The
Marconi Review

. 113 2nd QUARTER 1954 Vol. XVII

CONTENTS:

Atmospheric Electricity and Long Distance Very High Frequency Scatter Transmissions - - - - - - - - 37

Book Review - - - - - - - - - - 60

Re-Radiation from Resonant Ship's Aerials - - - - - 61

Publication Notice - - - - - - - - - - 64

IARCONI'S WIRELESS TELEGRAPH COMPANY LIMITED

ead Office, Marconi House, Chelmsford *Telephone, Chelmsford* 3221 *Telegraphic Address, Expanse, Chelmsford*

THE MARCONI GROUP OF COMPANIES IN GREAT BRITAIN

Registered Office : Marconi House,
Strand,
London, W.C.2.

Telephone : Temple Bar 1577.

MARCONI'S WIRELESS TELEGRAPH COMPANY, LIMITED

Marconi House,
Chelmsford,
Essex.

Telephone : Chelmsford 3221.
Telegrams : Expanse, Chelmsford.

THE MARCONI INTERNATIONAL MARINE COMMUNICATION COMPANY, LIMITED

Marconi House,
Chelmsford,
Essex.

Telephone : Chelmsford 3221.
Telegrams : Thulium, Chelmsford.

THE MARCONI SOUNDING DEVICE COMPANY, LIMITED

Marconi House,
Chelmsford,
Essex.

Telephone : Chelmsford 3221.
Telegrams : Thulium, Chelmsford.

THE RADIO COMMUNICATION COMPANY, LIMITED

Marconi House,
Chelmsford,
Essex.

Telephone : Chelmsford 3221.
Telegrams : Thulium, Chelmsford.

THE MARCONI INTERNATIONAL CODE COMPANY, LIMITED

Marconi House,
Strand,
London, W.C.2.

Telephone : Temple Bar 1577.
Telegrams : Docinocram.

MARCONI INSTRUMENTS, LIMITED

St. Albans,
Hertfordshire.

Telephone : St. Albans 6161/5.
Telegrams : Measurtest, St. Albans.

SCANNERS LIMITED

Woodskinners Yard,
Bill Quay,
Gateshead, 10
Co. Durham.

Telephone : Felling 82178.
Telegrams : Scanners, Newcastle-upon-Tyne.

THE MARCONI REVIEW

No. 113. Vol. XVII *2nd Quarter, 1954.*

Editor: L. E. Q. Walker, A.R.C.S.

ATMOSPHERIC ELECTRICITY AND LONG DISTANCE VERY HIGH FREQUENCY SCATTER TRANSMISSIONS

By G. A. Isted

During an investigation into the behaviour of long distance transmissions on very high radio frequencies, a new phenomenon has been encountered which has a direct relation to electrical discharges from ordinary clouds in the lower atmosphere. Signals radiated in the 30–100 Mc/s band, and transmitted to distances of 500 Km and more, arrive at the receiver in a succession of impulsive bursts. Many of these impulsive bursts are arranged in trains having a very rigid time separation between bursts.

Evidence of cloud discharges, not necessarily amounting to lightning, has been obtained. These discharges are also often arranged in trains with time separations between discharges similar to the time separation of impulsive bursts. Although the discharges from clouds occur in the lower atmosphere the impulsive bursts of signal are reflected from localised pockets of ionization situated in the E region.

A theory has been evolved to show how electrical discharges from clouds can form pockets of intense ionization in the E region; furthermore, the theory suggests that ordinary clouds, distinct from thunderstorm clouds, may be the chief electrical generators which maintain the fine weather vertical potential gradient.

.. *It is also suggested that when energy is transferred from discharging clouds to fine weather areas, continuous partial ionization of the E region conduction path is set up and in extreme cases may result in the formation of Sporadic E.*

It is considered that the partial ionization of the E region by this transfer of energy, together with the impulsive bursts of ionization, is the main mechanism by which very long distance radio transmissions are achieved in the very high frequency band.

Introduction

FOR many years it has been considered that the utility of radio frequencies above 30 Mc/s is restricted to the optical, or near optical, ranges afforded by the combined aerial heights of the transmitter and receiver.

From time to time instances of successful transmissions considerably in excess of these ranges have been noted; many of these transmissions were due to special meteorological conditions of the lower atmosphere causing either elevated reflecting strata, or a deviation of atmospheric refraction from normal. Some instances were due to abnormal conditions in the E region of the ionosphere (E_s), and others to normal conditions of the ionospheric F_2 layer during the period of sunspot maximum.

From the point of view of reliable communication planning, the first two mechanisms, to all intents and purposes, are unpredictable. The third mechanism, although predictable, is only operative above 30 Mc/s for short periods in the years around sunspot maximum. In all three cases the utility of very high frequency radio wave transmissions is relatively short-lived.

Eckersley ([5]) ([6]) has shown that scattered signals from high-power short-wave transmitters, operating on frequencies well above the vertical incidence critical frequency, could be received at all distances through the skip zone up to extreme ranges. He has further shown that part of this scattered signal is of a random and sporadic nature, and emanates from clouds of ionization situated mainly in the E region. Eckersley also implies that as more and more power is radiated, so more and more of this type of scatter will emerge from receiver noise.

Eckersley refers to this type of scatter as " short-distance " scatter, but as this nomenclature is likely to introduce ambiguity and confusion into some sections of this paper, the term " impulsive " scatter will be used whenever the Eckersley " short-distance " scatter is referred to. " Impulsive " scatter does in fact describe the phenomenon more accurately, because the scatter echoes are impulsive in duration, in time of occurrence and in location within the E region.

Work done during the 1939–45 War, using very high power pulse transmitters, on frequencies around 60 Mc/s, showed that this impulsive scatter, described by Eckersley, was still present at these much higher frequencies.

No completely satisfactory explanation of the mechanism causing this impulsive scatter has yet been given, although it is known that meteors and meteoric dust, on entering the earth's upper atmosphere, evaporate and cause local clouds of ionization to be formed. The remainder of the scatter mechanisms are vaguely described as " momentary irregularities and turbulences " in the E region.

More recent work carried out in America by Bailey and others ([1]) has shown that this impulsive scatter, together with a residual ionization of the regular E region, was capable of producing coherent and sustained weak signals, over distances between 1000 and 2000 Km, on a frequency of 49 Mc/s. An attractive feature of this signal, from the communication point of view, is that it is ever-present, even during ionospheric disturbances when many of the orthodox radio-communication systems completely fail; moreover, it is claimed that this signal is actually enhanced during these disturbances—a fact previously pointed out by Eckersley in regard to impulsive scatter activity.

An investigation has been made by the author into the behaviour of signals, within the 30–100 Mc/s band, transmitted over relatively long distances, with particular regard to their detailed structure. The object of the investigation was to determine the amount of intelligence a given system of modulation would provide, on a radio communication channel utilising these scatter signal transmissions.

It was decided to commence the investigation by making use, during their normal transmission hours, of signals radiated from the B.B.C. Television sound transmitters situated in different parts of Great Britain. Other specific experiments, carried out over much greater distances, show that the character of signals at these greater distances is exactly the same as those described in this paper.

Apparatus was accordingly designed to permit the automatic recording of the signals in great detail, and for that reason sample recordings only were made at frequent but irregular intervals. No long term continuous automatic recording was undertaken.

During the course of these experiments a new impulsive scatter phenomenon was encountered, having a very strong association with atmospheric electricity. This particular phenomenon is the main concern of this paper.

FIG. 1
Disposition of Transmitters with respect to receiving site.

Description of Experimental Arrangements and Instrumentation

Experimental Arrangements

The transmitting stations mainly concerned in the experiments described in this paper are the B.B.C. Television sound transmitters situated at Wenvoe, Wales, and Kirk-o-Shotts, Scotland.

Reference to Fig. 1 will show at a glance the positions of these transmitters relative to the receiving site at Great Baddow, Essex, England.

Observations were made on the B.B.C. transmissions during their normal programme times which extended intermittently between 1000 and 2300 hours GMT (or BST).

The Kirk-o-Shotts and Wenvoe amplitude modulated sound transmitters radiate an effective mean power of approximately 26 Kw from omni directional, vertically polarized aerials, on frequencies of 53·25 and 63·25 Mc/s respectively.

The distances of Wenvoe and Kirk-o-Shotts from the receiving site are 290 and 530 Km respectively.

Radio Receivers and Recorders

In order to obtain a suitable signal to noise ratio with the weak signals available, narrow-band receivers are a necessity.

To make it possible to record simultaneously, signals radiated on two different frequencies, or a signal on the same frequency received under two conditions, the receiving apparatus is virtually a twin channel arrangement. It will be sufficient for the purpose of this paper to describe only one channel and to give the additional information that the second channel is a replica of the first.

A crystal controlled V.H.F. converter, capable of being tuned to a spot frequency between 38 and 95 Mc/s, precedes a standard type commercial H.F. receiver, used in this case as the intermediate amplifying stage. A pass-band-width of 1200 c/s is always used.

The second detector D.C. output of the H.F. receiver is connected to a D.C. amplifier, the A.V.C. and all time-constants greater than 0·01 seconds having already been removed. The output of the D.C. amplifier is then fed into one side of a twin channel high-speed moving coil recorder, the stylo of which leaves a permanent mark by electro-chemical action, on a suitably treated paper moving under the stylo at a constant speed.

The whole apparatus is capable of recording faithfully amplitude variations of signal up to a rate of 50 c/s.

Second time-marks are recorded in the centre of the recording paper by means of an impulsed fixed stylo.

The sensitivity of the whole receiving apparatus is such that a signal of —20 db with reference to 1 μV at the input to the V.H.F. converter will give a readable deflection above noise on the recording paper. Saturation of the receiver and recorder occurs at 1 μV ; thus a range of 20 db change in signal level can be comfortably accommodated within the minimum to maximum deflection of the recorder.

As an alternative to the twin channel recorder an impulse counter may be connected to the output of the D.C. amplifier and arranged to count the number of excursions the signal makes beyond any preselected amplitude.

A second recorder of the magnetic tape type is used to record signals from the normal audio frequency output from either receiver.

Receiving Aerials

Several aerials are used, all of which are tuned to spot frequencies in the 38–100 Mc/s band, and each capable of being arranged for the reception of either vertically or horizontally polarized waves.

Each aerial consists of a simple half-wave dipole and a single element half-wave reflector with a spacing between them of a quarter wavelength. The gain of these

" H " aerials is approximately 3 db with reference to a half-wave dipole. The aerial is connected to the receiver by a 70 ohm coaxial feeder having a loss of approximately 1 db. A " balun " transformer is used between the balanced aerial and the unbalanced feeder.

The aerials are installed about 20 feet from the ground and 140 feet above sea level.

" Static " Receiver

Evidence will be presented in this paper to show a relation between events which happen in the very high frequency radio band, and the incidence of impulsive electrical disturbances in the atmosphere.

In order to observe these electrical disturbances an unusual, yet very simple, receiver is used.

This receiver consists of a straightforward audio frequency amplifier having a gain of 70–80 db. A 30-foot vertical aerial is connected to the amplifier input. Precautions are taken to eliminate, by suitable filtering, long wave radio transmissions and the 50 c/s electrical supply voltages; consequently the pass-band of the arrangement is of the order of 200 c/s to 12 Kc/s.

The output of the amplifier can be connected either to the twin channel paper recorder, or to the magnetic tape recorder.

This receiver will be referred to as the " static receiver " in the following sections of this paper.

Ionosphere Sounder

Evidence will also be given in this paper to show the connection between ionospheric impulsive scatter, lightning, and events which happen in oblique transmissions of very high frequency radio waves.

The ionospheric impulsive scatter records were made by means of an ionosphere sounder, the technique of which is so well known that only the briefest description of the sounder used is necessary. Only the frequency of 10·6 Mc/s was investigated in this particular series of experiments, which was not conducted simultaneously with the very high frequency experiments under discussion.

The transmitter was modulated by 100 μS long pulses at a repetition rate of 25 per second. The peak pulse power radiated from the half-wave horizontal dipole was 25 Kw.

A vertical rhombic aerial, the polar diagram of which was directed vertically, energised a suitable receiver, the output of which was connected to an " A scan " cathode ray oscilloscope.

The transmitted pulse was arranged to trigger the oscilloscope time-base on which range marks appeared. A continuously moving film camera recorded the information given by the system.

A five-minute sample was recorded at hourly intervals over a period of approximately two years.

Experimental Results

Recordings of Kirk-o-Shotts Transmissions

The distance between the transmitter and the receiving site, and the combined heights of the aerials, results in a very non-optical path; the direct signal arriving at the receiver by means of diffraction and tropospheric mechanisms is, therefore, usually extremely weak. Nevertheless, a continuous signal of slowly varying amplitude, having a mean value of something less than 20 db below 1 μV/m, is observed.

Superimposed on this weak background signal is a succession of impulsive bursts of signal, the duration of which vary between 0·1s and 1·0s, and the amplitude of them varying from —15 to more than +10 db with reference to 1 μV/m. These bursts of signal will now be referred to simply as " bursts."

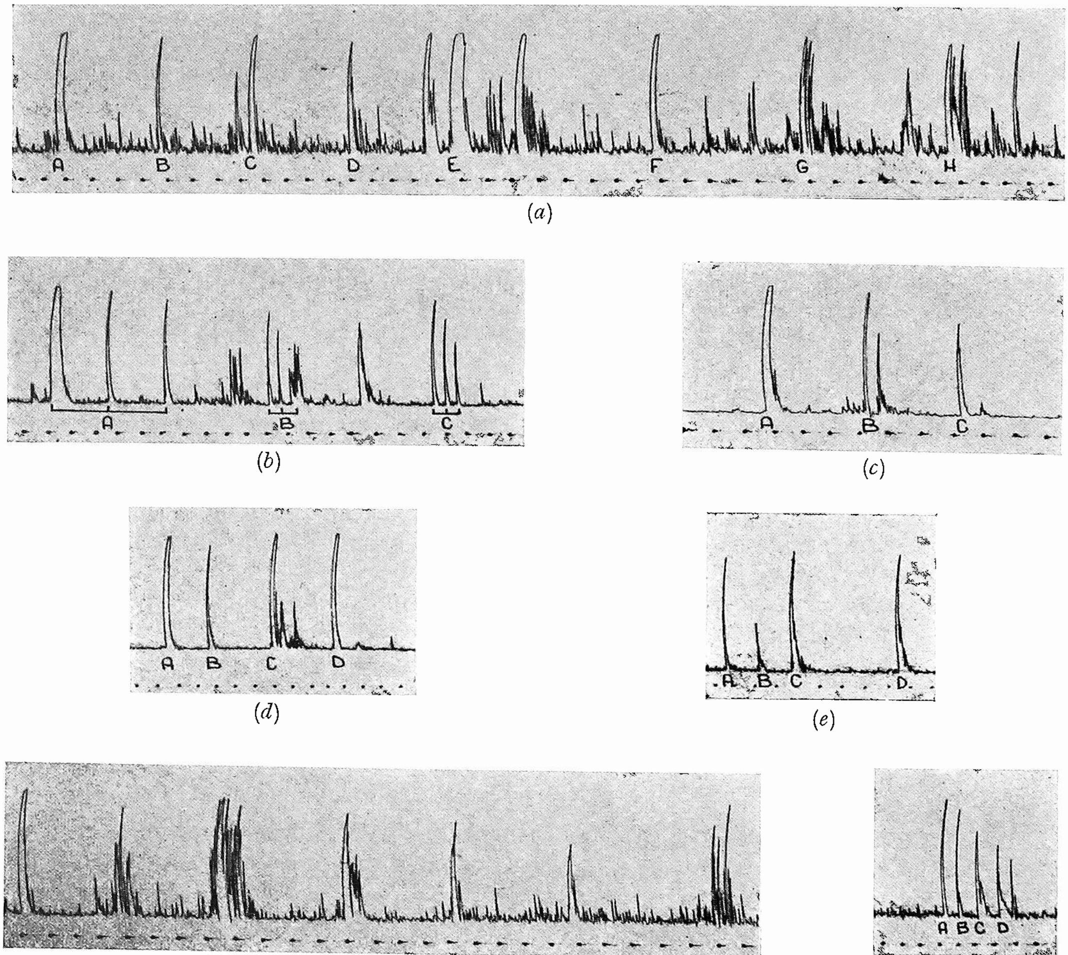


FIG. 2

Recordings of Kirk-o-Shotts Transmissions showing Equi-spaced Signal Bursts.

A typical portion of a record, taken at Great Baddow, of the Kirk-o-Shotts transmission is shown in Fig. 2 (a). In this particular case only one receiver has been used, consequently only one trace of the twin channel recorder is seen.

Increases of amplitude appear as vertical deflections. Time increases from left to right and is marked off in this instance at second intervals along the foot of the record. The ragged base line of the record represents the weak background signal; set-noise in the absence of the signal only just breaks the base-line.

It will be seen that within a period of 45 seconds sixteen notable deflections occur. Many of these deflections reach the limiting deflection of the recorder; this limit is indicated by the square top to the deflections.

All these deflections represent sudden increases in signal amplitude of values between 5 and at least 20 db above the mean background signal. The actual amplitude calibration of the recorder is unimportant from the point of view of this paper; it will be sufficient to state that it is approximately linear in db except at maximum and minimum deflection where a small amount of compression takes place.

The curvature of the leading and lagging edges of the bursts is caused by the radial motion of the recorder stylo.

A casual inspection of Fig. 2 (a) suggests a semblance of regularity in the occurrence of the stronger bursts, and closer inspection does, in fact, reveal some surprising time relations between them. It reveals, for instance, that a time separation of 4·5s exists between bursts C and D and between D and E; the same time separation exists between A and B. A regular spacing will be found between bursts F, G and H, but in this case the spacing is 6·0s.

From this we may deduce that at least three events have happened to cause this time relation. Event causing F, G and H is probably unrelated to the event which caused C, D and E, while event C, D and E is probably related to event A and B inasmuch as their time separation is identical.

Other events obviously occur between A and H which cannot be related, with the limited information on this particular record, to any other event.

A very good example of a triple burst is shown in Fig. 2 (b) at A, which has a time spacing of 2·4s between bursts; another good example, with a spacing of 0·5s, can be seen at C; a second triple, with the same spacing, can be distinguished at B although the third burst in this group is slightly confused by another burst.

A frequent variation of the triple grouping is illustrated in Fig. 2 (c). It will be seen that burst A has the semblance of a small secondary burst overlapping the tail of the main burst; at B the secondary burst has split well away from the main burst, while at C the split has progressed still further. Evidence of this progressive splitting can also be seen in Fig. 2 (a) at F, G and H.

Another very common type of multiple burst is reproduced in Fig. 2 (d) where it will be seen that bursts B, C and D have a regular spacing of 3·2s. This triple burst is preceded by an associated burst, A, which has no obvious time relation with the rest of the event. It is possible that double splitting may be occurring at C and D.

It is frequently found that some bursts in a multiple train are missing, as is shown in Fig. 2 (e), where it is found that there is a spacing of 1·6s between bursts AB and BC, while the spacing between CD is 4·8s. This suggests that, in this particular record the fourth and fifth bursts in a train of six failed to arrive.

Not all the identifiable multiple trains of bursts have regular spacing. It will be seen in Fig. 2 (f) that seven bursts which suggest a regularity to the eye are, in fact irregular in their time spacing.

A combination of bursts that is very prevalent is the pair. Pairing has been deduced from the fact that a given spacing between two bursts is repeated several times, at random intervals, in the space of a few minutes. Another way of deducing pairs is by the configuration of individual bursts. Fig. 2 (g) illustrates the identification of pairs by configuration. Bursts AB, with a spacing of 1·0s, suggests a pair while CD, with a spacing of 1·3s suggests a second pair. Both pairs would seem to be unrelated one to the other.

From the evidence contained in these illustrations it is evident that some mechanism is capable of producing regularly spaced bursts of signal ranging from two bursts up to six or seven in number. There is a strong probability that the same mechanism can also produce single unrelated bursts.

At quite an early stage in these investigations, three important trends were noted.

Firstly, it was found that there was a marked difference in burst activity between mid-morning and mid-afternoon. The activity in the morning being far greater than in the afternoon in the ratio of about 2·5 : 1.

Secondly, that there was a marked decrease in activity during the winter months compared to the summer months.

Thirdly, that during periods of widespread fine weather the activity was very markedly less than during widespread bad weather. In particular, the fact emerged that the multiple trains of bursts are most likely to occur when cumulonimbus cloud is present.

Simultaneous Recordings of Wenvoe and Kirk-o-Shotts Transmissions

The burst activity from the Wenvoe transmitter is very much less than that

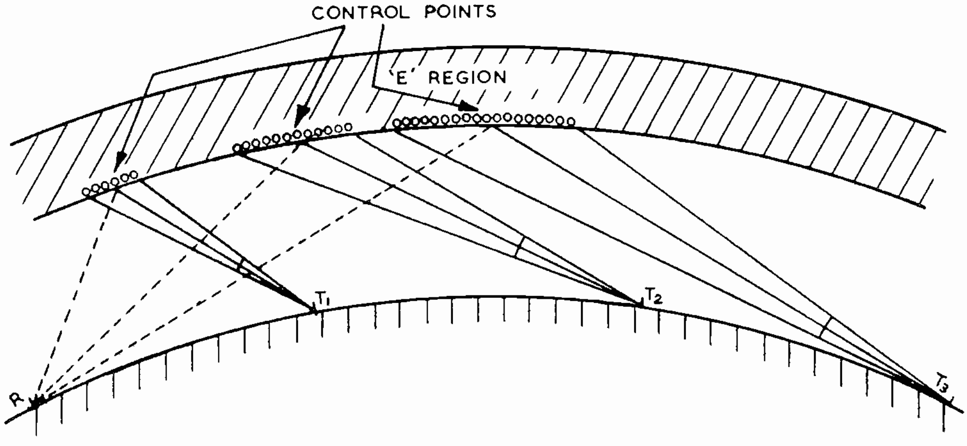


FIG. 3
Oblique Transmission Mechanism.

from Kirk-o-Shotts although the same general trends appear to be identical. This difference is attributable to the increased obliquity of the ray path of Kirk-o-Shotts compared to the ray path of Wenvoe. A brief reference to Fig. 3 will show that rays travelling from transmitters T_1, T_2 and T_3 to Receiver R, could be reflected at the mid-path control point in the E region. As the distance between R and T is increased the angle of incidence of the ray at the reflection control point becomes more glancing, and consequently the reflection coefficient at that point is increased for the more glancing angles, therefore for a given amount of ionization the reflection from it will be stronger and last longer than would be the case for shorter distances with correspondingly steeper angles of incidence. The number of random reflecting sources embraced by a given cone of rays will also increase as the incidence becomes more glancing at the control point.

The same diurnal trend is present on the Wenvoe transmissions as was noted on transmissions from Kirk-o-Shotts in that the signal is much less active in the mid-afternoon than in the mid-morning. Similarly the same difference is present between widespread fine weather and widespread bad weather.

In the case of the Wenvoe signal it is rather difficult to prevent the tropospheric wave from swamping the bursts completely.

In the main, there is a marked lack of correlation between signal bursts from Wenvoe and Kirk-o-Shotts but, at times, strong evidence is recorded that similar events happen at slightly different times along the two routes. Instances have been recorded showing a certain arrangement of signal bursts from Kirk-o-Shotts lagging as much as 4·2 seconds behind a similar signal arrangement from Wenvoe. These records, which are by no means unusual, suggest that a common agency affects the reflection control points at different times.

Simultaneous Recordings of Kirk-o-Shotts Transmissions and Lightning

In an early communication, pointing out the connection between multiple bursts and lightning, the author (10) stated that evidence had been obtained to show that separate bursts and pairs of bursts frequently followed a lightning flash. Since that time more opportunities have occurred on which to observe more carefully the events which happen during lightning storms.

The statement made in the above communication has been confirmed but other important events, not appreciated at the time of the communication, have since been observed.

The following records, illustrating the behaviour of signal bursts during lightning storms, were made by arranging for one radio receiving channel to record the Kirk-o-Shotts signal, (and inevitably the lightning flash " atmospheric "), and the second channel to record the " atmospheric " alone by detuning the receiver away from the Kirk-o-Shotts frequency. By this simultaneous method of recording, radio bursts and lightning flashes can be clearly identified.

The event recorded on Fig. 4 (a) shows radio frequency bursts A, B *preceding* a lightning flash atmospheric C. The time separation between the two bursts and between the second burst and the flash is 3·0s.

In Fig. 4 (b), burst A precedes a flash B which is in turn followed by another burst C. The spacing between the burst and the flash and between the flash and second burst is 4·2s.

A flash followed by two bursts is shown in Fig. 4 (c). The spacing in this particular case is not so accurate as in other examples of this combination.

A very complicated train of events is illustrated in Fig. 4 (d). A, B, C, D and E are all spaced 3·3s ; of these B and E are flashes. F, H, I and J are all spaced 7·0s and of these H is a flash. F, G and H are equally spaced and of these G and H are flashes. It would thus appear that F and H are common to two trains. At K a burst immediately follows a multiple lightning flash, a fairly common occurrence.

Lastly in this series of lightning flash records Fig. 4 (e) shows three lightning flashes spaced 1·4s apart. From an inspection of the top trace one would suspect also that bursts occur simultaneously with the flashes.

Simultaneous Recordings of Kirk-o-Shotts Transmissions and Electrostatic " Clicks "

If the output of the " static " receiver is connected to the high-speed paper recorder a succession of extremely short clicks can be seen on the trace.

These clicks sound, to an experienced observer, quite different from the characteristic sound produced by lighting flash discharges, but there is no doubt that they indicate rapid changes of an electric field.

The analysis of these records is extremely difficult on account of the great number of clicks of varying amplitude recorded in a period of a minute ; nevertheless the evidence clearly shows that pairs of clicks, and multiple trains of clicks with regular spacing, very frequently occur.

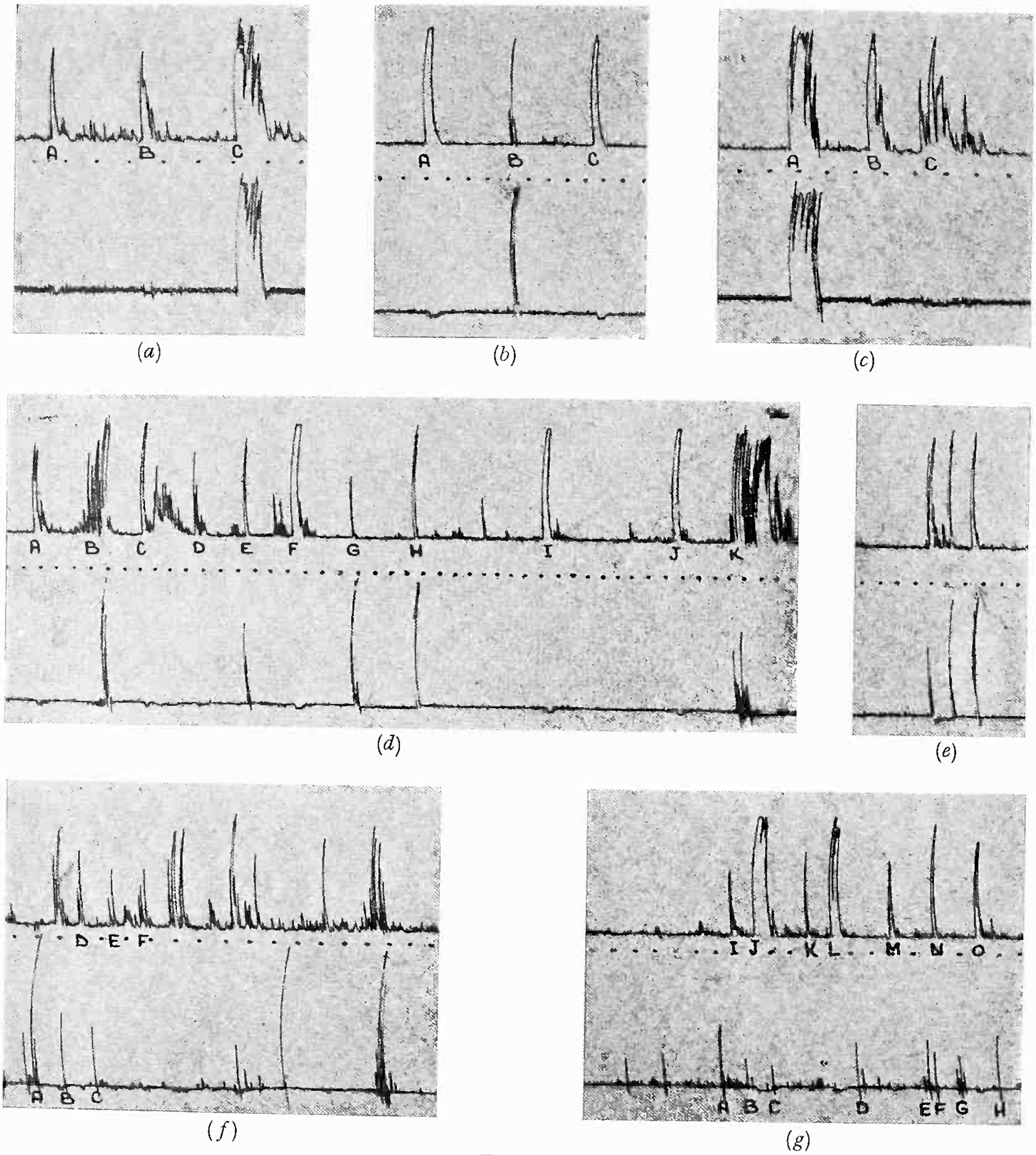
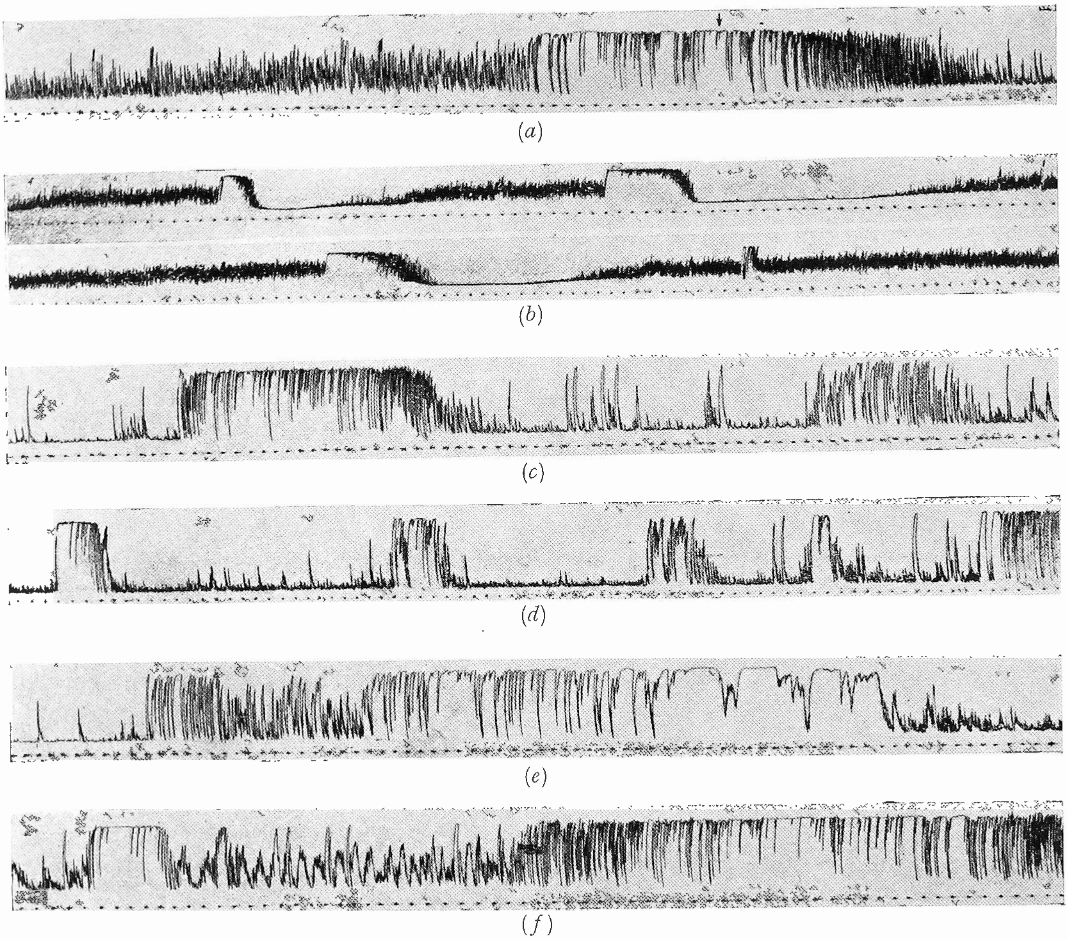


FIG. 4

Recordings showing connection between Kirk-o-Shotts Signal Bursts and Lightning (a), (b), (c), (d) and (e). The connection between Signal Bursts and Atmospheric "Clicks" is shown in (f) and (g).

The time intervals between paired clicks, and multiple trains of clicks, are of the same order as the time separation between pairs, and multiple trains, of radio bursts. Moreover, the activity of clicks shows the same trends as the radio bursts.

In the simultaneous record reproduced in Fig. 4 (f), the Kirk-o-Shotts signal appears on the top trace and the static clicks on the bottom. It will be seen that three clicks, equally spaced by 1·3s, occur at A, B and C. Three bursts having the same spacing occur at D, E and F. If the two events are in fact associated, the bursts are retarded on the clicks by 1·8s.



(a)

(b)

(c)

(d)

(e)

(f)

FIG. 5

Examples of "Step" Bursts.

A further example of this type of record is reproduced in Fig. 4 (g). It will be seen that triple clicks A, B and C are equally spaced by 1·4s, and that a pair of clicks, F and G, occurring later on have the same spacing. Two pairs of bursts—I, J and K, L—have the same spacing as clicks A, B, C and F, G but otherwise there is no correlation between clicks and bursts; there is no correlation between the triple clicks D, E, H, having a spacing of 3·2s, with the triple burst M, N, O immediately above, and having a spacing of 2·0s.

Recordings of Non-repetitive Effects

Other effects attributed to electrical charges and discharges are very prevalent during stormy weather. Fig. 5 (a) is a relatively long recording of the Kirk-o-Shotts transmission. It will be seen that the signal builds up in a very ragged manner until a definite step of high level signal occurs. Within this step a lightning flash occurs at the point marked by the arrow ; immediately afterwards a fairly rapid decrease of signal down to the base-line takes place.

The records illustrated in Fig. 5 (b) were made during a local lightning storm, without precipitation ; the record consists entirely of static noise received on the V.H.F. radio receiver. The static noise builds up slowly over a period of time until a sudden step in intensity occurs ; lightning followed shortly after and caused the static noise to rapidly fall to zero. This last event was accompanied by an audible whistle of decreasing pitch at the audio output of the receiver. The complete cycle of events was repeated several times at irregular intervals and is typical of local storms.

It is interesting to note the similar characteristics exhibited by the two phenomena illustrated in these two records, particularly as they are both accompanied by lightning.

Long signal bursts, which are believed to be similar to the steps mentioned above are shown in Figs. 5 (c), (d) and (e), but in each case the initial build-up is not seen. No lightning flashes were identified during the period.

A frequent type of storm record is illustrated in Fig. 5 (f) where a low Doppler frequency shift beat can be clearly seen preceding a step. This Doppler beat is interpreted as being due to the reflection from a moving charged cloud beating with some other source of the same signal.

Recordings of Ionospheric Impulsive Scatter

The results obtained from oblique transmissions described on pp. 41 and 45, suggested that similar effects should be seen in records of impulsive scatter, made at vertical incidence on lower frequencies. A long series of these recordings, made during 1944 and 1945, were re-examined with greater care and, as expected, the same effects were clearly discernible. Some of these records, taken with the aid of the Ionospheric Sounder described in page 41, will now be discussed.

A typical record is reproduced in Fig. 6 (a).

In this record time increases from left to right ; an approximate time calibration is given on the top of this figure. The direction of the time-base of the oscilloscope is from the bottom to the top of the record. The heavy white lines running completely across the record from left to right are range marks and indicate units of fifty kilometres and the smaller intermediate white lines units of ten kilometres. The broad black band passing completely along the bottom of the record, where letters of the alphabet have been printed, is the direct ray travelling over the ground.

The sporadic black marks which occur above the ground ray, some of which have white circles scribed round them, indicate a ray returned after a short interval of time, from some reflection point at heights, or more strictly speaking, ranges, given by the white calibration marks.

A cursory glance at Fig. 6 (a) suggests that the impulsive scatter reflections, or echoes, are randomly distributed but a more careful inspection shows that this is very far from the truth. For instance, the echoes ringed with white circles and indicated by C, D, E and F underneath, are in fact regularly spaced in time by 12·0s. Echoes A and B have the same spacing as C, D, E and F. All these echoes occur within the range between 160 and 200 Km.

Echoes G, H and I are spaced 7·0s apart and occur at ranges between 130 and 150 Km.

In Fig. 6 (b) B, C and D are equally spaced by 9·0s while A, which is believed to be associated with B, C and D, is spaced from B by only 4·0s. This record is considered to be a perfect example of the same type of triple burst from Kirk-o-Shotts which has been illustrated in Fig. 2 (d).

A rather more complicated set of events is illustrated in Fig. 6 (c). Echoes A, D and G, occurring at about 360 Km, are equally spaced 9·0s. It will be noted that G is very much elongated and lasts for about 4·0s.

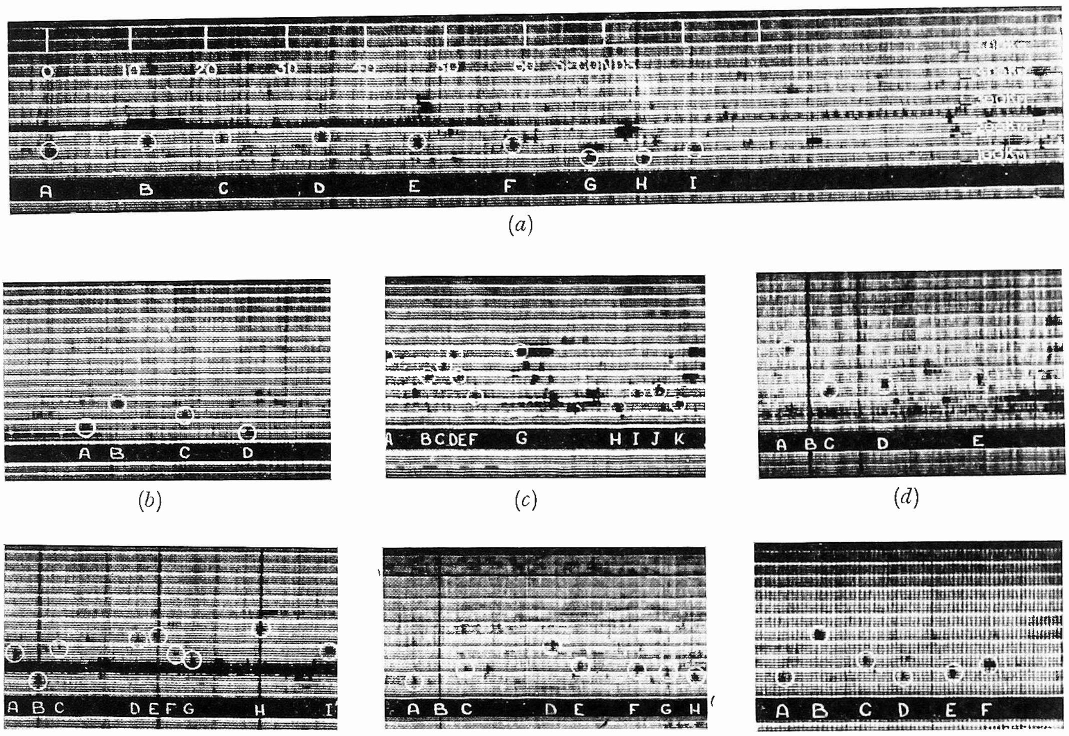


FIG. 6

Typical examples of Ionospheric Impulsive Scatter are shown in (a), (b), (c) and (g). The connection between Lightning and Impulsive Scatter is seen in (d), (e) and (f).

The quadruple train of echoes B, C, E and F are equally spaced by 2·0s while the quadruple train H, I, J and K is spaced 3·0s. Two pairs are probably present just below G.

Some connection has been found in these records between scatter echoes and lightning.

A lightning flash would cause a sharp black vertical streak to appear across the record. Interference from another transmitter on the same frequency would be likely to produce a much broader, and more diffuse band. The records now to be described are considered to be true examples of lighting.

One example of lightning is shown in Fig. 6 (d) at the position marked B. Echoes A and C are equally spaced by 3·0s on either side of the flash. It will be remembered that a record of lightning and radio bursts from Kirk-o-Shotts, showing a similar arrangement has been shown in Fig. 4 (b). Echoes A, D and E in

Fig. 6 (d) are all equally spaced by 9·0s. Thus it appears that two distinct events are related to lightning through echo A.

Three lightning flashes are shown in Fig. 6 (e) each of which is associated with three echoes. Related to flash B are echoes A and C displaced on either side of the flash by 3·0s; a third echo occurs at the position of the flash and is ringed in white.

D, E and F show the same arrangement with a spacing of 2·0s. G, H and I are similarly arranged with a spacing of 9·0s. In both cases an echo again appears at the same position as the flash.

A fairly continuous echo at 180 Km runs completely across the record and lasts for at least 42 seconds.

Another record showing scatter echoes related to lightning is shown in Fig. 6 (f). Scatter bursts A and C are equally spaced by 3s on either side of flash B. The two echoes, D and E, have the same spacing as the A and C echoes have with respect to flash B. A triple train of echoes with a spacing of 4s is present at F, G, H.

A record, which is not easy to interpret, is reproduced in Fig. 6 (g). There may be a triple echo train at A, C and E and another triple train at B, D and F; both of these trains have the same time spacing of 11·0s. Alternatively the record may be interpreted as containing three echo pairs AB, CD and EF, all of which have a spacing of 4·0s. Of the alternative interpretations, the latter is probably the true one. The lightning flash on the record does not appear to be related to any of the echoes.

These ionospheric impulsive scatter records provide striking confirmation that equi-spaced reflections do occur in the E region, and that they are often rigidly related to lightning.

Further work is needed to decide whether the apparent changes in height in a train of impulsive scatter bursts, as shown in the records, are really changes of height above the earth, whether they are geographical changes of position, or whether they are due to retardation in the E region.

Discussion of Experimental Results

General Discussion

Sufficient evidence has been submitted in this paper to establish, beyond reasonable doubt, the fact that multiple trains of ionization bursts, having fairly rigid time separations between bursts, are a very frequent occurrence and influence both very high frequency radio wave transmissions, and impulsive scatter echoes at lower radio frequencies.

Tests over a long period of time have failed to produce evidence that subsequent bursts in a multiple train are in any way echoes of the first. On the contrary, an analysis of magnetic tape recordings made of the modulation contained in the bursts from Kirk-o-Shotts indicate quite clearly that the modulation in each burst is not a replica of any preceding burst.

We are therefore forced to the conclusion that the mechanism causing multiple ionization bursts is a relatively local recurrent condition of the ionizing agent.

In a preliminary communication the author [10] suggested that these multiple bursts frequently followed a lightning flash. From the evidence submitted in this paper it is obvious that the mechanism is more complicated and probably more important than at first imagined.

With the object of determining whether these multiple bursts had any significant connection with known lightning storm centres, ten days on which multiple trains of bursts had been prolific were selected and compared with information supplied by the " Sferics " Organization of the Air Ministry Meteorological Office.

The result of this comparison showed that on only four days out of the ten under test were there lightning storms within the British Isles. On the other six days the nearest storm centres were either in the Azores or in the Balkans.

This information makes it certain that lightning is not essential to the production of multiple radio wave reflections ; but, should lightning storms be present along or near the radio path, there is a strong relationship between them and the multiple reflections.

In view of the unexpected result of this comparison, the investigation of these ten test days was carried a stage further by analysing the cloud formation of the British Isles, for evidence of cloud types which might have some association with lightning.

The Daily Weather Report of the Meteorological Office, London, contains a section devoted to classified cloud reports from fifty-six weather stations in the British Isles. Low, medium and high clouds are each classified under nine different types, the legend of which may be found in the Introduction to the Daily Weather Report.

The total number of reports of each cloud type during the day, averaged over ten days, was made the basis of comparison. The ten test days were compared with ten days selected at random, and with ten consecutive days during a long period of widespread fine weather.

The result of this comparison showed that the types of cloud significantly more prevalent on the test days than on both the randomly selected and the fine weather days were as follows :—

Low cloud :	No. 7.	Fractostratus or Fractocumulus of bad weather.
	No. 9.	Cumulonimbus, with cirroform top, often anvil-shaped.
Medium cloud :	No. 2.	Thick altostratus or nimbostratus.
High cloud :	No. 3.	Cirrus, often anvil-shaped ; usually associated with cumulonimbus.

This evidence suggests that some of the cloud formations usually associated with stormy, or bad weather, have some connection with the multiple radio wave reflections under discussion.

This evidence, together with the demonstrated connection of lightning with multiple reflections, leads one to believe that the prime cause of the regular recurrent condition of the medium must be situated in the clouds. On the other hand, the evidence contained in the recordings of impulsive signal bursts, from transmitters situated at different distances, indicates that the actual reflecting medium must be situated very much higher in the earth's atmosphere. This point is confirmed by evidence of the same type of multiple reflections occurring at vertical-incidence from the E region at lower radio frequencies.

Very strong evidence that an impulsive burst of signal is, in fact, produced when a cloud is discharged is shown in Fig. 7. This record, originally in a continuous strip, has been cut in two places for more suitable reproduction. It will be seen that a Doppler beat, interpreted as being produced by the reflection from a charged cloud beating with some other source of the same signal, stops suddenly in three places upon the arrival of an impulsive signal burst. The sudden stopping of the beat when an impulsive burst arrives can only mean that the charged cloud became discharged at that instant. This record was taken during a snowstorm but no lightning was observed. This type of signal continued for several minutes but a failure in the recording paper supply made it impossible to continue recording.

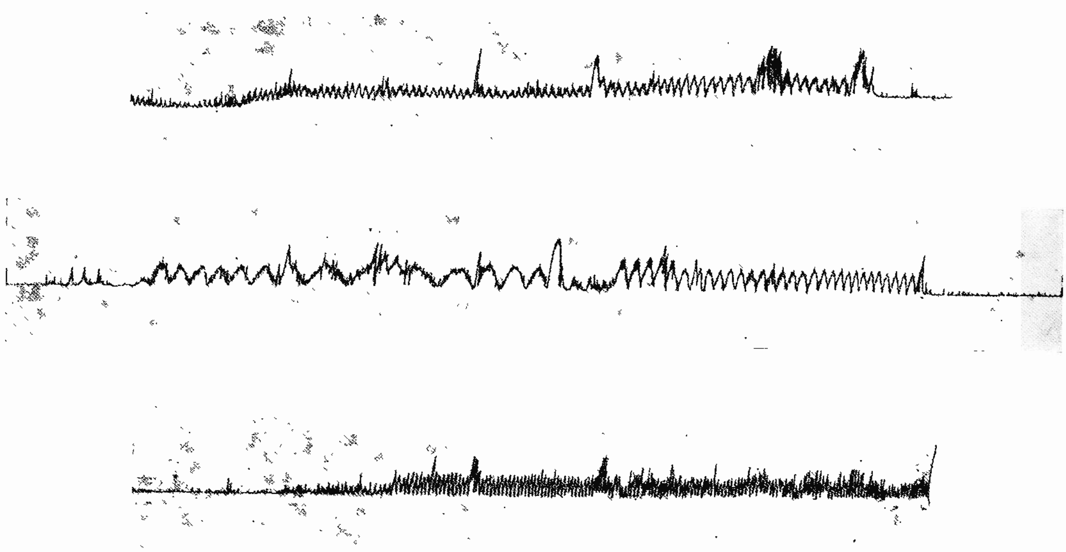


FIG. 7
Evidence of Signal Bursts occurring when a Charged Cloud is discharged.

We are confronted, then, with the fact that a charging and discharging cloud can cause recurrent ionization in the E region, and a theory must therefore be found which will rigidly connect the two phenomena.

Atmospheric Electricity

Let us, for a moment, consider what is already known about the relevant phenomena of atmospheric electricity.

The fundamental phenomenon of atmospheric electricity is the vertical electric field measured under conditions of serene sky. The magnitude of this vertical potential gradient near to the ground is of the order of 100 Volt/metre, positive with respect to earth. Care has to be exercised in making measurements of this potential gradient, for it is dependent upon the conductivity of the air. The air over land, and particularly that over large industrial areas, suffers greatly from pollution which seriously affects its conductivity and for this reason only measurements of the electric field made over the oceans, free from atmospheric pollution, are reliable.

Wilson ([14]) has suggested that this fine weather vertical potential gradient is maintained by energy generated by lightning storms all over the world, and has further suggested that the highly conducting E region of the ionosphere is the means by which lightning storm energy is transferred to areas of serene sky, where it leaks to earth by conduction through the air. Gish and Wait ([8]) have, indeed, found evidence of high conduction currents flowing from thunderheads upwards towards the E region. Whipple (13) has provided very convincing curves of the diurnal variation of world-wide lightning storms which are extremely well correlated with Mauchly's (11) curve of the diurnal variation of the fine weather vertical potential gradient over the oceans.

There is little doubt, therefore, that lightning storms do play a big part in maintaining the potential gradient and Wilson's theory is accepted by meteorologists as fundamentally correct.

The potential gradient in itself is relatively unimportant to the present discussion ; it is, however, evidence of a factor which will later be shown to be important. As the conductivity of the air over the oceans remains very nearly constant, and as the highly conducting E region is considered to be the distributor of energy, any variation of the vertical electric field must mean that the actual potential of the E region itself, with respect to earth, must also undergo a similar variation. We therefore infer that the potential of the E region has a diurnal variation similar to that of the vertical potential gradient.

To complete our picture of the essentials involved in the transfer of energy from storm clouds to the E region, we must understand that there is no fine demarcation between the E region and the upper atmosphere. It is known that the air between the E region and 5–8 Km from the ground is ionized by cosmic radiation and for this reason the conductivity of the air at 15 Km from the ground is so great that it is practically at the same potential as the more highly ionized E region some 70 Km above.

Discharging Clouds and E Region Ionization

With the evidence presented in this paper, together with what is already known concerning the origin of the fine weather potential gradient, it is now suggested that many ordinary cloud formations, not necessarily accompanied by lightning, contribute to the energy which maintains the E region potential. Frenkel (7) has made the same suggestion but, up till now, there has been no experimental evidence to support it. It would seem that these clouds are capable of discharging energy, not only in the form of a continuous conduction current, but at regular intervals upwards to the E region. Upon reaching the E region, which is already ionized mainly by solar radiation, the energy so released intensifies this ionization. The increased density of ionization is then capable of reflecting radio waves at frequencies which would normally have penetrated the regular E layer.

Let us consider in more detail, and with the aid of Fig. 8, how such a mechanism could operate.

The column of ionized air, between the E region and the cloud, may be likened to a gas discharge tube. As the charge across the capacity formed by the E region and a charging cloud reaches a critical striking potential, an ionization current flows upwards to the E region until the potential across the capacity falls below the critical value.

The regeneration of the charge across the capacity is a function, then, of the capacities and resistances in the system, and upon the rate of potential generation of the cloud. Provided that all these factors remain constant, the critical striking potential will be reached at regular time intervals.

Gish (9) states that the relaxation time of charge-cloud regeneration has an average value of about 5·0s. This statement lends considerable weight to this present theory, for, the experimental evidence indicates that the relaxation time

Fig. 6 (d) are all equally spaced by 9·0s. Thus it appears that two distinct events are related to lightning through echo A.

Three lightning flashes are shown in Fig. 6 (e) each of which is associated with three echoes. Related to flash B are echoes A and C displaced on either side of the flash by 3·0s ; a third echo occurs at the position of the flash and is ringed in white.

D, E and F show the same arrangement with a spacing of 2·0s. G, H and I are similarly arranged with a spacing of 9·0s. In both cases an echo again appears at the same position as the flash.

A fairly continuous echo at 180 Km runs completely across the record and lasts for at least 42 seconds.

Another record showing scatter echoes related to lightning is shown in Fig. 6 (f). Scatter bursts A and C are equally spaced by 3s on either side of flash B. The two echoes, D and E, have the same spacing as the A and C echoes have with respect to flash B. A triple train of echoes with a spacing of 4s is present at F, G, H.

A record, which is not easy to interpret, is reproduced in Fig. 6 (g). There may be a triple echo train at A, C and E and another triple train at B, D and F ; both of these trains have the same time spacing of 11·0s. Alternatively, the record may be interpreted as containing three echo pairs AB, CD and EF, all of which have a spacing of 4·0s. Of the alternative interpretations, the latter is probably the true one. The lightning flash on the record does not appear to be related to any of the echoes.

These ionospheric impulsive scatter records provide striking confirmation that equi-spaced reflections do occur in the E region, and that they are often rigidly related to lightning.

Further work is needed to decide whether the apparent changes in height in a train of impulsive scatter bursts, as shown in the records, are really changes of height above the earth, whether they are geographical changes of position, or whether they are due to retardation in the E region.

Discussion of Experimental Results

General Discussion

Sufficient evidence has been submitted in this paper to establish, beyond reasonable doubt, the fact that multiple trains of ionization bursts, having fairly rigid time separations between bursts, are a very frequent occurrence and influence both very high frequency radio wave transmissions, and impulsive scatter echoes at lower radio frequencies.

Tests over a long period of time have failed to produce evidence that subsequent bursts in a multiple train are in any way echoes of the first. On the contrary, an analysis of magnetic tape recordings made of the modulation contained in the bursts from Kirk-o-Shotts indicate quite clearly that the modulation in each burst is not a replica of any preceding burst.

We are therefore forced to the conclusion that the mechanism causing multiple ionization bursts is a relatively local recurrent condition of the ionizing agent.

In a preliminary communication the author [10] suggested that these multiple bursts frequently followed a lightning flash. From the evidence submitted in this paper it is obvious that the mechanism is more complicated and probably more important than at first imagined.

With the object of determining whether these multiple bursts had any significant connection with known lightning storm centres, ten days on which multiple trains of bursts had been prolific were selected and compared with information supplied by the " Sferics " Organization of the Air Ministry Meteorological Office.

The result of this comparison showed that on only four days out of the ten under test were there lightning storms within the British Isles. On the other six days the nearest storm centres were either in the Azores or in the Balkans.

This information makes it certain that lightning is not essential to the production of multiple radio wave reflections ; but, should lightning storms be present along or near the radio path, there is a strong relationship between them and the multiple reflections.

In view of the unexpected result of this comparison, the investigation of these ten test days was carried a stage further by analysing the cloud formation of the British Isles, for evidence of cloud types which might have some association with lightning.

The Daily Weather Report of the Meteorological Office, London, contains a section devoted to classified cloud reports from fifty-six weather stations in the British Isles. Low, medium and high clouds are each classified under nine different types, the legend of which may be found in the Introduction to the Daily Weather Report.

The total number of reports of each cloud type during the day, averaged over ten days, was made the basis of comparison. The ten test days were compared with ten days selected at random, and with ten consecutive days during a long period of widespread fine weather.

The result of this comparison showed that the types of cloud significantly more prevalent on the test days than on both the randomly selected and the fine weather days were as follows :—

Low cloud :	No. 7.	Fractostratus or Fractocumulus of bad weather.
	No. 9.	Cumulonimbus, with cirroform top, often anvil-shaped.
Medium cloud :	No. 2.	Thick altostratus or nimbostratus.
High cloud :	No. 3.	Cirrus, often anvil-shaped ; usually associated with cumulonimbus.

This evidence suggests that some of the cloud formations usually associated with stormy, or bad weather, have some connection with the multiple radio wave reflections under discussion.

This evidence, together with the demonstrated connection of lightning with multiple reflections, leads one to believe that the prime cause of the regular recurrent condition of the medium must be situated in the clouds. On the other hand, the evidence contained in the recordings of impulsive signal bursts, from transmitters situated at different distances, indicates that the actual reflecting medium must be situated very much higher in the earth's atmosphere. This point is confirmed by evidence of the same type of multiple reflections occurring at vertical-incidence from the E region at lower radio frequencies.

Very strong evidence that an impulsive burst of signal is, in fact, produced when a cloud is discharged is shown in Fig. 7. This record, originally in a continuous strip, has been cut in two places for more suitable reproduction. It will be seen that a Doppler beat, interpreted as being produced by the reflection from a charged cloud beating with some other source of the same signal, stops suddenly in three places upon the arrival of an impulsive signal burst. The sudden stopping of the beat when an impulsive burst arrives can only mean that the charged cloud became discharged at that instant. This record was taken during a snowstorm but no lightning was observed. This type of signal continued for several minutes but a failure in the recording paper supply made it impossible to continue recording.

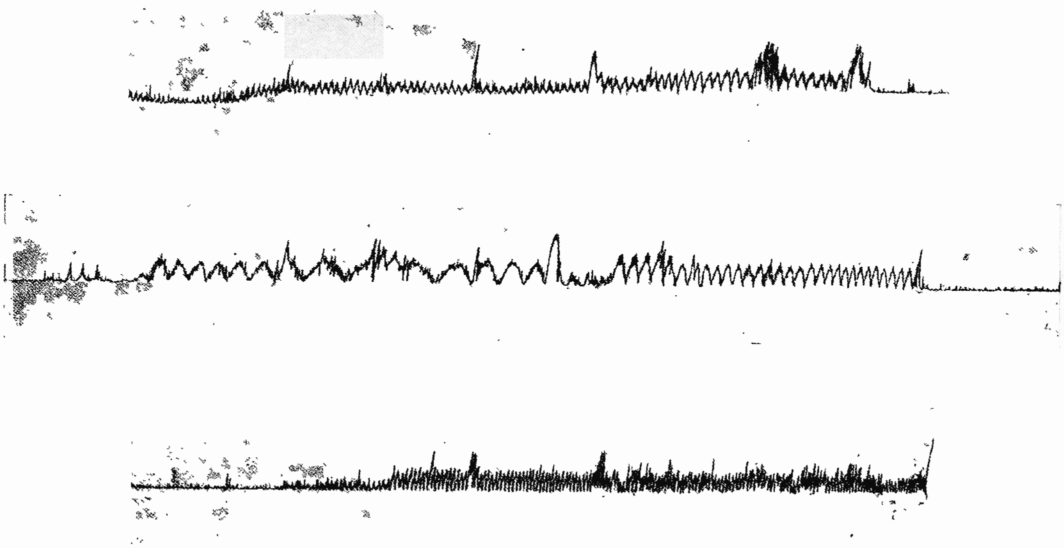


FIG. 7

Evidence of Signal Bursts occurring when a Charged Cloud is discharged.

We are confronted, then, with the fact that a charging and discharging cloud can cause recurrent ionization in the E region, and a theory must therefore be found which will rigidly connect the two phenomena.

Atmospheric Electricity

Let us, for a moment, consider what is already known about the relevant phenomena of atmospheric electricity.

The fundamental phenomenon of atmospheric electricity is the vertical electric field measured under conditions of serene sky. The magnitude of this vertical potential gradient near to the ground is of the order of 100 Volt/metre, positive with respect to earth. Care has to be exercised in making measurements of this potential gradient, for it is dependent upon the conductivity of the air. The air over land, and particularly that over large industrial areas, suffers greatly from pollution which seriously affects its conductivity and for this reason only measurements of the electric field made over the oceans, free from atmospheric pollution, are reliable.

Wilson (14) has suggested that this fine weather vertical potential gradient is maintained by energy generated by lightning storms all over the world, and has further suggested that the highly conducting E region of the ionosphere is the means by which lightning storm energy is transferred to areas of serene sky, where it leaks to earth by conduction through the air. Gish and Wait (8) have, indeed, found evidence of high conduction currents flowing from thunderheads upwards towards the E region. Whipple (13) has provided very convincing curves of the diurnal variation of world-wide lightning storms which are extremely well correlated with Mauchly's (11) curve of the diurnal variation of the fine weather vertical potential gradient over the oceans.

There is little doubt, therefore, that lightning storms do play a big part in maintaining the potential gradient and Wilson's theory is accepted by meteorologists as fundamentally correct.

The potential gradient in itself is relatively unimportant to the present discussion ; it is, however, evidence of a factor which will later be shown to be important. As the conductivity of the air over the oceans remains very nearly constant, and as the highly conducting E region is considered to be the distributor of energy, any variation of the vertical electric field must mean that the actual potential of the E region itself, with respect to earth, must also undergo a similar variation. We therefore infer that the potential of the E region has a diurnal variation similar to that of the vertical potential gradient.

To complete our picture of the essentials involved in the transfer of energy from storm clouds to the E region, we must understand that there is no fine demarcation between the E region and the upper atmosphere. It is known that the air between the E region and 5–8 Km from the ground is ionized by cosmic radiation and for this reason the conductivity of the air at 15 Km from the ground is so great that it is practically at the same potential as the more highly ionized E region some 70 Km above.

Discharging Clouds and E Region Ionization

With the evidence presented in this paper, together with what is already known concerning the origin of the fine weather potential gradient, it is now suggested that many ordinary cloud formations, not necessarily accompanied by lightning, contribute to the energy which maintains the E region potential. Frenkel (7) has made the same suggestion but, up till now, there has been no experimental evidence to support it. It would seem that these clouds are capable of discharging energy, not only in the form of a continuous conduction current, but at regular intervals upwards to the E region. Upon reaching the E region, which is already ionized mainly by solar radiation, the energy so released intensifies this ionization. The increased density of ionization is then capable of reflecting radio waves at frequencies which would normally have penetrated the regular E layer.

Let us consider in more detail, and with the aid of Fig. 8, how such a mechanism could operate.

The column of ionized air, between the E region and the cloud, may be likened to a gas discharge tube. As the charge across the capacity formed by the E region and a charging cloud reaches a critical striking potential, an ionization current flows upwards to the E region until the potential across the capacity falls below the critical value.

The regeneration of the charge across the capacity is a function, then, of the capacities and resistances in the system, and upon the rate of potential generation of the cloud. Provided that all these factors remain constant, the critical striking potential will be reached at regular time intervals.

Gish (9) states that the relaxation time of charge-cloud regeneration has an average value of about 5·0s. This statement lends considerable weight to this present theory, for, the experimental evidence indicates that the relaxation time connected with charging and discharging clouds has an average value of the order of 4·0s. This average value is based upon an analysis of 100 time-spacings of triple and quadruple trains of bursts selected at random.

The energy flowing to the E region from these discharging clouds causes short-lived intensification of ionization, and is then conducted away to fine weather areas, where it leaks away by conduction through the air to the earth. The circuit equilibrium is then completed by lightning discharges between ground and cloud and by point discharges from ground to air.

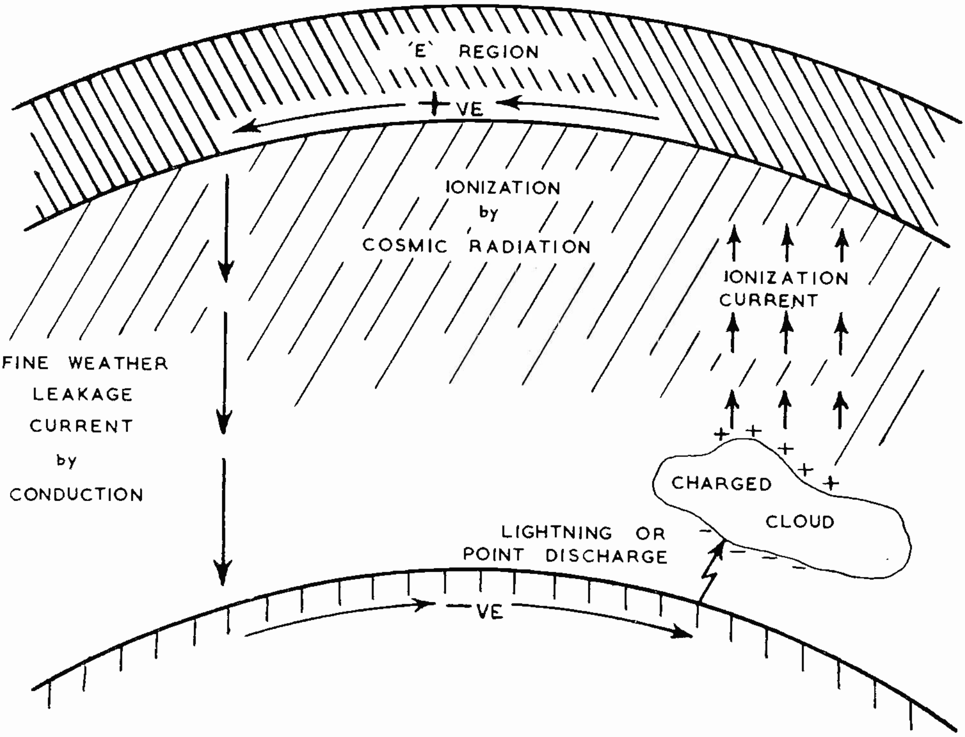


Fig. 8
Mechanism of Cloud Discharges.

No explanation has been given in this paper to account for the fact that a lightning flash, occurring in the lower atmosphere, can be rigidly related in time to recurrent cloud discharges in the upper atmosphere. Any explanation for this event must, for the present, be mainly guesswork, but it is possibly due to the need for an emergency establishment of potential equilibrium at an instant of particular stress, brought about by an upward discharge of energy from the cloud to the E region.

The clicks recorded by the static receiver and shown in Fig. 4 (f) and (g) are interpreted as being evidence of the change in electric field when cloud to E region discharges take place. Although no rigid correlation between clicks and radio wave impulsive bursts has been found under the present conditions of test it is probable that this correlation would be found if the clicks were observed immediately beneath the reflection control point.

The theory which has been suggested to explain the recurrent ionization in the E region, in terms of cloud impulsive discharges, is most probably an over-simplification. Many details most certainly remain to be filled in, but, if it is accepted as fundamentally correct, other things immediately fall into place.

The theory provides, in the first place, a much-needed explanation for ionospheric impulsive scatter which, in the past, has been attributed mainly to meteoric activity and irregularities in the E region.

It is well known that meteors, as they enter the earth's atmosphere, produce, upon combustion, a trail of ionization capable of reflecting radio waves up to fairly high frequencies. These reflections last anything from a few seconds to several minutes, and an experienced observer has no difficulty in identifying them by the characteristic initial Doppler frequency shift with which they are associated.

In the author's opinion most of the ionospheric impulsive scatter and the majority of impulsive bursts of signal received from the Kirk-o-Shotts transmitter, during the daytime, do not have their origin in meteors. Meteors possibly contribute no more than 0·1 per cent of these daytime bursts. This statement, for the present, has no statistical backing, and it is based entirely upon aural observations over a considerable period of time.

It should be pointed out, however, that some Doppler frequency shift does occur on many of the signal bursts in a train. When these bursts beat with the background signal the result is a kind of " grunt," and the indications are that there is a continuous frequency change, beginning at about 500 c/s, and ending at a few cycles per second.

A curve showing the diurnal distribution of ionospheric impulsive scatter is given in Fig. 9. This curve, marked " Ionospheric Impulsive Scatter " in the figure, has been compiled from hourly data of ionospheric soundings on a frequency of 10·6 Mc/s recorded over a period of nearly two years, and represents the average number of impulsive scatter echoes occurring in one minute for each hour of the day.

The curve, after Mauchly, in the same figure marked " Potential Gradient," represents the diurnal variation in the fine weather vertical potential gradient over the oceans, averaged over 47 days in one year.

It will be seen that there is a most striking negative, or anti-phase, correlation between the two curves.

Having good reason to believe that the fine weather potential gradient is maintained by lightning storms and having demonstrated the connection between cloud discharges, impulsive scatter, and signal bursts, it is reasonable to assume that the negatively correlated curves mentioned above are rigidly related.

It therefore seems probable that most of the impulsive scatter must be due to cloud discharges, with perhaps an exception to the rule in the early hours of the morning ; this period is believed to coincide with peak meteor activity.

However, Whipple's diurnal curve of world-wide thunderstorm activity, not shown in the figure, is positively correlated with Mauchly's potential gradient curve. Why, then, should the impulsive scatter diurnal curve, be negatively correlated with the potential gradient diurnal curve, when one would expect maximum scatter activity at times corresponding to maximum storm activity ?

The answer to this question would seem to be that as the potential of the E region reaches a maximum, as indicated by the potential gradient curve, the potential differences between clouds and the E region become less ; in consequence, the critical striking potential mentioned in the theory is reached less often.

The same explanation can be given for one of the important trends mentioned earlier in the paper. This concerns the marked difference between mid-morning and mid-afternoon burst activity of the Kirk-o-Shotts transmission and similarly of the impulsive scatter activity, see Fig. 9, where in both cases it is found that the mid-morning activity is some two and a half times greater than in mid-afternoon.

Another marked trend has also been noted in that the daytime burst activity of the Kirk-o-Shotts transmissions is considerably less in the winter than in the summer. This trend is also seen in the winter and summer curves grafted on to the Ionospheric Impulsive Scatter diurnal curve in Fig. 9.

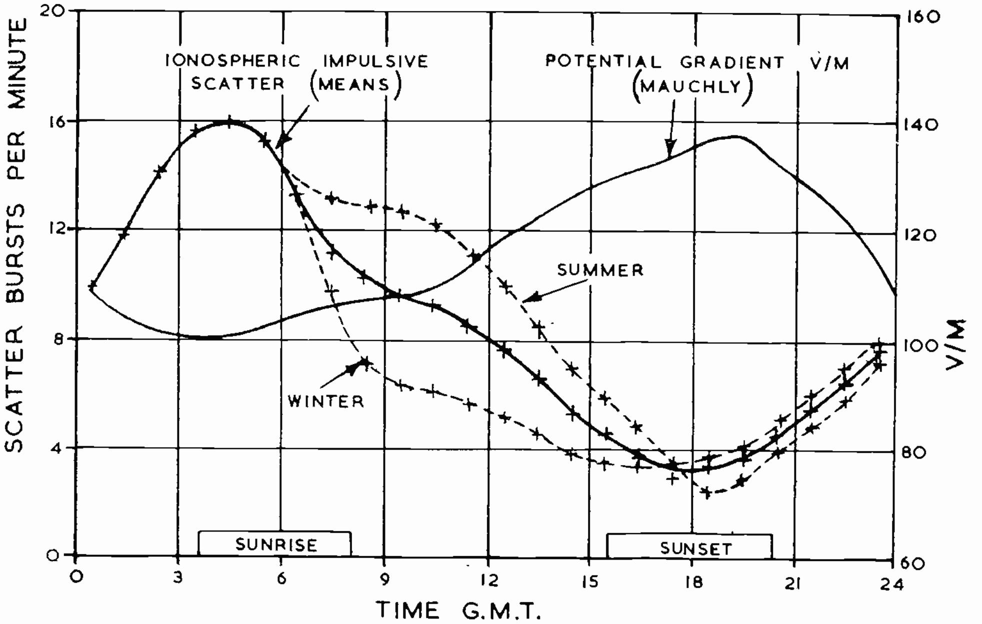


FIG. 9

Diurnal Variation of Ionospheric Impulsive Scatter and Mauchly Potential Gradient Curves.

The summer to winter trend is almost certain to be influenced by two factors. The first factor is the known difference between summer and winter lightning activity, and associated cloud formations, over the British Isles, and it is therefore a relatively local effect.

The second factor is the E region ionization which is maintained by solar radiation. This normal ionization, being greater in the summer than in the winter, is more susceptible, in the summer, to increases of ionization by cloud discharges to densities sufficiently great to reflect a radio wave of a given frequency than would be the case in the winter.

Further evidence on the influence of this last factor is demonstrated by the manner in which the impulsive scatter minimum activity is dependent upon sunset times. This sunset effect is shown in greater detail in Fig. 10, where monthly mean times of minimum scatter activity are plotted month by month against sunset times.

No corresponding effect at sunrise can be distinguished with any degree of certainty.

"Step" Bursts

Having suggested the theory that short impulsive signal bursts are produced by sporadic increases of ionization in the E region, which are in turn produced by electrical discharges from clouds, one can extend the theory to embrace other phenomena brought to light by the experimental evidence.

It seems likely that the " step," or longer, bursts associated with lightning and storm clouds, described in p. 47 and illustrated by Figs. 5 (a), (c), (d), (e) and (f), may be explained by a slight modification to the theory.

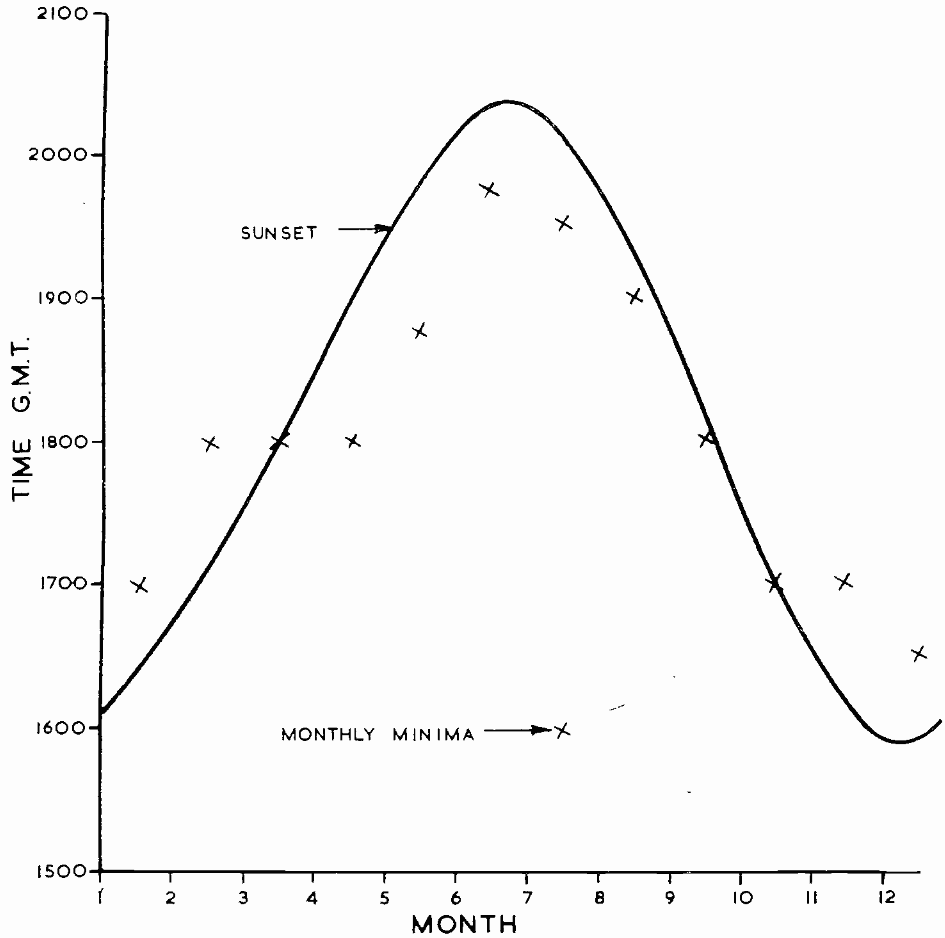


FIG. 10

Ionospheric Impulsive Scatter Dependence upon sunset times.

If the charge rate of a cloud is greater than the discharge rate of the capacity between the E region and the cloud, the potential difference over this capacity will never fall below the critical striking potential of the ionized column of air ; therefore there will be a continuous ionization current in the upward direction from cloud to E region, where the energy so transferred would almost certainly cause the same ionization as has been shown in connection with impulsive discharges, until such time as the cloud generator relaxes, or fails altogether.

Atmospheric Electricity and Sporadic E

In the introduction to this paper it was stated that it had been shown that impulsive scatter, together with a residual ionization of the E region, could produce coherent and sustained weak signals at long distances. We have discussed the impulsive scatter aspect of transmission but, so far, we have not considered the residual ionization of the E region, or given an explanation for its presence.

Is there a connection between atmospheric electricity and this residual ionization ?

We have now good reason to believe that energy from lightning storms and from ordinary cloud discharges is conveyed to areas of fine weather by means of the highly conducting E region where it leaks away by conduction through the air to the earth. It has also been demonstrated in this paper how the E region ionization is temporarily intensified by this transfer of energy at a localised point of entry.

Is it not possible that this continuous residual ionization which has been noted is, in fact, due to the flow of this energy from a disturbed area to one of fine weather ?

If this were so, it is but a short step to imagine that the occurrence of sporadic E (Es) is due to an abnormally intense distribution current flowing from a very disturbed area to an adjacent area of serene sky.

There would seem to be a certain amount of evidence in support of this line of thought. Gish and Wait (8) have measured values of upward conduction currents above thunderheads as great as 6·5 amperes. It is known also that in temperate latitudes the occurrence of Sporadic E is mainly a summer time effect inasmuch as it occurs from roughly April until September in the northern hemisphere, and from October to March in the southern hemisphere ; these periods correspond to the active storm periods in each hemisphere. In the equatorial storm belt, where storms occur all the year round, Sporadic E is present most of the year in the day-time.

It is furthermore known that Sporadic E occurs in localised areas not inconsistent with the area which might separate a storm centre from an ajdacent serene sky.

Sporadic E reflections have been recorded from the Kirk-o-Shotts transmitter on three occasions at Great Baddow. On one occasion there were lightning storms all over England ; on the second occasion active storm centres had been present over the North Sea and Holland a few hours earlier. On the third occasion very active storm centres were over Northern France while a disturbed area, not actually resulting in lightning, lay off the west coast of Ireland.

Bennington (2) has analysed the widespread occurrence of Sporadic E on May 17th, 1953, which introduced serious interference from distant transmitters into the London Television Service operating on 41·5 and 45 Mc/s.

He finds that between 1000 and 1800 GMT on that day there were considerable areas of intense Sporadic E present over France, Switzerland, Germany, Denmark, Holland and Southern England. There seemed to be a general north-easterly drift of these areas from the Bay of Biscay towards Scandinavia.

On this particular day and at the times of Sporadic E activity a cold front stretched from the Bay of Biscay to Scandinavia which gave rise to very active lightning storms over France, Germany, Switzerland and the East coast of England. The storm centres had a general north-easterly drift.

At 1600 GMT there was a marked decrease in lightning activity ; the last flash was recorded at 1900 GMT east of Brest. The last area of Sporadic E disappeared shortly after 1800 GMT.

It is evident, therefore, that widespread Sporadic E activity and widespread lightning storms were both present, on this particular day, at the same time over the same area. Furthermore the cessation of both forms of activity were reasonably well synchronised.

Many other workers have suggested that thunderstorms do influence the ionization of the E region. Ratcliffe and White ([12]) found some correlation between thunderstorms and abnormal ionization of the E region but, later, Best, Farmer and Ratcliffe ([3]) came to the conclusion that there was less correlation than at first claimed. Nevertheless Bhar and Syam ([4]) found strong evidence in Bengal, a position well suited to their investigations, that thunderstorms did, in fact, appreciably increase the E region ionization above normal values.

The work described in this paper suggests that impulsive ionization bursts and Sporadic E ionization are inextricably bound up one with the other. There is independent confirmatory evidence on this point by the work of Appleton and Naismith ([15]) who have provided evidence that impulsive ionization bursts are responsible for some abnormal ionization of the E region but, whereas the present work strongly suggests that the ionization bursts are caused mainly, but not exclusively, by cloud electrical discharges, Appleton and Naismith attribute them to meteors.

Conclusions

There is an abundance of experimental evidence to show that atmospheric electricity, and particularly electrical discharges from many types of cloud not necessarily accompanied by lightning, is mainly responsible for the impulsive scatter described by Eckersley. Furthermore the evidence suggests that partial ionization of the E region by conduction currents of atmospheric electricity is possible. This, together with the impulsive scatter, is probably the main mechanism by which the very high frequency radio transmission over long distances, described by Bailey, is supported.

From the meteorological point of view experimental evidence has been given to show that the chief generators responsible for maintaining the vertical potential gradient in fine weather areas, are some types of ordinary cloud and not necessarily cloud which produces lightning.

Acknowledgements

The author is indebted to the Marconi Wireless Telegraph Company Limited for permission to publish this paper. He wishes to acknowledge the great help given him by Mr. A. L. Maidens of the "Sferics" Organisation of the Air Ministry Meteorological Office. The author is very grateful for helpful discussions with members of the Nelson Research Laboratories and with his colleagues in the Marconi Research Laboratories. Finally the author would like to thank Mr. C. J. R. Pallemaerts for his valuable assistance in the work described in this paper.

REFERENCES

1 Bailey, D. K., and others. Phys. Rev., 1952, 86, No. 2, p. 141.
2 Bennington, T. W. B.B.C. Quart. Journ., 1953, 8, No. 3, p. 169.
3 Best, J. E., Farmer, F. T. and Ratcliffe, J. A. Proc. R. Soc., 1938, 164, p. 96.
4 Bhar, J. N. and Syam, P. Phil. Mag., 1937, 23, p. 513.
5 Eckersley, T. L. Nature, 1937, 140, p. 846.
6 Eckersley, T. L. Journ, I.E.E., 1940, 86, p. 548.
7 Frenkel, J. Journ. Franklin Inst., 1947, 243, p. 287.

[8] Gish, O. H. and Wait, G. R. Journ. Geophys. Res., 1950, 55, p. 473.
[9] Gish, O. H. Compendium of Meteorology (American Meteorological Society), 1951, p. 101.
[10] Isted, G. A. Nature, 1953, 171, p. 617.
[11] Mauchly, S. J. Terr. Mag., 1923, 28, p. 61.
[12] Ratcliffe, J. A. and White, E. L. C. Proc. Phys. Soc., 1934, 46, p. 107.
[13] Whipple, F. J. Quart. Journ. Royal Met. Soc., 1929, 55, p. 1.
[14] Wilson, C. T. R. Trans. R. Soc., 1920, 221, p. 73.
[15] Appleton, E. V. and Naismith, R. Proc. Phys. Soc., 1947, 59, p. 461.

BOOK REVIEW

This book* is really an introduction to Radar for the semi-specialised reader who is interested in Radar equipment, who wants to know what it contains and how it works. Rather too great an emphasis is laid on the electronic side of the subject, for instance, a whole chapter is devoted to the cathode follower, whereas the cheese aerial is dismissed in only ten lines ; yet five of the six civil marine sets described in the book use cheese aerials.

The last chapter of the book occupies about one-quarter of the volume and gives descriptions of contemporary British civil radar equipment. It is this part of the book which deserves the highest commendation, as it is unlikely that the information found there could be easily obtained elsewhere. It is regrettable, however, that the authors did not add a final integrating chapter summarising the properties of these equipments. A few synoptic charts and tables could easily have achieved this end.

The remainder of the book consists of 23 chapters and 3 appendices. This immediately occasions the reader to recall the 27 volumes of a famous series on radar, and to wonder why the bibliography given at the end of the book includes only volumes 1 and 6 of this series and makes no mention of the remaining 25 volumes.

The general treatment is descriptive with a non-mathematical approach, although most of the subject matter is basically mathematical and suffers from the attempt to avoid mathematics. A profusion of circuit diagrams are given, but their usefulness is limited by the avoidance of component values, operating conditions, valve types and the like. One realises that it is impossible to be completely specific in these matters, but more general information would facilitate understanding of the diagrams by the reader.

It is exceedingly disappointing in a modern book on the principles of radar to find no reference to Fizeau's experiments on the velocity of light. Without doubt the modern pulse radar is an electronic design of Fizeau's toothed wheel pulse generator and lens and mirror arrangement, and his work was done in 1849 ! It is an interesting fact that Fizeau's radar range was 5·36 miles.

It is also unfortunate that no mention is made of frequency modulation radar systems. The simplest of all radars, the Doppler-shift radar, is also ignored, although moving target indication on a pulse set is briefly considered.

Another noticeable omission is radar beaconry, the art of using co-operative targets, a technique as old as Fizeau's radar. To civil radar where the co-operative target can be a design element in the system, the beaconry can be even more important than the radar. This is particularly true in marine and air radar navigation, and it has been said that it is no use designing a radar until you have settled its beaconry. A book on radar published in 1953 should not avoid this subject altogether, as is done here.

In conclusion, the opening sentence of the Preface may be quoted—" This book assembles and co-ordinates the principles upon which Radar systems have been developed, so that the reader is given a rapid understanding of the subject," and the book may be recommended, if not entirely for its theoretical treatment of the subject then for the wealth of information on contemporary civil radar equipment.

---

* " Principles and Practice of Radar." H. E. Penrose and R. S. H. Boulding. Published by George Newnes Ltd. Price 50/-.

RE-RADIATION FROM RESONANT SHIP'S AERIALS

By J. H. Moon, A.M.I.E.E.

One of the disadvantages of Marine M.F. Direction Finding, as compared with other navigational aids, arises from the fallacy that it is essential to isolate all the aerials in the ship when using the Direction Finder. The use of the Direction Finder may, therefore, cause serious interruptions in the communication services as well as the safety watch for distress signals.

Recent experiments have shown, however, that the majority of these interruptions are quite unnecessary and this paper shows the relatively short distances at which various types of aerial may be used without detracting in any way from the accuracy and performance of the Direction Finder.

In the early days of Marine M.F. direction finding, it was frequently noticed that a direction finder which performed quite satisfactorily in the test room, developed a number of non-uniform errors as soon as it was installed on a ship.

Some of these errors were found to be due to wire stays in the ship's rigging behaving like aerials which received and re-radiated the incoming signals. In consequence of this re-radiation, the signals arrive at the D.F. aerial from two directions and so the normal D.F. minimum was displaced from its correct position to a new balance point at which the direct and re-radiated signals were of equal strength and opposite sign.

It was also found that the amount of displacement of the minimum was a variable quantity which could not be calibrated because it depended not only on the relative strengths of the two signals, but also on the physical relationship between the transmitter, the D.F. aerial and the re-radiating stay. For instance, there could be no displacement so long as these three were in line and, conversely, the maximum displacement would occur when the re-radiating stay was at right-angles to the line of bearing.

Similarly, the strength of the re-radiated signal would also be a variable quantity, since it depended on the inherent ability of the stay to act as an aerial : and this in turn depended upon its natural electrical constants, so that the re-radiation—and the consequent displacement of the bearing—only reached its maximum when the transmission frequency happened to tally with the natural resonance of the stay and the stay itself was at right angles to the line of bearing.

As the magnitude of any re-radiation error must be the resultant of these two variable factors, it cannot be measured and compensated as can the pure quadrantal error which originates in the solid mass of the ship's structure. There is, therefore, no means of dealing with a re-radiation error apart from eliminating it at its source, and for this reason it is a routine practice nowdays to insert several insulators in all stays and whistle lanyards, etc., which pass close to the D.F. aerials. These insulators break the stay into a number of short lengths, each of which has a natural resonance well above any of the D.F. transmission frequencies, and so they produce no ill-effects in the direction finder.

In view of the foregoing considerations, it appears obvious that a ship's aerial, which is specially designed to receive and radiate, will have a very serious influence on the direction finder, and for this reason it has been the accepted rule for the past 25 or 30 years that all wireless aerials must be isolated whilst using the direction finder.

The "Merchant Shipping (Radio) Rules, 1952," however, call for an uninterrupted watch for distress signals on 500 Kc/s., either by the Radio Officer or by the Automatic Alarm. The Auto-Alarm, however, is normally operated from the ship's main aerial, which it tunes to 500 Kc/s. in order to achieve its maximum efficiency.

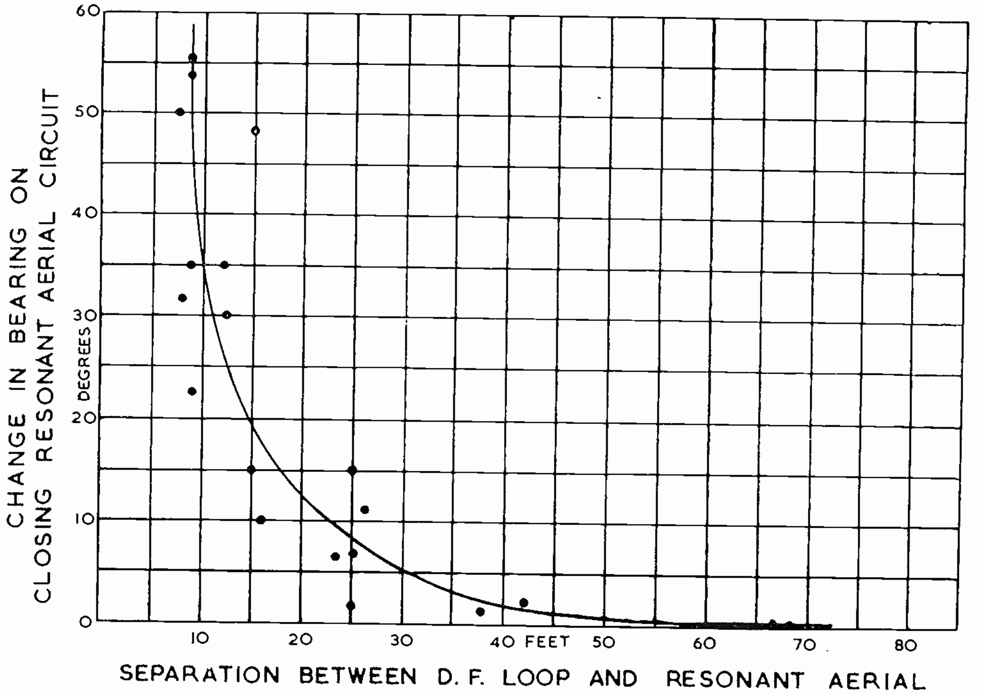


FIG. 1

D.F. errors on 500 Kc/s in relation to spacing between the D.F. loop and the down-lead of a ship's main aerial when the latter is also tuned to 500 Kc/s.

The new rules therefore call upon a direction finder to produce accurate results whilst it is literally overshadowed by a highly efficient aerial which, in the worst case, will be actually tuned to the frequency that is being used to obtain the D.F. bearing.

In view of this change in the rules it was decided to carry out a further investigation, and this immediately showed that the instruction to isolate all aerials was unnecessarily severe because the various tests clearly indicated that the displacement of the D.F. minimum by a resonant aerial diminishes very rapidly, as the distance between the aerial down-lead and the D.F. aerial is increased: and it is now safe to say that many ships which continue to isolate their aerials for direction finding are quite immune from this particular type of error.

This fact is illustrated in Fig. 1, from which it can be seen that an error of 55° with an aerial separation of 9 feet on one ship becomes almost negligible when the separation is increased to 50 or 60 feet on another. In this connection it is interesting to note that it is the vertical, rather than the horizontal limb of the aerial which is mainly responsible for displacing the D.F. bearings.

In view of these findings it would appear at first sight that the D.F. could be made to comply with the rules by merely calling for a 50-foot separation between the aerials in all instances, but although it is true to say that this separation already exists in certain cases and could be obtained in others, it is equally true that it would be physically impossible—for one reason or another—to obtain anything like the required separation on a large number of existing installations.

Conclusions

In view of the foregoing considerations, it is obvious that the new rules cannot achieve fully their ideal of operating all direction finders without *any* interruption of the communication services, although it is equally obvious that the previous unqualified insistence on the isolation of *all* aerials was quite unjustified.

Since it is impracticable to comply with the new rules in all cases, the installations may have to be graded into two or perhaps three separate categories such as those suggested in the following table :—

Loop to Down-lead Separation	Utilization of Direction Finder
Greater than 60 feet	All frequencies without isolation of aerials
30 to 60 feet (particularly where down-lead inclines away from D.F. aerial)	All frequencies without isolation of aerials, but subject to individual test and approval.
Less than 30 feet	200-315 Kc/s. without isolation of aerials. 315-800 Kc/s. all aerials to be ISOLATED. 800 to 4,000 Kc/s. without isolation of aerials. (All subject to individual test and approval.)

It is, of course, possible that there may be a few cases in which the aerial down-lead is so close to the D.F. aerial that it will be impossible to operate the direction finder on any frequency at all without isolating the main aerial, but such instances could be dealt with individually, so that in the course of time, all ships would fall into one of two categories. The first category would permit independent operation of the D.F. on all frequencies, whereas the second category would only allow independent operation on Marine Radio Beacons (285—315 Kc/s.), and the interfering aerials would have to be isolated when taking special bearings on other frequencies.

AMPLITUDE-FREQUENCY CHARACTERISTICS OF LADDER NETWORKS

IN the *Marconi Review*, No. 108 (Vol. XVI, 1st Quarter 1953) an article appeared entitled "Exact Amplitude Frequency Characteristics of Ladder Networks," by E. Green, M.Sc. Reference was made therein to a more detailed discussion of this subject which was to follow at a later date. This has now been completed and will be published in book form by the end of May, 1954. It will be entitled "Amplitude-Frequency Characteristics of Ladder Networks" (pp. 164 with 88 diagrams, price 25s.). The book is published in the hope that it will form the first of a series of Marconi Monographs dealing with Telecommunication subjects of contemporary interest. These Monographs will be introduced under the auspices of the *Marconi Review*, and will be obtainable by application to:—

Technical Information Division,
Marconi House,
Chelmsford.

"Amplitude-Frequency Characteristics of Ladder Networks" deals with the design of Ladder Networks to give desired exact amplitude characteristics. The general synthesis of these networks to give Butterworth or Chebyshev amplitude response in the pass band, dealt with in the first part of the book, is applied, in the second part, to the design of normal filters, broadband valve couplings or couplings between a transmission line and a reactive load. A full bibliography of the subject is given and a foreword has been written to the book by Milton Dishal of the Federal Telecommunication Laboratories, U.S.A.

ADEN.
hell Cotts & Co. (Middle East) Ltd., Cotts House, Crater.

ARGENTINA.
blecimientos Argentinos Marconi, Avenida Cordoba 645, Buenos Aires.

AUSTRALIA.
lgamated Wireless (Australasia) Ltd., 47, York Street, Sydney, N.S.W.

BAHAMAS.
. Binnie & Co. Ltd., 326 Bay Street, Nassau.

BELGIUM.
été Belge Radio-Electrique S.A., 66, Chaussée de Ruysbroeck, Forest-Bruxelles.

BELGIAN CONGO.
Anonyme International de Télégraphie sans Fil, 7.B, Avenue Georges Moulaert, Leopoldville.

BOLIVIA.
lonald & Co. (Bolivia) S.A. P.O. Box 879, La Paz.

BRAZIL.
panhia Marconi Brasileira, Caixa Postal No. 126, Rio de Janeiro.

BRITISH EAST AFRICA.
ıya, Uganda, Tanganyika, Zanzibar.) Kinleven Ltd., P.O. Box 3000, Nairobi, Kenya.

BRITISH GUIANA.
stons Ltd., Lot 4, Lombard Street, Georgetown.

BURMA.
nese Agencies Ltd., P.O. Box 176, Rangoon.

CANADA.
ıdian Marconi Co., Marconi Building, 2442 Trenton Avenue, Montreal 16.

CENTRAL AMERICA.
temala, San Salvador, Honduras, Costa Rica, Panama.) Keilhauer, Pagram & Co. Ltd., 9A, Avenida No. 20-06, Guatemala, C.A.

CEYLON.
ker Sons & Co. Ltd., P.O. Box 166, Colombo.

CHILE.
s & Co., Casilla 67 D, Santiago.

CHINA.
oni (China) Ltd., Queens Building, Chater Road, Hong Kong.

CYPRUS.
. Petrides & Son, Ltd., P.O. Box 359, Nicosia.

DENMARK.
ıus Berendsen Ltd., Post Box 372, Copenhagen V.

ECUADOR.
pañía Pan Americana de Comercio S.A., P.O. Box 926, Guayaquil.

EGYPT.
ciated British Manufacturers (Egypt) Ltd., Building B, 11, Sharia Emad el Din, Cairo.

ERITREA.
hell Cotts & Co. (Middle East) Ltd., P.O. Box 1212, Asmara.

ETHIOPIA.
hell Cotts & Co. (Middle East) Ltd., P.O. Box 527, Addis Ababa.

FAROE ISLANDS.
I. Jakobsen, Radiohandil, Postbox 35, Torshavn.

FINLAND.
Mercantile ABs, Mannerheimvagen, 12, Helsinki.

FRANCE AND FRENCH COLONIES.
ıpagnie Générale de Télégraphie sans Fil, 79, Boulevard Haussmann, Paris, 8e.

GREECE.
C. Lycourezos, Ltd., Kanari Street 5, Athens.

HOLLAND.
emene Nederlandse Radio Unie N.V., Keizersgracht 450, Amsterdam.

INDIA.
rconi's Wireless Telegraph Co., Ltd., P.O. Box 195 New Delhi.

INDONESIA.
o & Co., 78, Djalan Garuda, Djakarta.

IRAQ
C. A. Bekhor Ltd., P.O. Box 138, Baghdad.

ISRAEL.
Middle East Mercantile Corpn., Ltd., 5, Levontin St., Tel-Aviv.

ITALY.
Marconi Italiana S.p.A. Via Hermada 2, Genoa-Sestri.

JAMAICA.
The Wills Battery Co. Ltd., 20 Orange Street, Kingston.

JAPAN.
Cornes & Co., P.O. Box 158, Tokyo.

LEBANON.
Mitchell, Cotts & Co. (Middle East) Ltd., P.O. Box 251, Beyrouth.

LIBYA.
Mitchell Cotts & Co. (Libya) Ltd., Meiden Esciuhada, Tripoli.

MALAYA.
Marconi's Wireless Telegraph Co. Ltd., Far East Regional Office, P.O. Box 1158, Singapore.

NEW ZEALAND.
Amalgamated Wireless (Australasia) Ltd., P.O. Box 830, Wellington.

NORWAY.
Norsk Marconikompani, 35, Munkedamsveien, Oslo.

NYASALAND.
Lake Nyasa Development & Trading Co. Ltd., P.O. Box 112, Blantyre.

PAKISTAN.
International Industries Ltd., P.O. Box 225, Karachi.

PARAGUAY.
ACEL S.A., Casilla de Correos No. 651, Asuncion.

PERU.
Milne & Co., S.A., Lima.

PORTUGAL AND PORTUGUESE COLONIES.
E. Pinto Basto & Ca Lda., 1, Avenida 24 de Julho, Lisbon.

SAUDI ARABIA.
Mitchell, Cotts & Co. (Sharqieh) Ltd., P.O. Box 31, Jedda

SOMALILAND PROTECTORATE.
Mitchell Cotts & Co. (Middle East) Ltd., Street No. 8 Berbera.

SOUTH AFRICA (INCLUDING N. RHODESIA).
Marconi (South Africa) Ltd., 321-4 Union Corporation Bldg., Marshall Street, Johannesburg.

SOUTHERN RHODESIA.
Faraday Engineering Co. Ltd., P.O. Box 2259, Salisbury & P.O. Box 717, Bulawayo.

SPAIN AND SPANISH COLONIES.
Marconi Española S.A., Apartado de Correos No. 509, Madrid.

SUDAN.
Mitchell Cotts & Co. (Middle East) Ltd., P.O. Box 221, Khartcum.

SWEDEN.
Svenska Radioaktiebolaget, Alstromergatan 12, Stockholm.

SWITZERLAND.
Hasler S.A., Belpstrasse, Berne.

SYRIA.
Levant Trading Company, 15-17 Barada Avenue, Damascus.

THAILAND.
Yip in Tsoi & Co. Ltd., P.O. Box 23, Bangkok.

TRINIDAD.
Masons & Co. Ltd., 4 St. Vincent Street, Port-of-Spain.

TURKEY.
G. & A. Baker Ltd., Prevuayans Han, Tahtakale, Istanbul.

URUGUAY.
Regusci & Voulminot, Casilla de Correo 532, Montevideo.

U.S.A.
Mr. B. G. H. Rowley, 23/25 Beaver Street, New York City 4, N.Y.

VENEZUELA.
J. M. Manzanares C.A., Apartado 134, Caracas.

YUGOSLAVIA.
Farchy Ltd., 14-18 High Holborn, London, W.C.1. and Terazije 39, Belgrade.

Marconi