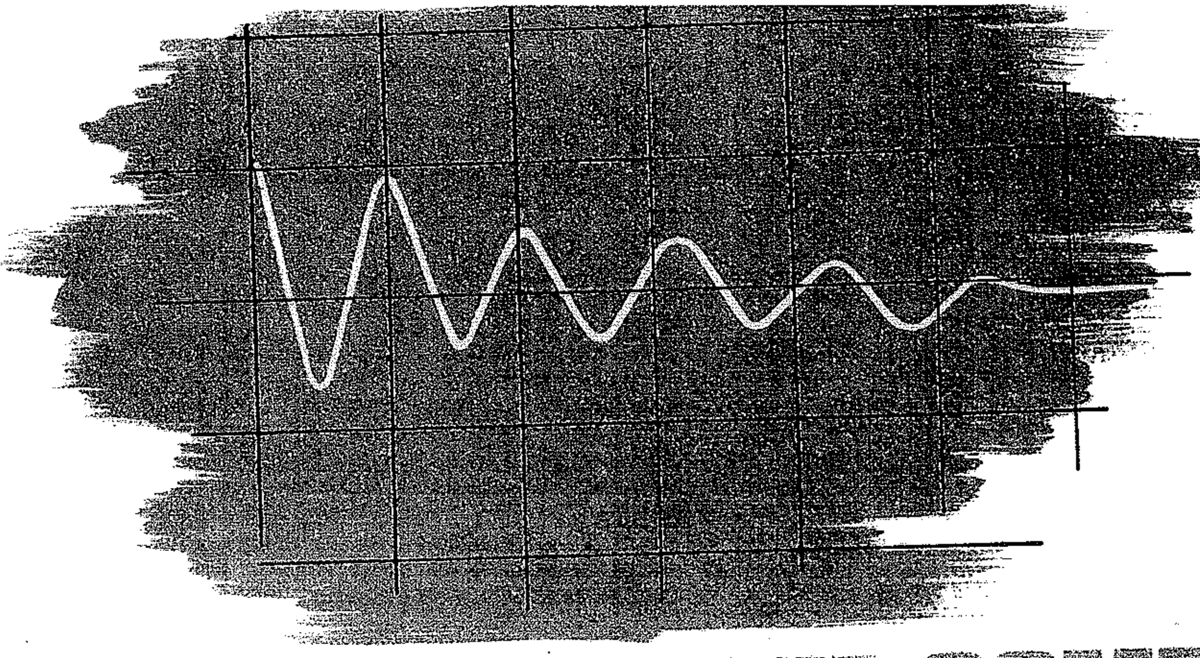


★ **Ten Amplifiers**

★ **Eight Coefficient Multipliers**

★ **Two Four Quadrant Multipliers**

★ **Over Voltage Indicators on all Amplifiers**

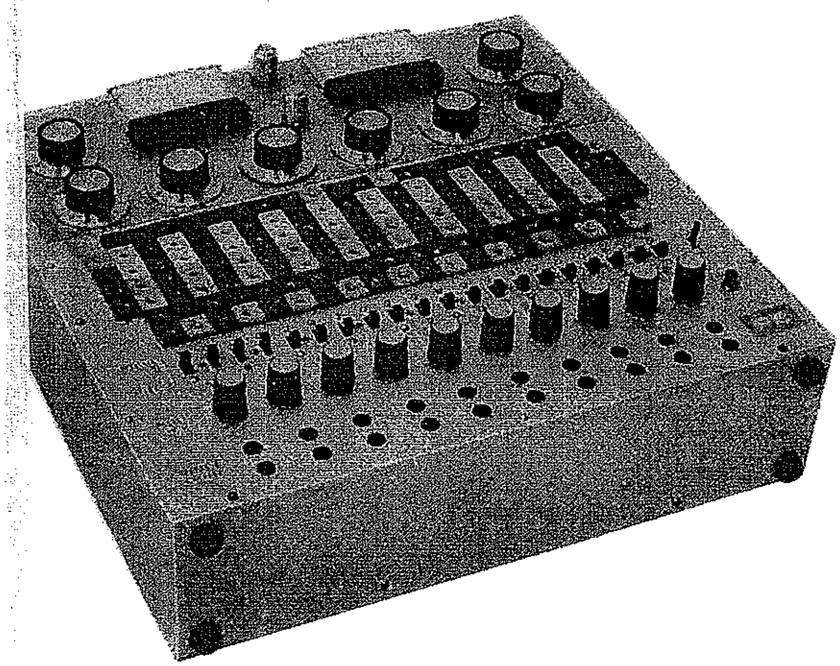
★ **Provision for "Initial Conditions"**

★ **Offset Null on all Amplifiers**

ANALOGUE COMPUTER

P. J. KRONIS B.Sc.

PART 1



THE analogue computer is a piece of equipment designed to satisfy mathematical equations, usually differential. Mathematics in general and differential equations in particular are the subjects of an exact science which describes the behaviour of physical systems.

Because computers cannot tell us how to solve a physical problem a mathematical model of the problem has first to be formed by the programmer. This is where computers are useful because the formation of the mathematical model is usually easier than the solution of the equations especially as differential equations can be particularly difficult to solve manually and some virtually impossible.

The analogue computer works by handling continuously changing variables using electrical potential or voltage as the analogue, in contrast to the digital computer which manipulates discrete pulses to obtain the solution to a problem.

Fig. 1.1 was produced by the analogue computer to be described here and it will be explained in this article how to program the computer to produce these interesting and artistic designs.

The analogue computer can be used in engineering to simulate the behaviour of complex systems before they are constructed, the behaviour of these complex systems can be thoroughly studied and various parameters changed simply by turning a potentiometer until the system functions in a satisfactory manner. This procedure allows considerable savings both in the cost and time of development.

Analogue circuits similar to those used in analogue computers are employed in a variety of applications, i.e. automatic control in industry, aircraft and spacecraft.

One of the examples to be given in this article will be a simple program to simulate the vertical take-off of an aircraft like the Harrier jump jet, and also a spacecraft moonlanding.

MATHEMATICAL OPERATIONS AND CIRCUITS

The advances in miniaturisation have enabled more computing power to be packed into a smaller space and it is these advances that have helped the digital computer on its way towards becoming a household object. In the analogue

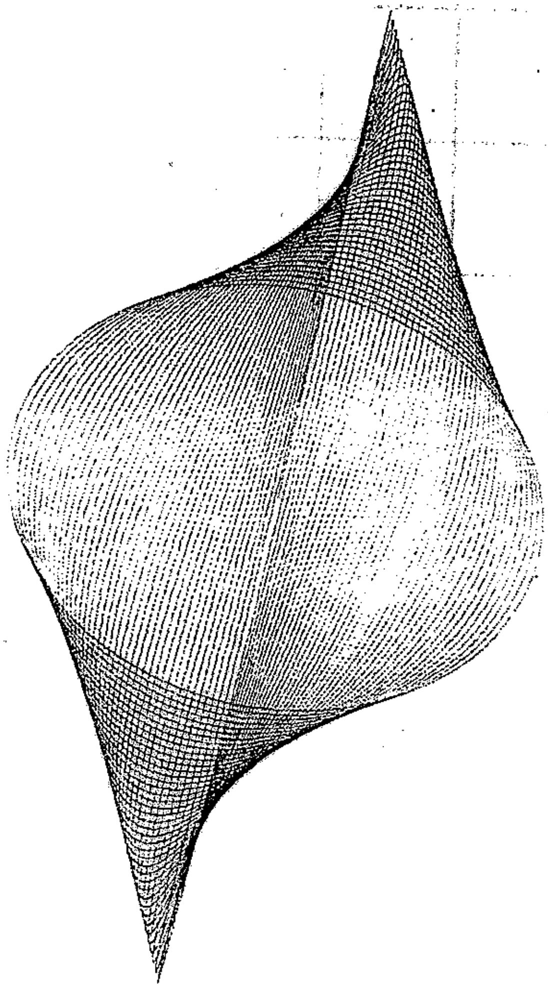


Fig. 1.1. A typical lissajous figure produced using the Analogue Computer and an X–Y plotter

field the high gain d.c. amplifier or operational amplifier which is the main element of the analogue computer, has also come a long way since its inception. It was originally designed for use in computers but has since found many applications in other fields. This large market for other applications has reduced the cost of such devices to very low levels. Of the numerous op-amp i.c.s available on the market the 741 was chosen for the prototype because it is both cheap and easy to handle. More advanced op-amps are available albeit at a higher price and constructors can experiment with these if they wish.

By connecting an op-amp to input and feedback components certain mathematical operations can be performed; addition (and subtraction) integration, and multiplication by a constant. Differentiation can also be performed but is generally avoided due to problems associated with noise generated by components. Multiplication by constant coefficients between zero and one is also performed using potentiometers with some special circuits being employed to enable the multiplication of two variable voltages.

THE ADDITION CIRCUIT

It is possible to add various voltages by means of a resistance network with the output voltage being proportional to the sum of the input voltages. The serious drawback of this method is that this is only true if the load resistance remains constant.

This would be an unacceptable constraint since the output voltage may be applied to other points in the circuit which have different values of load resistance.

To overcome this difficulty a high gain d.c. amplifier is employed in the feedback circuit as shown in Fig. 1.2.

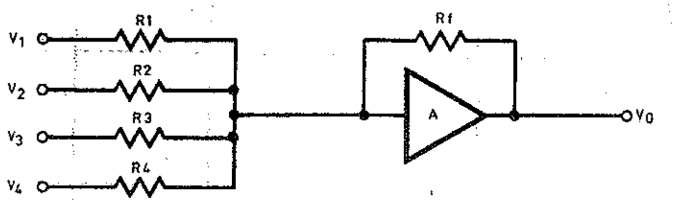


Fig. 1.2. "Addition" circuit

If a voltage V_1 is applied via R_1 to the summing junction the output voltage V_0 is equal to

$$-V_1 \frac{Rf}{R_1}$$

The polarity of the input voltage is also changed by the operational amplifier.

With the output voltage now independent of the load resistance each input voltage is factored by the same ratio of feedback resistance to input resistance.

$$V_o = -\left(V_1 \frac{Rf}{R_1} + V_2 \frac{Rf}{R_2} + V_3 \frac{Rf}{R_3} + V_4 \frac{Rf}{R_4} \right)$$

THE INTEGRATOR CIRCUIT

As with the addition circuit integration can be achieved by using an R.C. network but this method also suffers from a number of serious drawbacks.

The circuit in Fig. 1.3 shows how an operational amplifier can be used to perform integration.

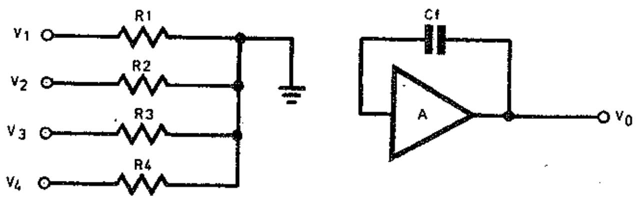


Fig. 1.3. "Integrator" circuit

With a capacitor connected in the feedback loop, and if the open loop gain of the amplifier is very large, the output voltage is given by

$$V_o = -\left(\frac{1}{R_1 Cf} \int V_1 dt + \frac{1}{R_2 Cf} \int V_2 dt + \frac{1}{R_3 Cf} \int V_3 dt + \frac{1}{R_4 Cf} \int V_4 dt \right)$$

The output voltage is the sum of the integrals, with respect to the time the voltage is applied to the inputs, factored by $-\frac{1}{Rin}$ Cf.

By choosing suitable values of Rin and Cf the factors can be given the required values.

THE COEFFICIENT MULTIPLIER

The coefficient multiplier is used to multiply a voltage by a constant between zero and one. This is the only mathematical operation that is usually performed without the use of an op-amp. A potentiometer is connected as shown in Fig. 1.4.

At one extreme of the slider's travel Vo=Vin, i.e. Vin is multipled by 1, whereas at the other extreme Vo=0 i.e. Vin is multiplied by zero.

Any intermediate value can be set up by moving the slider. The dial of the potentiometer can be calibrated to facilitate this. However, it is not normal practice to set up a value on the dial of the potentiometer because this circuit also suffers from the effects of load resistance.

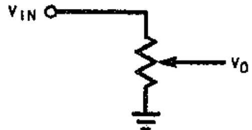


Fig. 1.4. Coefficient Multiplier

An op-amp employed as a voltage follower could be connected as a buffer to isolate the effects of the load resistance, but this is an unnecessary addition because the problem can be overcome by measuring the output of the potentiometer using a voltmeter, after the circuit has been connected, i.e. in the presence of the real load to be applied in the particular problem being examined. The value desired is then set by adjusting the potentiometer and ignoring the graduations on the dial.

The circuits described so far form the fundamental building blocks of the analogue computer. Various special circuits have been developed over the years for other operations. The most important of which is the formation of the product of two variables. One of the early methods developed was the cumbersome servo multiplier. This involved the control of potentiometers using servos. Nowadays this operation can be achieved electronically using four-quadrant multiplier integrated circuits.

INTEGRATION

Addition, subtraction and multiplication are concepts that are easily understood; integration, however, is not so easily grasped by the non-mathematically minded and so a simple explanation may be useful at this point.

If for example a motor car is cruising on a motorway at 50 miles per hour this can be represented by a graph of speed against time (Fig. 1.5). Since the speed is constant the distance travelled will increase by equal amounts in equal time intervals. These distances are shown plotted on a graph of distance against time for intervals of one hour (Fig. 1.6).

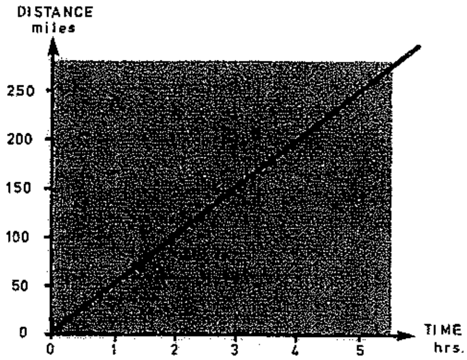


Fig. 1.6. Graph of distance against time

It can be seen from Fig. 1.5 that the distance travelled during a period of time is represented by the area shown shaded on the velocity-time graph. (Velocity × time representing the height × base of the shaded rectangle.) Now if the results of all these intervals were added up, the result would be the total distance travelled in a period of time.

The mathematical way of saying this is that the distance travelled is the integral of velocity with respect to time between two time limits. In the above example since the speed was constant one could have arrived at the required result by multiplying the total period of 5 hours say, by the velocity of 50 m.p.h. to obtain 250 miles travelled, without going into the trivial process of integrating, by considering small time intervals.

In reality the velocity may vary as shown in Fig. 1.7, i.e. in a random manner. To obtain the required result then, the velocity would have to be integrated over the required period of time by considering small time intervals. This is how a digital computer would be programmed to solve the problem. The accuracy in that case would depend on how small the time intervals were made. This is left to the discretion of the programmer. If the intervals were made too big, then the result would be inaccurate. On the other hand too small a time interval would mean that the computer would take longer to solve the problem and involve the programmer in unnecessary expense. The analogue computer programmer need not worry about this since the computer integrates continuously, i.e. it deals with

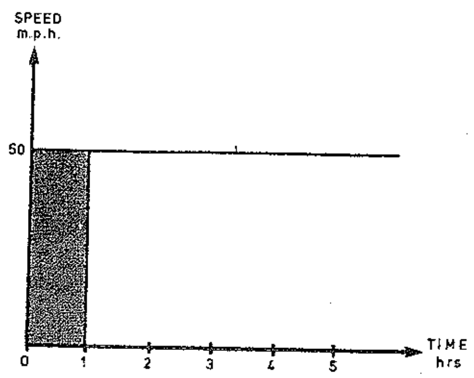


Fig. 1.5. Graph of speed against time

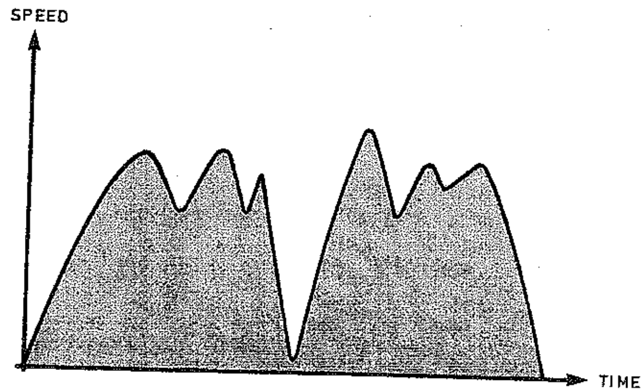


Fig. 1.7. Graph showing variations in velocity

infinitesimally small time intervals and does this at high speed.

Each of the circuits that have been described so far constitutes a computing element. When the computer is programmed to solve a problem, systems of equations can be set up by connecting together combinations of computing elements, and the results can be obtained by measurements taken at various points in the system.

The computer will of course be required to solve many different problems and the computing elements will have to be rewired every time. To facilitate this a patch panel is used, with sockets connected to each computing element in the computer. By using wire leads the computing elements can be connected in any order.

At the beginning of a computation the variables of the problem will have certain values, not all of which need be zero. The requirement here is that is should be possible, if desired, to give the output of integrators a value, before the computation commences. This facility is called "Initial Conditions".

Fig. 1.7 shows how the "Initial Conditions" for the "Compute", "Hold" and "Reset" facilities are achieved for summers and integrators. In the case of the summers no change in the circuit is necessary. For the integrators, the "Hold" mode requires that the input resistors are disconnected from the op-amp and grounded. In this way the charging or discharging of the capacitor stops and the op-amp maintains the charge at a constant level.

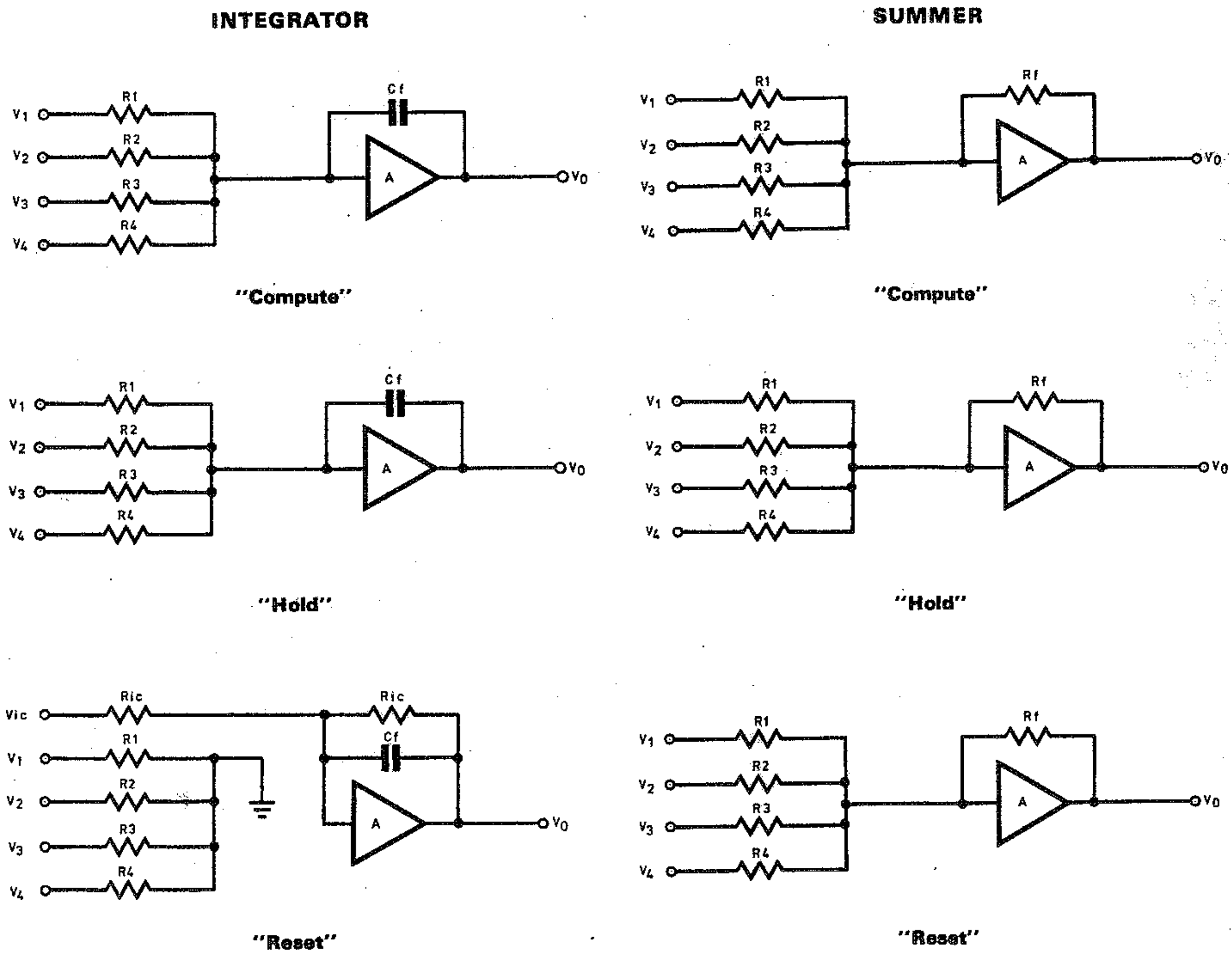


Fig. 1.8. "Initial Condition" circuits for Integrators and Summers

MODE CONTROL AND INITIAL CONDITIONS

The main modes of operation are compute, hold and reset. When in the compute mode the computer proceeds to solve the problem. As it is sometimes desirable to stop the computation after a certain period of time this is achieved by putting the computer into the "Hold" mode. The "Reset" mode is used to make the output of all computing elements take their initial value. Sometimes this mode is called "problem check".

The calculation is therefore frozen and the results can then be observed at leisure. This, however, should not be practised literally, since electronic components, like everything else, are not perfect and some drift will always affect the results. These should therefore be noted as soon as the "Hold" mode has been selected.

The "Reset" mode for the integrators has two resistors R_{ic} in the circuit. These are the "Initial Conditions" resistors and when an initial condition voltage, V_{ic} is applied as shown, the

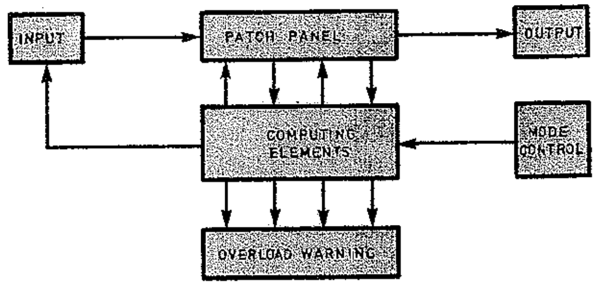


Fig. 1.9. Block diagram of the Analogue Computer

feedback capacitor charges up to this value. When "Compute" is selected these resistors are disconnected and the output of the amplifier, i.e. the voltage across the feedback capacitor, may vary above or below the initial condition value. When "Reset" is reselected the feedback capacitor discharges or charges, through R_{ic} to V_{ic} and the computer is again ready for a repeat of the calculation.

THE OVERLOAD WARNING FACILITY

This facility, usually employed in analogue computers, is necessary because the voltage range over which operational amplifiers operate linearly, is limited to approximately ±13V for readily available i.c.s. In the course of the solution of a problem, all computing elements must operate within this range, otherwise the wrong results will be obtained. The overload warning circuit warns the programmer of any amplifiers that have saturated. Measures can then be taken to scale down the values of the variables.

It is now possible to imagine the general arrangement of an analogue computer and this is depicted by Fig. 1.9 in a block diagram form.

To summarise, input signals are fed to the computing elements via the patch panel and are processed. The results are fed back through the patch panel to the output, which may be an ordinary voltmeter, a CRO or an X-Y recorder. The operation of the computing elements is controlled by the Mode Control and the overload warning circuit monitors the output of the computing amplifiers and warns the programmer of any saturating amplifiers.

NEXT MONTH: CONSTRUCTION DETAILS

readout

. . . a selection from our postbag

Readers requiring a reply to any letter must include a stamped addressed envelope.
Opinions expressed in Readout are not necessarily endorsed by the publishers of Practical Electronics.

Champ Waves

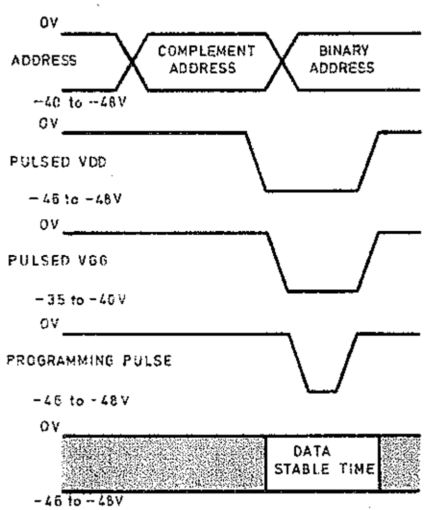
Sir—I hope you can clear up the confusion that has arisen about your EPROM programmer in the CHAMP series.

When purchasing INTEL 1702A EPROMS I was sent a data sheet, which detailed the programming voltages as completely different from those produced by CHAMP-PROG. Since you said that INTEL had supplied the basic circuit for your project, and use it in their "Intellec" development systems, it has resulted in much head scratching on my part.

The waveforms given on the data sheet are as shown.

Any clarification you can give will be greatly appreciated.

T. G. Keslake
Romford
Essex



I can understand your confusion over the difference between the 1702A data sheet and the operation of the CHAMP-PROG board, but really it is quite simple. You will notice in the data sheet that all voltages are related to GND or 0 Volts, and this means that all chip voltages are related to the Vcc pins. In CHAMP-PROG the voltages appear to be positive going, but if you look at the Vcc reference pins you will find that they rise to +47V during programming, and this means that the program pulse is a 3ms −47V pulse as required. As with many things in electronics, the secret lies in viewing the circuit operation with one's feet firmly on the ground (or in this case, the ceiling!). If you check the other supplies with this new perspective, you will find that they are substantially as dictated in the data sheet.

Once again, I quite understand your initial confusion!

R. W. COLES

Too Powerful

Sir,—Working as Product Marketing Engineer for the UK's largest distributor of National Semiconductor products I was highly amused by the letter which appeared in the July issue of P.E. from reader R. G. Silson.

I can only assume from reading his letter that he must be extremely well versed in the world of microprocessors—indeed he must know far more than the vast majority of industry's electronics engineers.

Dealing with engineers every day from all fields of the electronics world I quite naturally get a very good indication of their thoughts and feelings towards various projects.

The number of times I have spoken to customers about the Pace microprocessor, only to be told "Not interested—it's too powerful for what we need", is more than ample evidence for myself that Mr Silson is completely out of touch with the amount of knowledge possessed by the average amateur actively engaged in microprocessors. Further proof of this is the vast amount of 8 bit SC/MP chips sold related to the relatively slow moving Pace.

P. V. Hodson,
Melton Mowbray,
Leicestershire.