British Rail

SYSTEM ELECTRONICS

(SE)

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RAILWAY ENGINEERING SCHOOL

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SYSTEM ELECTRONICS COURSE

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SECTION 1

ELECTRICAL THEORY & THE AVO

1. ELECTRICAL UNITS

The basic electrical units are:

CURRENT	(I)	measured in	AMPS	(A)
VOLTAGE	(V)	" "	VOLTS	(V)
RESISTANCE	(R)	" "	OHMS	(Ω)
POWER	(P)	" "	WATTS	(W)

We use multipliers as a short-hand way of referring to large or small units, e.g. kilowatt, milliamp. The most common multipliers in electrical use are:

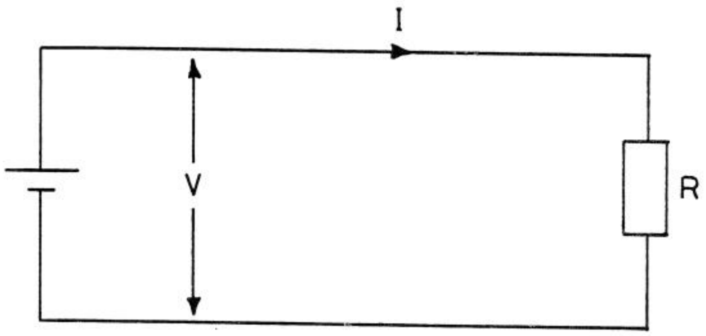
mega	M	=	10^6	
kilo	k	=	10^3	
milli	m	=	10^{-3}	or 0.001
micro	u	=	10^{-6}	or 0.000 001

So 1 millivolt (1mV) is the same as 0.001V
1 kilovolt (1kV) is the same as 1,000V

You may also come across:

nano	n	=	10^{-9}
pico	p	=	10^{-12}

Don't forget to take account of multipliers where they are used, for example in ohm's law:

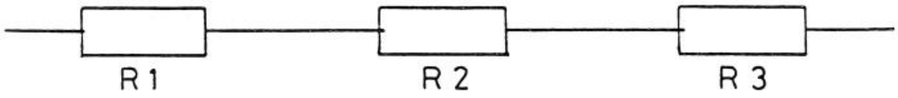


If V = 10v, R = 5kΩ, then $I = \frac{10v}{5{,}000\Omega} = 2mA$

or if I = 6mA, R = 3kΩ, then V = _______________

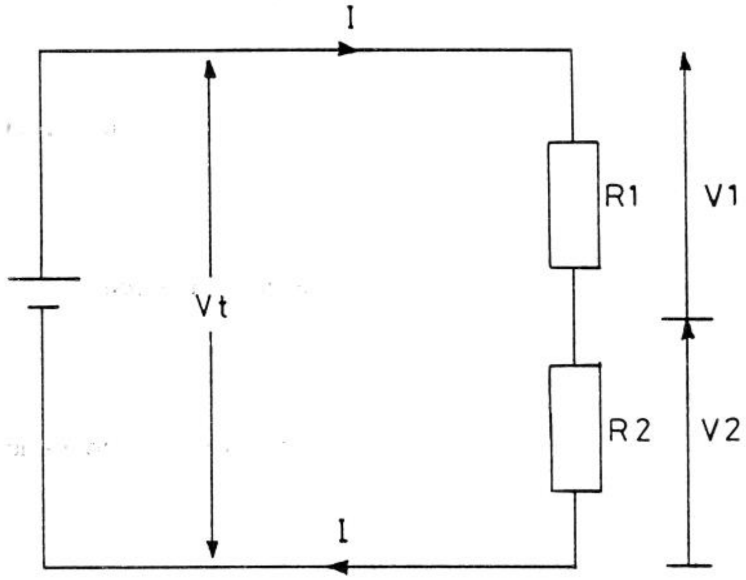
2. RESISTORS IN SERIES

If we add extra resistors in series in a circuit, we increase the resistance of the circuit. The total resistance is then obtained by adding all the individual resistances:



$$Rt = R1 + R2 + R3$$

If a voltage source is connected across two (or more) resistors in series, the same current will flow through all of them, and a voltage will appear across each resistor. The circuit acts as a POTENTIAL DIVIDER.



$$Vt = V1 + V2 \qquad I = \frac{Vt}{Rt}$$

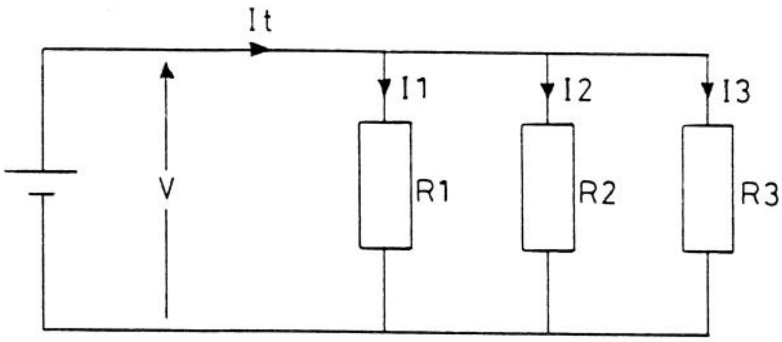
The current is the same at any point in the circuit, so the voltage across each resistor will depend on the size of that resistor:

$$V1 = I \times R1 = Vt \times \frac{R1}{Rt}$$

similarly $$V2 = Vt \times \frac{R2}{Rt}$$

Note that if one of the resistors, say R2, is very small compared to the other, then R2/Rt will be small. The voltage across it will also be small, so a *small series resistor can often be ignored.*

3. RESISTORS IN PARALLEL



If we add additional parallel resistors to a circuit, we make it easier for the current to flow, and so reduce the resistance of the circuit. The total resistance will be less than the smallest of the resistors. It can be calculated using the formula:

$$\frac{1}{Rt} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

For example, 3 ohms added in parallel with 6 ohms gives a combined resistance of only 2 ohms.

For two resistors in parallel, a simpler formula may be used:

$$Rt = \frac{R1 \times R2}{R1 + R2}$$

In the circuit above, the voltage across each resistor is the same:

$$V = It \times Rt$$

where $It = I1 + I2 + I3$

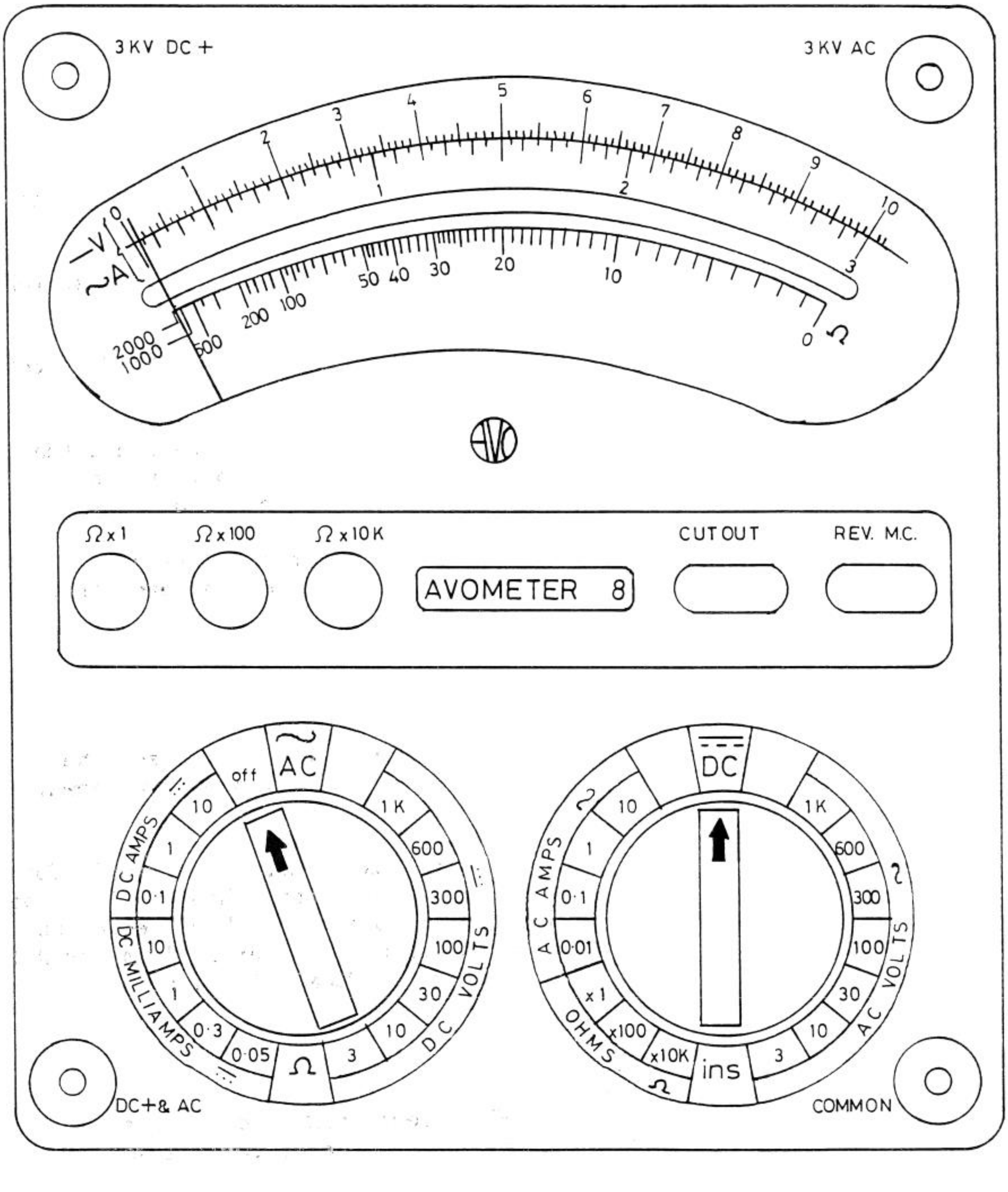
So the current through each resistor will depend on the size of that resistor:

$$I1 = \frac{V}{R1}$$

$$= It \times \frac{Rt}{R1}$$

similarly $I2 = It \times \frac{Rt}{R2}$

If one of the resistors, say R2, is very large compared to the other, then Rt/R2 will be very small (remember the combined resistance Rt is *less* than the smallest resistor R1). The current through R2 will also be small in comparison, as most current will flow through the smallest resistor, so a *very large parallel resistor can often be ignored.*



AVOMETER MODEL 8

4. THE MODEL 8 AVO (See Diagram)

The standard B.R. lineman's meter, and the AVO Model 8 are both moving-coil meters. This section of the notes will concentrate on the Model 8 AVO as it is more suitable for measurements on electronic circuits.

4.1 Range Controls

The left-hand switch provides all the DC current and voltage ranges and the right-hand switch provides the resistance ranges and AC current and voltage ranges.

To measure:-

DC SIGNALS: set the right-hand switch to "DC" and the left-hand switch to the required range.

AC SIGNALS: set the left-hand switch to "AC" and the right-hand switch to the required range.

RESISTANCE: set the left-hand switch to "Ω" and the right-hand switch to the required range.

If you do not know the size of the voltage or current always use the highest range and work downwards until you reach the most suitable range. You do not need to disconnect the leads to do this.

The cut-out will operate if you attempt to use too low a range, or otherwise mis-use the meter. It may not always save the meter from damage, so do not rely on it.

4.2 Voltage Measurement

Set the meter to a suitable AC or DC voltage range and connect the leads across the voltage to be measured. If the voltage is unknown, start at the highest range and work down.

The test leads should be connected to the lower pair of terminals for all ranges except 3kV (3,000V). If a voltage of more than 1kV is to be measured, then the appropriate 1kV range should still be selected but the positive lead connected to the appropriate 3kV terminal (AC or DC). The negative lead is always connected to the COMMON terminal.

4.3 Current Measurement

Set the meter to a suitable AC or DC current range and connect it in SERIES with the circuit under test, so the current flows through the meter.

4.4 Resistance Measurement

The model 8 AVO has three resistance ranges covering measurements up to 20 megohms. When you make a resistance measurement, an internal battery drives a current through the meter and through the resistor being measured. Note that a POSITIVE voltage appears at the BLACK terminal when set to a resistance range.

The zero of the resistance ranges is at full scale deflection of the needle. To compensate for changes in battery voltage and lead resistance each resistance range has an adjustment button. Before using a meter on any of the ohms ranges it is good practice to set the zero on every range. Then you don't have to remember to set the zero again if you have to change to a new range. To set the zero, select the range, connect the leads together, and rotate the adjustments button until the needle is above the 0 mark.

You must not attempt to measure the resistance of any component that is already carrying a current. Also, if a component is connected in a circuit, you may need to disconnect one of its leads to prevent false readings through parallel connections.

4.5 Polarity Switch (REV M.C.)

Under certain conditions the polarity of the measurement may change (for example in a circuit where the current flow may change direction). To allow measurements to be made without disconnecting the leads, the REV M.C. switch is provided. This reverses the polarity of the internal meter circuit.

4.6 General

You must use the meter horizontally to ensure correct readings. If the pointer is not at zero you may set it by using the adjustment screw on the front panel.

To obtain a true reading on any meter, you should always look straight down on the needle. On the AVO, a mirror is provided to assist with this. When you read the meter, always make sure that the needle lines up with its reflection.

Do not switch off the meter by turning either of the range switches to a blank position.

Before transporting the meter, set the left-hand switch to "OFF" and the right-hand switch to "DC". This damps the needle and protects it against damage.

SECTION 2

USE OF THE OSCILLOSCOPE

In this section, we will see:-

a) how to set up an oscilloscope

b) what effect the various controls have

c) how to display a waveform

d) how to use the oscilloscope to take simple measurements of electronic signals.

We shall be using the Gould OS300, but the principles are applicable to other types of oscilloscope.

1. INTRODUCTION

1.1 Electronic Signals

An electronic signal is a variation in some electrical quantity by which information can be conveyed. For example, sound waves (variation in air pressure) may be changed into voltage variations by a microphone. This voltage can in turn be reconverted into sound waves by a receiver some distance away - we then have a telephone.

The electronics engineer will need to take measurements on such signals as part of his day to day duties, but unfortunately the moving-coil meter has severe limitations when used in this way.

For example, an AVO8 would not be able to tell whether a telephone call was distorted or not - even if it were able to register the very small signal voltage concerned. This is because the difference between a "distorted" signal and a "pure" signal is not necessarily a matter of the *magnitude* of the signal voltage, but more a matter of *how* the voltage varies with time.

1.2 The Oscilloscope (CRO)

It is primarily for the measurement of TIME VARYING VOLTAGES that the OSCILLOSCOPE is designed and used. It is the "eyes" of the electronic engineer, because it allows him to see *how* voltages are varying, even if those variations are taking place very quickly.

With a scope, you can find out the frequency of a signal, how much of it is a.c. and how much d.c, and how much noise there is on it. Using a scope you see all these things together, rather than needing separate measuring instruments.

The scope produces a visible display on a cathode ray tube (similar to a television set). The display is caused by a stream of electrons, focussed into a fine beam. When an electron hits the screen a momentary spot of light is seen; when a stream of electrons hits the screen a continous spot is seen.

The oscilloscope itself controls the horizontal (X) position of the spot, which is made to travel repeatedly from left to right over the screen. So with no vertical control, we see a horizontal line. The speed at which the spot travels from left to right is controlled by the TIMEBASE generator.

The voltage input to the oscilloscope controls the vertical (Y) position of the spot. As the spot travels across the screen, its position is directly related to the way in which the input voltage varies. So the spot traces out a picture of the voltage, which we can examine and measure. This picture of the way in which the voltage varies with time is known as the signal WAVEFORM.

2. INTRODUCTION TO THE OSCILLOSCOPE

2.1 BEFORE PLUGGING INTO THE MAINS:-

2.1.1 Turn the MODE switch to "CH1"

2.1.2 Turn the POWER/INTENSITY control anticlockwise to the OFF position (until it clicks).

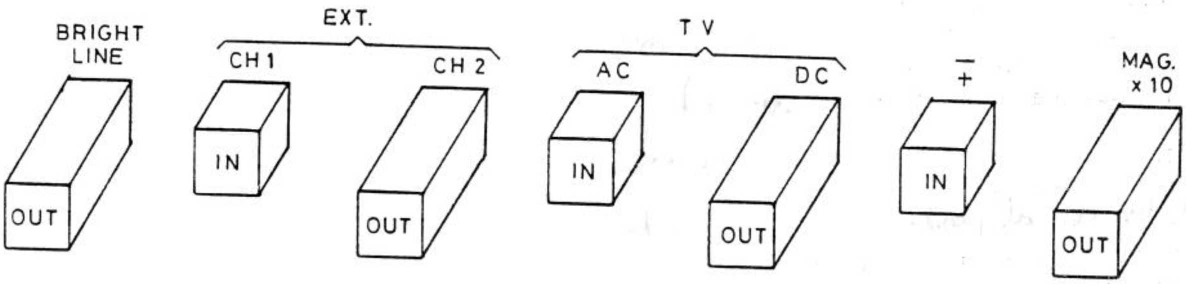
> **W A R N I N G !**
>
> A very bright spot can damage the screen. Make sure that you have followed the above instructions.

2.2 Setting Up the Oscilloscope

2.2.1 Turn the POWER/INTENSITY control clockwise until it clicks, and check that the red "power on" indication lights up.

2.2.2 You now use the same button to control the screen INTENSITY, or brightness (in the same way as the on/off and volume controls are combined on some TV Sets). Turn the button halfway (pointer straight up).

2.2.3 Set the seven square TRIGGER buttons as below :-



2.2.4 Set the "CH1" AC/GND/DC input selector to GND.

2.2.5 Set these controls to mid-position (pointer straight up) :-

a) FOCUS
b) CH1 ⇕ (Y shift)
c) TRIG LEVEL
d) ◄► (X shift)

2.2.6 The scope takes about a minute to warm up, after being turned on. If no trace appears:

a) try increasing INTENSITY, by turning clockwise
b) try adjusting TRIG LEVEL
c) try adjusting CH1 ⇕ about the mid-position
d) ensure trigger buttons are correctly set.

2.2.7 When you have obtained an image , adjust the FOCUS and INTENSITY controls to give a sharp and easily visible trace.

2.3 Connecting the Input Signal

2.3.1 Turn CH1 VOLTS/CM (amplitude) to 2v

2.3.2 Turn TIME/CM (timebase) to 20 us

2.3.3 Set CH1 AC/GND/DC input selector switch to AC.

2.3.4 Connect a co-axial lead to the CH1 BNC connector.
Connect the red and black 4mm plugs on the other end of the lead to terminals A & B on the bench, red to A.

2.3.5 You should now be able to see a waveform.
If not, try adjusting:

a) TRIG LEVEL
b) Amplitude (Volts/cm)

2.4 Oscilloscope Controls

Try adjusting the controls listed below, and noting the effect. Return each control to its starting position before going on to the next.

2.4.1 ◄► (X shift) clockwise Moves image right

anticlockwise Moves " left

2.4.2 TIME/CM clockwise broadens image of signal

anticlockwise narrows "

2.4.3 MAG x 10 button in stretches " x10 = ÷ time/cm by 10

2.4.4 VAR SWEEP clockwise spreads "

should be in cal position anticlockwise closes "

2.4.5 CH1 ▲▼ (Y shift) clockwise raises " up screen

anticlockwise Drops " down "

2.4.6 CH1 VOLTS/CM clockwise heightens "

anticlockwise shortens "

2.4.7 CH1 VAR SENS clockwise ____________

should be in cal position anticlockwise ____________

2.4.8 Try adjusting the CH2 controls (▲▼, VOLTS/CM and VAR SENS).
What effect do they have?
none

2.4.9 Try turning the TRIG LEVEL fully clockwise and fully anticlockwise. What effect does this have?

TRIG LEVEL controls the point on the waveform where the trace begins at the left-hand side of the screen. If this is the same each time the spot goes across the screen, then the picture will always be the same, and so the waveform will appear steady.

If however, TRIG CONTROL is lost or erratic, you may get unsteady or multiple images on the screen. These images are WRONG, and are due to incorrect setting of the scope. You must always adjust the TRIG LEVEL if you suspect that you have multiple images. However, some waveforms are particularly difficult to trigger properly, as we will see later. Another symptom of poor TRIG settting is the blank screen.

You can select between various different methods of triggering an image using the square TRIGGER pushbuttons.

2.5 Dual Traces

2.5.1 Set the CH2 controls similar to CH1.

2.5.2 Turn the MODE switch to DUAL (white line uppermost).

2.5.3 You should now have a second, straight-line trace.
Try moving it around the screen.

2.5.4 Can the two traces, CH1 & CH2, be controlled independently:

a) Vertically (⬍) ? .... Yes/No

b) Horizontally (◄►) ? .... Yes/No

c) Amplitude (Volts/cm) ? .... Yes/No

d) Timebase (Time/cm) ? .... Yes/No

2.6 Setting Up

You must be able to set up a scope in under two minutes.

Practice this by getting your colleague to upset all the controls. Now obtain a straight line trace on CH1 and a triggered signal from terminals A-B on CH2 while your colleague times you.

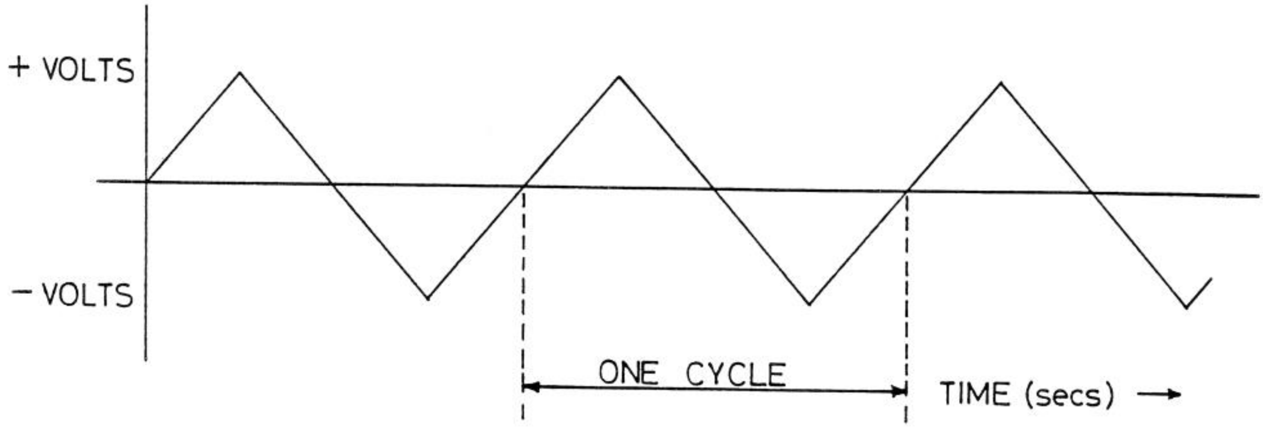
Then get your own back by timing him!

Repeat this exercise a couple of times, until you are happy with it.

3. CHARACTERISTICS OF WAVEFORMS

3.1 Periodic Waveforms

On this course, we shall mainly be dealing with periodic waveforms. A periodic waveform is one in which a basic pattern is continually repeated, as in the following example:-



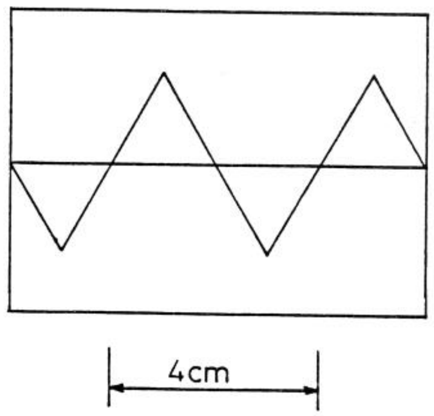
A CYCLE is the basic element of the waveform which is continually repeated.

3.2 Period

PERIOD is the time taken by one cycle.
The width of a waveform when measured on the scope is a measure of its period:

period = width (cm) x scope setting (time/cm)

e.g.



Scope set at 5msec/cm

so period = 4 cm x 5msec/cm
= 20 msec

3.3 Frequency

FREQUENCY is the number of cycles occurring in one second, and is measured in hertz (Hz).

1 cycle each second = 1 Hz
1,000 cycles each second = 1,000Hz or 1kHz

If each cycle lasts 1/50th second (20 msec),
then there are 50 cycles per second (50 Hz).

$$\text{Thus period} = \frac{1}{\text{frequency}}$$

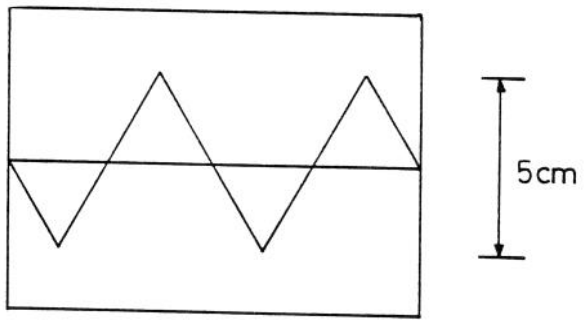
$$\text{or frequency} = \frac{1}{\text{period}}$$

3.4 Amplitude/Voltage

The height of a waveform when measured on an oscilloscope is a measure of its amplitude, or voltage:

Voltage = height (cm) x scope setting (volts/cm)

e.g.



Scope set at 0.5v/cm

so voltage = 5cm x 0.5v/cm
= 2.5v

PEAK-TO-PEAK voltage is measured between the lowest and the highest values, as shown above. This is the easiest value to measure with an oscilloscope.

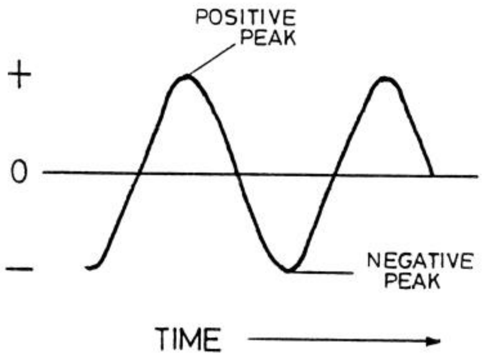
PEAK voltage is measured from the centre point of the waveform to the maximum in either direction. Peak voltage is half the peak-to-peak measurement.

RMS (Root Mean Square) voltage is sometimes quoted, but cannot be measured directly on an oscilloscope.

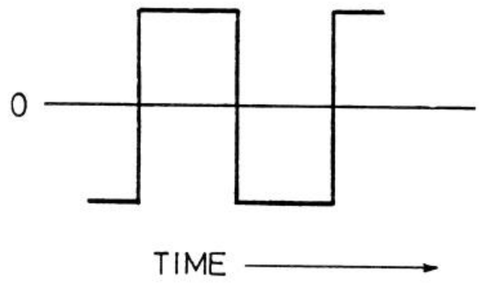
3.5 Waveform Shape

As well as its amplitude and frequency we also need to describe a waveform's shape. These are some of the more important types:-

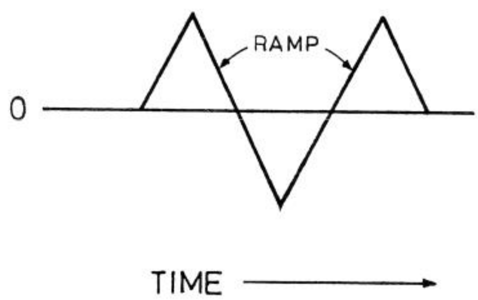
SINE WAVE :



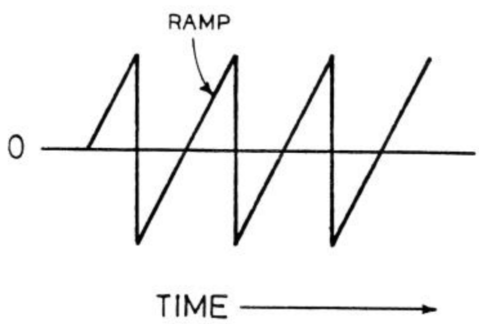
SQUARE WAVE :



TRIANGLE WAVE :



SAWTOOTH WAVE :



3.6 To Measure Amplitude

3.6.1 Set up the oscilloscope as before, for one trace (Mode switch turned to CH1).

3.6.2 Connect the signal and adjust the timebase to give a few cycles on the screen. Readjust TRIG LEVEL to stabilise the trace if necessary. Adjust the controls to give a clear image.

3.6.3 Set the VAR SENS control to CAL (fully clockwise). This must always be done before taking volts/cm readings.

3.6.4 Adjust VOLTS/CM to give the maximum height trace on the screen, without losing any of the top or bottom.
Adjust the Y Shift (⬍) if necessary.

3.6.5 Measure the height of the waveform in cm.
You may adjust the X shift (◀▶) to move the trace across the screen, but you must NOT TOUCH the Y shift (⬍) while taking the measurement.

3.6.6 Height of waveform = Y = 4.2cm ~~X 2 = 8~~ (p-p) 4

Scope V/cm setting = S = 2 v/cm 5

Amplitude = Y x S = 8.4 20

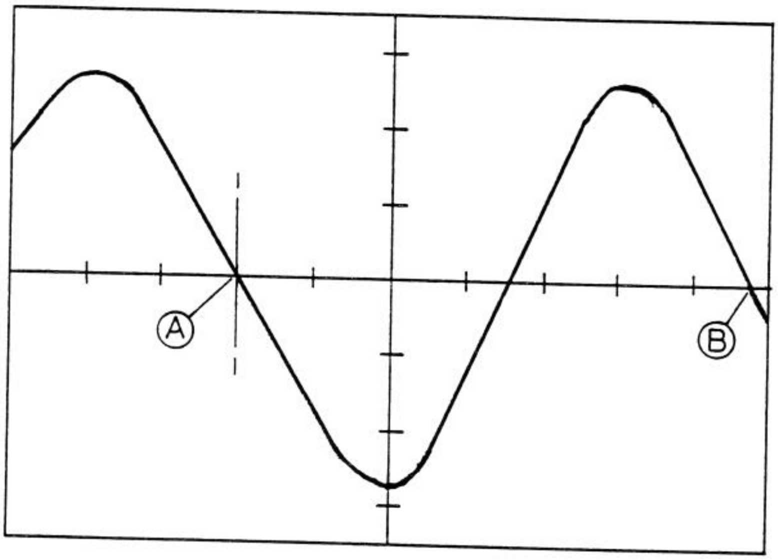
(Don't forget the units!)

3.7 <u>To Measure Period & Frequency</u>

3.7.1 **Set up the scope, as before.**

3.7.2 Set the VAR SWEEP control to CAL. This must always be done before taking time/cm readings.

3.7.3 Adjust the timebase to give between 1 & 2 cycles on the screen.



3.7.4 Choose any two repetitive points on the waveform (choose points on the steepest part of the waveform, e.g. A and B, as these give most accurate measurements). Adjust the Y shift (▲▼) so these points lie on the scope centre-line.

3.7.5 Adjust the X shift (◄►) to move one of the points, e.g. (A), to a vertical line as shown.

3.7.6 Measure the distance in cm between the two points, A and B.

3.7.7 Width of one cycle = X = 5 ______________________ 5·2

Scope Time/cm setting = S = 20 µS ______________________ ·1 ms

Period = T = X x S = 100 µS ______________________ ·52 ms

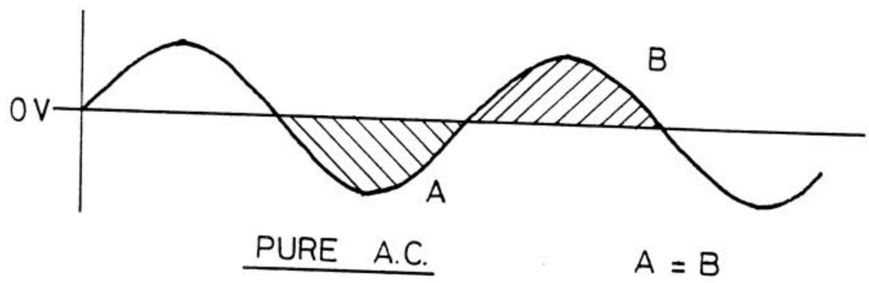
Frequency = $\frac{1}{T}$ = $\frac{1000\,000}{100}$ = ~~MHz~~ 10 Khz ______ 2KHz 1923

(Don't forget the units!)

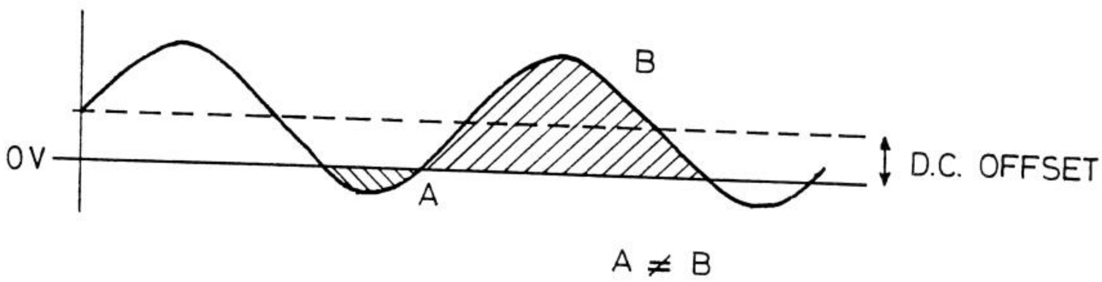
4. D.C. OFFSET

4.1 A.C. & D.C. Waveform Components

With a pure A.C. waveform, the positive part of each cycle is always equal to the negative part:



In the following example, the waveform is similar, but the positive and negative parts are not equal:



The positive and negative parts are not equal because the waveform is offset from the 0 volt axis. The A.C. waveform is said to have a D.C. offset, or "superimposed D.C. level".

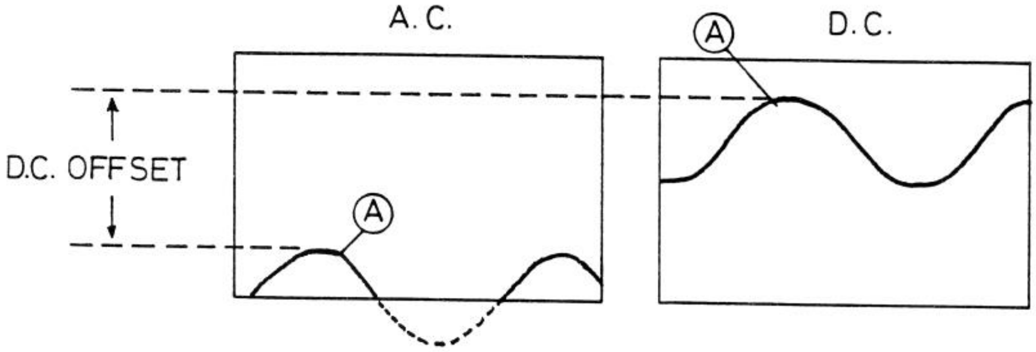
In general, most waveforms can be regarded as having both an A.C. component and a D.C. component, which have to be measured separately.

4.2 To Measure D.C. Offset

4.2.1 Set up the oscilloscope, as before. Adjust the timebase to give a few cycles on the screen. Ensure the VAR SENS control is set to the CAL position.

4.2.2 If you now switch the AC/GND/DC input selector from AC to DC, you should see the waveform move up or down the screen.

4.2.3 Choose one point on the waveform, and use the X shift (◀▶) control to position it over the centre vertical line. You can use either the top (as shown) or bottom of the trace.



4.2.4 Adjust the VOLTS/CM and Y shift (▲▼) controls to obtain the largest on-screen movement of the chosen point, when switching between AC and DC. It does not matter if the rest of the waveform is lost off the top or bottom of the screen.

4.2.5 Measure the offset in cm when switching between AC and DC and calculate the DC offset voltage by multiplying by the VOLTS/CM setting.

4.2.6 i) If the trace moves **UP** the screen when the input selector is moved from AC to DC, then the offset is POSITIVE.

ii) If the trace moves **DOWN** from AC to DC, then the offset if NEGATIVE.

4.2.7 If measuring the D.C. offset on CH2, make sure that the "INV" button isn't pressed - otherwise you will get the positive/negative wrong!

-1·6 × 2 = -3·2

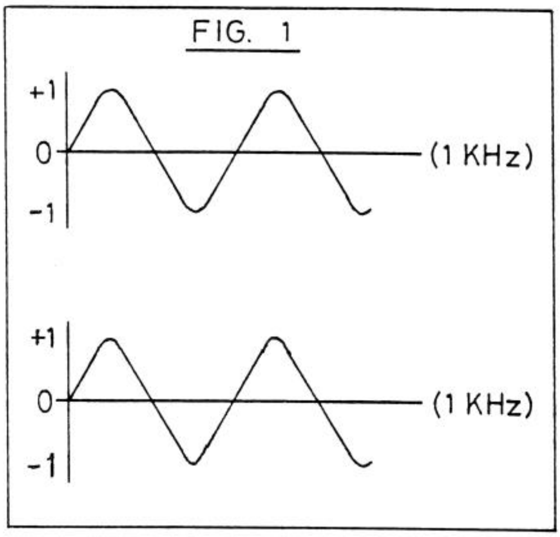
+5·5 × 2 = +11

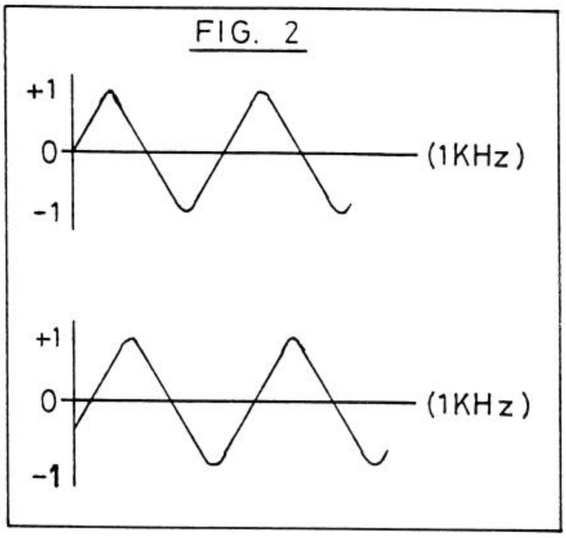
TERMINAL	AMPLITUDE	PERIOD	FREQUENCY	D.C. OFFSET
A B	~~6·6~~ 3·3V	~~[illegible]~~ 1·6 mS	625 Hz	-6·5V
E F	6·8V	116 μS	8·62 KHz	0
J	10V	32 μS	31·25 KHz	-9V
K	3·2V	1·04 mS	962 Hz	-·02V
A B	2·75V	14 mS	71·5 Hz	0
E F	3·25V	66 mS	15·1 HZ	0
G H	·2V	55 μS	18·2 KHz	+11V
K	4·5V	11 μS	91 KHz	0
A B	4V	200 mS	5 Hz	0
E F	1·6V	12·5 μS	80 KHz	0
~~G H~~ J	2V	3·3 mS	303 Hz	0
K	3V	~~45~~ ·9 mS	1111 Hz	0

TERMINAL	AMPLITUDE	PERIOD	FREQUENCY	D. C. OFFSET

5. PHASE RELATIONSHIPS

5.1 Figures 1 & 2 both show a pair of AC waveforms. Both pairs of waveforms have the same frequency, amplitude and shape, but the two figures are different.





In fig. 2, the two waveforms are not doing the same thing at the same time. They are said to be "OUT OF PHASE".

The waveforms in fig. 1 are said to be "IN PHASE".

To define the phase of a signal, we need to state whether it happens before or after the reference signal, and by how much.
We follow this convention :-

If signal X happens BEFORE signal Y,
then X is said to be LEADING Y.

If signal X happens AFTER signal Y,
then X is said to be LAGGING Y.

To specify how much a waveform leads or lags, we divide the cycle into 360 degrees. So a waveform which leads by a quarter of a cycle, for example, is said to be 90° leading.

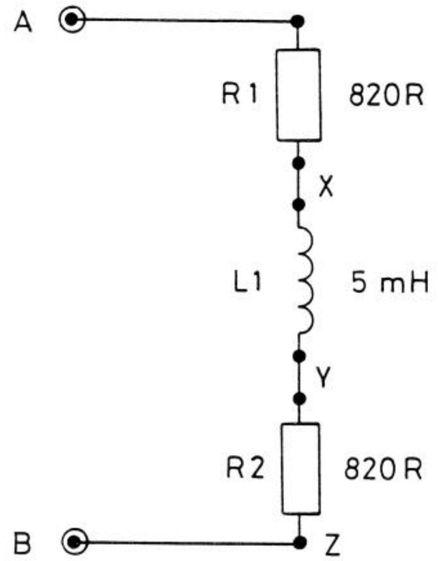
When the two signals are exactly opposite in phase, or 180° out of phase, then they are said to be in ANTIPHASE.

Note that we can only describe signals as being in or out of phase if they have the same frequency - but they need not have the same amplitude.

Also, we can only refer to the phase of a signal if we have another signal to refer it to - it is meaningless to talk about the phase of one signal alone.

5.2 To Measure Phase

5.2.1 An a.c. signal is present on terminals A-B. Connect the circuit shown below :



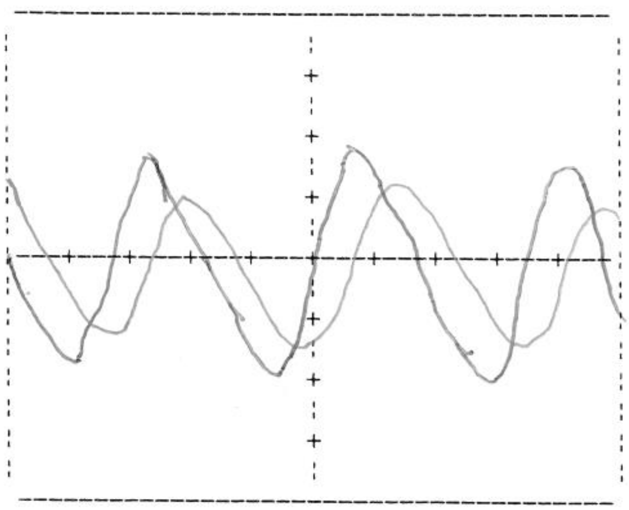
5.2.2 Connect CH2 of the scope across R2, and CH1 across both L1 and R2 :

CH1 : Red to X, Black to Z

CH2 : Red to Y, Black to Z.

5.2.3 Sketch what you see, indicating which is CH1 and which CH2 :

ch1
ch2



5.2.4 Are the signals in or out of phase?

5.2.5 If they are out of phase:

a) Which is leading? ...Ch1...

b) What angle is it leading by? ~~90°~~ ...54.5°...

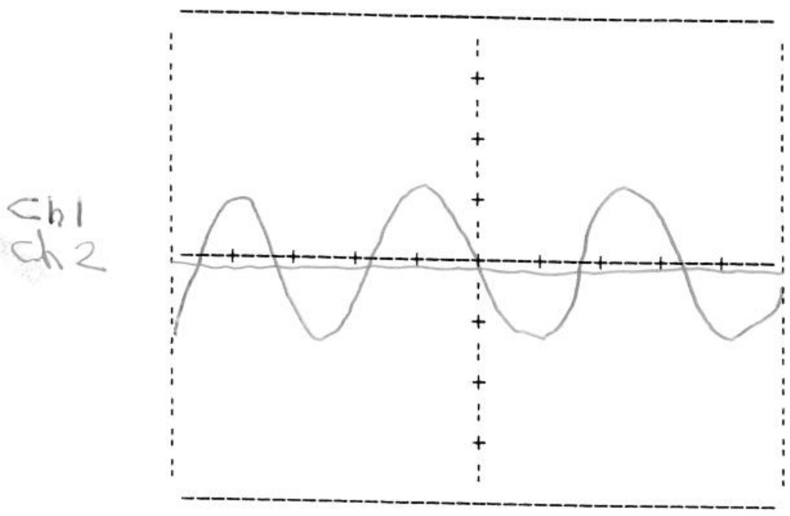
f increased lag gets bigger

5.2.6 Now connect CH1 across L1 only, keeping CH2 across R2:

CH1 : Red to X, Black to Y

CH2 : Red to Y, Black to Z (as before)

5.2.7 Sketch what you see, indicating which is CH1 and which CH2 :



5.2.8 Why has the voltage on CH2 changed from the previous page?

channel 2 can't sense anything because the two probe grounds are common therefore as soon as ch1 black is connected to Y the signal goes through the two black leads giving no sig to R2

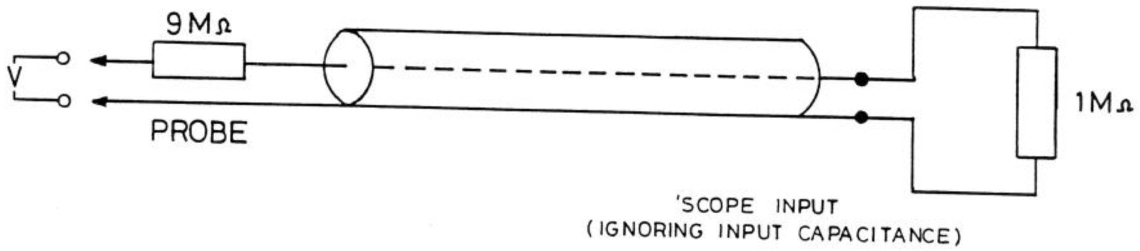
6. EARTHING

The negative test lead on an oscilloscope is connected to earth at the scope. You should be careful when using a scope on an earthed circuit, that you do not introduce an earth on a second part of the circuit through the scope lead. Doing this would effectively short-circuit a part of the circuit.

Similarly, when using both channels of the scope, you should remember that *both* negative leads on the scope are earthed. Even if the circuit you are measuring is free from earth, the two scope negative leads are connected together via the scope earth. If you connect the two negative probes to different part of the circuit, you will be shorting between them. In practice, both negative probes should preferably be connected to the same reference point in the circuit.

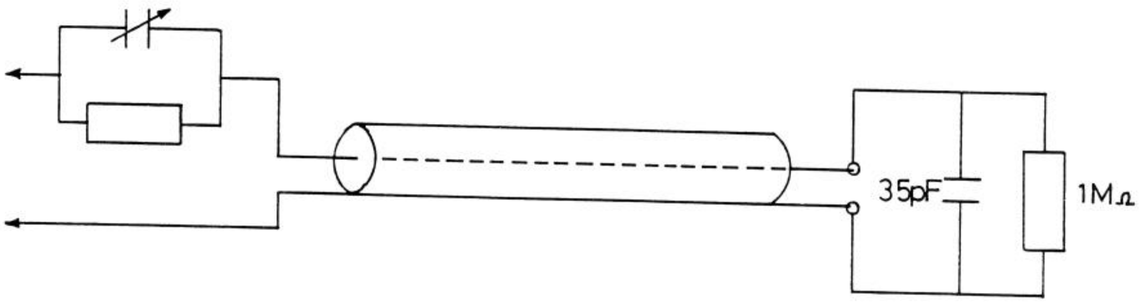
7. HIGH IMPEDANCE PROBES

7.1 High impedance probes are used to increase the resistance of the scope input, and to allow higher voltages to be measured. A x10 probe has a 9MΩ series resistor in the probe. This forms a potential divider with the 1MΩ input resistance of the oscilloscope.



The total input resistance is now 10MΩ (9MΩ + 1MΩ). Remember to multiply the displayed voltage by 10 as it is only 1/10 of the actual voltage.

Many high impedance probes have a series capacitor to adjust the probe to suit the scope being used. When the probe is connected you must calibrate it correctly before making any measurements.



x100 probes also exist - they have a 99MΩ series resistor (100MΩ input resistance). The voltage displayed is only 1/100 of the actual voltage.

7.2 x10 Probe Calibration

To measure voltages accurately with a x10 probe, it must be accurately calibrated.

a) Connect the probe to the "CAL 1V" stud underneath the timebase control.

b) Obtain a trace.

c) Locate the screw adjuster in the side of the X10 probe. Adjust this with the special screwdriver in the X10 probe kit to give the best square wave.

The probe is now calibrated for use at any frequency on this scope.

7.3 If a x10 probe is used when it is not calibrated it can give WRONG measurements if the signal is not d.c. or very low frequencies.

a) Connect a standard probe to Ch1 of the scope, and a x10 probe to Ch2.

Calibrate the x10 probe.

Set the signal generator output to a 2v RMS sine wave at 300Hz.

Connect both probes to the output of the signal generator.

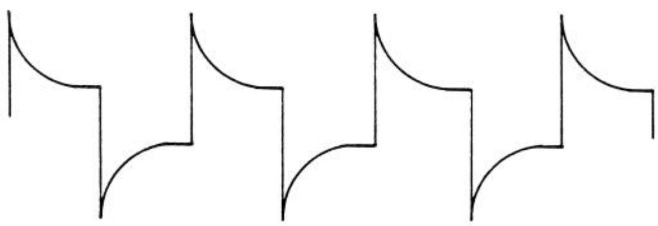
Arrange the traces so that they almost coincide.

It should now be obvious if the traces stay the same size.

Increase the frequency in steps to 300Hz (use the switch), and observe the traces. You will need to alter the scope time base.

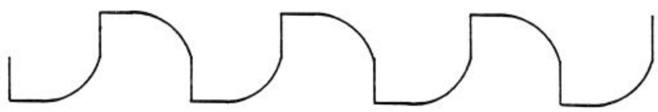
With the x10 probe calibrated it reads THE SAME AS x1 probe.

b) Connect the x10 probe to "cal" and adjust the probe until it is as far out of calibration as possible so that the waveform looks like this:-



Observe both traces as you vary the frequency from 300Hz to 300kHz.

c) Repeat again with the probe out of calibration so that the Cal waveform looks like this:-



Observe both traces as you vary the frequency from 300Hz to 300kHz.

For anything other than d.c. or low frequency signals with the x10 probe out of calibration it may read HIGHER OR LOWER THAN the x1 probe.

SECTION 3

MEASURING DIGITAL SIGNALS

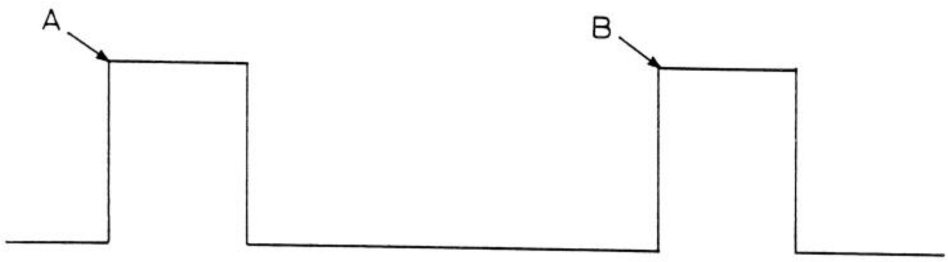
1. INTRODUCTION

A digital signal is one that is either ON or OFF. The simplest example of a digital signal is the relay line-circuit, the relay is either "up" or "down". Digital systems use pulses of varying frequency or width, the voltage does not vary - it is either on or off.

In this section, we will investigate the properties of pulses, and how to measure them with an oscilloscope.

2. P.R.R. (Pulse Repetition Rate)

Defined as the number of pulses per second, this quantity is the equivalent of FREQUENCY.



To measure P.R.R., we must first measure the waveform period. More correctly, this is called the "Pulse Repetition Period" (P.R.P.). P.R.P. can be measured on a scope in the same way as a sinewave's period. For the above example, the P.R.P. is measured between any two repetitive points, for example the start of two consequetive pulses, eg. points (A) and (B). P.R.P. is measured in seconds.

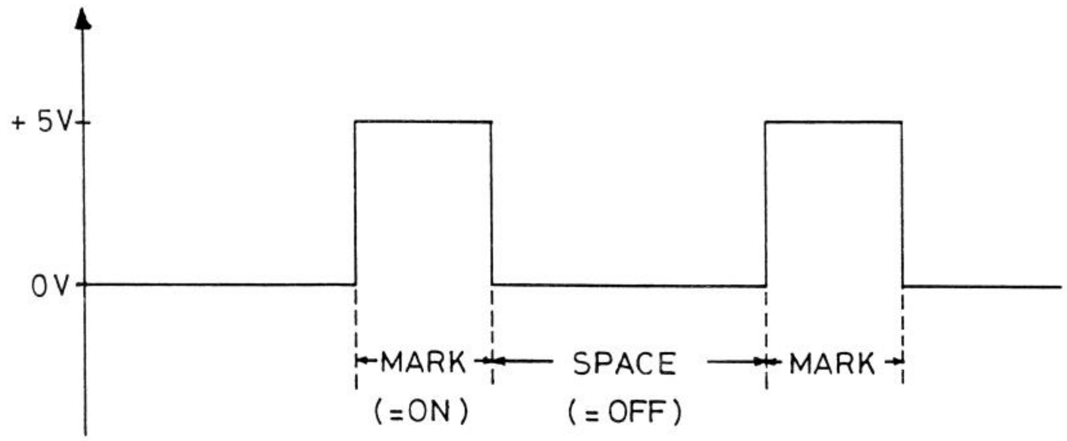
just as $f = \frac{1}{T}$ so $P.R.R. = \frac{1}{P.R.P.}$

and P.R.R. is measured in Hertz (Hz).

3. PULSE WIDTH & MARK TO-SPACE RATIO

Normally pulses consist of two voltage states, which are referred to as the "MARK" and the "SPACE", the "Space" voltage often being 0v.

In the example below, the voltage never goes negative, so this signal is described as "PULSATING DC". It is typical of a pulse train found with T.T.L. components.



Any set of pulses with marks and spaces can be said to have a "Mark to Space Ratio" . This is obtained by measuring the time represented as a "Mark" and dividing it by the time representing a "Space" i.e.

$$\text{M/S Ratio} = \frac{Tm}{Ts}$$

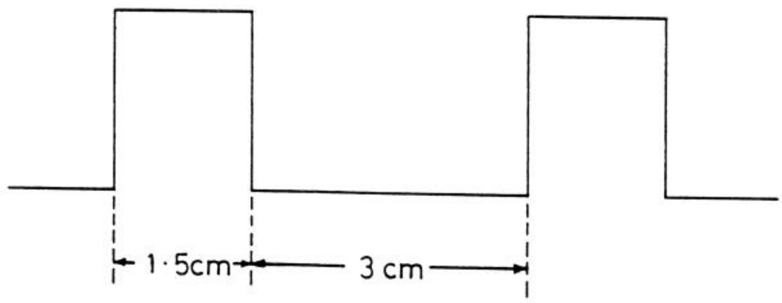
where Tm = MARK time
and Ts = SPACE time

e.g. M/S Ratio = 5 means the marks are five times as long as the spaces.

M/S Ratio = 0.2 means the spaces are five times as long as the marks.

Note that the mark to space figure is a ratio of one quantity to another, so does not have a unit (e.g. seconds, volts, etc). So, when measuring on a scope, we can simplify calculations by using the number of divisions representing the mark and the space, rather than working out their actual periods.

For example:

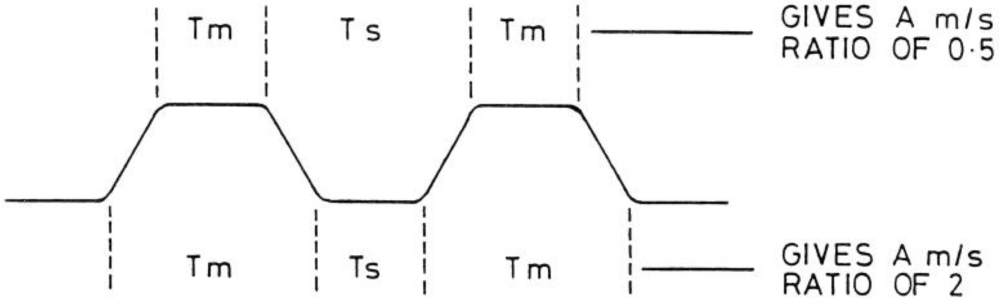


$$\text{M/S Ratio} = \frac{Tm}{Ts} = \frac{1.5}{3} = 0.5$$

For a square wave, the M/S Ratio is 1.

Unfortunately pulses are very often not perfectly square, even though the circuitry responsible for their processing would like them to be so. When dealing with real pulses, a consistent method of measurement must be adopted.

Consider the waveform below:



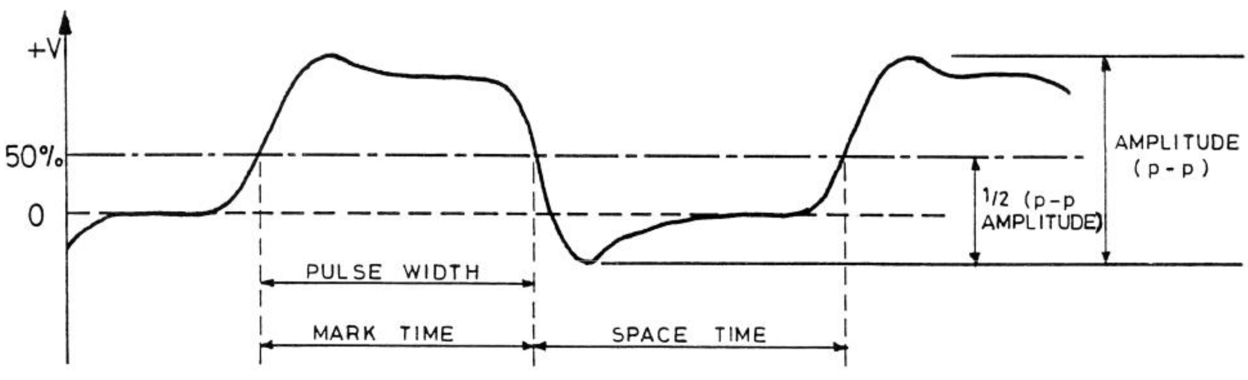
If we were to measure the M/S ratio at the very top of the waveform, we would obtain a value of 0.5.

If the same measurement is carried out at the bottom, we would obtain a value of 2.

Actually neither of these results looks particularly accurate to the eye, which tends to look at the waveform as being a "rounded off" square wave with a M/S ratio of 1:1 or 1.

Consequently we adopt a convention: we measure pulse width and M/S ratio at the centre point of the waveform.

Below is a real pulse train:-



PULSE WIDTH is defined as the width of a pulse measured half way between the top and bottom of the pulse. Very high speed transients may have to be ignored when measuring pulse width or M/S ratio.

MARK/SPACE RATIO should be measured at the same point on the waveform as pulse width.

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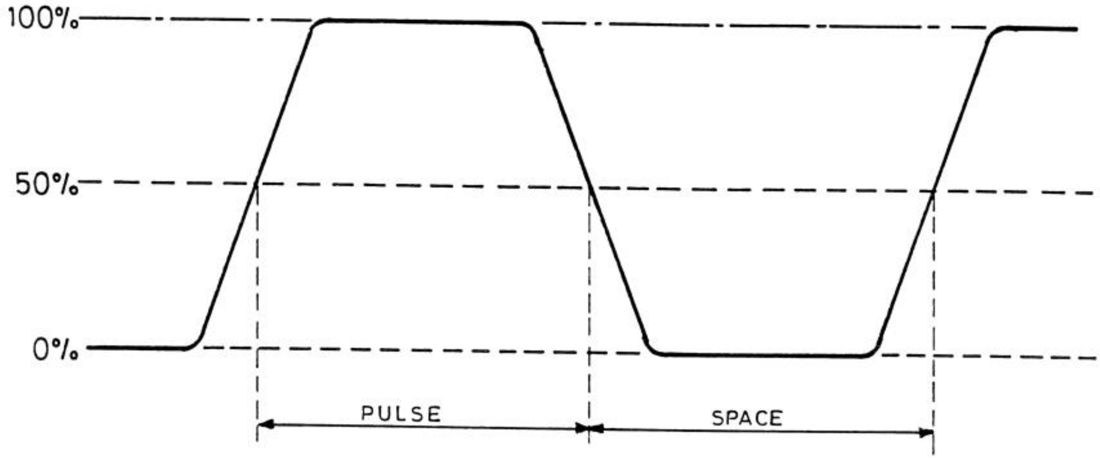
4. TO MEASURE PULSE WIDTH & MARK/SPACE RATIO

4.1 Obtain the largest picture of one pulse on the screen, and adjust the picture so that it lies between the 0% and 100% lines.



4.2 Now do NOT touch the VAR SENS or VOLTS/CM controls. Ensure that the VAR SWEEP is set to the CAL position.

4.3 To calculate the pulse width, measure the width of the pulse in cm along the scope centre (50%) line, and multiply by the scope TIME/CM setting.

Pulse width in cm = X = 2·5

Time/cm setting = S = ·5 ms

PULSE WIDTH = X x S = 1·25ms

4.4 To measure the mark/space ratio, first adjust the timebase to give between 1 and 2 pulses on the screen. Do NOT adjust the VAR SENS or VOLTS/CM controls - the pulses should still lie on the 0% and 100% lines. Now measure the width of one pulse (mark) and the distance between two pulses (space). Both measurements should be made in cm along the scope centre (50%) line.

4.5 Mark = 1·25 ms 2·5

Space = 2·75 ms 5·5

Mark/Space Ratio = $\frac{M}{S}$ = $\frac{5}{11}$ 0·45̇

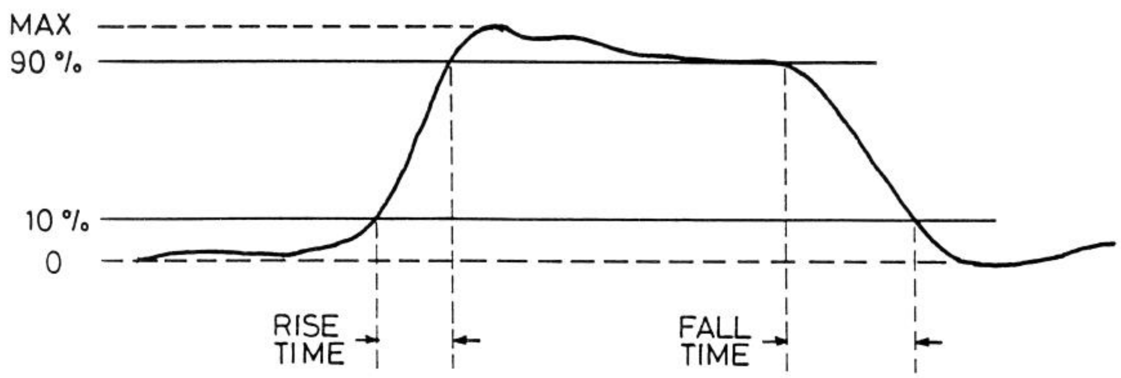
5. RISE & FALL TIMES

We use rise and fall times to define how long the pulse takes to turn on and off, its "switching time". For a perfect pulse, both rise and fall times would be zero.

Ideally, the rise and fall times would be defined as the times between minimum and maximum voltages. However, these two points are often difficult to determine accurately, and can be misleading, so we adopt a compromise:-

RISE TIME is the time (in seconds) taken for the voltage to rise from 10% to 90% of the maximum voltage of the pulse.

FALL TIME is the time taken for the voltage to fall from 90% of maximum voltage to 10% of maximum voltage.



Note that a pulse can have a rise time different to its fall time.

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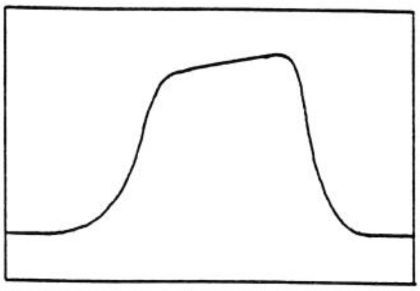
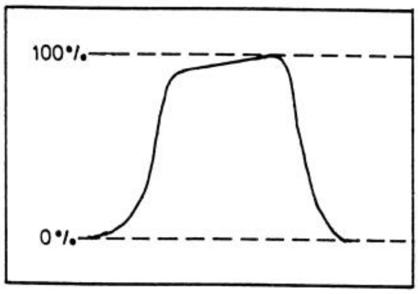
6. TO MEASURE RISE TIME

6.1 Obtain the largest picture of one pulse on the screen without losing any :

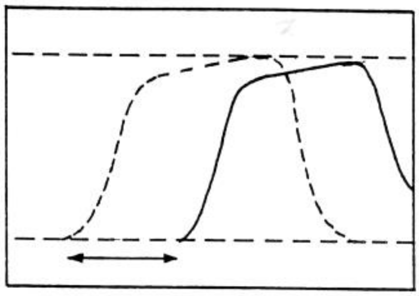


6.2 Adjust the ⬍ Y SHIFT, VAR SENS and VOLTS/CM controls to position the trace with its top on the dotted 100% line, and its bottom on the 0% line :



6.3 NOW DO NOT TOUCH VAR SENS OR VOLTS/CM

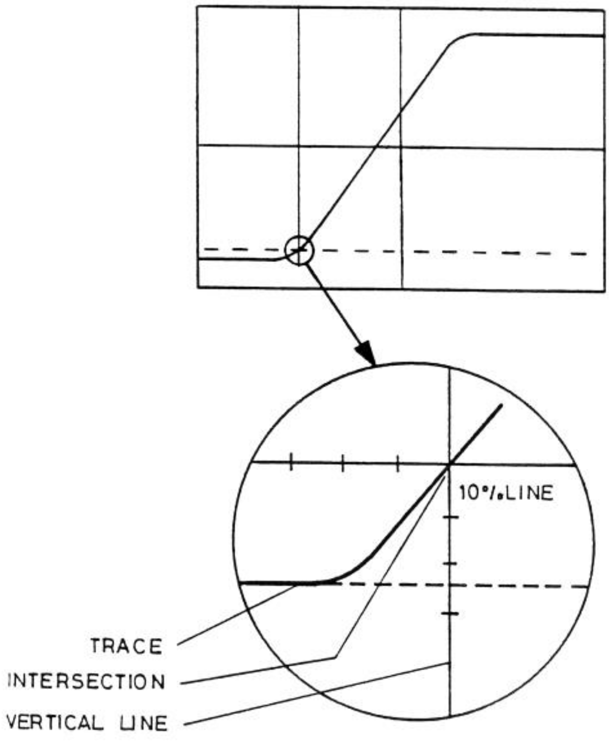
You may use ◄► X SHIFT to position the trace on any chosen vertical line as opposite :



6.4 Ensure VAR SWEEP is on "CAL".

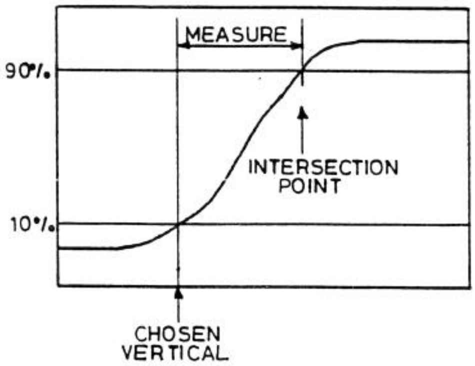
6.5 Adjust timebase or select x10 timebase to expand the rise of the pulse - you do not need the rest of the pulse. See opposite :

6.6 Adjust ◄► X SHIFT to align the trace 10% point with a vertical line on the left of the screen. See exploded view opposite :



6.7 Measure along the <u>90%</u> line from the chosen vertical to where the trace intersects :

This measurement represents the rise time.



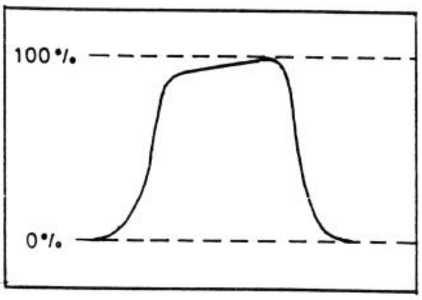
6.8 To calculate the rise time multiply this measurement by the setting of the timebase.

(Divide by 10 if you have used the x10 button)

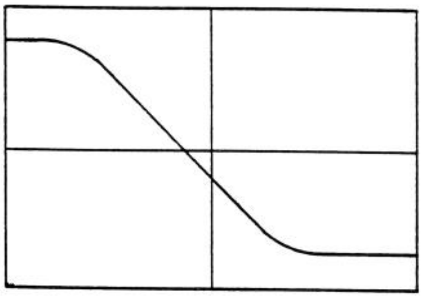
$3 \cdot 5 \times 2ms = \frac{7ms}{10} = 0 \cdot 7ms$

7. TO MEASURE FALL TIME

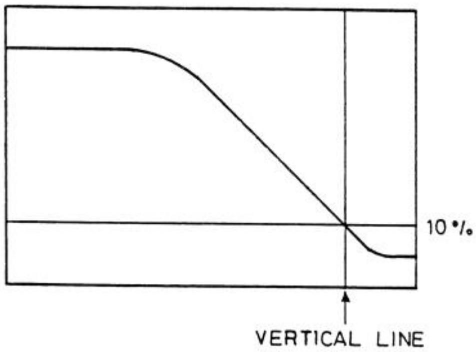
7.1 **The procedure for measuring fall time is similar to that for measuring rise time. First set up the scope as explained in 6.1 to 6.4.**



7.2 Adjust timebase, this time to expand the fall time of the pulse :

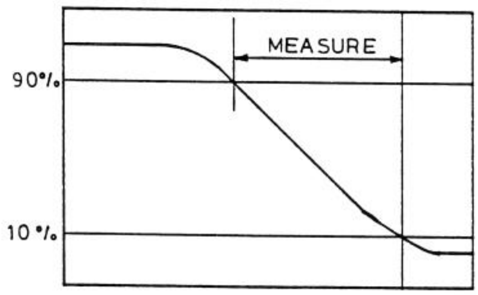


7.3 Adjust ◄► X SHIFT to align the trace 10% point with a vertical line on the right hand side of the screen :



7.4 Measure along the 90% line from the chosen vertical to where the trace intersects :

This represents the fall time.



7.5 Calculate fall time by multiplying by the timebase setting.

(Divide by 10 if you have used the x10 button)

4 x 2 = 8/10 0.8ms

TERMINAL	AMPLITUDE	PERIOD or P.R.P.	FREQUENCY or P.R.R.	D.C. OFFSET	DIGITAL SIGNALS PULSE WIDTH	M/S RATIO	RISE TIME	FALL TIME
A	1·75V	5 ms	200Hz	-8V				
E	3.5V	2 ms	500Hz	2V	1·04 ms	1/1	·2 µs	·2 µs
G	1·2V	·45 ms	2·2KHz	8V				
K	3·2V	4 ms	250Hz	1V	·5 ms	3/1·5	·7x5 ms	·7x5 ms
J	3·5V	2·1 ms	475Hz	-1·65V	1·34 ms	2·6/1·8 1·44	·3 ms	·2 ms
A	·6V	1 ms	1KHz	9V				
E	2V	1 ms	1KHz	2V	·5 ms	1/1	·4 ms	·4 ms
G	4·5V	16 ms	62·5Hz	7V				
J	2·5V	365 µs	2·74KHz	-1·75V	175 µs	3·8/3·5	65 µs	45 µs
K	3·25V	4 ms	250 Hz	-2V	1·85 ms	[illegible]	·3 ms	·2 ms
E	2·6V	2 ms	500Hz	+·5V	·6 ms	4·6	375 µs	800 µs
A	1·3V	·4 ms	400Hz	-6V	·2 ms	1	35 µs	35 µs

TERMINAL	AMPLITUDE	PERIOD or P.R.P.	FREQUENCY or P.R.R.	D.C. OFFSET	DIGITAL SIGNALS			
					PULSE WIDTH	M/S RATIO	RISE TIME	FALL TIME
J	2·85	2·2 mS	455 Hz	-1·25	1·3 mS	1·44	100 µS	50 µS
K	3	375 µS	2·6 KHz	-1·75	175 µS	[illegible]	45 µS	30 µS
E	3	2 mS	500 Hz	+1·2	800 µS	·32	550 µS	700 µS
A	4	108 µS	9·26 KHz	0	52 µS	·93	24 µS	24 µS
G	5	33 mS	30·3 Hz	0				
J	1·8	8 mS	125 Hz	-1·1	4 mS	1	·6 mS	·3 mS

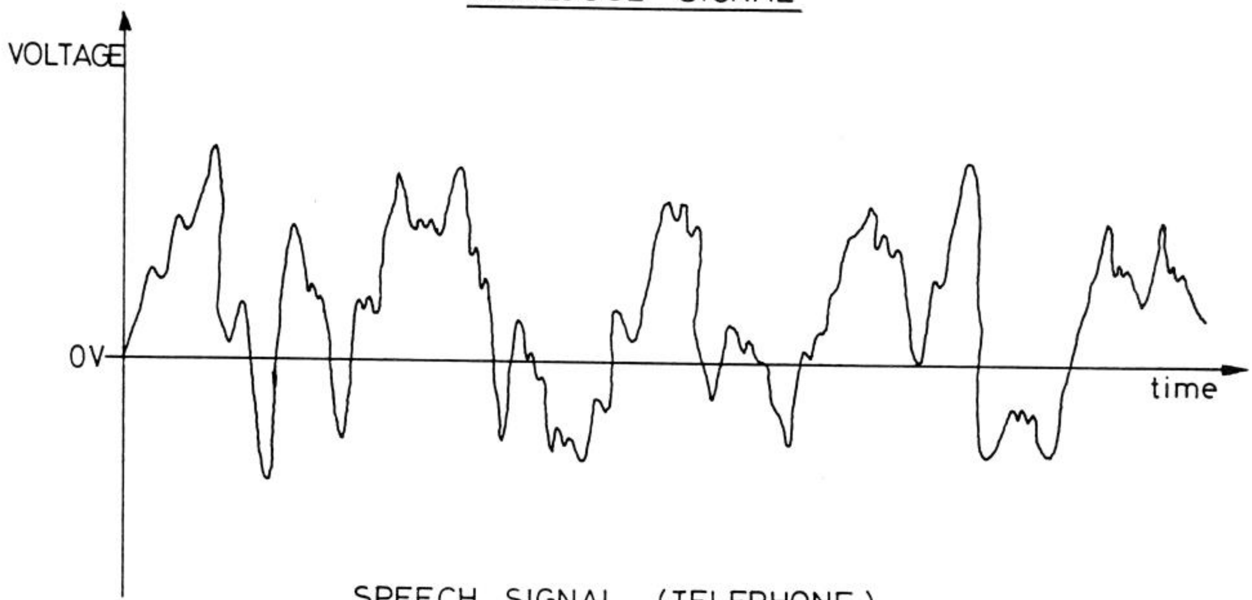
SECTION 4

TRANSMISSION SYSTEMS

1. ANALOGUE SIGNALS

1.1 An analogue signal comprises a continuously changing voltage (or frequency) which can take any value within a given range. Examples of analogue signals are the simple telephone circuit, or a base-band CCTV link.

ANALOGUE SIGNAL

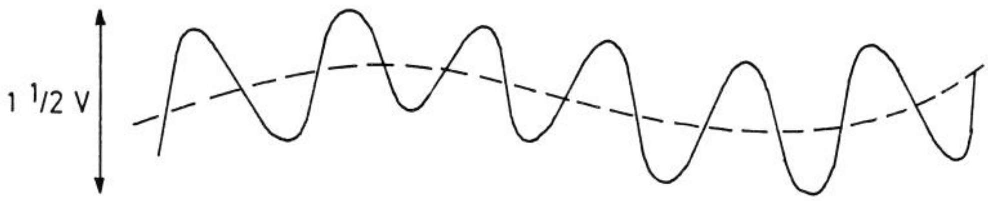


SPEECH SIGNAL (TELEPHONE)

All electronic signals are subject to noise, or interference. Low frequency interference (HUM) usually comes from the mains power supply. Higher frequency interference (CROSSTALK) is caused by signals induced from adjacent circuits or equipment. Random spikes may be generated by power surges, electrical ignition, relay circuits, etc. All these mix together with the original signal. Because analogue signals can take any value, the receiver often cannot distinguish between interference and the original signal.

1.2 When measuring an analogue signal, we often need to measure not only the signal but also the interference. The analogue signal can be regarded as having two components:-

These combine to give a waveform which looks like this:-



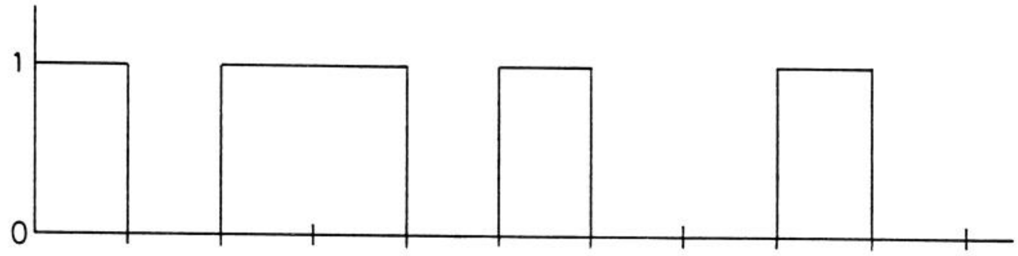
You must try to estimate the real signal and interference amplitudes by examination of the waveform.

1.3 You will find two examples of simple analogue signals on terminals A/B and K. Try measuring them:-

		A – B	K
SIGNAL	amplitude	5v 5.5v	1v
	frequency	165Hz 833.3Hz	30 KHz
INTERFERENCE	amplitude	1.5v 1.6 v	1.3v
	frequency	1.6KHz 50Hz	1K
TYPE OF INTERFERENCE	(hum/crosstalk)	Mains hum	Crosstalk

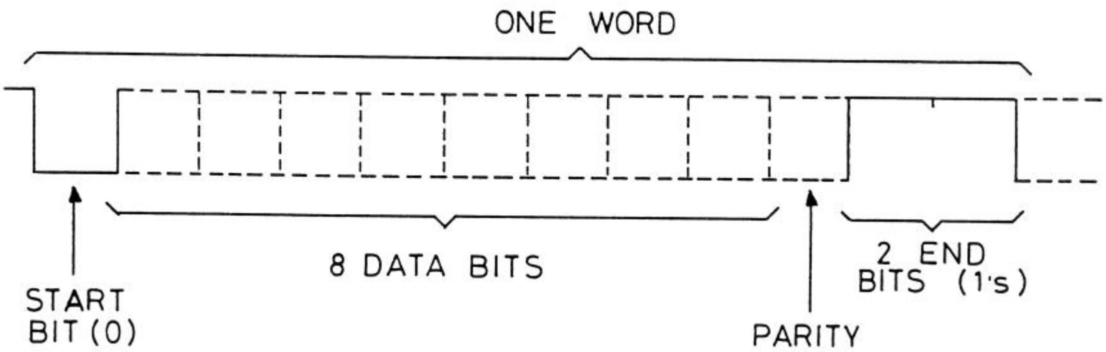
2. DIGITAL SIGNALS

2.1 A digital signal consists of only two voltage levels, or "states" : it is either on or off. These two states are commonly referred to as 0 (off, or 0 volts), and 1 (on). A simple example of digital transmission is the relay line-circuit, the relay is either "up" or "down". More complex systems encode the information to be transmitted as a series of pulses, or "bits", each of which is either a 0 or 1.

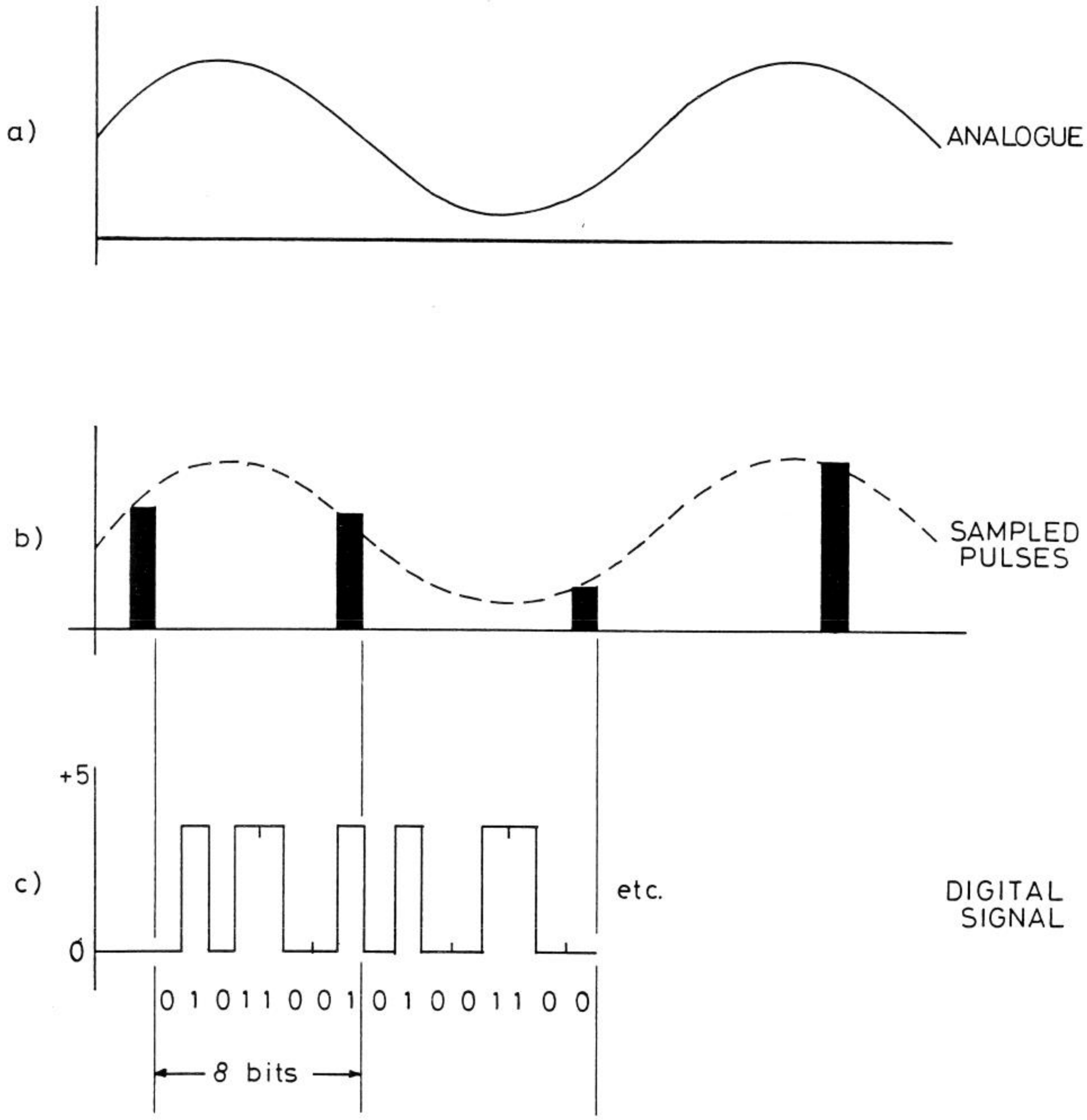


The advantage of digital signals is that, because they can only be either on or off, it is easy to filter out and ignore any interference. In addition, it is possible to add extra check (or "PARITY") bits to allow the receiver to verify that the data has not been corrupted by noise.

In practice, the digital bits to be transmitted are grouped into WORDS. Typically, each word has one start bit added to the front, and a parity bit and two stop bits added to the end.



2.2 It is possible to "digitise" an analogue signal, in order to transmit it digitally. The analogue signal is measured at regular intervals, and the voltage reading is transmitted as a binary number, represented by a series of digital pulses. At the receiver, the reverse process is carried out to reproduce the analogue signal from the series of voltage readings received.



2.3 Measuring Digital Signals

a) You will find an example of a digital signal on terminal J.

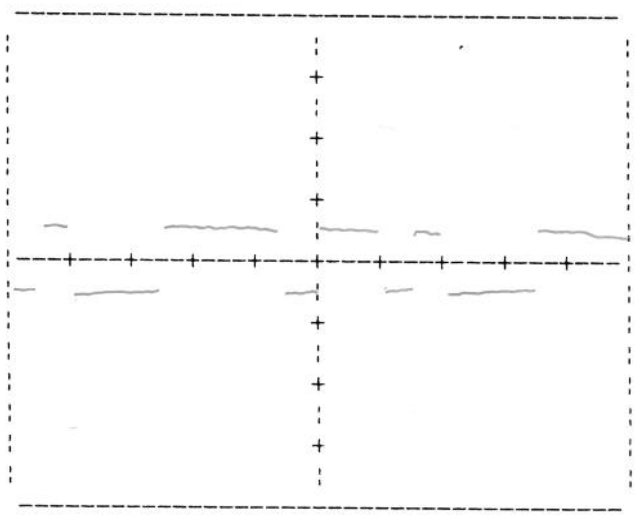
A digital signal is not a periodic signal : it does not consist of a regular pattern. We need some way of ensuring that the scope always triggers at the start of the digital word.

The signal on E-F is called a TRIGGER or SYNCH signal. It operates at the start of each digital word. By triggering the scope from this signal, we obtain a steady picture of our wanted digital signal.

Connect the TRIGGER signal to the scope "EXT TRIG" input, and set the scope to :

EXT trigger (both buttons 2 and 3 IN)
-ve trigger (button 6 IN)
AC/GND/DC to DC
10 ms/cm timebase.

b) Connect the signal on terminal J to the scope channel 1 input.
Sketch what you see :



c) Now examine the digital signal. You should be able to identify the start bit (a "0") and the two stop bits ("1"'s).

What voltage is a "0"? ....0....... volts.

What voltage is a "1"? ...+5....... volts.

And is the signal AC or DC? ~~AC~~ / ~~DC~~ pulsed DC

Now that you know what voltage represents a "1" and what voltage a "0", what data is being transmitted?
(don't include the start, stop or parity bits).

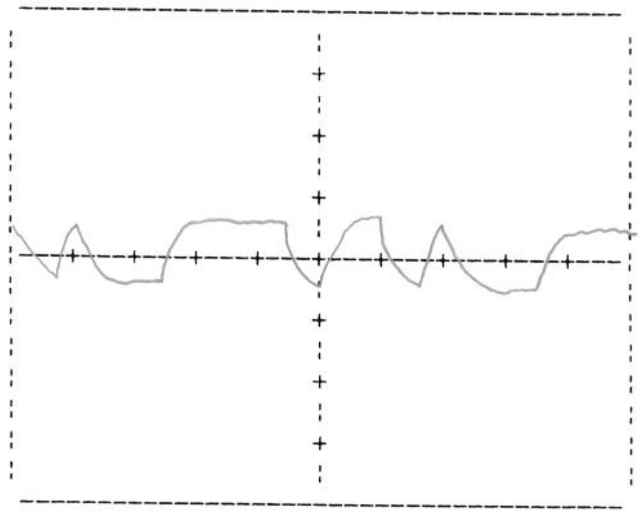
1 0 0 0 1 1 1 1

d) The frequency at which the digital signal is transmitted, in bits per second, is called the BAUD rate.

Measure the bit or pulse width : ....5ms..........secs.

Calculate the bits per second : .....200..........baud.

d) Now connect the signal on terminal K to CH2. This is what happens to the digital signal if it is passed down a long cable.
Sketch what you see:-

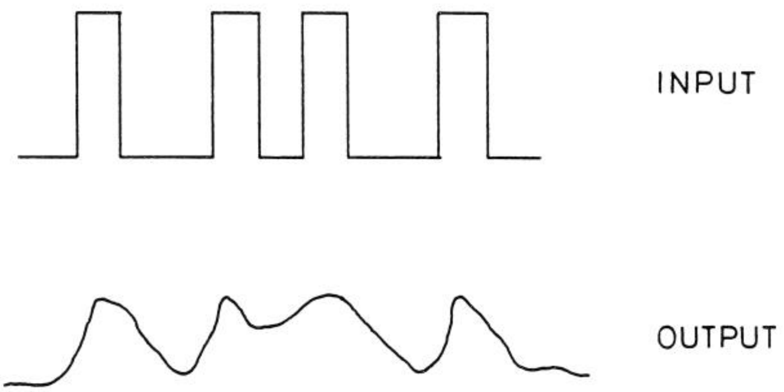


What has happened to the digital signal?

the signal has been attenuated

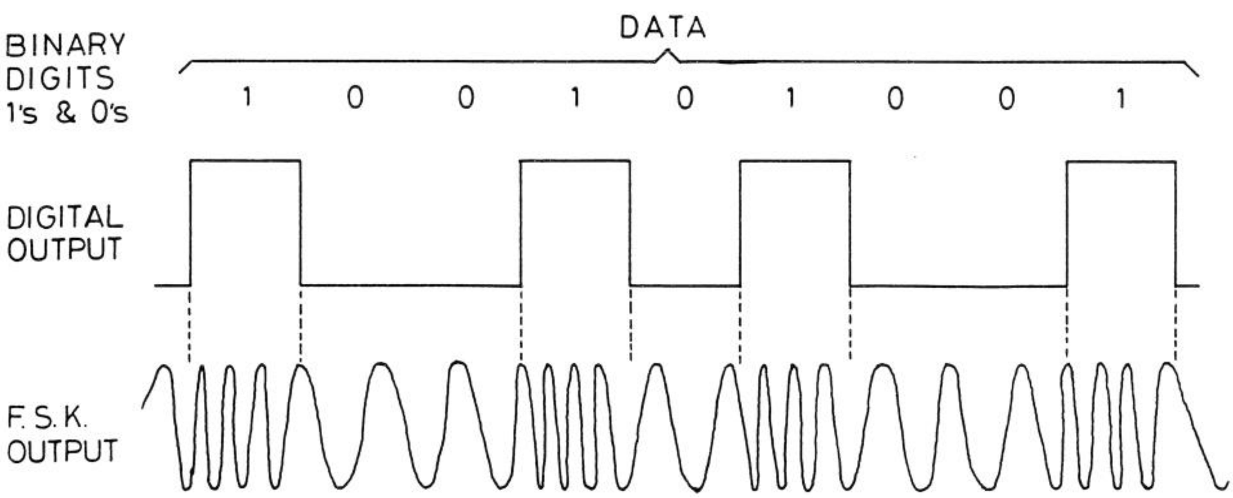
3. FREQUENCY SHIFT KEYING

Unfortunately it is not easy to transmit pulses over long distances, because of a phenomenon known as DISPERSION. The cable or transmission line has capacitance and inductance, so behaves like a filter. It both attenuates (reduces) the pulses, and rounds them off, as shown:-



The effects of dispersion get worse the faster we transmit the pulses. In low pulse-rate systems such as relay circuits, dispersion effects are minimal; but in higher frequency circuits such as T.D.M. links, dispersion is a very real problem.

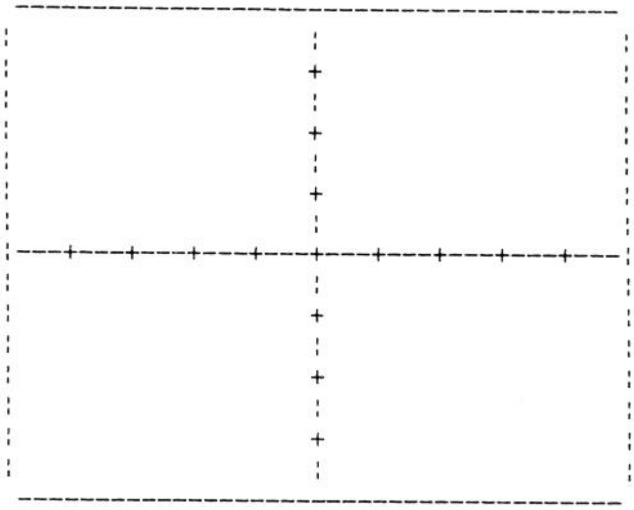
To overcome the effects of dispersion, we use a technique known as Frequency Shift Keying (F.S.K.). Instead of transmitting pulses, we transmit pure sine-waves - one frequency for 0 and another frequency for 1. Provided we choose frequencies that are not affected by the cable's filter effect, then the signal will not be affected by dispersion. Also, because we are only transmitting two pure frequencies, it is easy for the receiver to reject any interference. Normally, we use two frequencies that lie within voice range, so that the signal can be transmitted over standard telephone circuits.



The device that converts pulses to F.S.K. and back is called a "MODEM".

a) Connect the scope CH1 to the signal on terminals C-D. This is what a digital signal looks like after it has been Frequency Shift Keyed.

Disconnect the other inputs (CH2 and EXT TRIG), and set the timebase to 0.2 ms/cm. Sketch what you see:-



Can you tell what data is being transmitted?

You can see 2 sine-waves, one of which represents "0" and the other "1". When the instructor sets the digital word to all "1"'s you will see that one sine-wave gets brighter as it occurs more often. Measure its frequency, and also that of the other sine-wave which represents "0".

"1" frequency = ..1923...... Hz

"0" frequency = ..1755...... Hz

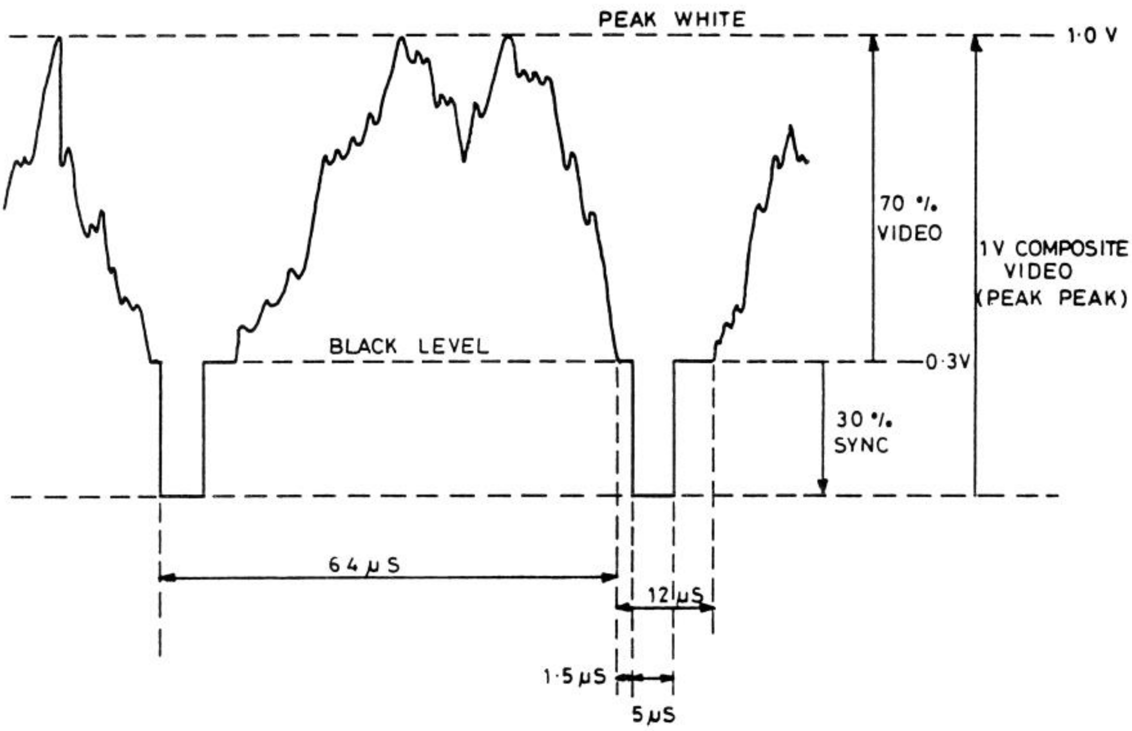
4. EXAMPLES OF TRANSMISSION SYSTEMS

4.1 Analogue

a) Telephone : the amplitude of the voltage on the line represents the loudness of the sound at the transmitter.

b) Radio : in this case the sound at the transmitter varies the amplitude (A.M.) or frequency (F.M.) of the radio waves.

c) CCTV : the amplitude of the signal represents the light intensity as the beam moves over the screen.



CCTV COMPOSITE VIDEO SIGNAL

4.2 Digital

a) Relay Interlocking : voltage on the line causes a relay to energise, making its front contacts and breaking its back contacts; whereas with no voltage on the line the relay is de-energised. The relay is either up or down, its contacts either made or broken.

b) Computers : information is stored and processed within a computer in digital form, as groups of bits. The groups of bits can be used to represent numbers or characters.

c) Ring Train Describer : this consists of a number of computers connected together in a ring. Train description and other data is passed from one computer to the next as a stream of 5v pulses.

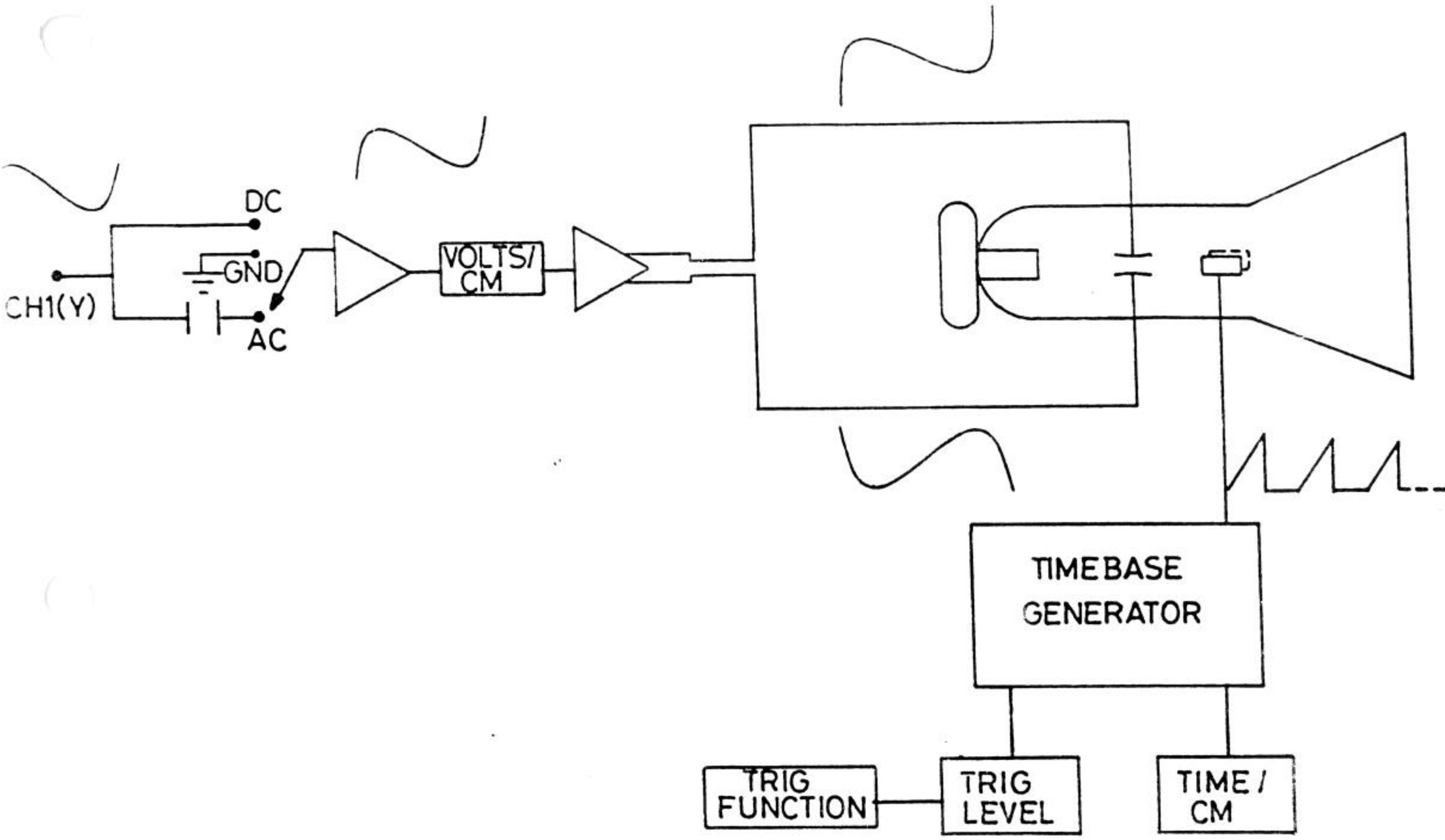
d) Computer peripherals (eg printers, VDU's) : information to be displayed on VDU's or printers is usually sent in groups of digital pulses, each group representing one character.

4.3 Composite

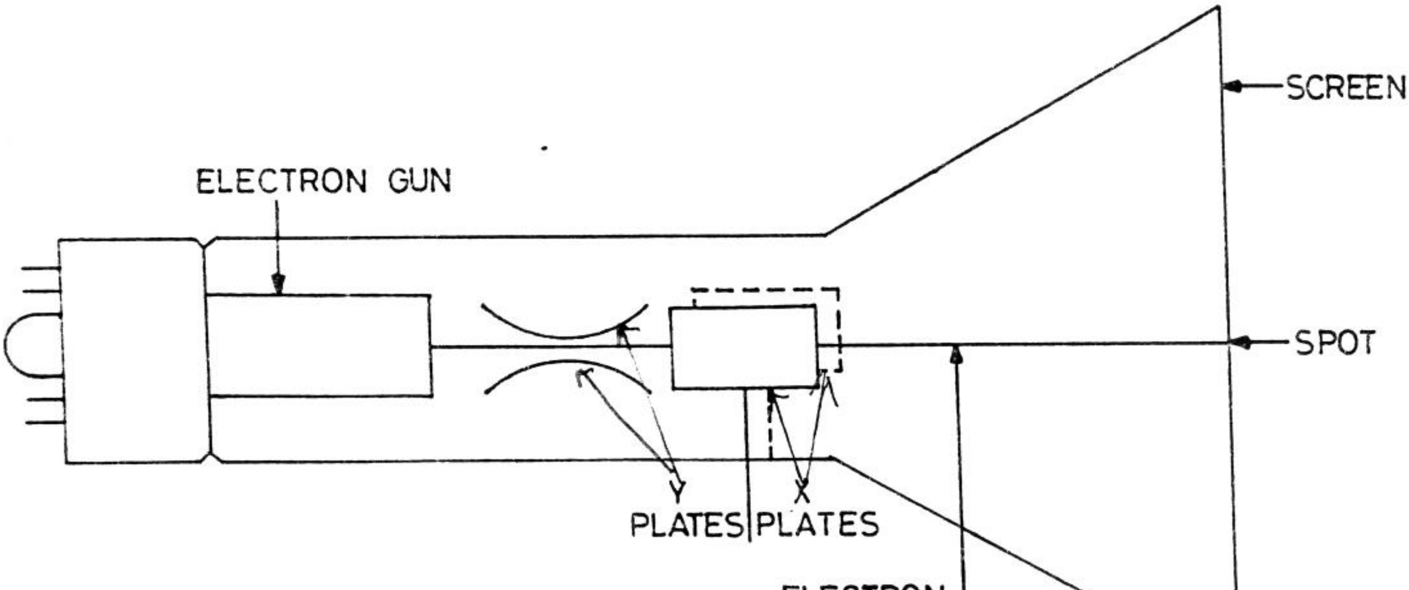
a) T.D.M. Remote Control : this transmits digital data, but the signal is converted by Frequency Shift Keying (F.S.K.) to a stream of frequency variations rather than a stream of pulses.

b) P.C.M. (Pulse Code Modulation) : This is a method of carrying many telephone circuits down one pair of wires. Each circuit is first digitised, and then the data for all the circuits is sent down the one pair of wires as a stream of digital pulses.

c) Computer Transmission : for transmission over long distances, computer data has to be frequency-shift keyed. The device which converts the digital pulses to frequency variations is called a modulator, a demodulator carries out the reverse process: the term MODEM (Modulator/DEModulator) is commonly used to describe both.



THE CATHODE RAY OSCILLOSCOPE



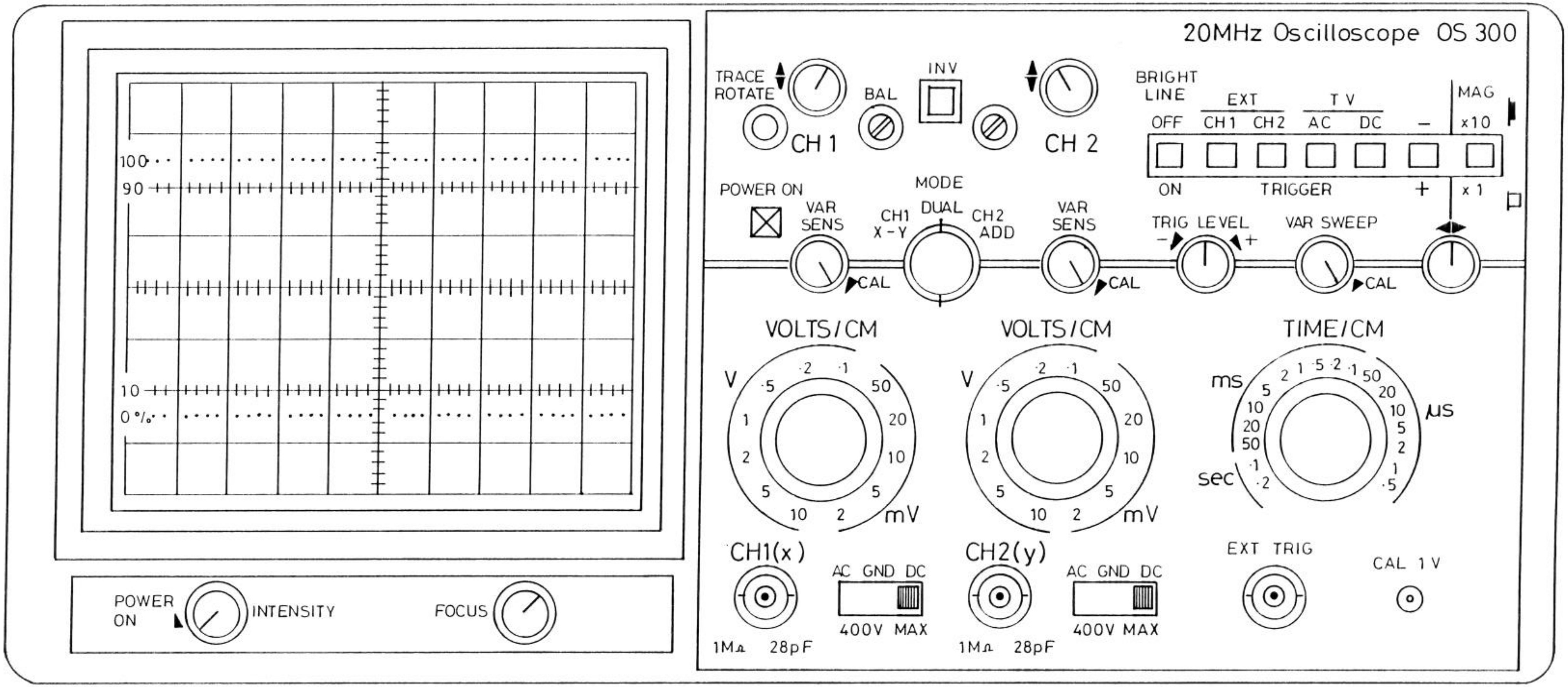
THE CATHODE RAY TUBE

APPENDIX

GLOSSARY OF CONTROLS - GOULD OS300 SCOPE

CONTROL	USE
POWER ON/INTENSITY	To switch on mains power and adjust brightness of trace.
FOCUS	To obtain a sharp, thin-line trace.
VOLTS/CM (CH1)	Channel 1 Y sensitivity control. Controls the amount of vertical spot movement for a given input signal to channel 1.
VOLTS/CM (CH2)	Ditto above for channel 2.
VAR SENS (CH1 & CH2)	Variable Y sensitivity control. Continuous adjustment of Y sensitivity between click positions of VOLTS/CM control. Normally left in position "CAL" which means that the Y sensitivity is as marked on VOLTS/CM. One control for each channel.
Y SHIFT (⬍)	Shifts the trace up and down the screen. Used for centering trace.
MODE	Selects various single or dual trace modes of operation. Normally in CH1, CH2, or DUAL mode.
INV.	Inverts signal from CH2 only.
A.C./Gnd/D.C.	Input selector - one for each input channel. A.C. - capacitor connected - A.C. signals between 4Hz and 20MHz accepted. D.C. - no capacitor - DC to 20MHz accepted. Gnd - input disconnected.
TIME/CM	Timebase control. (X deflection) controls rate of movement of spot from left to right across the screen.
VAR SWEEP	Variable X deflection. Continuous adjustment of the above. Normally left in position "CAL" which means that the deflection rate is as marked on TIME/CM control.
X SHIFT (◄►)	Shifts both CH1 and CH2 traces left and right on the screen. Used for centering.

CONTROL	USE
TRIG LEVEL	Selects the point on the input signal at which the scope trace should start. Should be adjusted to give a steady trace with no multiple images or flicker.
7 SQUARE PUSH BUTTONS	Button 1 : (left) OUT - Bright line ON - scope gives a trace even with no signal input (Normal Setting) IN - Screen blank with no input.
	Button 2 : IN - Triggers from CH1 Button 3 : IN - Triggers from CH2 Both 2 & 3 : IN - External trigger
	Button 4 : IN - A.C. triggering Button 5 : IN - D.C. triggering Both 4 & 5 : IN - T.V. sync separator
	Button 6 : IN - negative edge triggered OUT - positive edge triggered
	Button 7 : (right) IN - timebase rate increased by 10 (divide TIME/CM results by 10) OUT - normal



DISPLAY CONTROLS | CH1 AMPLIFIER | CH2 AMPLIFIER | TIMEBASE/TRIGGER CONTROLS

UNITS REVISION SHEET

Fill in the blanks.

Quantity	1/1,000,000s	1/1000s	BASE UNIT	1000s	1,000,000
Voltage	microvolt(μV)	millivolt(mV)	Volt(V)	kilovolt(kV)	Megavolt(MV)
Current					
Resistance					
Time				XXXXXX	XXXXXX
Frequency	XXXXXX	XXXXXX			

$$\text{Frequency (Hz)} = \frac{1}{\text{Period (s)}} = \frac{1000}{\text{Period(ms)}} = \frac{1,000,000}{\text{Period (us)}}$$

$$\text{Frequency (kHz)} = \frac{1}{\text{Period(ms)}} \qquad \text{Frequency (MHz)} = \frac{1}{\text{Period}(\mu s)}$$

Calculate the frequency of signals with the following periods :-

1) 10 ms
2) 100 ms
3) 50 μs
4) 0.001 s
5) 0.0006 s
6) 30 μs
7) 0.000002 s
8) 5.2 ms
9) 0.33 s
10) 1/1,000,000 s

SECTION 5

SELECTION OF TEST INSTRUMENTS

1. INTRODUCTION

When you take a measurement on an electronic circuit, you must choose the most appropriate type of measuring instrument. You have already used a Model 8 AVO and an oscilloscope. This section will look at the advantages and disadvantages of these instruments together with a digital multimeter and a lineman's meter.

2. METER SENSITIVITY

Sometimes we need to know the resistance of the meter we are using. This depends on the scale we are using, and the sensitivity of the meter on that scale. Sensitivity is measured in Ohms/Volt.

Meter Resistance = Sensitivity x Full Scale Voltage

For the model 8 AVO the sensitivities are:-

DC Ranges	-	20kΩ/V
AC Ranges	-	100Ω/V on 3V range
	-	1kΩ /V on 10v range
	-	2kΩ /V on 30V range and above

We will need to know the meter resistance on certain DC ranges later. Fill in the values below:

D.C. SCALES

Scale	3V dc	10V dc	30V dc	100V dc
Meter Resistance	60KΩ	200KΩ	600KΩ	2MΩ

A.C. SCALES

Scale	3V ac	10V ac	30V ac	100V ac
Meter Resistance	300Ω	10KΩ	60KΩ	200KΩ

3. INPUT IMPEDANCE OF MEASURING INSTRUMENTS

3.1 Meters

As we have seen, the resistance of a model 8 AVO depends on the scale in use. This also applies to the lineman's meter, but as it is much less sensitive, its resistance is also lower.

3.2 Model 8 AVO

Scale	3V	10V	30V	100V
Resistance: d.c. scales	60kΩ	200kΩ	600kΩ	2MΩ
Resistance: a.c. scales	300Ω	10kΩ	60kΩ	200kΩ

3.3 Linemans AVO

Sensitivity: d.c. ranges 1000Ω/V
a.c. ranges ...... 3V range 40Ω/V
15V range 100Ω/V
150V, 750V ranges 500Ω/V

Scale	1.5V	3V	15V	75V	150V
Resistance: d.c. scales	1.5kΩ	3kΩ	15kΩ	75kΩ	150kΩ
Resistance: a.c. scales	-	120Ω	1.5kΩ	-	75kΩ

3.4 Digital Multimeter

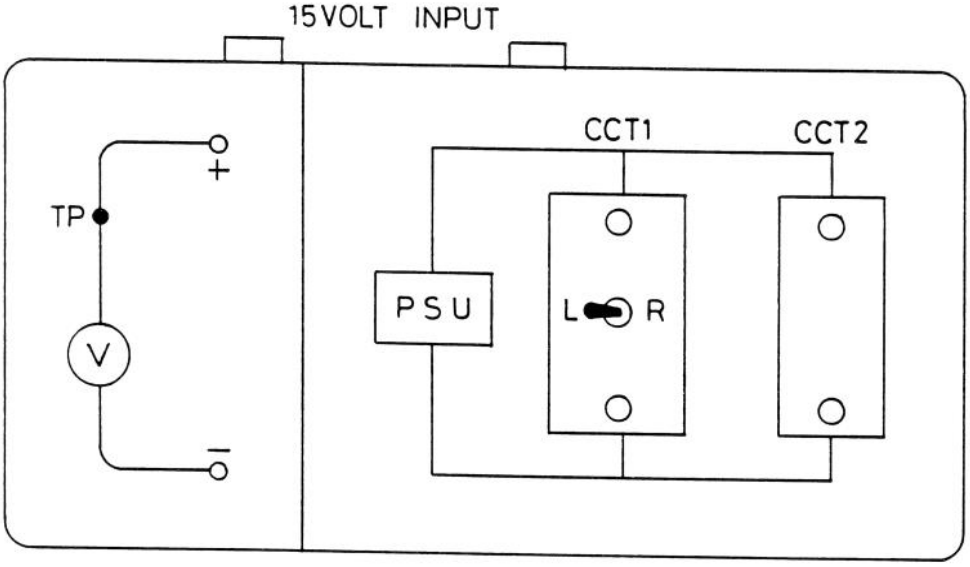
This has an input resistance of 10MΩ on all voltage scales.

3.5 Oscilloscopes

The OS300 Oscilloscope has an input resistance of 1MΩ. This does not depend on the range in use. The input impedance of an oscilloscope can be increased by using a high impedance probe.

4. LOADING EFFECT OF MEASURING INSTRUMENTS

4.1 Connect the loading test box to the 15volt supply (Red to +15, black to -15).



Measure the voltage between the + and - terminals on the left of the box using the 30V dc and 100V dc ranges of the AVO 8. (Both readings will be less than 30V).

Meter Reading (100V scale) = 12.5 25.5 V

Meter Reading (30V scale) = 9.75 19.5 V

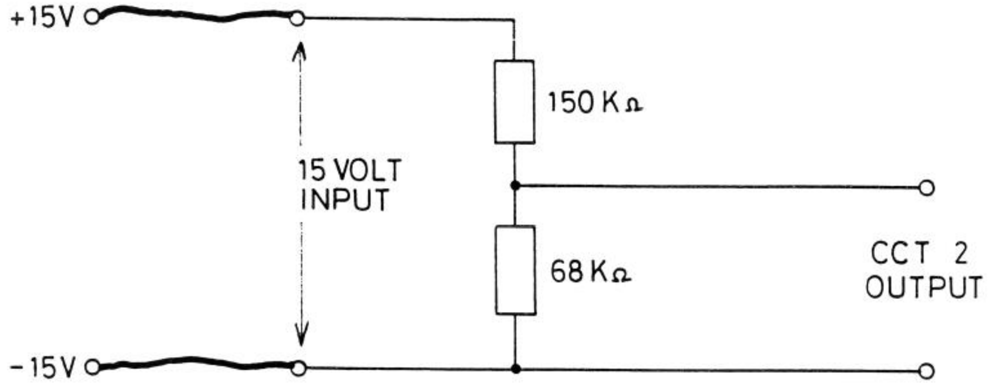
Do you get the same meter reading on both scales? YES / NO

With this circuit, you are able to measure the TRUE voltage by measuring between the - terminal and TP stud. (Use the 100v scale). Remember that this is not possible with a real circuit!

Correct Reading = 14.5 V 29.5

4.2 We have seen that when we used the meter above, we did not get an accurate voltage reading - we even obtained different values using different meter scales!

4.3 Connect the loading test box to the 15v supply as before, and measure the voltage at the terminals of circuit 2 using the instruments listed.



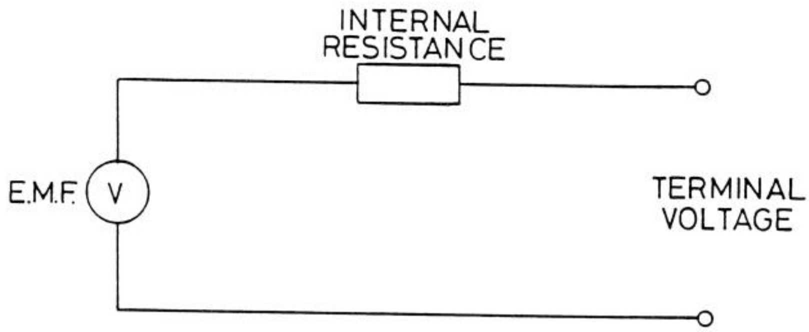
Instrument	Input Impedance	Voltage Reading
Scope	1MΩ	9.2
Scope (x10 probe)	10MΩ	.9 x 10 = 9v
AVO 8 (30v d.c.)	600kΩ	8.5
AVO 8 (10v d.c.)	200kΩ	7.4
D.M.M.	10MΩ	9.08
Linemans AVO (15v d.c.)	15kΩ	~~[illegible]~~ 2.2v

Which measuring instruments give the most accurate reading?

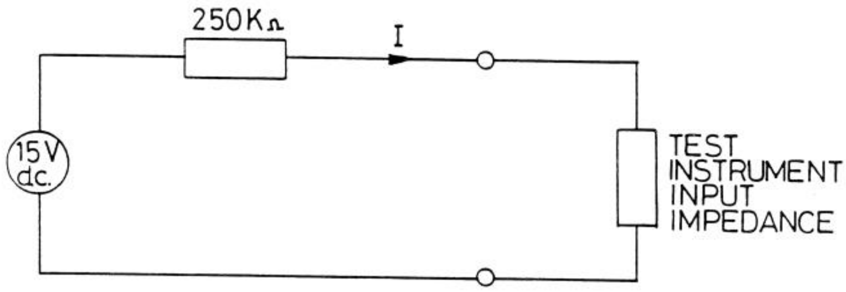
Scope & DMM

4.4 Representation of a Voltage Source

Any source of voltage can be thought of as a voltage (or E.M.F.) in series with a resistor. This resistor is usually called an internal resistance.



As long as no current is drawn through the internal resistance, the terminal voltage is the same as the E.M.F. In order to measure the E.M.F., we connect a meter across the terminals. Unfortunately the current that flows through the meter reduces the terminal voltage and gives us an incorrect reading.



For example, if we measure the 15V supply above using an AVO, the voltage is shared between the internal resistance and the meter input resistance. The same applies to any measuring instrument.

The instruments with the higher input impedance give a more accurate reading because the loading on the circuit is less.

4.5 Connect the loading test box to the 15V supply as before.

Put the switch in circuit 1 to "L".

Use the AVO-8 on 10V, 30V and 100V d.c. ranges to measure the voltages between the terminals on circuit 1, and then on circuit 2.

Scale	10V d.c.	30V d.c.	100V d.c.
Cct 1	6·4	10·25	13
Cct 2	7·4	8·5	9

Now write down what you think the true voltage (or E.M.F.) should be:

True Voltage	Student (guess)	Instructor
Circuit 1	15	15
Circuit 2	10	9·4

Which scale has loaded the circuit least?
(ie. which scale gave the most accurate reading?)

The ......100v dc.......... scale is most accurate.

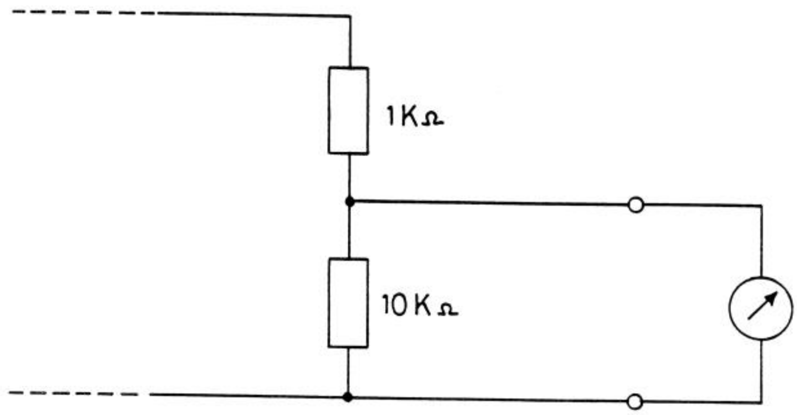
We often have to compromise between the scale that is most accurate, and that which is the easiest to read.

4.6 Provided that the input impedance of the instrument is at least 10 times greater than the circuit impedance, the error from loading the circuit will be limited to 10%. For accurate measurements the instrument's impedance should be 100 times the circuit impedance. The error from loading the circuit will then be less than the error from other sources (for instance, calibration error) and may be ignored.

If the internal resistance of the voltage source is low, the loading effect can be ignored.

Note : When you make a measurement on a potential divider, the circuit impedance will never be more than the smaller impedance.

e.g.



Circuit impedance less than 1kΩ

4.7 Now connect the loading test box to the 10v supply instead, and put the switch to "R". Measure the output voltage of circuit 1 using the AVO-8 10v d.c. scale.

What happens to the meter reading after the meter is first connected to the circuit?

Goes up to about 3.8v then drops to 2.2v

The circuit includes a capacitor. When you measure the output voltage, it changes. Why?

capacitor discharges

Now use the scope to measure the output voltage of circuit 1, both when you first connect the scope and when the voltage has had time to settle down.

Initial Reading ....5................v

Final Reading ....4..............v

Note: you should leave the scope disconnected from the circuit for about 10 seconds, if you want to repeat the measurements. (Switching the AC/GND/DC switch to GND has the same effect as disconnecting the input lead).

Which reading do you think is closest to the true voltage before the scope was connected?

~~INITIAL~~ / FINAL

Now disconnect the scope from the circuit for only 2 seconds before repeating the readings:

Initial Reading ....4.5...........v

Final Reading ....4..............v

The final reading is the same as it was before, but the initial readings are not. Why?

the cap hasn't had opportunity to charge to its full potential

Now measure the voltage using the instruments and scales shown below. If you get a reading that changes, enter the reading you think is closest to the true voltage.

Scope ....4............... ✗

Scope (x10 probe) ....4.8.......... ✓

AVO 8 (10v d.c.) ....2.2 <4.. ✗

AVO 8 (30v d.c.) ....3.3 >4.. ✗

D.M.M. ....4.67..... ✓

Indicate which of those instruments are suitable for measuring this voltage with a tick, and those which are not with a cross.

5. FREQUENCY RESPONSE

a) Set the signal generator to 100Hz sine wave, 5v RMS (on internal meter), and measure its output with the AVO 8. Now increase the frequency until the meter reading has dropped by 5%. (Check that the generator's own meter is still reading 5v while you do this).

Record this frequency: ....17.5K Hz

Above this frequency, the AVO 8 is no longer giving an accurate reading.

Repeat with the D.M.M. The D.M.M. is accurate up to ..10..K.. Hz.

b) Now set the signal generator to 10Hz, and measure its output with the AVO 8. Reduce the frequency using the variable control, and note when the AVO needle is flickering too much to allow an accurate reading:

........2........Hz.

Repeat with the D.M.M., and note when the reading becomes too jumpy and erratic to read:

......6.5......Hz.

5.1 AVO 8

At low frequencies the accuracy is limited because of needle flicker : the needle attempts to follow the variation in voltage. At high frequencies internal capacitance and inductance of the meter begin to affect the readings.

As long as the frequency is between 15Hz and 15kHz, the indicated value is within 3% of the "true" value. (For sinewaves only).

5.2 Digital Multimeter

At low frequencies, the reading becomes erratic and jumpy, again the same effect as needle flicker. The upper frequency limit is also very poor, typically a few kHz.

5.3 Oscilloscope

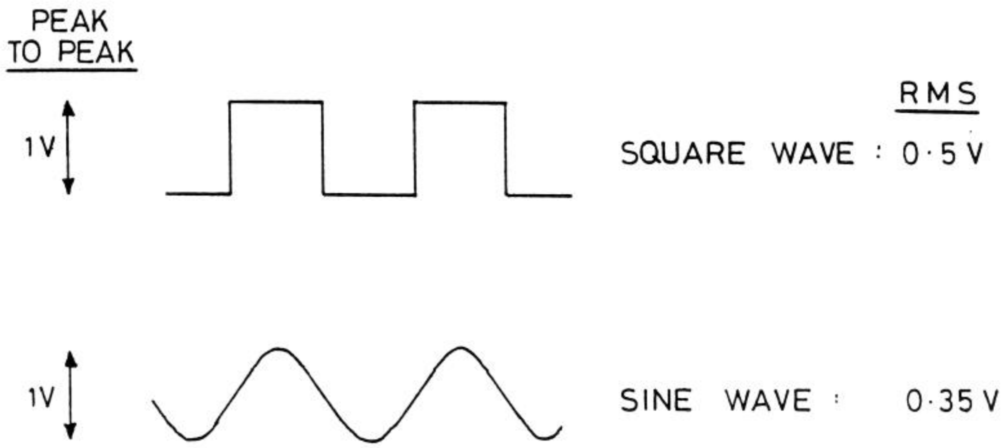
At low frequencies, following the trace on the screen can be a problem - the same effect as needle flicker. At high frequencies the accuracy is limited by the frequency response of the input amplifiers.

The bandwidth of the OS300 is approximately D.C. to 20MHz.

6. RESPONSE TO WAVEFORM SHAPE

As we have seen, the amplitude of an A.C. signal can be measured in a number of ways: peak value, peak to peak, or RMS. Of these, the RMS value is the most useful as it represents the equivalent DC voltage. The RMS voltage of an A.C. waveform equals the D.C. voltage that would give the same heating power in a resistor, for example.

The amount of power developed in a resistor will depend on the waveform of the voltage across it. So the RMS voltage of a waveform will depend on the shape of that waveform, as well as the peak voltage. For example:-

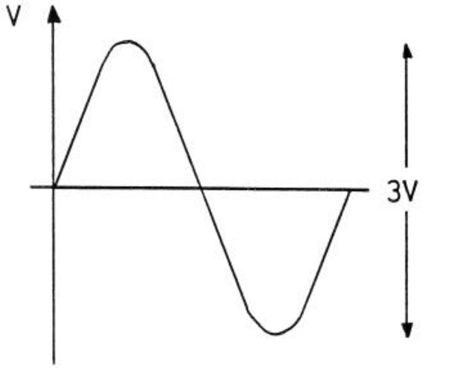


6.1 Oscilloscope

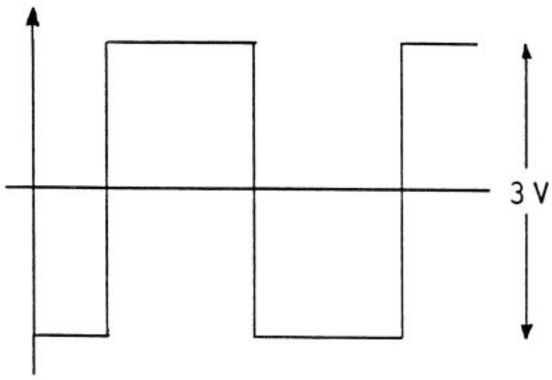
The oscillscope displays the waveshape directly. It is easiest to read the peak to peak value of the amplitude. This then needs to be converted to RMS by multiplying by a conversion factor. This conversion factor is different for each different wave shape. For the two most common wave shapes they are:-

Sine wave: RMS = 0.35 x peak to peak

Square wave: RMS = 0.5 x peak to peak



AMPLITUDE = 0·35 x 3V
= 1·05V RMS



AMPLITUDE = 0·5 x 3V
= 1·5V RMS

6.2 Moving Coil Meter (AVO 8, Lineman's Meter)

On a.c. ranges a moving coil meter reads the average full wave rectified value. This average value is not the same as the RMS value, and the difference between them depends on the shape of the waveform. To avoid the need to calculate the RMS value from the average value actually measured by the meter, the AVO 8 and lineman's meter have a correction factor built in. This correction factor applies only to one wave shape - the meter is calibrated for SINE WAVES. If used to measure a square wave, the meter will read high; for triangular waveforms it will read low.

6.3 Digital Multimeter (DMM)

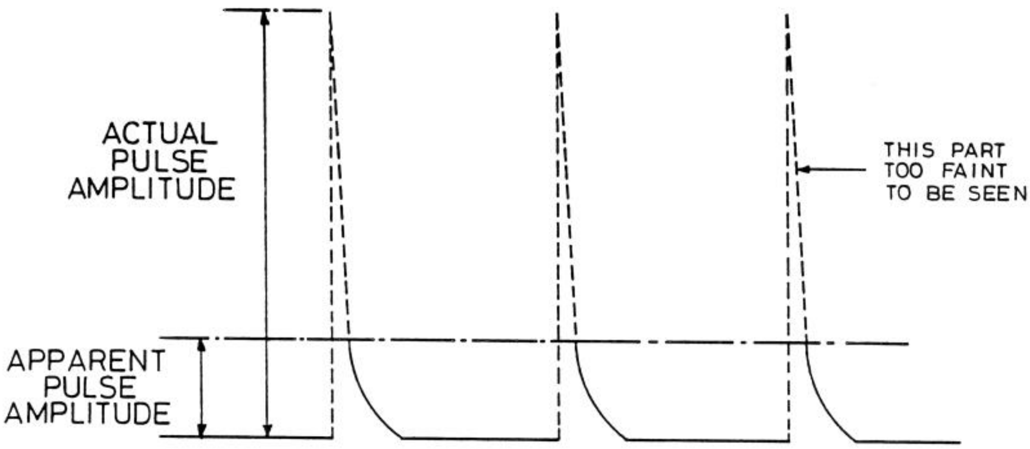
Some DMMs read RMS directly, and may be used on any waveform without any compensation. Other DMMs measure an average rectified value and then internally compensate for sine waves. As with a moving coil meter these are only accurate for use with sine waves.

7. RESPONSE TIME

Some signals are only available for a short time. When measuring such signals you must ensure that the instrument you use will respond to the signal for long enough to allow you to read it before the signal disappears.

7.1 Oscilloscope

When a scope lead is first connected to a circuit, there may be a delay of up to 1 second. Once the scope is connected, further changes will be displayed very quickly. Spikes on a waveform will usually be displayed, but because of the rapid variation of voltage the full size of a spike may not be obvious.



7.2 Moving Coil Meters (AVO 8, Lineman's Meter)

The mechanism of a moving coil meter is damped to prevent wild fluctuations of the pointer and to ensure that it settles down to a steady value fairly quickly. This makes it slow to respond about 1 sec. to reach full scale deflection. Rapid changes such as spikes or ripple on a power supply will be ignored by the meter. Sometimes this is an advantage sometimes it is a disadvantage.

7.3 Digital Multimeter

The DMM takes approximately two samples per second, and averages out the reading during that time. Signals that vary in size will give a misleading reading which will be different each time the meter takes a sample.

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8. SUMMARY

	AVO 8	Oscilloscope	DMM
Input Impedance	depends on range	1MΩ (10MΩ with x10 probe)	Typically 10MΩ
Loading Effect	May be a problem with any instrument More likely with AVO due to low impedance. Input Impedance needs to be 10 times circuit impedance (or 100 times for accurate work)		
Frequency Range	15Hz - 15kHz	DC - 20MHz	depends on meter, and range.
Waveform	Sinewave ONLY (others not accurate)	Displays any waveform (Calculate RMS from wave shape)	Some read RMS directly. Others sinewave only.
Response Time	Slow (1s)	Fast (us)	Slow (0.5s)
Ease of Use	Quick & Portable	Slow. Needs power supply	Quick & Portable. Needs batteries
Accuracy of Reading Scale	Good-but reading may be low due to loading	Poor	Good

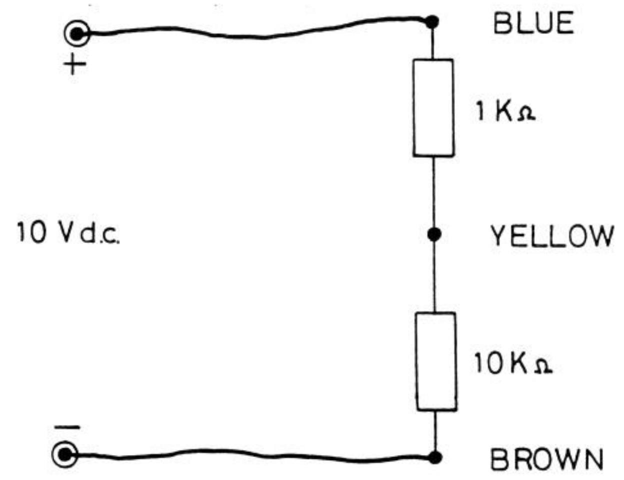
For many readings, the AVO will be the first choice. It is convenient, quick and available. For measuring the values of power supplies it is ideal. For mesuring signal levels on electronic circiuts it is not so well suited as circuit impedances are often high enough for the AVO to adversely affect the circuit. It would then be necessary to use a scope, which is much more versatile when measuring the complex waveforms found in electronic equipment.

x10 Probe
Reduces loading effect of scope by increased impedance. Needs calibration first. For small readings may not be able to increase sensitivity of scope to compensate - means reduced accuracy.

Lineman's AVO
Same as AVO 8 except input impedance is smaller - meter will load the circuit more.

EXAMPLE 1

Connect the 1kΩ/10kΩ resistance box to the 10 volt supply as shown below, and measure the voltage across the 10kΩ resistor using the instruments listed.



Scope ....9·6.......... volts

Scope (x10 probe) ....9·5..........

AVO 8 (30v d.c.) ....9..........

AVO 8 (10v d.c.) ....9..........

D.M.M. ....9·1..........

Why do all the instruments give similar results?

because the circuit is a PD + the measurements were taken accross the highest res.

If you had to decide between using a scope or an AVO 8 to measure this voltage, which would you choose?

DMM for ease of use

EXAMPLE 2

Now connect the 1kΩ/10kΩ resistance box to the signal generator. Set the signal generator to give a 1kHz sine wave signal, at 3.5v RMS on its meter.

Now measure the voltages across the 10kΩ and 1kΩ resistors. Note: for the scope, you will need to calculate the RMS value from the peak-peak value.

	10kΩ	1kΩ
Scope RMS	3·5v	·35v
AVO 8 (30v a.c.)	3	·25
AVO 8 (10v a.c.)	2·7	·2
D.M.M.	3·1	·3

Why has the AVO 8 loaded the circuit in this example, but not in example 1?

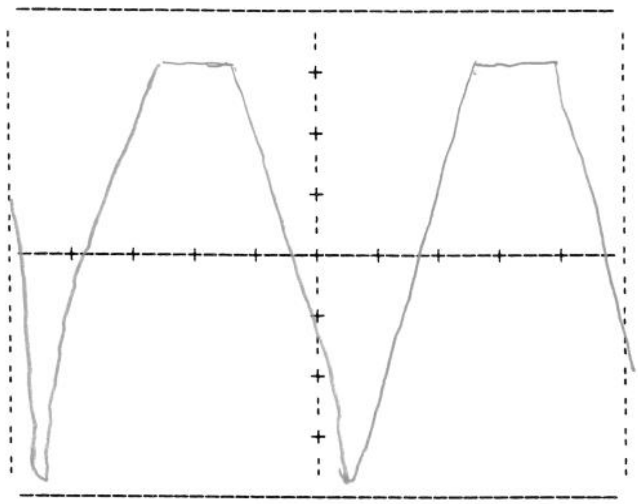
lower ~~Higher~~ resistance on AC settings so loads circuits more

Why is it difficult to measure the voltage across the 1kΩ resistor accurately using the AVO 8?

~~Because of the scale size at the setting~~
the resistance in the meter is nearly the same as the resistances being read across

EXAMPLE 3

Examine the signal on terminals A-B with the scope. This signal is the output from a 50 volt transformer rectifier. Sketch what you see:-



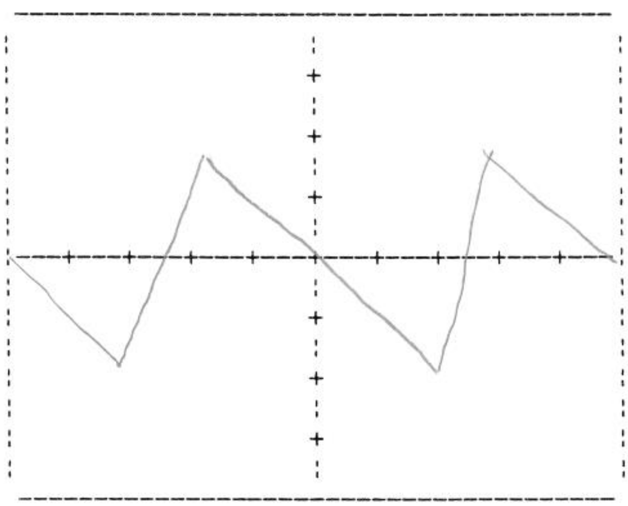
A relay connected to the transformer rectifier would draw power from it to operate, so when we measure the voltage across the terminals we are looking for an indication of the power available.

If you had to decide between using a scope or an AVO 8 to measure this, which would you choose?

AVO

EXAMPLE 4

Now examine the signal on terminals C-D. This is the output from the same transformer - rectifier as before, but smoothed by a capacitor. Sketch what you see on the scope:-



Measure the peak d.c. voltage with the scope: ......7.5..v

Measure the d.c. voltage with the AVO 8: ....7.5v.....v

Which instrument would you choose to measure this voltage?

AVO

Now measure the a.c. ripple voltage on the supply:

with the scope : ....·7......v

with the AVO 8 (a.c. setting) : .....4.1v.....v

Which instrument would you choose to measure the ripple voltage?

Scope

SYSTEM ELECTRONICS

PRACTICE PAPER

NAME ..Nick Whaley.......... GRADE ..Tech 2..........

HOME STATION ..Hartlepool..... REGION ..E....... DATE 17/10/91

DESK NUMBER.............

EXAM INSTRUCTIONS

1. Use the instruments provided, to carry out measurements on the voltages applied to the terminals in front of you. These measurements are designed to test your ability to use the oscilloscope and the AVO 8. This answer sheet indicates the actual measurements required for each pair of terminals. No test voltage is sufficiently high to cause electric shock if the terminals are touched.

2. The results of your measurements should be written in INK in the spaces provided on the exam answer sheet. You may use the margin for any additional notes or calculations.

3. 1 Hour is allowed to complete the test, including time to read the instructions.

   No marks will be gained by completing the test in a shorter time.

4. An accuracy of ±10% of the actual value will be acceptable for your measurements. Assume the instruments are correctly calibrated.

   DO NOT forget to show the units of measurement (eg. volts, msec. etc.).

5. The instructor may freely supply information about the conduct of the test, but will not supply knowledge of the subject, or techniques without deducting marks from the section concerned. If you are doubtful about a specific course of action, or if you suspect that the equipment has failed, you should ask the instructor's advice.

6. Start the test when you are ready, begin by completing your personal details.

1. The signal on socket J is a pulse train which has been distorted. Use the oscilloscope to measure the signal as accurately as you can.

a) Measure the a.c. p-p amplitude. 2·7V

b) Measure the pulse width. 1·32 mS   2·2 − 1·32 = ·88

c) Measure the pulse repetition period. 2·2 mS

d) Work out the pulse repetition rate. 455 Hz

e) Measure the mark/space ratio. 1·5

f) Measure the fall time of the pulse. 500 µS

A B

The signal on terminals C and D is an a.c. signal
Use the AVO 8 and the Oscilloscope to measure the signal as accurately as the instrument will allow.

a) Measure the a.c. peak to peak voltage using the most suitable volts/cm setting of the Oscilloscope. 31 V

b) Place an X below the volts/cm setting used.

10V	5V	2V	1V	0.5V	0.2V	0.1V	50mV	20mV	10mV	5mV	2mV
	X										

c) Work out the RMS value of the a.c. signal from the Oscilloscope reading (a). 15.5 V RMS

d) Measure the a.c. voltage using the most suitable scale on the AVO 8. 16.5 V

e) Place an X below the meter range used.

3V	10V	30V	100V
		X	

f) Place an X below the instrument that is most suitable for measuring this signal.

AVO 8	Oscilloscope
	X

g) Place an X in the answer panel for each of the following statements about the signal on terminals C and D to indicate whether it is true or false.

A. The frequency of the signal is too low for the AVO 8 to respond correctly.

B. The AVO 8 is not calibrated to give a correct reading for this waveshape.

C. The frequency of the signal is too low for the Oscilloscope to respond correctly.

D. The AVO 8 gives a more accurate reading of the signal than the Oscilloscope.

E. The Oscilloscope loads the signal.

	TRUE	FALSE
A		X
B	X	
C		X
D		X
E	X	

2. Connect the die-cast box (No's 021-xx) to the 10V d.c. supp
as follows
   i) red terminal to red 10V supply
   ii) black terminal to black 10V supply

Between the red and green terminals of the die-cast box is a d.c. signal of less than 10V. Use the AVO 8 and the Oscilloscop to measure the signal as accurately at the instrument will allow.

a) Measure the voltage using the most suitable volts/cm setting of the Oscilloscope. [9V]

b) Place an X below the volts/cm setting used.

10V	5V	2V	1V	0.5V	0.2V	0.1V	50mV	20mV	10mV	5mV	2mV
		X									

c) Measure the voltage using the most suitable scale on the AVO 8. [3V]

d) Place an X below the meter range used.

3V	10V	30V	100V
	X		

e) Place an X below the instrument that is most suitable for measuring this signal

AVO 8	Oscilloscope
~~X~~	X

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

3. The signal on terminals G and H is an a.c. signal with a d.c. off
Use the Oscilloscope to measure the signal as accurately as you c

a) Measure the period of the signal. [12 mS]

b) Work out the frequency. [83·3]

c) Measure the d.c. offset. [+5V]

d) Is the offset positive or negative? [Pos]

I

E.