement on an earlier version which relied upon a sensitive "touch-boom" arrangement. This scheme was found to be somewhat unsatisfactory due to both the single-ended sensitivity of the boom and the awkwardness of its aspect.

The later concept incorporated in EMMA has quite a different basis of operation. Indeed the system adopted here, whilst retaining a good measure of sensitivity to tactile stimuli, additionally makes provision for monitoring loads. Currently the response to loads is set for some predetermined threshold, but because the model is capable of being modified *ad infinitum* there is no reason why the load-sensing system could not ultimately constitute one of the inputs to a learning network.

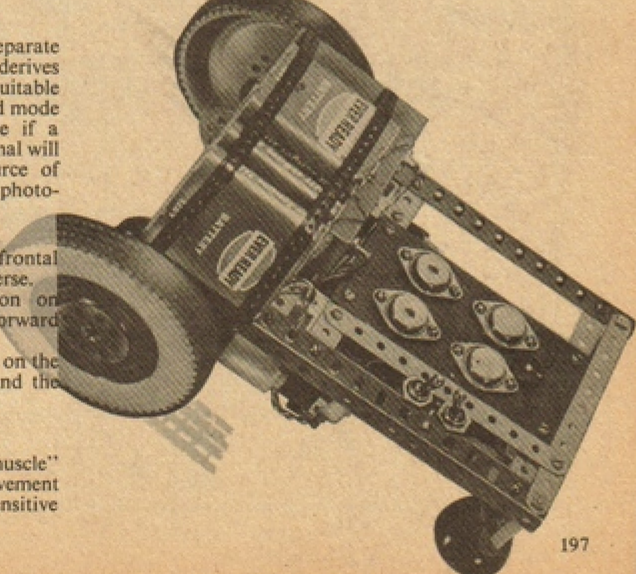
Load sensing then is achieved by monitoring the current drawn by the drive motors. If some pre-set level is exceeded, as for example when the model encounters an obstacle, a Schmitt threshold circuit will be caused to fire. The output from this circuit can then either be fed to a memory system or, as in the present application, to an avoidance circuit.

AVOIDANCE REACTION

During the time that the model is moving around it is likely to meet situations that it finds difficulty in extricating itself from; chair legs and so on representing a particular menace in this respect. In order to improve its chances (of survival!) in these tricky encounters, an avoidance system is employed which, following initial triggering by the load sensing circuit, causes the model to reverse away from the offending obstacle then quite randomly turn either left or right.

The randomness is derived from the noise generator. By making a turn in this rather unreliable way it can be demonstrated that EMMA stands a far more optimistic chance of moving out of trouble than would be the case if the turn was predictable.

As will be seen from the block diagram (Fig. 1), following the load threshold being exceeded the Schmitt circuit will fire the 0·5 second monostable causing the reversing procedure to be adopted. On return of this monostable to its stable condition the trailing edge of its pulse will appear at the inputs of gates G3 and G4 simultaneously.



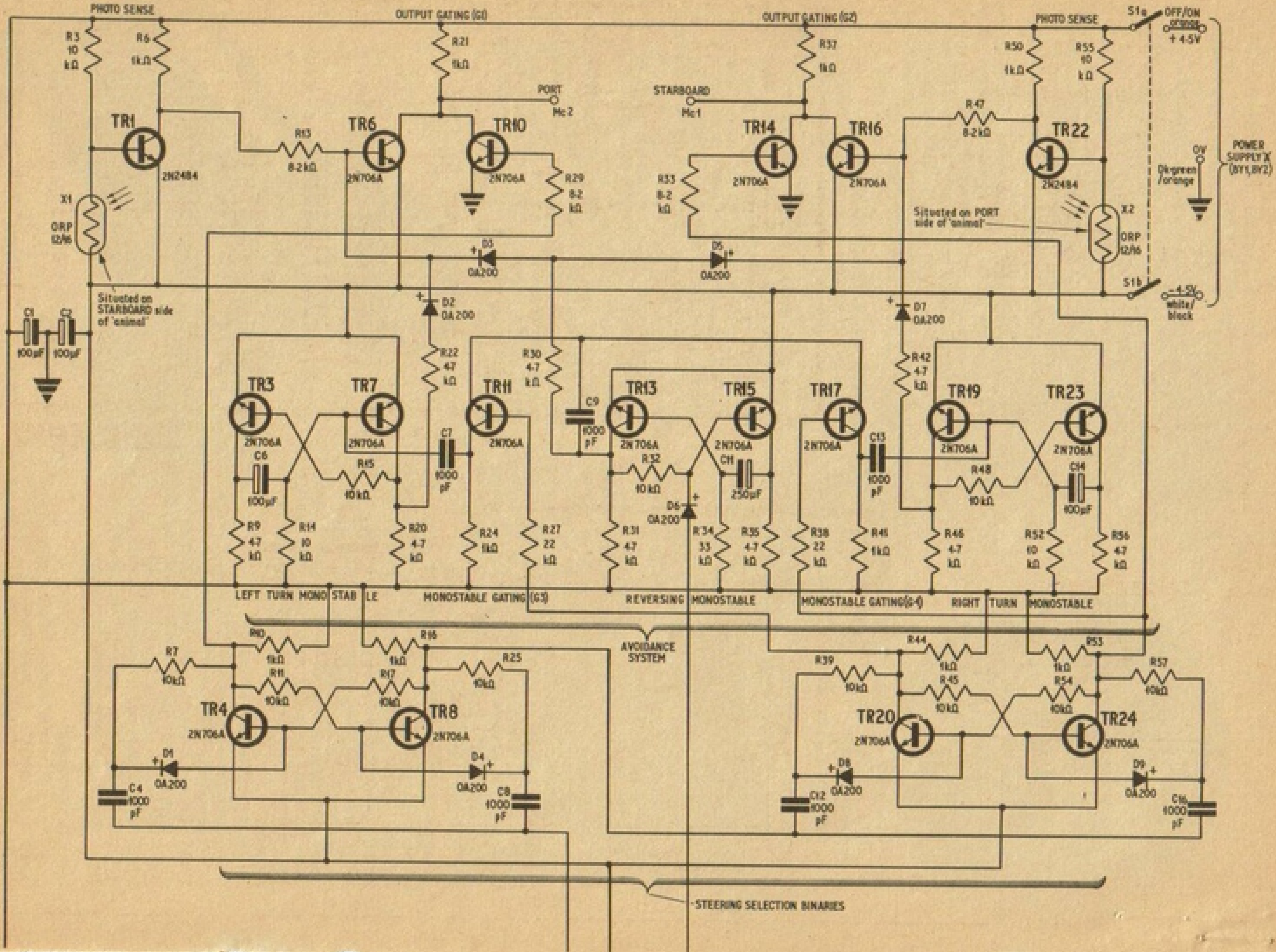


PHOTO SENSE
OUTPUT GATING (G1)
OUTPUT GATING (G2)
PHOTO SENSE
S1a
OFF/ON
orange
+ 4·5V
R3 10 kΩ
R6 1kΩ
R21 1kΩ
PORT
Mc 2
STARBOARD
Mc 1
R37 1kΩ
R50 1kΩ
R55 10 kΩ
TR1
2N2484
R13 8·2 kΩ
TR6
2N706A
TR10
2N706A
R29 8·2 kΩ
TR14
2N706A
R33 8·2 kΩ
TR16
2N706A
R47 8·2 kΩ
TR22
2N2484
0V
Dk-green /orange
POWER SUPPLY 'X' (BY1, BY2)
X1
ORP 12/16
D3 OA200
D5 OA200
Situated on PORT side of 'animal'
X2
ORP 12/16
Situated on STARBOARD side of 'animal'
S1b
- 4·5V
white/ black
D2 OA200
D7 OA200
C1 100µF
C2 100µF
R22 4·7 kΩ
R30 4·7 kΩ
R42 4·7 kΩ
TR3
2N706A
TR7
2N706A
TR11
2N706A
C9 1000 pF
TR13
2N706A
TR15
2N706A
TR17
2N706A
TR19
2N706A
TR23
2N706A
C6 100µF
R15 10 kΩ
C7 1000 pF
R32 10 kΩ
C11 250µF
C13 1000 pF
R48 10 kΩ
C14 100µF
D6 OA200
R9 4·7 kΩ
R14 10 kΩ
R20 4·7 kΩ
R24 1kΩ
R27 22 kΩ
R31 4·7 kΩ
R34 3·3 kΩ
R35 4·7 kΩ
R38 22 kΩ
R41 1kΩ
R46 4·7 kΩ
R52 10 kΩ
R56 4·7 kΩ
LEFT TURN MONOSTABLE
MONOSTABLE GATING (G3)
REVERSING MONOSTABLE
MONOSTABLE GATING (G4)
RIGHT TURN MONOSTABLE
AVOIDANCE SYSTEM
R10 1kΩ
R16 1kΩ
R7 10kΩ
R11 10kΩ
R17 10kΩ
R25 10kΩ
R44 1kΩ
R53 1kΩ
R39 10kΩ
R45 10kΩ
R54 10kΩ
R57 10kΩ
TR4
2N706A
TR8
2N706A
TR20
2N706A
TR24
2N706A
D1 OA200
D4 OA200
D8 OA200
D9 OA200
C4 1000 pF
C8 1000 pF
C12 1000 pF
C16 1000 pF
STEERING SELECTION BINARIES

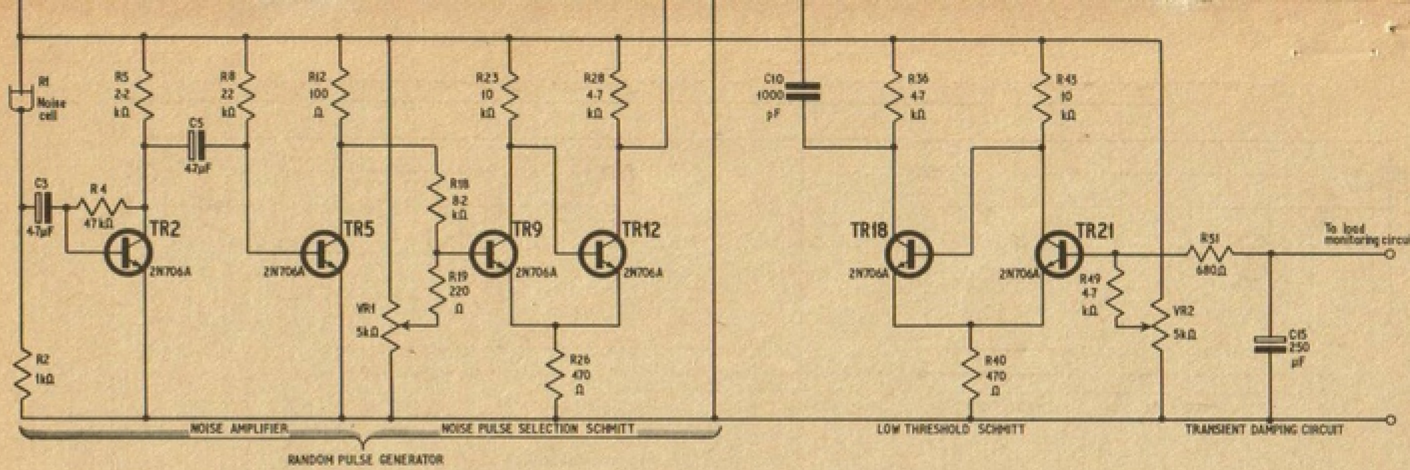


Fig. 2. Electronic mime mobile animal "EMMA" reflex circuits

COMPONENTS . . . REFLEX CIRCUITS

Resistors

R1 Electro-chemical cell (see text)

R2	1kΩ	R21	1kΩ	R40	470Ω
R3	10kΩ	R22	4·7kΩ	R41	1kΩ
R4	47kΩ	R23	10kΩ	R42	4·7kΩ
R5	2·2kΩ	R24	1kΩ	R43	10kΩ
R6	1kΩ	R25	10kΩ	R44	1kΩ
R7	10kΩ	R26	470Ω	R45	10kΩ
R8	22kΩ	R27	22kΩ	R46	4·7kΩ
R9	4·7kΩ	R28	4·7kΩ	R47	8·2kΩ
R10	1kΩ	R29	8·2kΩ	R48	10kΩ
R11	10kΩ	R30	4·7kΩ	R49	4·7kΩ
R12	100Ω	R31	4·7kΩ	R50	1kΩ
R13	8·2kΩ	R32	10kΩ	R51	680Ω
R14	10kΩ	R33	8·2kΩ	R52	10kΩ
R15	10kΩ	R34	33kΩ	R53	1kΩ
R16	1kΩ	R35	4·7kΩ	R54	10kΩ
R17	10kΩ	R36	4·7kΩ	R55	10kΩ
R18	8·2kΩ	R37	1kΩ	R56	4·7kΩ
R19	220Ω	R38	22kΩ	R57	10kΩ
R20	4·7kΩ	R39	10kΩ		

All (except R1) ±10%, ¼W carbon

Potentiometers

VR1, 2 5kΩ sub-miniature (Ardente) (2 off)

Capacitors

C1	100µF 15V elect.	C9	1,000pF ceramic
C2	100µF 15V elect.	C10	1,000pF ceramic
C3	4·7µF 15V elect.	C11	250µF 15V elect.
C4	1,000pF ceramic	C12	1,000pF ceramic
C5	4·7µF 15V elect.	C13	1,000pF ceramic
C6	100µF 15V elect.	C14	100µF 15V elect.
C7	1,000pF ceramic	C15	250µF 15V elect.
C8	1,000pF ceramic	C16	1,000pF ceramic

Transistors

TR1	2N2484	TR22	2N2484
TR2–21	2N706A (20 off)	TR23, 24	2N706A

Diodes

D1–9 OA200 (9 off)

Miscellaneous

S1 D.P.S.T. toggle switch
X1, 2 ORP12 *or* ORP16 (2 off)
Piece Veroboard 5in × 2½in (0·1in pitch)
Connecting wire: 22 s.w.g. plastic covered; 22 s.w.g. tinned copper. Silver wire, 18 or 20 s.w.g., 2·3in long; small quantity of silver nitrate (for R1)

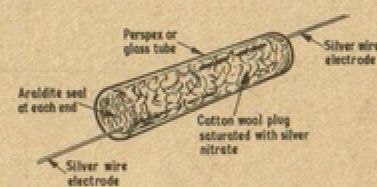


Fig. 3. Random pulse noise cell (R1)

If this input to the gates coincides with an enabling level from the random generator, one or other of the 0·2 second monostables will be fired. As a consequence although one motor will have begun driving forward, its opposite number will continue in the reverse direction for a further 0·2 seconds, resulting in the animal performing a turn. At the end of this period the avoidance reaction will be terminated, no further response being elicited unless the load threshold is again exceeded.

WORK AND REWARD

A further point of interest arising from this load-sensing/avoidance reaction system is that EMMA will tend to respond both to obstacles in its path and additionally display something of "annoyance" if direct loads (in the form of added weight—heavy books, etc.) are applied. The constructor will here see even more interesting possibilities—a creature able to determine loads need only be interconnected with a learning network to be in a position to receive payment in return for work. Thus if instead of attempting to shake-off an unwelcome load (e.g. when its battery is low) it accepted the task and was later rewarded (with a recharge), it would have learnt that to work was to survive—a not altogether unreasonable assumption! This more ambitious type of project will be a feature of the future article mentioned earlier.

TRANSIENT DAMPING AND LOAD THRESHOLD CIRCUITS

Because we have no wish to let our "animal" respond to transient loads (as for example would be caused by the initial stall currents when the motors turn on) it is necessary to include C15 (Fig. 2) to damp-out such effects. The response, as a result, is now more positive and only occurs when more continuous loads are applied.

The trigger circuit, shown in Fig. 2, comprising TR18 and TR21 has its threshold level set by VR2. Depending on the setting of this potentiometer the circuit can be made to fire for high or low load conditions. Prior to triggering, TR21 is cut off and TR18 is conducting; if the circuit fires, then TR18 collector will go positive. This transition is utilised in triggering the avoidance system as will be seen shortly.

OUTPUT GATING

The two output gates (G1 and G2 in Fig. 1) comprise TR6, TR10 and TR14, TR16. Whilst these gates are depicted in normal binary logic form in Fig. 1, they actually perform a ternary function (see Fig. 2). Their logic is such that the output function can be +1, 0, or −1 and is essential since EMMA is required to go forward, stop, and reverse. The gates are essentially of NAND/NOR format but differ in the respect that the transistors have their emitters returned to different potentials.

For example, with both TR6 and TR10 non-conducting their common collector point will be positive with respect to earth, corresponding to the forward condition in the port channel. If TR10 is made to conduct the collector point will drop to zero, corresponding to the stop condition. On the other hand if TR6 is caused to conduct the reversing condition will be initiated and override all else in the channel. At these times the common collector point will be negative with respect to earth. The gate for the starboard channel operates in an identical way.

RANDOM PULSE GENERATION

The requirement for a low-occurrence random pulse source in EMMA has given the author many a headache. Diodes and similar devices are of no real use in this application because the noise generated by them generally has a pulse rate which is inordinately high. An electro-chemical device finally proved to have the necessary characteristics. In an earlier project this took the form of a saline cell; although representing a practical proposition this needed frequently topping-up and could not unfortunately be sealed completely without the risk of high gas pressures developing.

A very much improved random pulse source is incorporated in EMMA and is depicted as R1 in Fig. 2. The device is a completely sealed electro-chemical cell and has a casing made either from glass or perspex tubing measuring approximately $\frac{1}{2}$in × $\frac{1}{4}$in diameter.

Contained within and leaving the tube at either end are a pair of silver-wire electrodes making contact with a cotton-wool plug. This plug is barely saturated with about a one per cent solution of silver nitrate. The open ends of the tube are sealed off using an epoxy-resin such as Araldite. See Fig. 3.

Caution; silver nitrate is a particularly corrosive chemical and care should be exercised in keeping it clear from the skin and eyes.

When the completed cell (R1) is subjected to quite low applied voltages, metallic ions are taken out of the solution and form silver threads which rapidly grow from the negative to positive electrodes (these threads are extremely fine and can only be seen with difficulty). The threads are supported by and grow through the cotton-wool plug; however, upon reaching the opposite electrode a thread will just make contact (causing a sudden reduction in the voltage drop across the cell) and then be disrupted by the increased current.

Following each break-down a new thread will begin and the process repeats. As the growth processes and disruptions are quite unpredictable so the changes in voltage across the cell occur randomly.

The output noise pulses from the cell have varying amplitudes and hence, following suitable amplification (TR2 and TR5), can be applied to the Schmitt threshold circuit which, once set by VR1, provides selection of only the higher amplitude pulses. In this way it is possible to obtain randomly distributed pulses having very low occurrence rates. The output derived from the collector of TR12 in the Schmitt circuit is taken to the steering selection binaries.

STEERING SELECTION SYSTEM

The pulses derived from the randomising circuit are fed direct to a conventional two stage binary counter controlling the forward and stop functions of the model (Fig. 2). Feeds to the output gating circuits are taken via resistors from the collectors of TR4 and TR24, and with both these transistors in the conducting state (collectors negative) forward drive will be selected.

The first random pulse to appear at the counter will result in both stages of the counter turning over and as a consequence TR4 and TR24 collectors will go positive causing the animal to stop. However, the next two pulses to arrive will result in the animal performing right and left turns. Forward drive will be resumed as a result of the fourth pulse; the cycle will then repeat.

As it is impossible to predict when each pulse will occur, the times between the various forward modes are thus random. Operation of the circuit although sequential does not always appear so in practice. This is because the pulses sometimes have a bunched

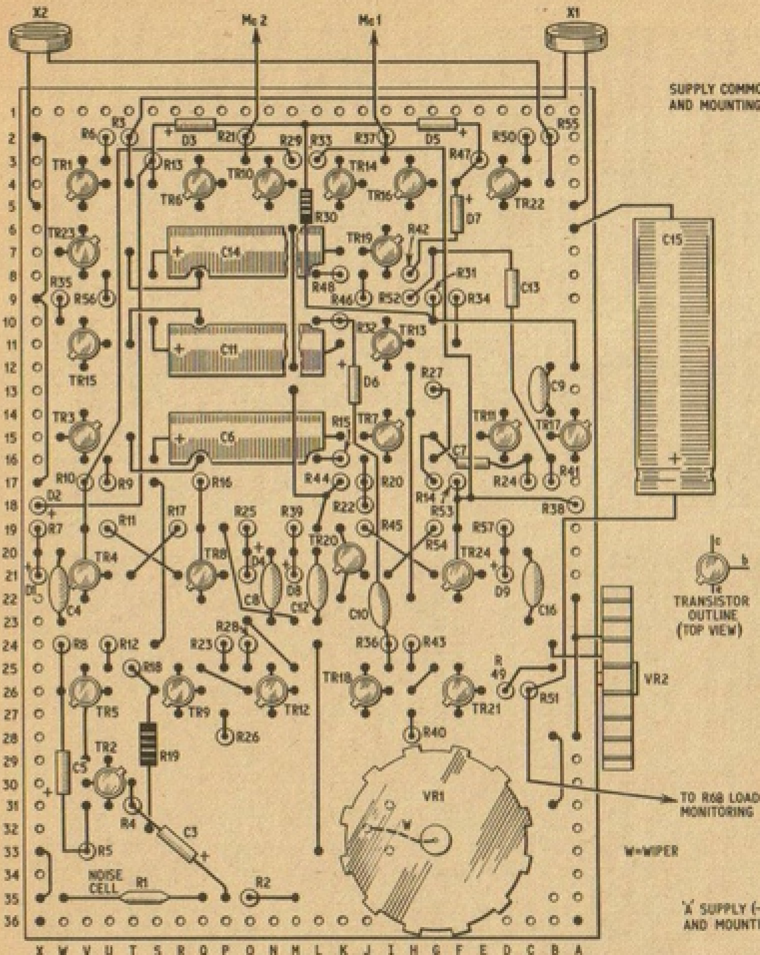


Fig. 4a. Layout of components on the reflex functions circuit board

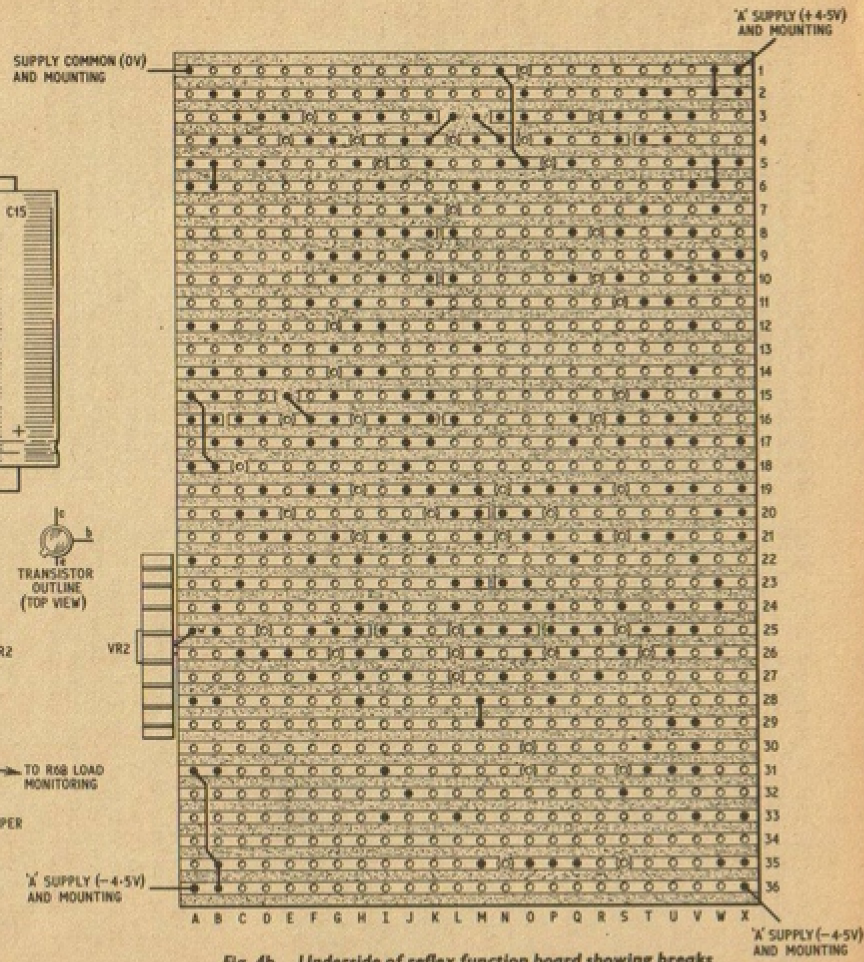
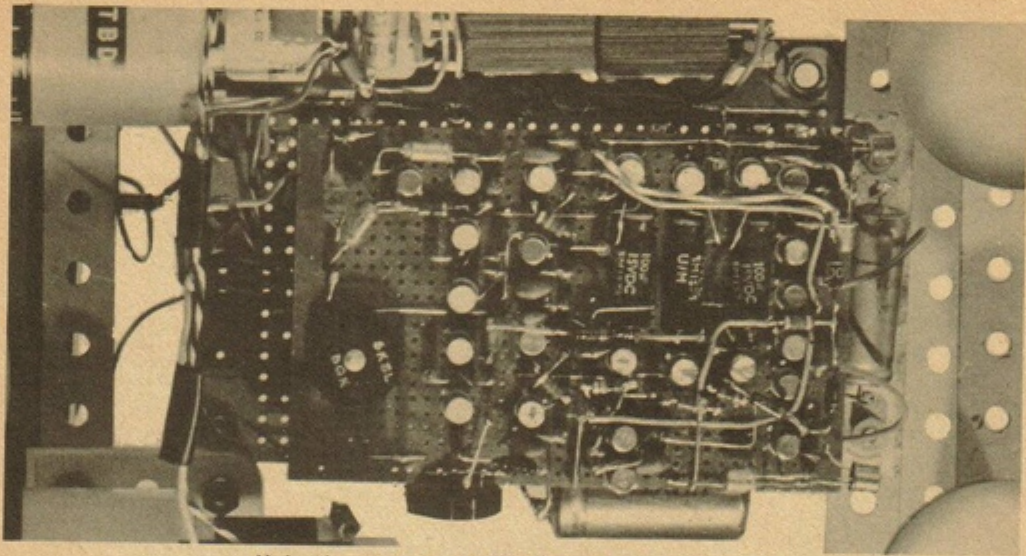


Fig. 4b. Underside of reflex function board showing breaks in copper strips. All link wires to be plastics sleeved



Underside view of EMMA showing the reflex functions board

characteristic and hence the counter may well be completely cycled several times without its effects being observed.

Additional outputs are taken from the last stage of the counter at the collectors of TR20 and TR24 and control the gating in the avoidance system.

AVOIDANCE SYSTEM

The avoidance system comprises the three monostables and random gating arrangement discussed earlier and shown in Fig. 2. Whenever a load is sensed which exceeds the set threshold level, the associated Schmitt TR18, TR21 will fire causing a positive pulse to appear at the base of TR15 in the reversing monostable. The monostable will therefore switch to its quasi-stable state and the positive level now appearing at the collector of TR13 will turn both TR6 and TR16 on, resulting in EMMA reversing.

Following a short period (about 0·5 seconds) the reversing monostable will return to its stable condition. In so doing, a negative pulse fed from TR13 collector will momentarily pull-down the emitters of gating transistors TR11 and TR17. Now at any particular time one of these transistors will be able to conduct because they are both under the control of the last stage in the steering selection system.

Thus, assuming TR17 base happens to be at a positive potential just when its emitter is taken negative, then TR19 will turn off and the right-turn monostable will fire. Therefore, although TR6 will have returned to normal, TR16 will maintain reverse drive in the starboard channel causing the turning mode to be to the right. Turning left after reversing will result from triggering of the left-turn monostable via TR11.

By employing the random output from the steering selection system to route pulses to one or other "turn" monostables, the avoidance reaction will hence in part also be random and therefore give a better chance of negotiating obstacles.

PHOTO-SENSORS

The animal relies for its photo-sense upon two CDS cells, X1, X2 (these can either be ORP12 or ORP16 types). Each cell is connected between the base of its associated photo amplifier and the negative rail. These cells must be mounted so that they face away from the circuit board in a direction which is parallel to the edge of the board.

In the un-illuminated condition of the cells, both TR1 and TR22 collectors will be at a negative potential. If, for example, X2 (physically located on the port side) is illuminated then TR22 collector will go positive, thereby turning TR16 on; as a consequence the starboard motor will drive in reverse causing the model to turn away. Similarly if X1 only is stimulated then the port motor will reverse.

Stimulation of both photo sensors results in the model backing away until it is out of the influence of the light source. Generally this backing-away mode will be terminated by a short turn in one or other directions due to slight differences in channel sensitivities; the process is thus unlikely to be uselessly repeated.

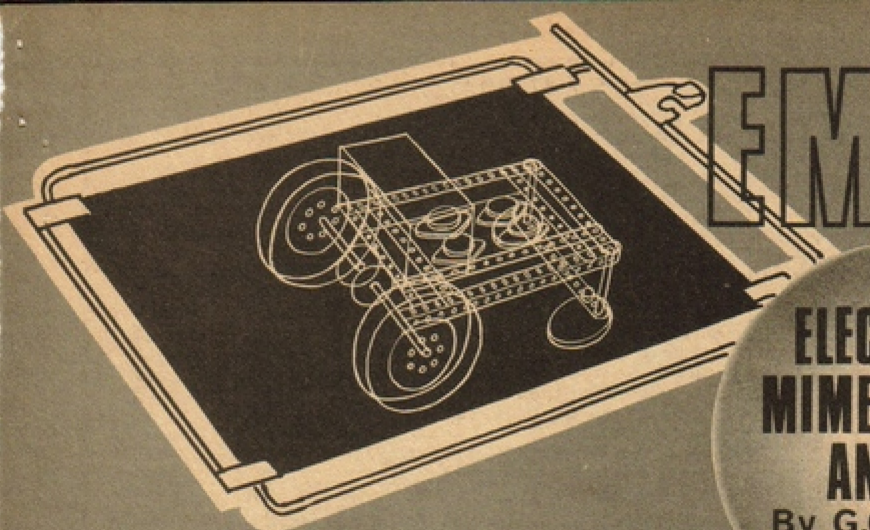
CONSTRUCTION OF THE CIRCUIT BOARD

Figs. 4a and 4b show the layout and wiring details of the main circuit board. This board contains all the electronic circuits which provide the reflex functions.

The Veroboard used only requires drilling for the randomising circuit potentiometer as shown in Fig. 4, all other components are mounted by means of their own leads. The breaks in the copper strips shown should be made before the components are fitted and care should be taken to ensure that the complete width of the strip has been cut.

It is advisable to mount the transistors and diodes after all the other components to avoid overheating when soldering.

Details of the motor control circuit board, power supplies and all mechanical construction and mounting of the various parts will be fully detailed next month.



EMMA

ELECTRONIC MIME MOBILE ANIMAL

By G.C.BROWN
M.S.H.A.A. A.M.R.S.H.

PART one of EMMA detailed the theory and wiring of the complete reflex functions board. This month we describe the "muscle" control and load monitoring circuit and board, the power supply wiring and the mechanical details of EMMA's "skeleton". The block diagram for the electronic parts was shown in Fig. 1 (last month), enclosed by a separate broken line, designated "Board No. 2".

"MUSCLE" CONTROL

The "muscle" (motor) control circuits (Fig. 5) consist of two channels providing power switching for the port and starboard motors. Each channel comprises a pair of OC35 power transistors driven by a complementary input arrangement. Due to their inexpensiveness, common types of power transistors have been used as an alternative to more exotic miniature devices connected in full complementary format. Although larger, the cheaper versions have the advantage that with the small current demands made upon them additional heat sinks are not required.

The motor in each channel is connected between the centre-point of its associated power transistors and, via R67, the common point. With either input Mc1 or Mc2 at ground level the input transistors will be effectively non-conducting and the motors will be switched-off. A positive level on Mc1, however, will turn-on TR26 causing TR28 to conduct and hence drive the starboard motor forward. Taking Mc1, negative will turn off TR26 and switch on TR25 thus causing TR27 to conduct and the motor to drive in the opposite direction. The channel controlling the port motor is operated in an identical fashion.

Despite the employment of separate power supplies, some interference resulting from motor "hash" inevitably reaches the reflex functions board. In an attempt to minimise this complaint and make the motor control system a little more sanitary, two 0·1μF capacitors (C17 and C18) are wired in parallel with the motors.

LOAD SENSING CIRCUIT

During forward motion of EMMA, the joint current demands made by the two motors are monitored by transistor TR33 (Fig. 5) which under no load conditions is arranged to be just cut-off. Any mechanical load applied to either or both motors will increase the current drawn through R67 and therefore take the emitter of TR33 more positive causing the transistor to conduct. The collector level of TR33 under these conditions will thus tend to go more and more positive with increasing loads and be an indication of the degree of loading. Potentiometer VR3 sets the level for no-load conditions and controls the sensitivity of the circuit.

Resistor R67 can be fabricated from easily obtainable electric-fire element wire. A few turns of this should be cut off and preferably measured on an ohmmeter for correct value. When the resistance is the correct value, the wire ends should be filed clean to facilitate soldering. R67 must obviously be kept low in value because the motors themselves only have a resistance of about 3 ohms.

CIRCUIT BOARD DETAILS

Illustrations of the "muscle" control board are given in Figs. 6a and b. The board should be drilled as indicated to accommodate the four power transistors. No heat sinks are required because the transistors are not called upon to dissipate any over-large currents.

The reflex functions board, which was detailed last month, is firmly mounted by way of 18 s.w.g. wire soldered between its four corners and the corners of the "muscle" control board. Such an arrangement lends itself well to instant modification and occasional "surgery", additional boards being freely accommodated in minutes.

POWER SUPPLIES

The "animal" requires two power supplies, termed "A" and "B". Two sources of supply are used in preference to one because of the demand for large de-coupling capacitors with a single supply. In fact the additional supply takes up less space than would the capacitors. Supply "A" feeds the whole of the reflex circuitry and consists of a pair of type 1289 batteries.

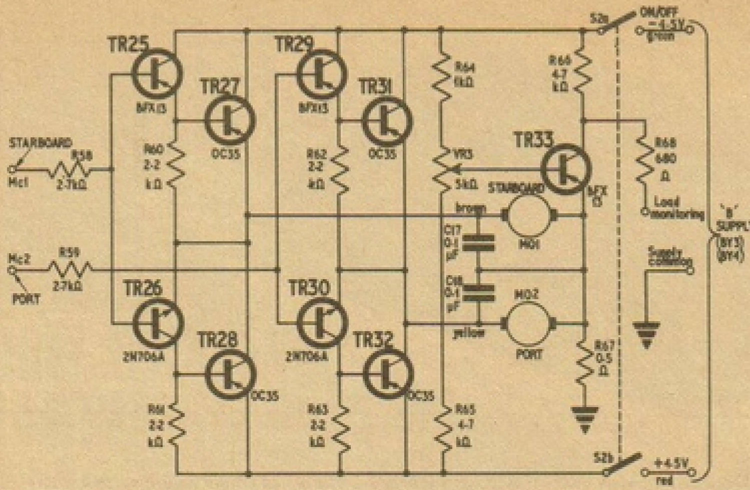


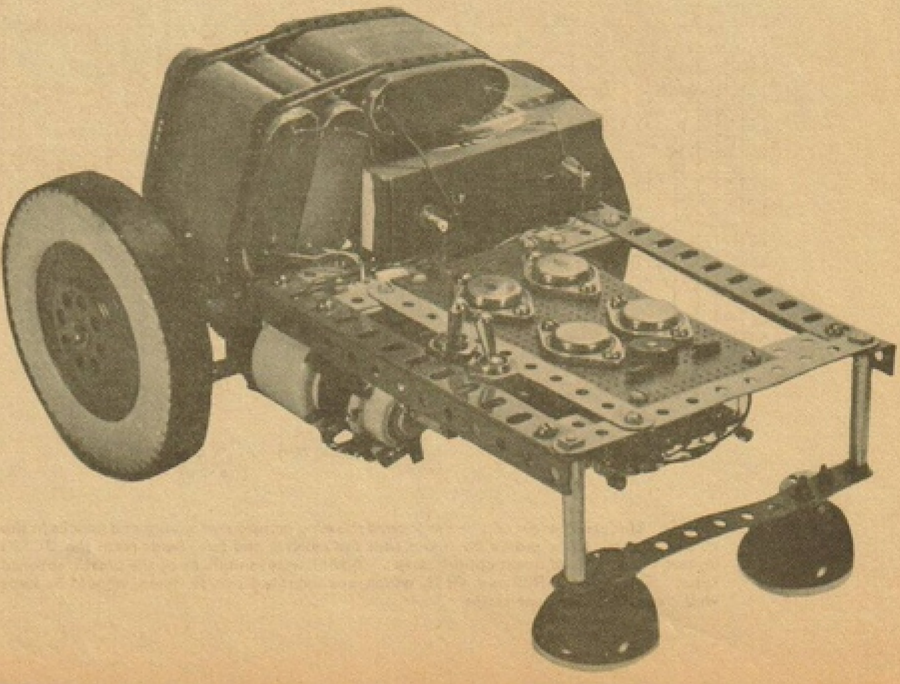
Fig. 5. Electronic mime mobile animal "EMMA". Circuit diagram of the motor control and load sensing circuits

Supply "B" feeds the motor control circuit and comprises a type 126 battery for forward drive (a heavy duty battery is used here because EMMA is more frequently in this mode) and a type 1289 battery for reverse drive. In both cases the supplies are connected so as to form 4·5V—0—4·5V sources (see Fig. 7), the zero point being common to "A" and "B".

CHASSIS DETAILS

In order to make the construction problem minimal, Meccano components were chosen for the model. The chassis which is of extremely simple construction is shown in Figs. 8, 9 and 10 and essentially comprises a rigid skeleton plinth, formed from two main longitudinal angle girders connected together by five cross members. The cross members in addition to lending strength to the chassis also carry the motors, motor control board, and override switches S1 and S2, the switches being mounted between two chassis members and thereby dispensing with the need for drilling.

Downward extensions at the front and rear of the plinth support the castors and axles respectively. At the rear of EMMA this is constituted by four double-angle strips bolted between the plinth and a tie-strip. The frontal (anterior) end comprises a pair of screwed rods running between the plinth and a lower cross member. This member and the plinth are separated by



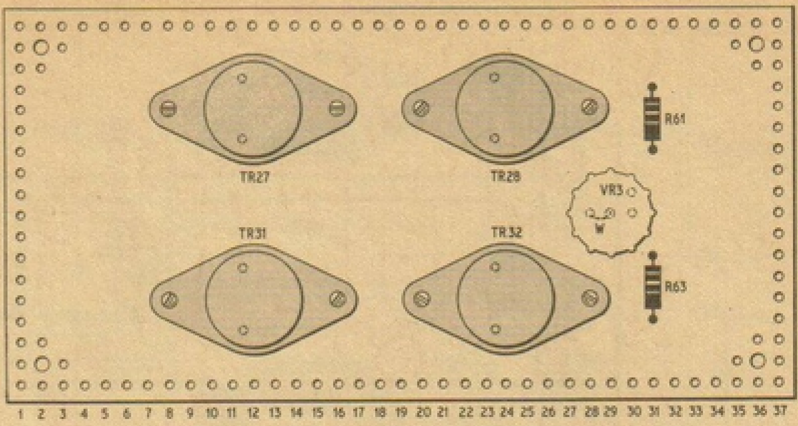


Fig. 6a. Top view of the motor control board. The board should be drilled to accommodate the OC35 mounting screws and the base and emitter pins. Mounting holes for the board are made at each corner to line up with the Meccano mounting strips

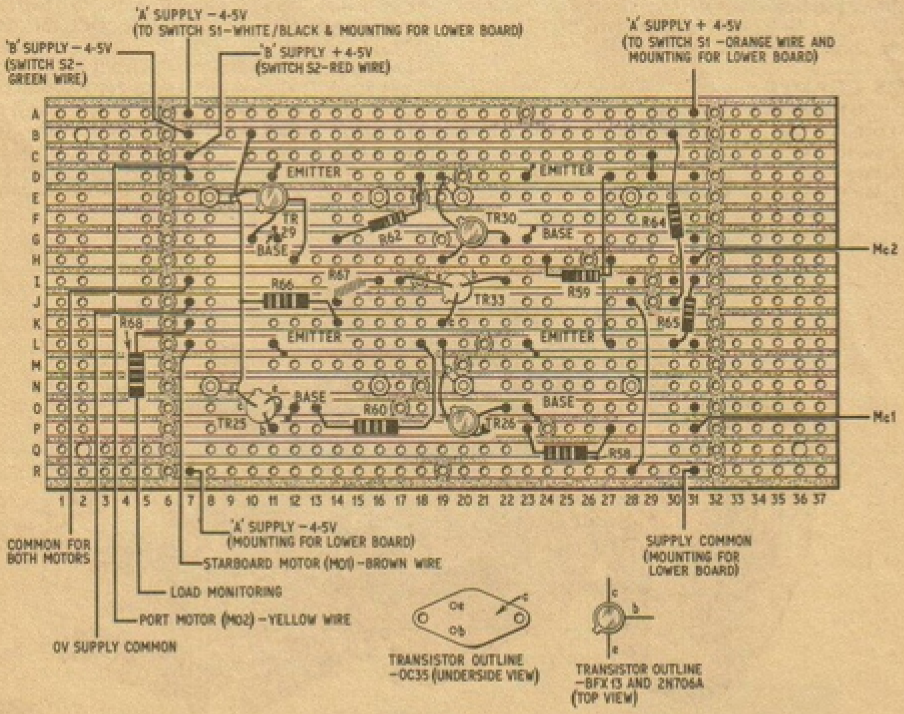


Fig. 6b. Underside view of the Veroboard showing component wiring and breaks in the circuit strips. Care should be taken that the emitter and base leads from the OC35's do not short with adjacent copper strips. All link wires should be of the plastic covered type. Transistors TR25 and TR33, which are mounted upside down, should be kept well clear of the copper strips

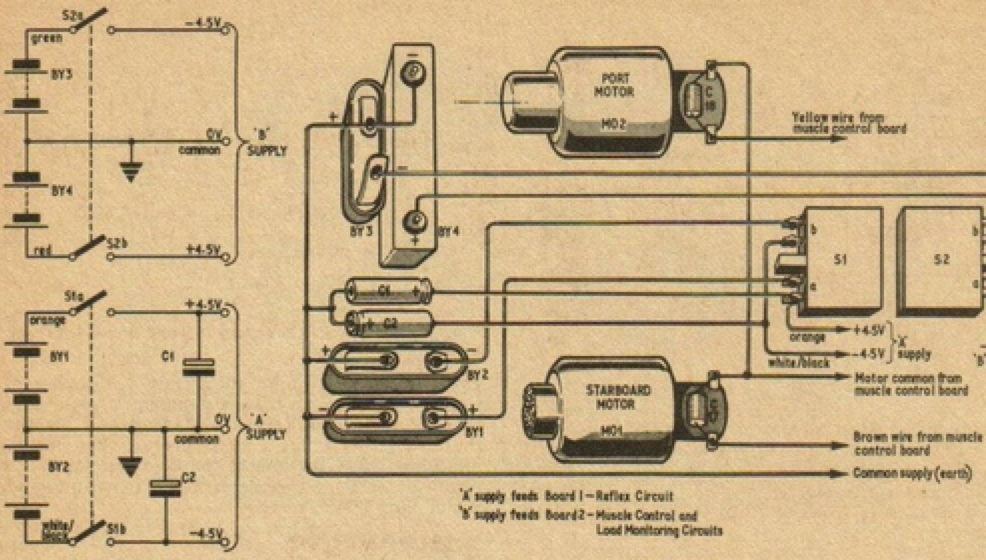


Fig. 7. Circuit and wiring of the two power supplies and motors. Capacitors C1 and C2 were shown in the main circuit diagram (Fig. 2) last month

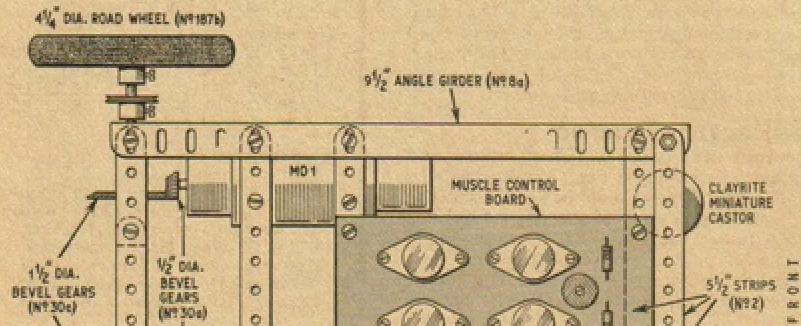
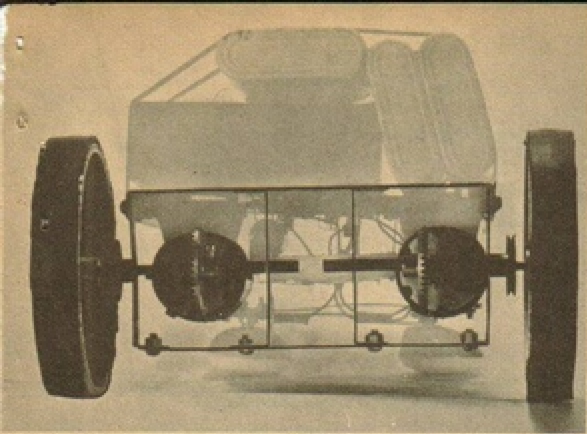


Fig. 8. Top view of EMMA's skeleton showing chassis construction and component mounting positions. Batteries BY1, 2, 3 and 4 occupy the rear end of the skeleton, above the motors (see photos)



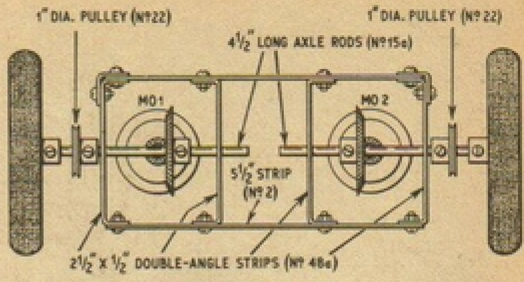


Fig. 9. Rear view of the chassis showing the drive arrangements

tubular pillars which slide over the screwed rods.

Space for the batteries is provided above and just rear of the motor mounting position. For easy access the batteries can be secured in place by way of elastic bands or plastics strips attached to either side of the chassis.

FINAL-DRIVE ARRANGEMENT

EMMA's motive power is derived from a pair of Meccano "Power Drive" motor/gearbox units; these are located port and starboard on the chassis and each is secured in position by four 4B.A. nuts and bolts. The gearboxes, which are of the epicyclic type, have provision for the selection of several gear ratios; in the model the lowest (60 : 1) is used. Output from the gearboxes is taken via bevel gears which provide a further 3 : 1 reduction, thus giving an overall figure of 180 : 1 between the motors and road wheels.

The final-drive axles which run through the centre holes of the double-angle strips each carry a road wheel, a large bevel gear, and a pulley. The pulley, properly adjusted, serves the purpose of reducing end-float and ensures correct meshing of the gears.

INTERCONNECTION WIRING

Wiring between the boards, switches, motors and power supplies is shown in Fig. 7. It must be emphasised that motor leads should be kept as short as possible and maintained clear of the reflex functions board and its wiring. The "A" and "B" power supply leads should not run in the same cableform and must have quite separate routes to avoid coupling motor "hash" into the reflex functions circuits.

SYSTEMS CHECK-OUT

When the circuit boards have been completed they should be carefully examined to ensure that components are correctly connected and no dry joints exist. Check too that there are no accidental solder bridge-overs between adjacent conductors.

Prior to check-out of the complete system, the inputs to the motor control board (Mc1 and Mc2) should be temporarily disconnected. At this time the "animal" is best raised off its wheels so that they are free to turn during the checks which follow.

MOTOR CONTROL AND LOAD SENSING

Connect both supplies and switch S2 on. Temporarily connect inputs Mc1 and Mc2 together and take this common input to zero (ground); under these conditions neither motor should run. Reconnect the common input to the positive supply rail; both motors should now run in the forward direction—if this is not the case, reverse the connections to the offending motor(s). Now disconnect the common input from positive and connect to the negative rail, ensuring both motors now run in reverse.

COMPONENTS . . .

MOTOR CONTROL

Resistors

R58	2·7kΩ	R64	1kΩ
R59	2·7kΩ	R65	4·7kΩ
R60	2·2kΩ	R66	4·7kΩ
R61	2·2kΩ	R67	0·5Ω (see text)
R62	2·2kΩ	R68	680Ω
R63	2·2kΩ		

Capacitors

C17, C18 0·1μF polyester 150V

Transistors

TR25	BFX13 or BFX12	TR30	2N706A
TR26	2N706A	TR31	OC35
TR27	OC35	TR32	OC35
TR28	OC35	TR33	BFX13 or BFX12
TR29	BFX13 or BFX12		

Miscellaneous

VR1 5kΩ min
MO1 Meccano "Power Drive" motor/gearbox
MO2 Meccano "Power Drive" motor/gearbox
S2 double pole on/off toggle switch
BY1, 2, 3 type 1289, 4·5V batteries
BY4 type 126, 4·5V battery
Veroboard 5⅜in × 2⅜in (0·15in pitch)
22 s.w.g. plastic covered wire

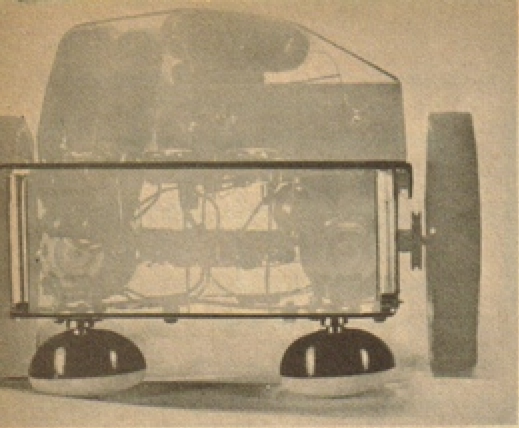
MECHANICAL

Chassis Components

No. 2 strips (8 off)
No. 8a angle girders (2 off)
No. 37a nuts (4 off)
No. 48a double angle strips (4 off)
No. 80 screwed rods (2 off)
} Meccano
2in × ¼in dia. dural pillars (2 off)
4B.A. and 6B.A. fixings

Drive Components

No. 15a axle rods (2 off)
No. 22 pulleys (2 off)
No. 30a bevel gears (2 off)
No. 30c bevel gears (2 off)
No. 187b road wheels (2 off)
} Meccano
Miniature slipper castors (Clayrite, 2 off)



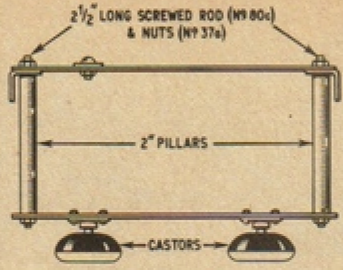


Fig. 10. View from the front of EMMA, with circuit boards removed, showing the castor mountings

Reconnect the common input (Mc1 and Mc2) to the positive rail and connect a voltmeter between the negative supply point and the collector of TR33. Adjust VR3 for zero indication under no-load conditions. Now gently load both motors, by slowing the road wheels, and ensure that the indicated voltage increases with increasing load. Disconnect the common input, separate Mc1 and Mc2 and return them to their normal connections with the reflex functions board. Switch S1 on.

LOAD THRESHOLD AND AVOIDANCE SYSTEM

Connect the voltmeter between the negative rail and the collector of TR18. Adjust VR2 so that the Schmitt fires at a point consistent with moderate loading; the circuit will fire after a short delay due to the transient damping.

During the load threshold checks one can simultaneously establish that the avoidance system is functioning correctly—i.e. that with application of loads exceeding the set threshold the motors reverse their direction of rotation and that one or other continues to reverse for a further period prior to resumption of the normal forward mode. Remember that there should be obvious randomness as to which motor runs-on in reverse. If not, adjust VR1 a fraction until some degree of randomness is present.

STEERING SELECTION AND FINAL CHECKS

Place EMMA on the floor and ensure that the random function also manifests itself in the forward mode of operation. EMMA should quite unpredictably stop, start and turn right or left. During encounters with various obstacles, EMMA should back and turn to commence a new, more favourable course. Finally, shine a light onto EMMA's photo-sensors to ensure that she turns away and then resumes her previous mode.

Although crude compared with some of the most simple living animals, EMMA demonstrates in a quite striking way that electronics can be used to model a few of the basic reflexes. In a later article EMMA will "fill-out" her structure with a learning faculty; in the meantime however the constructor will have his hands full with a "pet" running around the house that requires little exercise and lives a lifetime—provided the battery manufacturers stay in business! ★

EDUCATED EMMA

ELECTRONIC MIME MOBILE ANIMAL

By G.C. BROWN
M.S.H.A.A. A.M.R.S.H.

This article is an extension of the EMMA project published in the March and April 1969 PRACTICAL ELECTRONICS. It is expected that readers wishing to add EMMA's new capability will be familiar with the previous articles; the component numbering is carried on from the earlier circuits and reference is made to diagrams in the March and April 1969 issues. We regret that we are no longer able to supply copies of these issues.

SINCE the formative weeks following EMMA's rather difficult birth back in March she has, as we would have expected, already come of age. Indeed, she now exhibits a kind of self-preservation awareness which encourages her to perform simple work tasks for a living. More accurately, given the right situation EMMA really "wants" to work because to do so is now part of her make-up and she can learn that quite often this will pay-off.

In order to embody this new faculty EMMA's shape has filled out just a little with an additional circuit board. However, the modifications to her existing systems are not unduly complicated and the keen Bionics constructor will probably be overjoyed to know that at last he can have a semi-intelligent "animal".

ANATOMICAL CHANGES

To encourage EMMA to work in return for reward requires a few extra circuit blocks and if the reader refers to Fig. 1, a clear impression of the technique will be gained.

The philosophy behind the original scheme for EMMA has not been changed drastically, but there are now included such items as a Schmitt trigger which monitors the supply voltage level and of course the inevitable learning circuit with which by now we must all be familiar. This embodies a pair of monostables, one (the extension monostable) having a duration of 20 seconds and the other (the differential monostable) a period of 1 second.

As usual there are also included an AND gate and a summer with its attendant learnt threshold Schmitt which triggers upon the summer level reaching some pre-determined value.

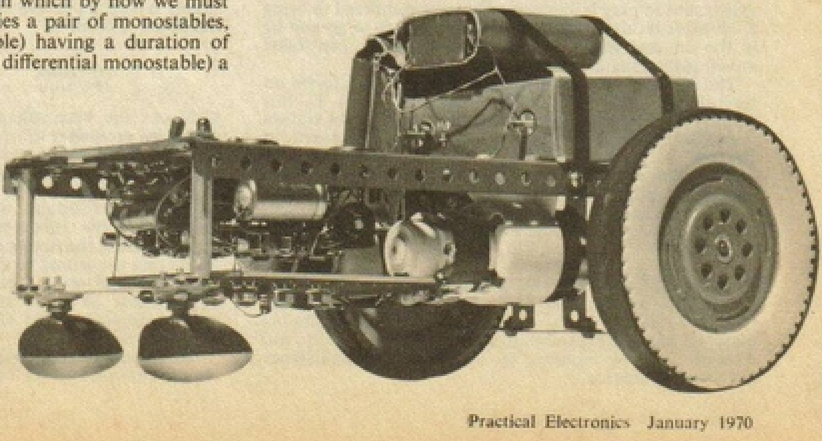
DESIGN PHILOSOPHY

Now it is intended that EMMA should learn to work, so this implies that she must additionally have a need to work in the first place. If a situation is made sufficiently attractive she will be prepared to do some simple chore provided she has a previous memory of being rewarded.

These requirements are largely accommodated by deliberately reducing EMMA's muscle control supply for short periods. This makes her hypersensitive to loads during which she is encouraged to carry a heavy book or similar object.

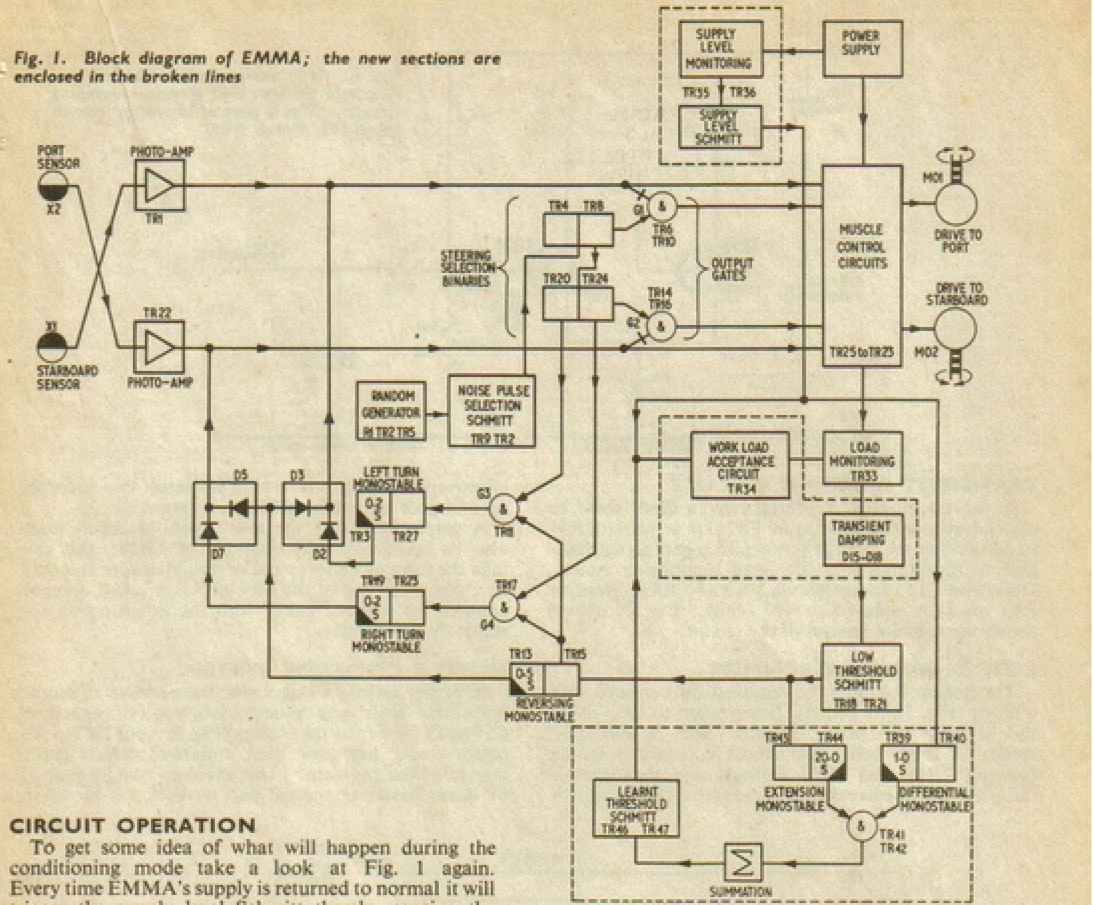
Periodically we may give her some "reward" by returning the supply to normal so that she realises that we intend to pay her when the work has been done.

We achieve all this in a somewhat synthetic way by switching out one of the cells forming part of the forward drive supply battery. Thus during conditioning her supply for the forward mode is a little less than 3 volts unless we provide a reward, in which case it rises to about 4·5V.



Complete "Educated EMMA", now with three circuit boards

Fig. 1. Block diagram of EMMA; the new sections are enclosed in the broken lines



CIRCUIT OPERATION

To get some idea of what will happen during the conditioning mode take a look at Fig. 1 again. Every time EMMA's supply is returned to normal it will trigger the supply level Schmitt thereby causing the differential monostable to fire.

Assuming just prior to this that a physical load has been applied then the load monitoring section will have previously fired the extension monostable. As a result, and provided the differential monostable fires during the time the extension monostable is in the quasi-stable condition, the AND gate will be enabled and consequently the summer output level will begin to rise.

If we repeat the process a number of times the existence of the reward can obviously become significant because the increasing level from the summer will ultimately reach a point where the learnt threshold Schmitt fires.

Immediately this occurs the work-load acceptance circuit will raise the threshold of the load monitoring system allowing EMMA to tolerate greater loads, indeed, the very same kind of loads she would accept were her supply to be at a normal level. However, she has at this stage learnt to understand that her supply will return to normal and so she "soldiers on" in the knowledge that all will be well.

Nevertheless, if we decide to stop rewarding EMMA her memory for the "good life" will gradually diminish as the summer level falls, until a point is reached where the load will no longer be tolerated. At such times she will "twist and turn", being thoroughly intractable as her normal reflexes take over and the avoidance system goes into operation.

Like any real creature EMMA, given the opportunity, can improve her chances for continued existence by taking advantage of certain situations. Thus she can adapt herself to doing a small task if it promises some form of payment and just as easily give the job up if not adequately reimbursed.

CIRCUIT IMPROVEMENTS AND MODIFICATIONS

In her existing form EMMA will normally function quite satisfactorily and so if it is not intended to add the new circuitry her "neurology" can be left as it is. Nevertheless, there are certain improvements that can be made and certain modifications that must be attended to before adding the learning system.

The changes are all extremely simple and so will be indicated in relation to the existing circuit diagrams for the reflex and muscle control sections discussed in the March and April issues of P.E. The relevant areas of discussion are in Figs. 2 and 5, in the March and April 1969 issues respectively.

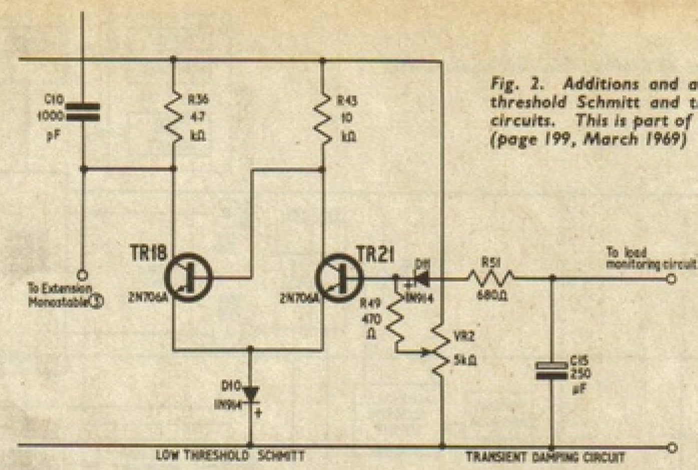


Fig. 2. Additions and alterations to low threshold Schmitt and transient damping circuits. This is part of the reflex circuits (page 199, March 1969)

TRANSIENT DAMPING CIRCUIT

In this circuit (Fig. 2, March 1969) a diode must be added (cathode end to base of TR21) in series with R51 to ensure that the voltage across C15 is entirely attributable to the output from the load monitoring system. Otherwise C15 can charge via VR2 and R49. Resistor R49 must be reduced to 470 ohms. Fig. 2 (above) shows the relevant section of the circuit.

LOW THRESHOLD SCHMITT

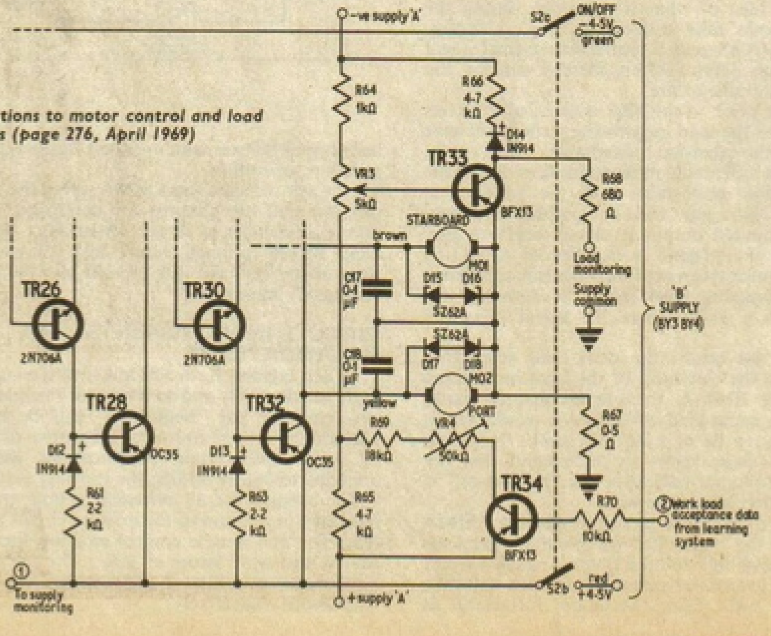
The resistor R40 must be removed and replaced with a diode (Fig. 2), its cathode being taken to the −4·5V rail of the "A" power supply. This modification results in there being an almost constant potential between TR18 and TR21 emitters and the negative rail. As a consequence the backlash of the Schmitt is effectively reduced to zero with the result that it comes on and goes off almost at the same point.

A connection from the low threshold circuit must also be taken from the collector of TR18; this can take the form of a short piece of insulated wire and may be coiled back out of the way until it is called upon to connect the reflex circuitry with the extension monostable discussed later.

MUSCLE CONTROL SYSTEM

In earlier articles we discussed the problem of motor noise; the "hash" was reduced using a pair of capacitors C17 and C18, across the motors (Fig. 5, April 1969). An improvement has now been embodied which really minimises the problem. This involves using a pair of 6V Zener diodes connected back-to-back (as shown in

Fig. 3. Alterations to motor control and load sensing circuits (page 276, April 1969)



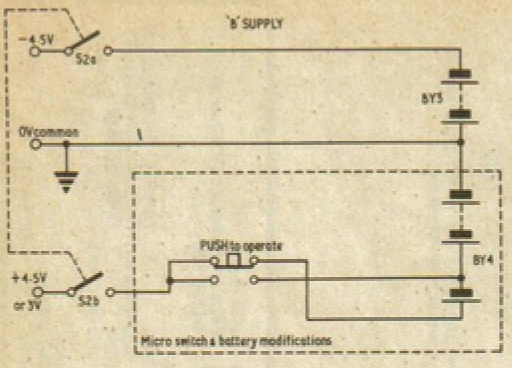


Fig. 4. Circuit diagram of the new "B" power supply and switch wiring

Fig. 3) across each motor. Noise spikes of either polarity and in excess of the Zener voltage of one diode and the forward voltage drop of the other are thus suppressed.

Additional diodes (D12 and D13) are connected in series with R61 and R63 (cathodes to the bases of TR28 and TR32 respectively) and also D14 in series with R66 (anode to collector of TR33). These are included to prevent any paths between the supply being monitored (the "forward" half of this supply) and the supply which feeds the monitoring circuit ("A" supply).

For similar reasons the load monitoring circuit is now not run from the "A" supply and suitable arrangements must be made to reconnect R64 and R66 to the negative rail of the "A" supply. The resistor R65 must go to the positive rail of the "A" supply and is shunted with the series combination R69, VR4, and TR34 (Fig. 3) which constitutes the work load acceptance circuit.

"B" POWER SUPPLY

The forward-mode battery (type 126) of the "B" supply requires a small modification so that either 3V or 4·5V may be obtained. This entails carefully opening the paper flap at the top of the battery with a razor blade and taking a connection from the 3V tapping (i.e. one cell down from the positive side of the battery). The 4·5V and 3V outputs thus obtained are then taken to a double pole changeover microswitch (Fig. 4) so that in use EMMA's forward operation can be obtained from either normal or reduced supplies.

This completes the various modifications to the existing hardware and we are now in a position to concentrate on the learning system, also to the way in which it interconnects with the rest of EMMA's person (see Fig. 5).

SUPPLY LEVEL MONITORING

This circuit comprises a Schmitt trigger which is similar in form to the type mentioned earlier (i.e. it has extremely little backlash) and has its input connected via R71 to VR5 which goes to the positive rail of the "B" supply. Adjustment of VR5 sets the threshold at which the Schmitt fires; generally this need only be just at the "B" supply level and no lower.

The capacitor between TR35 base and the negative rail of the "A" supply prevents transients switching the Schmitt.

Once set-up the Schmitt trigger will switch whenever the voltage at the positive rail of the "B" supply falls below normal (influenced by operation of the micro-switch). Hence TR35 will turn off and TR36 will come on with the result that TR37 will cease to conduct. With TR37 collector positive TR34 will turn off and consequently EMMA will be extra sensitive to loads.

When the supply is returned to normal TR35 will again turn on and TR36 will turn off. At this time the positive voltage at TR36 collector will be passed to the differential monostable causing it to fire. Simultaneously, TR37 will turn on again thereby raising the load threshold.

DIFFERENTIAL AND EXTENSION MONOSTABLES

Both monostables are a little unconventional in that they each use extra transistors forming the Darlington pairs TR38, TR39 and TR44, TR45. These provide higher gain and hence permit larger timing resistors to be used.

Diodes D22 and D23 provide a fair degree of noise immunity and so prevent the monostables from triggering prematurely if any short-term voltage drop occurs on the "A" supply. Under such conditions D22 and D23 are reverse biased and the associated capacitor (C21 or C22) effectively bridges the interval during a voltage drop "holding-up" the collector of the transistor that is turned off.

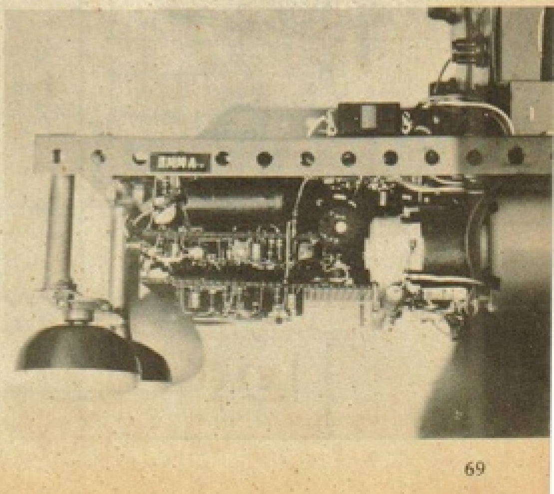
The extension monostable is triggered from the load threshold Schmitt and fires whenever the load exceeds a certain level. As mentioned earlier the differential monostable triggers whenever the positive end of the "B" supply is returned to normal.

COINCIDENCE GATE

The coincidence (AND) gate comprises TR41 and TR42. Assuming a sufficiently heavy load has been applied to EMMA then the extension monostable will have fired hence turning off TR42.

If during the 20 second period of the extension monostable the positive rail of the "B" supply has been returned from low to normal then the differential monostable will be triggered.

View of "Educated EMMA" showing the position of the new circuit board



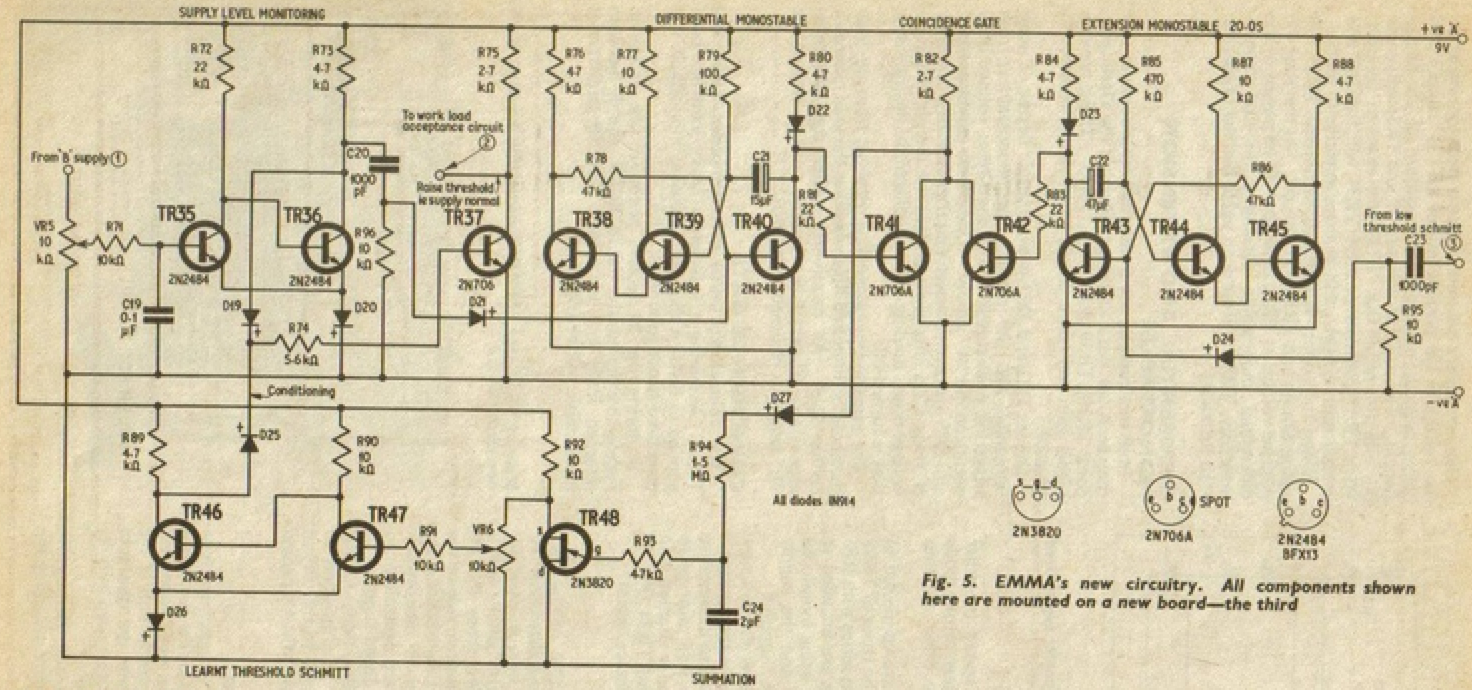


Fig. 5. EMMA's new circuitry. All components shown here are mounted on a new board—the third

COMPONENTS . . .

Resistors

R49	470Ω	R78	47kΩ	R88	4·7kΩ
R69	18kΩ	R79	100kΩ	R89	4·7kΩ
R70	10kΩ	R80	4·7kΩ	R90	10kΩ
R71	10kΩ	R81	22kΩ	R91	10kΩ
R72	22kΩ	R82	2·7kΩ	R92	10kΩ
R73	4·7kΩ	R83	22kΩ	R93	4·7kΩ
R74	5·6kΩ	R84	4·7kΩ	R94	1·5MΩ
R75	2·7kΩ	R85	470kΩ	R95	10kΩ
R76	4·7kΩ	R86	47kΩ	R96	10kΩ
R77	10kΩ	R87	10kΩ		

Potentiometers

VR4 50kΩ }
VR5 10kΩ } skeleton preset
VR6 10kΩ }

Capacitors

C19 0·1µF
C20 1,000pF
C21 15µF elect. 12V
C22 47µF elect. 12V
C23 1,000pF
C24 2µF non polarised 63V

Diodes

D10 to 14 IN914 (5 off)
D15 to 18 SZ62A or equivalent 6V Zener (4 off)
D19 to 27 IN914 (9 off)

Transistors

TR34 BFX13
TR35, 36 2N2484 (2 off)
TR37 2N706A
TR38–40 2N2484 (3 off)
TR41, 42 2N706A (2 off)
TR43–47 2N2484 (5 off)
TR48 2N3820

Miscellaneous

D.P.S.T. microswitch
Veroboard 5in × 2½in, 0·1in matrix

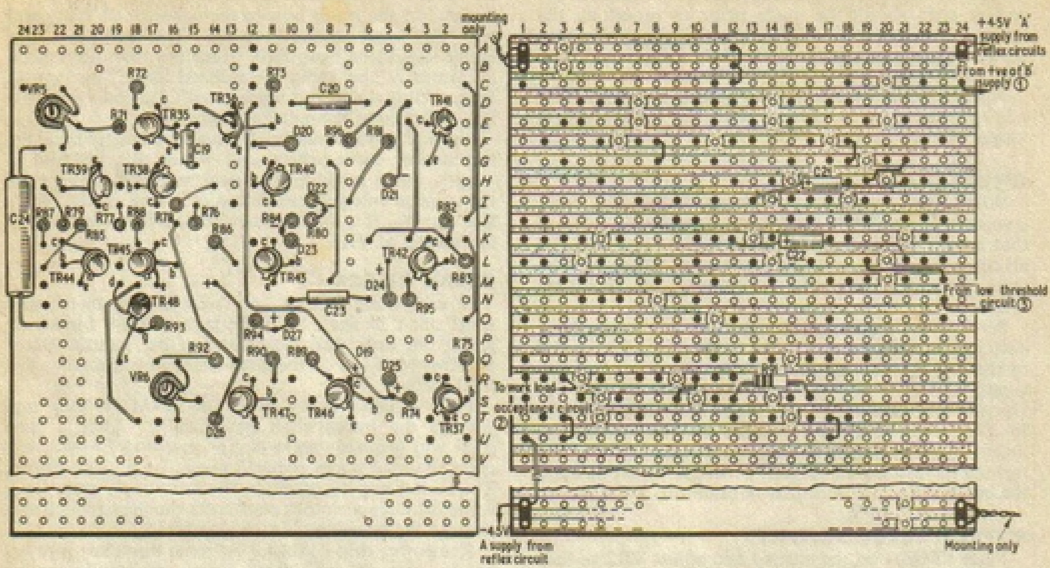


Fig. 6. Component layout and wiring for the new board: (a) component side, (b) copper side showing breaks in the copper strips

Transistor TR41 will also turn off, and the common collector point of TR41, TR42 will go positive for a time, essentially determined by the period of the differential monostable, i.e. one second or less if the extension monostable is close to the end of its quasi stable state. The output from the coincidence gate is taken to the summation circuit.

SUMMATION CIRCUIT AND "LEARNT" THRESHOLD

As implied by its designation, the summation circuit adds or integrates the output pulses from the coincidence gate and comprises TR48 and its associated components. Capacitor C24 and R94 provide a time-constant sufficiently long to ensure that the maximum summation limit extends to accepting greater than 15 input pulses.

Unwanted discharge of the capacitor is minimised by inclusion of D27 and by the very high input impedance presented by TR48 which is an f.e.t. Initially TR48 will be conducting, but as pulses from the coincidence gate gradually charge C24 so the voltage at TR48 source will climb towards the positive rail.

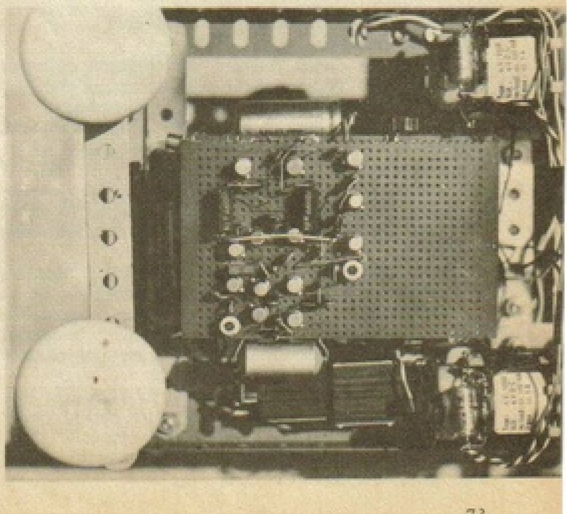
At some level of summation, dependent upon where VR6 has been set, the learnt threshold Schmitt will switch causing TR37 to turn on. This condition will remain until the level on C24 drops below the point necessary to maintain the Schmitt in the triggered state.

However, due to the reasons discussed earlier this will take a fair time and consequently TR37 will remain on to ensure that EMMA accepts higher loads at low supply levels. Of course, if this state of affairs is not reinforced periodically by giving EMMA a short rise in her "B" supply level then the voltage across C24 will gradually decay to a point where the load threshold drops again.

CIRCUIT BOARD CONSTRUCTION

The method for layout and wiring of the learning system circuit board is shown in Figs. 6a and 6b. Depending on the potentiometers used the Veroboard may require some drilling, however, all other components are mounted by way of their individual leads. The board itself is attached to the existing reflex board by 18 s.w.g. wire soldered to its four corners.

Underside view of EMMA showing the new circuit board



It is important to note that all necessary breaks in the copper strip should be made prior to mounting the various components.. Care should be taken to ensure that the complete width of the copper has been removed at each break.

Always mount transistors and diodes last and be sure not to keep them in contact with the soldering iron longer than necessary.

CHECKOUT

When the work on the circuit board has been completed it should be carefully examined to make sure that no dry joints or solder bridge-overs exist and that all components are carefully connected. It can now be inter-connected with the remainder of EMMA's anatomy.

Set EMMA's muscle control and the reflex system switches on. Connect a meter between the zero point of the supply batteries and the positive rail of the "B" supply to ensure that the level is approximately 4·5V. Operate the microswitch and check that this level falls to 3V. Release the microswitch and disconnect the meter. Inhibit EMMA's random generator circuit by turning the associated Schmitt permanently on through the use of VR1. Ensure that both motors are running.

SUPPLY LEVEL SCHMITT

Place EMMA on the ground and adjust VR2 so that she will carry a relatively heavy load, but goes into the avoidance reaction upon bumping into an obstacle.

Return EMMA to the work bench and with the meter connected between the collector of TR36 and the negative rail of the "A" supply, adjust VR5 until the supply level Schmitt *just* triggers, evidenced by the meter reading almost rail potential. Operate the microswitch and ensure that the meter reading drops to near zero level; if not, re-adjust the Schmitt. Disconnect the meter.

Now place EMMA back on the ground and replace the load. Ensure that, as before, the avoidance reaction does not occur unless she meets with an obstruction. Operate the microswitch and check that both EMMA's speed is reduced and that she immediately goes into the avoidance mode. If she is functioning correctly return EMMA once more to the table.

DIFFERENTIAL AND EXTENSION MONOSTABLE

Connect the meter between the common collector point of TR41, TR42 and the negative rail of the "A" supply; there should be an almost zero reading.

Now simulate a load by stalling the road wheels and, shortly following this, operate the microswitch. There should be a reading of almost rail potential. If not, check that the differential and extension monostables are functioning—the meter connected to either TR40 or TR43 collector will establish this following triggering.

Transfer the meter to the source of TR48. Momentarily short out C24 when the meter reading should be approximately 1V. Trigger the extension monostable, as before, and operate the microswitch every couple of seconds or so. Ensure that there is a gradual increase in the meter reading.

Note that it may be necessary to re-trigger the extension monostable because its time period could have elapsed during this check. Momentarily short out C24 again and check that the meter reading falls once more to about 1V.

LEARNT THRESHOLD SCHMITT

Connect the meter now to the collector of TR46 and set VR6 wiper about midway. The reading on the meter should be near zero. Operate the microswitch occasionally and apply a simulated load from time to time. Ultimately the meter will indicate that the learnt threshold Schmitt has triggered.

Naturally, it is a matter of choice as to the point in the summation curve where one wants this Schmitt to trigger, but a sensible arrangement would be to have the summer integrate about ten or eleven pulses before this occurs. It is simple to control this factor by varying the setting of VR6.

FINAL CHECK

If everything checks out remove the meter and short out C24 again to make sure EMMA forgets all about our unbridled inquisition of her internal parts. Set EMMA down on the floor once more and make this final check!

Place a fairly heavy book on EMMA's back and operate the microswitch periodically. After a time (that will probably seem like an eternity) EMMA will carry the load under reduced power supply conditions. The easiest way to maintain the low supply state for a while is to clip a clothes peg across the microswitch and so hold the operating button depressed.

Remember that EMMA's batteries don't last forever, so do start off with fresh ones. A heavily loaded supply on its "last legs" may make it virtually impossible to set up the monitoring circuits for reliable operation.

FINAL EMMA

You may have every reason to say "All this just to have a heap of electronics and metalwork behave in this odd fashion." But that is the very point, it *is* just a heap of electronics and metalwork—not a living creature! Crude though she may be EMMA definitely shows certain preferences and can learn that some actions are worth the trouble while others are not.

To demonstrate that a machine can have a kind of self preservation awareness, we have cheated a little by playing around with the power supplies used. The reason though is valid because had we employed, say, re-chargeable nickel cadmium cells it would have been virtually impossible to see EMMA exhibit this new ability.

However, there is no reason why a keen Bionics man should not attempt an even more ambitious scheme—after all there is a machine in existence which can go and plug itself into the nearest 13 amp socket when it feels peckish! ★