THE KENNELLY-HEAVISIDE & APPLETON LAYERS

INVESTIGATIONS ON THE KENNELLY-HEAVISIDE AND APPLETON LAYERS

by

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Thesis submitted to the Faculty of Graduate Studies and Research, McGill University, in part fulfilment of the requirements for the Degree of Doctor of Philosophy.

September 5th, 1933.

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A B S T R A C T

Radio ionosphere investigations in connection with the International Polar Year, carried out in Montreal between January and August, 1933, using the amplitude variation method of Breit and Tuve, are described. Especial attention is paid to the variation of equivalent layer height with frequency, and a statistical analysis of the records is carried out. This clearly shows the presence of an intermediate reflecting layer and of "midnight E". The phenomenon of "persistent E" reflections is described and a number of typical curves are discussed. Comparison of the results with solar and meteorological records fails to show any correlation. Marked scattering in the values for maximum layer ionization is taken to be an indication of unstable conditions which permit the frequent occurrence of the above anomalous effects.

STATEMENT OF CONTRIBUTION TO KNOWLEDGE

Required To Be Submitted With Ph.D. Theses.

1. Records of ionosphere conditions for Montreal have been obtained on days falling near the International Polar Days, and will therefore be of use when Polar Year data are compiled.
2. "Persistent E" phenomena, in which the E echo is returned at a frequency greater than one which penetrates the F layer are reported.
3. A statistical analysis of equivalent layer heights for successive frequency ranges has been carried out. This is shown to indicate that intermediate layer reflections, for some bands, are not only individually of interest, but occur in sufficient number to be statistically significant. The importance of "persistent E" reflections distorting the normal statistical-frequency-height polygon for the higher electrical frequencies is demonstrated.

ACKNOWLEDGMENTS

The writer is indebted to a number of persons for their assistance during the course of the experimental work and the subsequent preparation of the Thesis. Foremost among them is Dr. John Henderson, who initiated him into this branch of radio research, and whose continued advice and practical help have been invaluable. To Dean A. S. Eve he is grateful for the friendly supervision of the work, and to the Department of Physics for providing equipment and other facilities. Dr. Walter Smyth, in whose home the receiving station was set up, has been kindness itself in permitting every use to be made of his basement. Mr. Ross Smyth, during his time as assistant, proved a willing worker and an able engineer. To him much of the success of the work is due. The National Research Council, in providing funds to engage an assistant, made an otherwise impossible experiment feasible. Many people have willingly given advice and information when requested. Among these are : Mr. Meldrum Stewart, Director of the Dominion Observatory, Ottawa ; Dr. Ralph deLury, of the Dominion Observatory Staff ; Mr. J. A. Fleming, of the Department of Research in Terrestrial Magnetism, Carnegie Institution, Washington ; and Mr. W. P. Henry, of the McGill University Observatory Staff : to them the writer extends his thanks. A great deal of the smooth working of the equipment must be attributed to the mechanical skill of Mr. George Tweeddale, Mr. H. T. Pye, and Mr. J. Taylor, on the Staff of the McGill University Department of Physics. To these, and to the many others from whom casual assistance has been obtained, the writer acknowledges his sincere gratitude.

PREFACE -

In the summer of 1932, McGill University, collaborating with the National Research Council of Canada, decided to send out two expeditions to observe Heaviside layer phenomena during the total Solar Eclipse of August 31st. One party was to go to Vankleek Hill, Ontario, the other to Corner Brook, Newfoundland, these positions having been selected in accordance with general suggestions made by Appleton and Chapman (1) for eclipse observations. The investigation was under the direction of Dr. John T. Henderson, who, assisted by the writer, designed and superintended the construction and test of most of the necessary apparatus. Dr. Henerdson took one party to Vankleek Hill, while the writer was put in charge of the expedition to Corner Brook. The results of the observation made at this time have been published (2), and need not be recapitulated here. Suffice it to say that the equipment functioned in a satisfactory manner, and that rather strong evidence was secured indicating that the corpuscular theory of Chapman (3) (4) would have to be modified, if not altogether abandoned. (5) (6)

In the fall of 1932, it was suggested that the writer put the equipment which had been assembled for the eclipse investigations to further use, running a series of tests to determine the normal ionosphere conditions, and their perturbations, in this locality. The importance of this lies in the fact that Montreal is nearer the North

Magnetic Pole than any other station from which systematic records covering an extended period are at present available. (See Table 1. All Tables, Figures, and Plates are grouped together at the end of the thesis.) The tests were to conform as much as possible to the schedule laid down for the Second International Polar Year. (See Appendix 1.)

This was done, the services of Mr. H. Ross Smyth as assistant being made available through two grants from the National Research Council. Further consideration of the matter showed the necessity for replacing or redesigning some of the apparatus, part of which had been borrowed for the eclipse tests, and some of which, while functioning well enough for a temporary field programme, was not suited to long period tests. The remodelling was accomplished mainly by Mr. Smyth and the writer. (A description of the apparatus appears in a later section.) After some preliminary tests, regular observations were commenced on January 24th, 1933. The schedules of the 39 tests are shown graphically in Figure 1, and some notes regarding them will be found in Appendix B.

After test 25 had been run it became necessary for Mr. Smyth to resign his position. Dr. Henderson very kindly undertook to replace him, acting in the capacity of assistant for the balance of the programme, which concluded on August 1st.

HISTORICAL SURVEY -

The very practical bearing which the weather has on mankind's activities caused the early rise of the study of meteorological phenomena. Just as soon as rain, wind, and lightning ceased to be regarded as manifestations of a divine displeasure, the age-old popular weather signs developed, and the quest for more certain data on which to base predictions led to more regularity and greater refinement of observation. Records of aurorae have been discovered, for example, which date back to 503 B.C. (7), while Benjamin Franklin's famous kite experiments, performed in 1752, were but the culmination of much older speculations as to the identity of electricity and lightning.

It was not until the latter part of the 19th century, however, that electrical theory and technique had developed sufficiently to enable attempts at satisfactory explanations to be made with regard to the electrical state of the upper atmosphere. In point of fact, the most obvious starting point for theoretical speculations, namely the great mass of information about lightning, proved rather misleading in this case, since we now know that thunder clouds rarely rise above 10 km. in height, whereas the regions active in producing aurorae and magnetic variation, and affecting radio transmission, lie well above 50 km. This does not mean that the two are entirely independent, for as suggested by Wilson (8) in 1924, and recently developed by Appleton and Naismith (9), thunder clouds may prove to be an important factor in maintaining ionization in the upper atmosphere : we cannot, however, identify the two regions.

From the evidence obtained with sounding balloons, first put forward in 1899 by Teisserenc de Bort, we learn that there are indeed grounds, other than electrical in nature, for considering the atmosphere above about 11 km., or "stratosphere", as distinct in certain respects from the lower region, or "troposphere". The troposphere is responsible for most of our surface weather, and the gases in it are in a continuous state of turbulence, which manifests itself below as wind. As a result of this mixing, the constitution of the troposphere is fairly homogeneous, although the pressure decreases, and the temperature drops continuously, with increasing height. Sounding balloons, and occasional ascents of manned balloons, show that at about 11 km. the temperature becomes constant and is independent of height. It was thought at first that no winds existed here, and as a consequence the gases were sorted out by gravity into strata. It is believed now, however, that at times immense gas movements can take place with very high velocity, owing to the lowered viscosity in the rarified medium. The name is conveniently retained, nevertheless, to indicate the entire region between the troposphere and the upper limit of the atmosphere (wherever this may be : aurorae have been observed up to heights of 800 km.).

Evidence that certain regions of the stratosphere are in an ionized condition has led Mr. R. A. Watson-Watt to apply the apposite term "ionosphere" to them. It is with the direct investigation of the ionosphere by radio methods that the present thesis is concerned.

The credit for the first suggestion that an electrically conducting layer might be found above the earth's surface belongs to Balfour Stewart (10), who, in 1882, advanced it to account for the diurnal variation in the earth's magnetism. Schuster (12), in 1889, elaborating spherical harmonic analysis methods for investigating the distribution of a potential function, developed by Gauss (13) in 1838, found strong support for the theory. Later work by Schuster (14), Chapman (15) (16), Chapman and Price (17), Chapman and Ferraro (6), and others, has practically established, on magnetic grounds alone, the existence of conducting layers in the upper atmosphere.

By far the most direct methods of investigation, however, have resulted from the application of radio technique to the problem. Marconi's first trans-Atlantic experiments in 1901 demonstrated the necessity of providing an explanation as to why electro-magnetic waves followed the earth's surface. For some years thereafter a great deal of attention was focussed upon the efforts of Macdonald, Rayleigh, Poincare, Nicholson, Sommerfeld, Love, and others (18) (19) (20) (21) to account for the effect by diffraction at the earth's surface.

Not only could this theory not account for the size of the mean signal interval received at even quadrantal distances, but day and night effects and fading, first noticed by Marconi (22) in 1902, were not explained.

What is now regarded as the true explanation had been advanced, independently and yet practically simultaneously, by Kennelly (23) and Heaviside (24) in 1902. They suggested that the ionized regions, postulated by the magneticians, would serve as a partial reflector and so ensure the return of at least a portion of the emitted energy to the earth's surface. Fading and sunlight effects fit in easily with this scheme, the latter being due to the interrelation between the layer and solar phenomena required by magnetic theory.

Use of "Heaviside's reflecting layer" was made in 1912 by Eccles (25) (26) to explain certain propagation observations. In 1919 Watson (27) calculated the intensity distribution of signals sent out from a transmitter on a conducting earth surrounded by a concentric conducting layer, and the experimental work of subsequent investigators, notably Round, Eckersley, Tremellen, and Lunnon (28), showed good agreement with the predicted values, at least for long wave ~~base~~ communication over long distances.

The evidence for the Kennelly-Heaviside layer so far, while substantial, had been of an inferential nature.

It was clearly felt by some writers that there might be a still simpler explanation of the observed phenomena, which would not involve the undoubted difficulties of the layer explanation. These views were expressed in November, 1924, by Smith-Rose and Barfield, who wrote "There are two outstanding problems relating to the propagation of wireless waves over the earth's surface which at present remain unsolved, viz :- What is the agency which causes the waves to follow the curvature of the earth, thus rendering long-distance communication possible ? And what is the cause of the large and rapid variations of the intensity and apparent direction of the waves very commonly observed at the receiving station and confined almost entirely to the hours of darkness ?" (29) ; and in September of the same year "Adequate experimental evidence on the existence of the Heaviside Layer is still lacking." (30)

The desired evidence was soon forthcoming. Indeed it had been secured while the foregoing citations awaited printing, for Appleton and Barnett (31) (32) (33) published in the spring of 1925 an account of some experiments which they had conducted in December, 1924, and February, 1925, and their results put the matter beyond all reasonable doubt. The theory of the methods used has been thoroughly dealt with by a number of authors (33) (34) (35) (36), and need only be noticed in passing. Essentially the procedure consisted in making a study of the fluctuations in the photographic records of signal strength from a nearby transmitter. Interference took place between the direct signal travelling along the earth's surface, called the "ground wave" and the "sky" wave , i.e. that wave which had been refracted at practically vertical incidence from the layer overhead. In one case the frequency of the transmitter was kept constant and the angle of the downcoming ray was determined from natural phase-intensity-variation ; in the second case the frequency of the transmitter was continuously varied over a small known range, the resulting interference pattern enabling the difference between the "effective path" of the sky wave and that of the ground wave to be calculated. This procedure is now known as the "frequency variation" or "fringe" method. Simple triangulation gave the approximate height of the layer, regarded as a metallic reflector, as between 40 - 50 km. by day and about 85 km. by night, the frequencies used lying between 750 and 1000 Kilohertz. This is what would now be termed "lower layer reflection" . Had the frequency been higher, the upper layer might well have been discovered at the same time.

The pioneer work of Appleton and Barnett was almost immediately confirmed by further experiments carried out by G. Smith-Rose and Barfield (37) (38), who, by improved but similar methods obtained corresponding equivalent heights.

Meanwhile in the United States, an entirely different method of attack, now known as the "amplitude variation" method, or the "pulse" method, had been devised by Breit and Tuve. It was first reported in 1925 (39) and shortly afterward fuller accounts were published of their findings (40) (41) (42) which appeared to be somewhat at variance with the English results. Appleton (43) was able to reconcile the two sets of observations by taking into account the difference between the frequencies employed. As the method used by the present writer is a development of this scheme, the details will be given in a subsequent section. In brief the principle is this :- A transmitting set is adjusted to send out pulses of radio frequency energy and a receiver is set up nearby. The output of the receiver controls an oscillograph. For every pulse sent out, the receiver intercepts two signals (at least), one the direct, ground wave (TER, Fig. 2), the other the returned wave (TABCR). The time interval between the recording of the two signals as measured by the oscillograph, immediately gives the difference in equivalent path, and from this the equivalent height can be calculated.

The question at once arises as to whether the equivalent path difference thus measured is the same for both the frequency variation method and the amplitude variation method. At first sight it would seem that the former involves phase velocity and the latter group velocity, these, for a dispersive medium being of course different. Appleton (35) and , independently, Schelling, (44) examined the matter in detail, and in 1928 were able to shew that the quantity measured in both cases is essentially a group velocity.

Since the group velocity is altered in the ratio of the effective refractive indices when an electro magnetic wave passes from one dispersive medium to another, it is clear that the equivalent height, calculated by simple triangulation based upon the results of these experiments does not represent a physical path. Appleton (35) proved that the calculated height is in both cases that of the point D (Fig. 2). The discrepancy BD will, of course, depend on how the ion density varies with height as we pass into the layer. Very little is known about this function. The question has, however, been the subject of many enquiries, from Lorentz (45) and others (46) (47) (44) (48) (35) (49) (50) (51) (52) (34) (53) (54) (55) (56) to a recent very exhaustive paper by Taylor (57), of which the first part only has as yet been published. These writers have adopted empirical distributions and have thus been able to trace out the physical path using classical methods of attack. It has been pointed out, by Eckersley, (58) (59), Hartree (60) (61), and Namba (53) among others, that a strict analogy may be drawn between this treatment and that of classical particle dynamics, both systems breaking down in certain critical circumstances. Particular interest attaches to one of these : namely the case when the effective μ of the medium is approaching zero. Wave treatment has been applied by the above writers the results of which justify certain important conclusions drawn from the older methods.

One of these is that radiation of frequency f incident normally upon a stratum of ions (charge e, mass m, N per cm^3) will be returned to earth provided that N is <u>greater</u> than (51)

$$N_{max.} = \frac{3\pi m f^2}{2e^2} \quad \text{- - - - - - - - - - - -} \quad (1.)$$

When, for a given N, f is increased just beyond the point where relation 1 holds, the radiation penetrates and is not returned. If we determine this value of f called the Critical Penetration Frequency (abbreviated CPF), we thus have a measure of the maximum N in the ionized stratum.

Rather broad assumptions which are involved in the above relation, have been subjected to a critical analysis by Appleton and Naismith (51), Gutton (54), and Tonks (56). On the whole, however, it would appear that equation 1 will give at least approximate relative values of seasonal and diurnal variation of ionic density.

Before turning to a review of experimental results since the inception of the frequency - and the amplitude - variation methods, it will be as well to refer very briefly to the question of polarization. The topic is very fully treated in the literature, and will receive only cursory mention here, particularly since in the experiments carried out at McGill no equipment was available for measuring polarization.

In 1925 it was pointed out by Appleton (62) and also independently by Nicholls and Schelleng (63) that in the theories of radio propagation then current no allowance had been made for the effect of the earth's magnetic field.

If the active electric charges in the upper atmosphere are in reality electrons, as seems to be established, we shall get a double refraction effect, and the propagation of the components of a ray across the lines of magnetic force will be altered. By introducing gyratory terms into the Lorentz equation for dispersion, Appleton and Barnett (130) and Nicholls and Schelleng (65) were able to show that when any electro-magnetic wave passes through an ionized medium in a magnetic field, it should split up into two components of different velocities, different polarizations, and with different absorptions. This magneto-ionic theory has since been developed by Hollingworth (66), Goldstein (67), Appleton (34), and again quite recently by Appleton and Builder (68). A report by Green (69) contains, as a preface to some important experimental work referred to below, a discussion of the difference between the term "polarization" as used in optics and as used in electro-magnetic theory. Papers by Ratcliffe (70) and Taylor (57) illustrate graphically the effect of varying parameters in the functions encountered, so that the behaviour of waves under conditions approximately equivalent to those met with in practice may be estimated.

The experimental attack has been from two directions. Laboratory experiments with ultra short waves passing through an ionized medium in the presence of a magnetic field indicate that the agreement with theory is fairly good in the case of selective absorption (71), (72), (73A), effective refractive index (73B), and rotation of the plane of polarization (74). The technique is difficult, however, and since the wavelengths thus used have of necessity to be extremely short, it is still doubtful whether extrapolation to the conditions obtaining in practice is fully justified.

On the other hand one would have great difficulty in denying the essential validity of the magneto-ionic theory after considering the results of the vast amount of "field work" which has been carried out. The early experiments of Smith-Rose and Barfield (37) (38) in 1926 showed that the plane of polarization of the sky wave differed from that of the ground wave. Pickard (75) and Taylor (76) in America at about the same time produced similar evidence. A year later Appleton and Ratcliffe (77) (78) found that the polarization in England, for a frequency of 750 Khz, was very nearly circular, with a left-handed sense of rotation (The observer is supposed to look along the direction of wave propagation). Their analysis gave this as the expected result, and in addition predicted that in the southern hemisphere, on account of the altered sense of the magnetic field, the rotation should be right-handed. In 1932 Green (69), working in Australia, investigated the point, and produced clear evidence completely confirming the prediction. A number of very ingenious methods have been devised during the past year or so for distinguishing between right- and left-handed polarization, and for measuring the amplitudes of the components.

(79) (80) (51) (68) (81) (82). It is found that generally the state of polarization in the reflected ray agrees with the theoretical analysis, but during certain magnetically disturbed periods, the sense of rotation may be reversed.

Not only has technique improved in the matter of dealing with polarization phenomena, but it has progressed on general lines as well. For one thing more stable and efficient indicators have been introduced at the receiving end. The first investigators made use of Duddell oscillographs, Einthoven galvanometers, and the like. In 1930 Goubau (83) initiated the use of the cathode ray oscillograph, which is practically an ideal instrument for the purpose. He employed the amplitude variation method and imparted a synchronous circular motion to the spot of the oscillograph so as to utilize efficiently the circular screen. He and others have since used a linear time axis swept out in synchronism with the transmitter keying. It is somewhat easier to interpret the resulting cartesian figure at a glance than when the polar form is used. The introduction of a high resistance into the low potential grid coil lead of a single valve transmitter, thus producing "squegger" modulation, was described by Appleton and Builder (84) early in 1932. Certain inherent objectionable features have been recently pointed out by Mimno and Wang (85), who (86), as well as Herd (87), have designed thyratron relaxation oscillators for accomplishing the same purpose.

Perhaps the most important innovation, however, has been the introduction of automatic recording devices, all operating on the amplitude variation principle. Rukop and Wolf (88) made use of a television glow lamp connected in the output circuit of the receiver which scanned a stationary photographic film. Mimno and Wang (89) (90) and Gilliland (91) employ two slightly different forms of the same device in which the lamp does not rotate and scanning is done either with a revolving prism, or by affixing the photographic sheet on a barrel, as in the Marconi facsimile transmission system. Ratcliffe and White (92) and Goubau and Zenneck (93) retain the oscillograph but mask the face so that only a portion of the signal trace shows through a slit, and thus are able to photograph records on a slowly moving film strip. The latter writers make extremely ingenious use of the cathode ray spot's return stroke, whereby an automatic calibration of the height scale is registered on the film every half cycle.

One final improvement should be mentioned. Very recently Mitra and Rakshit (94) have rather amazingly succeeded in utilizing the same aerial for both transmitter and receiver, a procedure which few orthodix engineers would recommend. They thus not only approach the limit in installation economy, but at the same time avoid the screening effect of the quiescent transmitting aerial upon the aerial of the nearby receiver. Reflection at absolutely normal incidence from the ionized layer is also secured.

Before concluding this review of direct methods of studying the ionosphere, it is appropriate that we should note briefly the development of the multi-layer theory now in vogue. It has been mentioned in connection with Appleton and Barnett's original experiments (31) (32) (33) that had they employed higher frequencies, say in the neighbourhood of 2000 Khz, they almost certainly would have noticed that the "subsidiary fringes" (33) do not always give integral multiples of the "primary fringe" equivalent height. In Breit and Tuve's work (41), carried out on a freqnency near 4300 Khz, corresponding subsidiary echoes were found, but as the resolving power of the early appsratus used was not high, it was thought that these were multiple echoes which had reflected back from the earth. Breit, Tuve and Dahl (42), and Kenrick and Jen (95) later obtained equivalent heights in the ratio 1 : 2 : 4, which they again interpreted as reflections from a single layer but with the third reflection mysteriously absent. Appleton, taking into consideration all the available evidence, communicated a letter to "Nature" (96) in 1927, expressing his conviction that there were in reality two layers, one at a height of about 100 Km., to which he referred as the "Kennelly-Heaviside" or "E" layer, the other at about 200 Km. which he called the "F" layer. Subsequent investigation, notably by the same writer (97) (34), and by

Builder (98), based on the published results of many other workers, have amply confirmed this theory. Appleton's nomenclature has become standard, and the upper ionized region is now distinguished from the lower, in most of the current literature, by the name "Appleton Layer". The double layer theory is also particularly attractive from the magnetic point of view, which Chapman (16) and others have treated in some detail. Frequently echoes will be returned with an equivalent height not an integral multiple of either the E or the F value. This has been accounted for in a number of ways, one being that a sparsely ionized region, referred to as "D", exists beneath the E layer capable of absorption but not reflection (99). The velocity of propagation through such a medium would be reduced, thus producing abnormalities in the effective height. There is some indication that under unusual conditions echoes may be reflected from the D region. Evidence will be offered from the present writer's experiments to show this. Splitting may also be a cause of the irregularity, for very often indeed the reflected signal appears double, the explanation being that the differently polarized components suffer unequal velocity alterations in any ionized medium through which they pass, thus being separated on their return. As the coefficients of absorption are also different the relative intensity of the split echo components is disturbed, one or the other frequently disappearing altogether at times. This will also be illustrated with records obtained by the writer in a later section. A third possibility has recently been discussed by Ratcliffe and White (81), who propose an "M" reflection, the signal passing from the transmitting aerial to the bottom of the F layer, thence down to the top of E, back to the bottom of F, and finally to the receiver. This would give effective heights of M= 2F - E (using their nomenclature) which they find experimentally and which also appear in records of the McGill investigators detailed below.

It is not unusual, however, to find echoes returned from an equivalent height in the neighbourhood of 165 Km, indeed, sometimes a continuous range of heights is registered from some 100 Km to 250 Km. Henderson encountered this in his eclipse experiments of 1932, although it was not mentioned in his paper (2), and Naismith (100) Schaffer and Goodall (101), and Appleton (102) have since reported finding evidence of one or more intermediate regions. This has also been found in the writer's experiments.

The following table gives a summary of what is at present known from radio investigation of the ionosphere :-

<u>D layer</u>

Thought to exist beneath the E layer. Height perhaps 60 Km. (99) Low ionization. May occasionally reflect waves, but usually merely absorbs and partly polarizes them.

<u>E layer</u> (Kennelly-Heaviside region)

Height from 80 - 130 Km. Highly ionized during the day. Approximate ion densities : Summer noon,

6×10^5 electrons / cm^3, winter noon, 3.7×10^5 electrons / cm^3. (103). Sparsely ionized during the night.

Intermediate layers

Only recently discovered. Height 175 Km (say) (102). Thought to be usually less intensely ionized than E layer.

F layer (Appleton Region)

Height from 190 - 300 Km. Approximate electron density : Summer noon, 7.5×10^5 per cm^3, winter noon, 5.6×10^5 (lat. about 40° N) (55). Night time height and ionization vary greatly. As a rule, however, more heavily ionized than E. Thought to be "stepped" or stratified in ion density.

General

Ratio of Summer to Winter noon ionization, approx. 2.2 to 1 (9).

Ratio of Sunspot Maximum to Sunspot Minimum, approx. 1.5 to 1 (55).

The sketch shown in Figure 3, redrawn with slight additions from Appleton's recent letter to "Nature" (102) illustrates some of these points. Heights and electron densities are only very approximately to scale. Those portions of the curve drawn with full lines are fairly well established in their relative positions, for normal days, while the broken line section indicates conditions in the intermediate region which must for the present be regarded as tentative.

Any theory dealing with the origin of the ionosphere must not only account for the above phenomena, but must also explain the not infrequent occurrence of "midnight E". Appleton (97) in 1930 and later Appleton and Naismith (51), Schafer and Goodall (105) and Ranzi (106) as well as a number of subsequent investigators (particularly those who have been operating continuously recording mechanisms,) reported that now and then during the night, when recombination in the E layer has normally progressed so far that reflections do not occur, suddenly echoes will be returned from the lower region. This effect lasts for a short while, after which conditions revert to normal as abruptly as they have departed from it. It is usually found that the intensity of the F layer echoes increases noticeably at the same time, but the relation is not invariable. Appleton and Naismith (9) and Ratcliffe and White (92) have discussed the matter, both finding traces of correlation with magnetic storms, and the former, fair correlation with a special "thunder storm index". Gilliland (91) in a very recent paper reproduces some highly interesting photographic records showing, among other things, the "midnight E", with magnetic curves plotted to the same time scale. He, as well, finds no absolute correlation with magnetic abnormalities.

A phenomenon which appears to be connected with the above has been noticed by the writer for the first time, so far as he is aware. This is an infrequent condition of the lower layer, occurring during the daytime as well as at night, such that complete penetration does not take place until a very high frequency has been attained. The F layer seems to behave in a normal manner, but when it is penetrated at about the usual frequency, E echoes are still being returned, and these persist until frequencies are reached which usually completely penetrate both layers (at normal incidence). A letter has been communicated to "Nature" describing the occurrence, by Dr. Henderson and the writer. The point will be treated in more detail in a later section dealing with the McGill experimental results.

No attempt will be made here to deal at all thoroughly with the various theories which have been advanced from time to time to account for the formation of the ionized layers and of aurorae. Very soon after Balfour Stewart and Schuster's preliminary work on magnetic variation had been published, it was recognized that the presence of a conducting region in the upper atmosphere would aid materially in explaining many phenomena connected with aurorae. An association between magnetic variation and polar lights had been known to exist since P.V.Wargentin had drawn the attention of the Royal Society to it in 1750, and the prospect of a logical basis for the observed correlation undoubtedly acted as a stimulus to those investigators who, at the beginning of the present century, commenced intensive study of the nature and occurrence of aurorae, and associated phenomena. The results of the pioneer work of such men as Birkeland, Störmer, Bjerknes, Vegard, and McLennan leave little doubt that aurorae may be regarded as an electrodeless discharge resulting in the main from the action of the "dynamo theory" currents, which also produce magnetic perturbations (107) (108) (4).

Upon Marconi's (22) discovery of the day and night effects in radio transmission it was realized that the chief agency causing this must be propagated rectilinearly from the sun. Various hypotheses were put forward, ranging from Hertzian waves to alpha particles, among the lot being ultraviolet light. Commercial operation of long distance radio circuits aided in the gathering of a vast quantity of data on such things as fading, seasonal variation, and sunset effects, and attempts were made at correlation with variations in the solar constant, appearance and disappearance of sunspots, aurorae, and the like. No very satisfactory progress resulted, however, because signal strength and atmospheric noise which were the quantities usually observed, are functions of a great many variables. It was fairly well established by 1925, however, that two agencies were at work, both propagated linearly from the sun, but one, causing the sunrise-sunset-night effects, travelling with the velocity of light, thought to be ultraviolet light ; and the other, travelling much more slowly, producing delayed auroral and magnetic effects, which in turn were connected with radio propagation (109). Much speculation existed (and not a small proportion still remains) as to the nature of the latter entity : auroral workers, such as Störmer, favouring electrons, and the magneticians, such as Chapman, regarding neutral particles, or an ionized but resultantly nearly neutral stream of particles as being more likely (110). Among those who have collected radio data may be mentioned Pickard (111) (112) (113), Stetson (114) (115), Plendl (116), Austin (117), and Colwell (118).

Meteorologists, not particularly interested in the question of radio propagation, have meanwhile been attempting to discover definite correlation between solar, terrestrial, magnetic, and auroral phenomena. Typical examples of the immense amount of labour expended on this aspect of the problem will be found in papers by Glover (119), Chree (120), Clough (7), and Bartels (121). One point stands out strongly in this work, as it does in attempts at correlating radio reception with solar phenomena, and that is this : no amount of investigation has revealed a significant correlation coefficient when it has been confined to short periods of observation. Quite good coefficients can be, and have been, obtained, using linear regression, when the means of years are available, but even then such smoothing devices as weighted moving averages are commonly employed. But while graphical comparison may oftentimes appear to indicate an hourly or diurnal similarity of trend, and indeed, may furnish valuable qualitative information, statistical analysis, which in the end, offers the real test, shows that the agreement is all but fortuitous.

When it had been demonstrated that direct measurements on the Kennelly-Heaviside Layer could be made, it was hoped that herein was to be found a method of eliminating a great number of the conflicting factors which necessarily vitiate signal strength observations, and that direct correlation could be shown. It is unfortunately true, however, that if we except the recent work of Appleton and Naismith (9) with thunderstorms, and that of Ranzi (103) and Colwell (118) with barometric pressure, no observations have yielded satisfactory diurnal correlation with aurorae or magnetic storms, so far as the writer is aware.

Notwithstanding this, great progress has been made in the field of ionosphere theory (4) (122) (123). That ultraviolet light is the chief agent in ionizing the upper layer at least, has been confirmed, and fairly complete theories of aurorae (124) (125) and magnetic variation (121) (17) (6) yield results which agree remarkably well with observations. A "tempting" hypothesis, that the four ionization maxima found in the two layers (Fig. 3) arise from the four ionization potentials of oxygen and nitrogen atoms and molecules, has been advanced by Appleton (102), but this is, as he admits, so far a matter of conjecture. Skellett (126), in seeking for an explanation of the "midnight E" phememenon, has investigated the known possible causes of night time ion-production. He makes the interesting suggestion that ionization caused by the passage of meteors and meteoric dust through the upper atmosphere may account for the observed sudden increases in lower layer concentration. Schafer and Goodall (127) attempted to verify this by making a continuous determination of layer height during the Leonid Meteor shower of November, 1931, but their results were unfortunately rendered of little value by a magnetic storm which took place on the critical days. The verdict is still "not proven".

Considerable importance was attached to radio ionosphere measurements carried out during the total solar eclipse of August 31st, 1932. The results obtained by Henderson (2) and Rose (128) confirmed almost completely by observations in the United States, the British Isles, and Europe, indicated that ultraviolet light is the main cause of lower layer ionization, although a more restricted action by neutral corpuscles, as favoured by Chapman, is not altogether ruled out. (5) (16).

At the present time, therefore, we may say that at least two ionized layers exist in the stratosphere, the concentration in the upper one being generally much greater than that in the lower. Fairly satisfactory and mutually consistent theories now account for normal day and night effects, for seasonal variations, and, on the whole, for auroral, magnetic, and sunspot phenomena. Short period correlation between abnormal occurrences, both in meteorological data and in ionosphere observation, is not generally good. Notwithstanding this, the outlook is not unpromising, for it is to be hoped that when continuous records have been extended over a number of years, greater experience may furnish the basis for a satisfactorily detailed treatment of these effects. A remark of Brunt's, although made in another connection, may well apply to the present situation (129) :

> "The difficulties to be met . . . are enormous, and their successful solution will demand the zeal for facts of a Whitaker's Almanack combined with the analytical power of a Newton."

DESCRIPTION OF EQUIPMENT

As has been previously mentioned, the amplitude variation method of Breit and Tuve was exclusively used in this investigation. The transmitter was situated in the attic of the Macdonald Physics Laboratory, McGill University, and the receiving equipment was set up in the basement in the home of Dr. Walter Smyth, 4822 Western Avenue, Westmount, the separation distance being very nearly 3.5 Km. Transmission thus took place roughly from NNE to SSW. A special direct telephone line between the two stations was installed so that communication could be maintained at all times. To ensure power synchronism, a circuit on the Montreal Light, Heat, and Power Company's system was brought to the receiver location. This system also furnishes A.C. to the Physics Laboratory.

(a) Transmitting Equipment

To send out the brief pulses required for the experiment, a special transmitter was built. Its circuit is shown in Fig. 4. As will be seen, it is a tuned plate - tuned grid arrangement. Switches were provided so that any one of five pairs of coils could be used for the inductances L_p and L_g, giving a frequency range of from 0.6 Mhz to something over 10.0 Mhz. A General Radio Precision Wavemeter was used as a standard by which to tune the transmitter. Three horizontal aerials were available, through another set of switches. The approximate dimensions were -- Height, 25 m ; lengths, 23 m, 35 m, 60 m. The smaller two of these were strung between the Physics and Chemistry Buildings, without masts. This aided in the absorption of horizontally radiated energy, thus reducing the ground wave. The transmitting set, being in the attic, was roughly on the same level as the aerial wires. High tension for the transmitter was obtained by using an 860 mercury vapour Rectifier Tube in a 2000 volt power pack. A short-circuiting switch was provided so that the filter condensers could be easily drained of their charge whenever a wave change was to be made. A resistance was also arranged so that it could be cut into the primary circuit of the high voltage transformer, thus reducing the anode potential to about 1000 volts during tuning operations. The transmitter was keyed with a chopper device run by a 1800 RPM self-starting synchronous motor. Into the rim of the fibre disk chopper commutator were let three brass plugs, two of which were wired together. Soft carbon brushes, in regulation spring tension brush holders on special mounting arms, formed the contacts on the rim of the commutator, which thus keyed the transmitter once per revolution, or 30 times per second. The pulses of R.F. power were usually arranged to last about 0.0006 ~~milli~~seconds. The arms holding the brushes were adjustable so that the length of time the circuit was made could be controlled. It was also arranged so that the pair of brushes could be swung around the commutator rim, while preserving their angular separation, for the "phase changing", to be mentioned later. The rated dissipation for the 852 valve is 150 watts, but the time-integral of power, taken over a number of cycles, was extremely small. We estimated it at less than 20 watts, although the instantaneous peak power was probably in the neighbourhood of 100 watts. A remodelled broadcast receiver was used in the transmitting room as a monitor. What was chiefly required was a device which would indicate to the operator whether the transmitter was keying properly or not. A loudspeaker was installed for this purpose, and when the set was in proper adjustment, the sound emitted was a rapid series of sharp clicks, resembling machine-gun fire. The audio amplifying system of the monitor was also connected to the telephone line so that the receiving station could instruct the transmitting operator to change frequency, etc., by merely speaking into the telephone. The transmitter was operated under the experimental call letters VE-9-AB.

(b) Receiving Equipment

At the receiving station the aerial was of the inverted-L type, the horizontal portion being about 15 m long, and 15 m high. Two receiving sets were used, one having been especially designed for ionosphere work, the other being a Silver Marshall, Type 728 SW, long- and short-wave commercial broadcast set. The latter, a superheterodyne, has a range of from 0.55 to 23.0 Mhz, a band-pass of 10 Khz, and a sensitivity of about 0.25 microvolts per meter. A switch was arranged so that the output from the power tube driver stage (itself resistance-coupled to the second detector) could be obtained across an anode resistor, which temporarily replaced the primary of the power stage input transformer. Thus ferromagnetic links in the receiver circuit, which introduce objectionable hysteretic effects into a pulse signal, were avoided, while the switch enabled the set to function normally for tuning purposes. It was not found necessary to touch the automatic volume control.

The other receiver was built for the eclipse experiments in the Radio Research Station at Slough by Dr. J. T. Henderson. It is a superheterodyne with a range (at present) of from 2.0 to 10.0 Mhz, using interchangeable sets of coils, although by winding others the range could undoubtedly be extended. It was designed with the frequency variation method in view, and so has a flat top band-pass of 17 Khz and a separate heterodyne oscillator for the output. Its sensitivity is slightly better than that of the Silver Marshall set, and this, together with its wide band-pass range, makes it difficult to use under electrically noisy conditions. The second detector is a diode rectifier, and there are no audio amplification stages, the output appearing across a resistor.

As shown in Fig. 5, the output of either receiver may be connected to the vertical deflector plates of the cathode ray oscillograph O. The horizontal deflection is obtained from a thyratron time scale unit, the circuit for which appears in Fig. 6. On account of the saturated diode across the output condenser in the latter unit, the sweep is nearly linear along the scale, a fact which is a great practical advantage. This time sweep device may be set to operate at 30 cycles per second by adjusting the diode filament current, when the frequency of the power supply is 60 cycles per second.

Thus a cartesian diagram is traced out on the oscillograph screen by the spot, the horizontal displacement being linearly proportional to time, and the vertical displacement being proportional to the receiver output. A Cossor Oscillograph Tube, type C, was used in conjunction with a General Radio Oscillograph Power Supply Unit. These tubes give a very small, bright spot, with excellent actinic characteristics.

While the receiver was intercepting signals sent out by the transmitter, keyed synchronously with the power supply, the thyratron unit, on the same power system, was producing horizontal deflections in step with it, and thus a stationary pattern appeared on the oscillograph screen. This pattern was recorded by taking a short exposure (about 1/5 sec.) with a special box camera, into which

100-foot rolls of fast bromide recorder paper (speed 250 H. & D.) could be fitted. After every few exposures the horizontal time scale was calibrated, as described below, and occasionally the camera was moved so that an illuminated watch was in focus. By making an exposure, a record was thus kept of the time, to aid in identifying the pictures on the long strip. At the conclusion of a test, the used film was removed from the camera, cut into convenient lengths, and developed. Some of these records are reproduced at the end of this Thesis. They are discussed in the next section.

In order to calibrate the time scale sweep, switch S_2 was used to connect the vertical deflector plates with an oscillator running at approximately 1000 cycles per second. If the oscillator had been set at exactly 1000 cycles per second, it is easy to shew that the horizontal distance traversed by the spot, per vertical motion cycle, represents a layer height of 150 Km. But 1000 cycles per second is not commensurable with the sweeping frequency of 30 cycles per second, and so a stationary pattern cannot appear on the oscillograph screen to be photographed. This difficulty was overcome by first adjusting the oscillator, by ear, to zero-beat with a 1000 cycle per second tuning fork.
The frequency of the oscillator was then slowly lowered until the pattern on the screen became stationary. The frequency

of the oscillator was then at 990 hertz (the next lower whole-number multiple of 30 hertz). The frequency of 990 is close enough to 1000 hertz for visual purposes, while the resulting allowance for the difference, when the records are being examined for height measurement, does not involve even an extra slide rule setting.

A single further point is of interest. When the synchronous chopper motor at the transmitter locks into phase with the power supply, its rotor, and consequently the chopper disk, can occupy one of only three discrete mechanical positions relative to the motor's rotating field. Now the thyratron unit, being a voltage operated device, is always tripped at approximately the same electrical phase angle with respect to the supply voltage wave (it depends somewhat on the grid bias voltage), and thus, unless the chopper disk happens to be keyed to the shaft in exactly the right position, the pattern at the receiving end, while stationary, may not be conveniently located on the oscillograph screen. To provide for this contingency, the brushes of the chopper are arranged to rotate, as described above, so that the instant of keying may be brought into any required phase relationship with the supply voltage wave. In this manner the operators can control the position of the pattern on the oscillograph screen, and so adjust it that the best use is made of the available screen surface.

DISCUSSION OF PHOTOGRAPHIC RECORDS.

Notation.- The symbols used in describing echo phenomena which have been developed in papers by Appleton, referred to in a previous section, is adhered to throughout the present discussion. They may be listed as follows:-

E - Refers to the Kennelly-Heaviside region, roughly 80 to 130 Km. in height.

E_1- First reflection from the E region.

E_2, E_3, etc.- Second, third, etc. successive multiple reflections between the E region and the earth's surface. (e.g. an E_2 echo has travelled from the transmitter to the E layer, down to the earth, up to the layer again, and thence to the receiver).

E'- The less delayed component of a split E echo: the one appearing nearest to the ground pulse in the photographic record.

E"- The component of greater delay in a split E echo.

E_1''; E_2', - Component of greater delay in the first split reflection of an E echo; component of less delay in the second split reflection of an E echo.

F - Refers to the Appleton region, roughly 190 to 300 Km. high.

(The same conventions as above, regarding subscripts and primes, are used with reference to the F layer).

<u>Synchronous Noise</u> - Disturbances in the power supply system such as those caused by leaking insulators, faulty transformers, etc., as well as most of the so-called "man made static" from electro-medical apparatus, sparking commutators on A. C. motors, etc., are for the most part in a fixed phase relationship to the supply voltage wave. Hence if these disturbances reach the receiver in an amplitude - variation experiment, in which the sweep frequency is a submultiple of the supply frequency (e. g. 30 cycles per second sweep frequency as in this case), a disturbance stationary in phase displacement may show on the oscillograph screen, and so hinder the correct interpretation of the records. It is fortunate that this type of disturbance is usually recognizable by its ragged appearance, and "fluttering" character, but such is not always the case. Nevertheless, although at times it is quite impossible to disentangle the echo deflections from these "synchronous noise" deflections, experience with pulse method work, and familiarity with the common noises peculiar to any receiving district will often enable a distinction to be made. Some examples of synchronous noise disturbances will be discussed below.

<u>Typical Photographs</u> - A selection of specimen photographic records is contained in Plates I to V. The sequence of events is from left to right, the first vertical deflection being the ground pulse, and subsequent ones, echoes. Under the

first picture of a group appear, at the left, the time of day (Greenwich Mean Time, or Eastern Standard Time, as indicated), and at the right, the frequency in Kilohertz. For example, the record of Plate I A was made at 1238, Feb. 23rd, 1933, on a frequency of 1800 Kilohertz. Below the echo picture appears a 990 hertz time scale calibration, taken immediately afterwards, as the hour mark indicates. That the time-displacement relation is nearly linear is apparent. The distance between corresponding portions of each cycle may be taken as representing roughly an equivalent layer height of 150 Km. In the original photographs the path of the illuminated spot is recorded as a black trace on a light background : in these reproductions, the colours have been again reversed, so that the appearance more nearly represents what is seen on the actual oscillograph surface. As a consequence, the pencil markings for the determination of effective height show up in white. Parallel lines, perpendicular to the time axis, are drawn in order to facilitate measurements, and the calculated height is afterwards written in. The first point of departure from horizontal travel is taken as defining the echo, this being standard practice.

Plate I A is a good representation of a single E echo returned from an equivalent height of 126 Km. The ground pulse has a duration of about 0.0003 seconds. Although this gives a clean, neat picture, it should always be recognized that, as recently emphasized by Gilliland (91), the strength of signals is unduly reduced if the pulse is decreased in length beyond what is necessary to secure good resolution of the echo of least delay. It should be noted that the square tops to the pulses, while apparently indicating an approach to the ideal form of pulse, are fictitious : they are not inherent in the transmitted waves. The receiver being used was the Silver Marshall set, and its automatic volume control produces the effect. Sometimes when conditions are noisy this square top is an aid in determining the actual beginning of the ground pulse, since the spot always traverses this line, no matter how noisy it is. A further point of interest is that, despite the elimination of ferromagnetic links in the receiver amplifier, the "tail" of the ground pulse is depressed below the normal quiescent line. While no exact reason has been found for this, it is believed that flux linkage with parts of the shielding or chassis probably account for it.

Plate I B is the record of a split E echo. The special "English" receiver was being used, and the difference in pulse shape is very evident. It is thought that long shielded leads from the receiver output account for the characteristic exponential capacity-and-resistance form of growth and decay, but since the end of the pulse is rarely used for measurement, the effect is of little consequence.

Split E, although it could not be called unusual, is of much rarer occurrence than is splitting of F echoes.

Plate I C is another rather pretty case of E layer splitting. The F layer multiples stand out strongly, while the E components, of which there appear to be three (thus putting it in the "boiling" class referred to below), are considerably less intense, on account of absorption. The rapid fluctuations in the character of the photograph are well illustrated here from the varied appearance of the echoes, all these pictures having been taken within the space of half a minute.

In Plate I D we see four multiple reflections from the F layer, in a characteristic pattern. The upper set of pictures was taken with the Silver Marshall receiver, and the lower set, shortly afterwards, with the "English" receiver. The pictures bear out the remark made above that the latter receiver was more sensitive, but admitted more extraneous noise.

Simple simultaneous reflection from E and F is shown for two frequencies in Plate I E. This is an example of "midnight E", since reflections from 3800 Khz, representing an ion density in the layer of not less than 2.7×10^5 electrons per cm^3, are hardly to be expected half an hour before midnight.

The last two photographs on Plate I, F and G, are records of someone else's impulses -- probably one of the continuous recorders on frequencies near 4.0 Mhz which have been in operation at the Bureau of Standards (91), and elsewhere in the United States (85). Wandering of the echo train, due to lack of time sweep synchronism, is apparent. The last record is quite unusual on account of the strong signals. Almost certainly, the first deflection in the series is an F_1 echo. At a distance of some 300 Km the ground pulse would be quite negligible.

Plate II A shows a signal record in which the intensity of the ground pulse is much less than that of the reflections. Indeed, the ground wave is almost negligible in the fourth picture. It is hard to assign any definite cause for this condition which occurs now and then. For some one or two frequencies, resonance or other effects must combine, either to absorb all the direct ray energy, or to concentrate most of the radiated power into the vertical component.

Plate II B is another record of normal multiple F. A fuzzy time scale calibration indicates that the local oscillator had drifted off the power line frequency harmonic (990 Khz).

Plates II C, D, and E are records of the appropriately named "boiling echoes". Instead of being broken up into two components, the reflected signal is greatly b oade: i, and seems to be made up of a number of small echoes ontinually dancing up and down. One explanation is at t: refracting region may not be homogeneous izor ally, or that discontinuities are present. other explanation hinging on the behaviour of the wave at n inst it when its state of polarization is changing very pidly as been recently discussed by Ratcliffe and White (81). phc graphs illustrate the broadening effect, and the or (E) especially the rapid nature of the "boiling". fou pictures were taken at intervals of about 8 seconds.

Plates III A, B, and C are further examples of ltipl F trains occasionally encountered. In B, a rticu rly large group (9) are clearly visible. It is fficu to get a good picture of this phenomenon on ount f the rapidity with which the higher members of the ies pear and disappear. As many as 12 multiple lect ns have been observed visually.

Plate III D shows the result of interference with nals aused by a nearby diathermy apparatus. In this tance he echo positions are clearly defined, but the se e ect varies with the adjustment of the spark gap, tes have not infrequently had to be suspended for over iour ecause all other signals were drowned out. mple , high-conductivity screen around patient, operator, mach e seems to be the only cure, and this is likely to wi objections from the owner.

Plate IV A is another case of multiple F reflections, with this peculiarity : the third echo is consistently absent, although the fifth is undoubtedly there. The pattern was steadily observed in this instance for over ten minutes, and no trace of the echo was found during that time. It seems difficult to account for the effect on conventional grounds. Plate IV B is another record of the same type. Here the second echo is missing, although the third is prominent. Plate IV C shows a group of multiple F reflections in which the intensity of the first component is practically constant, while the higher members of the series vary greatly in amplitude.

Plate IV D gives the picture of an F echo being returned at a frequency just below the critical penetration frequency. Note the large equivalent height due to the reduction in group velocity as the critical condition is approached.

Plate V A has been included, both as another sampke of "midnight E" (the time is GMT), and to show one of the routine identification photographs of the watch, used to guard against errors in identifying pictures appearing on the strip with log entries.

Pkate V B is a picture of the transmitter's "unmodulated CW". The effect of insufficient filtering in the power pack (insufficient, that is, for voice transmission) is quite evident. Compare it with Påate V D, where the record of the quiescent carrier of a police short-wave transmitter has been taken.

Another boiling echo record appears in Plate V C together with a typical example of the almost complete masking of the signal by sudden noise (not synchronous noise, however). The automatic volume-control limits the tip of the ground pulse, which makes it easily identifiable.

Plate VI A illustrates transition from region E to region F at the critical penetration frequency. Reading from top to bottom we find that on 2000 Khz, E echoes only were returned. The frequency was increased to 2500 Khz and F echoes alone appeared. A drop to 2398 Khz still showed F echoes (abnormal attenuation of the ground wave is present on this frequency), but at 2200 Khz E echoes again appeared. The C. P. F. was obviously somewhere near 2300 Khz.

Plates VI B, C, and D show unmistakeable intermediate region echoes. A very small E region echo in the top picture of B is also detectable.

Finally, in Plate VI E we have an example of "persistent E", here shown on 9220 Khz. More photographs of this important phenomenon are not reproduced here, although many are on file, because the echo appears the same as any other moderately small E. That there is an echo there, however, is beyond all doubt, as the photograph shows.

DISCUSSION OF SPECIMEN HEIGHT CURVES

In selecting curves of data obtained during the present series of tests, it has often been difficult to determine what is normal and what is abnormal. On the whole, results from the earlier runs, under winter conditions, resemble those commonly found by other investigators, while, as we proceed to the later summer tests, abnormalities, such as "midnight E" and "persistent E" occur more and more frequently. However, this is not to be taken to mean that "normal" conditions (i.e. conforming with observations obtained elsewhere) were uncommon.

Figure 7, for example, is a typical curve of equivalent layer height plotted against frequency, taken from the records of June 12th. E and F layers are quite well marked and occupy the commonly accepted positions.
At 3.6 Megahertz the lower layer was penetrated, corresponding to a maximum E ionization of 2.4×10^5 electrons per cm^3.
The E echoes appear to have been momentarily split at 2.8 Mhz, and an indication of intermediate layer, at a height of 183 Km, shows at the critical penetration frequency.
Figures 7 to 10 are a set taken from the same day's results.
If Figure 9 were omitted, the layer behaviour would be quite conventional, the CPF descending as time progresses (indicating that recombination is gaining on the ionizing effect of the sun) until, near midnight, reflections are returned from the upper layer only. But Fig. 9 shows that

about 10.30 p.m. the E layer became strongly ionized, so strongly, apparently, that no reflections were received from F. The high point at 2.0 Mhz is likely a second reflection from E (i.e. E_2). Normal conditions had been restored by midnight, as Fig. 10 indicates.

Figures 11 to 14 are again taken from the results of a single day, June 5th. At about 6.00 p.m., as shown in the first of the series, the E layer was normally ionized, but F reflections were rather erratic. It is possible that some of the upper points between 2.4 and 3.9 Mhz are not F region, but are multiple E ; however this would seem to be unlikely, as multiple heights are usually more regular than this. From Fig. 12 we see that, although evening was coming on, lower layer ionization had greatly increased. ($\measuredangle$ 7.8×10^5 electrons per cm^3) Both E and F echoes are found between 2.0 and 6.5 Mhz, where F was on the point of disappearing. Shortly after sunset (1942), as Fig. 13 shows, E ionization had begun to resume more normal values. I would attribute the break in the lower curve to unstable conditions. In Fig. 13 the E reflections are about to disappear at 6.5 Mhz, while in Fig. 14 the penetration frequency is 4.5 Mhz. This would account for the apparently abnormal height.

Figure 15 illustrates definite intermediate layer reflection, and resembles the curve recently published by Appleton (102). The characteristic negative slope at the commencement of the F curve, near E layer penetration, is present.

An example of "persistent E" is shown in Fig. 16. E ionization was very pronounced, for reflections were still being returned at a frequency of 6.0 Mhz (6.6×10^5 electrons per cm^3). F echoes had been lost after 2.4 Mhz (1×10^5 electrons per cm^3). It is true that a heavily ionized E region will prevent signal penetration to the F region, but the strong tendency upwards of F height, near the point at which reflections from it are lost, suggests true penetration. If this is correct, ionization in the E region was much more intense than in the F layer. The short curve for heights of about 240 Km may conceivably represent a true intermediate layer reflection, an E_2 reflection, or a lower branch of the F_1 curve. The first of these alternatives appears the most probable, since no points are found for frequencies below 1.95 Mhz, and the height is rather low for a multiple reflection from the E layer.

The curve of Fig. 17 is very unusual. It will be noted that the slope of the upper curve is continuously negative. The echo on this occasion was followed up to the highest frequency on which the receiver could operate, and yet was not lost. At the same time the equivalent height descended from above 300 Km to below 130 Km. The two E echoes obtained, although not unusual, indicate an ion density greater than what one would normally expect around midnight. If splitting of the F echo took place, the components either approached one another as the frequency increased, or else the upper one disappeared. The writer can offer no satisfactory explanation for the occurrence.

Figure 18 illustrates a continuous rise in effective height with frequency. The height starts at E region values, passes through the F region, and finally penetrates the latter at a commonplace enough frequency for that time in the morning. This is a sample of a number of such curves obtained during the tests, and would seem to imply that on occasion no distinction can be drawn between the E and the F regions.

In Fig. 19 we have another case of "persistent E", this time occurring in mid-afternoon. F echoes ceased to be returned at frequencies above 7.0 Mhz, but the E echoes remained. The critical penetration frequency was again beyond the range of the receiving equipment. There is, of course, the possibility that the upper curve may represent simply a second E reflection, and not an F echo ; but this does not affect the contention that the E layer maximum ionization passed the value 17×10^5 electrons per cm^3 (corresponding to the highest frequency recorded 9.66 Mhz). If the upper curve represents F echoes, the maximum ionization was not, at the time, greater than 9.6×10^5 electrons per cm^3.

Figure 20 has been included not only to furnish examples of splitting E echoes (an unusual phenomenon), and "persistent E" (this time about an hour after sunrise), but also to illustrate the methods employed in disentangling irrelevant echoes from those essential ones which indicate the true equivalent height of the layers. Obviously for this purpose, multiple echoes, the upper components of "boiling" echoes, and M echoes may be disregarded. Consideration of the original photographs in the case of points 1, 2, 4, 6, and 7 eliminated them on the grounds of "boiling", or complex splitting. No. 9, the effective height of which is very close to F + (F - E), was dismissed as being an M reflection, while 5 and 3 were considered to be E_2'' and F_2, respectively. This left point 8 still to be explained. Reference again to the photographic records disclosed the fact that the echo picture for this height was small and indistinct. Experience shows that synchronous noise very frequently photographs in this way, and so it was decided that point 8 could be safely disregarded. This clears away the confusing array of points which do not convey additional information. The exception is an unmarked point immediately above the F curve on 4.0 Mhz. It is likely that this is a splitting of the F echo, but the evidence available is not considered decisive, and so it is left as an isolated reading.

Figure 21 is yet another good example of "persistent

E". The maximum ionization for the E layer in this case is 10.5×10^5 electrons per cm^3, while that for F is 7.7×10^5.

STATISTICAL ANALYSIS OF HEIGHT CURVES

In order to determine to what variations in height the layers were subject, a statistical analysis was made of recorded heights. The frequencies used were grouped ? into 11 bands, and the equivalent heights for each were abstracted from the mass data. Frequency grouping was as follows :-

Class	Range (Mhz)	Class	Range (Mhz)
A	Below 1.25	G	3.75 - 4.25
B	1.25 - 1.75	H	4.25 - 4.75
C	1.75 - 2.25	J	4.75 - 5.25
D	2.25 - 2.75	K	5.25 - 6.0
E	2.75 - 3.25	L	Above 6.0
F	3.25 - 3.75		

Layer heights were grouped in five sets of classes :-

(a) Below 90 Km.

(b) 90 - 99, 100 - 109, ... 190 - 199 Km.

(c) 200 - 219, 220 - 239, ... 480 - 499 Km.

(d) 500 - 599 Km.

(e) Above 600 Km.

The increase in the class range at the greater heights is, of course, permissible, since the absolute error increases with the measured height. This analysis resulted in a list of the number of times a given height had been recorded for a given frequency (crudely speaking), the usual "frequency distribution" of statistical method. (In what follows the word "frequency" alone will be used for the electrical quantity, while "statistical-frequency" will denote the mathematical term.)

Statistical-frequency polygons have been plotted from these data and are reproduced in Figures 22 to 36. It should be noted that since the height class intervals are twice as wide above 200 Km as below, the middle ordinate values have been divided in two before plotting, so that the statistical-frequencies for the classes representing the greater heights will not be overemphasized.

Figure 22 shows the statistical-frequency polygon for frequencies below 1.25 Mhz. The area is small, since observations could only be taken in this band at infrequent intervals. A pronounced peak, however, shows up for the lower layer, with an approximate modal value of 125 Km, while the upper layer's modal height lies in the neighbourhood of 240 Km. I am inclined to regard what appear to be intermediate region values, at heights of 155 and 175 Km respectively, as being without individual significance, although they indicate that reflections sometimes occurred in this range.

Figure 23, showing the statistical-frequency polygon for the class 1.25 to 1.75 Mhz, is of the same general nature, the modal values in this case being about 115 Km for E, and 250 Km for F.

In Fig. 24 the effect of narrowing the frequency range is demonstrated. The full curve is for a band 1.75 to 2.25 Mhz, while the broken curve shows the distribution within the smaller range of 1.9 to 2.1 Mhz. The E layer mode remains unaltered at about 125 Km, while the F layer mode has shifted slightly in the narrowing process, from 250 Km to 270 Km approximately. This can hardly be regarded as significant, for it is apparent from the shape of the curve that the true modes, as determined by fitting normal error curves to the peaks, would lie close together between the two values quoted.

A further analysis of the data for the same (large) range is given in Fig. 26. Here the heavy line represents the statistical-frequencies of all the heights falling in the various classes. The light full line represents those observations taken during the daytime (ground sunrise to ground sunset), and the light broken line, those taken during darkness. The very interesting point is brought out that the F layer height remains about the same for day or night, while the E layer mode has shifted to a perceptibly higher value. One must not, of course, expect here the large ranges of height fluctuation found in individual runs. There are a considerable number of values in the intermediate region, but no peaks.

Between 2.25 and 2.75 Mhz the distribution is normal, as shown in Fig. 25, except that a pronounced intermediate layer peak appears. The modal height values are approximately : 125 Km for E, 185 Km for intermediate, and 230 Km for F.

Figures 27 and 28 need little comment. It is interesting to note, however, that as the frequency is increased, the proportion of F layer reflections becomes greater (since the E layer is more often penetrated). The distortion apparent in Fig. 28 may possibly be attributable to the fact that this frequency band was almost always noisy, thereby increasing the difficulty of interpreting the records.

In Fig. 29, the same narrowing process has been applied as that in Fig. 24. The full curve again represents the broader band, 3.75 - 4.25 Mhz, while the broken curve is for the band 3.9 - 4.1 Mhz. No alteration in the modal values is apparent.

Day and night values for the same range are shown in Fig. 30. Day measurements clearly predominate, as one would expect. It will be noted that so far, the frequency has risen in successive diagrams. We shall see that this tendency must shortly be reversed, for the large part played by "persistent E" echoes is clearly indicated by the definiteness and size of the "E" peak. The night curve shows poor concentration at the modes. Here again sampling errors may have vitiated the results. The large proportion of intermediate region echoes should be noted, although the peak is not necessarily significant.

Figures 31 to 33 are largely self-explanatory. In Fig. 31 the tendency of the F layer to split is very marked. This may be really due to F echo splitting, or it may be indicative of M reflections. The intermediate region heights are also prominent, with a modal value of 175 Km. Figures 32 and 33 show a falling off in F echoes and good intermediate peaks. The peaks at 350 and 430 Km in the latter figure may be due to sampling errors.

On the last chart in this group, Fig. 34, the trends noted above are evident. True F region reflection is very sparse and shows little if any modal tendency. The statistical dispersion about the E region, however, is remarkably small, and a well defined intermediate region peak is also present.

We may sum up the evidence furnished by this analysis as follows :- At low frequencies (i.e. around 2.0 Mhz), the E layer is prominent, the F layer mode is fairly well defined, and the intermediate layer is relatively unimportant. At higher frequencies (around 4.0 Mhz), the E layer is still well defined, the F layer has gained in importance, but at the expense of a much larger dispersion, and echoes from the intermediate range are often found. At still higher frequencies (around 6.0 Mhz), the E layer retains its definite modal tendency, the F layer has lost its former prominence, and the intermediate layer is very evident. "Persistent E" echoes clearly play a large part in determining the shape of the distribution polygons for the higher frequencies.

ATTEMPTS AT CORRELATION WITH METEOROLOGICAL DATA

Despite the fact that, as was pointed out in a previous section, other workers had been unsuccessful in trying to correlate diurnal ionosphere data directly with meteorological observations, it was thought worth while to consider what evidence there was available in this direction. Accordingly, auroral, sunspot, and magnetic character numbers were obtained from the Dominion Observatory, and the Carnegie Institution of Washington. In two instances, special abstracts were very kindly made from their records for the purpose. Unfortunately the auroral and sunspot data which came from the former source was unavoidably meagre, since weather conditions had interfered with the observations. The information furnished by the Carnegie Institution was, however, complete, and hopes were entertained that relationships might possibly be found.

Figure 35 is a compilation of the data as sent. The arrows at the bottom of the sheet represent days on which tests took place, and the other information is plotted above it.

No reported auroral displays took place on days of test, as may be verified by inspection.

The magnetic character numbers plotted are the provisional ones which can occupy only the discrete values 0, 1, 2, representing quiet, moderately disturbed, and highly disturbed days, respectively. The quiet days are not indicated. There were three highly disturbed days, none of which coincided with a test period. An examination of the records failed to disclose any relationship between such phenomena as "midnight E" with the "character 2" series.

The Mount Wilson and Zurich sunspot numbers looked at first more promising, but such rough comparison as there has been time to make since the figures were available is of a qualitative nature only. For example, the test of March 30th, following a rise in the sunspot curve, was notable for the difficulty experienced in obtaining echoes at all. There is some reason to think that the times of occurrence of "persistent E" may tend to cluster around the periods of sunspot rise, but until a much more detailed analysis can be made with records from several observatories available, the correlation must remain in the qualitative class where so much of the previous work lies.

<u>Thunderstorm Data</u> - On two occasions it was noted in the test log that a local thunderstorm had been either imminent or in progress when "persistent E" phenomena occurred. Data on local thunderstorms covering the past five years were therefore obtained from the McGill Observatory records, in order to determine first, if the present year was unusual in this respect, and second, if local thunderstorms, not entered in the radio log, showed correlation with unusual phenomena. The answer to the first question was definitely in the affirmative. The average number of storms, for months

covered by the tests, was 12. The highest on record (1931) was 14. This year the number of storms has been 17. Similar analysis by months showed that the number of storms in May and July of this year had been decidedly above normal. But when the question of individual daily association was tackled, the results led nowhere. The two phenomena seem to be quite unconnected. Had apparatus been available for establishing a "thunderstorm index" similar to that of Appleton and Naismith (9), this finding might have more weight, since the ionosphere can hardly be expected to reflect local electrical conditions in the troposphere. The high yearly value, however, may be an indication of a more than local perturbation which also manifests itself through an anomalous behaviour of the ionosphere.

IONIZATION DENSITY PHENOMENA

Appleton and Naismith (51) (9) and others have shown the value of obtaining records of the critical penetration frequencies of both layers, over extended periods, in discussing the variation of upper atmospheric ion density with the seasons, with sunspot maxima and minima, and during periods of solar eclipse. Special efforts were made to include as many determinations of C. P. F. as was possible in the McGill series of tests, in the hope that curves, at least comparable with those already published, might be obtained. The early tests were characterized by the presence of periods of severe noise, which made the detection of small echoes near the critical frequency very difficult, while the prominent intrusion of "midnight E" and "persistent E" into the later records, of great interest in itself, rendered C P F determinations not only erratic but also, so far as is at present known, possibly without significance. As a result, the plotted points representing ionic densities as a function of time, while exhibiting the usual general tendencies towards maximum around noon and minimum an hour or two before sunrise, are so badly scattered that they are of little use in formulating even approximate laws of behaviour. It seems probable that the very fact of their randomness may indicate an instability in conditions favourable for the production of the very unusual phenomena herein recorded.

CONCLUSIONS

The results of the observations described in this Thesis may be interpreted as indicating, not a complete departure from what is elsewhere considered normal, but a decided tendency towards unusual ionization conditions for protracted periods, especially during the summer months. Not only has definite individual, as well as statistical, evidence been found to indicate that sufficient ionic density may be present in the intermediate region to return echoes on frequent occasions, but such anomalous effects as "midnight E" and "persistent E" have appeared a remarkably large number of times. While attempts at the correlation of individually disturbed periods with meteorological data have met the fate of similar undertakings on the part of previous investigators, the significance of a perceptibly higher than normal thunderstorm count for the period under consideration, and of the great randomness discovered in values for maximum ionic density, lies in the suggestion that unstable conditions exist at present. The results obtained in this investigation will have to be considered in the light of other Polar Year Observing Station experiences before a satisfactory conclusion can be reached.

APPENDIX A

Circular Letter P3
Appendix A

International Polar Year Programme of Observations on the Ionization of the Upper Atmosphere.

The present programme is dorected towards the precise formulation of the general design embodied in the Report of U. R. S. I. Sub-Commission on Radio-Work during the Polar Year 1932/33, Copenhagen, 1931, P 2 a, b, and c. It is based on recognition of the fact that there will be great variationa from one national programme to another in respect of available personnel, apparatus, means, and methods. It is proposed that interchange of information on the plans for national programmes should take place through the U. R. S. I. Sub-Commission on the Polar Year (President Professor E. V. Appleton ; Secretary Mr. R. A. Watson Watt, Radio Research Station, Slough, Bucks, England) in order that National Committees may have an opportunity of remodelling their own programmes to attain the greatest possible degree of similarity. The international, as opposed to the national, programme is restricted to include only such measurements as can readily be undertaken by every participating national committee ; to call for such measurements on such infrequent occasions as to be within the scope of the smallest expedition ; and to choose such occasions as will provide the maximum quality in the other geophysical measurements with which the determinations by radiotelegraphic means may ultimately be compared.

The measurements called for are (a) equivalent layer heights at fixed hours, for one or two fixed frequencies : (b) such rapid determinations of equivalent layer heights for a variety of frequencies as will enable deductions to be made as to the ionization content. The occasions chosen are the International Days of the Polar Year, which are the same for the magnetic, electric, meteorological, aerological, and radio programmes. In order to avoid ambiguities due to differences in longitude, however, the radio programme is fixed on the following conventions as to time, viz :-

The International Day is taken as beginning at 1600 G.C.T. Wednesday and ending at 1600 G.C.T. Thursday. No other use is made of "universal" time in this programme.

All times of observations are to be read as local mean times for the observing station concerned.

To ensure uniformity of interpretation the actual dates of each observation are tabulated, thus obviating the need for reference to lists of International Days.

On International Days of the First Order, i.e. on one day per month, the following measurements will be made within the quarter hour periods ending at noon and midnight, local mean time, viz :-

Using central frequencies of 4 mc/s and 2 mc/s (wave-lengths of 75 m. and 150 m.), determination of the equivalent height of the ionized regions effective in returning these emissions to earth at substantially vertical incidence (i.e. over base lines not exceeding 25 k). These determinations will be indicated by "NM" (Noon-Midnight) in the calendar attached.

Where observations on a third frequency can be made, this frequency should be 8 mc/s (37.5m). The observations on 4 mc/s are most important, those on 2 mc/s next in importance ; those on 8 mc/s will be useful only when ionization density is high (comparable with or higher than noon values for F region in latitude 50°).

On International Days of the Second Order, i.e. on one day per month displaced by fourteen days from the day of the first order, the following measurements will be made throughout the twenty-four hours :-

Using the one central frequency of 4 mc/s (wavelength 75 m), determination at each hour local mean time, throughout the twenty-four hours, of the equivalent height of the region returning emissions of this frequency to earth at substantially vertical incidence (base lines not exceeding 25 k). This series of determinations will be indicated by "24" (24 hour runs) in the calendar.

On International Days of the Third Order, i.e. on the Wednesdays to Thursdays of the weeks intervening between weeks containing first and second order days, determinations of the following general type will be made, viz :- Measurement of the approximate ionization density in the ionized regions by methods involving essentially the determination of the critical frequencies for the lower (E) and upper (F) ionized regions (i.e. for either region the highest frequency at which the waves are returned by that region in substantial amounts, at vertical incidence), near noon local mean time. Attention will be concentrated on the upper and on the lower regions respectively on alternate days of the third order, in accordance with the attached calendar, in which days devoted to the lower (E) region are denoted by "E", those devoted to the upper (F) region by "F". It is recognized that differences in technique will probably produce greater variety of method in the conduct of this type of measurement by different national committees than will prevail in other parts of the fixed programme. National Committees are on this account requested to study with care the individual detailed national programmes which will, as far as possible, be circulated in first draft to all participating committees, with a view to obtaining the best practicable approach to uniformity in essential procedure.

In addition to these operations on International Days, certain national committees will be able to arrange for continuous recording of equivalent heights at other times. It is recommended that if recording on one frequency only is undertaken, that frequency should be 4 mc/s (75 m) ; if recording on two frequencies is practicable the second frequency should be 2 mc/s (150 m), if three, the third should be 8 mc/s (37.5 m). The days chosen for continuous recording should be chosen in accordance with the following order of preference, viz :-

(1) International days of the First Order.

(2) Five days following days of the First Order.

(3) International days of the Third Order.

(4) Days preceding days of the Second Order.

(5) Days following days of the Second Order.

(6) Days preceding days of the First Order.

(7) Days following days of the First Order.

(8) Days preceding days of the Third Order.

(9) Days following days of the Third Order.

(10) Other days.

In setting out this order of preference it is assumed that the recording systems will, in the first instance, have been applied to the programme for the International Days of the Second Order, for which they are especially suitable.

Where continuous recording apparatus is not available, but where work additional to the minimal programme already outlined can be undertaken, it is recommended that observations of type NM should be made on each of the five days following International Days of the First Order.

It may be possible for additional critical frequency determinations to be made on fixed days other than "E" and "F" days. It is recommended that where possible such determinations should be made on International Days of the Second Order, and preferably on all International Days.

It is further recommended that special observations be made on days of marked magnetic disturbance or of marked auroral activity. It would appear probable that "critical frequency" determinations, in which it may be necessary to use exceptionally high frequencies, are the most promising means of studying relations with aurora. While the detailed mechanism of these relations is not yet established, it appears probable that the ionization density in E region may reach abnormally high values in conditions of auroral and magnetic disturbance. Wherever possible provision should be made for immediate notification, to the radio observers, of magnetic or auroral activity. The most desirable arrangement would be that a magnetic indicator should be directly visible to the radio observer at all times.

In all the observations made in accordance with and in addition to this International Programme it is desirable that data of the relative effective reflection coefficients of the conducting regions should be obtained. The absolute determination of the effective coefficients will not normally be possible, since the determination from single reflections involves knowledge of the distribution of radiation from the emitting antenna, with corresponding data for the receiving antenna, and since the effective coefficients depend on the states of polarization of the emitted and received waves. Where single reflections are obtained the relative amplitudes of the "ground pulse" to the echo should be noted, where multiple reflections are present the ratio of amplitudes of first and second echoes is a close measure of the product of the effective reflection coefficients of ground and ionized region. The receiving apparatus should, of course, be tested for linearity of response, and changes in antenna arrangements and the like should be as infrequent as possible.

This programme is designed to cover observations at stations outside the Arctic and Antarctic Circles as well as those actually in the polar zones.

Dates for Observations "NM"

1932 :- Aug. 10-11, Sept. 14-15, Oct. 12-13, Nov. 9-10, Dec. 14-15.

1933 :- Jan. 11-12, Feb. 8-9, Mar. 8-9, Apr. 12-13, May 10-11, June 7-8, July 12-13, Aug. 9-10.

Dates for Observations "24"

1932 :- Aug. 24-25, Sept. 28-29, Oct. 26-27, Nov. 23-24, Dec. 28-29.

1933 :- Jan. 25-26, Feb. 22-23, Mar. 22-23, Apr. 26-27, May 24-25, June 21-22, July 26-27, Aug. 23-24.

Dates for Observations E

1932 :- Aug. 4, Sept. 1, 22, Oct. 20, Nov. 17, Dec. 8.

1933 :- Jan. 5, Feb. 2, Mar. 2, 30, Apr. 20, May 18. June 15, July 6, Aug. 3, 31.

Dates for Observations F

1932 :- Aug. 18, Sept. 8, Oct. 6, Nov. 3, Dec. 1, 22.

1933 :- Jan. 19, Feb. 16, Mar. 16, Apr. 6, May 4, June 1, 29, July 20, Aug. 17.

APPENDIX B

(Memorandum prepared for inclusion in a Preliminary Report on Polar Year Radio Work being carried out on the American Continent.)

PRELIMINARY REPORT ON STATUS OF POLAR YEAR RADIO WORK AT McGILL UNIVERSITY, MONTREAL, QUE.

A series of thirty-nine observation periods, starting in January, 1933, has just been completed. The Impulse Method of Breit and Tuve was used, the transmitter consisting of a 150 watt valve in a self-oscillating circuit. The receiving station, about 2.5 km. away, was fitted with two types of super-heterodyne receiver. Photographic records of the pattern on a Cathode Ray Oscillograph were taken throughout. The equipment was under manual control at both stations.

Extraneous circumstances laid severe restrictions upon the possible periods of test : these were, however, arranged to fit in with the International Polar Days as closely as was practicable. The following table shows the nominal test schedules :-

<u>Group A</u> - <u>Jan. 24 to Feb. 2</u> -

Five one- to seven-hour tests at different times of the day.

<u>Group B</u> - <u>Feb. 8 to May 4</u> -

Fifteen twelve-hour tests, in three shifts, commencing at 1300 E.S.T. Wednesday, 2100 E.S.T. Wednesday, and 0500 E.S.T. Thursday, one shift each week. This covered the whole 24 hours in three weeks, the day being either on, or adjacent to, the International Polar Day (Wednesday).

<u>Group C</u> - <u>May 26 to Aug. 1</u> -

Nineteen eight-hour tests, in three shifts, commencing at 0000, 0800, 1600 E.S.T., carried out on Mondays and Thursdays, two per week, thus covering 24 hours in a week and a half.

In some instances departures had to be made from the above schedule, the nominal periods being occasionally lengthened, and sometimes shortened.

The test routine consisted of 2000 kc. and 4000 kc. echo records, as well as determination of the critical penetration frequency of both layers when possible. This was done every hour. At intervals, series of records were taken on certain frequencies between 1604 kc. and 6425 kc. for effective height determination.

Numerical results from these records are how being compiled and will be reported later.

(Signed) W. BRUCE ROSS

A. S. EVE

Macdonald Physics Laboratory,
McGill University,
August 1, 1933.

BIBLIOGRAPHY -

NOTE - A very comprehensive bibliography, compiled by the U. S. Bureau of Standards, appears in the Proceedings of the Institute of Radio Engineers, Vol. 19, pp 1034-1089, 1931, dealing with the Propagation of Radio Waves and kindred topics almost exhaustively, up to about the end of 1930. The following list includes the more important papers appearing in that of the Bureau of Standards, together with a selection from the literature since published, illustrating the development to date of the topics dealt with in the Thesis.

REFERENCES

1. Appleton, E.V., and Chapman, S. - Nature, 129, 757 (1932).
2. Henderson, J.T. - Can. J. Res., 8, 1 (1933).
3. Chapman, S. - Phys. Soc. Proc., 43, 26 & 483 (1931)
4. Chapman, S. - Roy. Soc. Proc., A132, 353, (1931).
5. Nature, 130, 385 (1932).
6. Chapman, S., and Ferraro, V.C.A. - Terr. Mag., 36, 77 & 171 (1931), and 37 147 & 421 (1932), and 38 431 (1933).
7. Clough, H.W. - Monthly Weather Review, 60, 99 (1933).
8. Wilson, C.T.R. - Phys. Soc., Proc., 37, 32D, (1925).
9. Appleton, E.V. & Naismith, R. - Phys. Soc. Proc., 45 389 (1933).
10. Stewart, Balfour - Encyc. Brit. 9th ed. 16 183 (1882).

11. Schuster, Sir Arthur,- Roy. Soc. Phil. Trans., A180, 467, (1889).

12. Schuster, Sir Arthur - Roy. Soc. Proc. A45 481 (1889).

13. Gauss, K.F. - Allgemeine Theorie der Erdmagnetismus (1838)

14. Schuster, Sir Arthur - Roy. Soc. Phil. Trans. A 208 163 (1907).

15. Chapman, S. - Terr. Mag. 37 269 (1932).

16. Chapman, S. - Terr. Mag. 38 175 (1933).

17. Chapman, S. & Price, A.T. - Roy. Soc. Phil. Trans. 229 427 (1930).

18. Macdonald, H.M. - Roy. Soc. Proc. A 71 251 (1903) and A 72 59 (1904).

19. Rayleigh and Poincaré - Roy. Soc. Proc., A 72 (1903) and Roy. Soc. Phil. Trans. A 210 p. 113 (1910)

20. Sommerfeld, A. - Ann. der Physik, 28 665 (1909).

21. Love, A.E.H. - Roy. Soc. Phil. Trans., A 215 125 (1915)

22. Marconi, G. - Roy. Soc. Proc. A 70 344 (1902).

23. Kennelly, A.E. - Electrical World, 39 473 (1902).

24. Heaviside, O. - Encyc. Brit. 10th ed. 33 215 (1902).

25. Eccles, W.H. - Roy. Soc. Proc. A 87 79 (1912).

26. Eccles, W.H. - Nature, 119 157 (1927).

27. Watson, G.N. - Roy. Soc. Proc. A 95 546 (1919).

28. Round, H.J., Eckersley, T.L., Tremellen, K., and Lunnon, F.C.,- I.E.E. Jour., 63 994 (1925).

29. Smith-Rose, R.L. & Barfield, R.H.- Roy. Soc. Proc., A 107 587 (1925).

30. Smith-Rose, R.L. & Barfield, R.H. - Exper. Wireless, 2 737 (1925).

31. Appleton, E.V. & Barnett, M.A.F. - Nature 115 333 (1925)

32. Appleton, E.V. & Barnett, M.A.F. - Roy. Soc. Proc. A 109 621 (1925).

33. Appleton, E.V. & Barnett, M.A.F. - Roy. Soc. Proc. A 113 450 (1926).

34. Appleton, E.V. - I.E.E. Jour., 71 642 (1932).

35. Appleton, E.V. - Phys. Soc. Proc. 41 43 (1928), and 42 321 (1930).

36. Naismith, R. - Phys. Soc. Proc., 45 235 (1933).

37. Smith-Rose, R.L. & Barfield, R.H. - Roy. Soc. Proc. A 110 580 (1926).

38. Smith-Rose, R.L. & Barfield, R.H. - Roy.Soc.Proc. A 116 682 (1927).

39. Breit, G. & Tuve, M.A. - Nature, 116 357 (1925), and Terr. Mag. 30 15 (1925).

40. Breit, G. & Tuve, M.A. - Phys. Rev. 21 554 (1926), and I.R.E. Proc. 17 1513 (1929).

41. Breit, G. & Tuve, M.A. - Phys. Rev. 28 568 (1926).

42. Breit, G., Tuve, M.A. & Dahl, O. - I.R.E. Proc. 16 1236 (1928).

43. Appleton, E.V. - Nature, 123 445 (1929).

44. Schelling, J.C. - I.R.E. Proc. 16 1471 (1928).

45. Lorentz, H.A. - Chap. 4, (1923).

46. Larmor, Sir J. - Phil. Mag. (6) 48 1025 (1924).
also Proc. Calcutta Math. Soc., Jubilee Vol. (1928).

47. Lassen, H. - Zeits f. Hochf. 28 109 & 139 (1926).

48. Forsterling, K. - Elek. Nach. Tech. 5 530 (1928).

49. Hartree, D.R. - Camb. Phil. Soc. Proc. 27 143 (1930/31).

50. Forsterling, K. & Lassen, H. - Zeits f. Techn. Physik 12 10 p. 453 & 11 p. 502 (1931).

51. Appleton, E.V. & Naismith, R. - Roy. Soc. Proc. 137 36 (1932).

52. Gilliland, T.R., Kenrick, G.W. & Norton, K.A. - I.R.E. Proc. 20 286 (1932).

53. Namba, S. - I.R.E. Proc. 21 238 (1933).

54. Gutton, C. - L'Onde Elec. 12 61 (1933).

55. Hulbert, E.O. - Physics 4 196 (1933).

56. Tonks, L. - Nature 132 101 (1933).

57. Taylor, Mary - Phys. Soc. Proc. 45 245 (1933).

58. Eckersley, T.L. - Roy. Soc. Proc. A 132 83 (1931).

59. Eckersley, T.L. - Roy. Soc. Proc. A 136 499 (1932).

60. Hartree, D.R. - Camb. Phil. Soc. Proc. 25 97 (1929).

61. Hartree, D.R. - Roy. Soc. Proc. 131 428 (1931).

62. Appleton, E.V. - Phys. Soc. Proc. 37 22D (1924/25).

63. Nicholls, H.W. & Schelling, J.C. - Nature, 115 334 (1925)

64. Appleton, E.V. & Barnett, M.A.F. - Electrician, 94 398 (1925).

65. Nicholls, H.W. & Schelling, J.C. - Bell Syst. Tech. Jour. 4 215 (1925).

66. Hollingworth, - Roy. Soc. Proc. A 119 444 (1928).

67. Goldstein, S. - Roy. Soc. Proc. A 120 260 (1928).

68. Appleton, E.V. & Builder, G. - Phys. Soc. Proc. 45 208 (1933).

69. Green, A.L. - Radio Res. Board of Australia Report No.2, 11 (1932).

70. Ratcliffe, J.A. - Wireless Engineer, 10 354 (1933).

71. Appleton, E.V. & Chapman, S. - Phys. Soc. Proc. 44 246 (1932).

72. Todesco, G. - Nature, 129 203 (1932).

73.A. Todesco, G. - Accad. Lincei Atti. 15 144 (1932).

73.B. Appleton, E.V. & Childs, E.C. - Phil. Mag. 10 969 (1930).

74. Keck, P. & Zenneck, J. - Hochf. u. Elek. 40 153 (1932).

75. Pickard, G.W. - I.R.E. Proc. 14 205 (1926).

76. Taylor, A.H. - I.R.E. Proc. 14 521 (1926).

77. Appleton, E.V. & Ratcliffe, J.A. - Roy. Soc. Proc. A 115 291 (1927).

78. Appleton, E.V. & Ratcliffe, J.A. - Roy. Soc. Proc. A 117 567 (1928).

79. Eckersley, T.L. - Nature, 120 398 (1932).

80. Ratcliffe, J.A. & White, E.L.C. - Nature, 129 364 (1932).

81. Ratcliffe, J.A. & White, E.L.C. - Phil. Mag. 16 125 (1933).

82. Goubau, G. - Elek. Nach. Tech. 10 72 (1933).

83. Goubau, G. - Physik Zeitschr. 31 333 (1930).

84. Appleton, E.V. & Builder, G. - Phys. Soc. Proc. 44 76 (1932).

85. Mimno, H.R. & Wang, P.H. - Phys. Rev. 43 769 (1933).

86. Mimno, H.R., Wang, P.H. & King, P.B. - Phys. Rev. 43 501 (1933).

87. Herd, J.F. - Phys. Soc. Proc. 45 221 (1933).

88. Rukop, H. & Wolf, P. - Zeit f. Techn. Phys. 13.2 132 (1932).

89. Mimno, H.R. & Wang, P.H. - Phys. Rev. 41 395 (1932).

90. Mimno, H.R. & Wang, P.H. - I.R.E. Proc. 21 529 (1933).

91. Gilliland, T.R. - U.S. Bur. of Stan. Jour. of Res. 11 141 (1933).

92. Ratcliffe, J.A. & White, E.L.C. - Phys. Soc. Proc. 45 399 (1933).

93. Goubau, G. & Zenneck, J. - Hochf. u. Elek. 41 77 (1933).

94. Mitra, S.K. & Rakshit, H. - Nature, 131 657 (1933).

95. Kenrick, G.W. & Jen, C.K. - I.R.E. Proc. 17 710 (1929) and 17 2034 (1929).

96. Appleton, E.V. - Nature, 120 330 (1927).

97. Appleton, E.V. - Roy. Soc. Proc. A 126 542 (1930).

98. Builder, G. - Wireless Engineer, 9 667 (1932).

99. Green, A.L. - Radio Res. Board of Australia Report, #2 37 (1932).

100. Naismith, R. - I.E.E. Jour. 72 246 (1933).

101. Schafer, J.P. & Goodall, W.M. - Nature, 131 June 3 (1933).

102. Appleton. E.V. - Nature, 131 872 (1933).

103. Ranzi, I. - Nature, 130 545 (1932).

104. Hulbert, E.O. - I.R.E. Proc. 16 174 (1928).

105. Schafer, J.P. & Goodall, W.M. - I.R.E. Proc. 20 1131 (1932).

106. Ranzi, I. - Nature, 130 368 (1932).

107. McLennan, J.C. - Roy. Soc. Proc. A 120 327 (1928).

108. Vegard, L. - Geofysika Publ. 9.11 (1932).

109. Chapman, S. - Roy. Met. Soc. Q. Jour., 52 224 (1926).

110. Roy. Soc. Proc. A 111 1 (1926).

111. Pickard, G.W. - I.R.E. Proc. 15 83-341 (1927).

112. Pickard, G.W. - I.R.E. Proc. 15 1004 (1927).

113. Pickard, G.W. - I.R.E. Proc. 19 353 (1931).

114. Stetson, H.T. - Frank. Inst. Jour. 209 403 (1930).

115. Stetson, H.T. - Terr. Mag. 36 1 (1931).

116. Plendl, H. - I.R.E. Proc. 20 520 (1932).

117. Austin, L.W. - I.R.E. Proc. 20 280 (1932).

118. Colwell, R.C. - I.R.E. Proc. 21 721 (1933), also Nature, 130 627 (1932).

119. Glover, P.W. - Terr. Mag. 38 107 (1933).

120. Chree, C. - Roy. Soc. Proc. A 109 1 (1925).

121. Bartels, J. - Terr. Mag. 37 1 (1931).

122. Bartels, J. - Zeit f. Techn. Physik, 13 - 12 p.611 (1932).

123. Bartels, J. - Elek. Nach. Tech. 10 1 (1933).

124. Maris, E.B. & Hulbert, E.O. - Phys. Rev. 33 412 (1929).

125. Hulbert, E.O. - Phys. Rev. 34 344 (1929), and 36 1560 (1930).

126. Skellett, A.M. - I.R.E. Proc. 20 1933 (1932).

127. Schafer, J.P. & Goodall, W.M. - I.R.E. Proc. 20 1941 (1932).

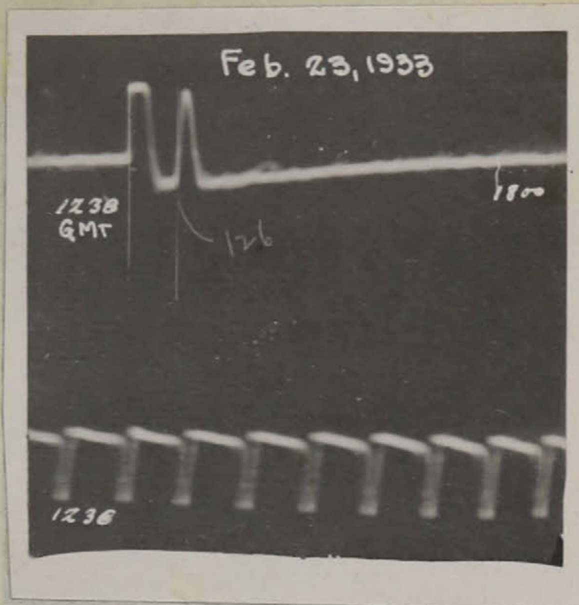
128. Rose, D.C. - Can. J. Res., 8 15 (1933).

129. Brunt, D. - Roy. Met. Soc. Quar. Jour. 59 2 (1933).

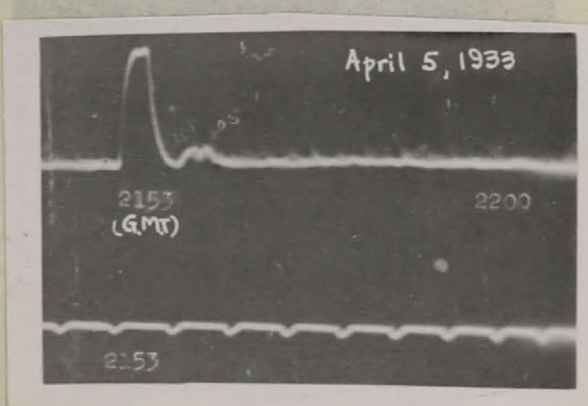
130. Appleton, E.V. & Barnett, M.A.F. - Electrician 94 398 (1925).

-o-

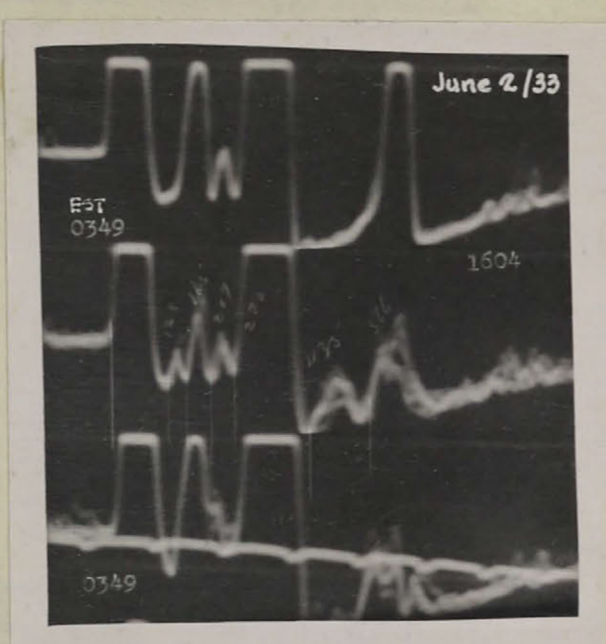
PLATE I.



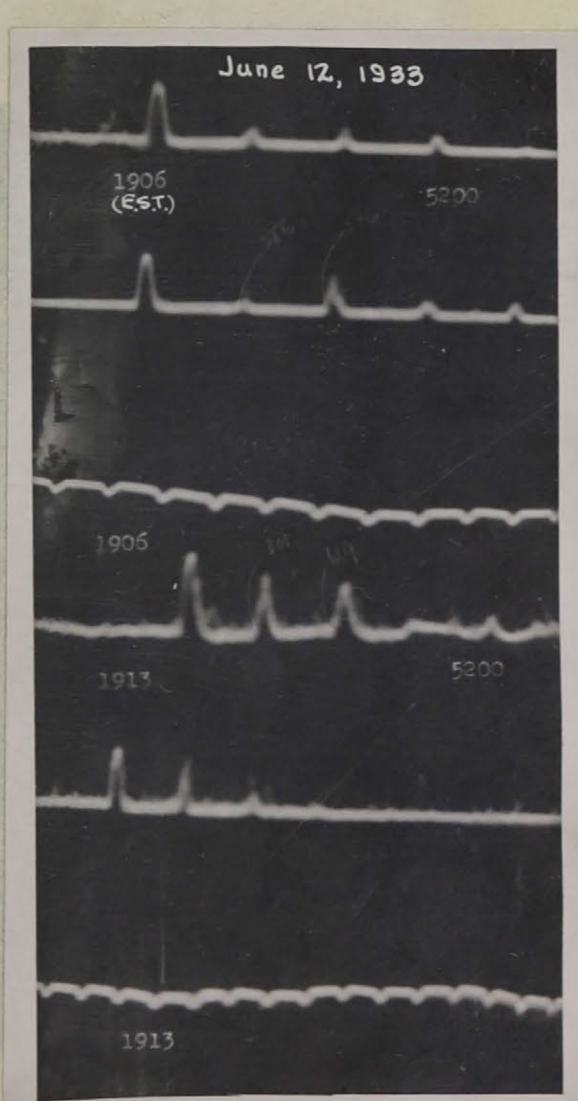
A



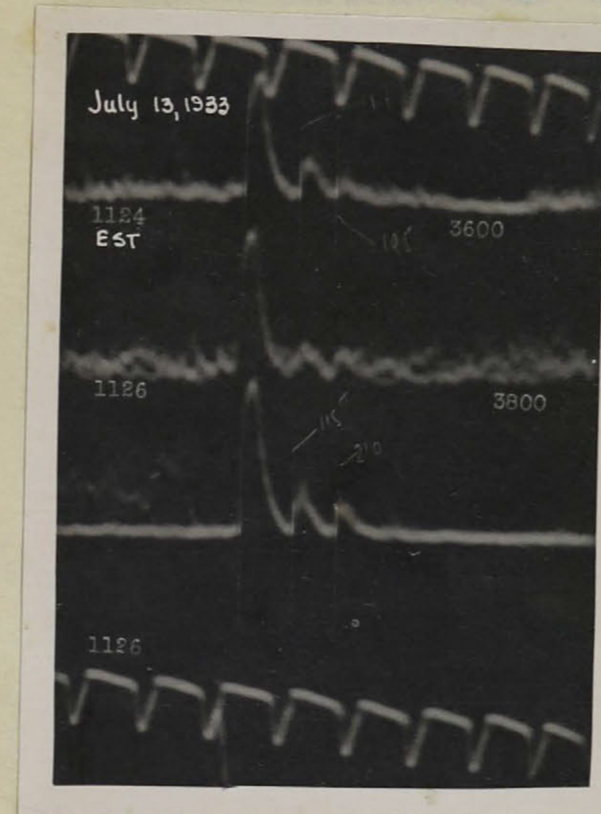
B



C



D



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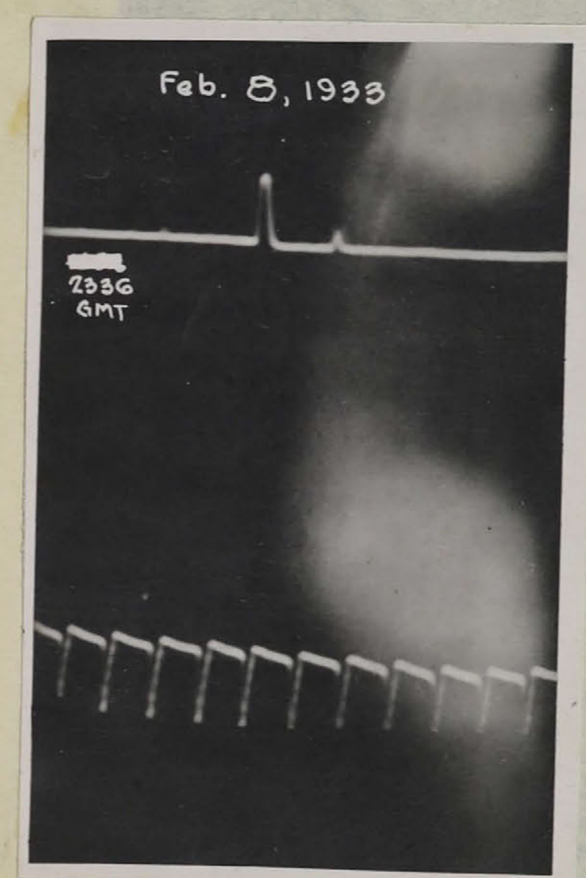

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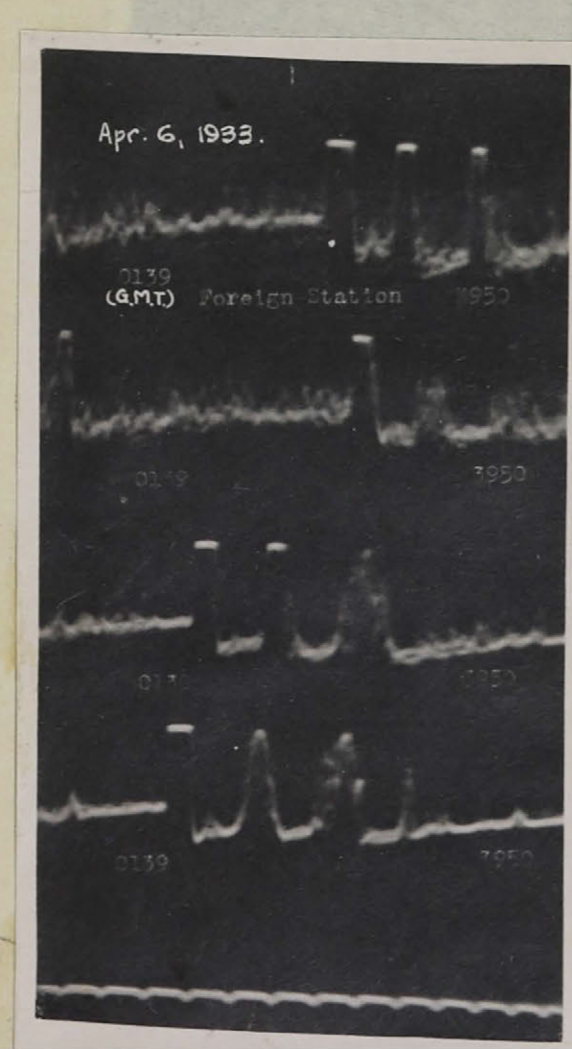
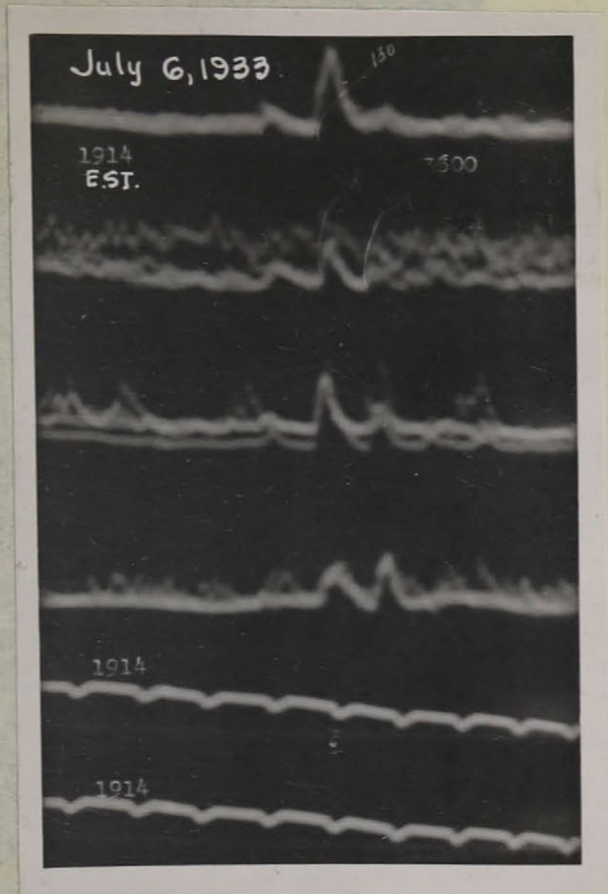
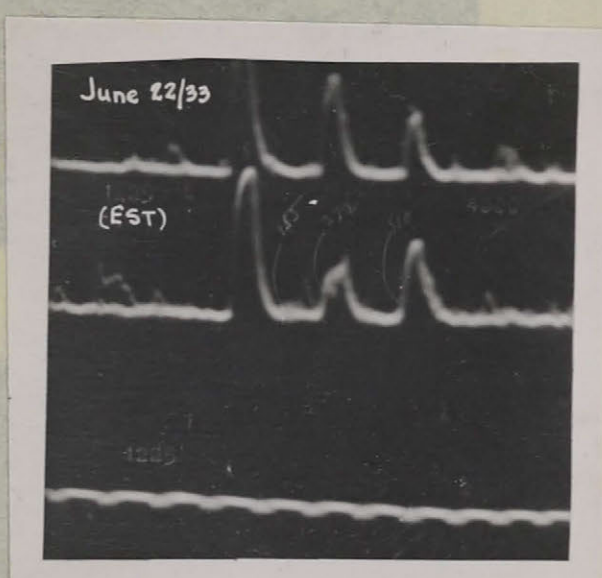


G

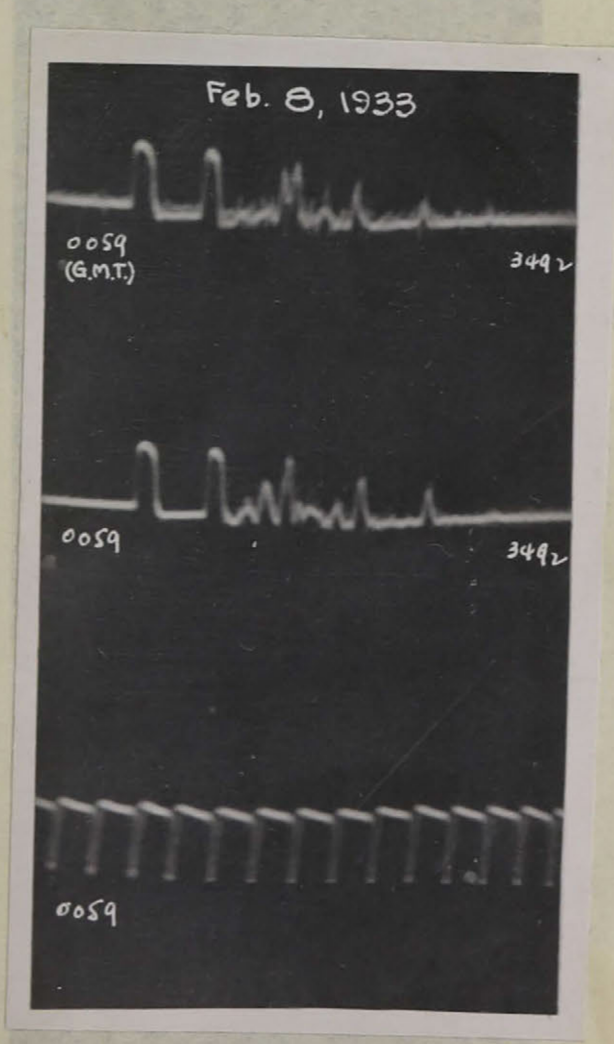
PLATE II.



A



B



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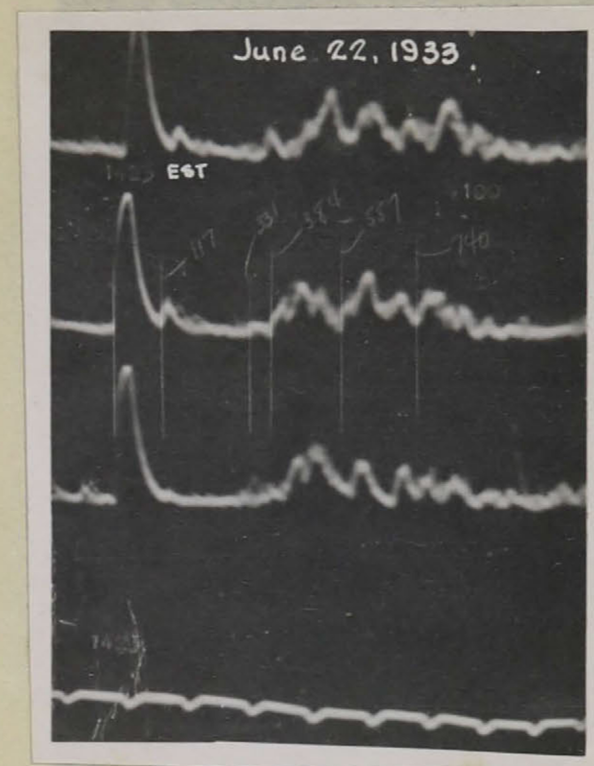
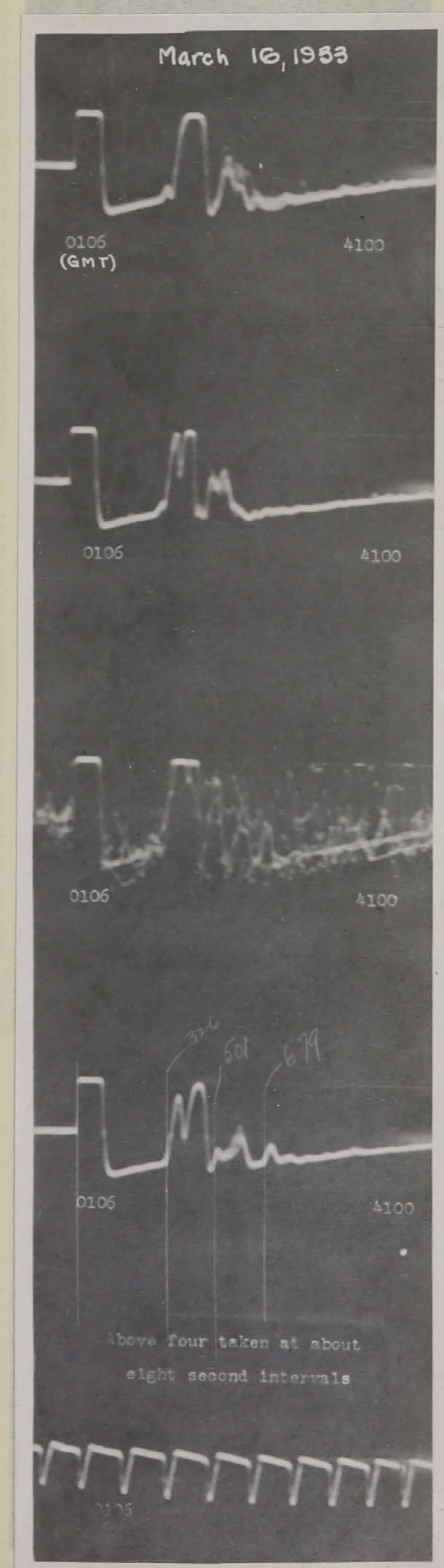
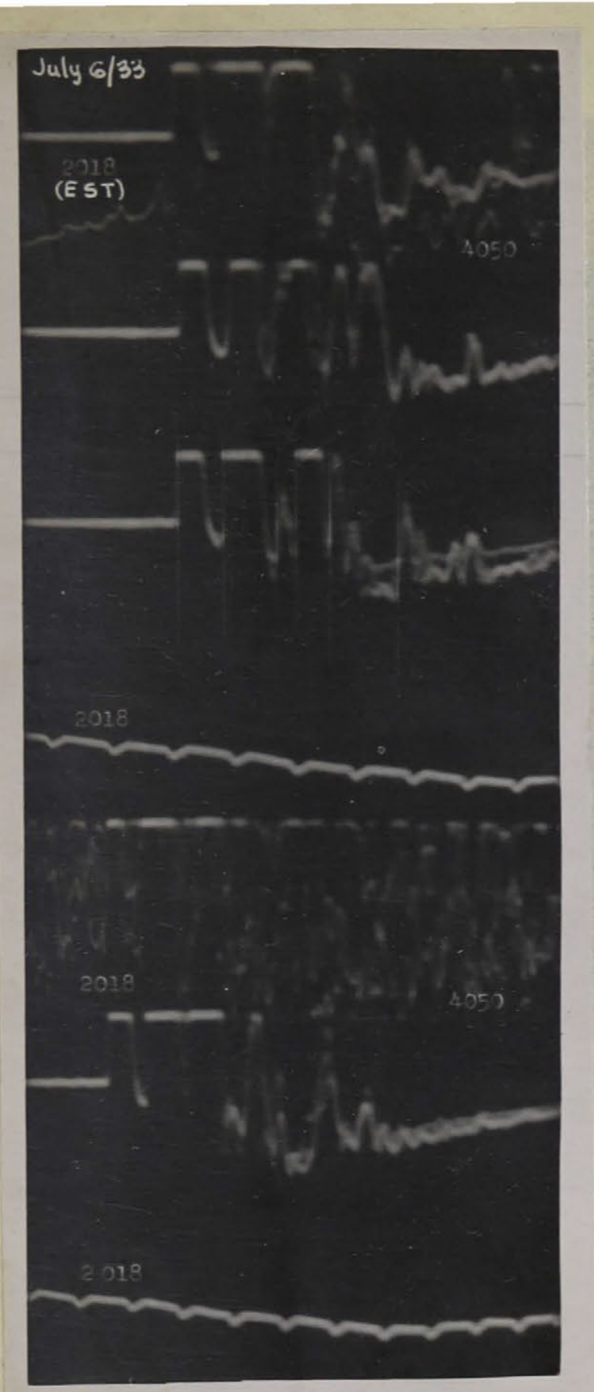


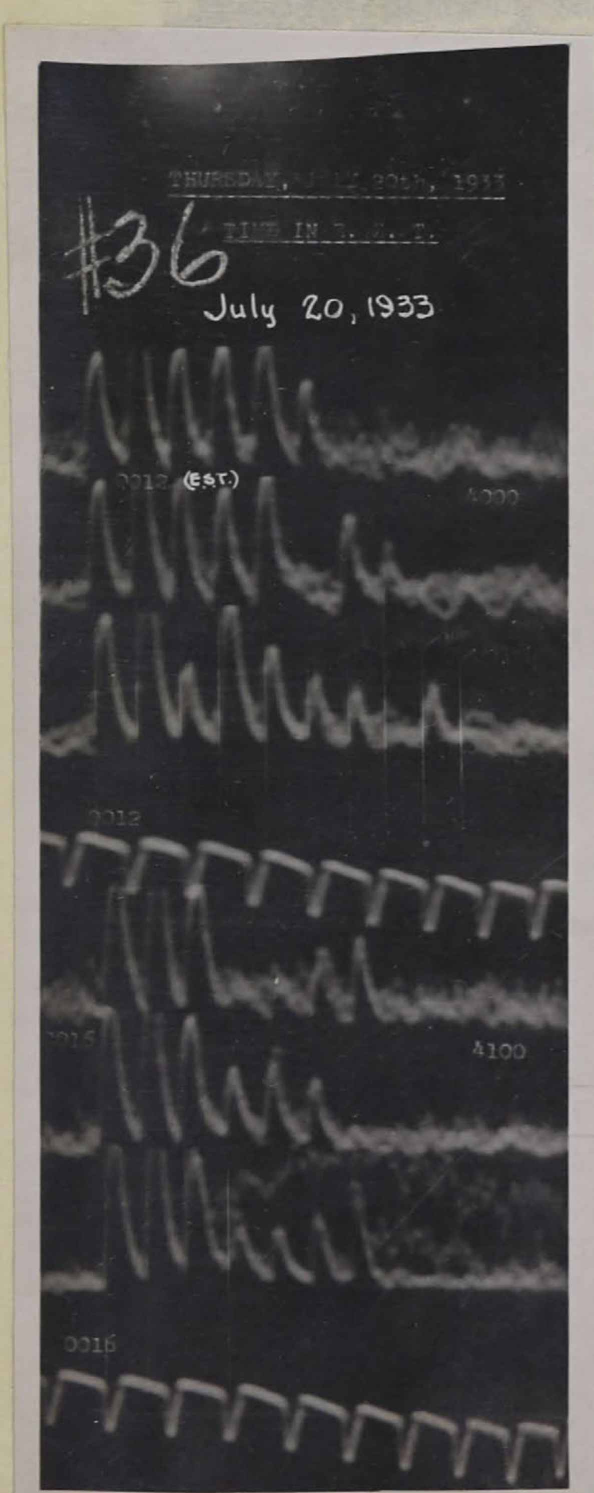
D



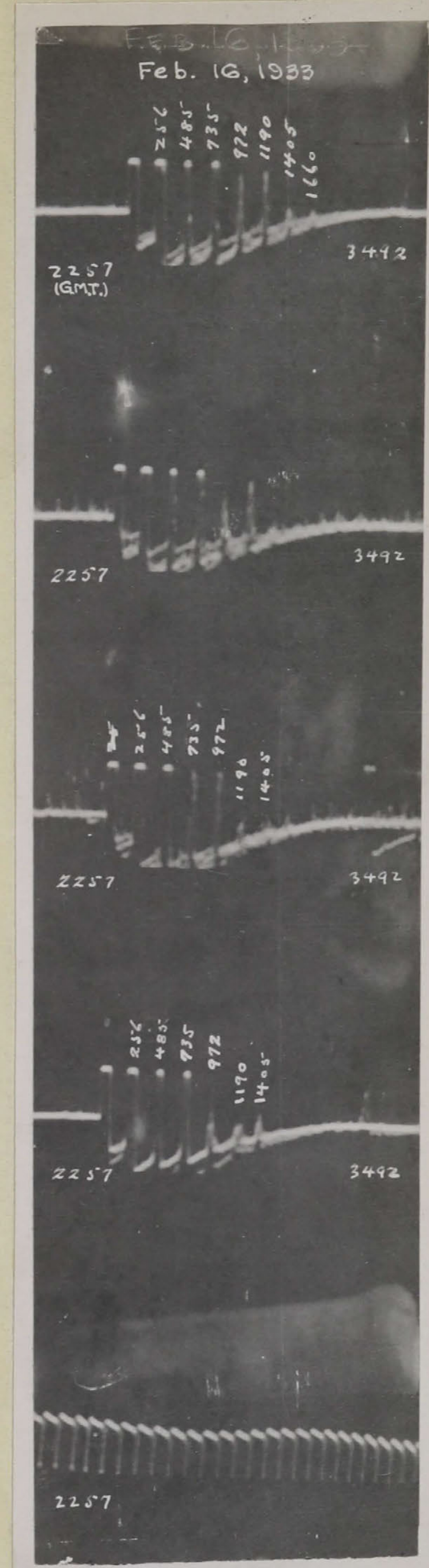
E


July 6/33
2018
(EST)
4050
2018
2018
4050
2018

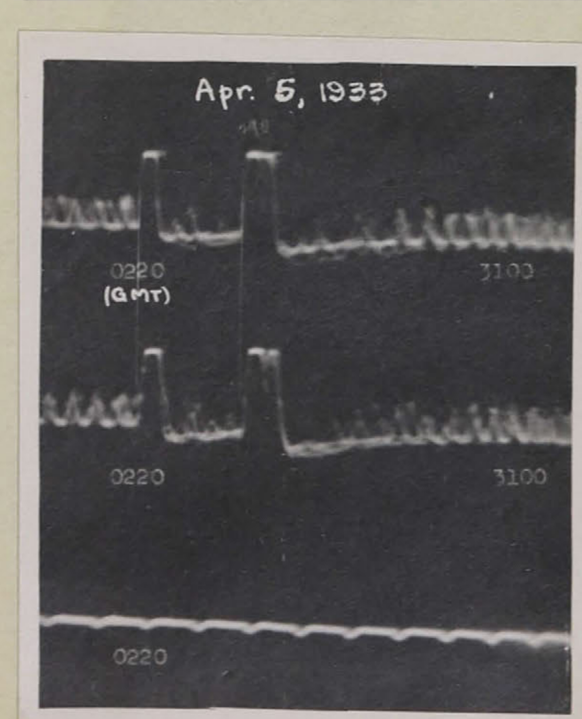
A


#36
July 20, 1933
0012 (EST)
4000
0012
0016
4100
0016

B

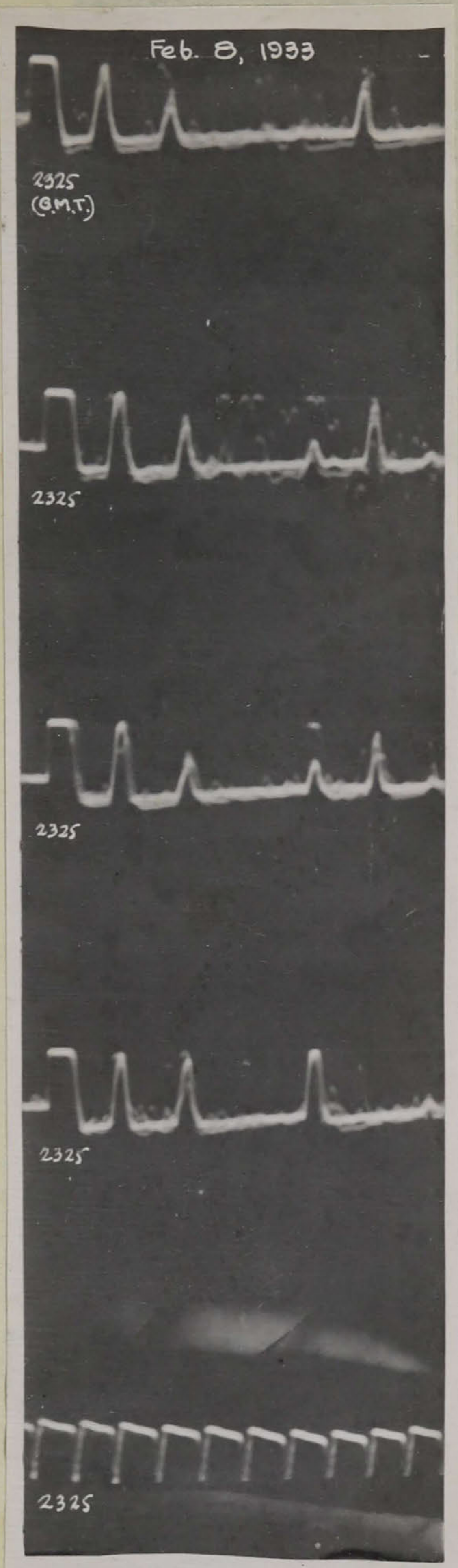

Feb. 16, 1933
256
485
735
972
1190
1405
1660
2257
(GMT)
3492
2257
3492
256
485
735
972
1190
1405
2257
3492
256
485
735
972
1190
1405
2257
3492
2257

C

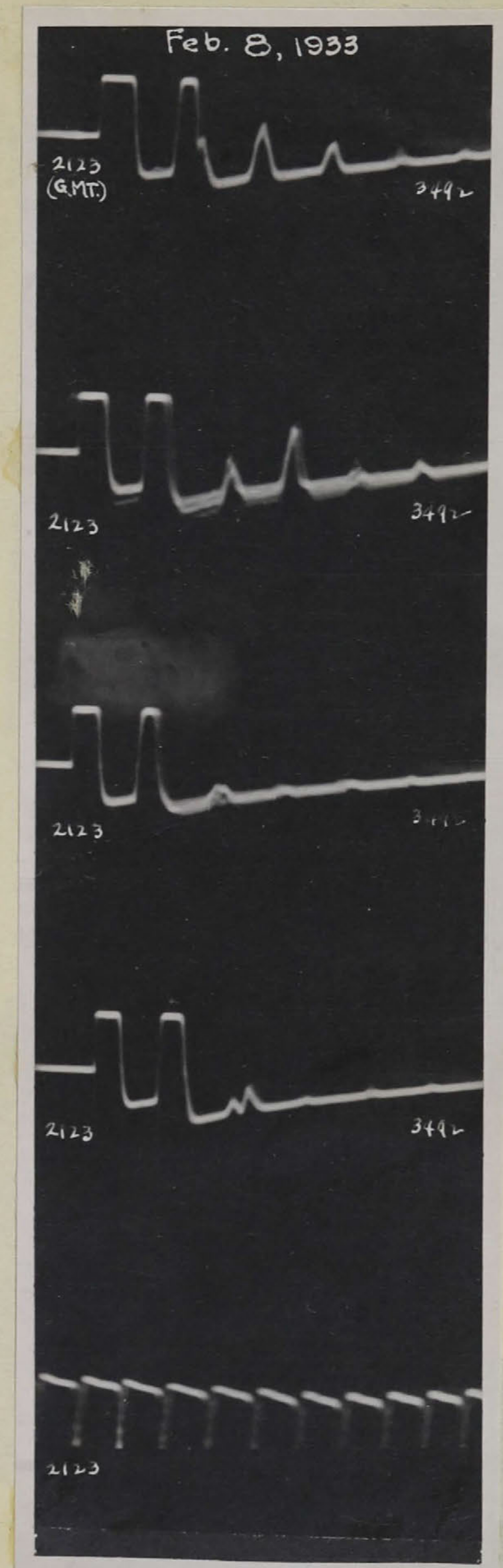

Apr. 5, 1933
0220
(GMT)
3100
0220
3100
0220

D

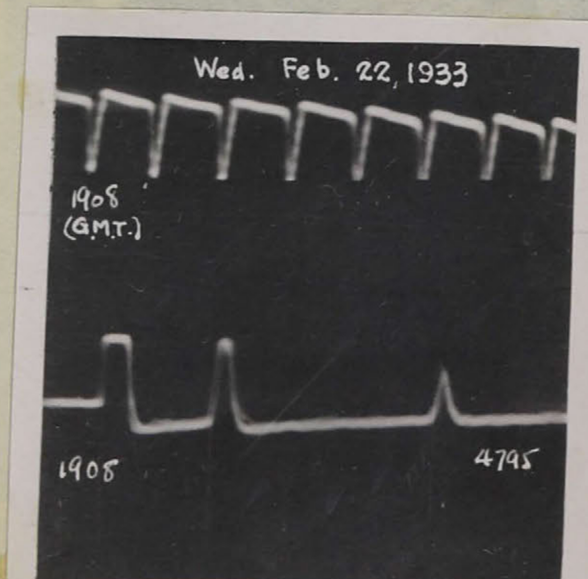
PLATE IV.



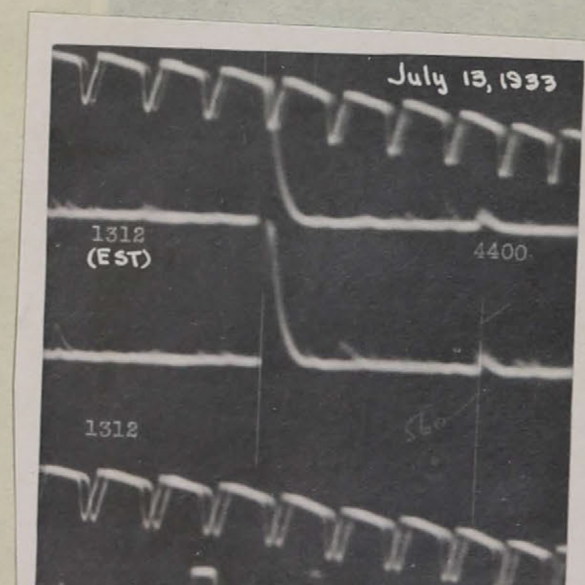
A



C

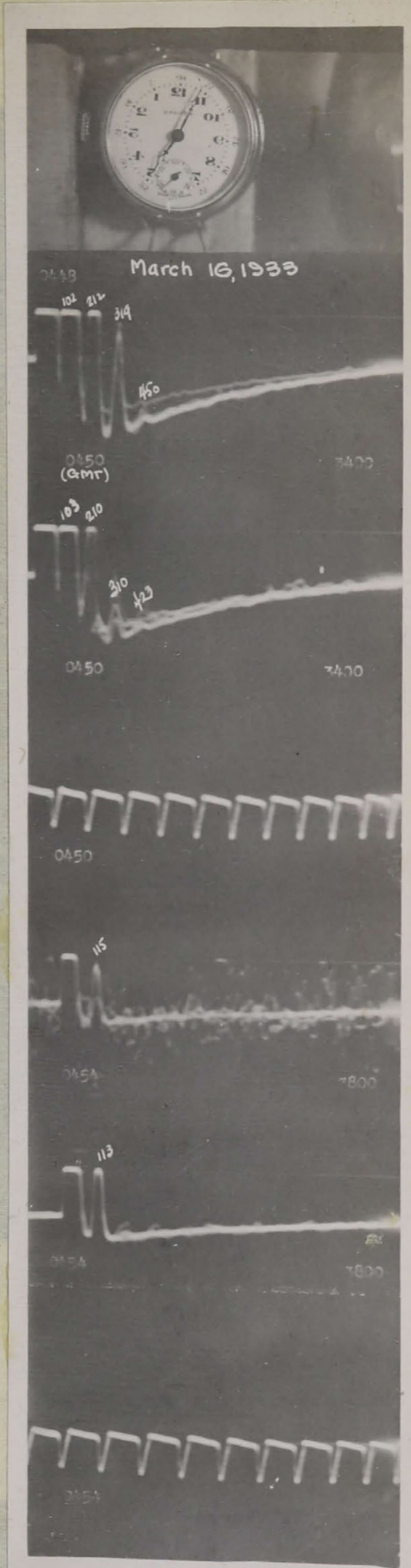


B

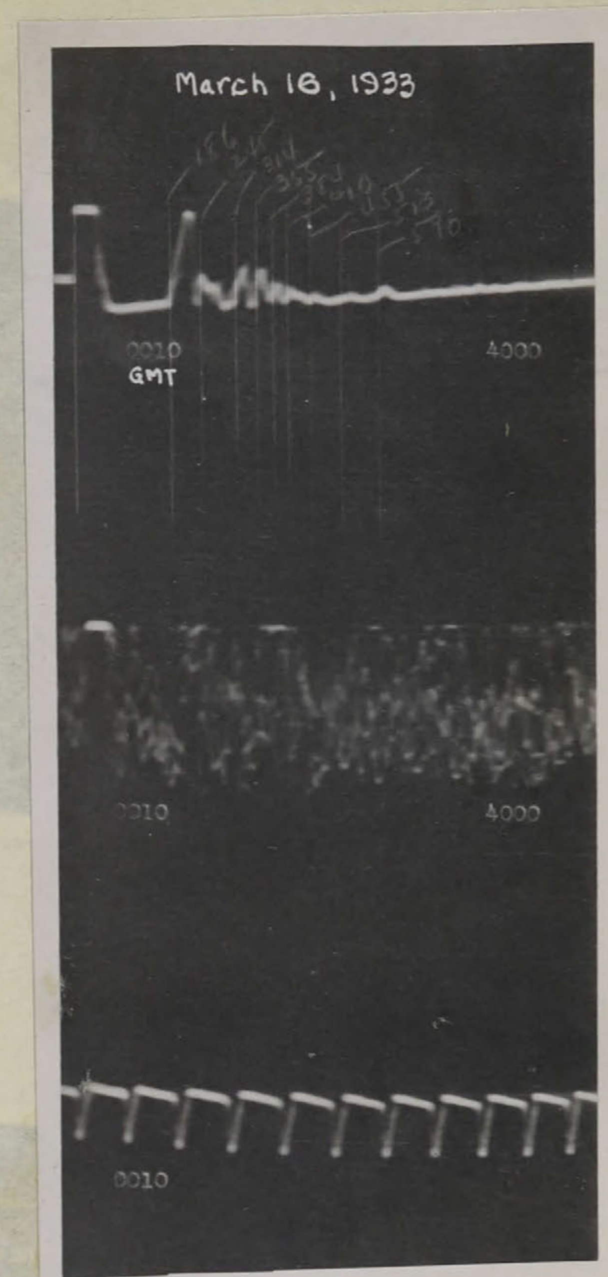


D

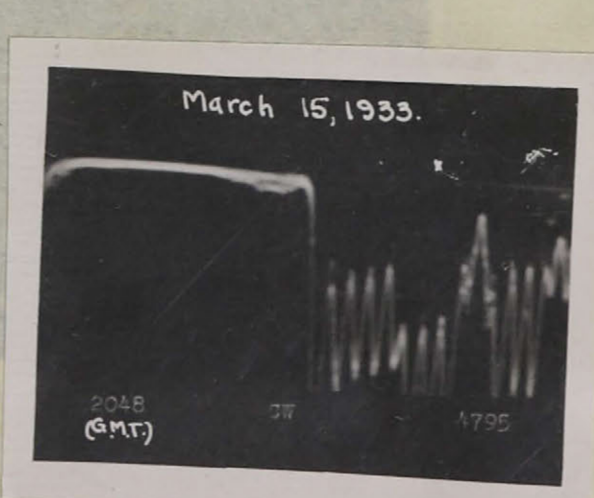
PLATE V.


March 16, 1933
102
212
319
450
0450
(GMT)
3400
103
210
310
423
0450
3400
0450
115
0454
7800
113
0454
7800

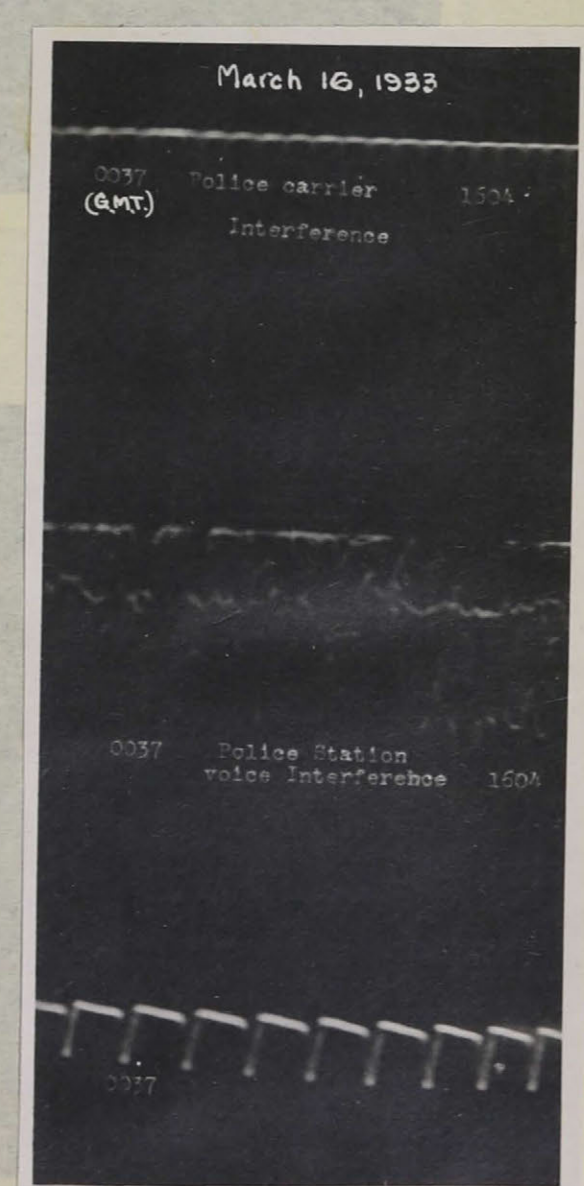
A


March 16, 1933
0010
GMT
4000
0010
4000
0010

C

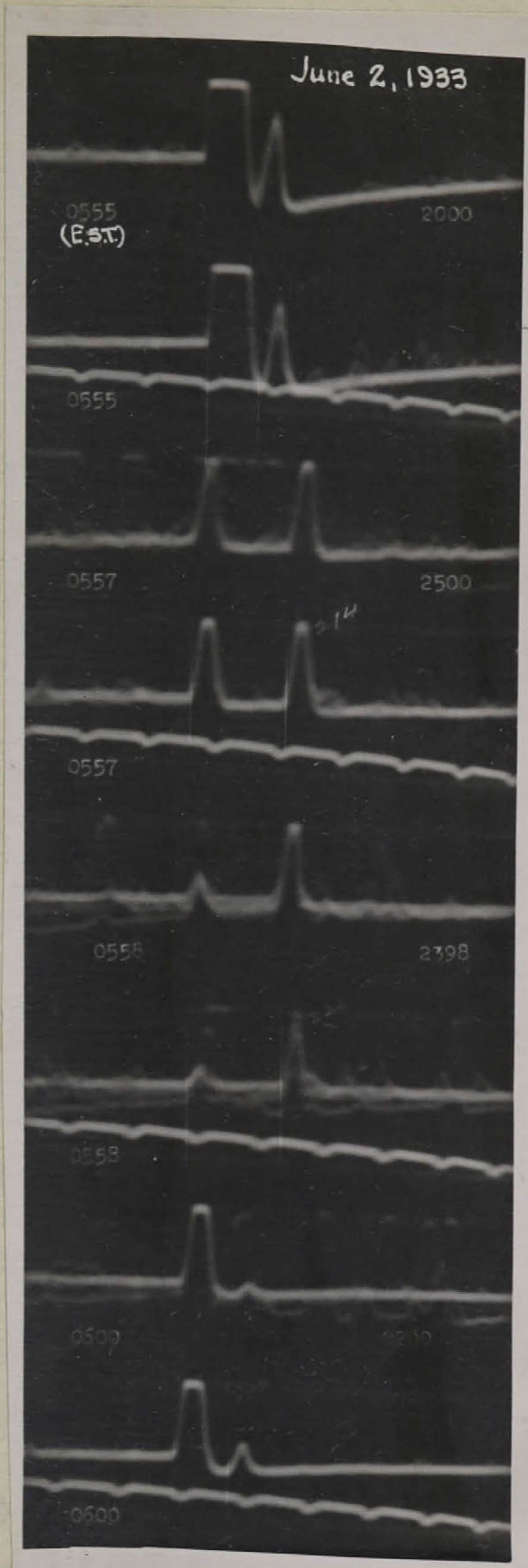

March 15, 1933.
2048
(G.M.T.)
4795

B

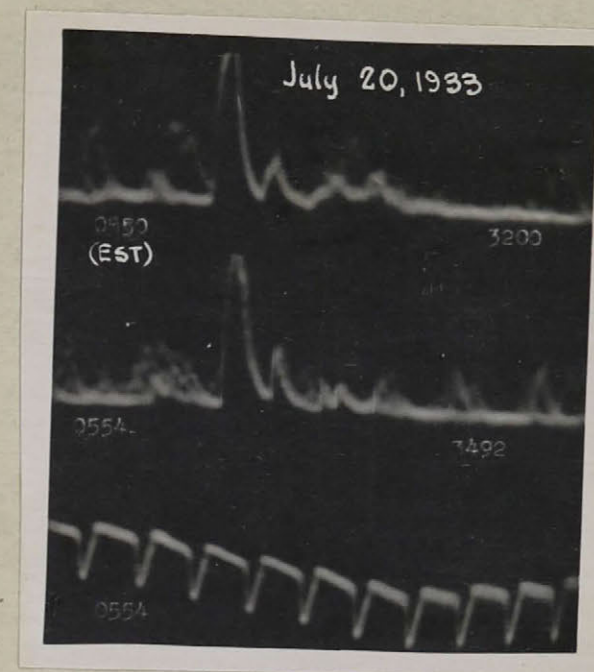

March 16, 1933
0037
(G.M.T.)
Police carrier
Interference
1604
0037
Police Station
voice Interference
1604

D

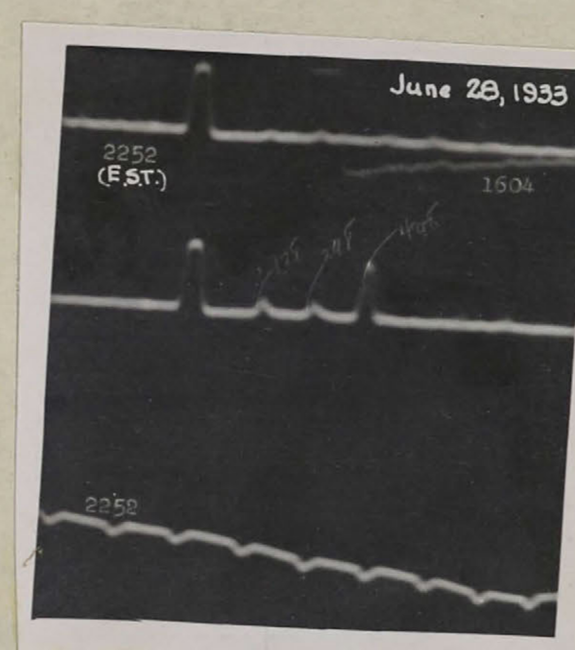
PLATE VI.



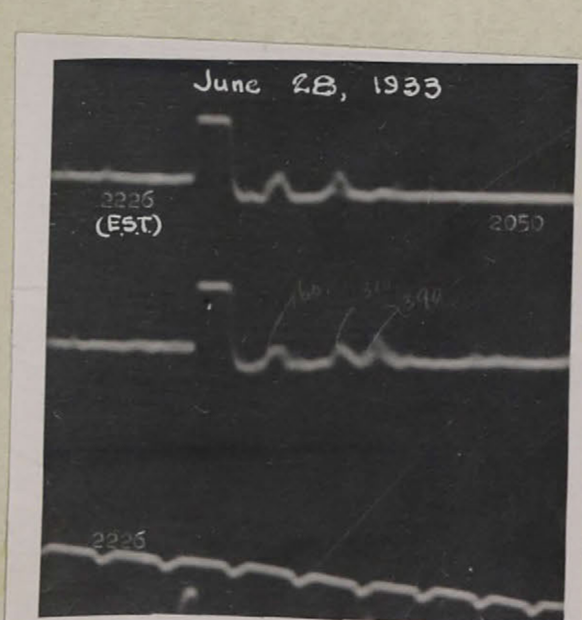
A



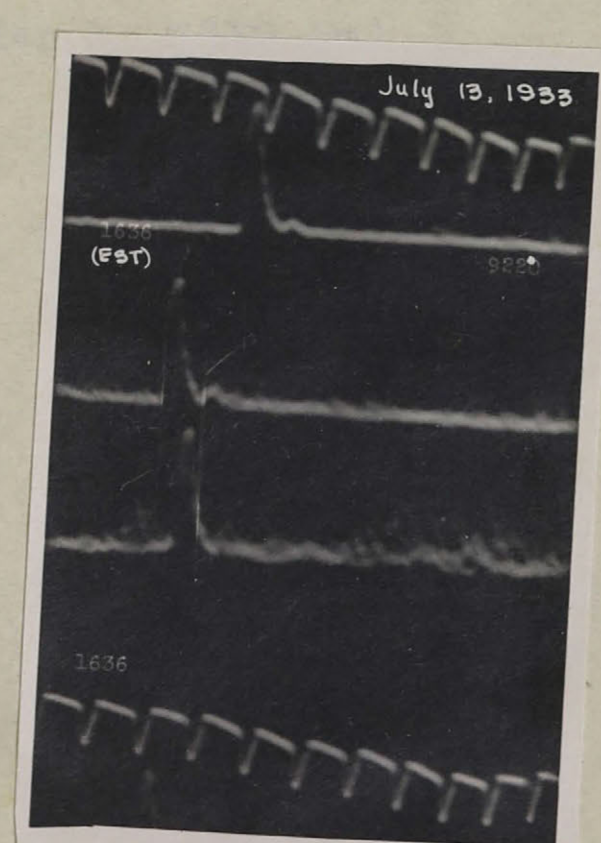
C



D



B



E

APPROXIMATE DISTANCES OF CERTAIN RADIO IONOSPHERE OBSERVING STATIONS FROM NORTH MAGNETIC POLE

Station	Position		Dist. from N. Mag. Pole (Km)
	Lat.	Long.	
(Magnetic Pole)	70° 05'N	96° 46'W	--
Fairbanks, Alaska	64° 30'N	147° 40'W	2194
Montreal, Que.	45° 30'N	73° 35'W	3010
Cambridge, Mass.	42° 23'N	71° 14'W	3402
Washington, D.C.	38° 55'N	77° 04'W	3644
Tromso, Norway	69° 39'N	18° 32'E	3752
Slough, England	51° 31'N	00° 36'W	4947
Cologne, Germany	50° 56'N	6° 57'E	5243
Munich, Germany	48° 08'N	11° 35'E	5667
Tokyo, Japan	35° 40'N	139° 45'E	7416

(Earth's radius taken as 6370 Km)

TABLE 1

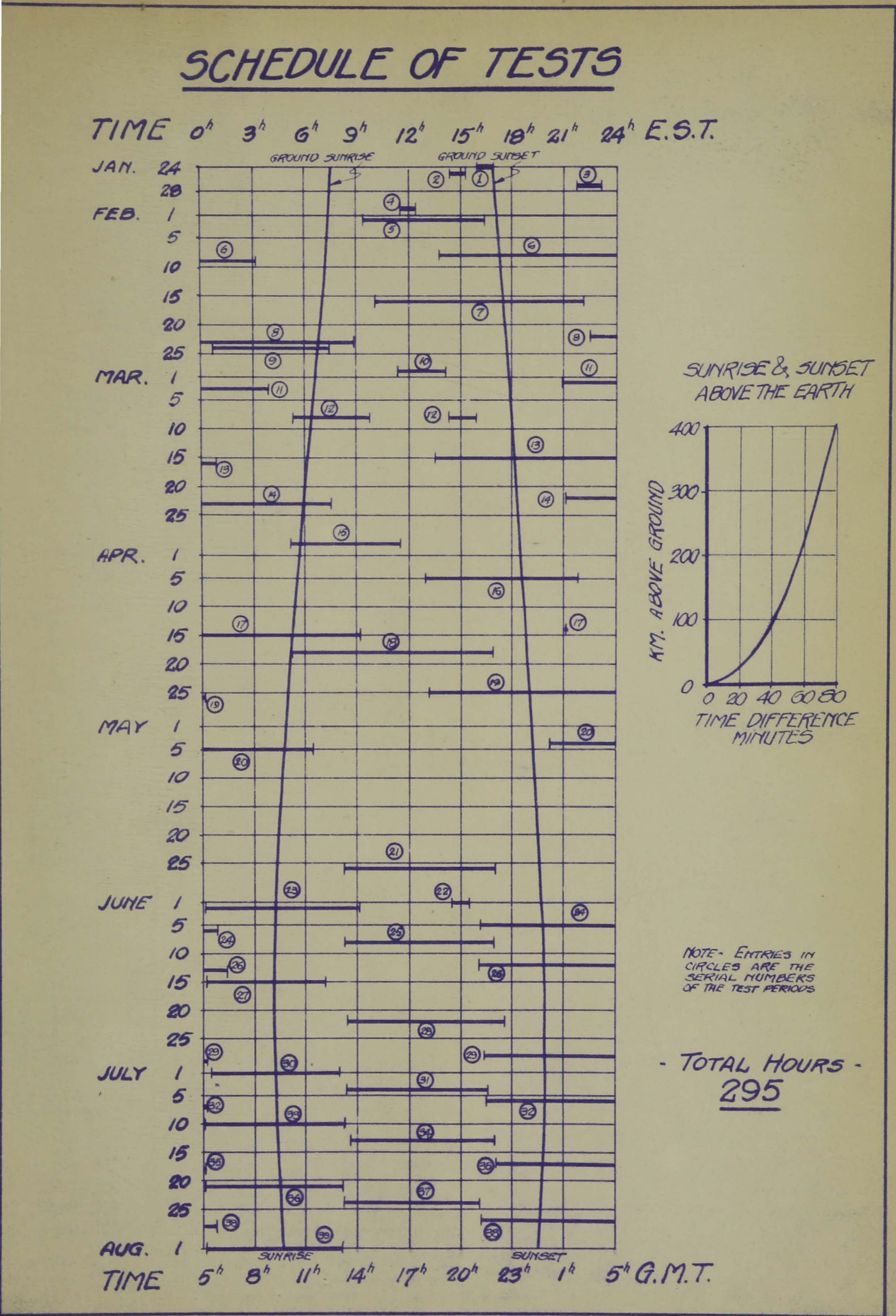

SCHEDULE OF TESTS
TIME 0h 3h 6h 9h 12h 15h 18h 21h 24h E.S.T.
GROUND SUNRISE
GROUND SUNSET
JAN. 24
28
FEB. 1
5
10
15
20
25
MAR. 1
5
10
15
20
25
APR. 1
5
10
15
20
25
MAY 1
5
10
15
20
25
JUNE 1
5
10
15
20
25
JULY 1
5
10
15
20
25
AUG. 1
SUNRISE
SUNSET
TIME 5h 8h 11h 14h 17h 20h 23h 1h 5h G.M.T.
SUNRISE & SUNSET ABOVE THE EARTH
KM. ABOVE GROUND
400
300
200
100
0
0 20 40 60 80
TIME DIFFERENCE MINUTES
NOTE - ENTRIES IN CIRCLES ARE THE SERIAL NUMBERS OF THE TEST PERIODS
- TOTAL HOURS -
295

Fig. 1

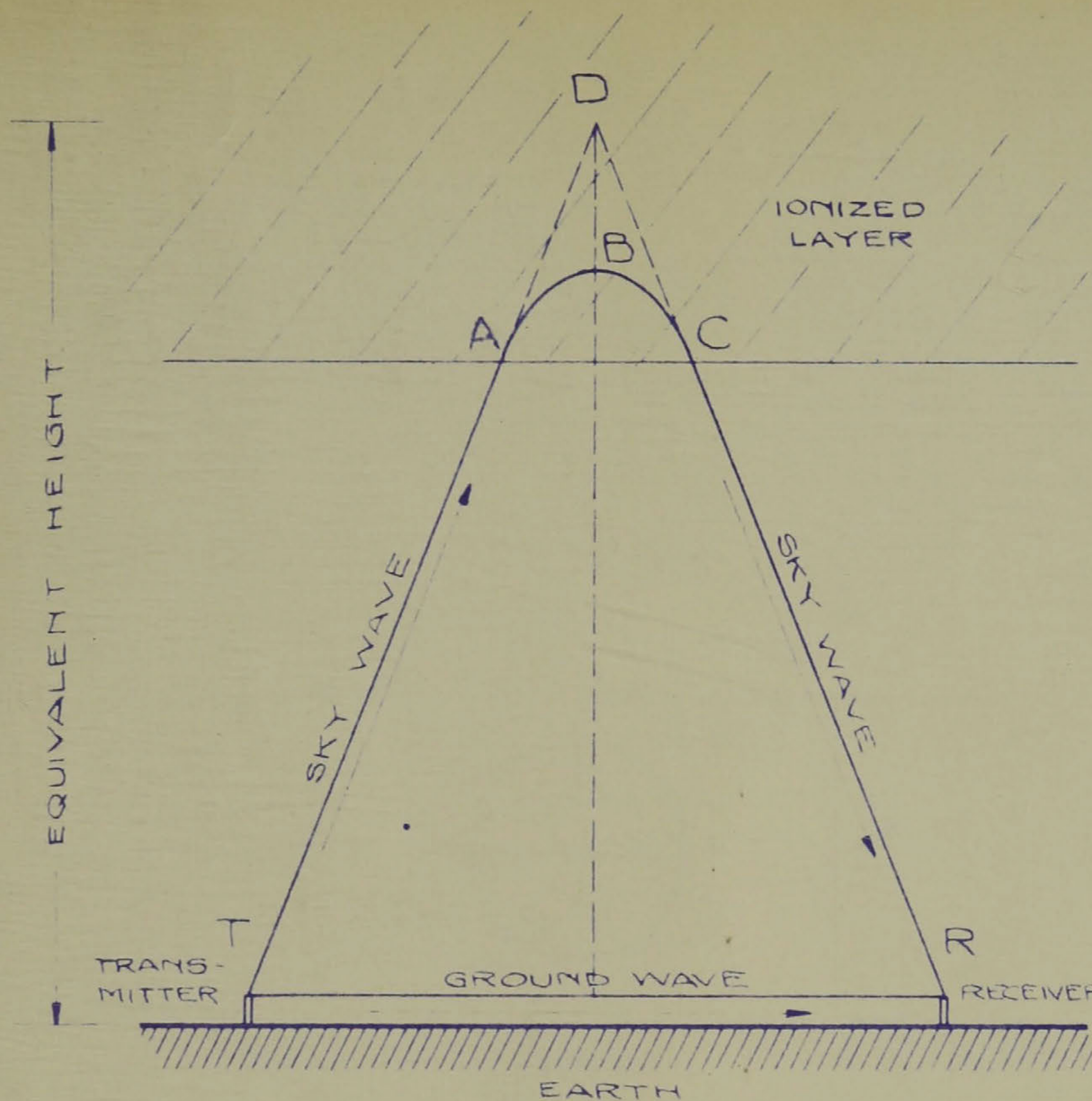

D
IONIZED LAYER
B
A
C
EQUIVALENT HEIGHT
SKY WAVE
SKY WAVE
T
R
TRANS-MITTER
GROUND WAVE
RECEIVER
EARTH

Fig. 2

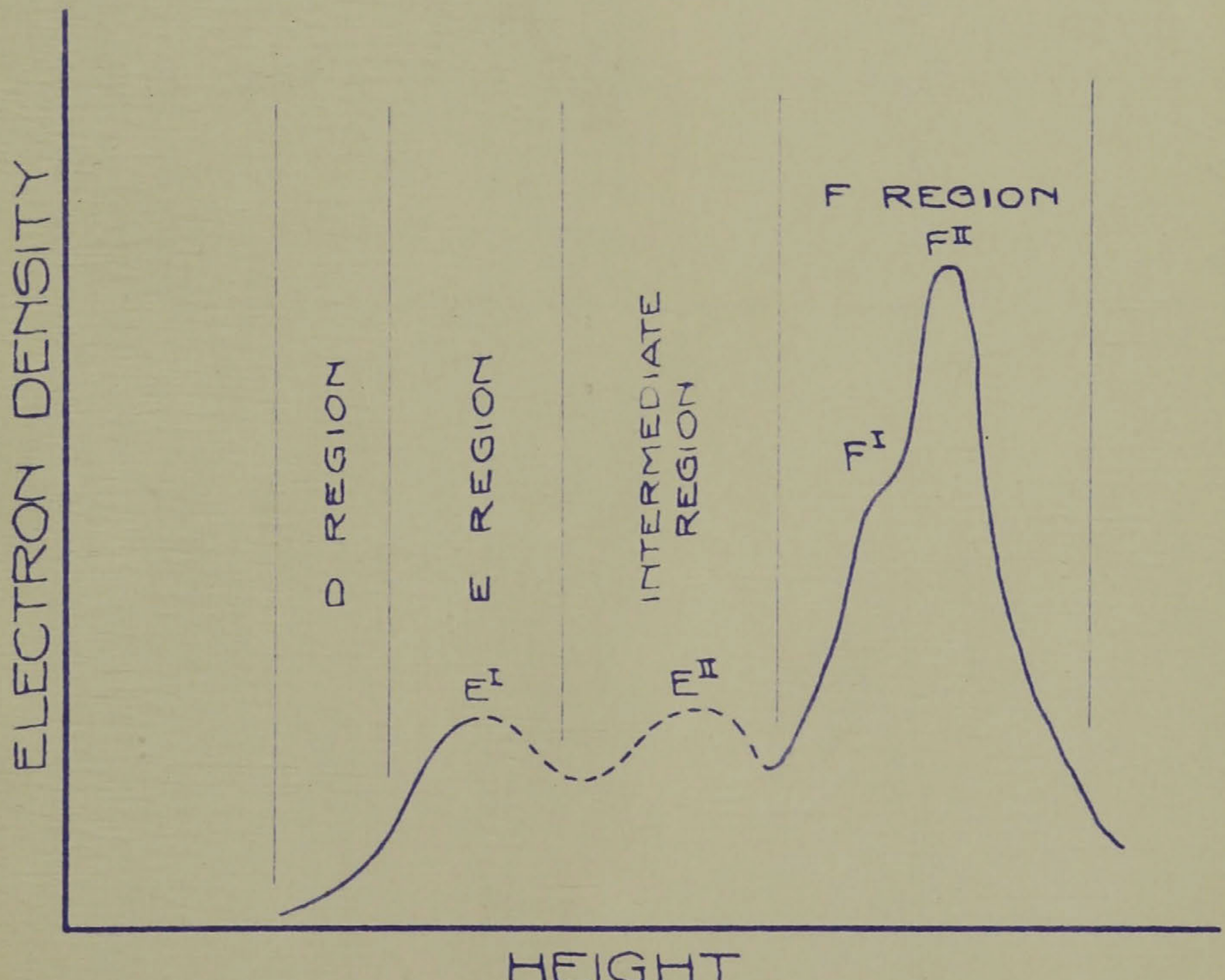

ELECTRON DENSITY
F REGION
FII
FI
D REGION
E REGION
INTERMEDIATE REGION
EI
EII
HEIGHT

Fig. 3

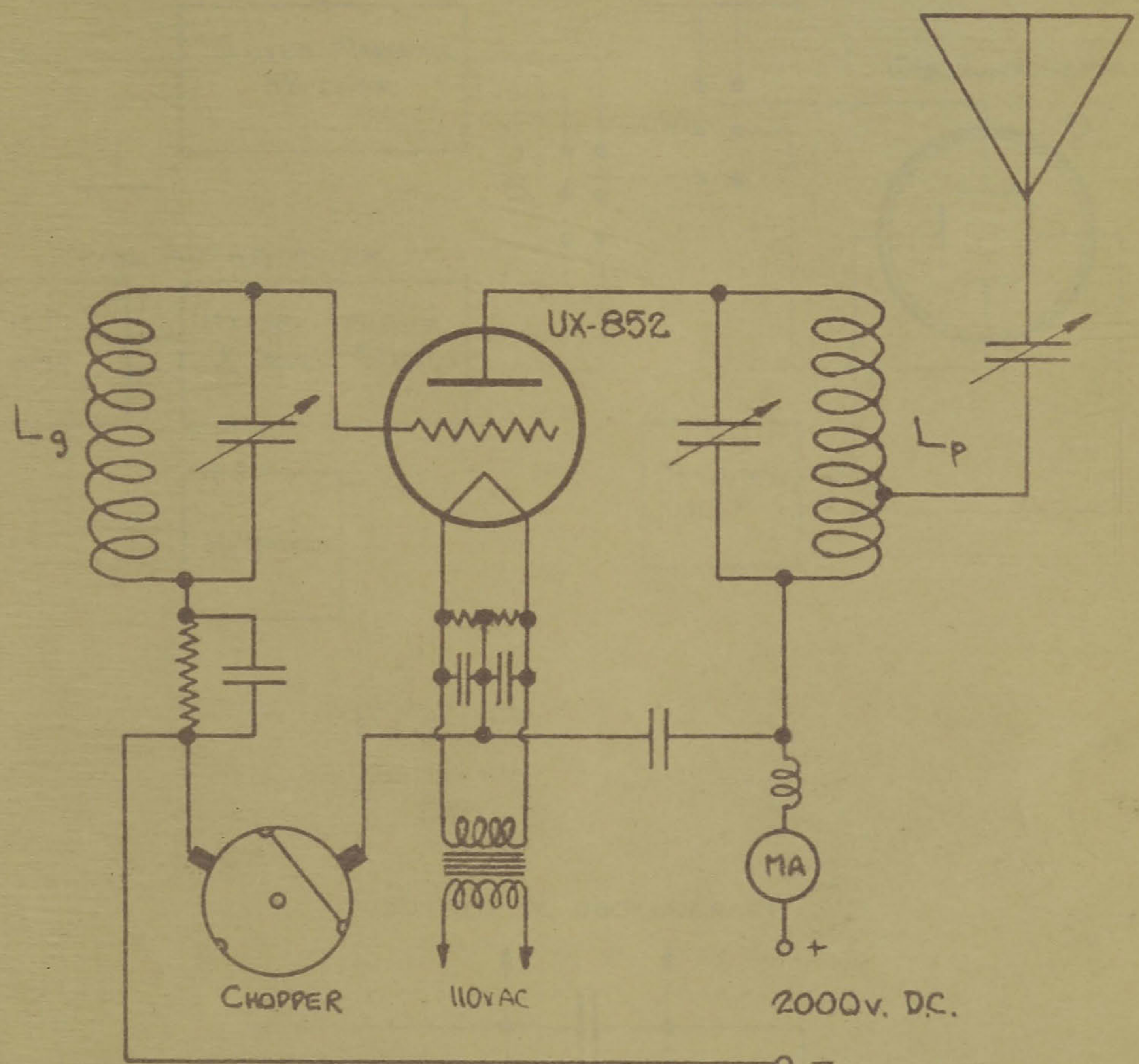


FIG. 4

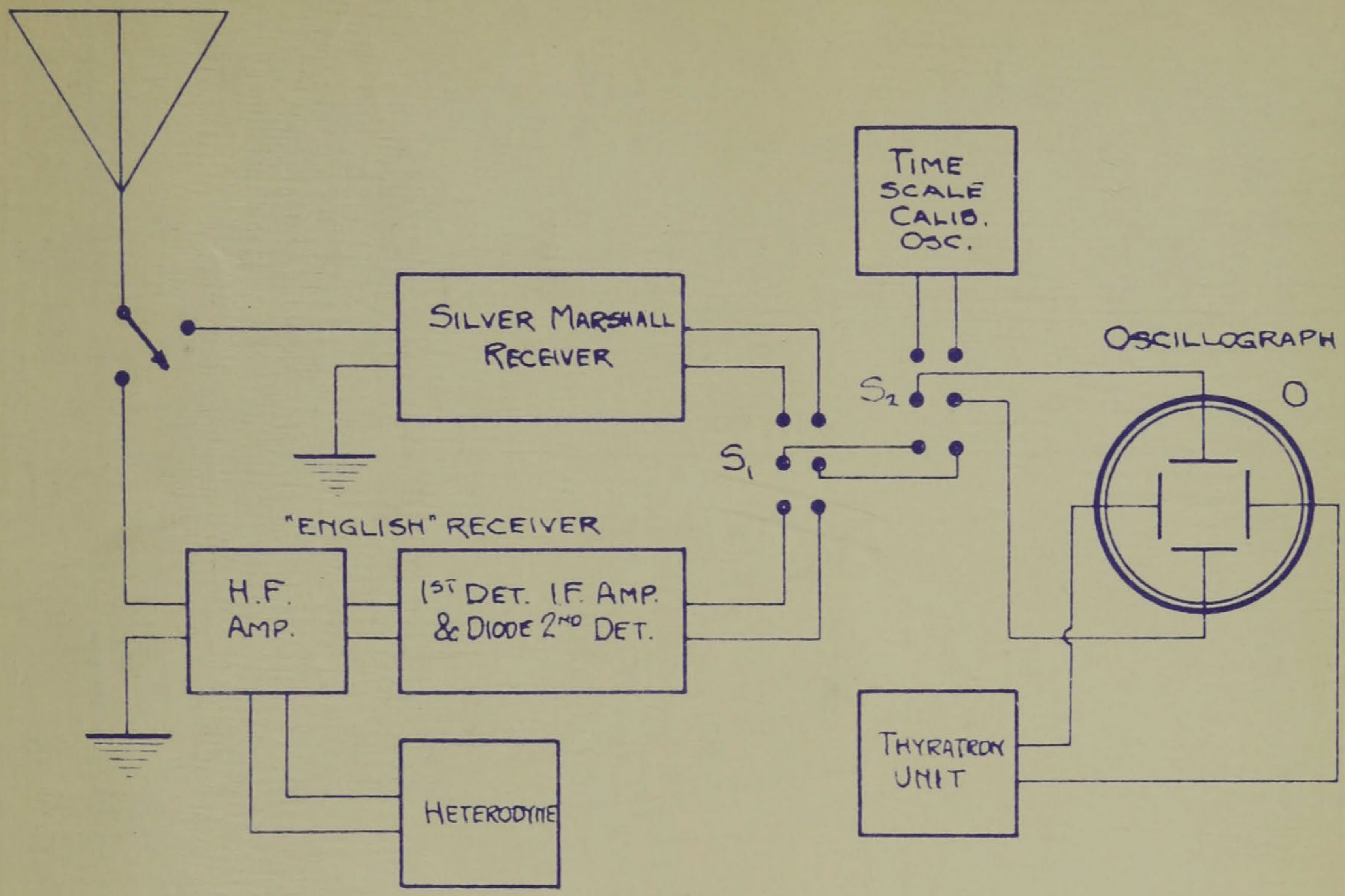

TIME SCALE CALIB. OSC.
SILVER MARSHALL RECEIVER
OSCILLOGRAPH
S_2
O
S_1
"ENGLISH" RECEIVER
H.F. AMP.
1ST DET. I.F. AMP. & DIODE 2ND DET.
THYRATRON UNIT
HETERODYNE

FIG. 5.

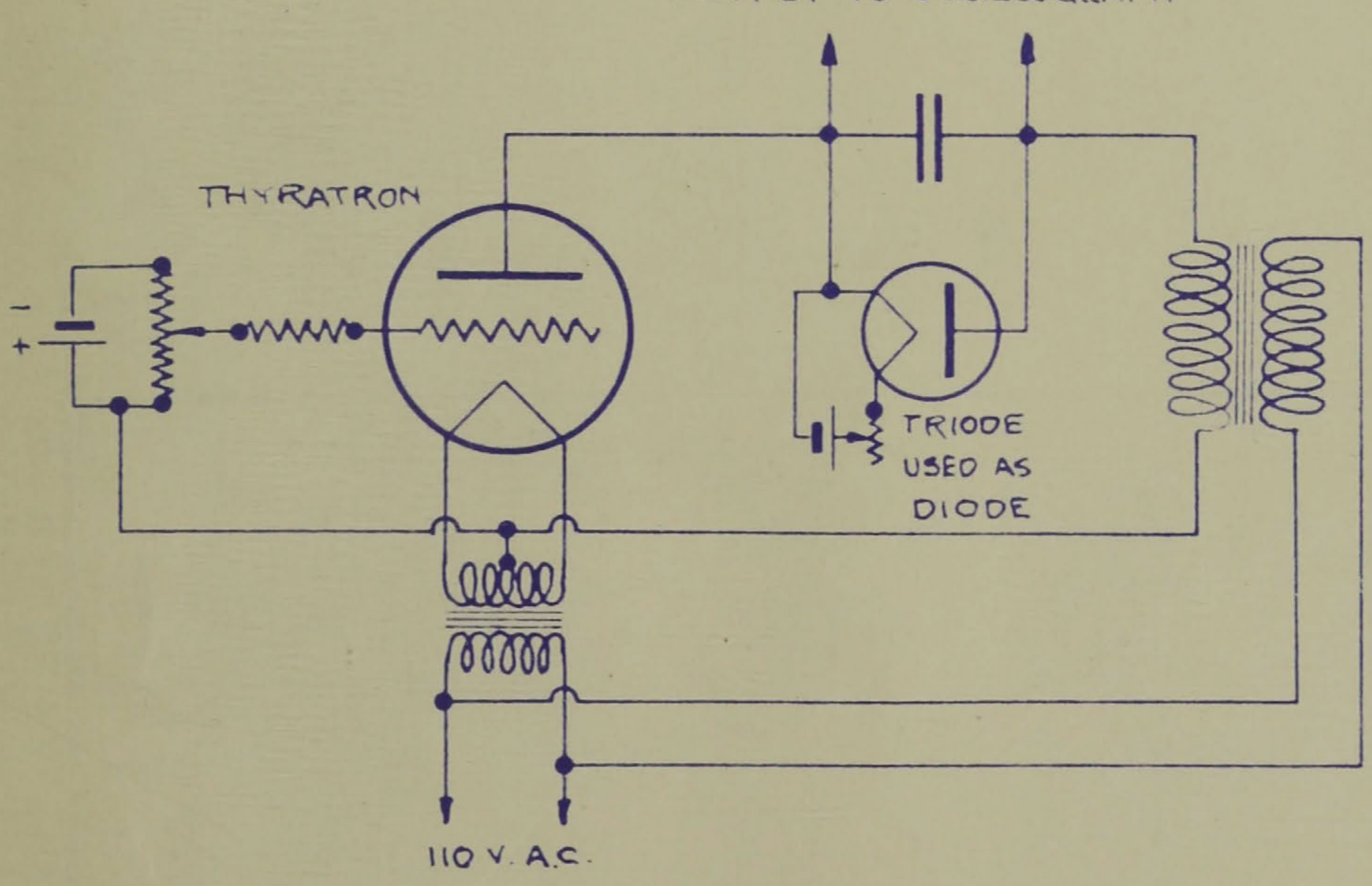
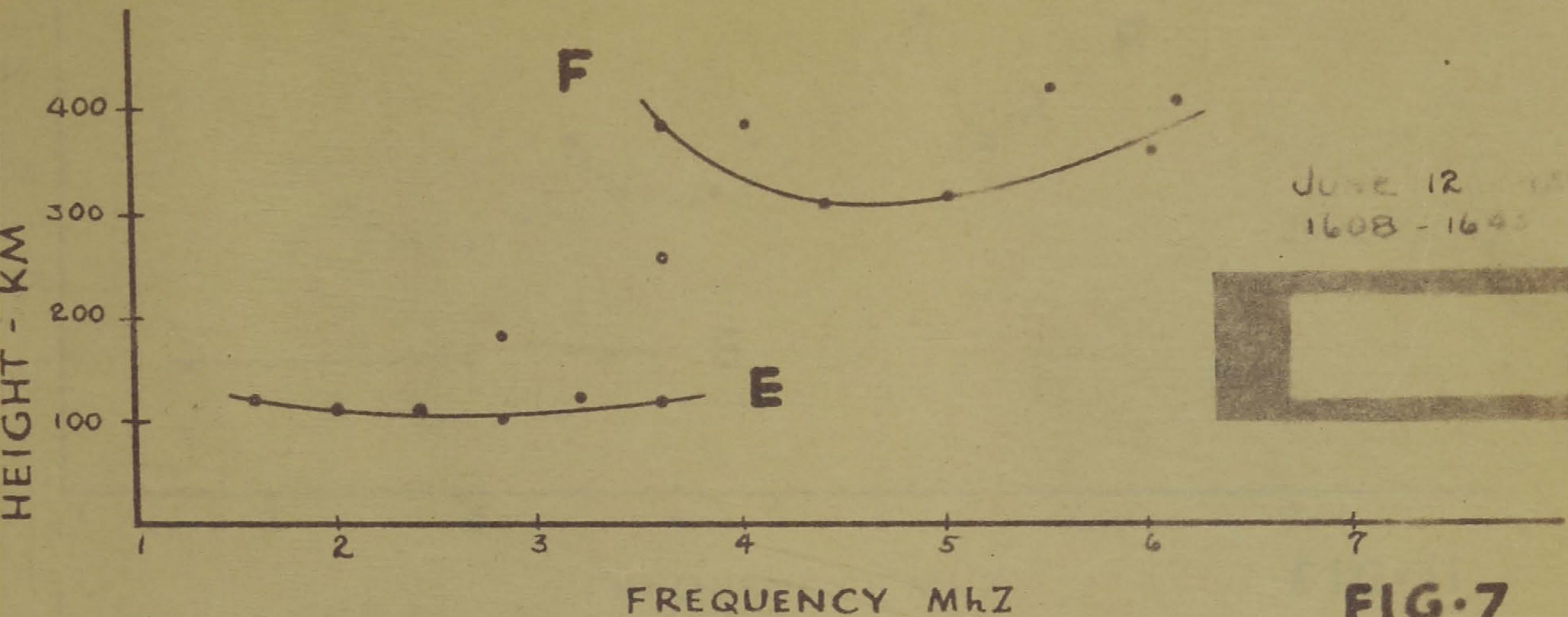
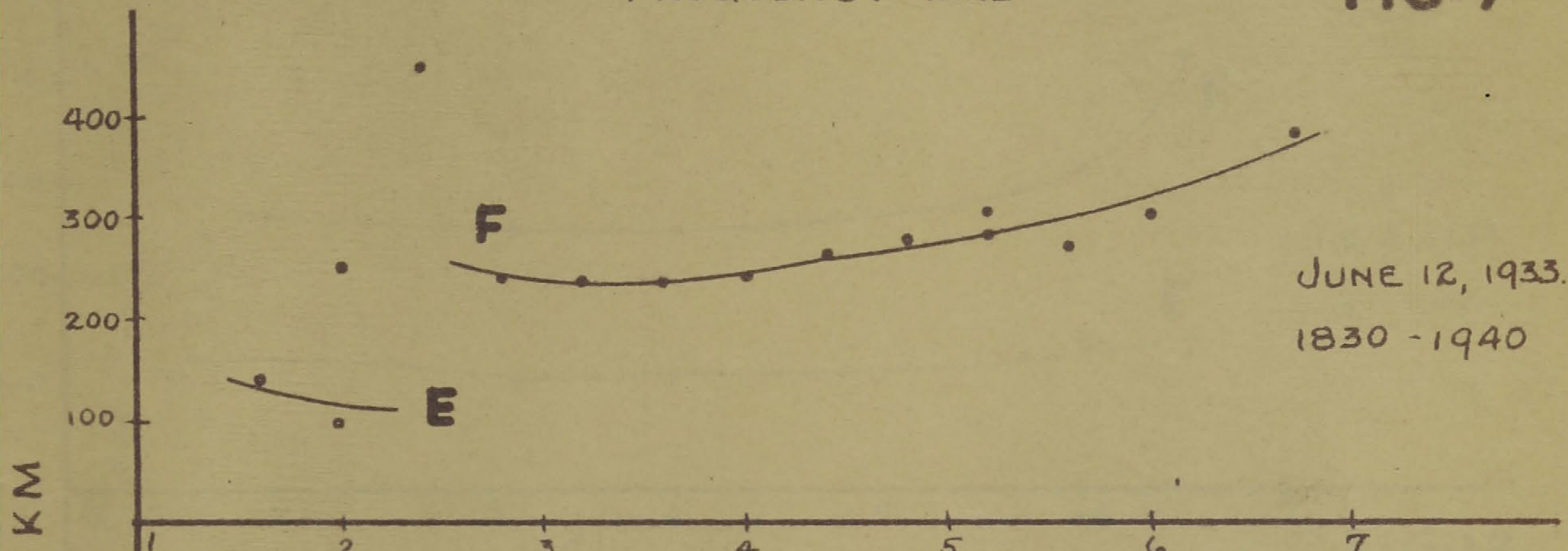

OUTPUT TO OSCILLOGRAPH
THYRATRON
-
+
TRIODE USED AS DIODE
110 V. A.C.

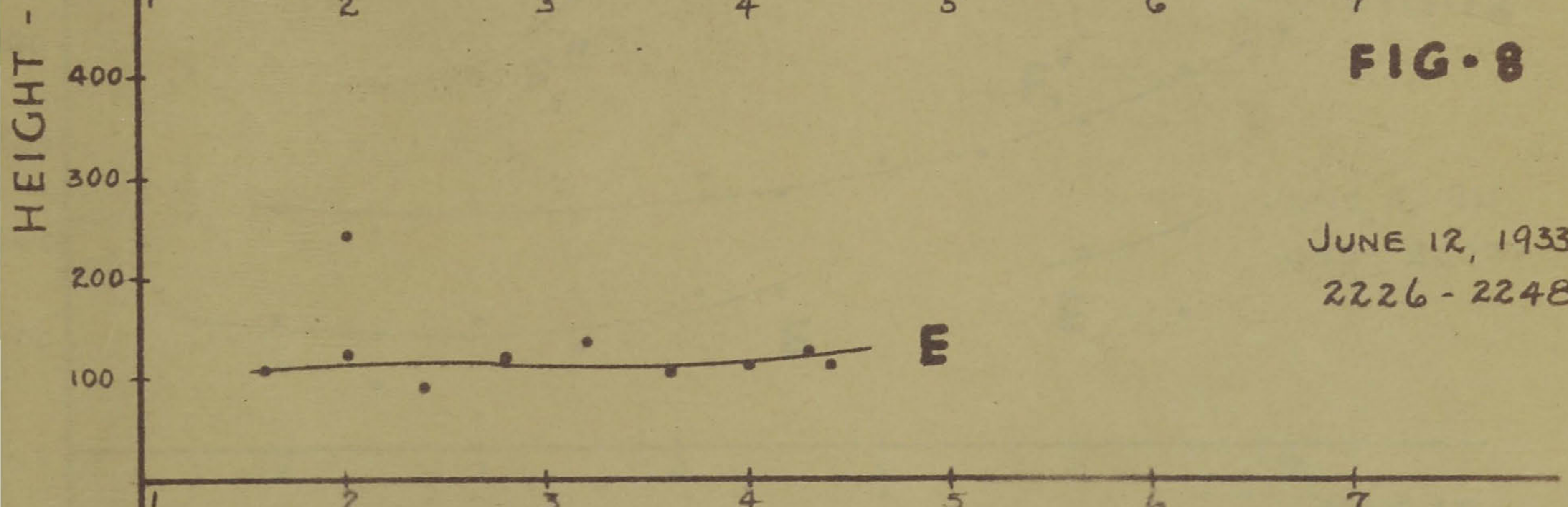
FIG. 6



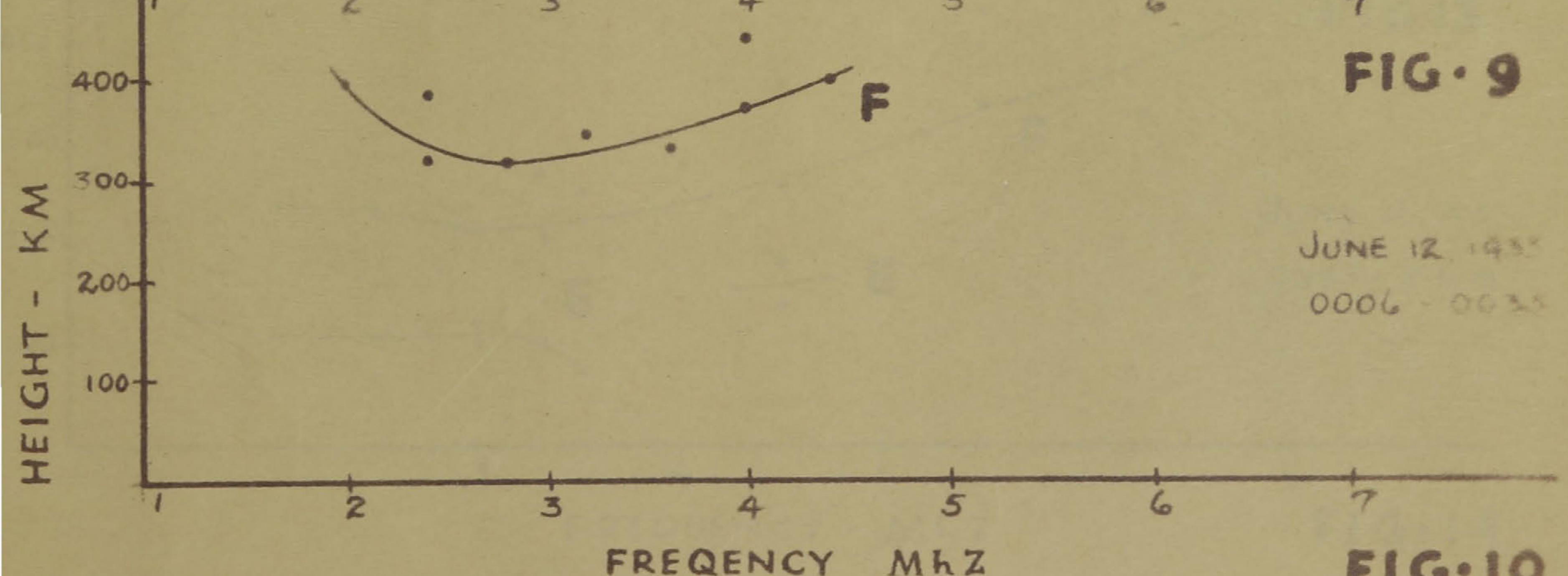
FIG·7



FIG·8



FIG·9



FIG·10

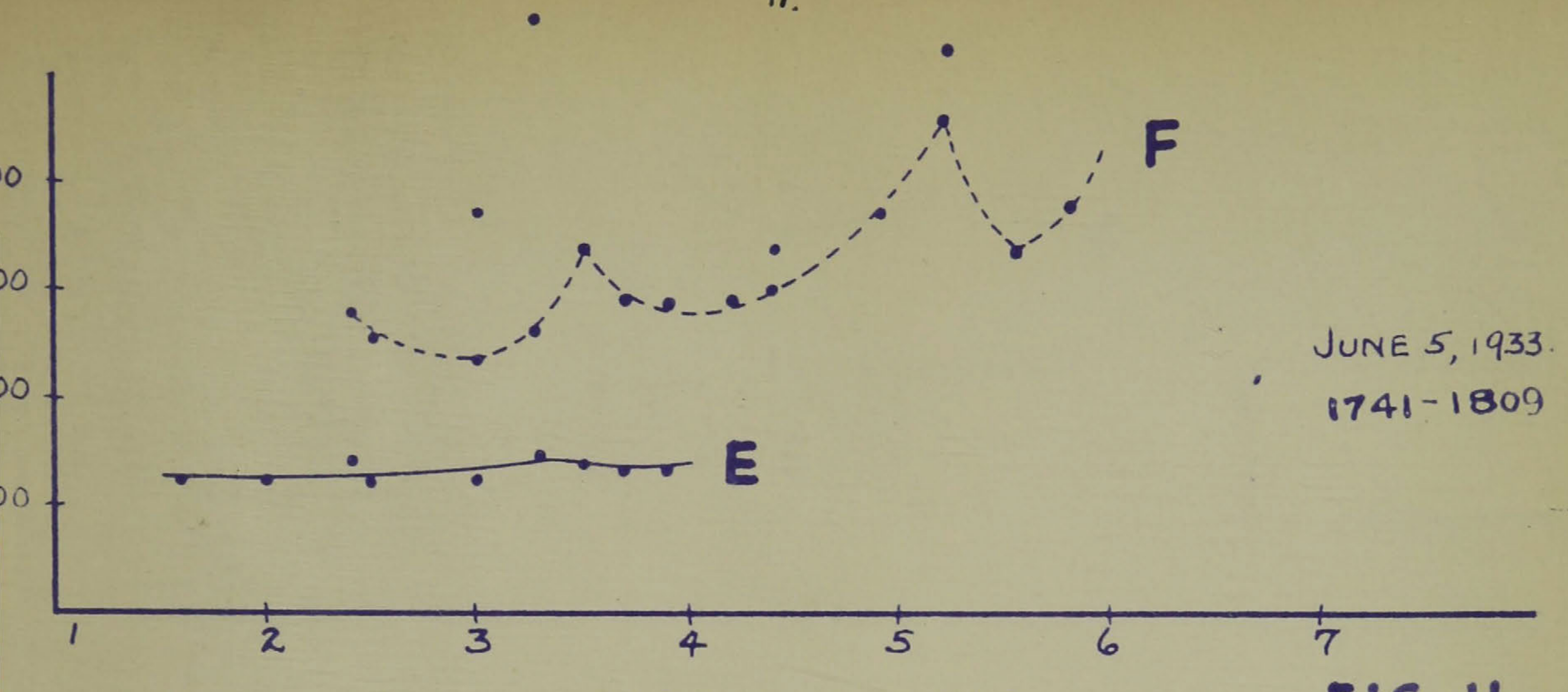


FIG. 11

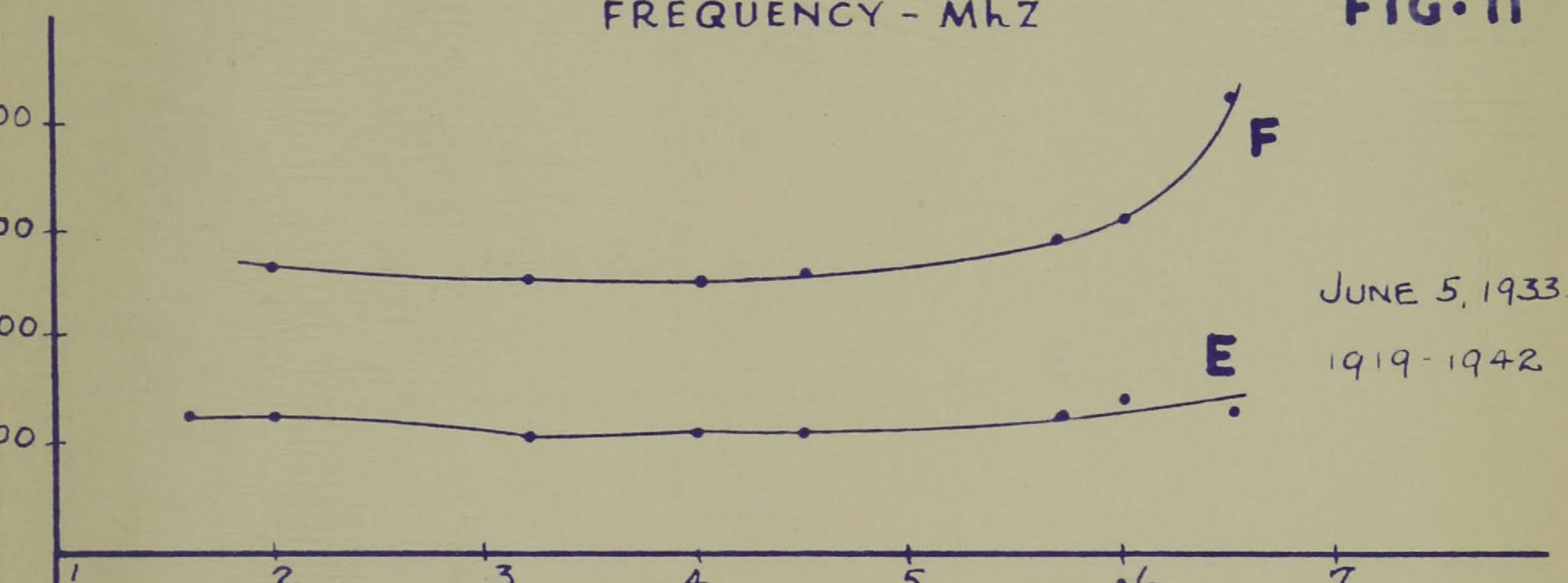


FIG. 12

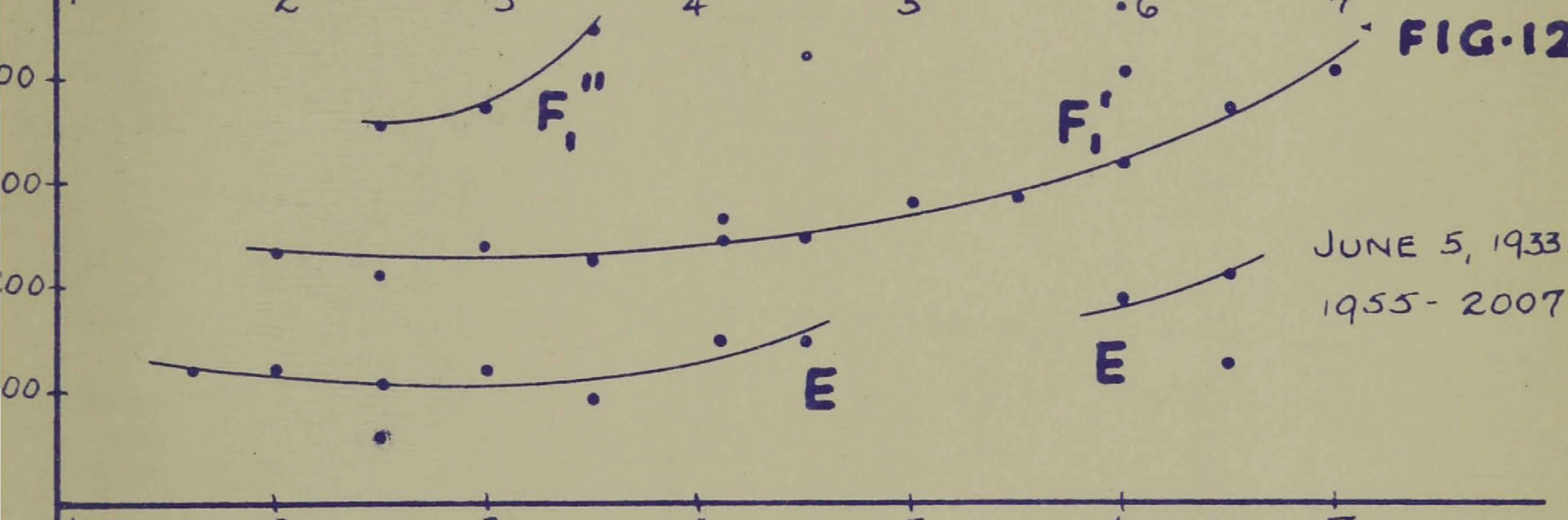


FIG. 13

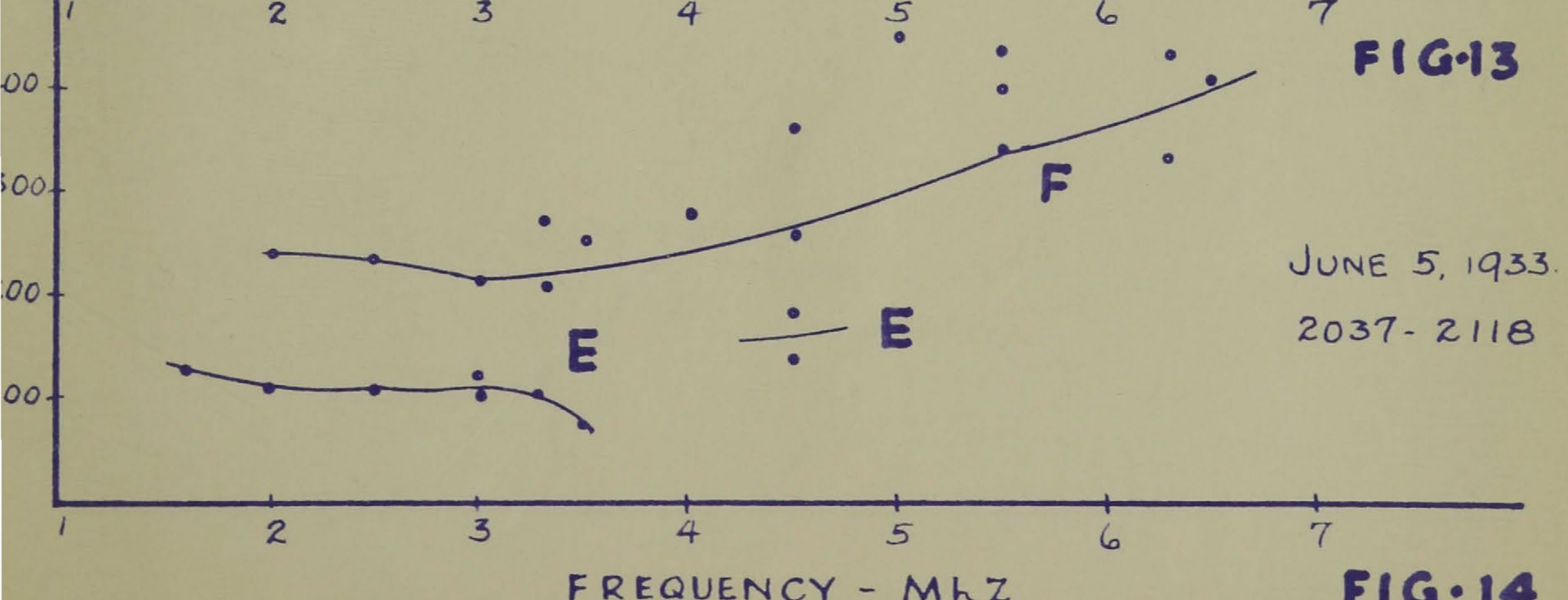
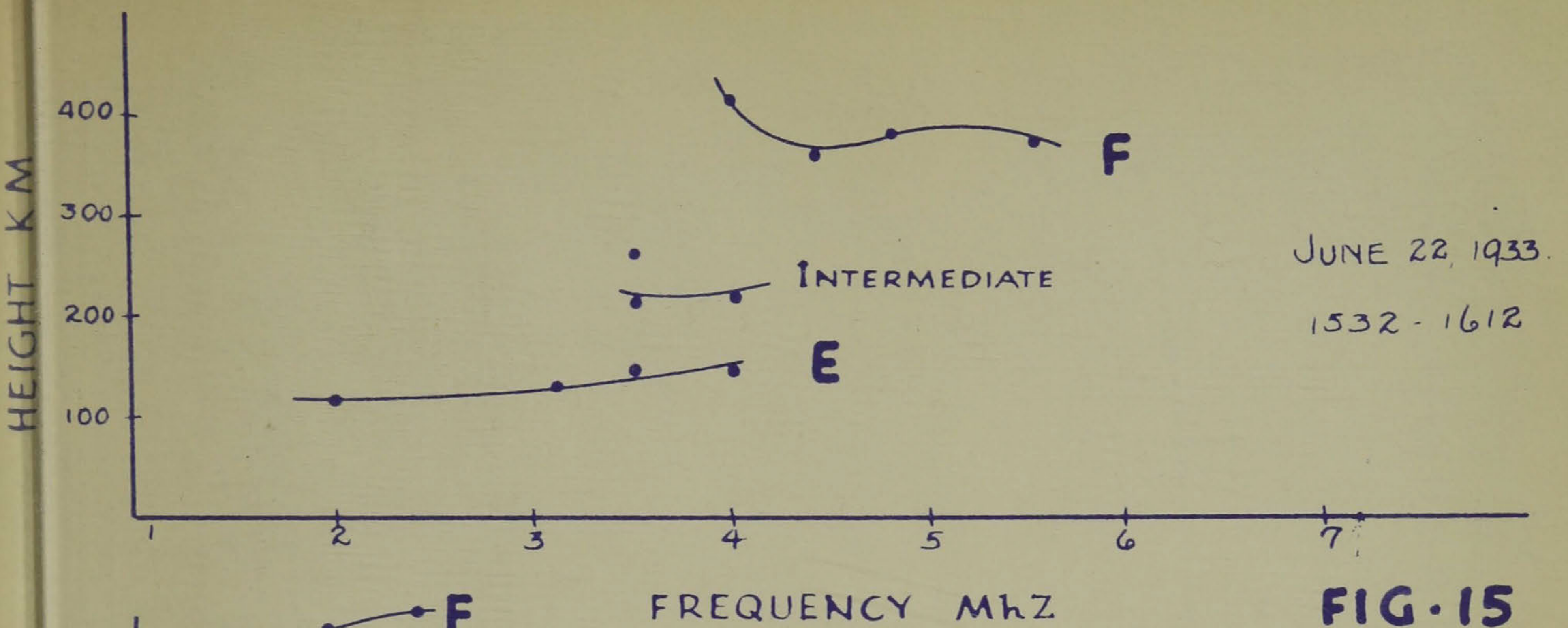
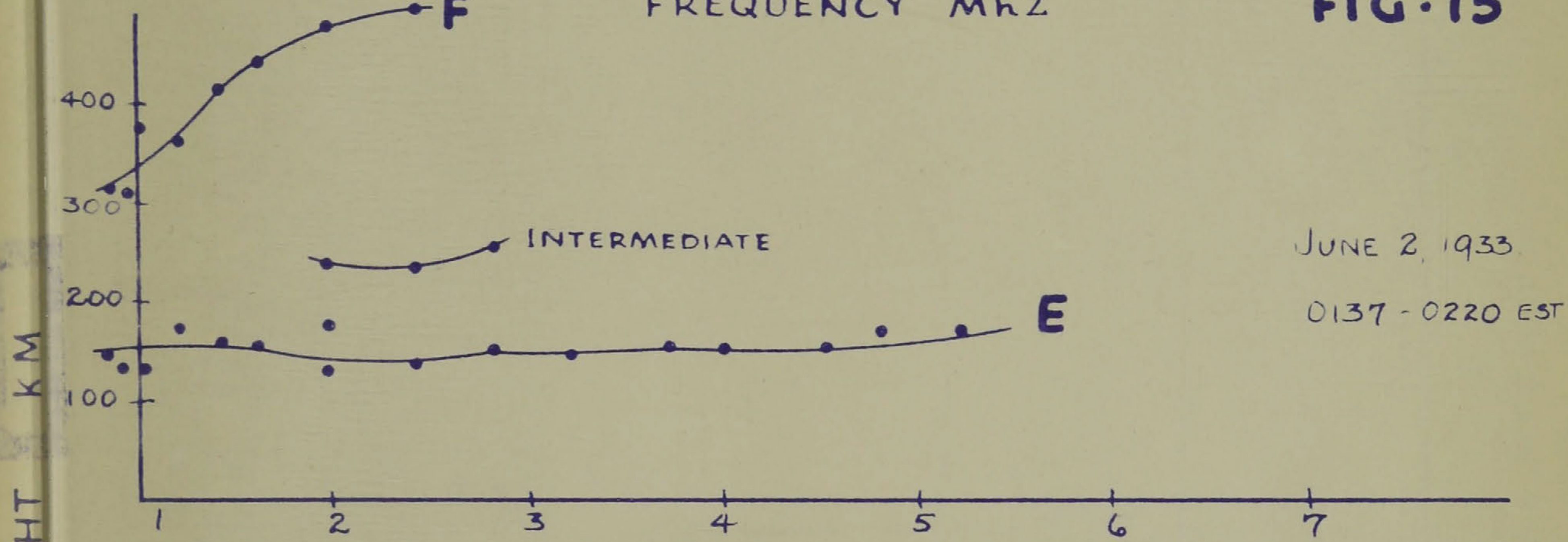


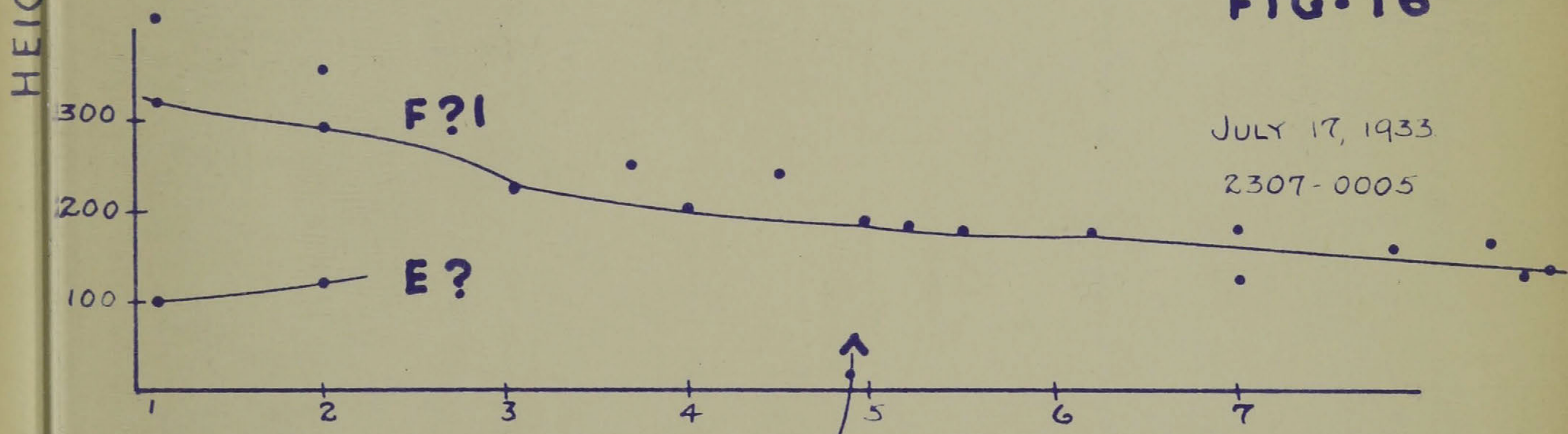
FIG. 14



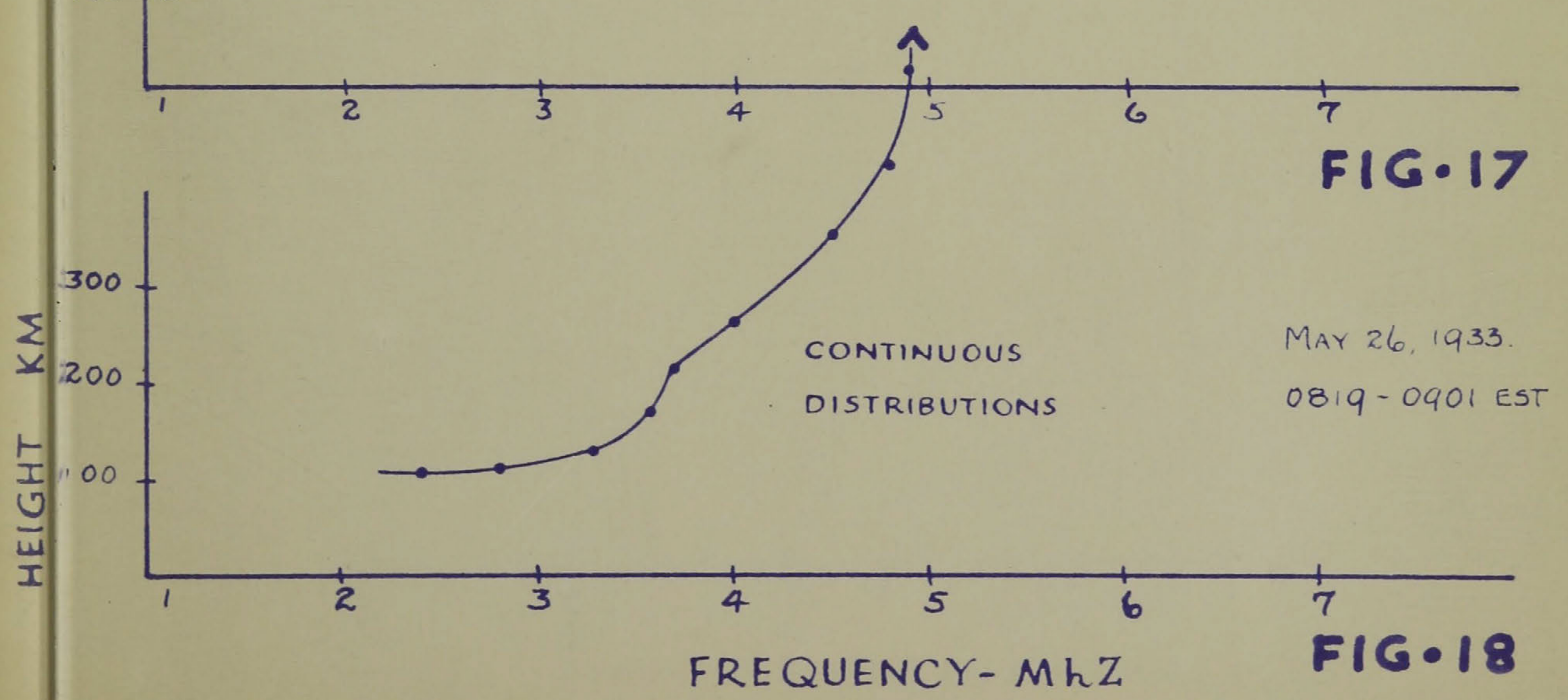
FIG·15



FIG·16



FIG·17



FIG·18

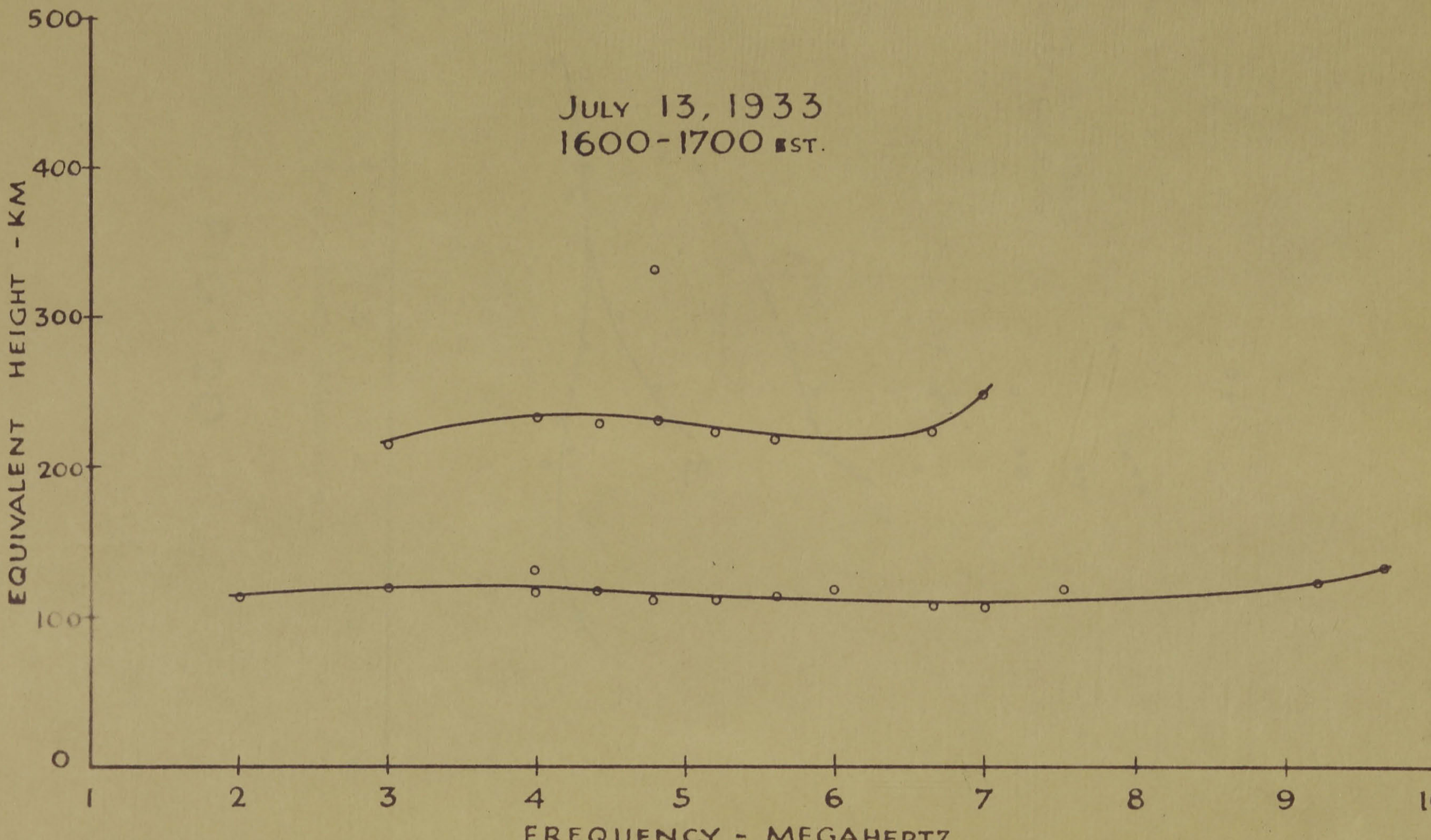

JULY 13, 1933
1600-1700 EST.
EQUIVALENT HEIGHT - KM
0
100
200
300
400
500
1
2
3
4
5
6
7
8
9
10
FREQUENCY - MEGAHERTZ

FIG. 19

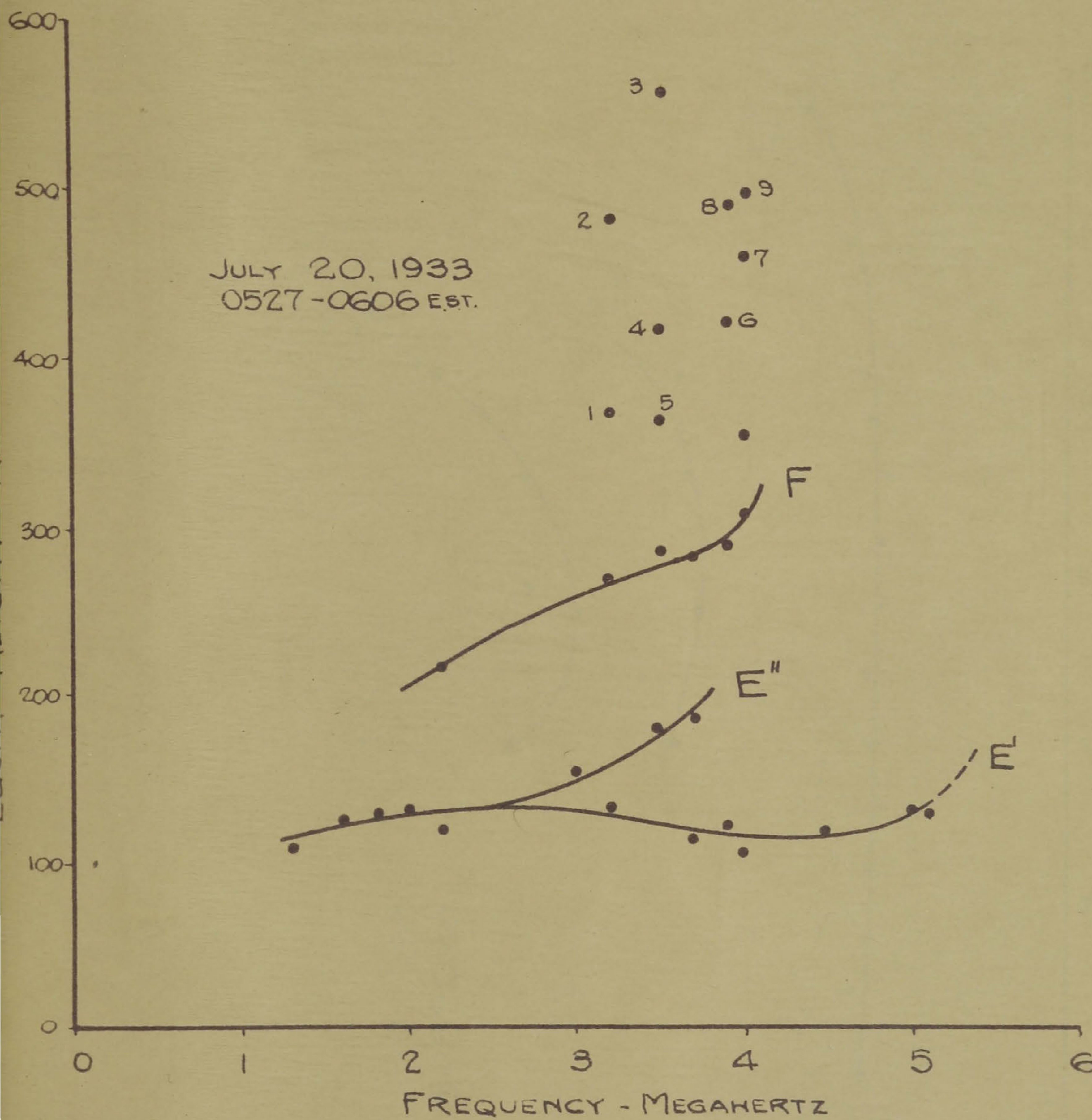

600
500
400
300
200
100
0
JULY 20, 1933
0527-0606 E.S.T.
1
2
3
4
5
6
7
8
9
F
E''
E'
0
1
2
3
4
5
6
FREQUENCY - MEGAHERTZ

FIG · 20

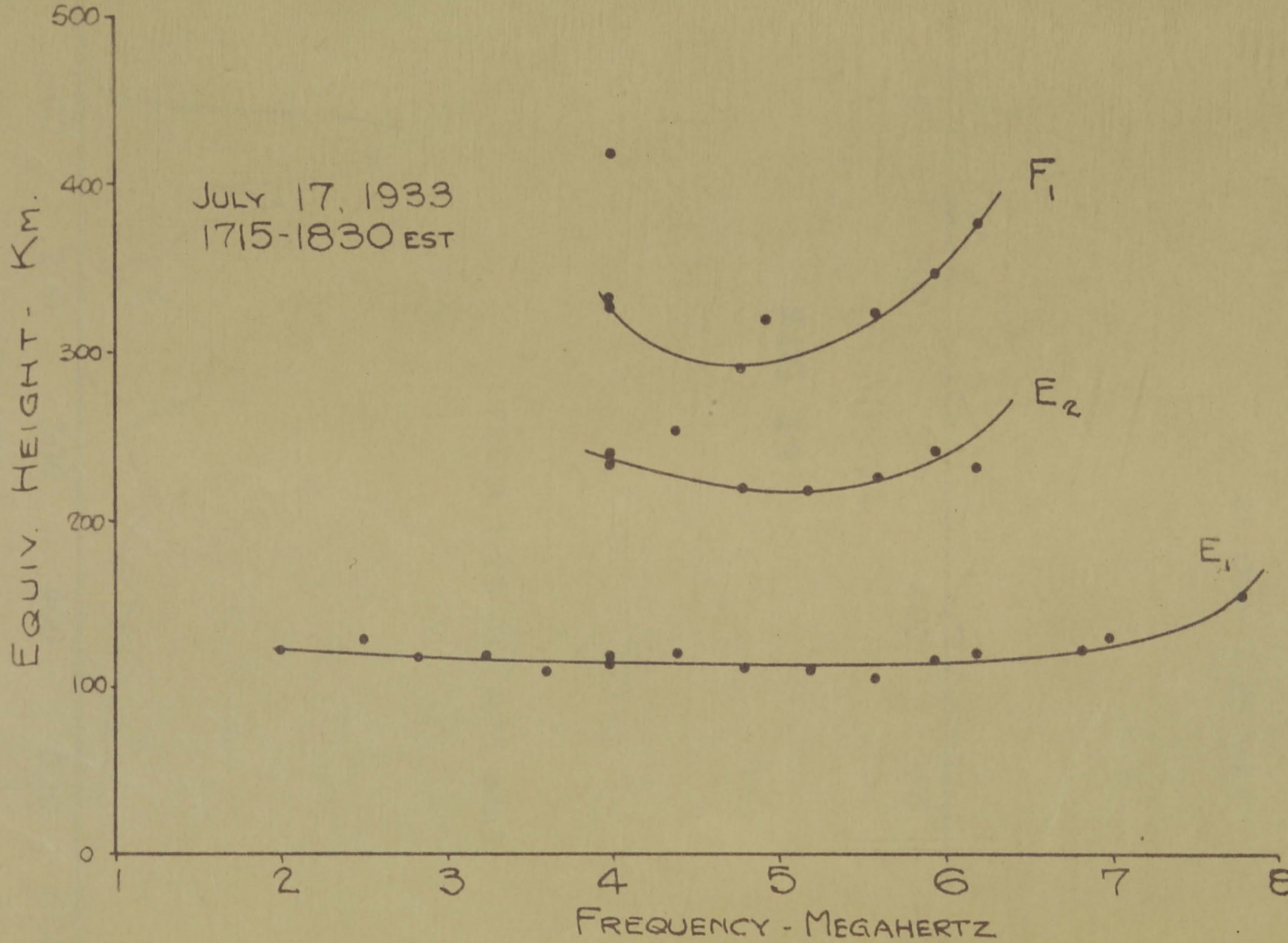
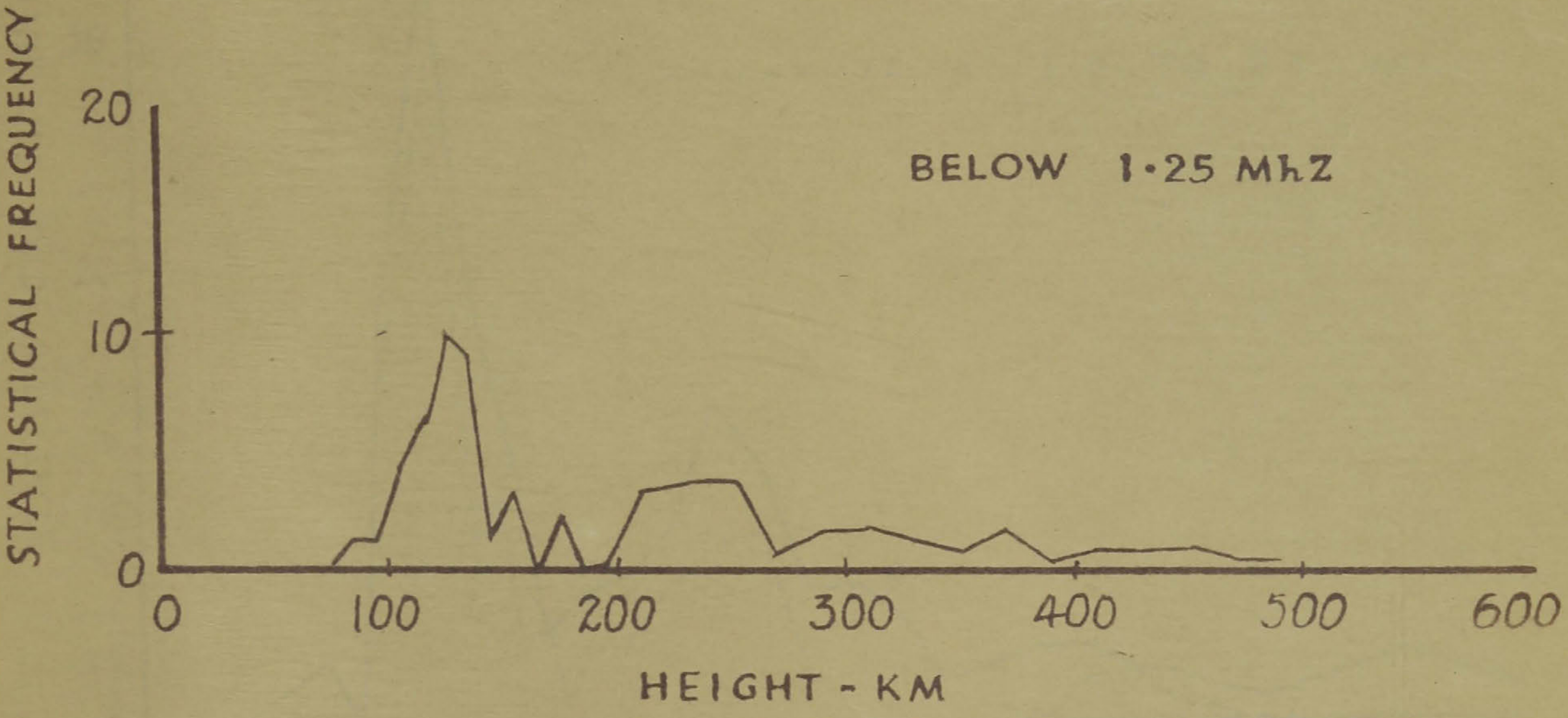
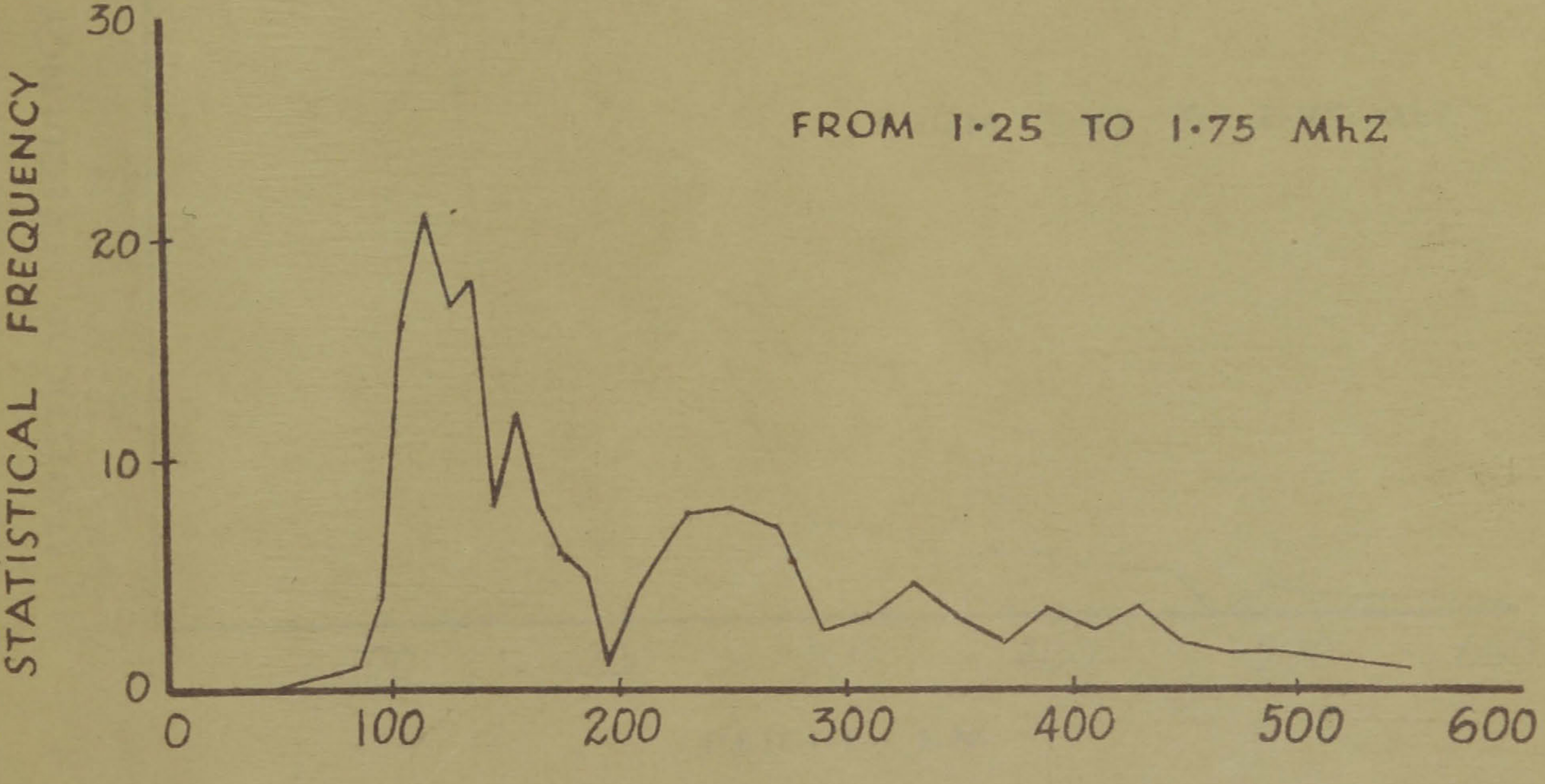

JULY 17, 1933
1715-1830 EST
F1
E2
E1
EQUIV. HEIGHT - KM.
500
400
300
200
100
0
1
2
3
4
5
6
7
8
FREQUENCY - MEGAHERTZ

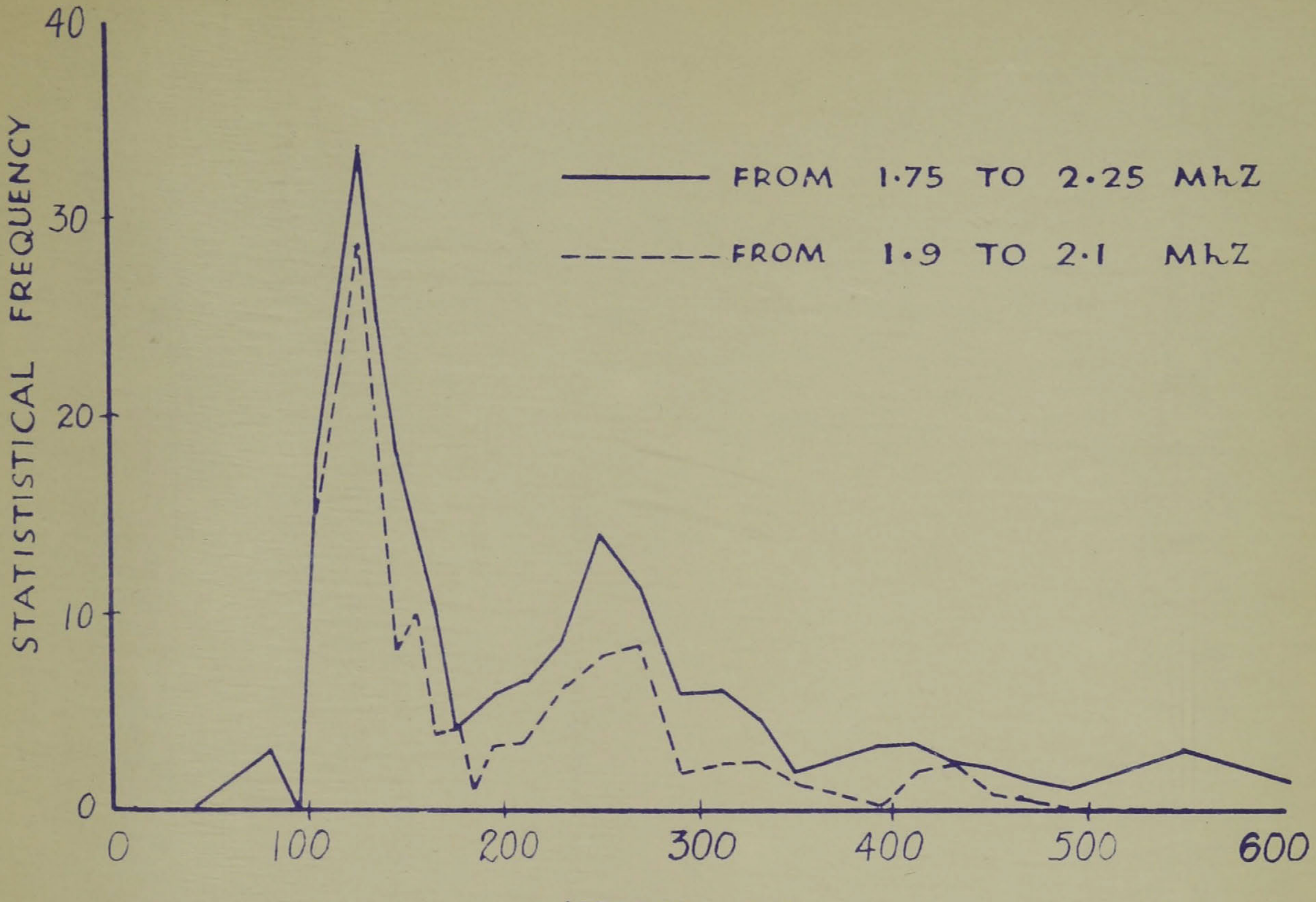
FIG. 21


STATISTICAL FREQUENCY
20
10
0
BELOW 1·25 MhZ
0
100
200
300
400
500
600
HEIGHT - KM

FIG·22

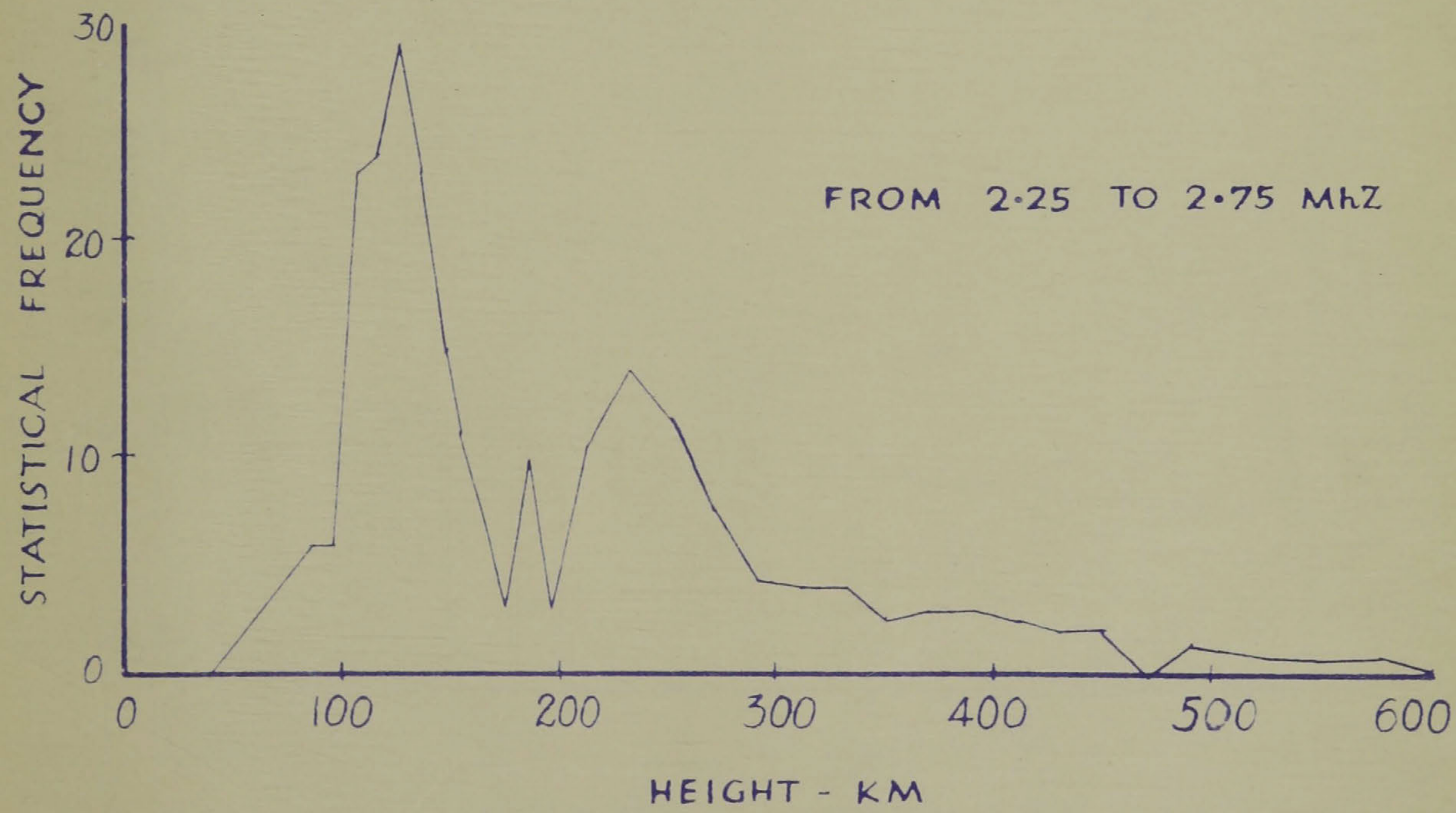

STATISTICAL FREQUENCY
30
20
10
0
FROM 1·25 TO 1·75 MhZ
0
100
200
300
400
500
600
HEIGHT KM

FIG·23



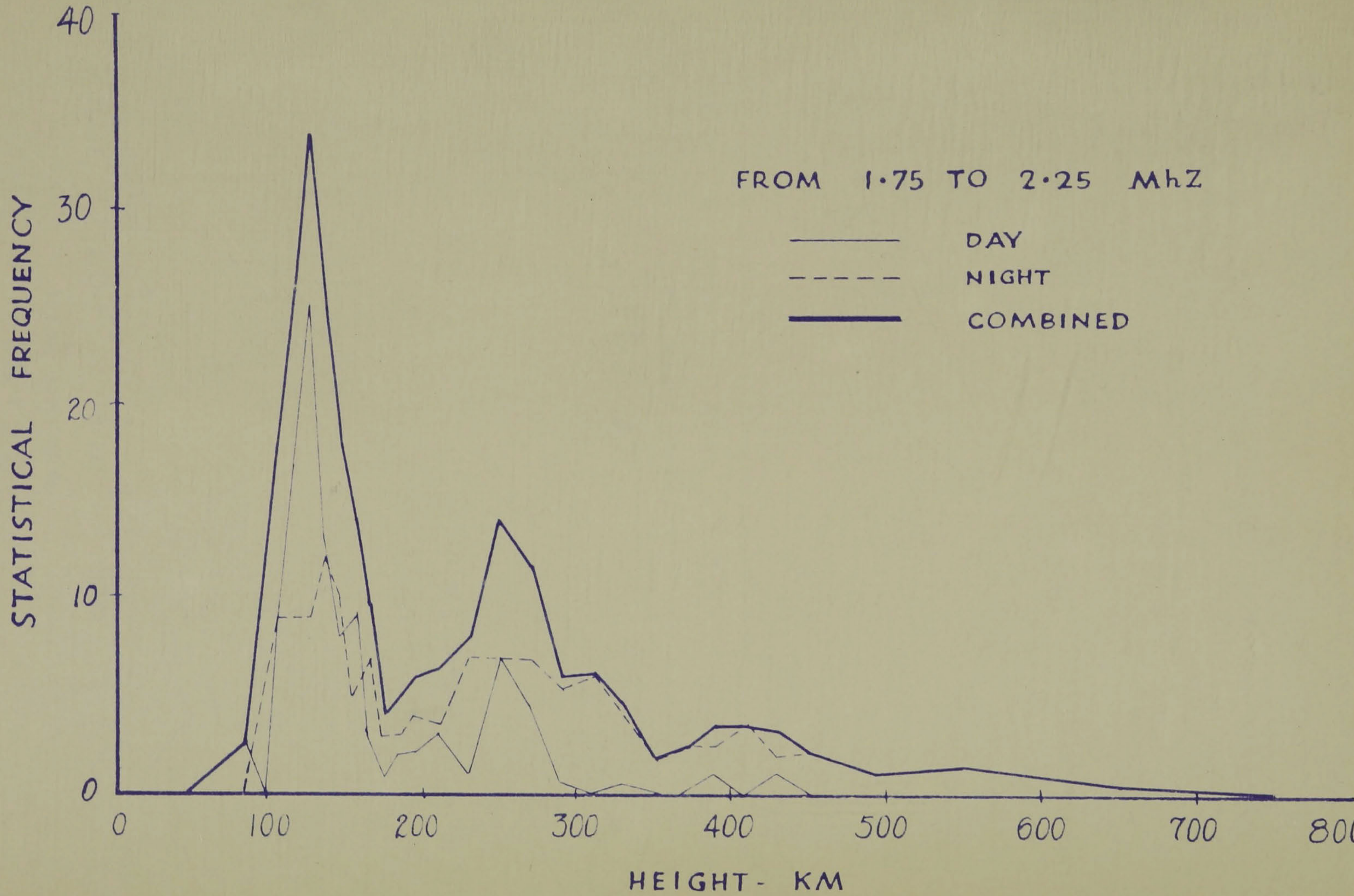
STATISTICAL FREQUENCY
40
30
20
10
0
FROM 1·75 TO 2·25 MhZ
FROM 1·9 TO 2·1 MhZ
0
100
200
300
400
500
600
HEIGHT - KM

FIG·24



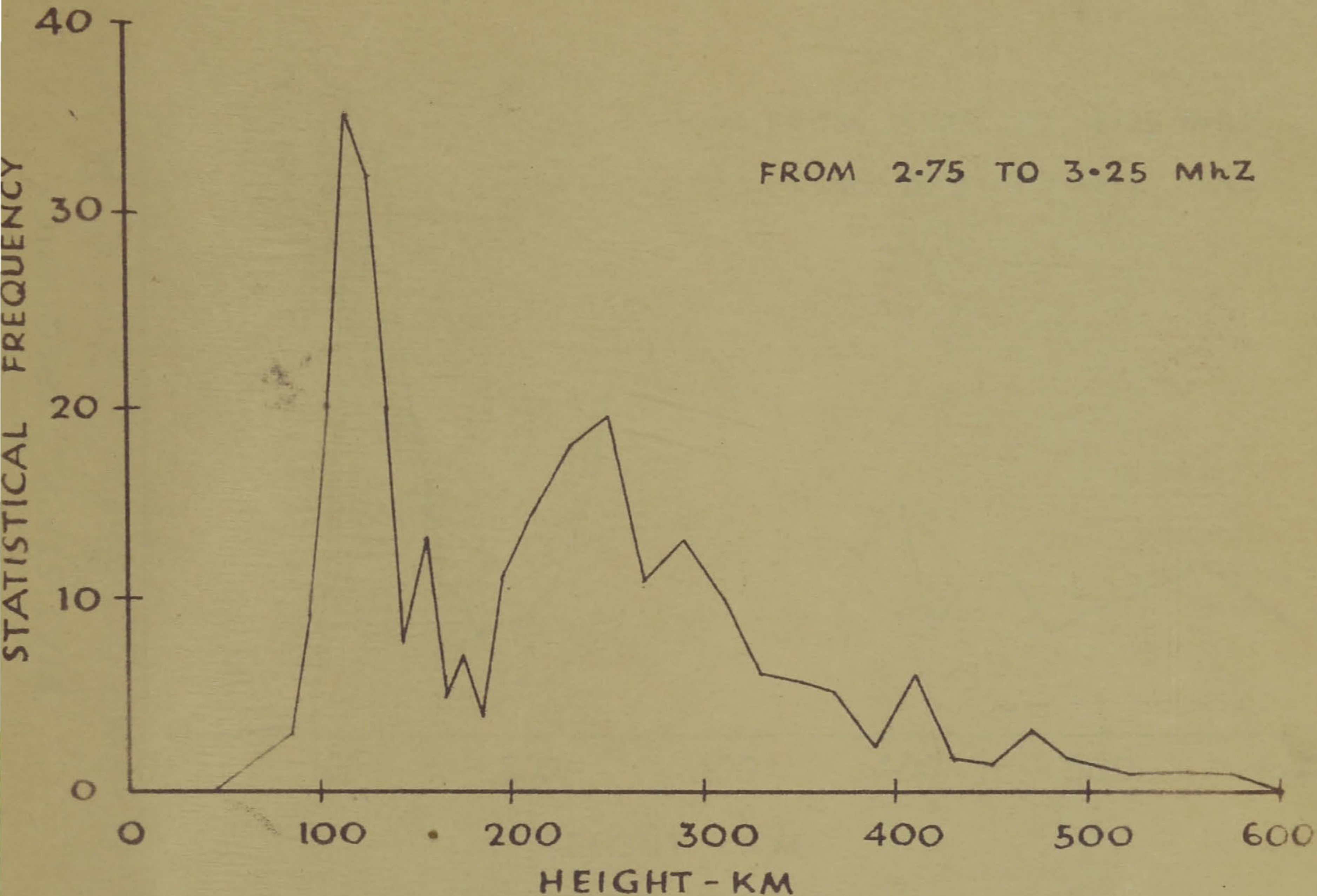
STATISTICAL FREQUENCY
30
20
10
0
FROM 2·25 TO 2·75 MhZ
0
100
200
300
400
500
600
HEIGHT - KM

FIG· 25



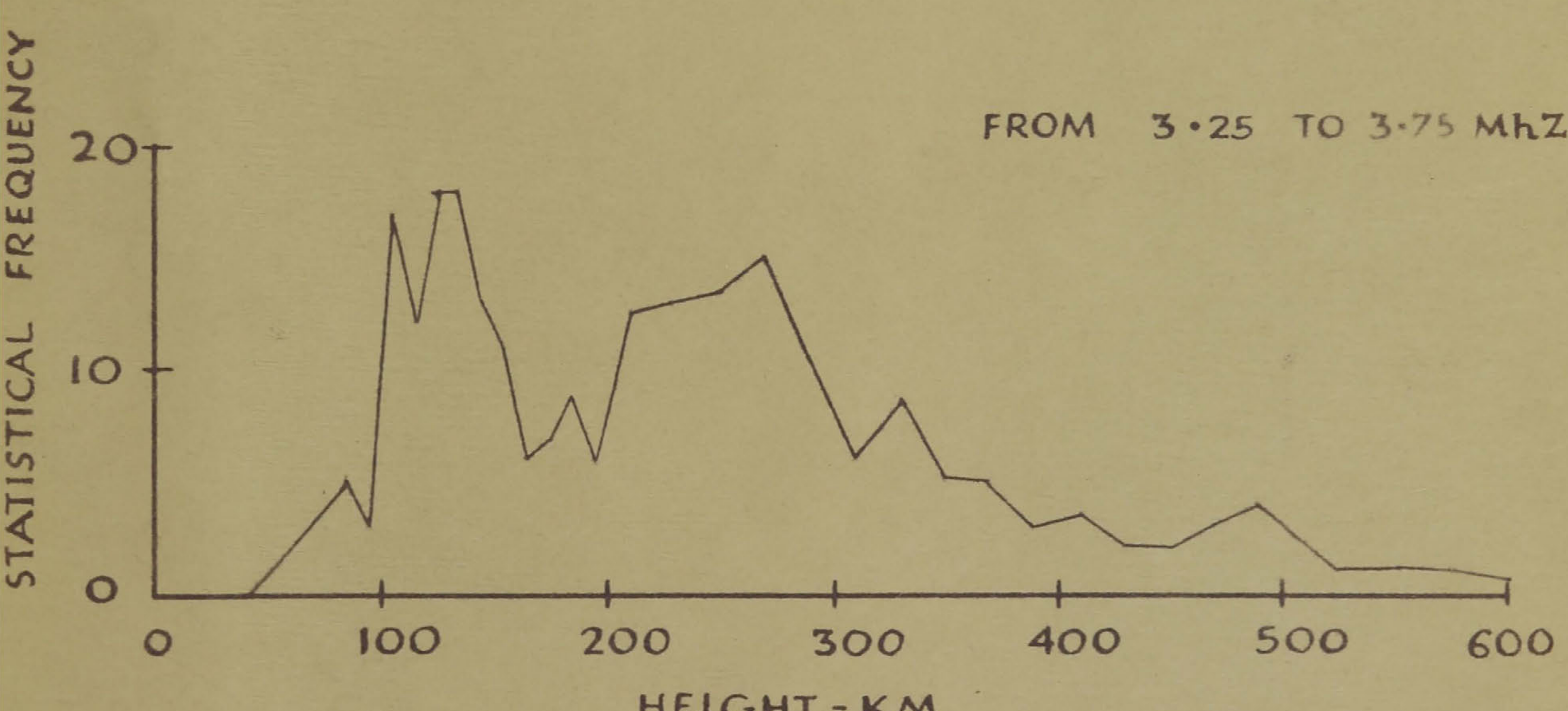
FROM 1·75 TO 2·25 MhZ
DAY
NIGHT
COMBINED
STATISTICAL FREQUENCY
40
30
20
10
0
0
100
200
300
400
500
600
700
800
HEIGHT - KM

FIG·26



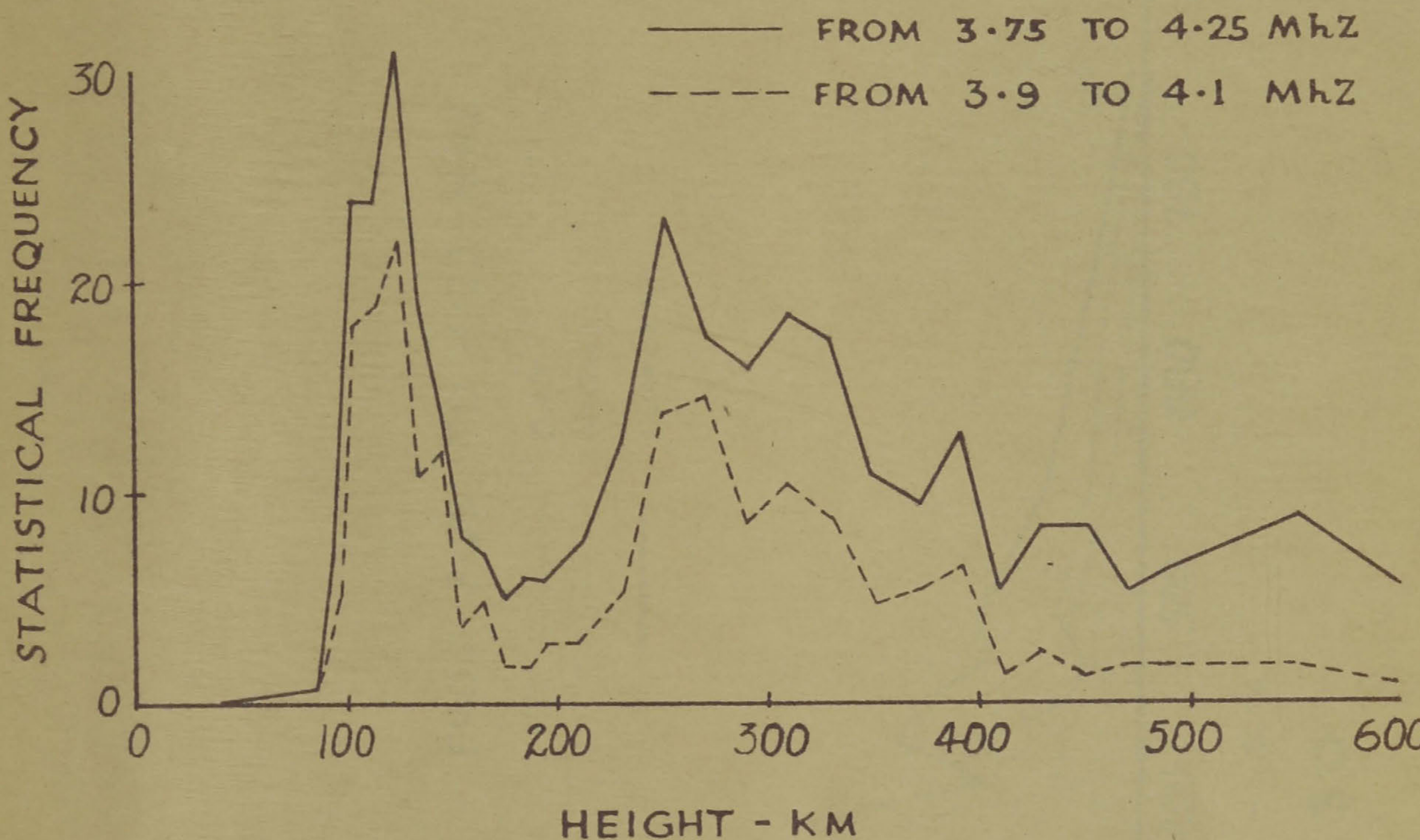
FROM 2·75 TO 3·25 MhZ
STATISTICAL FREQUENCY
40
30
20
10
0
0
100
200
300
400
500
600
HEIGHT - KM

FIG ·27



FROM 3·25 TO 3·75 MhZ
STATISTICAL FREQUENCY
20
10
0
0
100
200
300
400
500
600
HEIGHT - KM

FIG·28


FROM 3·75 TO 4·25 MhZ
FROM 3·9 TO 4·1 MhZ
STATISTICAL FREQUENCY
30
20
10
0
0
100
200
300
400
500
600
HEIGHT - KM

FIG·29

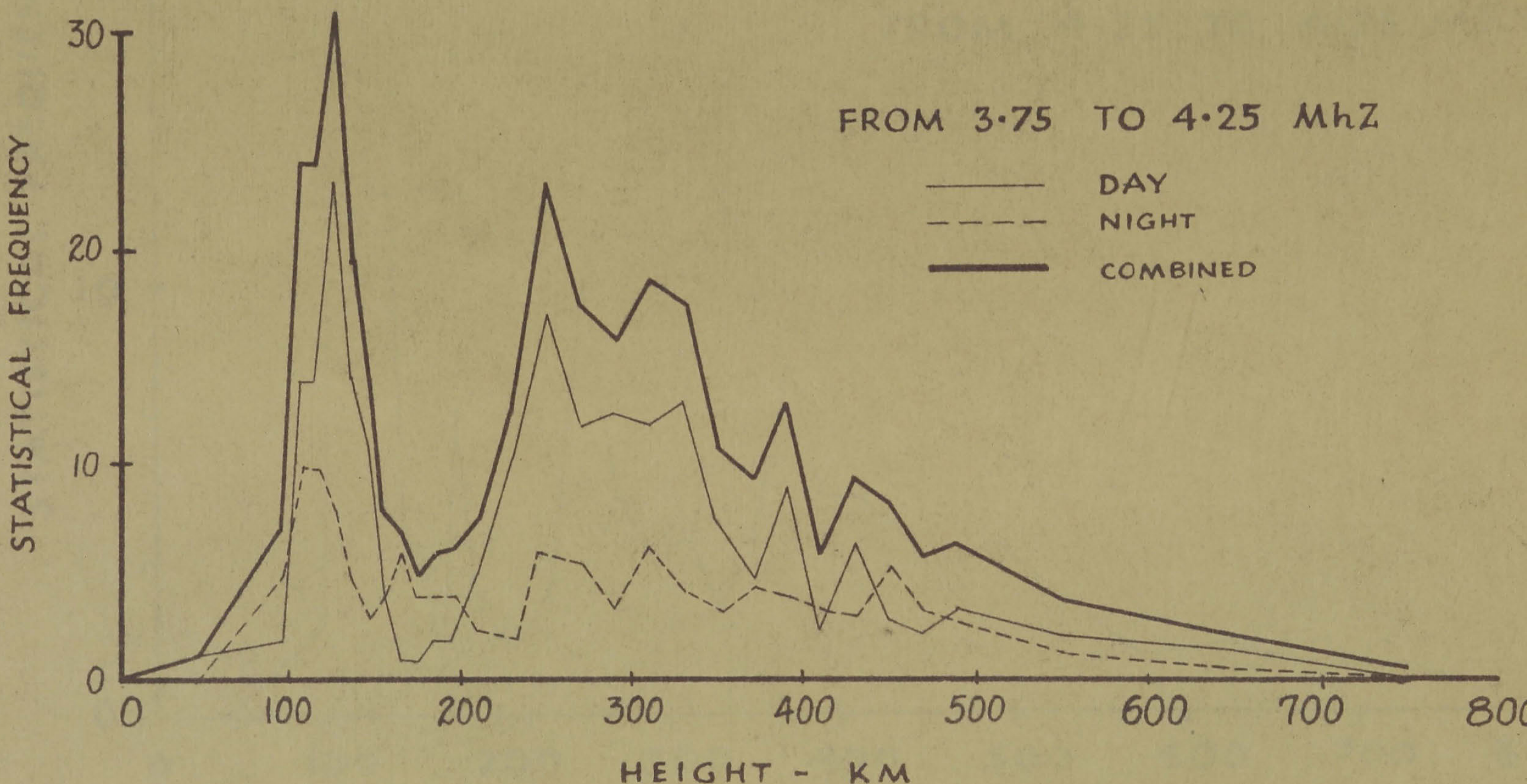
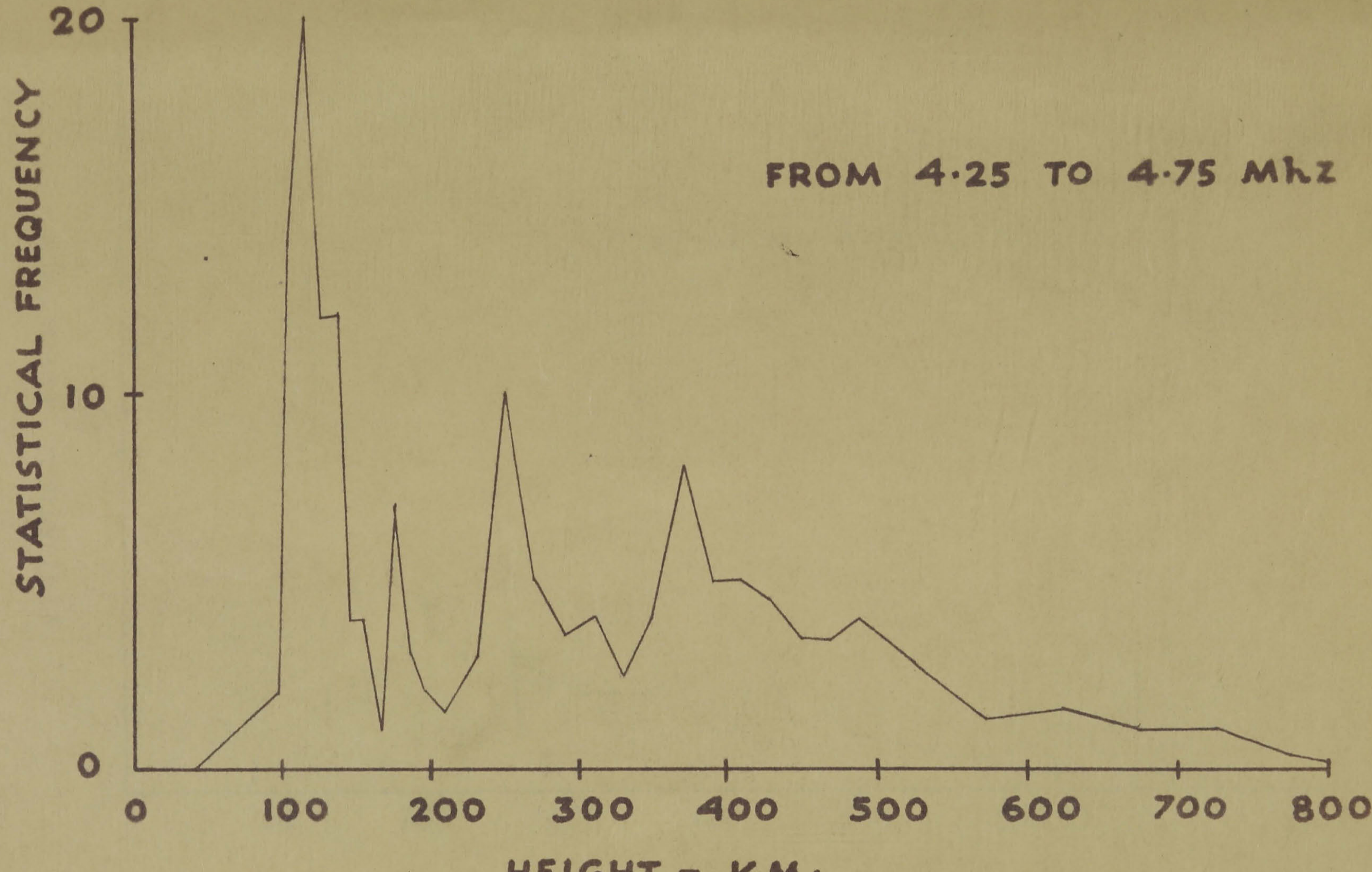
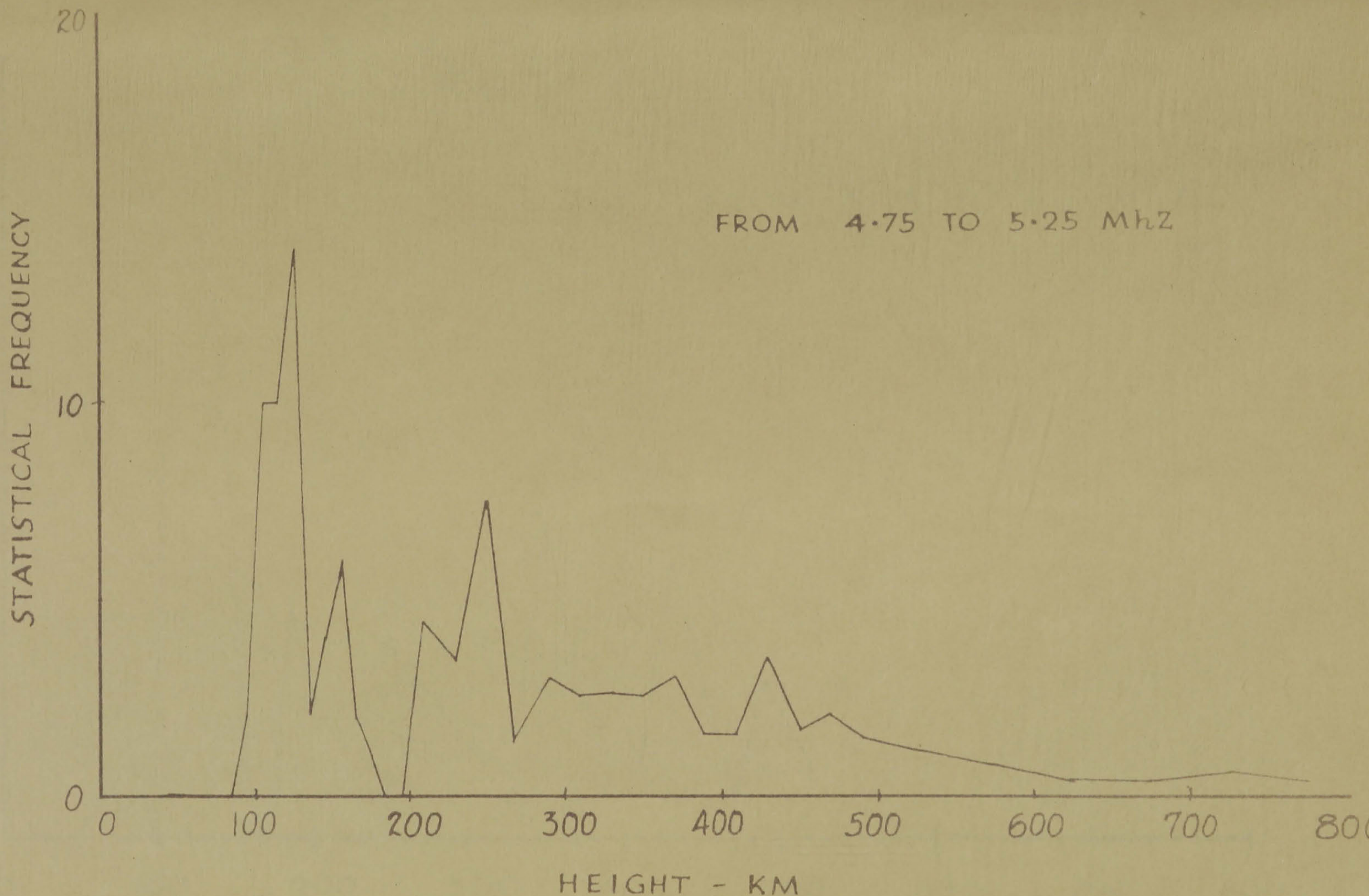

FROM 3·75 TO 4·25 MhZ
DAY
NIGHT
COMBINED
STATISTICAL FREQUENCY
0
10
20
30
0
100
200
300
400
500
600
700
800
HEIGHT - KM

FIG · 30


FROM 4·25 TO 4·75 Mhz
STATISTICAL FREQUENCY
20
10
0
0
100
200
300
400
500
600
700
800
HEIGHT - KM·

FIG·31


FROM 4·75 TO 5·25 Mhz
STATISTICAL FREQUENCY
20
10
0
0
100
200
300
400
500
600
700
800
HEIGHT - KM

FIG·32

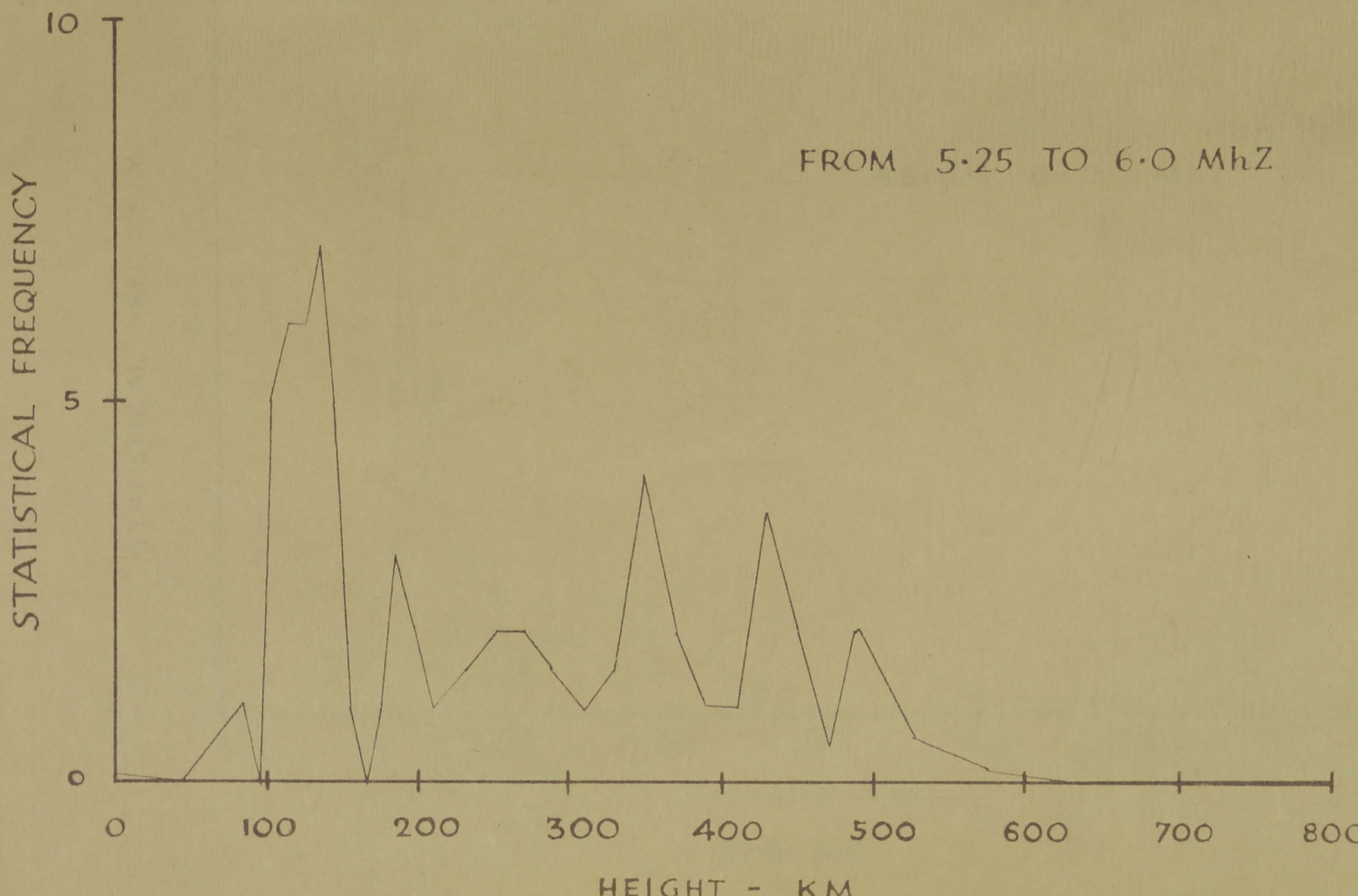
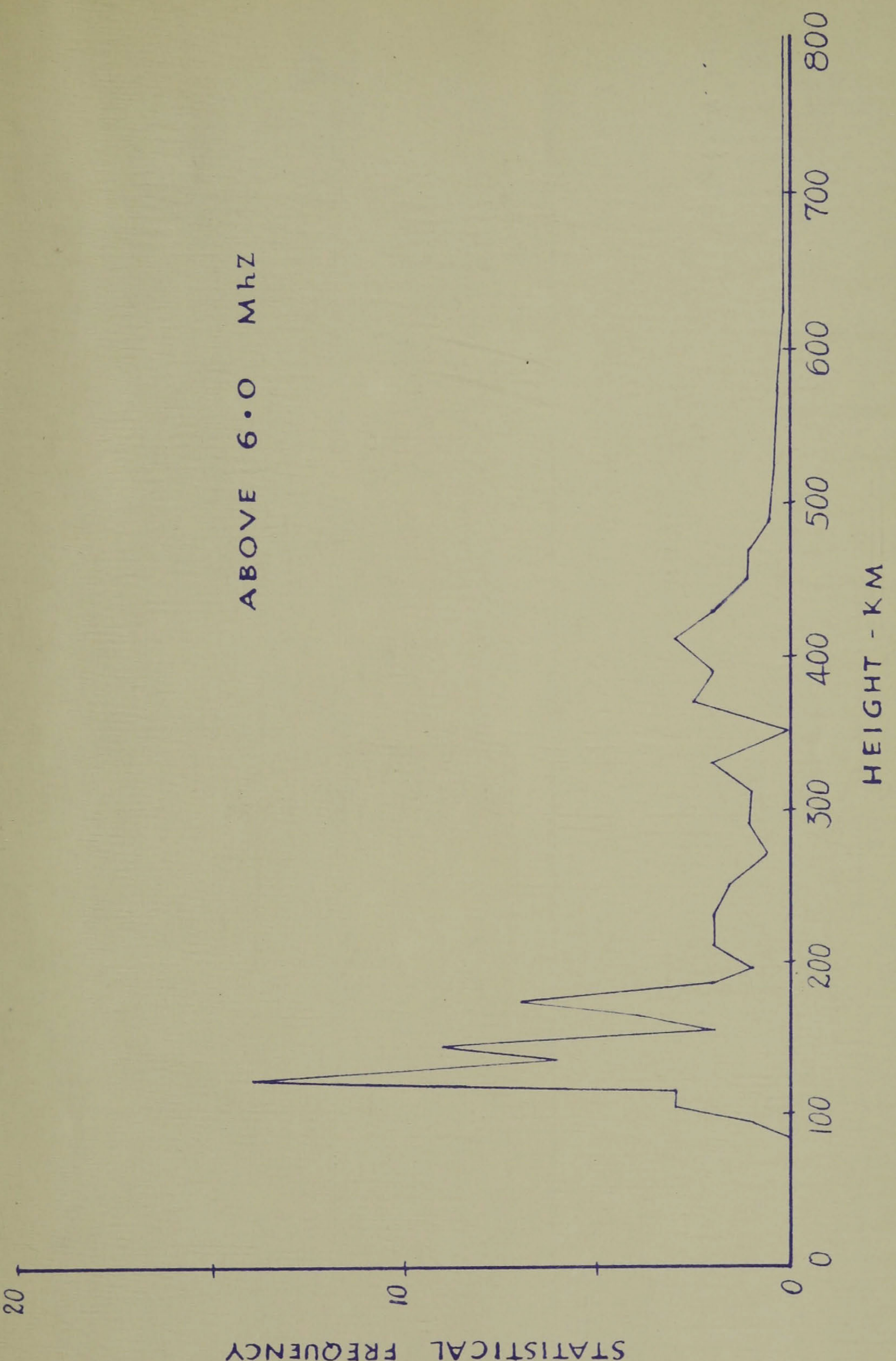

FROM 5·25 TO 6·0 MhZ
STATISTICAL FREQUENCY
10
5
0
0
100
200
300
400
500
600
700
800
HEIGHT - KM

FIG. 33


ABOVE 6·0 MhZ
20
10
0
STATISTICAL FREQUENCY
0
100
200
300
400
500
600
700
800
HEIGHT - KM

FIG·34

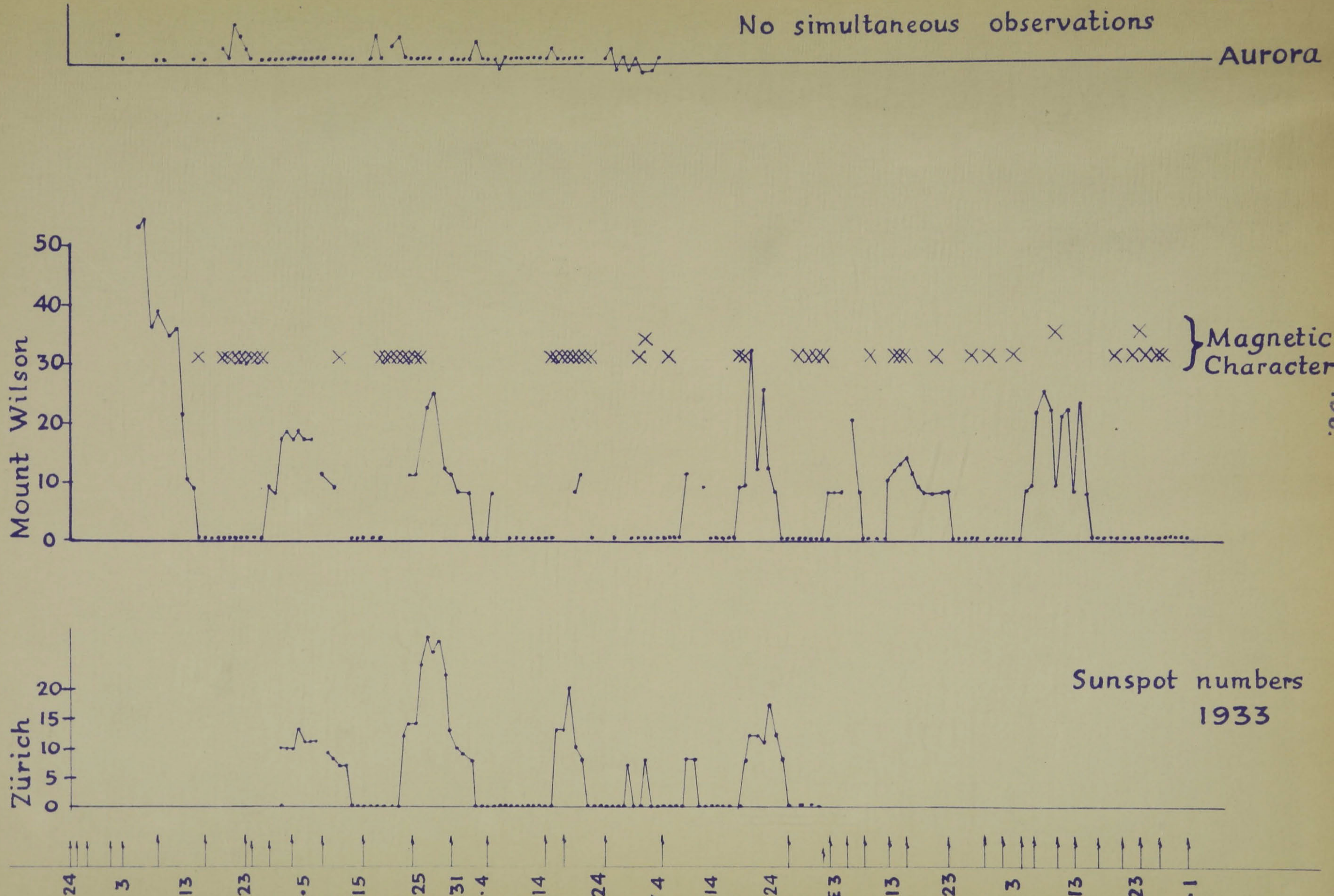

No simultaneous observations
Aurora
Mount Wilson
50
40
30
20
10
0
Magnetic Character
Zürich
20
15
10
5
0
Sunspot numbers
1933
JAN·24
FEB·3
13
23
MAR·5
15
25
31
APR·4
14
24
MAY 4
14
24
JUNE 3
13
23
JULY 3
13
23
AUG·1

FIG. 35