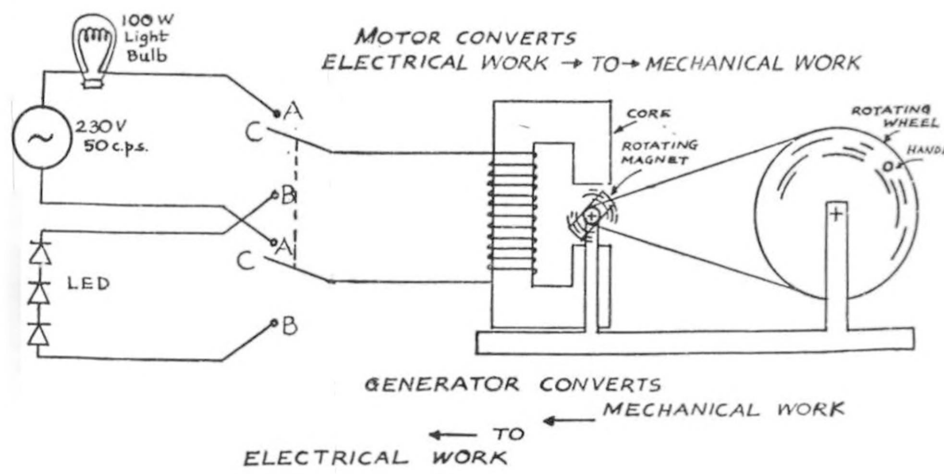
Low Cost Electromagnetic Induction Kits out of the Condemned Chokes of a Fluorescent Tube



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(National Council of Educational Research and Training)
1986

Illustrations and Diagrams have been prepared by the author himself

FOREWORD

Faraday's law of electromagnetic induction plays an important role in the building of the civilisation in which we live today. The generation and transmission of electricity in large scale has been possible from this discovery. In this book are presented a set of low cost experiments based on electro-magnetic induction developed by Dr. Somnath Datta, Professor of Physics, with the assistance of some others in the college. These experiments can be fabricated out of discarded fluorescent tube chokes and other easily available materials using simple tools like a hacksaw blade and perhaps, a drilling machine.

The most interesting piece of these experiments is a motor-cum-generator in which a single device can be made to act both as a generator and a synchronous motor and can be used to measure, with high accuracy, the frequency of the a.c.mains. These experiments are all meant for school children.

A review chapter on the theoretical basis of electromagnetic induction will indeed satisfy many inquisitive teachers. The entire material covering theory and experiment is brought out in the form of this book for a wider dissemination of the ideas which have been developed by Dr. Datta and tried at RCE Mysore, hoping that they are found beneficial to school education.

It is also hoped that such simple and inexpensive teaching aids can be duplicated by many schools of India for a clearer appreciation of Faraday's Law, the principles of electric power generation, synchronous motors and transformers, with acknowledgements to this reference material.

I greatly appreciate this contribution of Dr. Somnath Datta, which is a positive input for improving school science programmes.

A. K. SHARMA
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Ugadi, 10th April 1986

PREFACE

I had an enterprising M.Sc.Ed. student in 1981-83 by the name Sri T. Venugopal who desired that I suggest some new models that he could fabricate in the college workshop. He took my design seriously and made the electric generator out of a discarded tube light choke I gave him. This forms the central theme of this booklet. He was amply assisted by Sri S. Mohanta, our Work Experience Teacher. In making this newly born generator overcome some teething trouble, my good friend Dr. B. Vema Reddy suggested some 'medicine' which worked. Later on, to my surprise, I discovered that this new born model could fit into two distinct roles—to work not only as a generator, but also as a synchronous motor working on A. C.—and that its secondary role was even more exciting than the primary, because one could count accurately the number of times the alternating current from the mains fluctuated every second.

All these models are very inexpensive. We, in this College would be ready to render assistance to any school that may approach us for guidance.

Although the motor-generator model occupies the centre stage in this booklet, I have tried to expand the suggested activities by introducing a few other inexpensive activities that may enrich the school laboratories. I have also added a logical explanation of electromagnetic induction which some dedicated teachers may find appetising to their intellectual taste.

These teaching aids were introduced, for the first time, to the participants of a UNESCO Teacher Training Workshop conducted in our College in December 1981—January 1982 for the benefit of the teachers from some Asian countries. A year later, in August 1983, sixteen schools of Mysore city were invited to a workshop conducted in this college and were taught how to fabricate these devices using the materials and the facilities of this College. At the end of the one week workshop, the participants of these schools were donated the models, made jointly by them and our workshop, under the overall guidance of our Workshop Superintendent Shri D. V. Verghese, and Work Experience Teacher Shri S. Mohanta.

Schools who may wish to refabricate the models to enter them in some competitions and exhibitions may do so by acknowledging the source and authorship of the models.

I would like to record my appreciation of the leadership of our Principal Professor A. K. Sharma for his emphasis on generation and dissemination of new ideas in Science Education—to which stands as testimony this publication. I also share my gratitude to Professor A. N. Maheshwari, who, as Head, Department of Science, has been at the forefront in encouraging all

innovative activities in science education in this college, and of the unstinted cooperation rendered by the workshop and physics laboratory staff—Mr. Nanjaiah, Mr. C. Puttaswamy, Mr. K. Changala Raju, Mr. Y. Venkataramanaiah, Mr. K. R. Siddaramaiah and Mr. M. Mahadev.

I dedicate this book to my mother Smt. Snehalata Datta, my first teacher.

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Ugadi, 10th April 1986

CHAPTER 1

A Brief Review of Electromagnetic Induction

1. What is electromagnetic induction ?

We can talk about pure electric field or pure magnetic field under a static condition only. A stationary bar magnet or a steady current in a stationary coil of wire will produce pure magnetic field over a region of space. Similarly, a charged capacitor or an ebonite rod rubbed with fur will create pure electric field over a region if the capacitor and the ebonite rod are held fixed. If, however, the magnet is moved about, or if the current in the coil is altered, the magnetic field at a given location will also be altered. This fluctuation of the magnetic field will automatically induce an accompanying electric field. That means, a fluctuating magnetic field cannot exist all by itself —it must invariably be associated with a fluctuating electric field.

In the same manner, if the charged ebonite rod is moved about, or if the total charge on the capacitor is altered, the electric field at any given point will be altered. Such a fluctuating electric field cannot exist all by itself–it must invariably be associated with a fluctuating magnetic field.

Electric field and magnetic field have their separate existence only so long as each one of them is kept unchanged. Any change in one of them automatically creates the other by induction. Electric and magnetic field are married together, so to say, under an unsteady condition–electric field generates a magnetic field, and the magnetic field in turn generates an electric field. They generate each other–and this generation-regeneration effect propagates outwards through space —away from the sources that were responsible for the effect. And we get what is known as an electromagnetic wave, propagating with the speed of light—carrying the message that something is changing. The velocity of this electromagnetic wave is 3×10^8 m/sec in free space.

When we say electromagnetic induction, we usully refer to the generation of electric field due to a fluctuating magnetic field. The reverse effect, *viz*, generation of magnetic field due to fluctuating electric field does not have any special name.

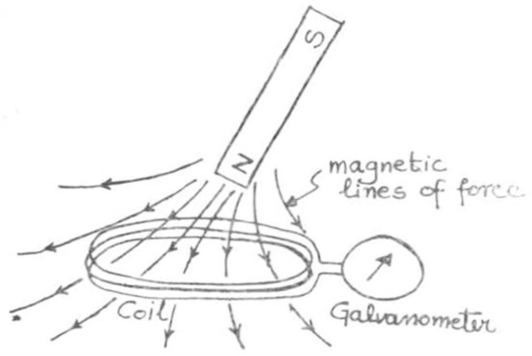

Fig. 1

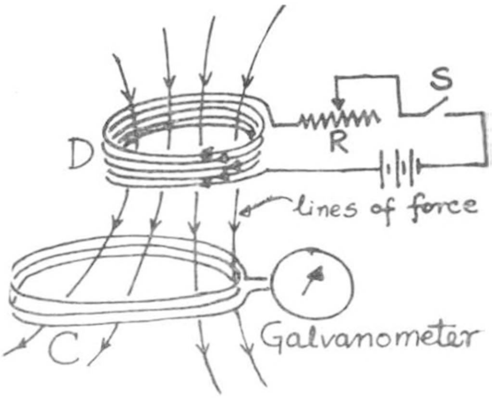

Fig. 2

Electromagnetic induction can be demonstrated by moving a magnet back and forth near a coil of wire whose terminals are connected through a galvanometer (Fig 1) The rocking motion of the magnet causes fluctuation of magnetic field strength at the location of the wire. When the magnet is near, the magnetic field through the coil is strong and when the magnet is far, the field is weak. The rocking motion of the magnet, therefore, alternates the strength of the magnetic field through the coil and this alternation induces electric field. Inside the wire, which is made up of a conducting material, only the tangential component of the electric field can exist the perpendicular component being neutralised by a readjustment of the positions of electrons. The average tangential electric field multiplied by the length of the wire is called the *emf* around the wire. Thus, the rocking motion of the magnet induces an *emf* (electromotive force) around the wire. As a consequence, alternating current flows in the wire causing deflection of the galvanometer needle.

Electromagnetic induction can also be demonstrated by changing the current in a second coil D in the neighbourhood of the first coil C by, for instance, changing the resistance R in the second coil or by alternately closing and opening the switch S (Fig. 2). Current through the coil D produces magnetic field. Fluctuation of this current fluctuates this magnetic field and, hence, produces current through the coil by electromagnetic induction.

2. Why is there electromagnetic induction ?

Before answering this question we shall need to answer " what is a magnetic field ?" and " what is an electric field ?"

Take a charged pith ball and find out the force on it due to (i)the presence of a charged ebonite rod and also due to the (ii) presence of a bar magnet. In the first case the pith ball experiences a force. In the second case it does not. The charged end of the ebonite rod produces electric field and the bar magnet produces magnetic field. We therefore conclude :

Conclusion 1 : Electric charges *at rest* experience a force in an electric field but *not* in a magnetic field.

However, this does not mean that electric charges will never experience a force in a magnetic field. One can very neatly demonstrate the force on electrons exerted by a magnetic field with the help of a gas discharge tube (Fig. 3). Such tubes are commonly used in physics

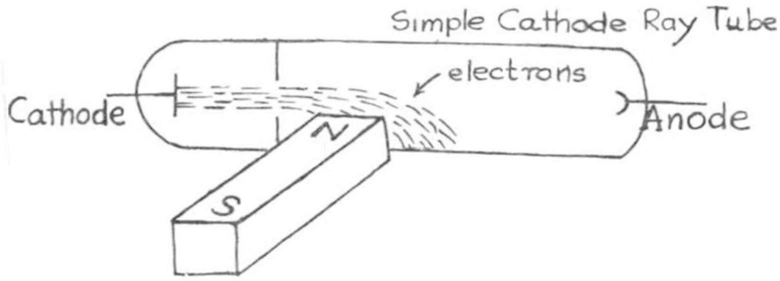

Fig. 3

laboratories for demonstrating cathode rays. If one holds a magnet near the cathode rays in the manner shown in Fig 3, the rays will be found to bend in a plane perpendicular to the direction of the magnetic field. The cathode ray consists of electrons. The trajectory of the deflected beam of cathode rays will show that the force acting on the electrons is perpendicular to their velocity and also perpendicular to the direction of the magnetic field. This brings us to the conclusion :

Conclusion 2: Magnetic field exerts a force on a charged particle *in motion* and this force is perpendicular to the plane containing the velocity **v** and the magnetic field vector **B.** The sense of the force on a positive charge is given by the direction of the thumb of the right hand fingers, if the fingers, curl from the directon of v to the direction of **B**.

$$\mathbf{F} = e(\mathbf{v} \times \mathbf{B}),$$

where e is the charge of the particle.

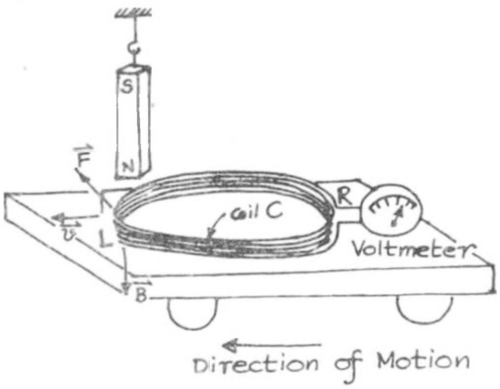

Fig. 4

Now think of the arrangement shown in Fig. 4. A coil of wire C is carried on a wooden trolley. This trolley is moving past a post from which is hanging a bar magnet. As the left end L of the coil crosses the region of strong magnetic field just under the bar magnet, the field will exert a force on the electrons in the wire in the direction shown in Fig. 4, according to conclusion 2, because the electrons in the wire are moving from right to left and are negatively charged. The right end of the coil is still quite far from the magnet, so that the magnetic field will have little influence on the electrons there. However, because there is a force on the electrons at the left end of the coil, all the electrons will be pushed around in a clockwise manner (when viewed from top) and the voltmeter across the terminals of the coil will show deflection. We are here using a voltmeter because a voltmeter will not allow any current to flow through the wire (rather it will allow very negligible current to flow), so that we can maintain that the only motion of the electrons in the wire is due to the motion of the trolley.

Let us look at the deflection of the voltmeter needle from the trolley. An observer on the trolley, call him Mr. Rider, notes this deflection and realises that there is a force on the electrons in the wire. However, the coil is stationary with respect to Mr. Rider—and so are the electrons in the wire. Therefore, according to conclusion 1, the force on the eletrons is ***not*** due to a magnetic field, but due to an ***electric field induced*** underneath the magnet. But then how is it that there is an electric field under the magnet when seen from the trolley and there is no electric field when seen from the ground? Because the magnet is moving when seen from the trolley. It is at rest when seen from the ground. In other words Mr. Rider concludes that a moving magnet causes both electric and magnetic field even though a stationary magnet is known to produce only magnetic field.

This same conclusion can be put in a slightly different language if we prefer to talk in terms of fields rather than magnet (keep the magnet hidden inside a black box—the effects will not change if the box is non-magnetic). Now the phrase "moving magnet" in the previous sentence has to be replaced by "changing magnetic field"—the approaching magnet represents rapid intensification of the field. In other words the conclusion of Mr. Rider should be written more appropriately as follows.

Conclusion 3: A changing magnetic field induces electric field.

The above statement is the statement of electromagnetic induction. In retrospect we can therefore reason that electromagnetic induction occurs because electric force is purely velocity independent and magnetic force is purely velocity dependent.

3. Faraday's law.

Before discussing Faraday's law it is essential that we discuss certain concepts associated with curves and surfaces. Consider the plane curve C shown in Fig. 5a. This curve may not represent an

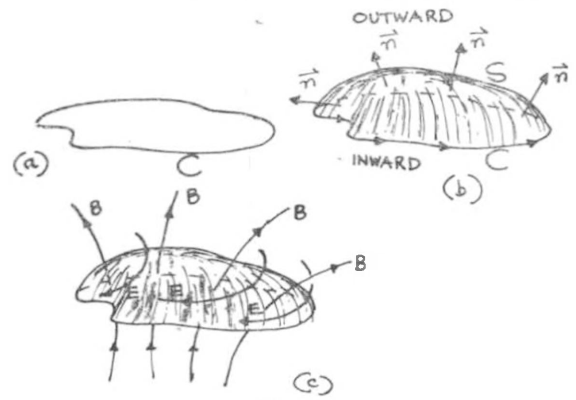

Fig. 5

actual metallic wire. It may even represent an *imaginary* curve in empty space. Imagine also any bounded surface S such that every little segment of C lies entirely on this surface S. We can as well say that C is the boundary of the Surface S. At each point on the surface S imagine a unit normal vector **n**, each pointing to only one side of this surface which we call the outer side (Fig. 5b), (the other side of the surface being the inner side). The normal **n** pointing to the outer side is to be called the outward normal.

Before continuing further, several doubts have to be cleared here. The surface S which terminates on C is not unique. There are infinite number of surfaces whose boundaries can be the same curve C. The surface S shown in Fig. 5 is only one of them. Secondly, the decision as to which side of the curve is outward and which is inward is purely arbitrary. In Fig. 5 we have arbitrarily taken the upper side of the page to be the outer side for the surface. Nothing would go wrong if we decide to call the lower side to be the outer side of the surface.

Now view the curve *from the outer* side of the surface and identify the *anticlockwise* direction of the curve C and call this direction the *positive* direction of the curve. Mark this positive direction by means of arrows. Alternatively, point the thumb of your *right* hand in the direction of outward normal and curl the other fingers along the curve. The direction of curling of the fingers is the positive direction of the curve C. Note — which direction of the curve is positive is determined purely by our choice of which side of S is outward.

Now imagine a magnetic field in space intercepting the surface S. Find out the number of lines of force* intercepting S—call it the *magnetic flux*—denote it by the Greek symbol ϕ. ϕ is the number of lines of force crossing S *from the inward side to the outward side* minus the lines of force crossing S the other way. Therefore whether ϕ is positive or negative, depends on which side of the surface S is called outward.

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* Theoretically this has to be done by integrating the magnetic field B over the surface S, a procedure which we shall not discuss here.

If the magnetic field changes, then ϕ changes, and electric field is induced in space over and around the curve C (Fig. 5c.) Take the ***component*** of this induced electric field along the ***positive*** direction of the curve. Multiply this component by a small segment ***ds*** of the curve. Add up this product once around the entire curve C. This sum is the ***emf*** (electromotive force) around C. In other words, ***emf*** is the average component of the induced electric field around the curve multiplied by the length of the curve. Note that whether the ***emf*** is positive or negative depends on which direction of the curve is positive—and this has been already decided by our choice of the outward direction of the surface S.

We represent the ***emf*** by the symbol ε. Then Faraday's law tells that (1)

$$\varepsilon = -\frac{d\phi}{dt}$$

If instead of the imaginary curve C we take a metallic wire wound into a coil of N turns, each of these N turns having the shape of the closed curve C, then the emf around the wire is (2)

$$\varepsilon = -N\frac{d\phi}{dt}$$

4. Electromagnetic induction in the service of mankind.

If people ask, "what is the greatest discovery of the 19th century ?", some of us will feel tempted to answer "Faraday's law of electromagnetic induction". Indeed, no other discovery has revolutionised civilization as much as this one has. Electricity is the backbone of modern living and supply of electricity on a large scale is possible because of electric generators which work on Faraday's law of electromagnetic induction.

Another important application of Faraday's law lies at the heart of every transformer. Using a transformer it is possible to send large electric power over large distances say, from a dam to a distant city, without using a cable of proportionately large diameter. Electric power is voltage multiplied by current. Heavy current requires large diameter cables, small current requires small diameter cables. Transmission of electric power is accomplished by transmitting very large voltage (of the order of 330,000 volts) and relatively small current. At the receiving end of the transmission line this dangerously high voltage is calmed down to a low 220 volt by using transformers. Thus, we employ Faraday's Law both for generation as well as for transmission of electric energy.

Transformers are used not only in power transmission, but also in a wide variety of appliances and gadgets—in radio, television, amplifiers, stereo systems—where different components of the appliance require different voltages. In a TV, for instance, the picture tube requires 4000 volts or more, whereas the different amplifiers and oscillator circuits inside the set require low voltages, say about 6 V. Such transformations of voltage can be accomplished by transformers working on Faraday's law.

Other common-place devices working on Faraday's law include the recording head of a tape recorder, the speedometer mounted on a scooter and others. The recording head picks up alternating magnetic field as the magnetic tape, containing a magnetic imprint of the sound recorded, rubs against the head. This alternating magnetic field generates alternating *emf* having the frequency of the sound recorded—this *emf* is amplified to produce sound. The speedometer has a magnetic rotor which is made to rotate at a speed proportional to the speed of the wheel. This rotation creates fluctuating magnetic field which is converted into electric current by electromagnetic induction.

In the following chapters we have suggested a few very low cost teaching aids to illustrate the phenomenon of electromagnetic induction. We shall conclude this chapter with another interesting application of Faraday's law by *viz.* the design of the electron accelerating machine called betatron.

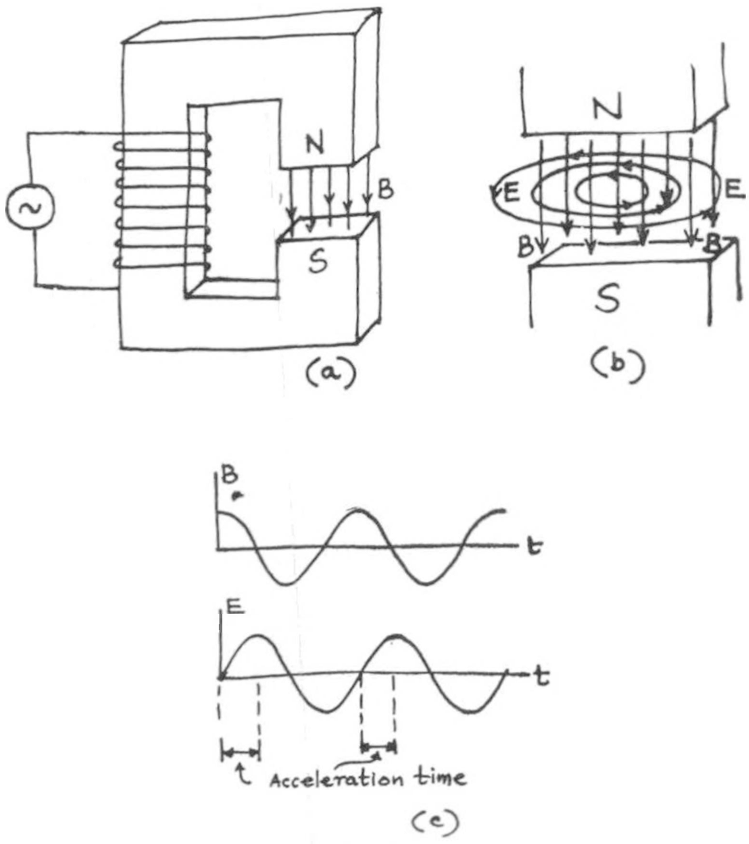


Fig. 6

The basic working principle is illustrated in Fig. 6. In Fig. 6(a) we show the electromagnet of the betatron. (This is not a very small electromagnet, it can be as big as the size of a one storied house or even bigger !) The electromagnet generates an alternating magnetic field between the pole pieces due to alternating current flowing through the coil of the electromagnet. A typical betatron this author has worked with used a source voltage of frequency 180 cycles per second to send this alternating current. The magnetic field alternates at this same frequency. In the figure we have shown polarities of the betatron magnet at a particular instant of time. After every 1/360 of a second the polarities reverse. As a result of alternating magnetic field, a circulating electric field develops between the pole pieces—due to Faraday's law. We have shown the magnetic lines of force **B** and the electric lines of force **E** at a particular instant of time.

The betatron uses an evacuated hollow porcelain ring—called the doughnut—inside the gap between the pole pieces. Electrons are injected inside this doughnut and are made to accelerate along the circular cavity of the doughnut by the circulating electric field while the magnetic field provides the necessary centripetal force. It is obvious that the electrons can be accelerated so long as the electric field keeps on increasing In Fig. 6(b) we have shown a time plot of the magnetic field and the induced electric field and have also indicated the period during which the electrons can be accelerated. The electrons are injected into the dougunut and are removed from the doughnut at the begining and at the end of each acceleration period. Within this short acceleration period of 1/720 second the electron energy can be increased from zero to about 30 MeV.

In conclusion, we can say that Faraday's law of electromagnetic induction is one of the pillars of our present civilization. All of us use it, or enjoy the fruits of it, in different forms in our every-day life.

CHAPTER 2

Condemned Fluorescent Tube Chokes as Teaching Aids

It has been discussed how condemned chokes of fluorescent tubes can be reused to make an electromagnet and a multitap transformer. These teaching aids can be used profitably to illustrate the principles of magnetism and Faraday's law.

1. Introduction. A typical fluorescent tube choke available in India contains about 100 identical ferromagnetic laminae of the shape and approximate dimensions shown in Fig. 1(a). Half of these laminae are placed on one side and the other half on the other side so as to make a closed magnetic circuit as shown in Fig. 1(b). Windings of copper or aluminium wire, A and B, are mounted on the two arms of the core so as to give it the appearance shown in Fig. 1(c).

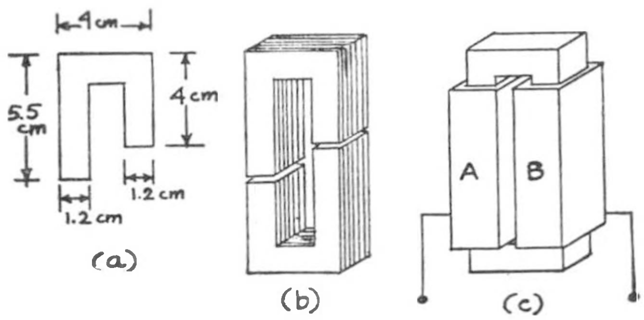


Fig. 1

When a choke is burnt out, the core can be removed from the choke box and put to excellent uses as a teaching aid. We consider this discarded core as a zero cost teaching aid. Very often it is found that out of the two windings A and B, one is still in good condition, particularly if the coil is made of copper, in which case the two projects we are suggesting in this article will be almost zero cost. Aluminium coils, on the other hand, are found to have shorter life and are usually somewhat difficult, but not impossible, to reuse when the choke is burnt out. The core laminae can always be reused.

In this article we discuss two useful teaching aids made out of such a discarded core. In the two following articles we shall discuss two other low cost projects designed out of such discarded cores, *viz.*, (1) a reversible work conversion machine, or electric motor–cum–generator and (2) a magnetic dipole antenna receiver.

2. Electromagnet.

(a) *Construction* : About 50 laminae (Fig. 1a) are taken and the extra length on the longer arm is removed using a hacksaw. The core now looks like an inverted U (Fig. 2a). 300 turns of thin enamelled wire is wound (commercially available 33 gauge or .254 mm diameter winding wire insulated with a layer of varnish has been used in our setup) on two identical frames made out of card board paper (Fig. 2b) and then the frames are slipped onto the two arms of the core (Fig. 2c). Varnish is removed from the terminals A, B, C and D. A and B are jointed (either by soldering or by twisting the wires) in such a way that if current flows clockwise around one of the arms, it must flow anticlockwise around the other arm (Fig. 2d). The terminals A and B are connected to a set of four D–cell torchlight batteries held together in a battery holder (Fig. 2d). There is no need to use any extra resistance in the circuit. This completes the eletromagnet.

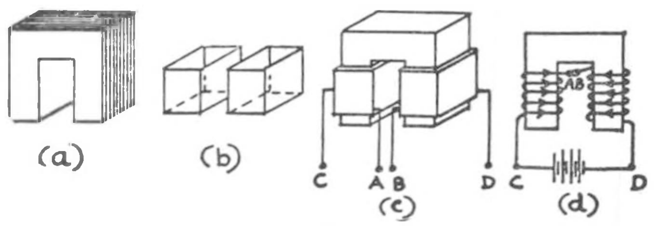


Fig. 2

In order to experiment with this device a few small pieces of steel laminae should be cut out, some of them from the extra half of the laminated core and some from a broken hacksaw blade (Fig. 3).

Fig. 3

(b) *Uses* : The device described above illustrates the following concepts :

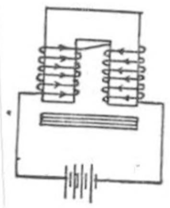
1. Current flowing through a coil produces magnetic field.
2. The magnetic field is intensified due to the presence of a ferromagnetic core.
3. If the windings in the two arms of an electromagnet are in opposite directions (clockwise and anticlockwise), then the pole faces develop opposite polarities.
4. Permanently magnetisable materials (like nails, hacksaw blades) can be converted into permanent magnets by hysterises.

The magnetic effect of current can be tested with the help of the laminae (Fig. 3). This improvised electromagnet can lift four or five laminae easily. The hacksaw blade can be magnetised permanently by bringing it repeatedly into contact with the pole faces (as shown in Fig. 3) and then gently removing it away from it.

3. Multitap transformer.

(a) *Construction* : In a freshly dissected core, the laminae are arranged as shown in Fig. 1(b). For our purpose, we need to change the orientation of the cores. The cores are joined on one side leaving a gap of about 3 cm on the other side (Fig. 4a). The pole faces will be formed on the opposite sides of this gap. This core will be called the primary core.

Fig. 3



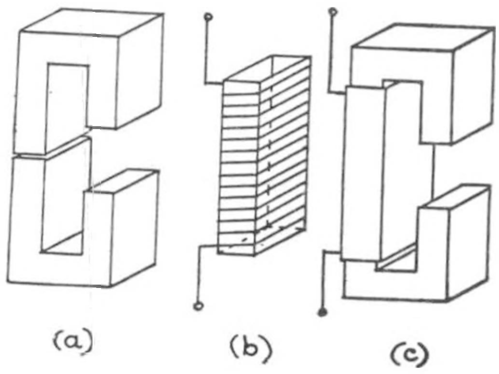


Fig. 4

Often it is found that one of the two coils A and B in a choke (Fig. 1c) is in good condition. This good coil can be reused.

Alternatively, a fresh coil can be wound as shown in Fig. (4a, b, c). This coil constitutes the primary winding.

The gap between the pole faces is now filled with another core, the *secondary* core, with the secondary coil wound around it (Fig. 5a, b, c). For this purpose about 2.5 cm of laminae from another

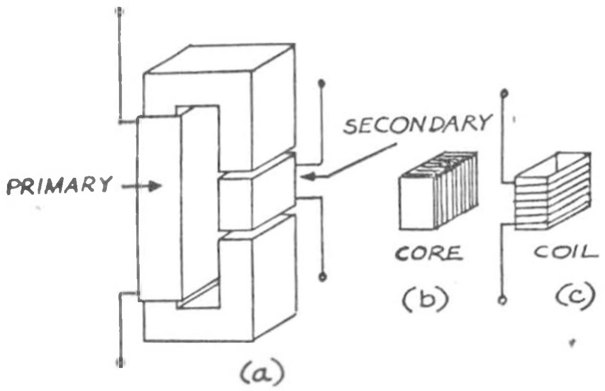


Fig. 5

condemned choke should be cut out and about 300 turns of wire should be wound around it with a provision for three tappings, each of 100 turns, as shown in Fig. 6. We shall call this device an improvised transformer.

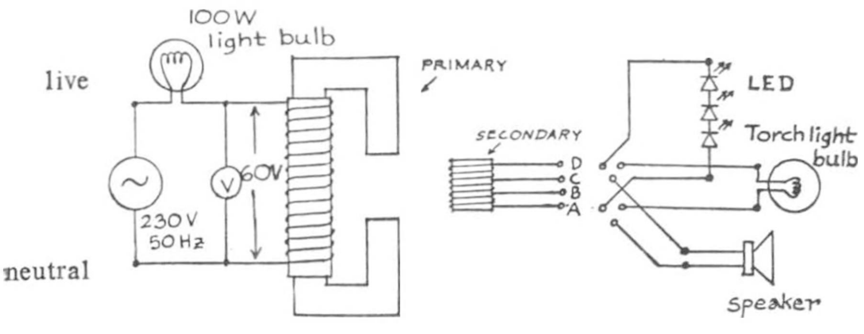


Fig. 6

(b) *Uses* : This device can be used to illustrate the following concepts :

1. Faraday's law of electromagnetic induction.

2. Transformer principle, *viz.*, voltage ratio between the primary and the secondary is equal to the ratio of the number of turns between them.

3. Alternating current in one region of space produces alternating electromagnetic field in another region of space.

The arrangement shown in Fig. 6 is recommended for verifying experimentally the above principles. The following four independent experiments are suggested.

1. The secondary S is placed in the gap as in Fig. 6. Voltage is tapped from a.c. mains and applied across the primary through a 100 W incandescent light bulb in series so as to drop the voltage from 220 V to about 60 V. Open circuit voltages V_B, V_C and V_D are measured across AB, AC and AD respectively. It will be found that $V_D = 3V_B$, $V_C = 2V_B$.

2. The secondary S is removed from the gap. The terminals A and D are connected to a few light emitting diodes (LED) in series (Fig. 6). One should experiment with one, two and three LEDs in series. The LEDs will be found to glow even when the sceondary is about two inches away from the gap.

3. A 3V torch light bulb is connected across AD. When the core is held with hand near the gap it will experience a strong pull towards the gap. As the core is gradually brought near the gap, the bulb will start glowing and will be gradually brighter. When the secondary is finally seated inside the gap, the bulb will glow brightly.

4. The terminals AD are connected to an 8Ω–4″ diameter speaker. As the secondary is brought near the gap a 50 cycle hum will be heard from the speaker.

Safety Measures : The following two precautions should be followed in order to avoid any possibility of getting electric shock.

1. Using a line tester the experimenter should verify which one of the two mains terminals is the live terminal. The 100 W bulb should be fixed towards the live terminal and the transformer towards the neutral terminal (Fig. 6).

2. The body of the transformer as well as the pole faces inside the gap (after the primary has been wound) should be covered with an insulating tape so that neither the fingers nor the secondary ever touch any metal surface of the primary.

CHAPTER 3

Reversible Work Conversion Machine Out of a Condemned Flourescent Tube Choke

It has been discussed how condemned chokes of fluorescent tubes can be reused to make a motor cum generator.

1. Introduction. In the last chapter we discussed how almost zero cost devices could be made out of condemned chokes of household fluorescent tubes. In this chapter we suggest another interesting device that can be fabricated with the above choke. This device will work as a motor if electric current from 220V, 60 cycle a.c. mains is used as the input into the system. In this mode of operation this device converts electrical work into mechanical work. This device will work as an electrical generator if mechanical work is used as the input. In this mode of operation the device converts the mechanical work into electrical work.

This device can be used as an excellent class room demonstration apparatus at the high school level and can convey to the school students (i) a vivid picture of alternating currents, and (ii) a better undestanding of Faraday's law of electromagnetic induction.

2. Description of the device. The device is described schematically in Fig. 3. Fig. 4 gives a photograph of the actual model. Fig. 2 shows the details of the heart of our apparatus, *viz.*, the electromagnet made out of the condemned choke and a commercially available ceramic magnet rotating about its longitudinal axis inside the gap between the poles of this electromagnet.

The basic raw material for the improvisations described in this chapter is a condemned fluorescent tube choke which was described earlier. In a freshly dissected core, the laminae are arranged as shown in Fig. 1(a). For our purpose the orientation of the cores is changed by joining the longer arms on one side and leaving a gap of about 3 cm on the other (Fig. 1b). Now a coil containing about

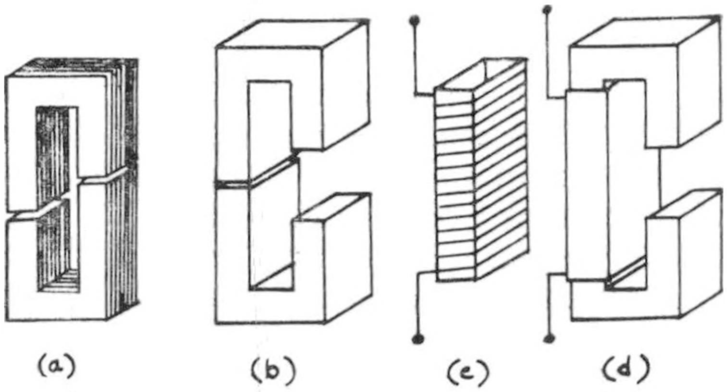


Fig. 1

1000 turns of 33 gauge (.254 mm diameter) winding wire is slipped into the stem forming an electromagnet (Fig. 1c, d)

The magnet used as the rotor in this arrangement is made out of two commercially available ceramic toy magnets, each of dimensions 3.6 cm × 1.2 cm × 0.35 cm, and having magnetic polarisation along the length of the bar (Fig. 2a). A thin metal rod, cut out of a spoke of a

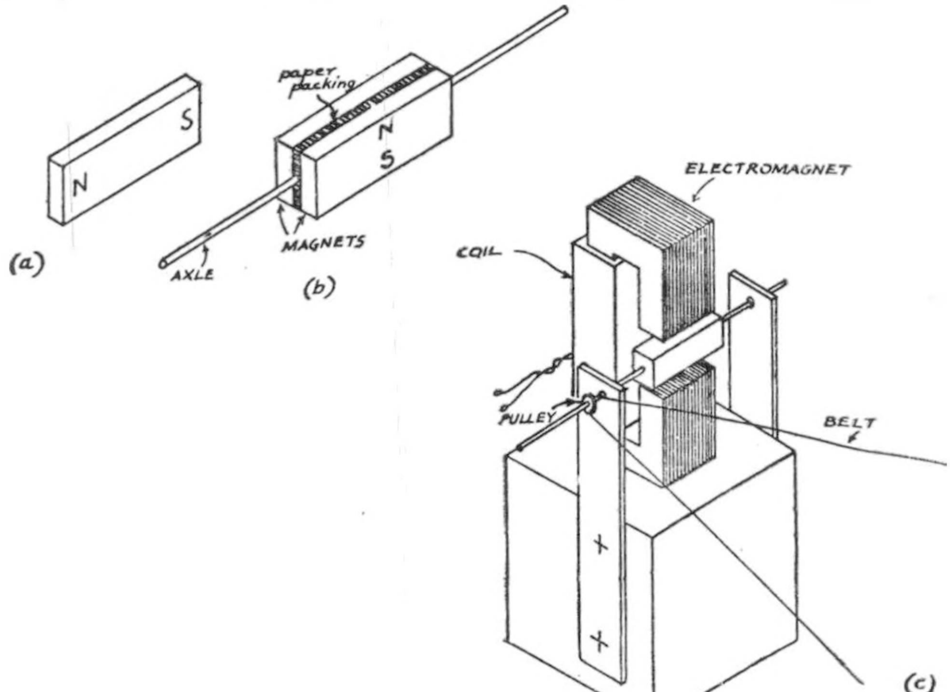


Fig. 2

bicycle wheel, is passed between the two magnets. The gap between the two magnets is filled with paper packing and the individual magnets are glued to the packing as well as to the axle by means of apoxy glue (Fig. 2b). The composite magnet is now remagnetised by hysterisis by placing it between the pole faces of a powerful electro-magnet so that it develops polarity as shown in Fig. 2(b). If, however, it is possible to find commercial toy magnets magnetised laterally (as in Fig. 2b), then this extra magnetising procedure (which requires access to a well equipped physics laboratory) is avoided.

This assembly, now completed, constitutes the rotor. The electromagnet is now clamped on a wooden block with aluminium strips and screws. The rotor is mounted on two thin aluminium plates (about 4 mm thick and 2 cm wide) screwed onto the sides of the wooden block as shown in Fig. 2c. The holes at the top of these plates provide a bearing for the axle of the rotor.

A thin pulley made out of aluminium is glued onto the axle (Fig. 2c). As shown in the photograph (Fig 4), a thin thread runs over this pulley and couples a wooden wheel of diameter about 15cm. This wooden wheel is mounted on another wooden block and the entire assembly, consisting of the rotor, the electromagnet, the wooden wheel and their supports are all firmly fixed on a wooden base. This completes the mechanical part of the device.

The electrical part consists of two sets of connections for two different modes of operations, *viz.*, the motor mode and the generator mode (Fig. 3).

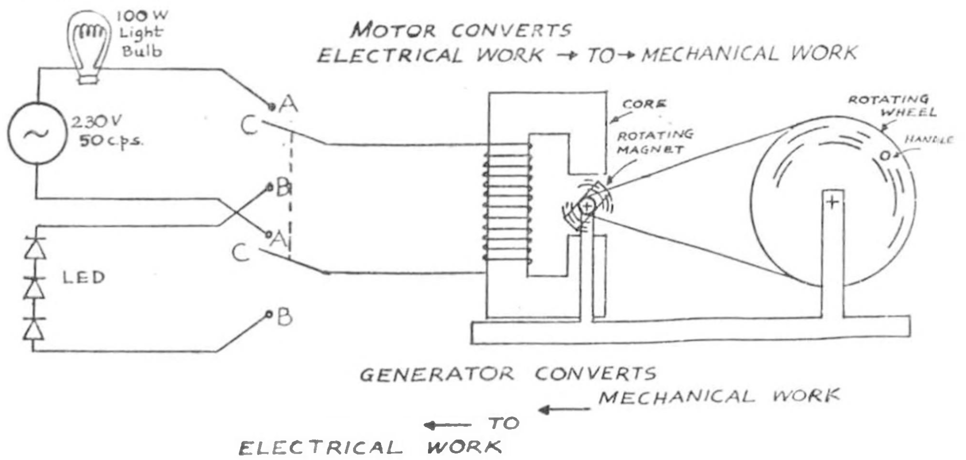


Fig. 3

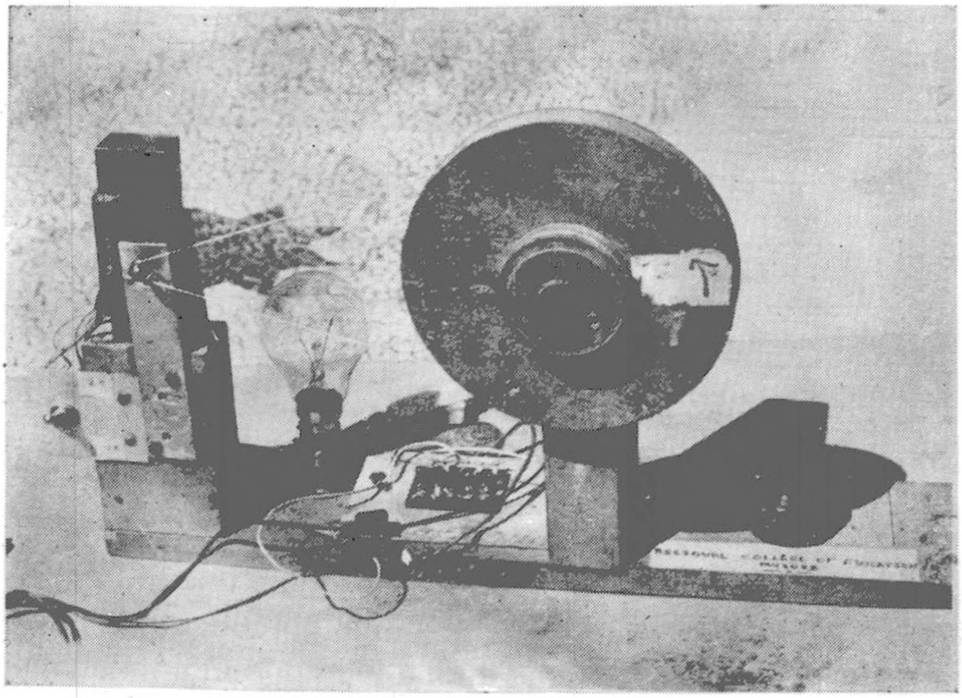


Fig.4 A photograph of the reversible work conversion machine

A view of the teachers from the schools of Mysore city experimenting with the models fabricated at our college workshop

For the motor mode, a 3-pin socket acts as the terminals from which electric power is received by the device. The electric current flows through a 100 W light bulb which acts as a simple resistor to drop the voltage from 220 V to about 60 V (Fig. 3). 3-pin socket is used as a safety measure (see p. 22).

For the generator mode three LED's (light emitting diodes) in series are used for receiving the electric power (Fig. 3). Four or five LEDs can also be used if connected in parallel. These LEDs are mounted on a patch board and are fixed on the wooden base of our device.

The thin enamelled copper wires from the electromagnet terminate on a 3-pin plug. This plug is to be connected to the above mentioned 3-pin socket when the device is acting as a motor, or to the crocodile clips of Fig. 4 when acting as a generator.

3. How to use this device.

(a) *As a Motor*: In the schematic diagram of Fig. 3 this mode of operation is achieved by connecting the terminals CC to the terminals AA. In actual practice the 3-pin plug is connected to the 3-pin socket which receives electrical energy from the 220 volt—50Hz mains through the 100 W light bulb. The 100 W bulb acts to reduce the voltage across the terminals of the electromagnet to about 60 V.

After this connection is made, the rotor magnet M will be found vibrating with its magnetic axis vertical. When experimenting for the first time, it is advisable to decouple the wooden wheel from the magnet by removing the belt. The protruding end of the rotor axle should now be given a sharp twist with fingers either in the clockwise or in the anticlockwise direction. This will induce rotation of the rotor inside the gap.

The rotor will rotate at 50 Hz, that is, at the frequency of the mains. The magnet will change its direction every time the direction of the magnetic field changes and, since the magnetic field alternates 50 times per second, the magnet will also rotate 50 times per second.

The wheel can now be coupled to the rotor M. The rotor is made to pick up the initial rotation by forcing the wooden wheel to rotate by hand. As the magnet M starts rotating in response to the alternating magnetic field, it will continue to transmit rotation to the wheel at a constant angular speed. One can actually measure the number of revolutions of the wheel, *f* per second, by means of a stop watch. If the diameters of the wheel W and the pulley on the rotor axle are also measured, the ratio of the numbers of revolution of the wheel and of the magnet in a given time is determined. Thus, by measuring the r.p.s. (revolution per second). of the wheel, one can determine the r.p.s. of the magnet. The interesting lesson that a school student can very profitably draw by conducting this experiment with a stop watch and callipers is that the household alternating current changes its polarity a fixed number of times per second and that the frequency is 50 Hz in our country.

(b) **As a generator.** In the schematic diagram of Fig. 3 this mode of operation is achieved by connecting the terminals CC to the terminals BB. In actual practice the 3-pin plug at the end of the enamelled wire from the electromagnet is connected to the crocodile clips feeding electrical impulse into the LEDs.

For generation of electrical voltage, the wheel W is rotated with hand. This forces the rotor magnet to rotate between the pole faces of the electromagnet. As a result, the LEDs glow.

Rotation of the wooden wheel is facilitated by fixing a handle near the rim of the wheel as seen in the photograph (Fig.4). For the dimensions we have used a rotation of the wheel of about 3 r.p s. (revolutions per second) corresponds to about 54 r.p.s. of the rotor magnet and results in the induced emf of about 6 V across *open* terminals of the winding wires of the electro-magnet, *i.e.*, across the open plug pins.

Even though the open circuit voltage is around 6 V, this will not be able to make even a 2-volt torch light bulb glow because such a bulb presents a very low resistance. Most of the emf will be lost in the coil around the electromagnet.

In order to prevent this loss of emf, LED's have been used in our device. LED's will present large resistance, and therefore almost no current will flow, unless the induced emf in the coil is 2 V. Current will flow only after dropping 2V across each LED. The remaining emf will be distributed over the coil. Thus, the LED's not only clamp the voltage across themselves at approximately 2V, but also prevent excessive current.

4. Concepts illustrated by the device.

The following concepts can be illustrated by the proposed device when it is working as :

I Generator :

(a) Faraday's law of electromagnetic induction—the *emf* generated around a coil is proportional to (i) the rate of change of magnetic flux linking the coil, (ii) number of turns linking the coil.

(b) Principles of electric power generation.

(c) Mechanical work can be converted into electrical work.

II Motor :

(a) Household alternating current/voltage alternates direction/polarity 50 times every second in India.

(b) A magnet follows the direction of the magnetic field even when the latter alternates—this tendency being utilised in the construction of synchronous motors.

(c) Electrical work can be converted into mechanical work.

III Both :

An electric motor and an electric generator are of the same basic construction but perform two different tasks depending on whether the input is electrical work or mechanical work.

The class-room teacher has to devise his own method of illustrating each one of the above concepts through this device. For example, the concept (Ia) can be illustrated by varying the speed of rotation of the wheel, the number of turns in the coil and measuring the open circuit voltage for different values of speed of rotation and number of turns.

5. Safety measures.

(a) The 3-pin plug and the 3-pin socket have been recommended in order to eliminate possibility of receiving electric shock. Using a line tester, the teacher should determine which one of the two terminals of the mains is live. The 100 W bulb in Fig. 3 should be fixed towards the live terminal and the transformer towards the neutral terminal. The 3-pin plug and socket will ensure that there is no mistake in connecting the device according to the above prescription. The electromagnet will now be safe because, even if due to erosion of insultation the body of the device is shorted to the line, the maximum voltage the experimenter can be subjected to will be around 60 V only.

(b) The body of the electromagnet and the pole faces inside the gap should be covered with an insulation tape. After the coil is wound on the coil frame, the coil and the frame should be adequately covered with cellotape so that the winding wire does not touch the body of the core of the electromagnet.

6 Acknowledgement.

Dr. B. Vema Reddy suggested that LED's should be used. when the author was having difficulty with torch light bulbs. T. Venugopal fabricated the wooden wheel according to the author's instruction in the college workshop and he was guided by Mr. S. Mohanta. The author is grateful to all of them.

CHAPTER 4

Magnetic Dipole Antenna Receiver to Illustrate Faraday's Law

1. Description of the teaching aid.

We are calling the building blocks of this teaching aid magnetic dipole antenna and receiver, although they are different from conventional radio antennas and receivers.

The antenna here is simply a bar shaped electromagnet with a ferromagnetic core and is acting as the transmitter of the electromagnetic field. This core is made out of laminae of size 5.5 cm$\times$1.2 cm and are cut out from one of the limbs of a condemned tube light choke (see Fig. 1a of Chap. 1) using a hacksaw. The individual lamina are tied

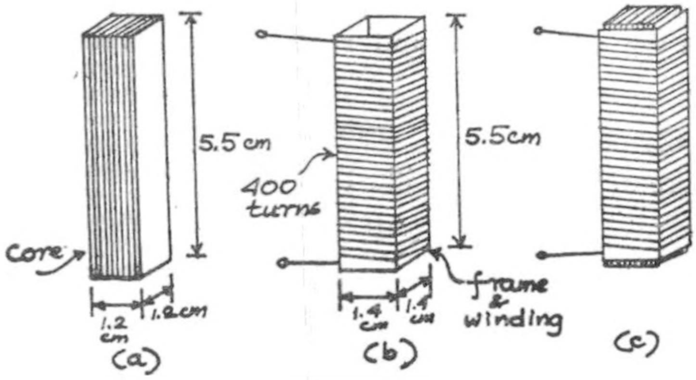


Fig. 1

together with cellotape to form this laminated bar (Fig. 1a) of dimensions 5.5cm$\times$1.2cm$\times$1.2cm. A frame of approximate size 5.5cm$\times$1.4cm$\times$1.4cm is now made (Fig. 1b) to contain this bar. (Fig. 1c). Approximately 400 turns of 33 gauge winding wire is wound around the frame before the bar is slipped into it.

The receiver is a rectangular frame (Fig. 2a) of dimensions 3cm$\times$3cm$\times$1.2cm on which a coil of about 300 turns of the above winding wire has been wound (Fig. 2b). A stand-by laminated core of dimensions 2.8cm $\times$ 2.8cm $\times$ 1.2cm is also made (Fig. 2c.) The frame with the coil wound on it should fit snugly onto the core (Fig. 2d) when necessary.

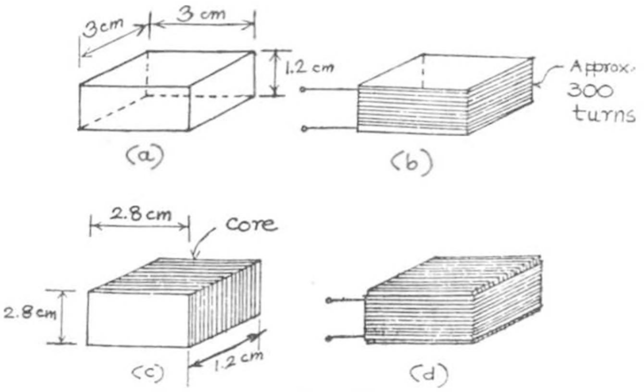


Fig. 2

Both the transmitter and the receiver terminate on crocodile clips. The receiver clips are connected either to an earphone or to a speaker. The antenna clips are connected to the leads coming from the speaker terminals or output terminals of a tape recorder. Thus, the transmitter is fed with electrical signals coming from a tape recorder. The receiver is to receive this signal without physical contact with the transmitter and is to play back this signal through the speaker.

2. Use of the device.

The use of the device is illustrated schematically in Fig. 3(a). The

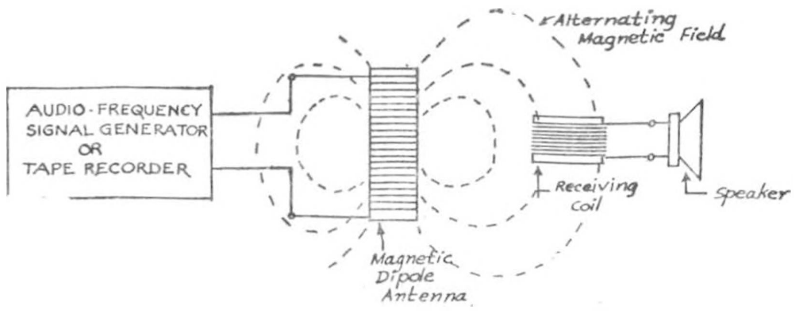


Fig. 3(a)

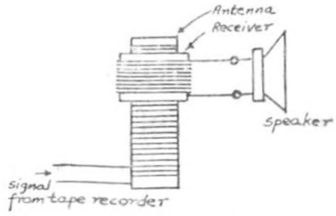


Fig. (3b)

transmitter produces its magnetic field which alternates with the frequency of the signal coming from the tape recorder. The alternating magnetic field produces a circulating electric field and hence, an *emf*, around the receiving coil. The *emf* drives an alternating current through the speaker and has the same frequency as that of the signal from the tape recorder. The speaker, therefore, reproduces the sound imprinted on the magnetic tape without coming into physical contact with the tape recorder.

The loudest sound from the speaker comes for the configuration shown in Fig. 3(b).

The ferromagnetic core can be inserted into the receiver for the configuration shown in Fig. 3(a), but not for the arrangement of Fig. 3(b).

A variation of this device is illustrated in Fig 4. Here the C–shaped electromagnet used for the multitap transformer (Chap. 1) or for the motor–cum–generator (Chap. 2) has been used as the antenna. The receiving coil has to be inserted into the gap between the pole faces of the electromagnet. In this case the transmitter and the receiver can be called the primary and the secondary coils of a transformer.

3. Why the device has been called a magnetic dipole antenna receiver?

Because a magnetic dipole antenna is essentially a coil through which alternating current is flowing. Such a coil produces magnetic

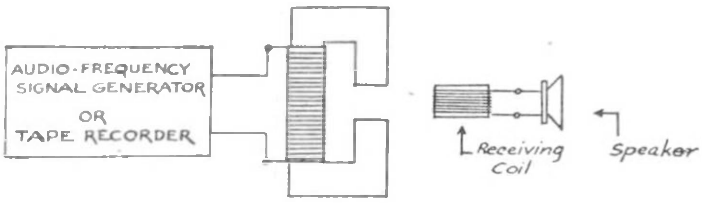


Fig. 4

field near the antenna as shown in Fig. 3. An electric dipole antenna (similar to those used for radio broadcasts) on the other hand, produces alternating *electric field* of the same pattern as shown for the magnetic field in Fig. 3. However, for both electric and magnetic dipole antennas, the field in the far away region (i.e. many wavelengths away from the antennas), called the radiation zone, consists of both electric and magnetic fields, each perpendicular to the direction of propagation (which is radially outward from the antenna) and also imutually perpendicular to each other.

In the present application the receiver is so near the antenna (distance between them being very small compared to one wavelength of electromagnetic wave which for a signal of frequency 300 Hz would be 106 km) that the electromagnetic signal received by the receiver should be called quasi-static magnetic field and not a electromagnetic wave.

4. Concepts illustrated with the device.

(a) Basic principle of transmission of radio waves. Any change in localised charge current distribution produces changing electromagnetic field everywhere.

(b) Faraday's law : Alternating magnetic field captured inside a coil produces an alternating electric field around the coil resulting in alternating current in the coil.

5. Acknowledgement :

The author had fruitful consultations with Dr. B. Vema Reddy during the execution of these experiments.