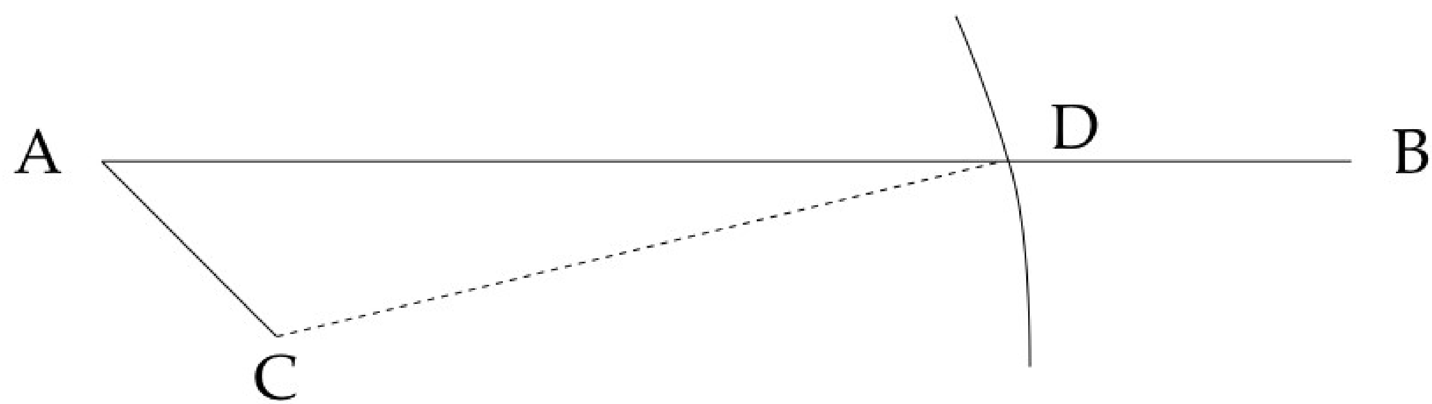
Analogue Computing

- Relies on some physical system obeying the same laws as the thing it simulates.
- Example: A 45 litre petrol tank takes 26.7 litres to fill up. How much was already in the tank?

  Analogue method: Draw a line 45 mm long. Measure off 26.7 mm. Measure remaining length (18.3 mm). Convert mm to litres = 18.3 l.
- Use of scaling: 1 litre = 1 mm.
- Both systems obey addition law.
- Limited accuracy.

Calculating Drift.

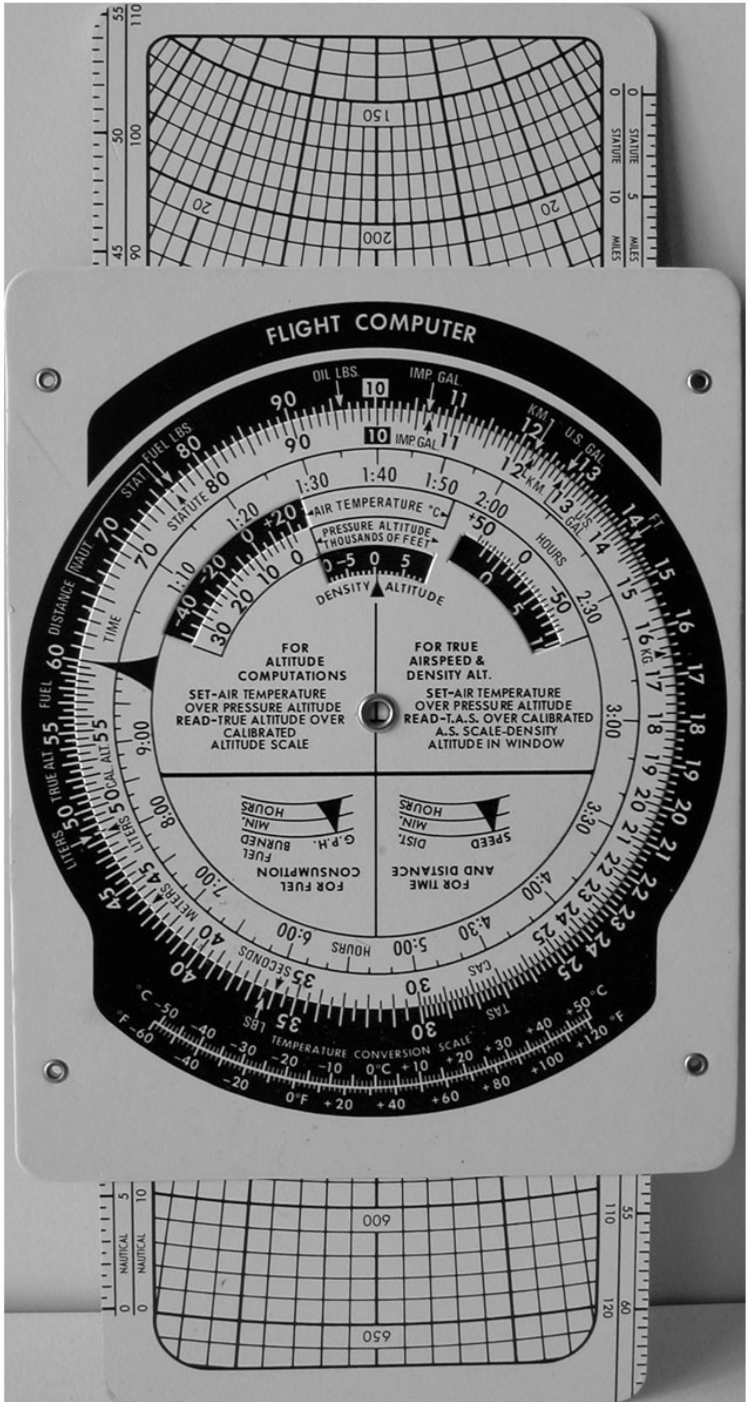
A pilot's destination lies due East. A fifty knot wind is blowing from the NW. The aircraft has an air speed of 250 knots. What heading should the pilot choose, and what ground speed results?



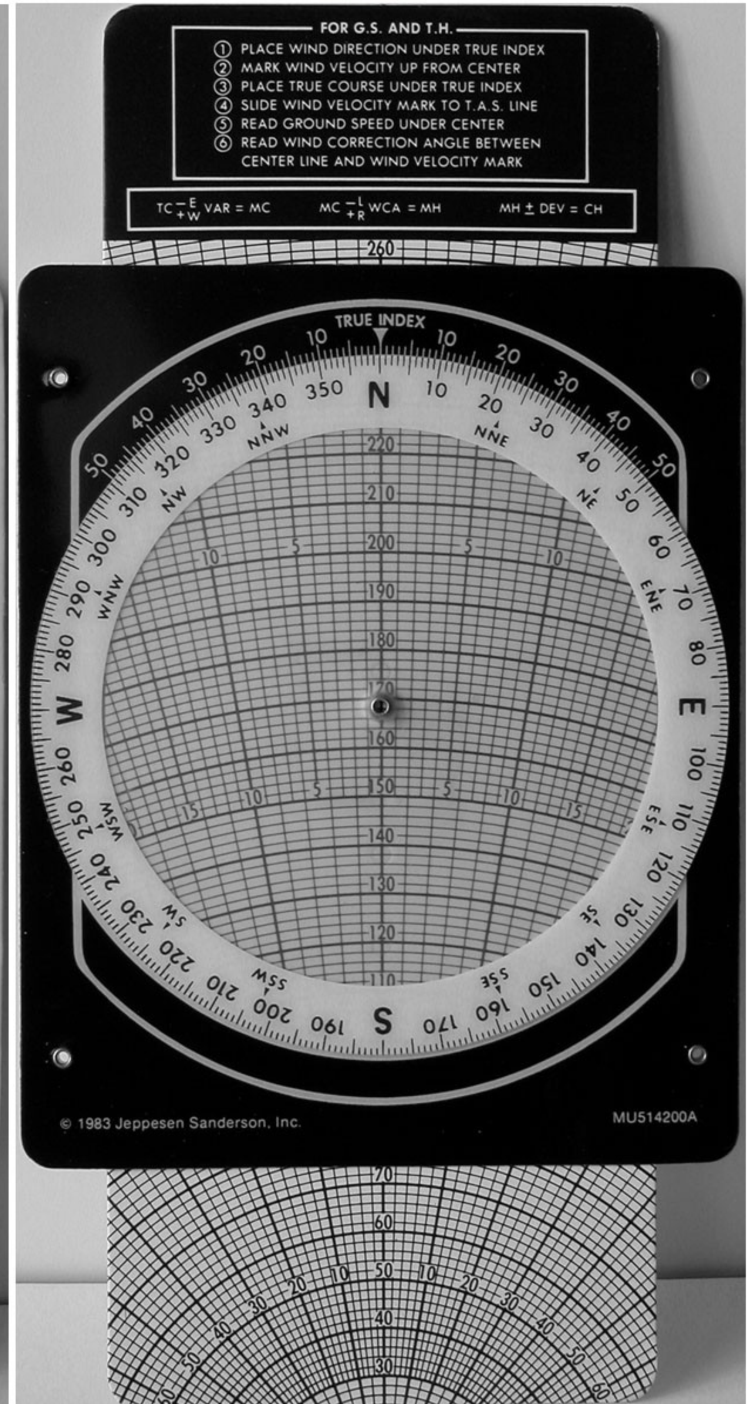
Draw a line AB running due East. Draw a 50 mm line AC running SE representing the drift. Use a pair of compasses to draw a 250 mm diameter arc centred at C. Line CD has the correct bearing and AD measures the ground speed.

Student E6B Flight Computer

Front

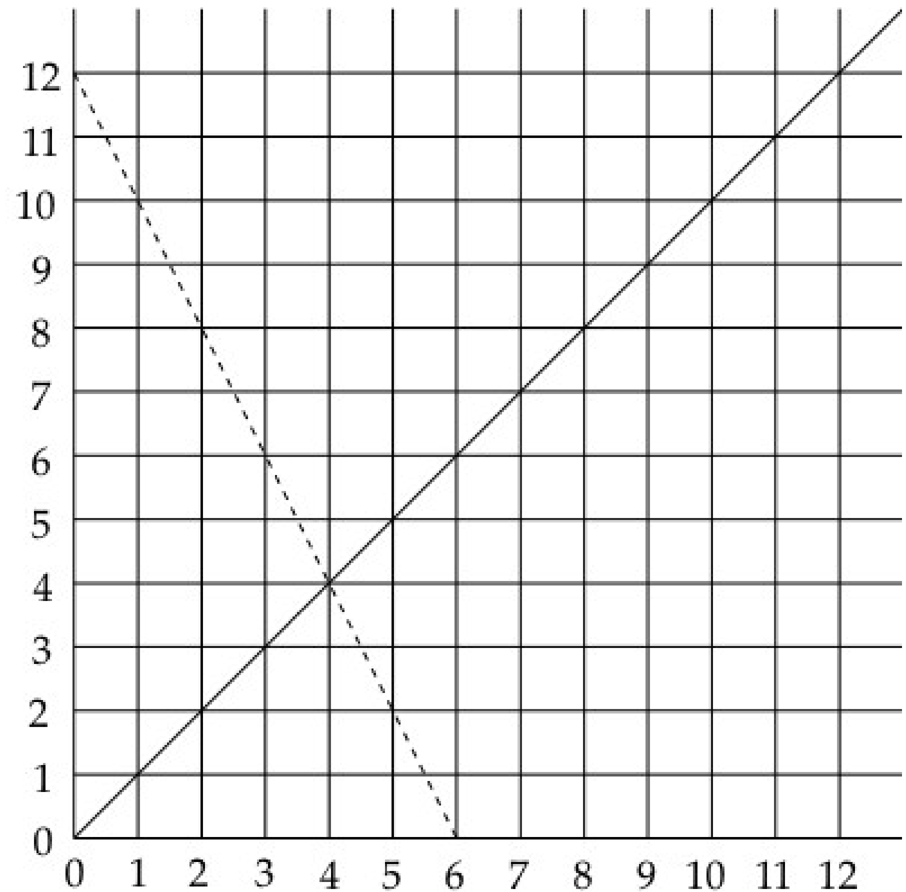


Back

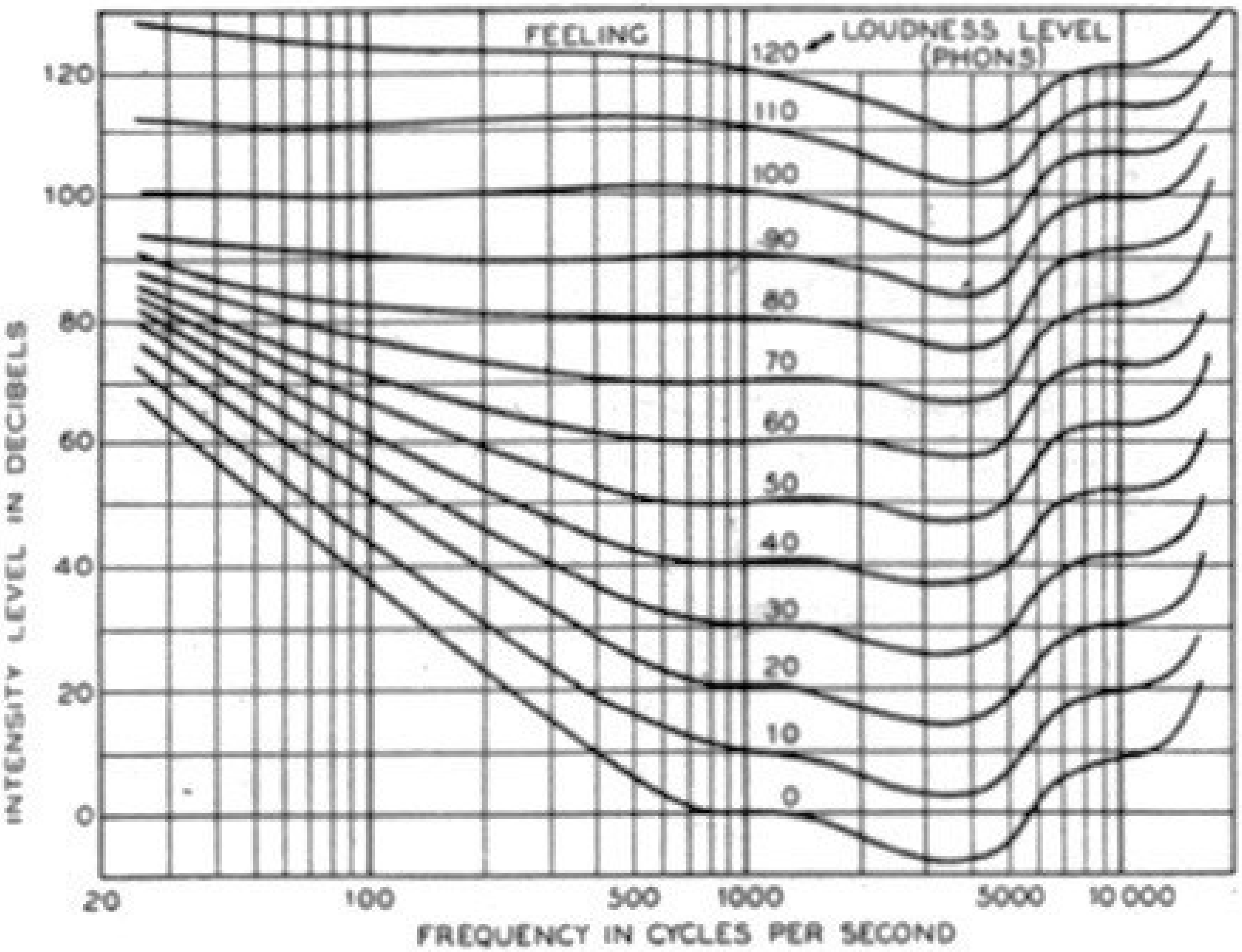


A Nomogram for Resistors in Parallel

Solves $1/(1/x + 1/y)$. (Works for lenses too!)
Dotted line shows calculation for $x = 6$, $y = 12$.
Read off its intersect with the diagonal line:
$x = y = 4$.

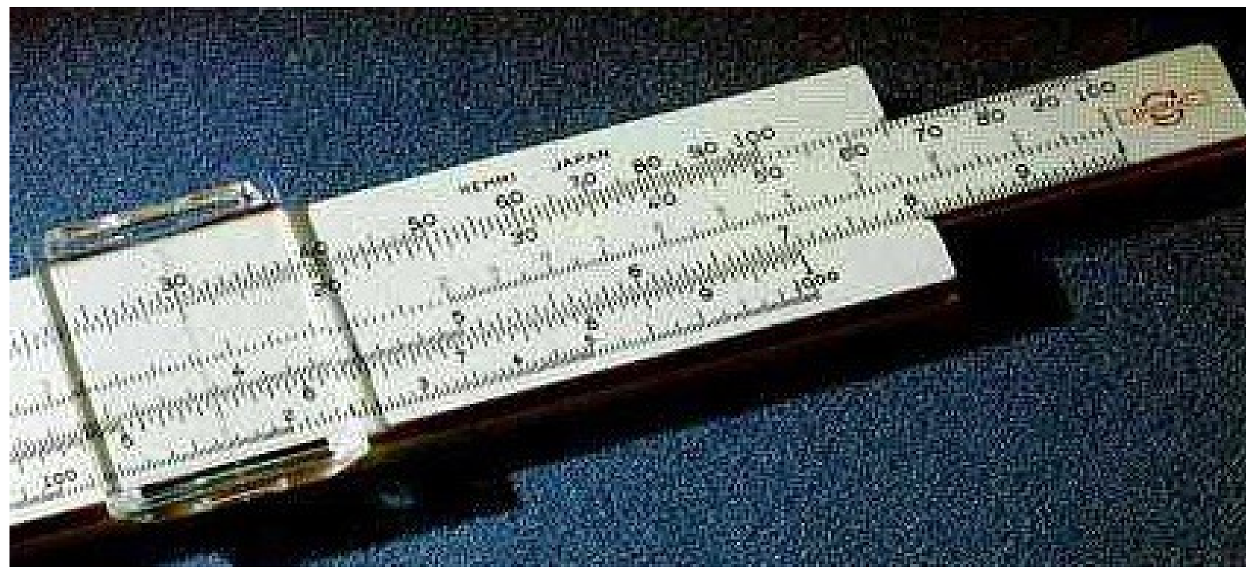


Log Scales: *Threshold of Hearing*



The Slide Rule

Equal distances represent multiplication by the same factor. For example 1:2, 2:4, 4:8, etc., all take equal space. Basic idea is 2^3 x $2^5 = 2^{(3+5)} = 2^8$, i.e., 8 x 32 = 256. Adding powers multiplies numbers.



The *A* and *B* scales are half the size of the *C* and *D* scales, making it easy to find squares and square roots.

A slide rule expects you to look after the powers of 10 for yourself. 100 x 0.001 = 10^2 x $10^{-3} = 10^{-1}$ = 0.1.

Some slide rules use a circular or a helical scale.

Slide Rules Can't Add

Sometimes we use special versions of well known formulas so we can simply add 1, e.g.,

$c = \sqrt{(a^2+b^2)}$ becomes

$c = b\sqrt{((a/b)^2+1)}$. (*Pythagoras theorem.*)

$R = 1/(1/R_1+1/R_2)$ becomes

$R = R_2/(R_2/R_1+1)$. (*Parallel resistors.*)

Experienced users tend to use a lot of other short cuts,

e.g., divide by reciprocal rather than multiply.

3 x 4 = 3 ÷ ¼. (Result won't fall off end of *D* scale.)

Flight Simulator: Electro-Mechanical

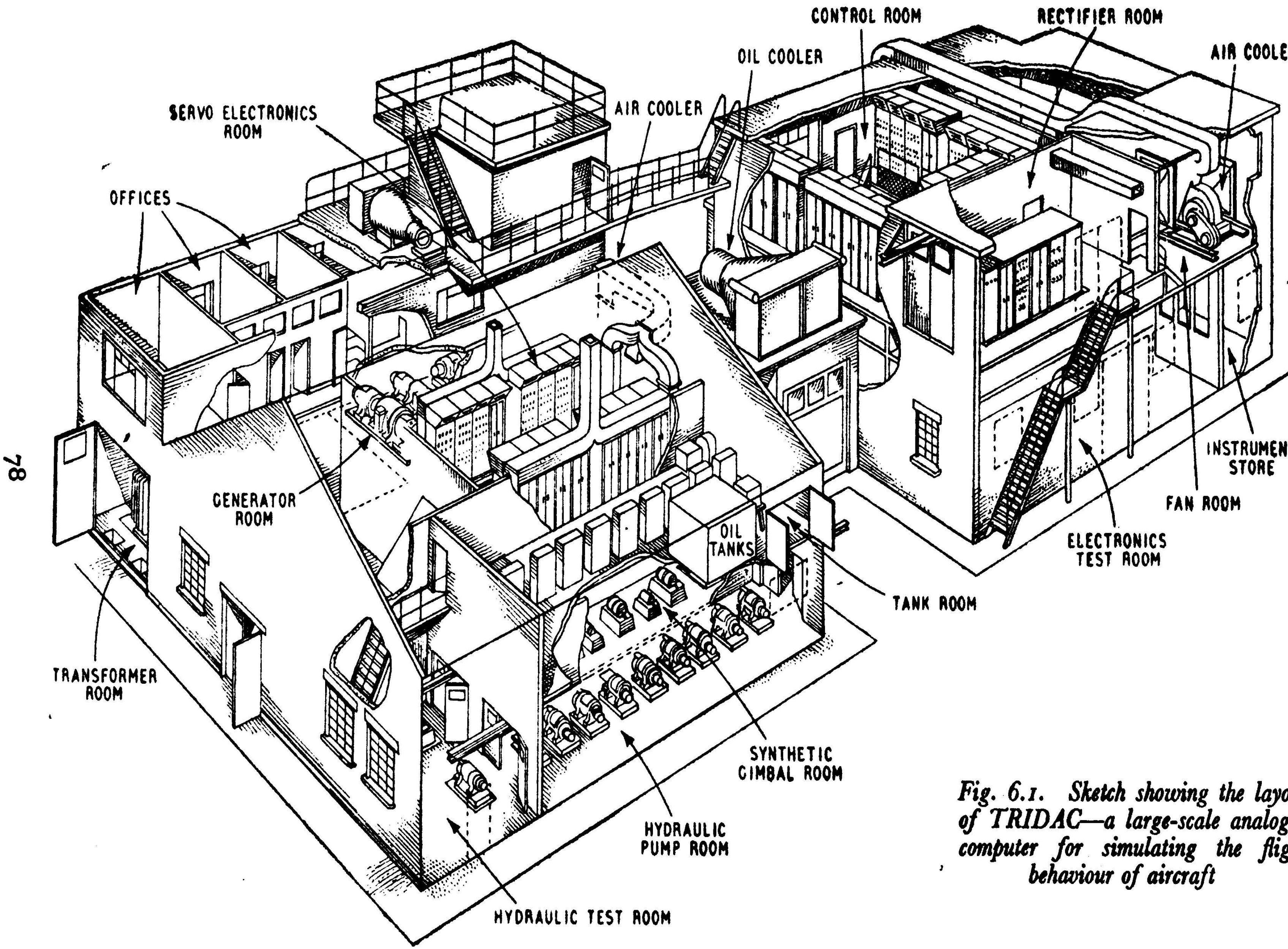


Fig. 6.1. Sketch showing the layout of TRIDAC—a large-scale analogue computer for simulating the flight behaviour of aircraft

Flight Simulator: Vacuum Tube Era

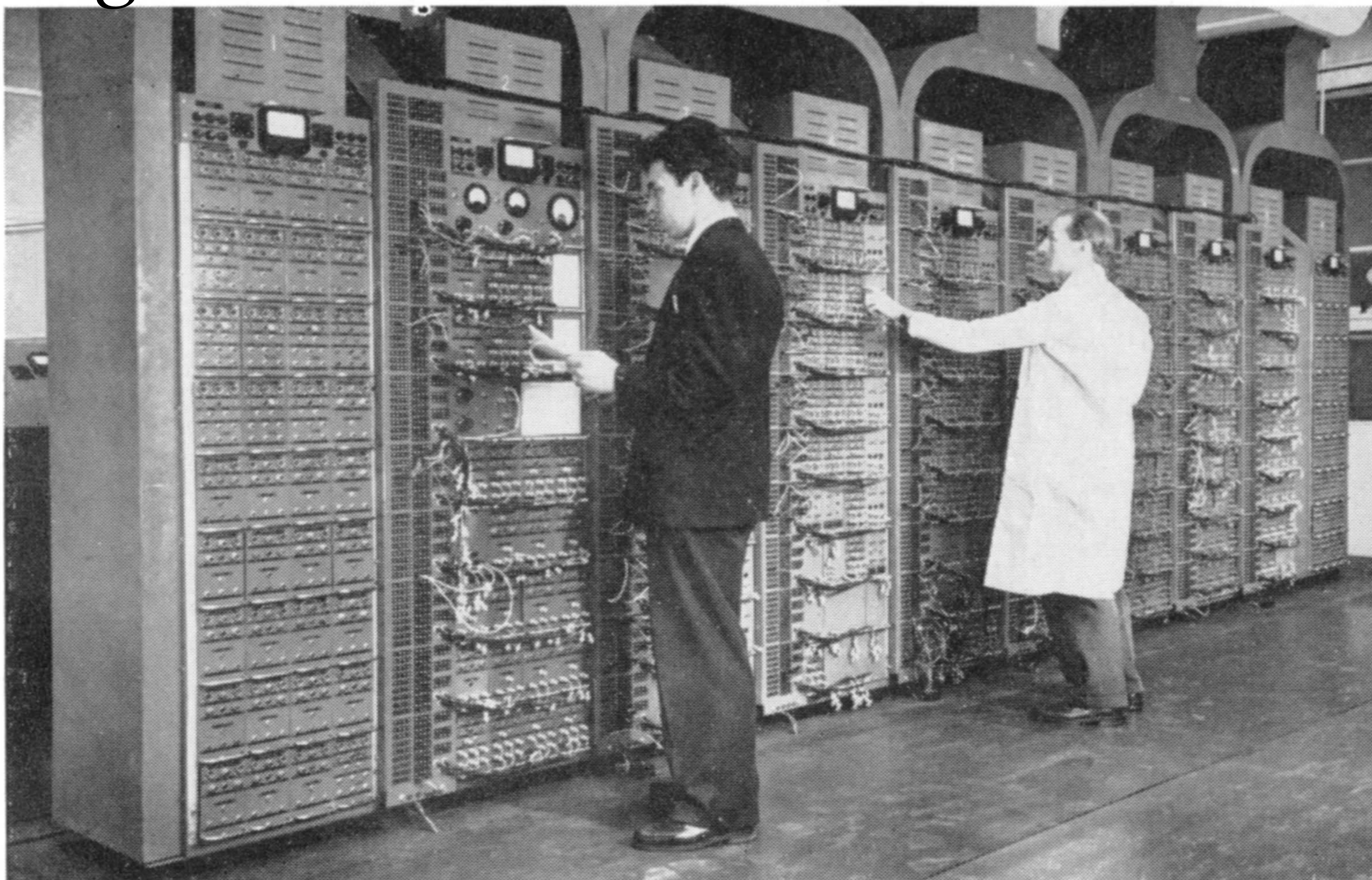
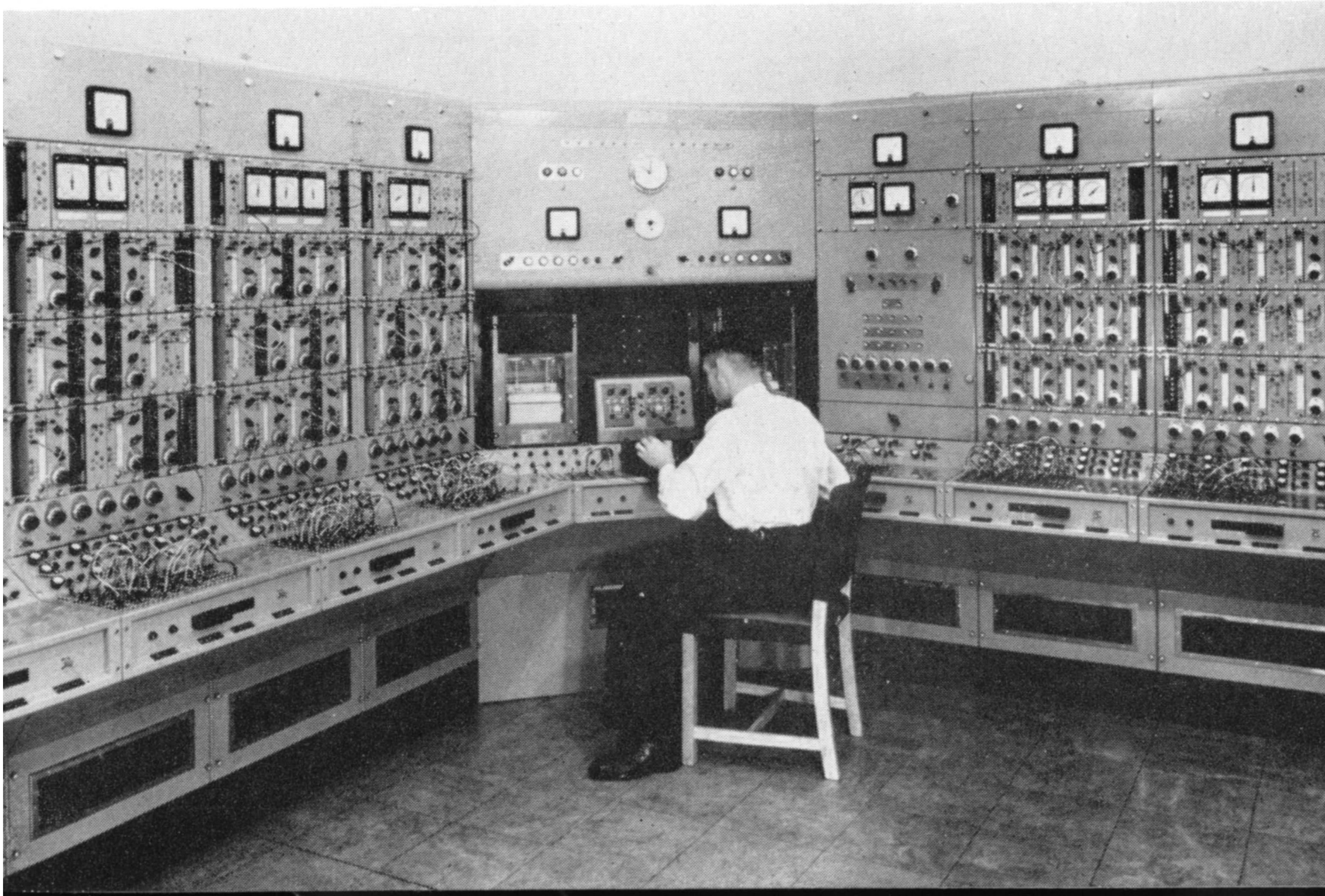


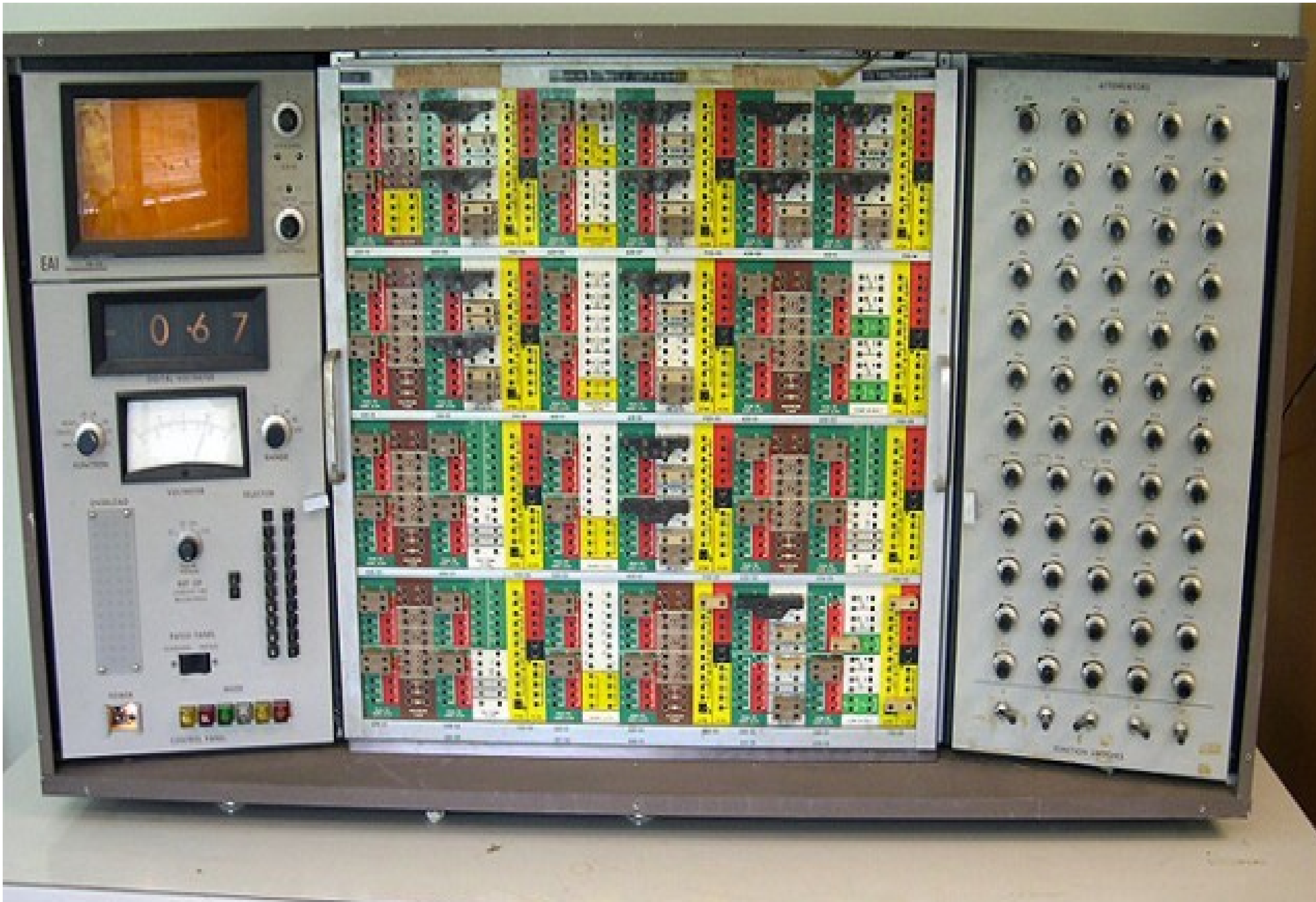
Plate 13 (a). Analogue computer system designed by E.M.I. Electronics as a simulator for studying complex control problems associated with guided weapons

Reactor Simulator: Vacuum Tube Era

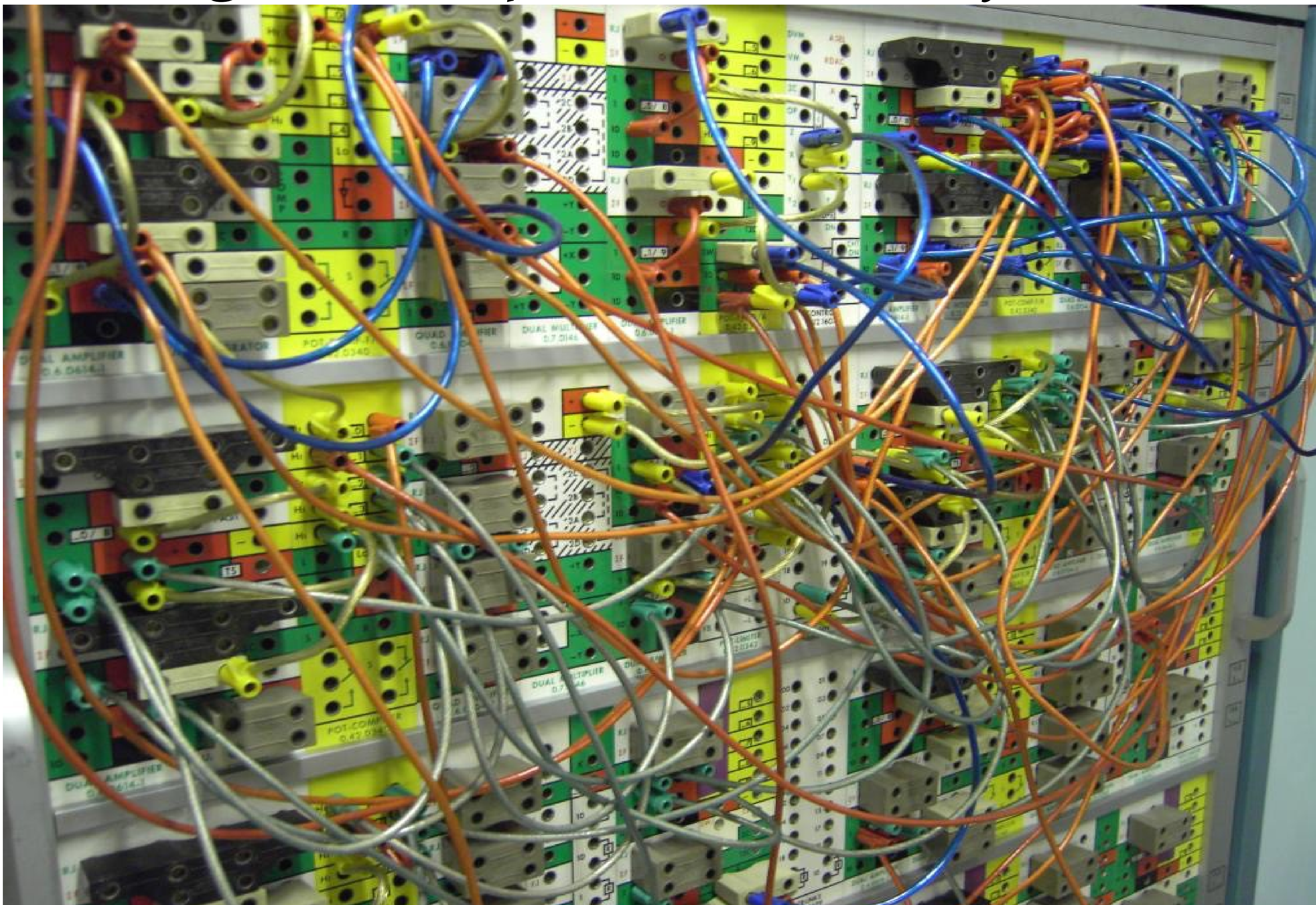
Plate 13 (b). Nuclear power station performance is simulated by this analogue computing system installed by the G.E.C. Simon-Carves Atomic Energy Group



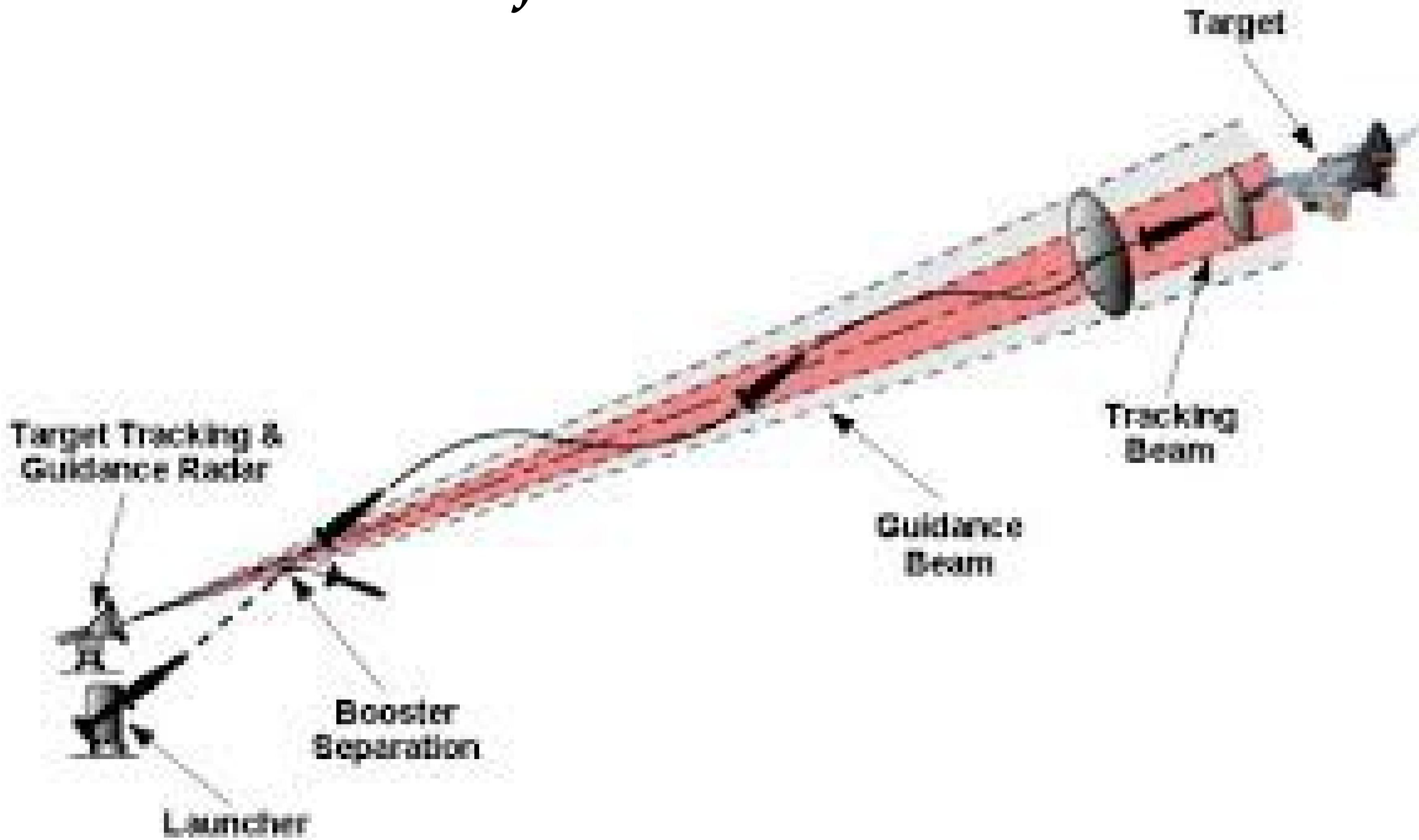
Analogue Computer: Transistor Era



Analogue Computer: The Awful Truth



Simulation of a Beam Rider Missile



Antenna spins a narrow radar beam to track the target.
Missile uses same signal to determine position relative to the beam.
This position is combined with rate gyro and control surface sensors to control ailerons, etc.

Characteristics of Radar Dish

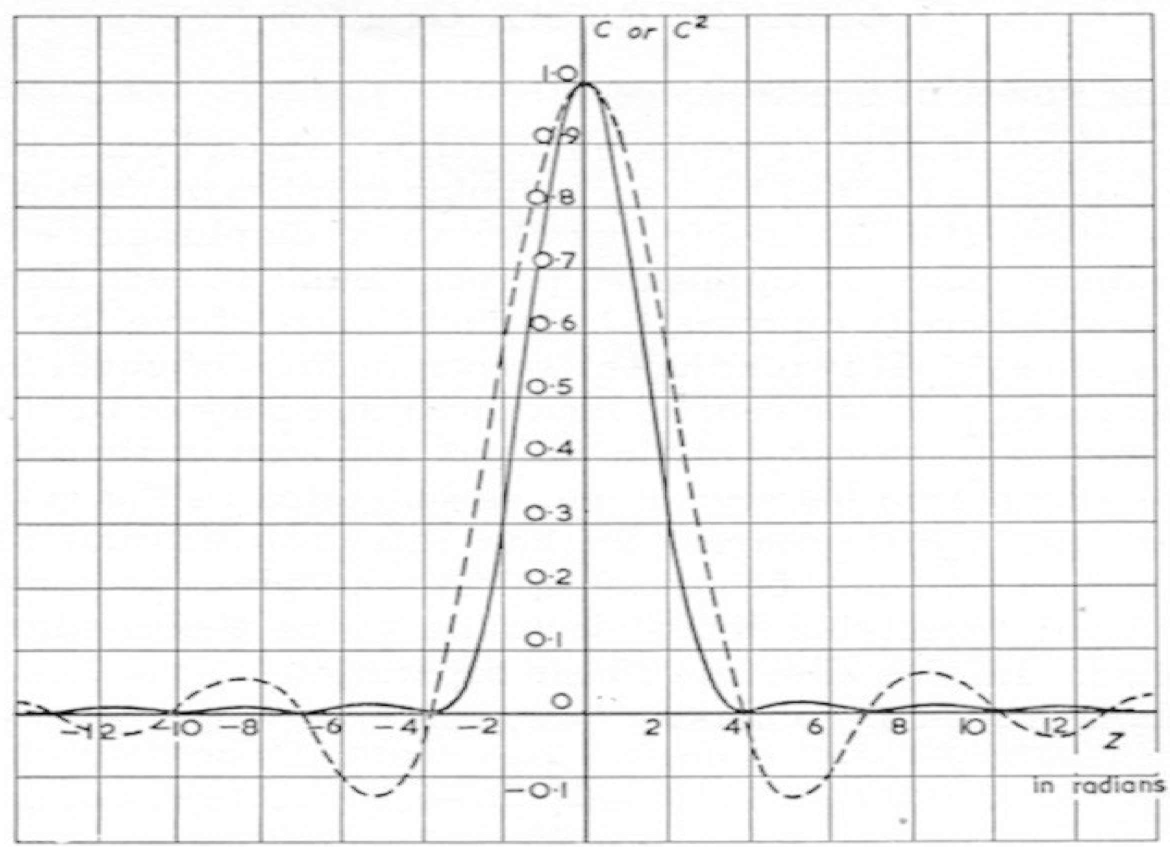
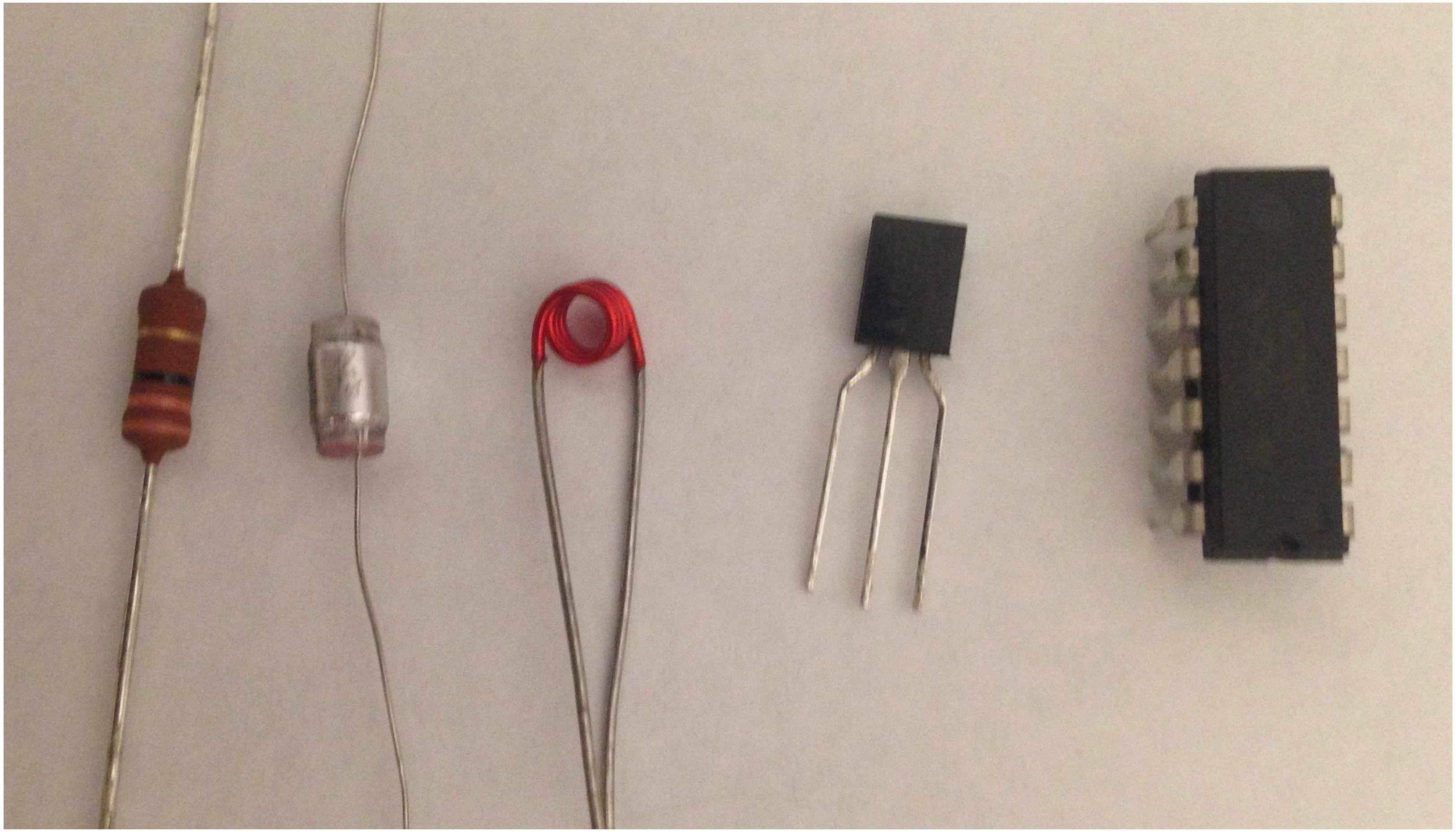


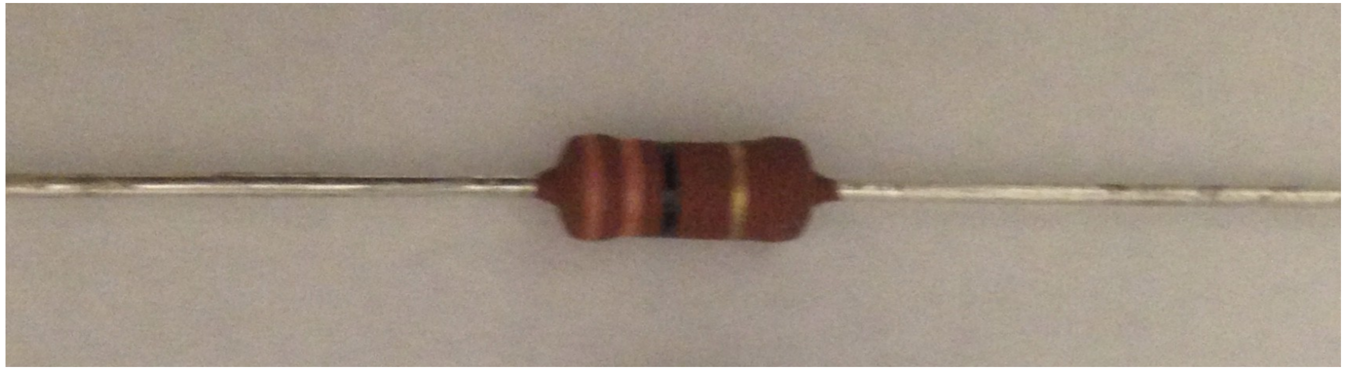
FIG. 82. Case of circular aperture.
Broken curve $C = \{2J_1(z)\}/z$
Full curve C^2

Given the wavelength of the radar and the diameter of the dish, the shape of the beam can be found in any book on optics.

Electronic Components

A resistor, capacitor, inductor, transistor, and an integrated circuit (quad operational amplifier).

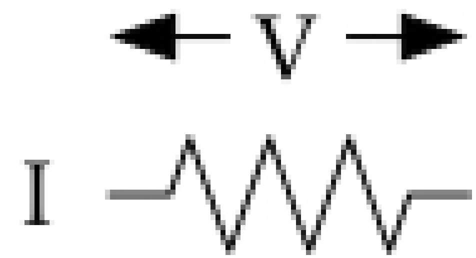




Resistor

Converts electrical energy to heat.

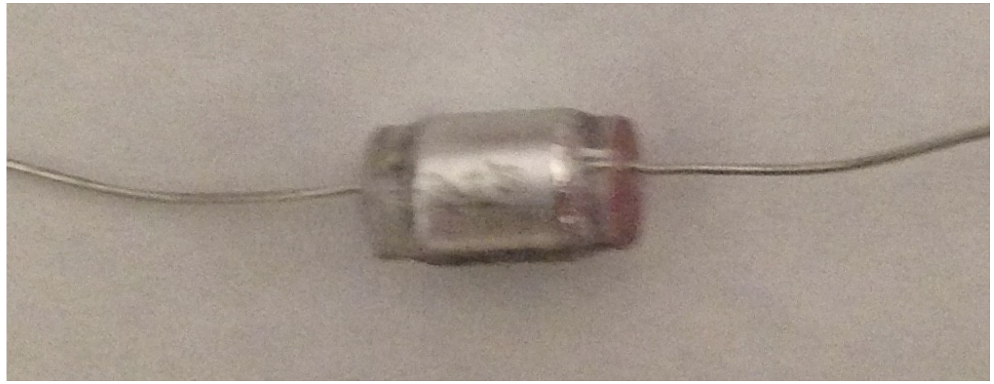
Basic equation V volts = RΩ x I amps.



Stock values: R = 1Ω to 10 MΩ (Ω = ohm).

In practice, Volts = R KΩ x I mA

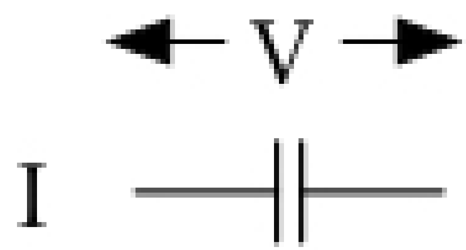
Used to control current.



Capacitor

Stores electrical energy in an electric field.

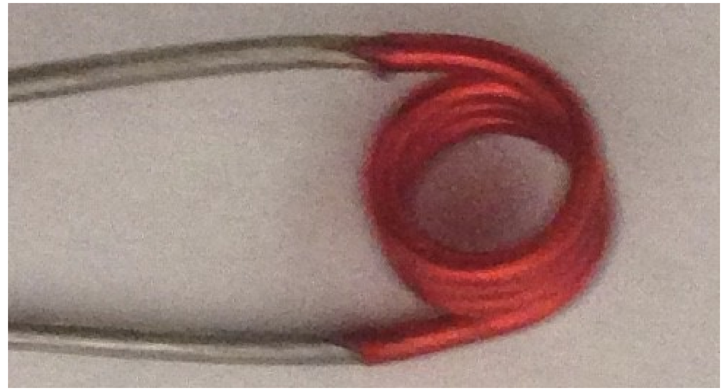
Basic equation: I = C x dV / dt, or V = 1 / C x $\int$I dt.



Stock values: C = .001μF to 1μF (F = Farad).

In practice Volts = R KΩ x I mA.

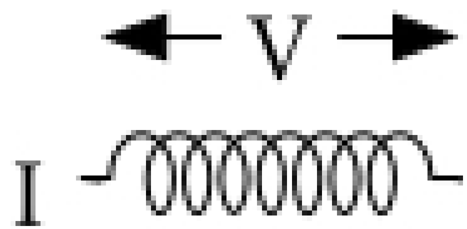
Used to stabilise *voltage* despite current changes.



Inductor

Stores electrical energy in a magnetic field.

Basic equation: V = L x *d* I/*dt*, or I = 1/L x $\int$V *dt*.



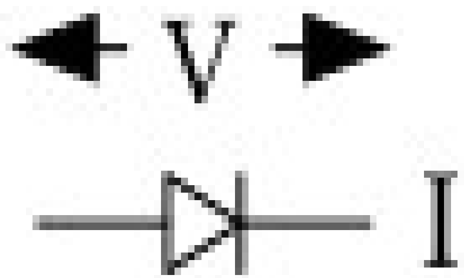
Stock values: L = .001mH to 1mH (H = Henry).

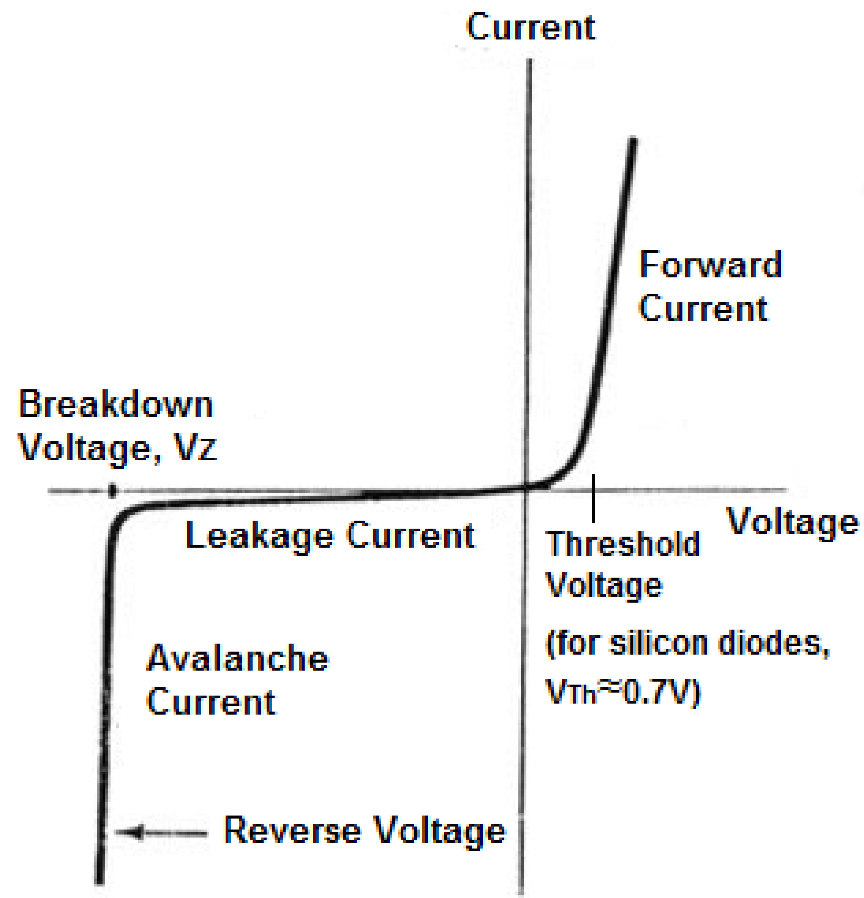
Not useful in analogue computing.

Used to stabilise *current* against voltage changes.

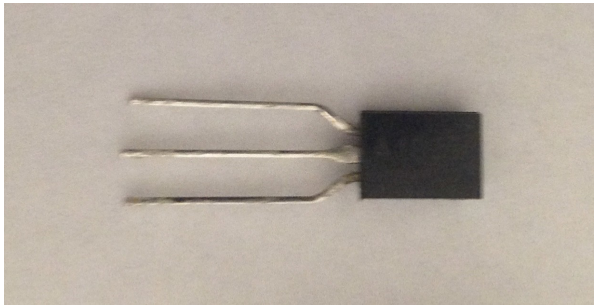
Diode

Has a low resistance in one direction, and high resistance in the other.





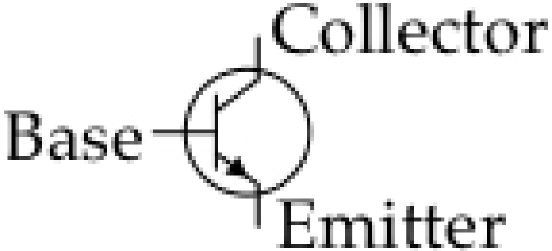
In computing, used to create non-linear functions.



Transistor

Allows small current to control a larger current.

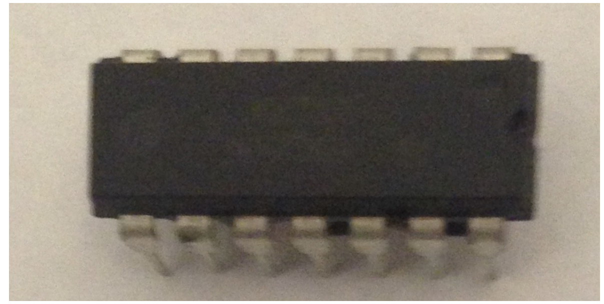
Basic equation: $I_{CE} = \beta \times I_{BE}$.



Typical values: $\beta = 100$, V_{CE}=100V, I_{CE} = 100mA.

In practice, discrete transistors are rarely used.

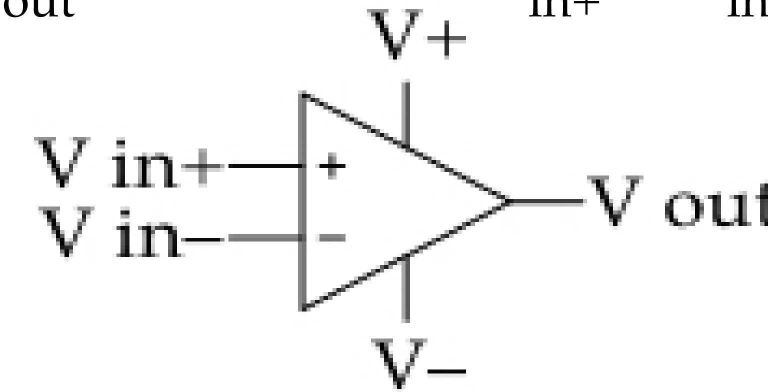
Used to *amplify* current.



Operational Amplifier

Allows a tiny voltage to control a larger voltage.

Basic equation: V_{out} = Gain x ($V_{in+} - V_{in-}$).



Typical values: V+ = V– = ±12V, V_{out} = ±10V.

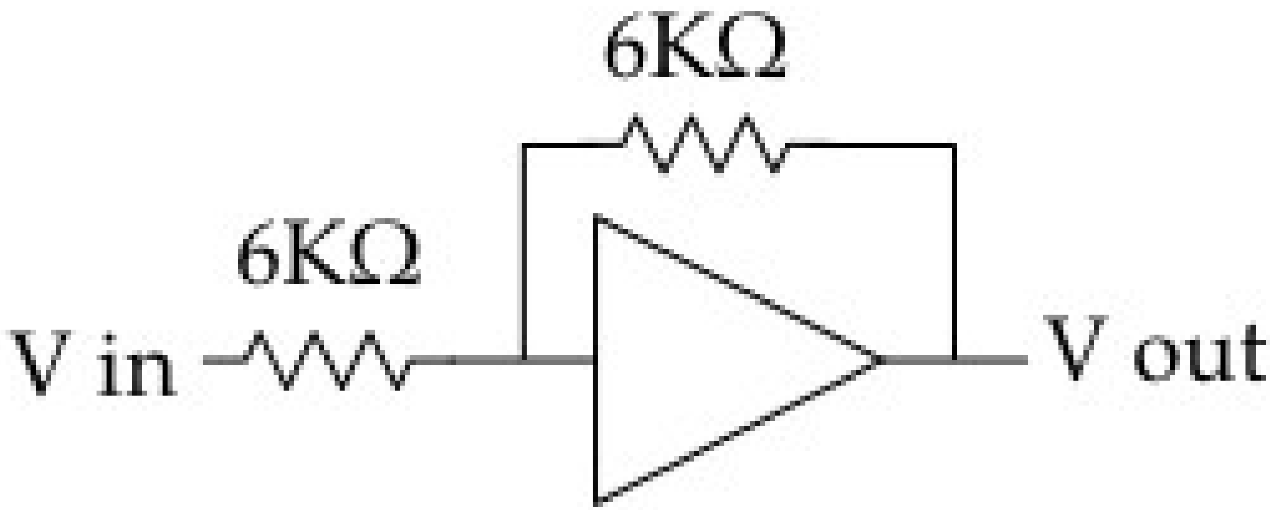
In computing, V_{in+} is earthed, only V_{in-} is active.

Used to amplify voltage, Gain >> 1,000.

(This IC contains 4 x 13 transistors, etc.)

Voltage Inverter

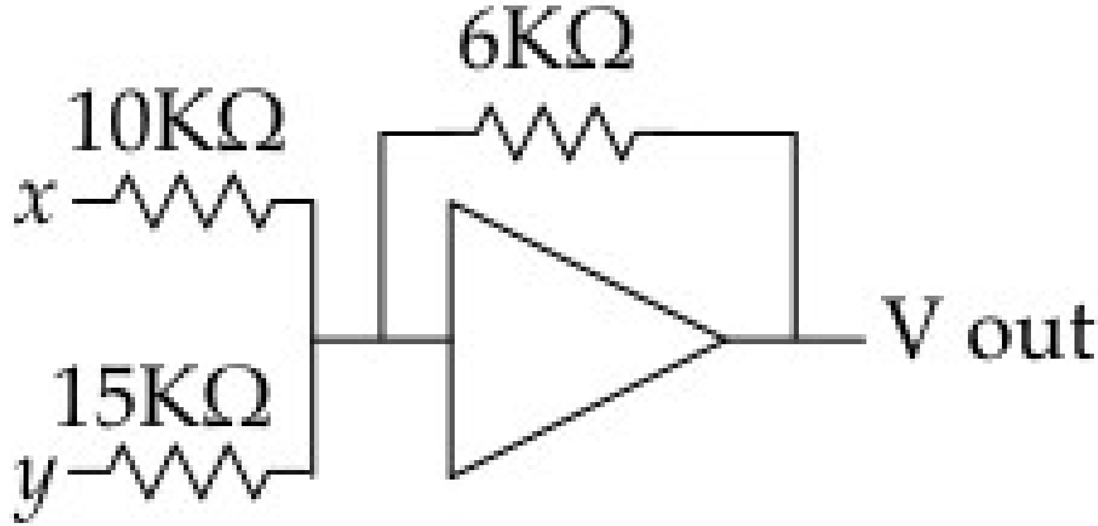
$$V_{out} = -V_{in}.$$



If gain is large, we can assume the input to the -ve input of the Op Amp is zero. For the *current* to be zero, forward and feedback currents must cancel.

Addition and Multiplication by a Constant

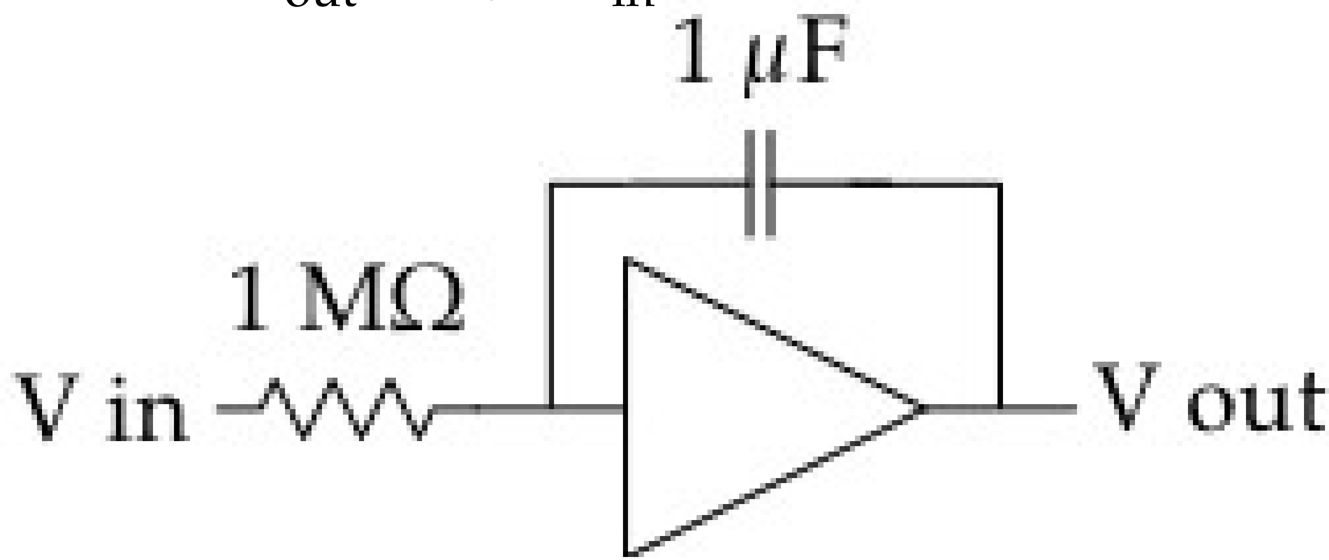
$$V_{out} = -(0.6x + 0.4y).$$



(6KΩ/10KΩ=0.6, 6KΩ/15KΩ=0.4.)

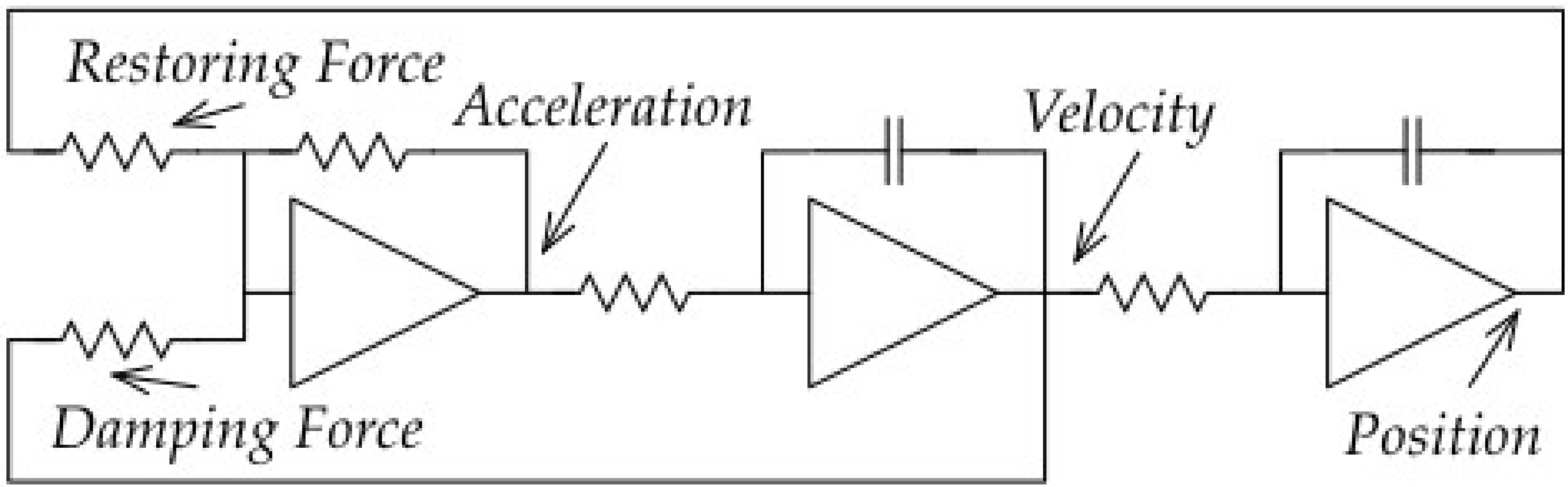
Integration

$$V_{out} = -\int V_{in}\,dt.$$



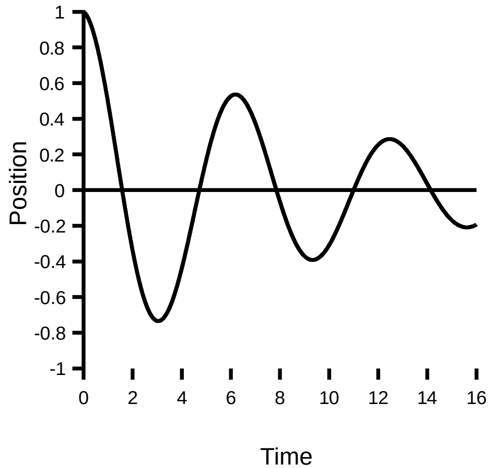
With these values, $V_{in} = 1V$ would cause V_{out} to increase negatively by 1V/sec.
The changing output will cause a 1 μA current to flow through the capacitor to balance the flow through the resistor.

Simulation of a Pendulum

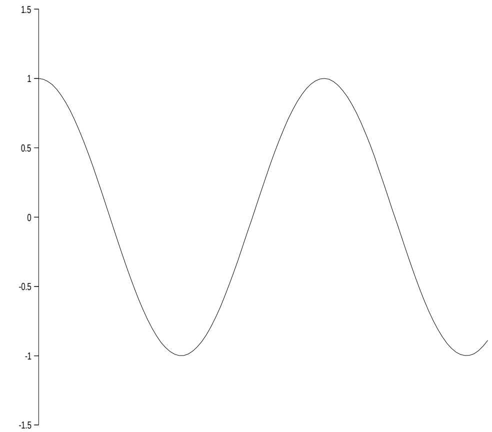


Acceleration is rate of change of *Velocity*, so *Velocity* integrates *Acceleration*. Likewise *Velocity* is change of *Position* and *Position* integrates *Velocity*. Acceleration results from two forces, a restoring force due to displacement from vertical, and velocity damping due to air resistance.

Behaviour of Second Order System



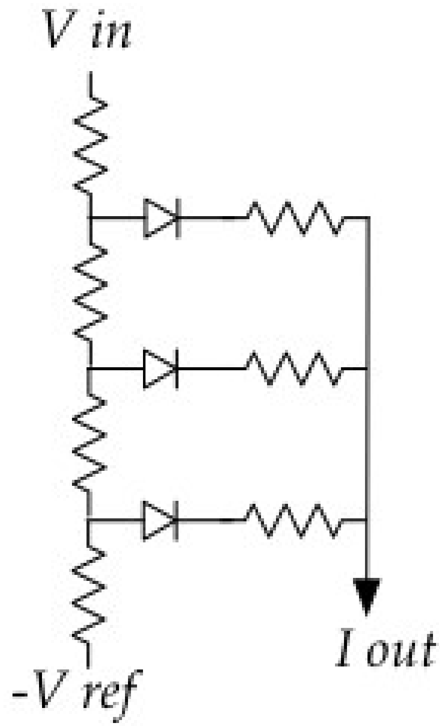
With Damping

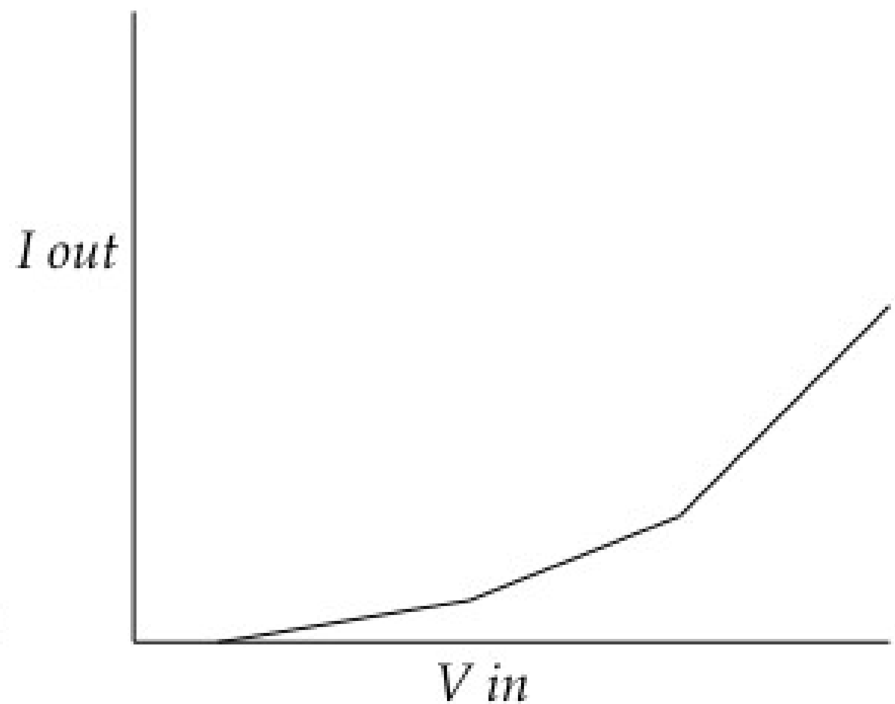


Without Damping

A missile control system contains many second order control systems: The flight computer sends a voltage to a solenoid that causes a current that causes a force to open a hydraulic valve. The force results in a setting allowing hydraulic pressure to flow to accelerate the ailerons, resulting in their movement. The ailerons apply an aerodynamic turning moment that results in constant rate of pitch. This results in lift causing acceleration across the guidance beam, and ultimately in a course correction.

Function Generation





Diodes conduct electricity in only one direction. A network of diodes and resistors can closely approximate any desired function, e.g., $I_{out} = k \times V_{in}^{2}$.

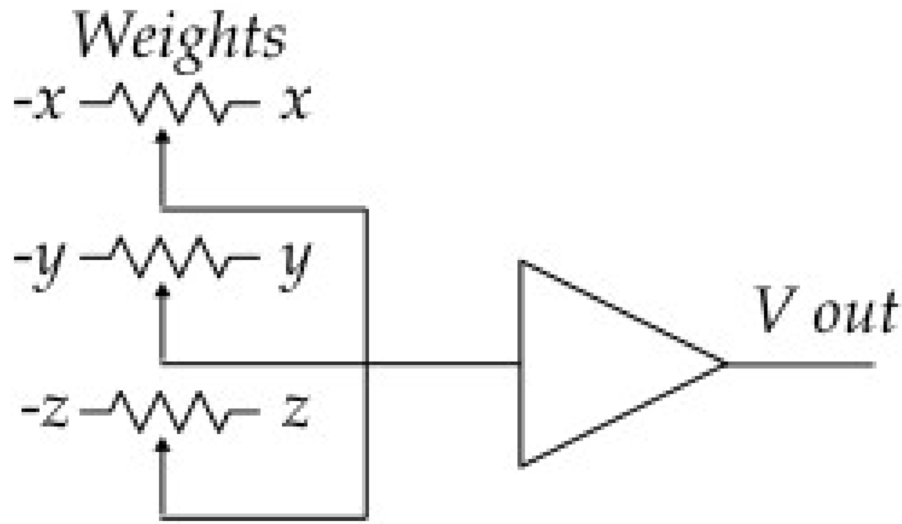
Multiplying Two Variables

Possible Approaches:
Hall Effect: Multiplies current by magnetic field to give voltage output. Low output, noisy.

Exponents: Similar to slide rule, but uses natural voltage/current characteristic of diodes to find exponents. Inaccurate, –ve values a problem.

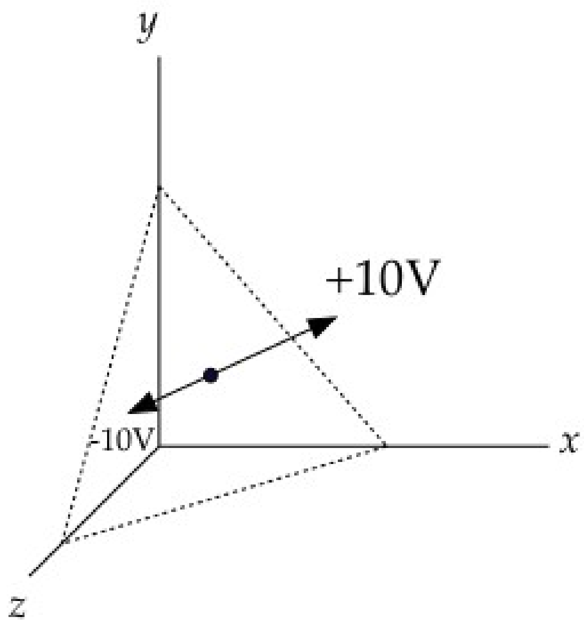
Quarter Square Multiplier:
$(x + y)^2 = x^2 + 2xy + y^2$, $(x - y)^2 = x^2 - 2xy + y^2$.
Therefore, $(x + y)^2 - (x - y)^2 = 4xy$.
(*Needs 4 function generators and a few op amps.*)

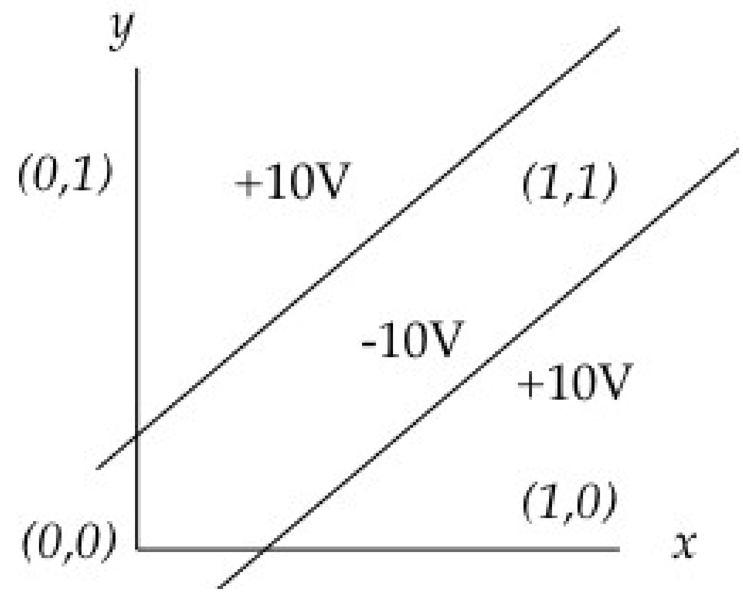
Neural Networks: The Perceptron



The absence of feedback means V_{out} is ±10V.
+10V = Yes, -10V – No.
Weights can be adjusted to vary the contributions of *x*, *y* and *z*, including negative values. (*Training*.)
x, *y*, and *z* might be factors that might predict rain.
If prediction is correct, leave well alone.
If prediction is false, adjust each weight in the direction that would give the correct answer.

Limitation of the Perceptron





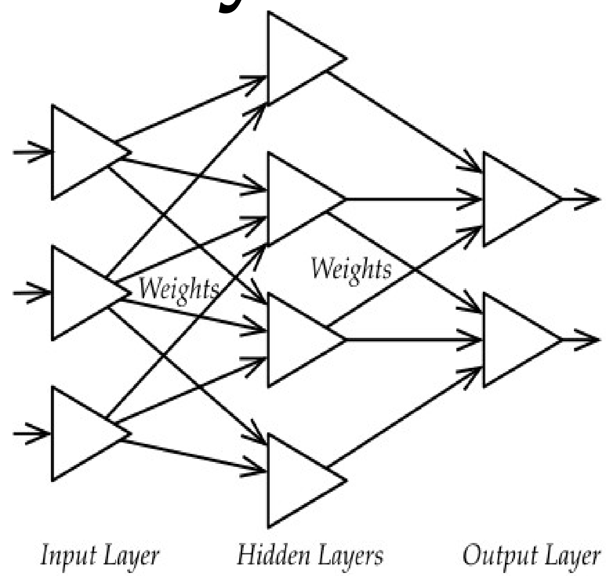
(*Typically, one input is constant.*)

Easy to prove perceptron divides input space into only two regions, separated by a plane.

Cannot solve exclusive OR problem, which requires three regions.

Solution: multiple layers of perceptrons feeding one another.

Multilayer Networks



Problem: How to train the network.
Back propagation: work from output to input.
Assign error to last hidden layer as weighted average of errors in the output layer, and so on.
More Art than Science:
How many layers?
What pattern of interconnections?
How to choose the best learning rate?