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KE5521 **Tutorial Oscilloscope with Thermionic Cathode**

Standard-type cathode ray tubes for oscilloscopes and television equipment are poorly suited for demonstration experiments in the field of cathode ray physics, because important sections of the tubes are electrostatically and magnetically shielded and thus concealed from the view of the observer. Furthermore, these conventional cathode ray tubes require high accelerating voltages of up to 20 kV so that it is too dangerous to operate them in open circuit rigs (so-called breadboard circuits) for educational purposes. To obviate all these disadvantages, we have developed a special experimental oscilloscope for teaching purposes.

The tube and the unit offer the following advantages :

1. The electron-optical system comprising the thermionic cathode, the Wehnelt cylinder and the anode, is clearly visible from the exterior. The tube is fitted with no shielding whatsoever.

2. A low anode voltage of only 250 V is employed. This can be provided from any conventional mains power pack whose output is efficiently smoothed. The cathode ray (electron beam) is very soft, i.e. it is very sensitively deflected by magnetic and electric fields. Its curvature in the terrestrial magnetic field can be observed.

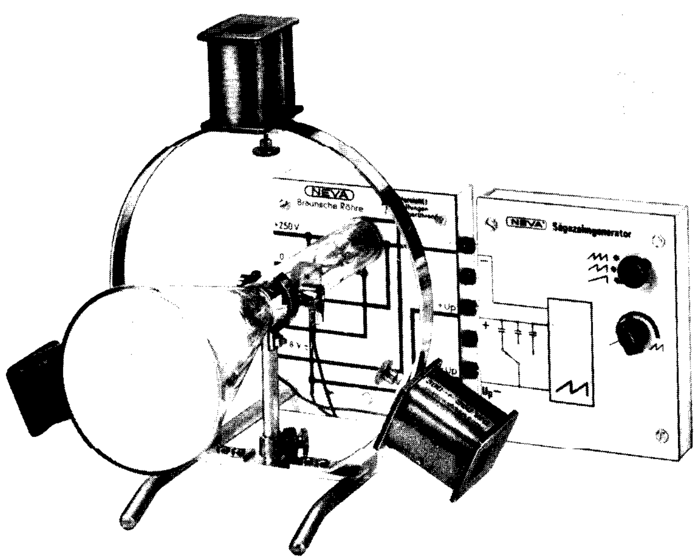

Fig. 1: The Experimental Oscilloscope

3. The cathode ray (electron beam) is focussed by the joint action of a simple electron-optical system (disc with axial hole serving as electron lens) and gas constriction. The beam is visible inside the tube.

4. The luminous spot can be focussed on the fluorescent screen by varying the negative bias voltage applied to the Wehnelt cylinder.

5. The tube has been provided with one pair of deflector plates for demonstrating electrostatic deflection of the electron beam.

6. Three solenoid coils which are mounted on a ring and which can be moved on this ring, serve for magnetic deflection of the electron beam.

7. The output voltage waveform of the sawtooth generator can be applied to the pair of electrostatic deflector plates in order to trace a timebase line on the fluorescent screen.

8. The cathode ray tube is mounted on a vertical plastic panel ready for connecting up. The connecting jacks are labelled on the panel and the wire connections on the rear are also drawn in.

9. The sawtooth generator module can be plugged directly onto the cathode ray tube panel, without requiring any connecting leads for this purpose.

Technical Data

Anode Voltage :	V_a = 250 V DC (efficiently smoothed)
Anode Current :	I_a = 1 mA
Filament Voltage :	V_f = 6 to 8 V
Wehnelt Cylinder Bias Voltage :	V_g = - 50 to 0 V DC
Size of Deflector Plates:	12 mm x 20 mm
Separation of Deflector Plates:	12 mm
Magnetic Deflector Coils :	each 2 x 300 turns, R_i = 5 Ohms

Its simple and synoptical construction makes this cathode ray tube unit particularly attractive for teaching purposes. However, by reason of this simple construction, no exaggerated demands may be made with regard to trace velocity, point brightness, point focus and point centering.

Description of the Tube

The Cathode Ray Tube 6721 consists of an evacuated glass bulb containing the following components :

a) Cathode with pre-focus system
b) Main focussing system
c) Deflector electrodes
d) Fluorescent screen

The electron-optical system of the tube (electron gun) consists of an indirectly heated cathode with a nearly point source emissive oxide spot, a Wehnelt cylinder and a disc anode with axial hole. The Wehnelt

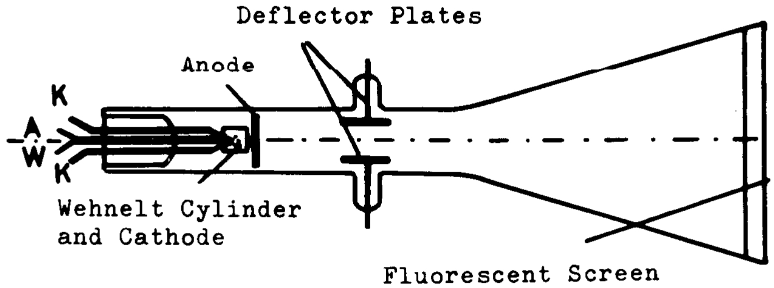

Fig. 2: The Cathode Ray Tube

cylinder is maintained at a negative bias voltage with respect to the cathode and constitutes the pre-focus system. The electrostatic lens formed by the electric field between the Wehnelt cylinder and the disc anode with axial hole, constitutes the main focussing system. An additional focussing effect is exerted on the electron beam by gas constriction - this is convenient and appropriate for cathode ray tubes which are run with low anode voltages. For this purpose, the tube is filled with the inert gas Neon at low pressure (0.01 mm of mercury). The prismatic deflection capacitor consists of two deflector plates 20 mm long and spaced 12 mm apart, positioned between the anode and the fluorescent screen. The fluorescent screen employs zinc silicate as phosphor, emitting green light when struck by the electron beam. For magnetic deflection of the electron beam, three solenoid coils are arranged on a ring such that their positions are variable on this ring. These solenoid coils are in the same plane as the electrostatic deflector plates. The DC resistance of each coil is about 5 Ohms.

Fig. 3 shows the complete circuit diagram of the equipment comprising the tube module and the sawtooth generator module.

Commencing Operation

To power the equipment, a mains power unit is required. This mains power unit must provide an efficiently smoothed DC output voltage of 250 V and a bias voltage which is continuously adjustable from zero to -50 V. The NEVA Mains Power Unit 5211 or the NEVA Stabilised Mains Power Unit 5224 is particularly suitable.

The connecting jacks on the tube panel should be connected to the mains power unit in accordance with the labelling. To avoid any disturbance from the magnetic field of the mains transformer, the distance between the tube and the mains power unit should be at least 50 cm. A ground connection can be made to the jack "+250 V".

CAUTION : Do not touch components or wiring on the tube panel and sawtooth generator module when the equipment is switched on. Voltages up to 250 V with respect to ground are present.

After about 2 minutes have elapsed during which the cathode warmed up, the cathode is seen to glow dull red and the luminous spot appears on the fluorescent screen. The brightness and focus of the luminous spot can now be adjusted by varying the negative bias voltage. A diametrically magnetised ring magnet is mounted on the aluminium rod of the tube fixture. With the help of this magnet, the luminous spot can be brought to the center of the screen, or moved to its periphery when using the sawtooth generator. For this purpose, turn the magnet as required and if necessary adjust its height.
The right edge of the tube panel carries five connecting jacks for the sawtooth generator module. All required connections are correctly established as soon as the plug pins on the edge of the sawtooth generator module have been inserted into the jacks on the edge of the tube panel.

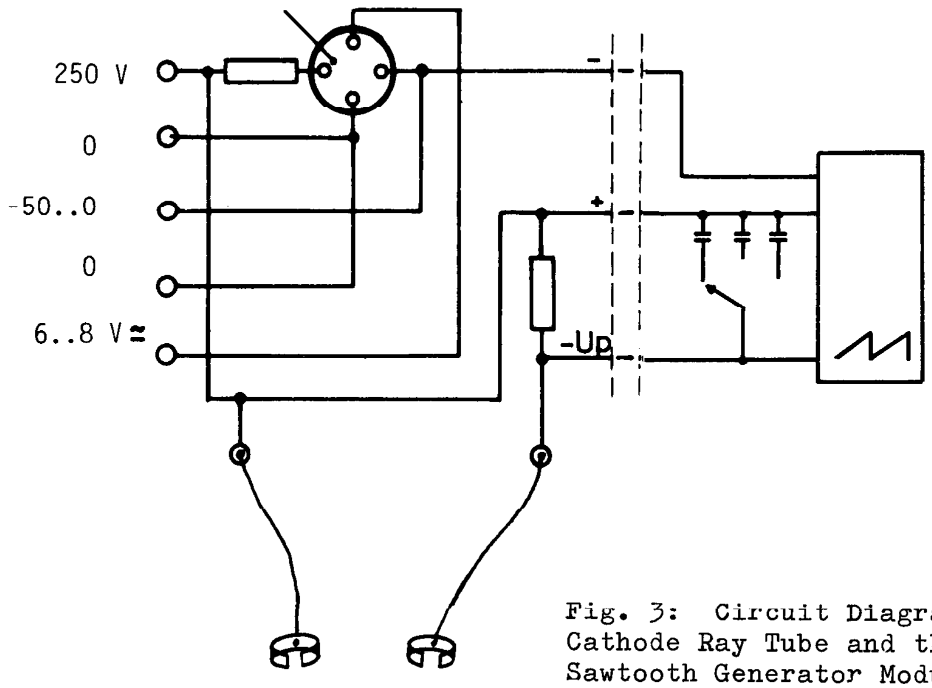

Fig. 3: Circuit Diagram of the Cathode Ray Tube and the Sawtooth Generator Module

Experiments with Cathode Rays

IMPORTANT NOTE : For all experiments, switch on the thermionic cathode only just prior to operating the tube, and switch off again immediately after concluding the experiment. Do not operate the tube idle for long periods.

Experiment No. 1 Magnetic Deflection of the Cathode Ray

Operate the tube without attached sawtooth generator and approach a bar magnet from above, about 10 cm behind the fluorescent screen.

Result : The vertically orientated magnetic field deflects the electron beam in the horizontal direction.

Explanation : Rapidly moving charged particles such as electrons represent an electric current. A force is exerted on a current-carrying conductor in a magnetic field. This force is proportional to the current magnitude I, to the length of the conductor l and to the magnetic field strength B , as well as to the sine of the angle between the vector directions of I and B . The expression for the force is thus:

$$F = I \; l \; B \sin(I, B) \qquad (1)$$

The direction of the force F is perpendicular to the particle track (direction of motion of the electron current) and it is perpendicular to the field direction B of the magnet, so that it can be determined according to the "Left Hand Rule" using three fingers of the left hand to depict the three vector directions.

The "Left Hand Rule" :

Form a rectangular (cartesian) coordinate axes cross with the thumb, first finger and second finger of the left hand. If the thumb is then placed parallel to the direction of the electron current (flight direction of the electrons from the cathode (-) to the anode (+)) and the first finger is placed parallel to the direction of the magnetic field such that it points from the North pole to the South pole, then the second finger automatically points in the direction of the resulting force exerted on the electron beam, i.e. in the direction of deflection of this beam.
N.B. If the left hand rule is applied to closed current circuits in which a conventional current is taken to flow from the positive pole of the voltage source through the external circuit back to the negative pole, according to obsolescent conceptions, the resulting force vector F will be indicated with reversed sense.

If the magnet is made to approach the cathode ray tube with the North pole downwards (Fig. 4/I), the luminous spot will move from the center of the screen to the left (0 to 1) as predicted by the left hand rule.
The downward directed arrow on the magnet indicates the direction of the magnetic field, which always runs from the North pole to the South pole. The direction of travel of the electron beam runs from the cathode (-) to the anode (+). Approach of the magnet thus produces a force which is directed to the left in Case I.
The magnetic field direction runs from below to above if the magnet is turned round. This causes the cathode ray to be deflected to the right .

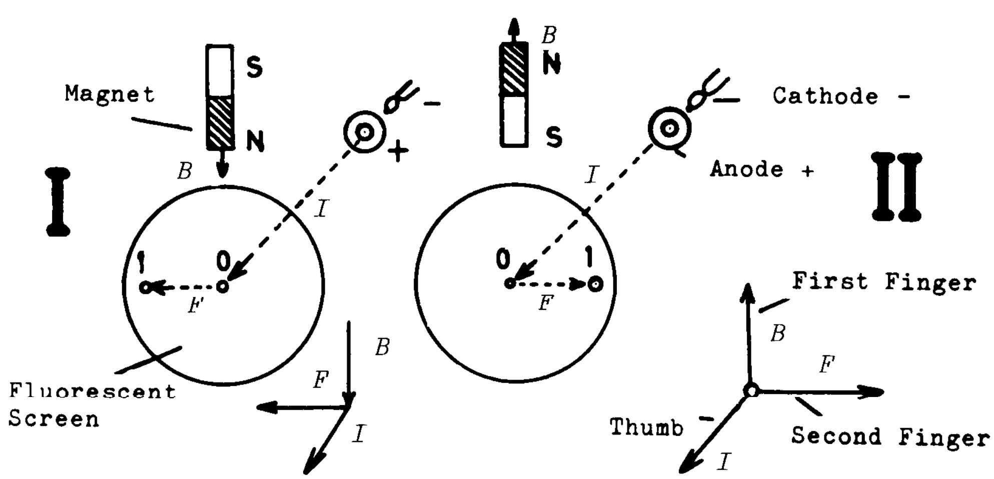

Fig. 4: Magnetic Deflection of the Cathode Ray

These and the following experiments are most impressive if carried out in a darkened or semi-darkened room. The cathode ray is then actually visible inside the tube as a narrow sharply focussed t h r e a d .

Experiment No. 2 Approaching the Magnet from the Side

The previous experiment is repeated, with the difference that the magnet is now approached from the side towards the electron beam.

Result : According to the direction of the magnetic field, the beam is deflected upwards or downwards.

Explanation : The same as for Experiment No.1, but rotating Fig. 4 on Page 5 through 90°.

Experiment No. 3 Deflection with Current-Carrying Coils

The electron beam can alternatively be deflected with current-carrying solenoid coils instead of with bar magnets. The magnetic field of a solenoid coil depends upon the current flow direction as far as its direction is concerned. The lines of force of the magnetic field run perpendicular to the planes of individual turns of the windings.

The experimental set-up should be carried out according to Fig. 5. Set the coil such that it is on the outside of the ring and connect it to a 2 V DC voltage source (single accumulator cell).

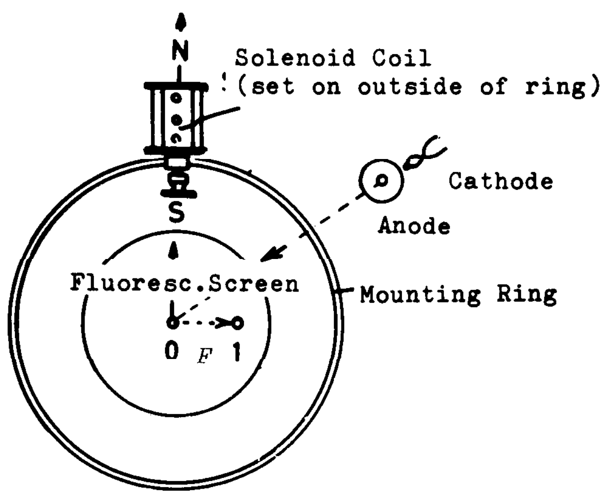

Fig. 5: Deflection of the Cathode Ray with Solenoid Coils

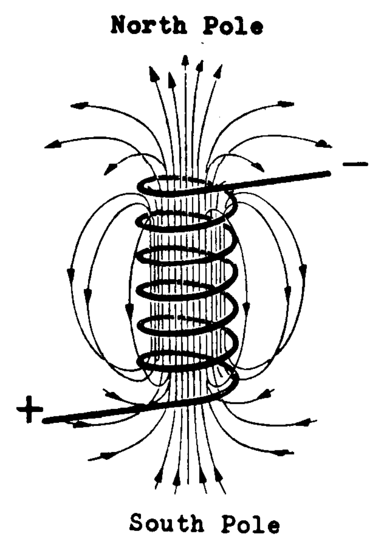

Fig. 6: The Magnetic Field of a Solenoid Carrying a Current

Result : According to the direction of the current, the deflection of the electron beam is to the left or right. The luminous spot moves 10 mm to the left or right when 2V are applied to the coil.
Thus the deflection sensitivity is 5 mm/Volt in this arrangement.

Explanation : The external field of a short solenoid coil is similar to that of a bar magnet. The electric current direction and the direction of the magnetic force lines have been entered in Fig. 6. The top end of the coil behaves like the North pole of a bar magnet and the bottom end of the coil like a South pole.
If one looks onto one end of the coil, this end behaves like a North pole if the current direction is in the anticlockwise sense.

Experiment No. 4 Deflection with Horizontal Coil

Repeat the previous experiment with a horizontally positioned coil.

Result : According to the direction of the current flowing through the coil, the luminous spot is deflected upwards or downwards.

Explanation : The same as for Experiment No. 3.
Orthogonally crossed magnetic fields (deflection coils whose planes are at right angles to each other) are used to make the luminous spot trace the picture raster on television picture tubes (as distinct from the intensity control = control of the brightness of the picture point). The picture spot can be moved to any desired point on the screen by passing corresponding currents through the coils generating a system of crossed magnetic fields. A line raster is produced in this manner, by making the spot move rapidly back and forth from left to right, and at the same time up and down at a slower rate.

Experiment No. 5 Variable Magnetic Field

Repeat Experiment No. 3, but with the difference that an alternating voltage of 2 V is now applied to the terminals of the coil instead of the former 2 V DC voltage. The alternating voltage may be drawn from the NEVA Universal Transformer-Rectifier Unit, Cat.No.5200.

Result : The luminous spot is drawn out to a horizontal straight line.

Explanation : When the solenoid is energised with an alternating current of 50 cycles per second frequency, the current and thus the magnetic field changes polarity 100 times during each second of time. Thus the luminous spot is deflected 50 times to the right and 50 times to the left during each second. Persistence of vision and afterglow of the screen phosphor thus lead to the impression of a continuous luminous line between the extremities of the spot deflection.

Experiment No. 6 Vertical Deflection

Mount a second solenoid coil, displaced through 90°, on the nickel-plated brass ring and connect 2 V AC to this coil to produce an alternating magnetic field in the horizontal direction.

Result : The luminous spot is deflected up and down to produce a vertical line on the screen.

Explanation : The same as for Experiment No. 4.

Experiment No. 7 Observation in Rotating Mirror

Use the same experimental set-up as previously. Observe the vertical luminous line

a) whilst moving the head sharply from right to left
b) in a rapidly horizontally moved hand-held mirror
c) in a rotating mirror

Result : We observe a sinusoidal waveform trace.

Explanation : Technical alternating voltages and currents from the power mains supply possess a sinusoidal waveform with respect to time. The deflection of the luminous spot is always proportional to the instantaneous voltage applied to the solenoid coil. Thus the luminous spot follows a simple harmonic motion up and down. Rapid shaking of the head or the use of a moving mirror introduces a timebase for the horizontal axis (X-axis), along which the simple harmonic motion of the luminous spot is thus extended to produce the visible sinewave.

Experiment No. 8 In-Phase AC Voltages applied to both coils

From the same output jacks of the transformer unit, connect the 2 V AC voltage in the same sense to both coils.

Result : We obtain a luminous trace in the form of a straight line inclined at 45° with respect to the horizontal axis (X-axis).

Explanation : The energising voltages for the two coils are identical in frequency, phasing and amplitude. Thus the vertical and the horizontal linear components of deflection of the spot are always equal. Both components are simple harmonic motions and it follows that the resultant of these equal horizontal and vertical motions is the observed line inclined at 45°.

Experiment No. 9 Other Phasing

Reverse the two connections to one of the two coils.

Result : The straight line trace shifts to a new orientation which is at right angles to the former one.

Explanation : The vertical and horizontal deflection components are still of equal magnitude at all instants, but the signs are now opposite. The resultant is thus still a straight line. Expressed mathematically, this means that the the resultant of two linear simple harmonic motions (sinusoidal with respect to time) is another linear simple harmonic motion whenever the phase difference between the component motions is zero or an even integral multiple of $\pi/2$.

Experiment No. 10 Phase Shift by introducing an iron Core into one Coil

Use the same experimental set-up as previously. Insert a suitable iron object, such as a key or pocket knife into the bore of one of the two coils.

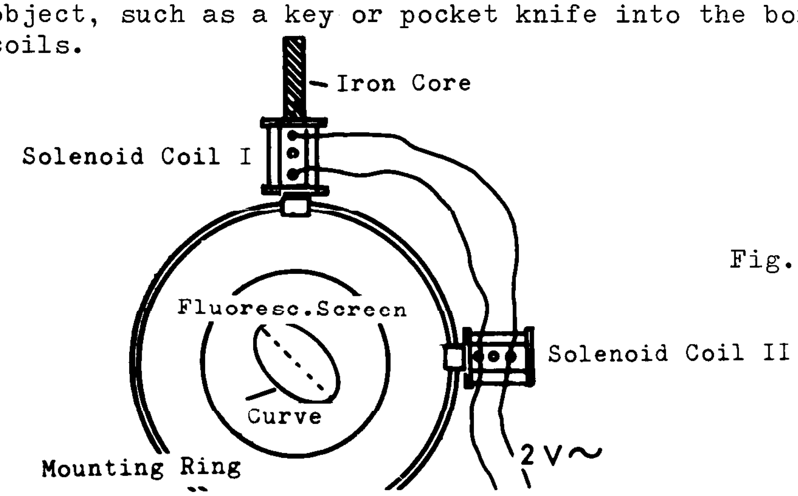

Fig. 7: Phase Shift by introducing an Iron Core into one Coil

Result : Instead of a straight line inclined at 45°, we now observe an elliptical trace in the form of a closed curve.

Explanation : A phase shift has been introduced in the iron-cored coil. The current here lags behind the current and voltage waveforms in the coil without an iron core, for all instantaneous values. We have seen that phase differences of zero or even multiples of $\pi/2$ give rise to l i n e a r simple harmonic motions of sinusoidal character. All other phase differences give rise to e l l i p t i c a l oscillations. Special Case : Circular oscillations produced by phase differences of $\pi/2$ and odd multiples thereof, for equal amplitudes of the component oscillations.

Experiment No. 11 Lissajous Figures

Energise one of the two deflection coils with 2 V AC from the transformer unit and the other one from a bicycle dynamo. The latter must supply alternating current. Connect its output terminals directly to the coil. Mount the bicycle dynamo on a clamp stand and drive it via suitable reduction gearing.

Result : As the speed of rotation of the dynamo is increased, we obtain the familiar Lissajous figures in various versions.

Explanation : Very complicated oscillograms are often produced when the frequencies and amplitudes of two superimposed component oscillations bear no simple relationship to each other

Experiment No. 12 Electrostatic Deflection

The Cathode Ray Tube 6721 has been fitted with a pair of electrostatic deflector plates. In conjunction with the sawtooth generator module, these can be used as X-plates to trace a timebase line. One of the two deflector plates rests at anode potential.

Connect a DC voltage which is adjustable from zero to 50 V, between the two deflector plates. This voltage must be provided by a source which is independent of the anode voltage supply, e.g. a battery or a second mains power unit.

Result : The luminous spot is deflected to the side (horizontally).

Explanation : The cathode ray consists of moving electrons, which are negatively charged particles. When moving through the space between the plates of a capacitor, these electrons are attracted by the positive plate and repelled by the negative plate. In this sense the deflection capacitor functions like an optical prism; the electron beam suffers refraction when passing through it.

Introducing a Timebase

Experiment No. 7 employed the antiquated method of introducing a timebase with a r o t a t i n g m i r r o r in order to be able to display the time waveforms of arbitrary oscillations in a cartesian coordinate system. The luminous spot was moved horizontally and linearly with respect to time whilst oscillating up and down at the 50 Hz AC mains frequency, so that the trace was pulled apart to reveal the sinusoidal waveform.

The use of mechanical devices to produce timebases nowadays serves only to facilitate understanding of the process. It is simpler, more elegant and of course capable of much greater working speed, to use electrostatic methods of tracing timebases - or electromagnetic methods as employed in the scan circuits of television equipment.

If we apply a linearly rising voltage to the pair of deflector plates of our cathode ray tube, then the luminous spot is deflected such that it moves at a steady rate to the right or left, according to the direction of the electric field (cf. Experiment No. 12). If the deflection voltage waveform is actually a repetitive sawtooth relaxation oscillation, then we obtain a linear (i.e. constant speed) periodically repetitive timebase deflection. Equal horizontal distances here represent the elapse of equal intervals of time.

The rate of voltage change is so rapid on the return flank of the sawtooth waveform, that the flyback of the luminous spot will hardly leave any visible trace in most cases.

The Sawtooth Generator

A neon lamp circuit as shown in Fig. 8 is the simplest device for generating a sawtooth voltage waveform. A capacitor C is slowly charged via a resistor R, until it has reached the striking voltage of the neon lamp. The capacitor can then discharge rapidly through the neon lamp, until its voltage has dropped back to the value at which the neon lamp extinguishes. The charging process then recommences. This manner of producing a sawtooth voltage waveform has the following disadvantages: the amplitude is determined by the characteristics of the particular neon lamp and can not be varied at will. The rising stroke is reasonably linear only if the terminal voltage of the charging source is made rather large compared to the sawtooth amplitude.

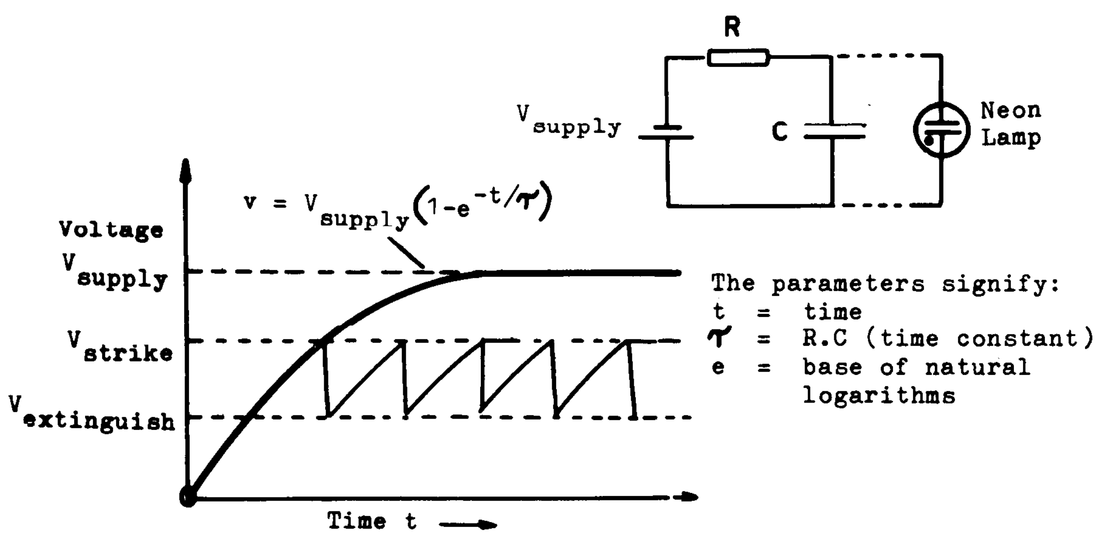

Fig. 8: Sawtooth Relaxation Circuit with a Neon Lamp

The Sawtooth Generator Module 6726 employs a modern sawtooth relaxation circuit. The voltage rise is essentially linear.

This sawtooth generator covers the frequency range from 5 Hz to 75 Hz
The sawtooth generator module is connected up simply by plugging it onto the cathode ray tube panel.

Experiment No. 13 Depiction of Voice Oscillations

Turn the horizontally orientated solenoid coil through 180° such that it rests between the mounting ring and the neck of the cathode ray tube. Connect the coil, a 4 volt battery and a post office type carbon granule microphone in series to constitute a closed circuit. Switch the sawtooth generator to "100" and speak into the microphone, e.g. the vowels a, e, i, o, u.

Result : The characteristic oscillograms of the vowel sounds are seen clearly. The fundamental frequency of the bright vowels i and e is considerably higher than that of the dark vowels o and u.

Experiment No. 14 Rotating Magnetic Field

If a three-phase transformer is available with secondary voltages of about 10 V, connect these respectively to three solenoid coils spaced at intervals of 120° around the mounting ring, to produce a rotating magnetic field. Connect the coils in star circuit and the secondary voltages of the transformer in delta circuit.
Result : In the rotating magnetic field, the cathode ray also rotates and thus sweeps out the surface of a cone, whereby the luminous spot describes a circle on the screen.

Experiment No. 15 Hysteresis Loops

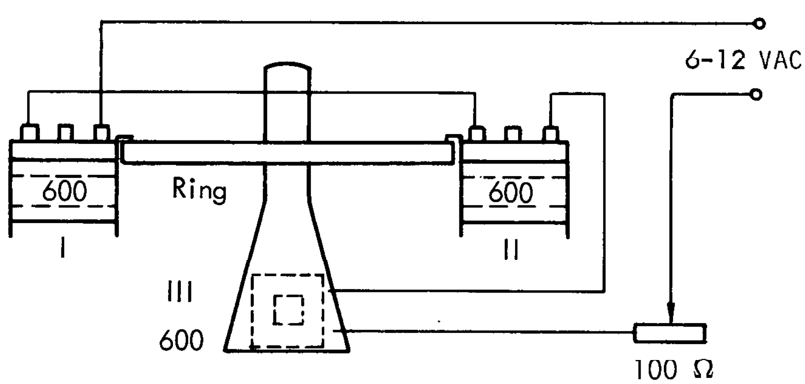

Fig. 9 Circuit producing hysteresis curves

a) As shown in Fig. 9, coils I and II are secured to the edge of the metal ring, while coil III is positioned under the tube in proximity to the screen, with its magnetic field flowing in a vertical direction. The magnetic fields of coils I and II must cancel each other out; this is achieved by short-circuiting coil III and if necessary, reversing the polarity of one of the coils I or II and displacing it up or down until the image point on the screen is no longer modified. The free coil III is moved in such a way that the image point is drawn out to become a 2-3 cm long, straight line (if necessary, also reverse the polarity of this coil).

Iron or nickel is now introduced into coil II, e.g. sheet iron (from a preserving tin, non-annealed or annealed), steel knitting needle, tripod leg, screwdriver, a bundle of 3-4 pieces of wire, 2-3 superimposed pieces of nickel plate, I-core etc.

Result: The hysteresis curve appropriate to the respective material appears on the screen.

Explanation: Since coil I and II fields cancel each other out, only that field produced by the iron or nickel remains. The curve will occur 50 times a second. The magnitude of the area enclosed by the curve provides a measurement for the energy required for the continuous magnetic reversal of the material, which is converted into heat. The magnetic reversal in transformer iron occurs practically without loss, with the result that in this case the curve becomes a straight line.

b) Instead of 50 Hz industrial AC voltage, perform the experiment with 1 Hz frequency from a sine-wave generator.

Result: The image point traverses the hysteresis curve once per second.

The illustrations depict various curves, e.g.

Fig. 10: Annealed iron sheet beyond saturation.
Fig. 11: Annealed iron sheet modulated to saturation limit only.
Fig. 12: Nickel sheet.
Fig. 13: Tripod leg (saturation not reached).
Fig. 14: Transformer iron, I-core.
Fig. 15: Steel knitting needle.

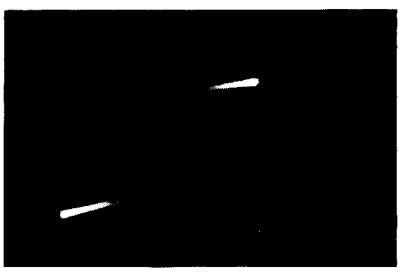

Fig. 10

Fig. 11

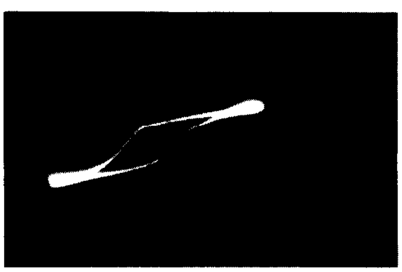

Fig. 12

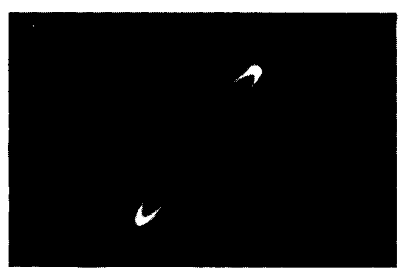

Fig. 13

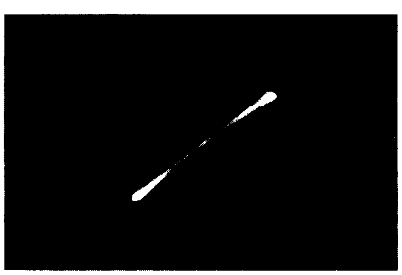

Fig. 14

Fig. 15