AERIALS

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TV AND FM RECEIVING AERIALS

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PREFACE

It was not so very long ago that the aerial was looked upon rather as the poor relation of the radio receiver.

Generally, when buying a radio set we judge the styling and enquire as to the performance, but disregard the fact that the fullest advantage can be taken of the performance, which includes sensitivity, satisfactory short-wave reception and quality of tone, — all very important details in themselves — only if the aerial to which the set is to be connected is installed in the proper manner and also meets certain conditions. For the best results the receiver and the aerial should be regarded as integral parts of a whole receiving system.

With the introduction of F.M. broadcasting and of television the importance of the aerial has come more to the fore, especially since a TV set can be a source of much irritation if used with an unsatisfactory aerial, or with one that has not been properly erected. Interference is thereby introduced which is a direct result of the shortcomings, either of an aerial itself, or of the down-lead to the receiver. Echoes, which take the form of ghosts in the picture, poor definition and interference picked up externally are among the troubles encountered.

In this book, which introduces the reader to various types of aerials, the many problems are considered only from the practical angle. A search through these pages for abstruse mathematical arguments will thus be in vain, for the work deals strictly with the different kinds of aerials and the difficulties encountered in practice by those whose job it is to install them.

Eindhoven, November 1963

D. J. W. Sjobbema

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CHAPTER I

THE ENERGY TRANSFER FROM EMITTER TO RECEIVER

Introduction

The transfer of electrical energy from a transmitting station to a receiver takes place in three stages. It is first fed from the transmitter to the transmitting aerial, whence it is radiated in the form of radio waves. These waves, which carry the sound and picture information for radio and television, span the distance from the transmitting aerial to the receiving aerial, where they once more become electrical energy to drive the receiver. It follows, then that this transfer from transmitter to receiver must depend to a very considerable extent on the properties and the behaviour of both the receiving aerial and the radio waves.

Before commencing a discussion of radio waves, however, it is necessary to say something about electrostatic and electromagnetic fields.

Electrostatic fields

When two electrically charged bodies, for example spheres, are placed at a certain distance from each other an electrostatic field is set up in the space around them. Fig. 1 shows two spheres *A* and *B* carrying charges of opposite sign; sphere *A* is positively charged and sphere *B* is negative. Now, if a third sphere, carrying a positive charge, is placed at a point *C*, this will be subjected to a force which tends to displace it, for the positive sphere *A* exercises a repelling force (arrow K_A in the figure), whilst the negatively charged sphere *B* imposes an attracting force (arrow K_B) on the positive charge in *C*. It is found that the magnitude of the force K_A is dependent on two factors, namely:

1. The extent of the charges in the spheres *A* and *C*.
2. The distance *AC* between the two spheres.

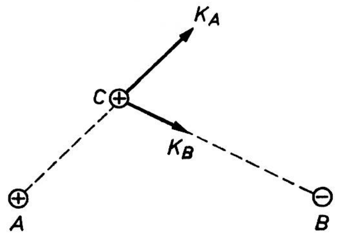

Fig. 1

The greater the charges in A and C, the greater the force K_A exerted upon C and vice versa. Also, this last-mentioned force is inversely proportional to the square of the distance AC; in other words the smaller the distance the greater the force exerted. Hence the force K_A can be said to have two attributes, i.e. a direction (the direction of the arrow K_A) and a magnitude. The arrow representing the force K_A is known as a vector, where the length of the arrow corresponds to the amount of the force.

What has been said in regard to the force K_A applies equally to force K_B, except that there the arrow points towards the negatively charged sphere B because B and C attract each other. Thus a force K_T operates on the positively charged sphere C which is equal to the sum of the forces K_A and K_B. The sum in this case is the sum of the vectors, which can be found by drawing a diagonal in the parallelogram the sides of which are the vectors K_A and K_B (Fig. 2). In general, such a vector sum is written:

$$K_T = \overline{K}_A + \overline{K}_B,$$

where the bars above the symbols K_A and K_B denote that the sum is not algebraic, but vectorial or geometrical.

Field strength

The strength of the electrostatic field at a given point is defined as the force to which a positive charge is subjected, per unit charge, at that point.

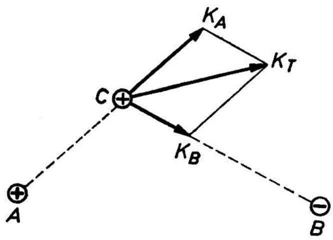

Fig. 2

In accordance with this definition the field strength at point *C* in Fig. 2 is K_T if the positive charge at that point is equal to the unit charge at *C*. Therefore, like the force, the field strength has magnitude and direction and can also be represented as a vector. From the above it is seen, then, that the magnitude and direction of the field strength at any given point must be dependent on the charges in the spheres *A* and *B* as well as on the position of the particular point relative to these spheres. In Fig. 3 the magnitude and direction of the field strength are shown at various points in the electrostatic field.

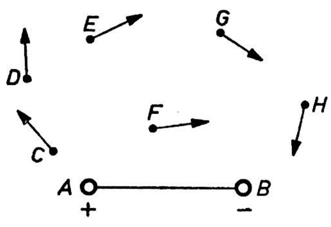

Fig. 3

Lines of force

It is usual to represent electrostatic fields by what are known as lines of force, defined as lines such that tangents drawn to them at a given point indicate the direction of the field strength at that point. Fig. 4 shows our electrically charged spheres *A* and *B* with the electrostatic field that exists in the air around them indicated by lines of force; these run from the positively charged sphere *A* to the negative sphere *B*. At three points

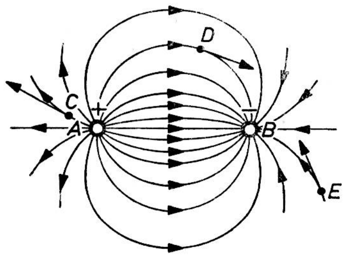

Fig. 4

in the field the direction of the field strength as it occurs at those points is also shown.

Potential difference

The potential difference between two points A and B in an electrostatic field is defined as the energy available per unit charge for transferring a positive charge from A to B. In an electrostatic field such as that

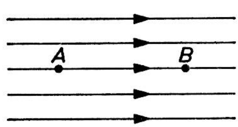

Fig. 5

depicted in Fig. 5 (homogeneous field) a positive charge at A is subjected to a force $K = F \times q$ which tends to displace it to the right (F is the strength of the field and q the magnitude of the positive charge). This force K is the same at every point between A and B because the field is uniform. It follows, then, that the work done in transferring the charge from A to B, i.e. for the distance A — B is equal to

$$A = K \times AB = F \times q \times AB. \quad (1)$$

According to the definition, this work is equal to the potential difference E between points A and B when the positive charge transferred (q) is equal to the unit charge. Thus the formula (1) can be written as

$$E = F \times AB. \quad (2)$$

In other words the field strength (F) is equal to the potential difference (E) per unit length (A — B) along a line of force

$$F = E/AB. \tag{3}$$

The field strength is accordingly usually given in volts per metre (V/m).

Example

Assuming the voltage between A and B to be 100 V and the distance between them 5 metres, the strength of the electrostatic field between these points will be:

$$F = E/AB = 100/5 = 20 \text{ V/m}.$$

Magnetic fields

When an electric current flows through a conductor, for example a copper wire, a magnetic field is set up round the wire. The presence of this field can be simply demonstrated with the aid of a magnetic needle; if a magnetic north-seeking pole is introduced at point A in Fig. 6, it is thereby subjected to a force that tends to displace it. In the same way as for electrostatic fields, both magnitude and direction can be attributed to this force, which can thus also be represented by a vector.

It is found that the direction of the force is governed by the direction in which the electric current is flowing; if this is from left to right along the wire shown in Fig. 6a, the force at point A will be in a backward direction, i.e. perpendicular to the plane of the paper. Conversely, if the direction of flow is from right to left, the force will act in the opposite direction, that is, upwards from the plane of the diagram (Fig. 6b). It should be noted here that the current flows from positive to negative, and not from negative to positive as in the case of electronic current.

The field strength at a point in a magnetic field is defined as the force to which a magnetic north-seeking pole is subjected at that point, per unit of magnetism (pole strength).

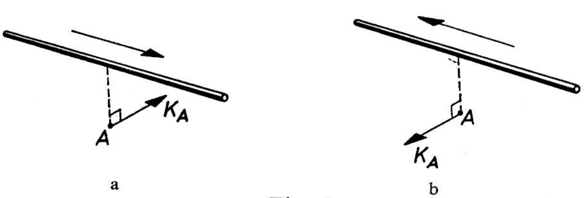

Fig. 6

According to this definition the direction of the field strength at point A is the same as that of the force K_A. The magnitude of the field strength at A is dependent on the current flowing in the wire and also on the distance of point A from the wire; it is proportional to the current I and inversely proportional to the distance r.

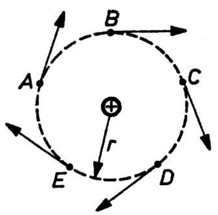

Fig. 7

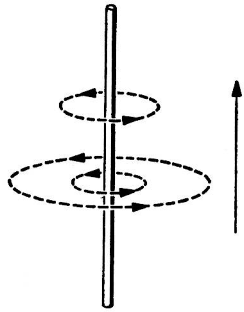

Fig. 8

Fig. 7 shows a circle drawn in a plane at right angles to the wire in which the current is flowing, the centre of the circle being the wire itself, with r as the radius. In accordance with the above definition the field strength is the same at all points on the circumference of this circle, the direction of the field strength being in each case at right angles to the radius. In other words, this direction at any given point is represented by the tangent to the circle at that point. This circle therefore conforms to the definition of a line of force as given above (see page 3). The magnetic field surrounding a wire carrying a current can accordingly be represented by lines of force in the form of concentric circles; Fig. 8 depicts a number of such lines of magnetic force surrounding a wire in which a current is flowing.

Electromagnetic fields

The above remarks concerning the magnetic field which surrounds a wire carrying an electric current refer to the case where a current is actually flowing through the wire, this current being the result of a potential difference between the extremities of the wire. Hence there will be not only a magnetic field but also an electric field. If the current is a direct current, a direct voltage will be present across the wire and there will also be an electrostatic field. The magnetic field set up by the current being constant, a certain condition of equilibrium then exists. With alternating current, however, a very different situation arises.

Fig. 9

Fig. 9 depicts two spheres *A* and *B* connected by means of a wire. Let us assume the condition whereby sphere *A* is positive and sphere *B* negative, but with no current actually flowing between them. In sphere *A* there is then a shortage of free electrons and in *B* a surplus, this condition being shown in Fig. 10a. At this moment, as no current is flowing, only an electric field exists around the wire; this field is represented in Fig. 10a by the paths of the lines of electric force. Now, as a result of the difference in the charges in spheres *A* and *B* a current will flow in the wire, that is, from *A* to *B*. (Note that we are not speaking of electronic current, which would pass from *B* to *A*). This current, which increases in strength, produces a magnetic field which also grows in strength. As an electric current is in effect a movement of mobile charge-carriers (electrons), the ends of the lines of electric force move towards one another. The charge in the meantime exists not only in the spheres, but also in the connecting wire, giving rise to the condition shown in Fig. 10b. Since the difference between the charges on the spheres decreases, the strength of the electric field also becomes less, whereas the magnetic field increases in intensity. A very short time later the current reaches its maximum, this being the moment when there is no longer any difference between the charges on *A* and *B*, i.e. the charge is then uniformly distributed in the spheres and connecting wire; the lines of electric force now reveal closed curves instead of curves which terminate at the charges on the spheres or wire as before. The magnetic field strength, which is directly proportional to the current flowing in the wire, is then also at a maximum, in accordance with the situation depicted in Fig. 10c. As will be seen from this figure, the lines of electric force form, as it were, a ring which diverges at a high velocity from the electric system; this velocity (in vacuum, but as an

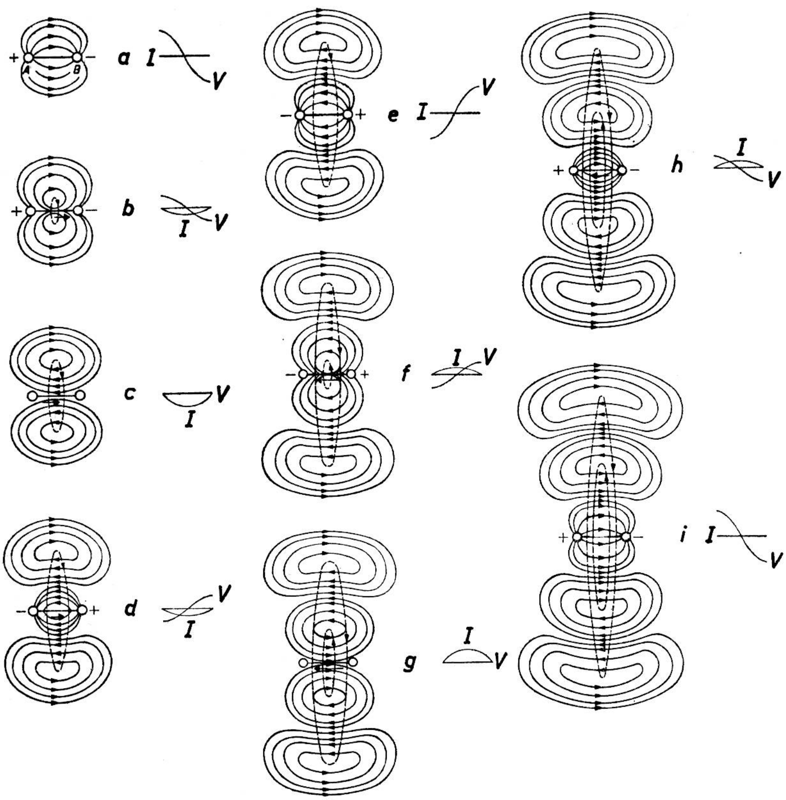

Fig. 10

approximation also in air) is found to be equal to the speed of light, i.e. 300 000 km/sec.

The current flowing through the connecting wire with decreasing strength now recharges the two spheres, i.e. it produces a difference in charge between them, but this time with sphere *B* positive with respect to sphere *A* (Fig. 10d). As a result of this difference in charge an electric field is again set up, differing, however, from the one previously discribed in so far that the lines of force now run from sphere *B*, which is positively charged, to sphere *A*. These lines of force have a repelling effect on the circular line of force produced in the previous phase and tend to depress it.

Subsequently the spheres will both be fully charged again; in other words no current will flow in the wire and a certain steady state is again reached (Fig. 10e). The strength of the electric field at that moment is at a maximum again, whereas the magnetic field strength is zero. The lines of magnetic force and also the closed lines of electric force produced in the previous phases of the process have now disappeared from the whole system of spheres and wire, being as it were pushed out by the new lines of force.

Figures 10f, g, h and i depict the successive phases of the development of the electromagnetic field as described above. In the light of the conditions as outlined, these phases should need no further elucidation, but it may be noted that the occurrence and growth of the electromagnetic field in Fig. 10 is depicted as taking place in the plane of the paper; in actual fact the process evolves in space around the electrical system. In order to clarify the nature of the electromagnetic field the two spheres have been redrawn in Fig. 11 with sphere *B* positively charged with respect to sphere *A* and current flowing through the connecting wire. Fig. 11 thus corresponds to Fig. 10f. Let us now consider the electromagnetic field present at the point *P* at that moment. To avoid making the issue too complicated the location of *P* has been so chosen that distances *AP* and *BP* are equal. The direction of the electric field strength at point *P* which, as stated above, is found by drawing the tangent to the line of electric force at *P*, is represented by the arrow *F*, and the direction of the magnetic field strength at point *P* by arrow *H*. It is seen at once from the figure that the electric and magnetic field strengths at the point *P* are at right angles to each other; the first (the electric field strength) varies in the

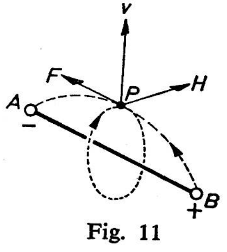

Fig. 11

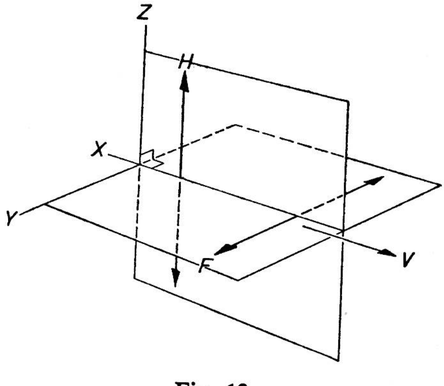

Fig. 12

plane of the paper and the other (the magnetic field strength) in the plane normal to the paper: propagation of the electromagnetic field, however, takes place in the direction *v*, as will be seen from the sequence of the phases (Fig. 10).

Three axes (*X, Y* and *Z*) are shown in Fig. 12, all at right angles to one another. If the electric field strength *F* in the horizontal plane as defined by the axes *X* and *Y* varies, the relative magnetic field strength *H* will vary in the vertical plane (axes *Z* and *X*). The direction in which the electromagnetic field develops is given by the *X* axis.

To return once more to Fig. 10, it is seen that zero magnetic field corresponds to maximum electric field (see Fig. 10a, e and i) and that, conversely, when the magnetic field strength is at its maximum the electric field strength is zero (Figs 10c and g). This means that there is a difference in phase of 90° between them. The three axes *X, Y* and *Z*, are again drawn in Fig. 13 with the successive intervals of time shown on the *X* axis, i.e. the line of intersection between the vertical and horizontal planes, which show the electric and magnetic field strengths at the point *P* in respect of the different times; the direction in which the field is propagated is here indicated by the arrow *v*. The phase difference between the electric and magnetic field strengths can now be clearly

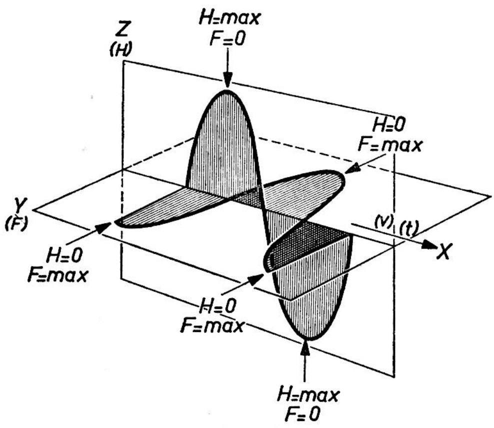

Fig. 13

observed. Electromagnetic fields such as those described above are known as quasi-stationary and they occur only at very short distances from transmitting aerials, or, in our example, from the spheres and connecting wire.