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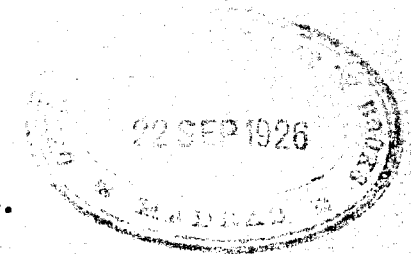
[Vol. 9B, Part II, pp. 9 to 19.]

JOURNAL

OF THE

Indian Institute of Science.

CONTENTS.



THE CHARACTERISTICS OF BEAM TRANSMITTING AERIALS.

BY

J. K. Catterson-Smith.

DR. M. O. FORSTER, F.R.S., CHAIRMAN OF EDITORIAL BOARD.

JOURNAL
OF THE
INDIAN INSTITUTE OF SCIENCE.

VOLUME I.—(1914-18)

Parts I-XXI.

VOLUME II.—(1918-19).

Parts I.-XV.

VOLUME III.—(1920).

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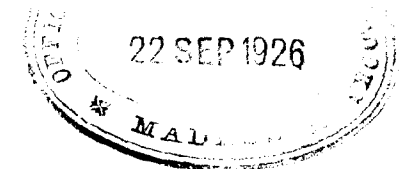
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THE CHARACTERISTICS OF BEAM TRANSMITTING AERIALS.

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THE CHARACTERISTICS OF BEAM TRANSMITTING AERIALS.

By J. K. Catterson-Smith.

22 SEP 1926

SYNOPSIS.

The phases of the components of the radiated field of multiple aerial systems are considered and polar distribution diagrams plotted. The production of a single beam with minor secondary rays is dealt with by means of examples. Cylindrical parabolic and plane reflectors of the double grid type are contrasted. Methods of reducing dispersion in both vertical and horizontal planes are considered.

INTRODUCTION.

The extensive experimental work carried out by C. S. Franklin and others of the Marconi Wireless Telegraph Company has resulted in the successful development of several new types of directive aerials. These possess features of considerable interest and promise of practical utility, especially in connection with ultra-short waves. The original sheet-metal reflectors of Hertz were replaced at an early date by vertical tuned wires arranged to form a cylindrical parabolic reflector at the focus of which the oscillator was placed. In this form the reflector gives a considerable degree of concentration in the desired direction and such systems have been utilised (Marconi, *J. Roy. Soc. Arts*, 1924, **72**, 607. C. S. Franklin, *J. Inst. Elec. Eng.*, 1923, **60**, 930).

The attainment of a beam by this means necessitates the use of a parabolic reflector which, having an aperture of several wavelengths, is consequently not altogether a simple structure excepting with wavelengths of the order of ten metres or less. Further, the whole of the power to be radiated must be supplied to the single oscillator at the focus of the reflector; this constitutes a drawback to the system for large powers.

A better arrangement of both radiator and reflector is the double grid form for the production of a single beam of exceedingly small dispersion. It is relatively simple to erect aerials of this type having, for instance, a width of ten wavelengths even for 100-metre wavelength transmission or reception. The whole of the radiation is then confined to within about six degrees on either side of the centre-line

of the beam. Thus it may be concluded the successful generation of beams has at last been accomplished and, unless the transmission from the beam stations now under construction reveals some unexpected phenomena, there is little doubt the majority of point-to-point transmissions of the future will be of the beam type.

POLAR DIAGRAMS AND DISPERSION.

The double grid aerial system comprises two rows of vertical conductors separated by one quarter wavelength. The front row forms the aerial grid supplied with equal in-phase currents, the conductors being spaced so that there is no resultant field in the plane of the conductors.

The whole of the radiation takes place on the two sides of the grid of wires. One half of this is reflected by the adjacent parallel row of reflector conductors, and the resultant field produced by the combined aerial and reflector currents is zero in all directions other than within a few degrees of normal to the aerial on the side opposite to the reflector.

Calculation of the directional properties or concentrating power of the grids does not present any difficulties, but it may nevertheless be of interest to examine the more important cases in some detail.

In the first place the case of a neighbouring pair of identical simple vertical aeriels may be considered. It may be assumed that either aerial alone would set up a uniformly distributed field in all directions in the equatorial plane, taken to be the horizontal for present purposes. Also the field at any point may be taken as the resultant of the fields of individual aeriels with due respect to their phase relations at that point.

Then, as is well known, under certain conditions the resultant field will possess a certain degree of directive quality; that is, at a distance, great compared to the wavelength, the field will vary with the angle θ in Fig. 1 (a) between the receiver and the plane of the two aerial wires. The phase difference in the component fields depends upon the angle θ and the distance separating the two aeriels, and also upon the time-phase relation of the current in the two aeriels. The time phase difference due to the distance apart of the aeriels may be represented by $\phi = 2\pi \frac{d_1 \cos \theta}{\lambda}$ radians while that due to the current phase is represented by ψ .

The resultant field therefore has components the phase difference of which is $(\phi + \psi)$.

If E_1 be the component due to one aerial then the resultant will be given by

$$E_r = 2E_1 \cos \left[\frac{\phi + \psi}{2} \right] \quad (1)$$

Case I.—The resultant field when $\theta = 90^\circ$ or 270° (normal to AB on either side of the grid) is $n \cdot E_1$ where n is the number of aerial wires; but when $\theta = 0$ or 180° the resultant depends upon d_1/λ and E_r is zero when $n\phi$ is an odd multiple of π , that is when $d_1 = \lambda/2, 3\lambda/2$, etc.

Thus any number of aeriels carrying equal in-phase currents may be placed in line so as to radiate a maximum field normal to the plane of the aeriels and zero field along the plane of the aeriels.

The polar diagram given by equation (1) has double beam directive characteristics which improve as n is increased for a given value of the ratio d_1/λ that is as the width of the grid aerial is increased. This is shown in Fig. 1 (b) for $n = 2$, $\psi = 0$, and $d_1 = \lambda/2$.

The polar diagram for other values of n may be plotted as follows:—

(a) When n is an even number,

$$E_r = 2E_1 \left[\cos \frac{\phi}{2} + \cos \frac{3\phi}{2} + \cos \frac{5\phi}{2} + \dots \right] \quad (2)$$

taken to $\frac{n}{2}$ terms.

(b) When n is an odd number,

$$E_r = 2E_1 \left[\frac{1}{2} + \cos \phi + \cos 2\phi + \cos 3\phi + \dots \right] \quad (3)$$

taken to $\frac{n+1}{2}$ terms.

It is useful to denote the ratio of the resultant field at any angle to the maximum field at right angles, i.e., $E_r/n \cdot E_1$, as the 'beam concentration factor' or β , where E_1 is the field which would be produced by a single aerial with $1/n$ amperes.

In a grid aerial there will be $1/n$ amperes per wire each contributing E_1 to the resultant field.

This factor is a measure of the theoretical dispersion of the beam as θ changes from 0 to 90 degrees.

It follows from equations (2) and (3) that the beam concentration factor may be calculated from:—

$$\beta = \frac{2}{n} \left[\cos \frac{\phi}{2} + \cos \frac{3\phi}{2} + \cos \frac{5\phi}{2} + \dots \right] \quad (4)$$

when n is even, or

$$\beta = \frac{2}{n} \left[\frac{1}{2} + \cos \phi + \cos 2\phi + \cos 3\phi + \dots \right] \quad (5)$$

when n is odd.

The condition for $E_r = 0$ is that s must be zero, and for a beam of small dispersion this should occur at $\theta = 0.1$ or 0.2 radian.

*Case II (Current phases $\psi = 90^\circ$).—*The resultant field for two aerials with d_2 spacing changes its directive characteristics with changes in ψ .

Thus when $n = 2$ and $d_2 = \frac{\lambda}{4}$, if the current phase difference is

$\psi = \pm \frac{\pi}{2}$, the resultant field is zero in one direction along AB (i.e., $\theta = 0$ or 180 degrees) and equals $2E_1$ along the other direction Fig. 1 (c). The field is $\sqrt{2}E_1$ on each side ($\theta = 90^\circ$ or 270°) when d_2 exceeds $\lambda/4$.

Two aerials under these conditions give rise to a one-sided radiation but the wide angle dispersion limits its usefulness.

The combination of two rows of conductors such as $A_1 B_1, A_2 B_2, A_3 B_3$, etc., shown in plan in Fig. 2 (a) reduces the dispersion the greater the width of the grids relative to the wavelength.

A single beam of small dispersion is radiated to the left or right according to whether the current in the conductors $B_1 B_2 B_3$, etc., leads or lags by a quarter of a cycle to the current in the conductors $A_1 A_2 A_3$, etc., in Fig. 2 (a), the two rows being separated exactly one quarter of a wavelength.

REFLECTED WAVES AND REFLECTOR CURRENTS.

If instead of supplying two-phase current to the two rows of conductors the rear row, $B_1 B_2 B_3$, etc., are disconnected from the supply and tuned to the frequency of the aerial currents in $A_1 A_2 A_3$, etc., the former will reflect the left hand radiation from the latter group.

The fields due to the aerial currents $A_1 A_2 A_3$ and the reflected currents $B_1 B_2 B_3$ combine to give an amplitude in the direction $\theta = 0$ of $2nE_1$ provided the reflector grid is placed at $\lambda/4$ behind the aerial grid and tuned accurately.

The reflector conductors carry currents which differ in phase to the aerial current by $(\pi - 2\pi \cdot \frac{d_2}{\lambda})$ the first term on account of the reversal of the electric field at the reflecting surface, and the second term on account of its distance from the aerial.

Hence when the spacing is $d_2 = \lambda/4$ the current in the reflectors leads by one quarter of a cycle or $\pi/2$ radians.

It may be remarked that the magnetic field is reflected without reversal and the current in the reflector wires is an out-of-phase image of that in the aerial wires.

The reflected and direct rays combine and the resultant field due to the double grid is given by:—

$$E_r = 2 E_1 \cos \left[\frac{\pi}{4} (1 - \cos \theta) \right] \text{ for a pair of conductors, e.g., } A_1 \text{ and } B_1.$$

Thus $E_r = 2 E_1$ when $\theta = 0$ and has approximately this value up to about $\theta = 45^\circ$ as shown in Fig. 1 (c).

LINEAR COMBINATION OF AERIAL AND REFLECTOR WIRES.

Each unit consisting of one aerial and one reflecting conductor contributes $2E_1$ to the distant field along the centre line of the beam.

On either side of the centre line the field E_θ for a wide range of θ is $2 \times n \times E_1$ and the dispersion measured by the field E_θ at any angle θ is given by:—

$$\begin{aligned} E_\theta &= E_r \times \text{the beam concentration factor, or} \\ &= \beta \times 2 \cdot n \cdot E_1 \end{aligned} \quad (6)$$

where β is given by equations (4) or (5).

Example I. Narrow Aerial and Reflector (Fig. 2).—In the case of a double grid having $n = 4$, $d_1 = \frac{\lambda}{2}$ and $d_2 = \frac{\lambda}{4}$

the width of the aerial is $(n - 1) d_1 = \frac{3}{2} \lambda$,

the phase angle is $\phi = 2\pi \frac{d_1 \sin \theta}{\lambda} = \pi \sin \theta$, and

the current phase is $\psi = \frac{\pi}{2}$ leading

from which :—

$\theta = 0$ degrees	$\phi = 0$ radians	$\beta = 1.0$	Primary field.
15	0.815	0.63	
30	1.57	0	
45	2.22	-0.268	Secondary field.
60	2.73	-0.183	
75	3.04	-0.052	
90	3.14	0	

RADIATORS SEVERAL WAVELENGTHS WIDE.

The conclusions to be drawn from the foregoing are :—

(1) The amplitude of the distant field on the centre line of the beam is independent of the width of the radiator.

(2) The dispersion is reduced as the width, in terms of wavelength, is increased.

(3) The spacing of the aerial and reflector conductors, (d_1) must be made a small fraction of a wavelength if leakages or secondary fields are to be avoided. The amplitude of the secondary fields at various angles is usually small.

In order, therefore, to obtain a concentrated beam, the width of the aerial may for instance be made equal to ten wavelengths while the spacing of the wires (d_1) is reduced to one-eighth of a wavelength.

BEAM CONCENTRATION FACTOR FOR LARGE VALUES OF 'n'.

The resultant of a large number of vectors each displaced by equal angles (ϕ) is given by the chord of the circular arc subtended by

the angle $n\phi$; the length of the arc is nE_1 . Hence the beam concentration factor, is given by :—

$$\beta = \frac{\text{chord}}{\text{arc}} = \frac{\sin \frac{n\phi}{2}}{\frac{n\phi}{2}} \text{ where } \phi = 2\pi \frac{d_1}{\lambda} \sin \theta \text{ radians, and at any}$$

angle θ from the centre line of the beam the dispersion field is

$$E_d = \beta \times 2n \cdot E_1 \quad (7).$$

ANGLE OF DISPERSION.

For present purposes this may be defined as the angle on either side of the centre line of the beam at which the field becomes zero, or θ when $E_d = 0$. This occurs when $n \times \phi = 2\pi$ or any even multiple. (8).

Example II. Wide Aerial and Reflector.—A double grid system about ten wavelengths wide has 80 aerial wires spaced $d_1 = \lambda/8$ in both aerial and reflector which are one quarter wavelength apart.

From (7) and (8) the angle of dispersion is given by :—

$$\theta = \arcsin \frac{\lambda}{nd_1} = \arcsin \frac{8}{80} = 5^\circ 45'.$$

The field distribution is plotted for this aerial in Fig. 3 from equation No. 7, for which figures are given below :—

TABLE I.

$n = 80$, $d_1 = \lambda/8$, and $d_2 = \lambda/4$.

θ degs.	$\sin \theta$	ϕ radian	$\frac{n\phi}{2}$ radian	β
0	0	0	0	1.00
2½	0.044	0.0349	1.40	0.700
5	0.087	0.0683	2.73	0.143
7½	0.130	0.102	4.08	-0.186
10	0.174	0.137	5.48	-0.130
15	0.259	0.204	8.16	+0.038
20	0.342	0.268	11.7	-0.083
25	0.423	0.332	13.3	+0.0483
30	0.500	0.392	15.7	0
45	0.707	0.555	22.2	-0.008
60	0.87	0.68	27.0	+0.032
75	0.97	0.76	30.0	-0.028
90	1.00	0.78	31.4	0

Note.—The function $\frac{\sin \theta}{\theta}$ has been termed 'cursin θ ' by Silvanus P. Thompson who gave some values for it in *J. Inst. Elec. Eng.*, 1915, 53, 240.

Experimental data relating to such small dispersions have not yet been published, but there appears no reason for doubting the practical possibilities of high degrees of concentration in one plane with wavelengths up to about 100 metres.

REFLECTORS OF CYLINDRICAL PARABOLIC FORM

The oscillator A is placed at the focus as shown in Fig. 4 distant $\lambda/4$ from the reflector apex conductor O in which the current leads by 90 degrees. The current in the reflector conductors at B, distant $\lambda/2$, is in-phase with the oscillator current and the reflector current beyond this point has a lagging or leading phase according to the distance.

If the reflector is to confine the radiation within an angle of dispersion θ its size is determined by:—

$$\text{Aperture} = \frac{\lambda}{2} + \left(\frac{1}{\sin \theta} - \frac{1}{\tan \theta} \right) \quad (9).$$

For instance, if the dispersion is not to exceed 15 degrees on either side of the centre-line the aperture must be 3.85 wavelengths. The aperture increases rapidly with the concentration.

C. S. Franklin has published (*J. Inst. Elec. Eng.*, 1922, 60, 933) polar diagrams of his observations made with 4.28 metre wavelengths for a reflector of 2.57 aperture etc., measured at four miles, which are in close agreement with the calculated field distribution.

This type of reflector appears more suitable for very short waves and moderate distances of transmission whereas the double grid plane reflector lends itself to great concentration of the beam for wavelengths up to 100 metres and the greatest distances. The reflector aperture required for a dispersion of only $5^\circ 45'$ works out from equation (9) as ninety-seven wavelengths compared with a plane reflector (see p. 15) which is ten wavelengths wide.

CONCENTRATION IN THE VERTICAL PLANE.

The aerial conductors must be supplied with equal currents and for this purpose feeder circuits have been developed by the Marconi Wireless Telegraph Company (*Ind. Pat. Spec.*, No. 10,420 and No. 10,421, 1924) which show vertical wires of $\lambda/3$ length spaced $\lambda/8$ as practical dimensions.

The wires being connected in parallel along top and bottom and fed at points along the base separated preferably by $\lambda/2$.

This patent discloses the use of two or more tiers of such grids with electrostatic coupling and giving an in-phase current distribution all over the units forming the grid.

In this way aërials and reflectors may be built with an area of several square wavelengths radiating energy substantially in one direction only. Combined with similar plane reflector receiving aërials it is claimed that a great magnification of the received signals results.

Aërials of one or more wavelengths in height give rise to a concentration in the vertical plane as will be examined for the case of a type, of more recent date, developed for this class of transmitter.

THE MARCONI BEAM AERIAL.

Ind. Pat. Spec., No. 11,543, 1925: Marconi Wireless Telegraph Company, divulges means whereby grid aërials may be made to carry stationary waves of current of the same phase at all points. By this means extreme sharpness of concentration of the field in the vertical, as well as in the horizontal, plane becomes possible and a beam of small solid angular dispersion obtained.

Referring to Fig. 5 which represents a simple oscillator, with current distribution as indicated by the sine curve, the polar distribution of the field in the plane of the oscillator is approximately;—

$$E = E_m \cos \theta'.$$

The same effect would be produced if the oscillator were replaced by an aerial one half a wavelength long excited at its base by capacity coupling in the ordinary manner.

If now the applied frequency be raised until the aerial is one wavelength long the stationary waves of current take the form of two loops; maximum amplitude occurring at $\frac{1}{4}$ and $\frac{3}{4}$ wavelength up the conductor. In this case there can be no field at right angles to the aerial on account of the phase opposition of the currents in the two loops; on the other hand radiation at about 45° and 135° all round the aerial will take place.

On raising the applied frequency still higher a condition will be reached when three loops of current form, the maxima occurring at $\frac{1}{4}$, $\frac{3}{4}$ and $1\frac{1}{4}$ wavelengths from the base. The aerial is then $1\frac{1}{2}$ wavelengths in height and the phase of the current loops at the $\frac{1}{4}$ and $1\frac{1}{4}$ points will be the same and opposite to that at the $\frac{3}{4}$ -point. The polar

diagram for the radiated field will become a six-loop figure, as shown in Fig. 6, and it is clear that for m loops of current there will be $2m$ loops in the polar diagram.

If by some means the radiation from alternate current loops such as AB, Fig. 6, be suppressed, the polar diagram reduces from $2m$ to 2 loops only, and a high degree of sharpness obtained as m is increased.

The patent referred to secures this condition, at least approximately, by forming the portions, such as AB in Fig. 6, so as to annul the radiation therefrom. This is accomplished by either doubling that part of the aerial wire back on itself or by replacing it with reactive coils, etc.

The phase of the current in the remaining portions of the long aerial is substantially the same throughout and the effect of the loops is additive at right angles to the aerial. This is indicated in Fig. 7 which is drawn for an aerial of vertical height $\frac{4\lambda}{2}$ carrying four current loops of the same phase and three current loops on the non-radiating portions.

The concentration in the vertical plane for a grid of such aerial conductors may be calculated in the manner already given for the horizontal concentration.

The angle of dispersion in the vertical plane is given approximately by equation (8); thus for m current loops,

$$m\phi = 2\pi \text{ or } \phi = \frac{2\pi}{m}$$

$$\text{also } \phi = \pi \sin \theta'$$

$$\text{hence } \theta' = \arcsin \frac{2}{m}$$

Thus when m has the value given in the first column of Table II the corresponding vertical dispersion is given in column three.

TABLE II.

Without Reflector.

m	$\frac{2}{m}$	VERTICAL DISPERSION
		Degrees and minutes
2	1.00	90° 0'
3	0.67	41° 45'
4	0.50	30° 0'
5	0.40	23° 30'
6	0.33	19° 30'
7	0.286	16° 35'
8	0.25	14° 30'
10	0.20	11° 30'
20	0.10	5° 45' = (10 λ high)

From this it is seen that a plane reflector grid 10λ wide and 10λ high should produce a single beam concentrated within 5° 45' of its centre line both vertically and horizontally.

A wide field for research is opened in connection with short wave reflectors giving such concentrated rays, the future applications of which appear unlimited.

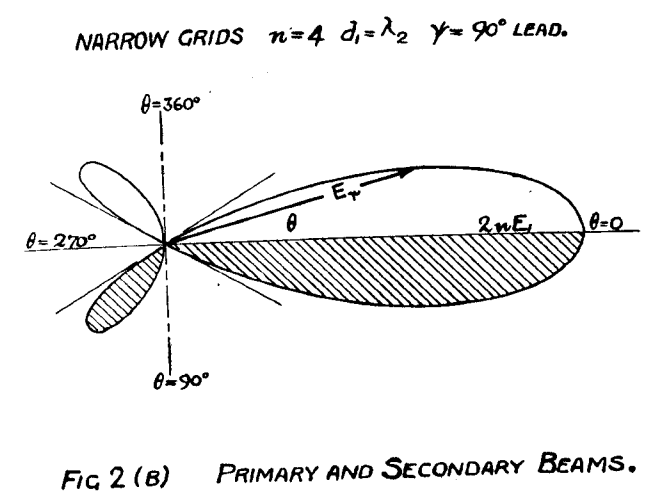
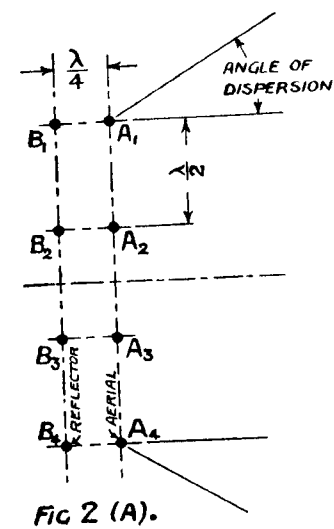
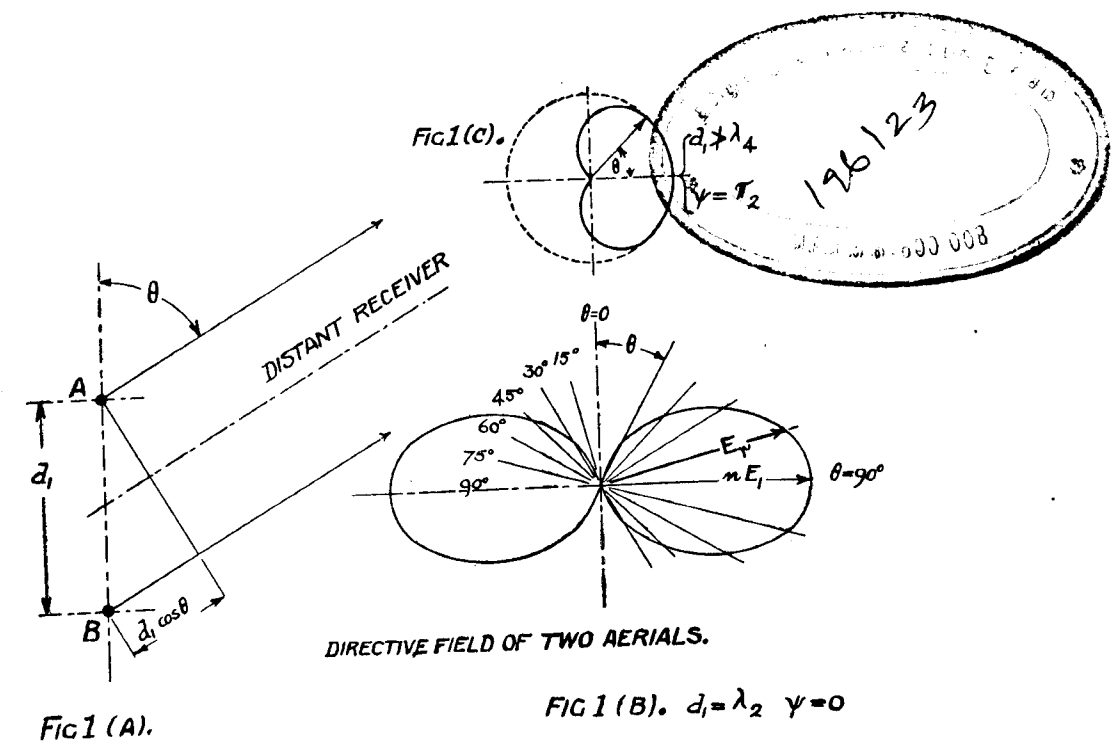
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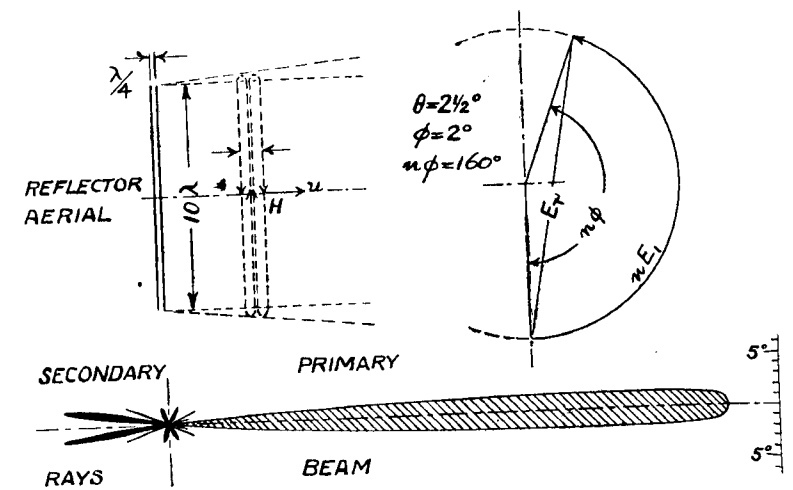
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[Accepted, 1-7-26.]

PRINTED AND PUBLISHED
BY GEORGE KENNETH AT THE DIOCESAN PRESS
POST BOX 455, MADRAS-1926. C13108





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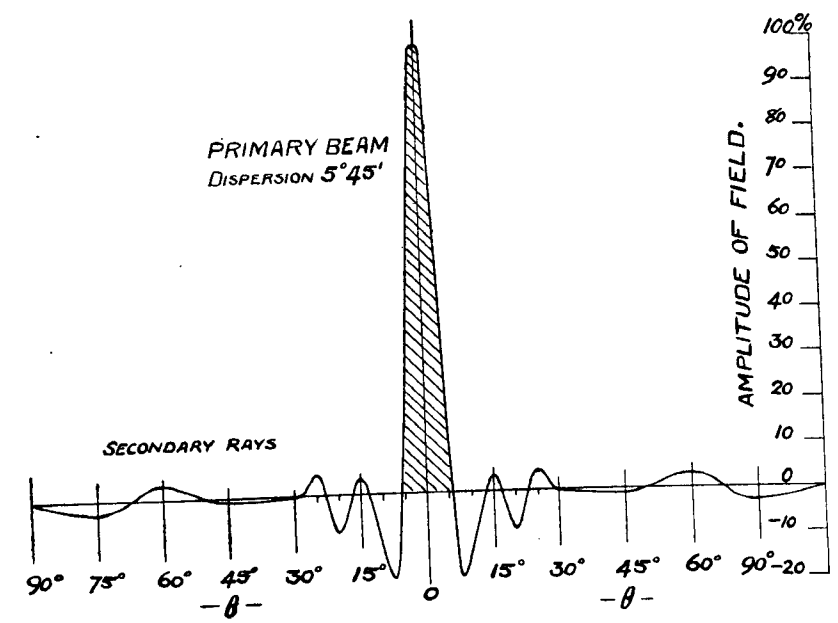


FIG 3 AERIAL AND REFLECTOR (10-WAVELENGTH).

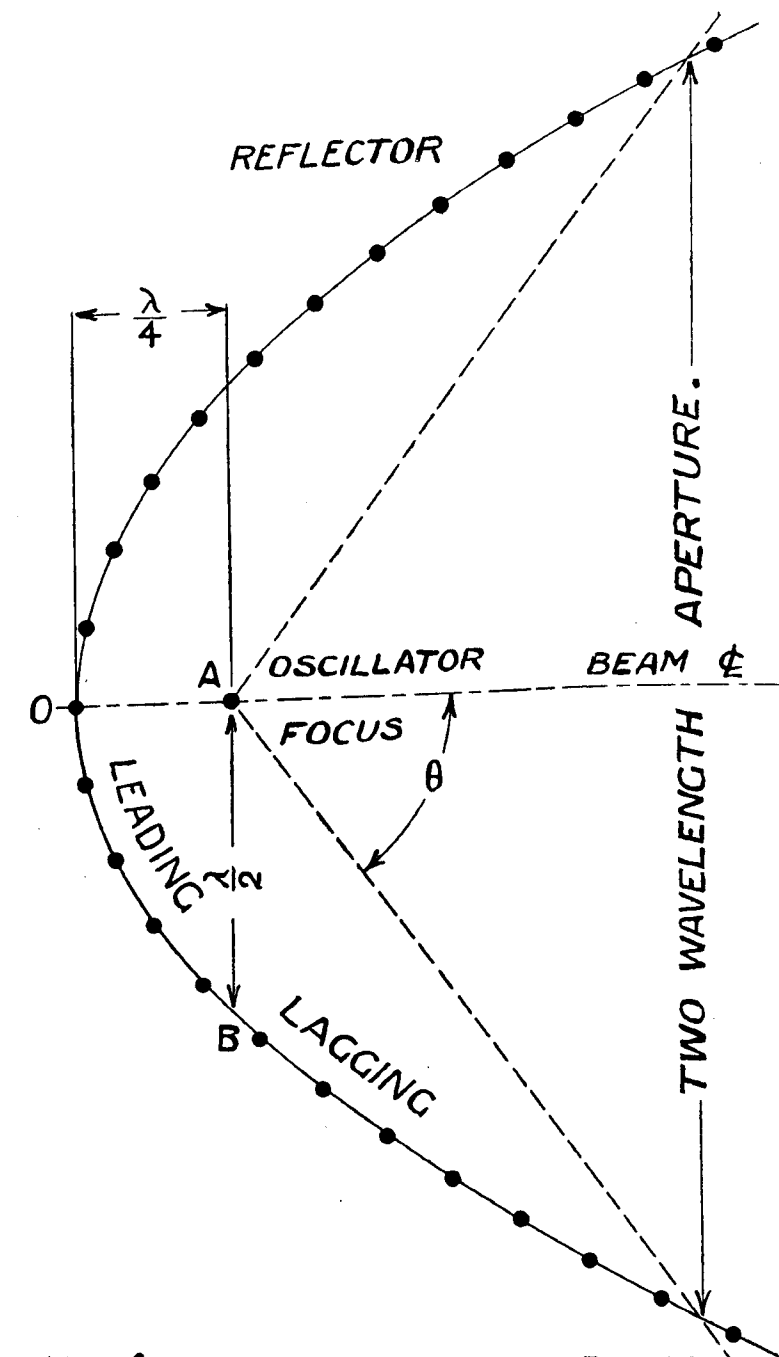


FIG 4. CYLINDRICAL PARABOLIC REFLECTOR.

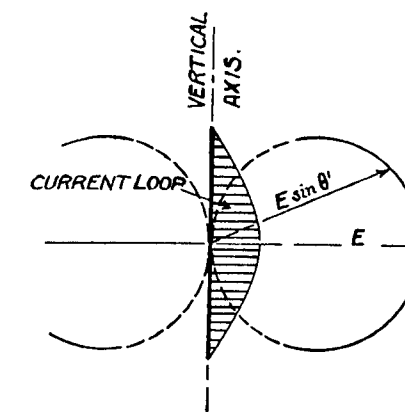


FIG 5. VERTICAL FIELD.

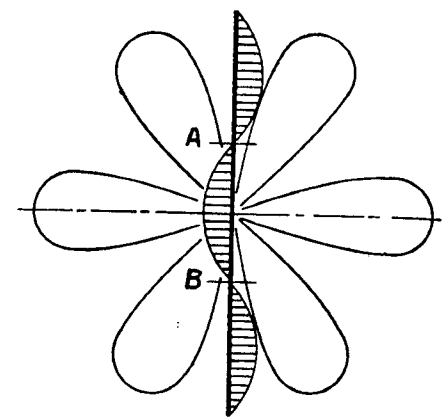


FIG 6.

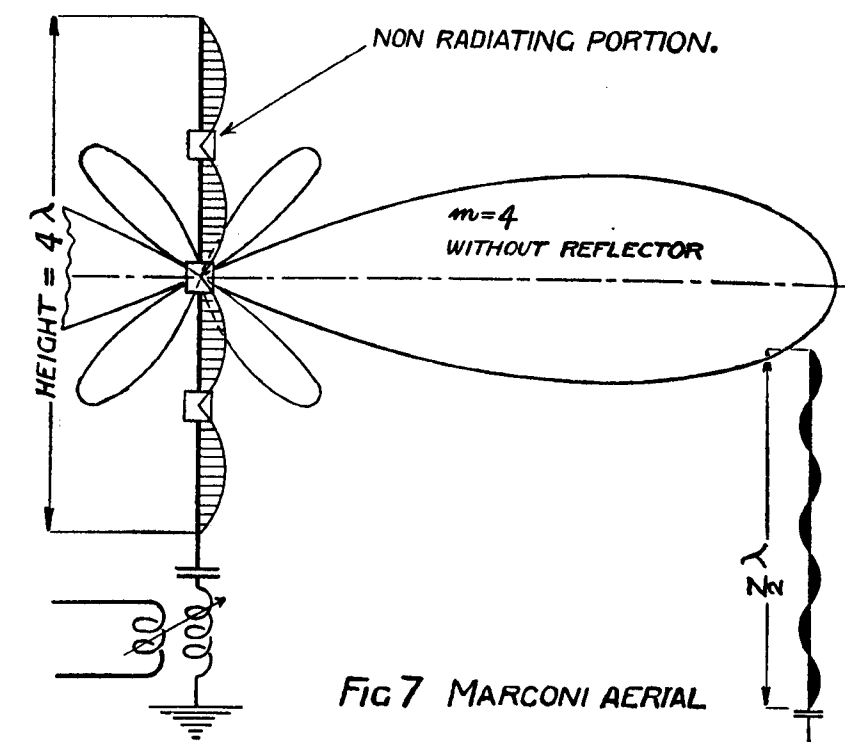
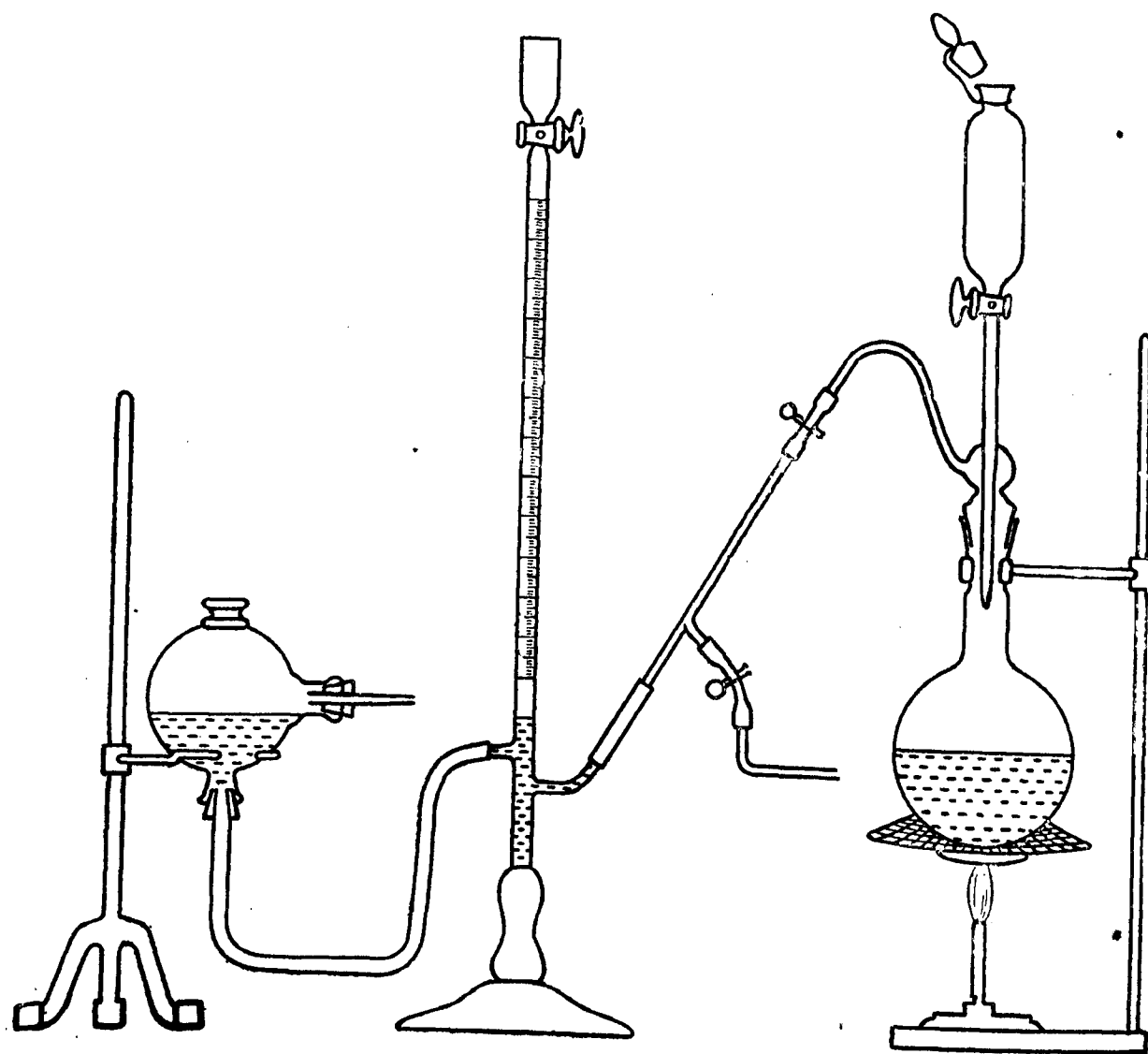


FIG 7 MARCONI AERIAL



about 400 c.c. was used in all. The extract was made alkaline with lime and evaporated to dryness in vacuum at $40-45^{\circ}$, the residue being dissolved in hot water, transferred to a 1000 c.c. measuring flask, treated with lead acetate and made up to 1000 c.c. After the precipitate had settled, the solution was decanted into a filter and 200 c.c. portions of the perfectly clear filtrate used each time for the estimation of nitrate nitrogen. The apparatus (see figure) included a 250 c.c. ground stoppered wash bottle in which the long tube was cut about 6 cm. below the neck and drawn to a capillary opening, a 50 c.c. separating funnel being fused on to the other end. The delivery tube was connected to a nitrometer through a T-piece by means of thick-walled rubber tubing; pinchcocks were used at the places indicated. The joint at the neck of the reaction flask escapes attack by the concentrated hydrochloric acid, and was ground with emery to make it perfectly air-tight; the length of the ground contact being about 5 cm., the pressure developed by steam during manipulation does not push up the stopper. The nitrometer was filled with 50 per cent. caustic alkali. The solution to be analysed for nitrate was concentrated in the flask to about 25 c.c., air in the apparatus being thus displaced by steam. After cooling, 25 c.c. of ferrous chloride solution (prepared by treating 400 g. of iron nails with a litre of concentrated hydrochloric acid) followed by 25 c.c. of concentrated hydrochloric acid was sucked through the separating funnel. The liberated nitric oxide was transferred to the nitrometer by alternate boiling and cooling of the mixture in the flask. The volume of nitric oxide collected in the nitrometer was measured at room temperature and pressure. Blank determinations were made with reagents alone. The blank value which came up to 0.05 c.c. after correcting the volume to N.T.P. was subtracted from the N.T.P. value of the nitrometer reading, and this figure was taken to represent the actual volume of nitric oxide evolved. The nitrate content in 0.2 per cent. potassium nitrate solution was also estimated, the results agreeing within 1 per cent. of the theoretical value.

The Ragihalli samples contained very small quantities of nitrate nitrogen, and accordingly the colorimetric method of estimation was used. The clear filtrate prepared as above (100 c.c.) was evaporated to dryness in a porcelain dish, treated with 1 c.c. of phenoldisulphonic acid, leached with water and then transferred to a Nessler's tube; 1 c.c. of 4 *N* potassium hydroxide was then added, and the volume made up to 50 c.c. The yellow tint was compared with that produced by a standard solution of potassium nitrate containing 0.01 mg. of nitrate nitrogen per c.c. of the solution. The data represented in Table IV (series 3) are the mean of more than one individual determination.

Nitrite Nitrogen.—The clear solution prepared for the nitrate determination (50 c.c.) was placed in a Nessler's tube to which was

added 1 c.c. of 1 per cent. sulphanilic acid and 1 c.c. of α -naphthylamine acetate. The volume was made up to 100 c.c. and the pink colour compared with that produced by a standard solution of sodium nitrite containing 0.01 mg. of nitrite nitrogen per c.c. The results are represented in Table IV (series 4).

Ammonia Nitrogen.—Ammonia nitrogen in the sandal leaves was estimated according to Grafe's method (Grafe and Erich, *Zeits. Physiol. Chem.*, 1906, **48**, 300). The leaf powder (10 g.) was placed in a 500 c.c. Claisen flask and washed down with 25 c.c. of ammonia-free distilled water, 25 c.c. of saturated sodium chloride solution and 12.5 c.c. of alcohol. The flask was then connected to a one litre filter-flask containing 40 c.c. of 0.05 *N* sulphuric acid to absorb the ammonia, and cooled in ice: saturated sodium carbonate solution (12.5 c.c.) was then added and the mixture distilled under reduced pressure (15 mm.) on a water bath at 42–44°. After 6 hours of distillation, the acid in the filter flask was back titrated against standard alkali. The ammonia found by this method was taken to represent the free ammonia in the aqueous leaf extract, and the values are represented in Table IV (series 6).

Water-soluble Nitrogen.—The determination of the distribution of water-soluble nitrogen was made according to Hausmann's method (Hausmann and Walther, *Zeits. Physiol. Chem.*, 1899, **27**, 95; Osborne and Harris, *J. Amer. Chem. Soc.*, 1903, **25**, 323) and as applied to the spinach materials by Jodidi and co-workers (Jodidi, Kellogg and True, *J. Agric. Research*, 1918, **15**, 385). The method of extracting the water-soluble nitrogen as well as the methods of determining the various nitrogenous constituents (amide, humin, basic, etc.) were strictly those detailed in the above paper, and a description of the methods will therefore not be attempted here. The amino-nitrogen in the water-soluble extract, however, as well as the mono-amino-nitrogen and the peptide nitrogen were determined according to the method of Van Slyke (*J. Biol. Chem.*, 1911, **9**, 185 and 1912, **12**, 275).

The results obtained by these methods are summarised in Table II, and are expressed as percentages on the weight of the moisture-free material. Table III expresses the same results as percentages of the total water-soluble nitrogen. Column I (Table II) gives the total water-soluble nitrogen as obtained by the digestion of 20 c.c. of the water-extract with sulphuric acid according to the method of Kjeldahl; and therefore the value of the total water-soluble nitrogen is possibly less by the amount of nitrate and nitrite nitrogen. Column 6 (Table II) gives the results of the mono-amino-nitrogen determinations made

according to the method of Van Slyke on 10 c.c. aliquots of the 100 c.c. of non-basic extract. The filtrate, after removing the phosphotungstic acid precipitate of basic nitrogen, was freed from excess of phosphotungstic acid by means of baryta, excess of which was removed by means of carbon dioxide. The filtrate was then concentrated, made up to 100 c.c. and was characterised as the non-basic extract. Column 7 (Table II) gives the difference between the total non-basic nitrogen (as determined by the Kjeldahl's method on 20 c.c. portions of the non-basic extract) and the mono-amino-nitrogen in column 6: and this is characterised as the non-amino-nitrogen in the non-basic extract. The difference between the amino-nitrogen found in 10 c.c. of the 100 c.c. of peptide extract and in a similar aliquot of the water-soluble extract gives the peptide nitrogen; the values are recorded in column 8 (Table II). The peptide extract was obtained by adding concentrated hydrochloric acid (20 per cent.) to 100 c.c. of the water extract and then hydrolysing the mixture for 8 hours. After removing the amide and humin nitrogen, the filtrate after concentration was made up to 100 c.c. and represented the peptide extract.

TABLE I.

*Percentage total nitrogen in the sandal leaves
on the moisture-free basis.*

No.	Sample	Healthy	Diseased
1	Ragihalli, 15-8-28 ...	1.733	2.052
2	Uttarahalli, 12-9-28 ...	3.318	3.030
3	Ragihalli, 15-2-29 ...	1.416	2.261

DISCUSSION OF RESULTS.

Table I shows that in the three sets of samples analysed, the total nitrogen of diseased leaves from Ragihalli is higher than that of the healthy leaves from the same area. The healthy leaves from the Uttarahalli area have a higher percentage of total nitrogen, obviously due to the association of a richly leguminous host with the sandal from which the samples were derived. This is an observation which has been confirmed by numerous analyses and is one of vital importance in the choice of samples for analysis. Uttarahalli samples always show a higher nitrogen content than the Ragihalli samples, which, as already shown, is attributable to the fact that, in the Uttarahalli area,

TABLE II.
Nitrogen distribution in the water-soluble portion expressed in percentages of the oven-dried sandal leaves (on the moisture-free basis).

No.	Material and date of collection	Treatment HCl per cent.	1	2	3	4	5	6	7	8
			Total water-sol. N	Ammonia N	Amide N	Humins N	Basic N	Mono- amino N	Non- amino in non-basic extract	Peptide N
1	Uttarahalli, 12-9-28 Healthy	20 for $\frac{1}{2}$ hr.	0.935	0.013	0.073	0.121	0.236	0.163	0.467	...
2	" " "	4 for 2 hrs.	0.935	0.013	?	0.118	0.214	0.110	0.501	...
3	" " "	20 for 8 hrs.	0.935	0.013	0.066	0.114	...	...	...	0.008
4	" " Diseased	20 for $\frac{1}{2}$ hr.	1.167	0.015	0.033	0.160	0.291	0.158	0.520	...
5	" " "	4 for 2 hrs.	1.167	0.015	0.030	0.167	0.306	0.111	0.586	...
6	" " "	20 for 8 hrs.	1.167	0.015	0.043	0.167	...	...	...	0.000
7	Ragihalli, 15-2-29 Healthy	20 for $\frac{1}{2}$ hr.	0.460	0.005	0.022	0.211	0.048	0.043	0.124	...
8	" " "	4 for 2 hrs.	0.460	0.005	0.020	0.166	0.046	0.042	0.177	...
9	" " "	20 for 8 hrs.	0.460	0.005	0.021	0.209	...	...	...	0.002
10	" " Diseased	20 for $\frac{1}{2}$ hr.	0.988	0.009	0.057	0.200	0.172	0.044	0.521	...
11	" " "	4 for 2 hrs.	0.988	0.009	0.055	0.177	0.179	0.034	0.593	...
12	" " "	20 for 8 hrs.	0.988	0.009	0.056	0.209	...	...	...	0.000

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TABLE III.

Distribution of water-soluble nitrogen expressed in percentage of the total soluble nitrogen.

No.	Material and date of collection	Treatment: HCl per cent.	1	2	3	4	5	6	7	8
			Total water-sol. N	Ammonia N	Amide N	Humins N	Basic N	Mono- amino N	Non- amino in non-basic extract	Peptide N
1	Uttarahalli, 12-9-28. Healthy	20 for $\frac{1}{2}$ hr.	100	1.390	7.81	12.9	25.2	17.4	49.9	...
2	" " "	4 for 2 hrs.	100	1.390	?	12.6	22.9	11.8	53.6	...
3	" " "	20 for 8 hrs.	100	1.390	7.06	12.2	...	...	...	0.856
4	" " Diseased.	20 for $\frac{1}{2}$ hr.	100	1.290	2.83	13.7	24.9	13.5	44.6	...
5	" " "	4 for 2 hrs.	100	1.290	2.57	14.3	26.2	9.51	50.2	...
6	" " "	20 for 8 hrs.	100	1.290	3.68	14.3	...	...	...	0.000
7	Ragihalli, 15-2-29. Healthy	20 for $\frac{1}{2}$ hr.	100	1.090	4.78	45.9	10.4	9.35	27.0	...
8	" " "	4 for 2 hrs.	100	1.090	4.35	36.1	10.0	9.13	38.5	...
9	" " "	20 for 8 hrs.	100	1.090	4.57	45.4	...	...	...	0.435
10	" " Diseased.	20 for $\frac{1}{2}$ hr.	100	0.911	5.77	20.2	17.4	4.45	52.7	...
11	" " "	4 for 2 hrs.	100	0.911	5.57	17.9	18.1	3.44	60.0	...
12	" " "	20 for 8 hrs.	100	0.911	5.67	21.2	...	...	...	0.000

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TABLE IV.
Nitrogen distribution in the sandal leaves.

No.	Form of nitrogen	UTTARAHALLI SAMPLES, 12-9-28				RAGIHALLI SAMPLES, 15-2-1929			
		Percentage of the oven dry material (on the moisture-free basis)		Percentage of total nitrogen		Percentage of the oven dry material (on the moisture-free basis)		Percentage of total nitrogen	
		Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
1	Total	3.318	3.030	100	100	1.416	2.261	100	100
2	Protein	2.038	1.690	61.42	55.78	0.981	1.235	69.28	55.89
3	Nitrate	0.234	0.056	7.053	1.848	0.004	0.001	0.283	0.044
4	Nitrite	0.003	0.001	0.090	0.035	0.0001	0.000	0.007	0.000
5	Total water-soluble	0.935	1.167	28.18	38.52	0.460	0.988	32.49	43.70
6	Ammonia	0.013	0.015	0.392	0.495	0.005	0.009	0.353	0.358
7	Amide	0.070	0.032	2.11	1.056	0.021	0.056	1.483	2.477
8	Total amino	0.275	0.377	8.288	12.44	0.076	0.143	5.367	6.325
9	Humin	0.118	0.165	3.556	5.446	0.210	0.205	14.830	9.067
10	Basic	0.225	0.299	6.781	9.868	0.047	0.176	3.319	7.784
11	Peptide	0.008	0.000	0.241	0.000	0.002	0.000	0.141	0.000

sandals are to be found in the midst of luxuriant and leguminous hosts aided by cultivation. The Ragihalli sandals do not have these advantages, the soil is barren and rocky, leguminous hosts are rare, and there is no cultivation. It is pertinent to reiterate that the composition of the parasitic sandal will vary with the nature of the associated host-plants and that the results of one area cannot be compared with those of another whose ecological environment is widely different.

However, the higher nitrogen-content generally found in the diseased tissues of sandal is in strange contrast with the usually lower percentages of nitrogen found in the diseased tissues of spinach blight, tobacco mosaic, curly top of sugar-beet, etc. The accumulation of the extra nitrogen in the leaves with the onset of spike disease is possibly due to one of the following factors:—(1) Abnormal distribution of the constituents due to unbalanced translocation, (2) Selective absorption of nitrogenous components from the host or soil or both by the sandal in its pathological state, and (3) The infective principle responsible for causing the disease being possibly a nitrogen-fixer.

An examination of Table IV (series 2), reveals that the protein content (as determined by Stutzer's method) is higher in the healthy than in the diseased leaves for both the areas when calculated as percentage of the total nitrogen. There seems to be a remarkable tendency in the plant to maintain an equilibrium between the total nitrogen and the protein nitrogen, an increase in the total nitrogen being followed by a corresponding increase in the protein nitrogen. In the diseased leaves also, the same phenomenon is noticeable, although the ratio of protein nitrogen to total nitrogen is less than that in the case of the healthy plants, due probably to the degradation of the proteins. The higher proteoclastic activity exhibited by the diseased tissues and the higher content of the total water-soluble nitrogen also testify to the above assumption. This higher content of the water-soluble nitrogen and the ratio of the protein to the water-soluble nitrogen given below, may well be marked as characteristics of the disease.

Ratio of the protein to the water-soluble nitrogen of leaves.

	Healthy	Spiked
Uttarahalli	2.18	1.44
Ragihalli	2.13	1.19

Reviewing the distribution of water-soluble nitrogen, we find that the humin nitrogen calculated as percentage of the dry-weight material (Table III, column 4) is not significant.

The nitrate-content of spiked leaves is strikingly low and possibly points to the poor absorption of the nitrates from the host or the soil, in view of the fact that in the diseased condition sandal loses its haustorial connections and root-ends.

Basic nitrogen is present in greater quantities in the diseased than in healthy samples for both areas, when calculated both in terms of water-soluble nitrogen and of moisture-free material. This seems to be a distinguishing characteristic of the disease.

Examination of Table II (column 6) shows that the value of mono-amino-nitrogen fluctuates according to the concentration of hydrochloric acid used in hydrolysing the water-soluble extract. The solution treated with 4 per cent. hydrochloric acid for 2 hours contains always a lower percentage of mono-amino-nitrogen than that treated with 20 per cent. hydrochloric acid for $\frac{1}{2}$ hour. This fact goes hand in hand with the observation that when the solution is treated with 4 per cent. hydrochloric acid for 2 hours there is present in the non-basic portion a greater quantity of non-amino-nitrogen than when the solution is treated with 20 per cent. hydrochloric acid for $\frac{1}{2}$ hour. The values represented in Table II (column 6) cannot, however, be taken to represent the true amount of mono-amino-nitrogen in the samples, because it has been proved that a part at least of the humin nitrogen is formed at the expense of the mono-amino-acids while boiling with hydrochloric acid (Hart and Bentley, *J. Biol. Chem.*, 1915, **22**, 477; Roxas, *J. Biol. Chem.*, 1916, **27**, 71).

An examination of Table IV reveals that the total amino-nitrogen is greater in the spiked than in the diseased plant for both areas, whether expressed as percentage of the dry-weight material or as percentage of the total nitrogen. This increase in amino-nitrogen seems to be another characteristic of the disease, indicating proteoclastic degradation of proteins in the leaf.

SUMMARY.

1. The total nitrogen in spiked leaves is generally greater than in healthy leaves, and the total nitrogen-content varies with the locality.

2. As physiological characteristics of the disease there may be put forward an increase in (1) total water-soluble nitrogen, (2) basic nitrogen, and (3) total amino-nitrogen, and a decrease in the nitrate nitrogen in the diseased leaves, both in reference to the dry-weight of the leaves and in reference to the total nitrogen.

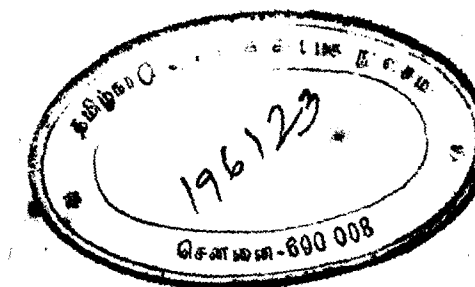
3. The lower content of protein nitrogen (with reference to the total nitrogen) taken along with the lower content of the polypeptide nitrogen and increase in amino- and water-soluble nitrogen seems strongly to indicate a proteoclastic degradation of the proteins proceeding in the diseased leaves.

4. A detailed investigation of the basic constituents has been undertaken and the work will be extended to an examination of the stems and roots of sandal.

In conclusion, we wish to express our grateful thanks to Professor Roland V. Norris for his many helpful criticisms and the keen interest he has evinced throughout this work.

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[Accepted, 7-8-29.]



Am 2, 2/14
226-98-2

PRINTED AND PUBLISHED
BY GEORGE KENNETH AT THE DIOCESAN PRESS,
POST BOX 455, MADRAS-1929. C8921.

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