WS No. 19 Mark III

RHOMBIC AERIALS

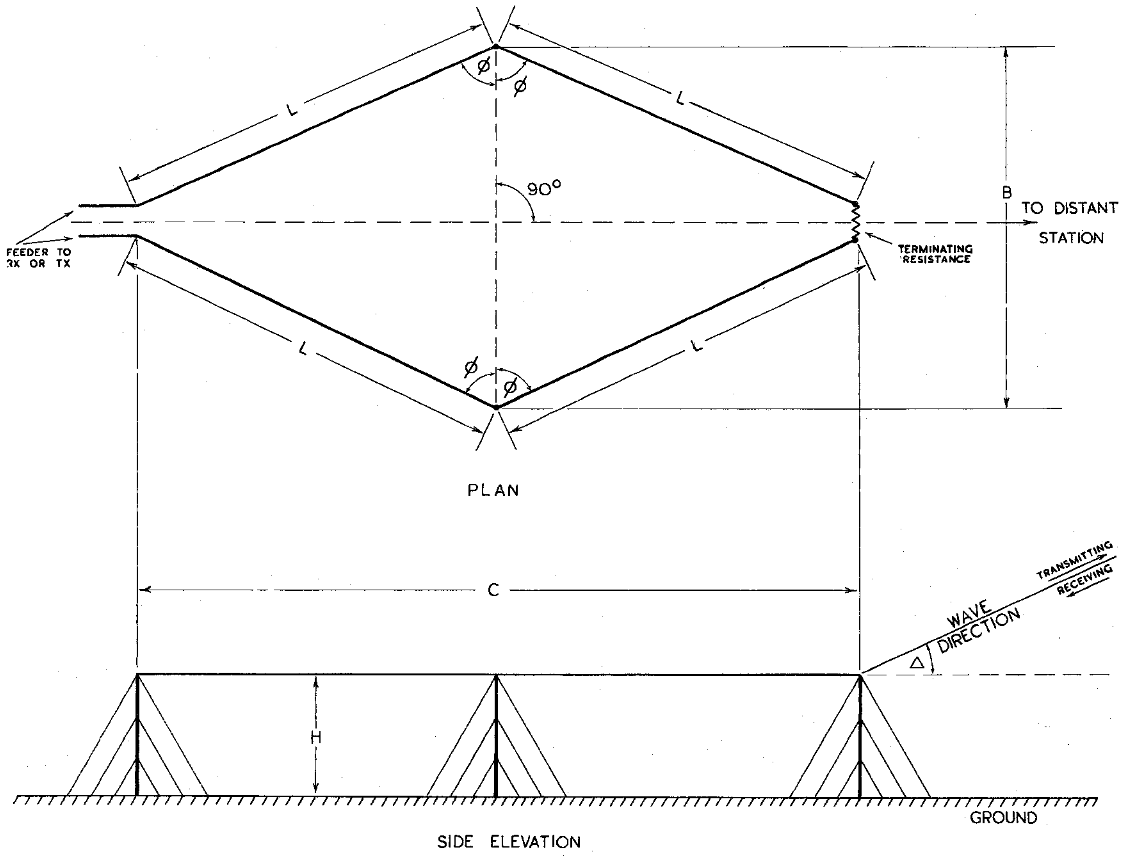
Design information

Notes: 1. This EMER has been redesignated from Tels A 344/1. Pages 1 and 2, Issue 2, show the new numbers and they supersede these Pages of Issue 1, dated 12 Mar 1946. The designation on Pages 3 to 6 and Pages 1001 to 1010 are to be amended to Tels A 346.

2. This information is provisional and is supplied for guidance pending the issue of more complete instructions. All errors of a technical nature should be notified in accordance with Tels. A 009.

Introduction

1. This information is provided to permit rhombic aerials to be designed as required. If a rhombic aerial is required quickly, the standard design (para. 9(c) and Figs. 1001 - 1005) should be used.



KEY

△ = WAVE ANGLE (ANGLE OF ELEVATION AT WHICH MOST RADIATION IS TRANSMITTED OR RECEIVED)
Ø = TILT ANGLE (THE HALF INTERIOR ANGLE OF THE RHOMBUS)
L = SIDE LENGTH OF THE RHOMBUS
H = HEIGHT OF THE RHOMBUS ABOVE GROUND
B = LENGTH OF THE RHOMBUS DIAGONAL AT RIGHT-ANGLES TO THE DIRECTION OF THE DISTANT STATION
C = LENGTH OF THE RHOMBUS DIAGONAL LYING IN THE DIRECTION OF THE DISTANT STATION

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Fig. 1 - Rhombic aerial

Brief description

2. The rhombic or Bruce Diamond aerial is a highly directive aerial used for long-distance, point-to-point communications. It is a development of the horizontal V aerial and consists of four straight sides of equal length, laid out in the form of a rhombus in a horizontal plane (see Fig. 1).

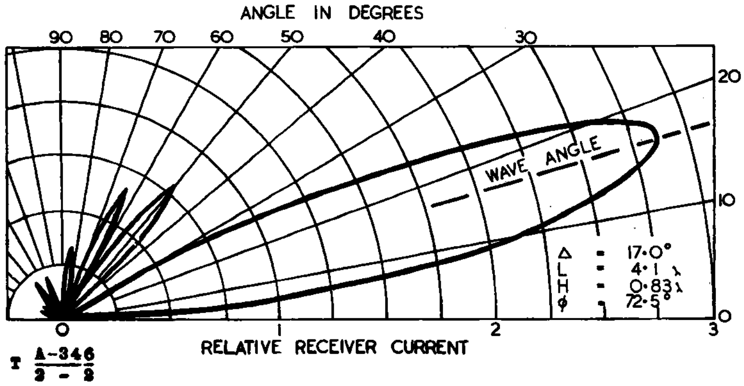

Fig. 2 - Typical rhombic aerial
polar diagram - vertical

3. The aerial is connected at one end to a feeder and the other end is terminated by a resistor (see para. 10).

4. Maximum pick-up and radiation occur in the direction away from the feeder, along the longer diagonal of the rhombus. This maximum direction of gain is inclined upwards away from the ground by an angle which varies with the dimensions of the aerial. Typical horizontal and vertical polar diagrams for an aerial of this type are given in Figs. 1 and 2, and it will be seen that the dimensions of this type of aerial are closely related to the wavelength (λ) for which it is designed.

Advantages and limitations of rhombic aerials

5. This type of aerial is capable of maintaining an approximately constant impedance over a wide (2:1) frequency band, while providing constant horizontal directivity. Its nearly constant impedance permits it to be connected to constant impedance feeder lines and resistively terminated.

6. The aerial has a considerably greater radiation efficiency than a dipole, gains of 10 to 15db., as compared with a non-directional aerial of similar height, being possible.

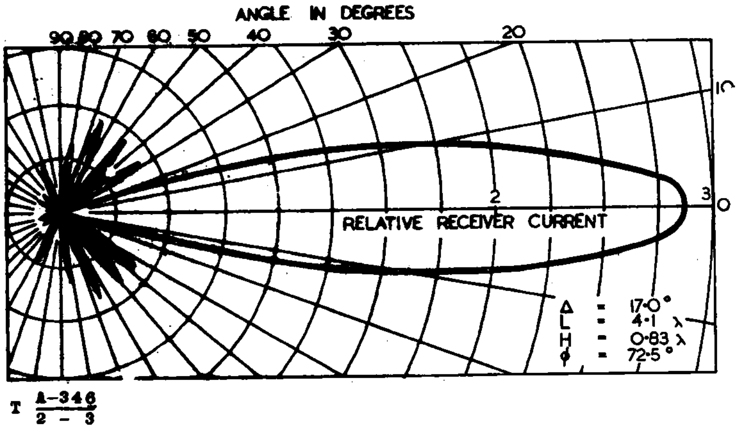

Fig. 3 - Typical rhombic aerial polar
diagram - horizontal

7. The main pitfall with an aerial of this type lies in trying to use it on widely differing frequencies. Due to the constant impedance characteristic previously mentioned, the transmitter or receiver can invariably be tuned with it at frequencies

p to twice that for which the aerial is designed, but the vertical radiation pattern will change drastically. This effect can be seen by consulting the design data.

8. The other limitations imposed by the aerial are that it requires high masts, considerable space and can be used efficiently only in the direction for which it is set up.

Design procedure

9. (a) Find the great circle bearing to the distant station. To do this, use the formula in para. 17. This bearing will be in the direction in which the longer diagonal of the rhombus must be.

(b) Find the distance to be worked. The formula in para. 17 will permit this to be calculated.

(c) From the distance to be worked, determine the wave angle Δ. The whole question of the value of the wave angle Δ is a major problem of propagation because this angle is determined not only by the distance to be worked but also by the height of the layer of the ionosphere which returns the radiation to earth. In some cases it may be possible to say fairly definitely what this height will be, and then the wave angle can be determined more accurately from Fig. 1006. For other cases the ABAC in Fig. 1001 gives a value which may be taken as a guide. For distances greater than those shown two or more hops should be assumed and the distance divided by the appropriate number (2 for two hops etc.)

(d) Having once decided the wave angle Δ and the mean working frequency f, several designs for the rhombus are possible. The variable quantities are (see Fig. 1):-

H height above ground
L length of side
Ø angle of tilt

It is generally convenient to know both the working frequency and the wavelength. Either can be obtained from the other by the use of Fig. 1007 (or the formula in para. 18 if high accuracy is required).

(e) The standard design.
A good design suitable for almost all purposes and complying with the usual Service limitations of maximum mast height, 100 ft., and maximum length of side, 750 ft., can be obtained by using the three ABAC's Figs. 1001 - 1004, the method of using these ABAC's being shown in Fig. 1005. It is important to note that the value $\emptyset = 90^\circ - \Delta$ is used (and NOT ABAC No. 3) in all cases where the side length L is less than 750 ft.

(f) The MAXIMUM design
This may be used for transmitter aerials, but only when the wave angle Δ is accurately known and only for one frequency. It gives the highest efficiency but is very critical as to wave angle and frequency. The formulae for this design are given in para. 19 and the results are shown graphically in Figs. 1008 - 1010.

(g) The ALIGNMENT design
This method can be used either for transmitting or receiving aerials, since it is less critical of wave angle and frequency. The design formulae are given in para. 20 and the results are shown graphically in Figs. 1008 - 1010.

(h) The ECONOMY design
This design is based on side lengths of two, three and four wavelengths and produces broad vertical directivity at the expense of efficiency. It should therefore be used when there is serious doubt about the value given for the wave angle. The graphs Figs. 1011 and 1012 permit the design to be worked out.

(j) The COMPROMISE ON SIDE LENGTH design
This design, which has properties similar to those of the alignment design (para. 9(g)), can be used where the wave angle is known with reasonable accuracy and it is necessary, owing to space limitations, to restrict the area occupied by the aerial. For this case three designs are provided, using side lengths of two, three and four wavelengths respectively. The other variables (H and ϕ) are then adjusted to suit these side lengths. The design may be found from the graphs in Figs. 1013 and 1014.

(k) The COMPROMISE ON HEIGHT design
This has similar properties to the alignment and compromise on side length designs. It is used when it is necessary to erect the aerial at a height lower than that obtained by other designs. The design fixes the aerial height at a half a wavelength and then adjusts ϕ and L to compensate for this. The design may be found from the graph in Fig. 1015.

(l) Having designed the required rhombus, the lengths of its diagonals can be obtained by the formula in para. 21. The masts should then be set out at somewhat greater distances to allow for the various insulators, halyards, etc.

Terminations for rhombic aerials

10. Every rhombic aerial should be terminated at the open end by a suitable resistance of 800Ω. If this is not done, a back lobe will appear and the aerial will no longer be unidirectional. For reception, this need be only a non-inductive carbon resistor of 1W rating. The type designed for Army use is fully enclosed and suitable for use in the tropics. Its designation is: RESISTOR, AERIAL, 800Ω, No. 1.

11. At the input or HOME end of the aerial, either a balanced 2-wire open feeder of 600 to 800Ω impedance, or a transformer to reduce to 80Ω for connection to a 80Ω coaxial feeder can be used. The use of such a transformer is possible only for reception where the power handled is negligible. The Army design is Transformer, aerial, 80/800Ω, NO. 1 (ZA 13745).

12. When several rhombic aerials are used for diversity working, the use of this transformer is advised so that buried coaxial feeders can be used all the way from the aerials to the receivers, thus obviating any undesirable pick-up.

13. For transmitting, the terminating resistor has to be capable of dissipating half the output power of the transmitter. The construction of such a resistor with negligible inductance and capacity becomes formidable when the power dissipated may be as much as 4kW.

14. In general, wire-wound resistors are not satisfactory, and groups of large carbon rods are best. Alternatively, a long 2-wire line employing iron wire elements is possible, but care is needed in the disposing of it relative to the aerial itself. A suitable resistor is Resistor, aerial, 800Ω, No. 2.

15. At the feed-in end, an open-wire feeder is almost essential for transmission, to avoid the difficulty of impedance transformation under power loading conditions.

References

16. Further information on the design of rhombic aerials will be found in:-
(a) "Rhombic Aerial Design" by A.E. Harper, published by D. Van Nostrand (New York 1941).

(b) "Horizontal Rhombic Antennas" by Bruce, Beck and Lowry "Bell System Technical Journal", January 1935.

(c) "Developments in Short-Wave Directive Antennas" by E. Bruce, "Bell System Technical Journal" October 1931.

(d) "Signal Training Pamphlet" No. 2, Parts 4 and 9.

Design formulae

17. Great circle bearing and distance

Let L_A = latitude of station A, positive for northern latitudes, negative for southern latitudes.

L_B = latitude of station B, positive for northern latitudes, negative for southern latitudes.

$L_O(AB)$ = Longitude difference between A and B.

C_A = Direction of B from A, (degrees E. or W. from north in the northern hemisphere and from south in southern hemisphere).

C_B = Direction of A from B (Degrees E. or W. from north in the northern hemisphere and from south in the southern hemisphere).

D_{A-B} = The great circle distance measured as an angle of arc. To convert this distance to miles use:-

1 degree = 69.063 miles
1 minute = 1.152 miles

Then:-

(1) $\cos D_{A-B} = \sin L_A . \sin L_B + \cos L_A . \cos L_B . \cos L_O(AB)$

(2) $\sin C_A = \cos L_B . \operatorname{cosec} D_{A-B} . \sin L_O(AB)$

(3) $\sin C_B = \cos L_A . \operatorname{cosec} D_{A-B} . \sin L_O(AB)$

Frequency - wavelength

18. $$\text{Frequency in Mc/s} = \frac{300}{\text{Wavelength in metres}}$$

$$\text{Wavelength in metres} = \frac{300}{\text{Frequency in Mc/s}}$$

$$\text{Wavelength in feet} = \frac{985}{\text{Frequency in Mc/s}}$$

Maximum design

19. (a) Find height from

$$H = \frac{\lambda}{4 \sin \Delta}$$

(b) Find tilt angle from

$$\phi = 90^{\circ} - \Delta$$

(c) Find side length from

$$L = \frac{\lambda}{2 \sin^{2} \Delta}$$

Alignment design

20\. (a) Find height from

$$H = \frac{\lambda}{4 \sin \Delta}$$

(b) Find tilt angle from

$$\phi = 90^{\circ} - \Delta$$

(c) Find side length from

$$L = \frac{.371\lambda}{\sin^{2}\Delta}$$

NOTE: (a) and (b) are the same as for the maximum design.
(c) This works out at approximately 74% of the value obtained for the maximum design.

Length of rhombus diagonals

21\. (a) Length of the diagonal C, lying in the direction of the distant station

$$C = 2L \sin \phi$$

(b) Length of the diagonal B at right-angles to the direction of the distant station $B = 2L \cos \phi$

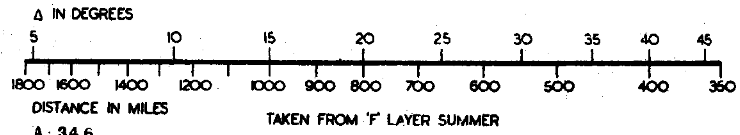

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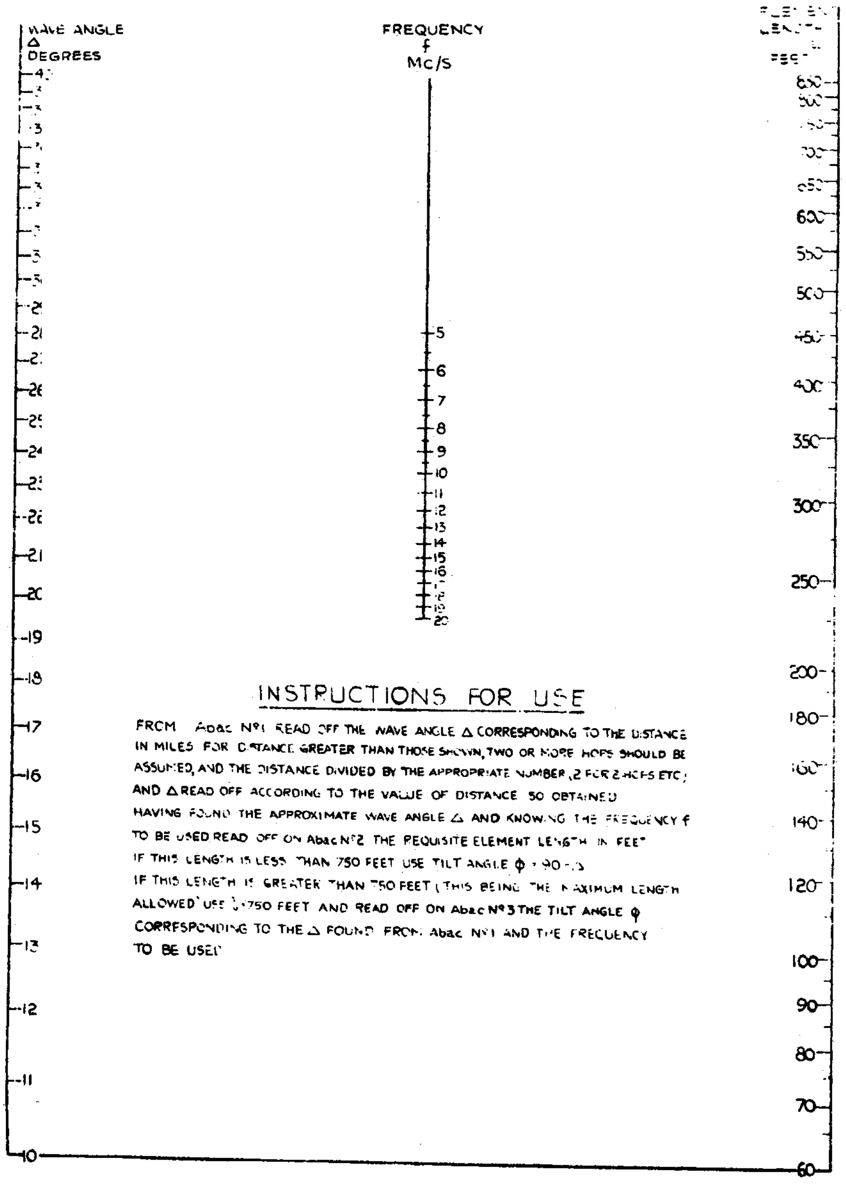
FIG. 1001. ABAC Nº 1.



INSTRUCTIONS FOR USE

FROM Abac Nº1 READ OFF THE WAVE ANGLE Δ CORRESPONDING TO THE DISTANCE IN MILES FOR DISTANCE GREATER THAN THOSE SHOWN, TWO OR MORE HOPS SHOULD BE ASSUMED, AND THE DISTANCE DIVIDED BY THE APPROPRIATE NUMBER (2 FOR 2 HOPS ETC) AND Δ READ OFF ACCORDING TO THE VALUE OF DISTANCE SO OBTAINED

HAVING FOUND THE APPROXIMATE WAVE ANGLE Δ AND KNOWING THE FREQUENCY f TO BE USED READ OFF ON Abac Nº2 THE REQUISITE ELEMENT LENGTH IN FEET

IF THIS LENGTH IS LESS THAN 750 FEET USE TILT ANGLE $\phi = 90 - \Delta$

IF THIS LENGTH IS GREATER THAN 750 FEET (THIS BEING THE MAXIMUM LENGTH ALLOWED) USE L = 750 FEET AND READ OFF ON Abac Nº3 THE TILT ANGLE ϕ CORRESPONDING TO THE Δ FOUND FROM Abac Nº1 AND THE FREQUENCY TO BE USED

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Fig. 1002 - Abac 2

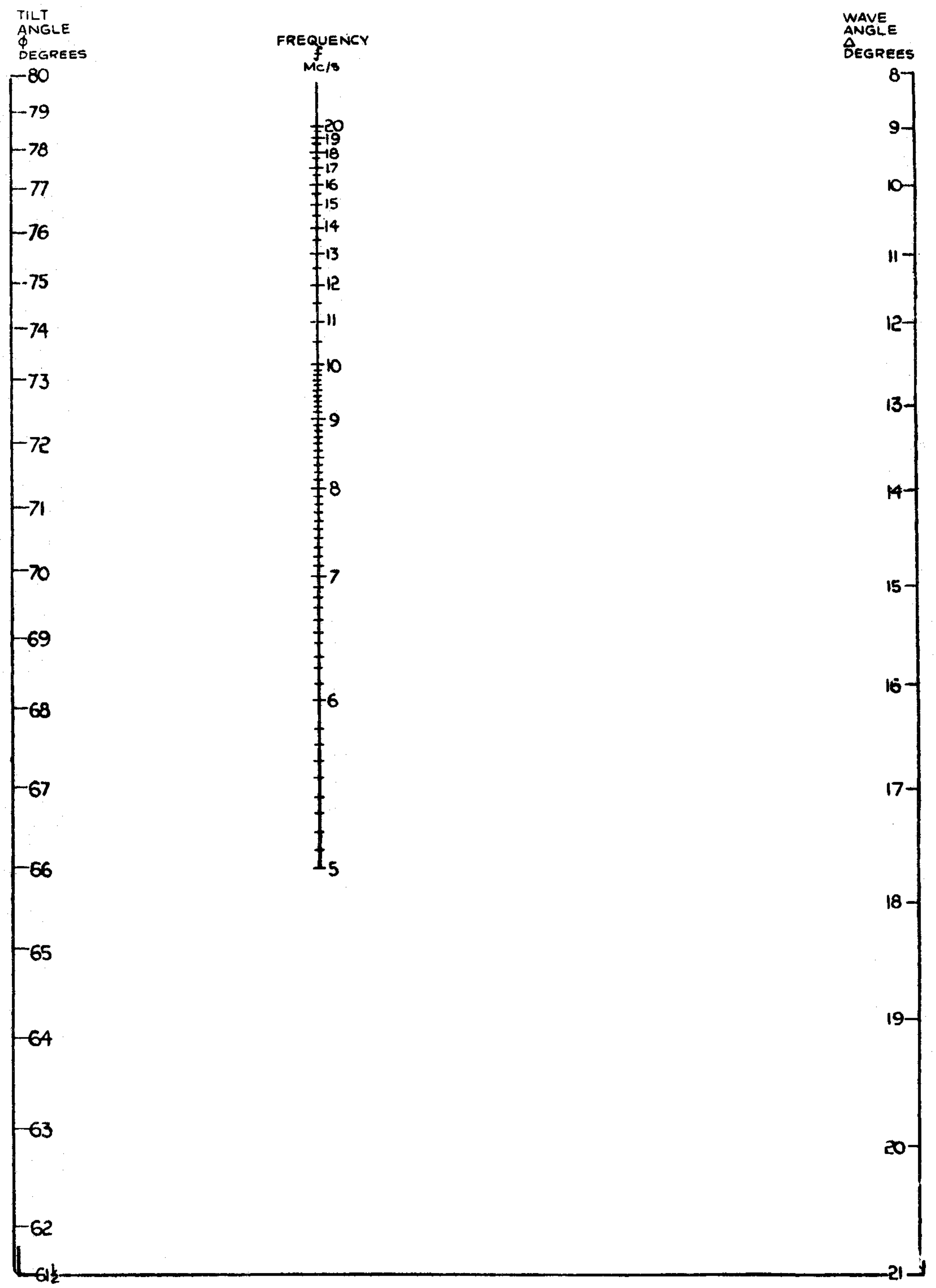

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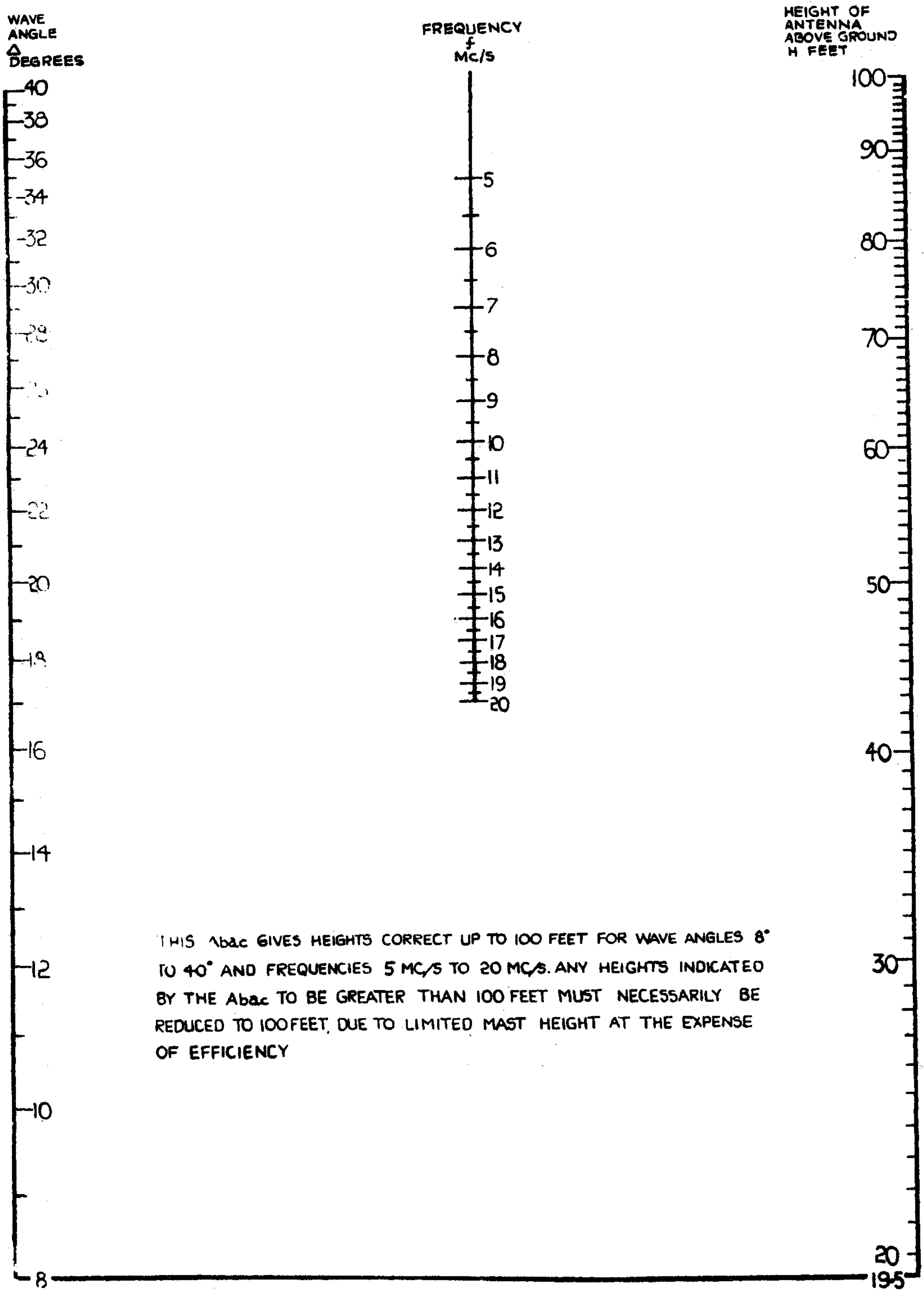
Fig. 1003 - Abac 3



THIS Abac GIVES HEIGHTS CORRECT UP TO 100 FEET FOR WAVE ANGLES 8° TO 40° AND FREQUENCIES 5 MC/S TO 20 MC/S. ANY HEIGHTS INDICATED BY THE Abac TO BE GREATER THAN 100 FEET MUST NECESSARILY BE REDUCED TO 100 FEET, DUE TO LIMITED MAST HEIGHT AT THE EXPENSE OF EFFICIENCY

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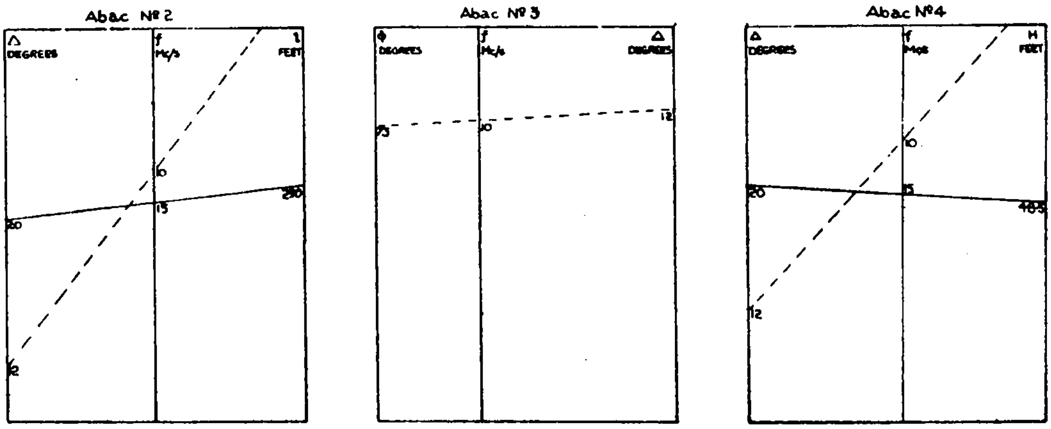
Fig. 1004 - Abac 4



EXAMPLE 1 (FULL LINE) FREQ = 15 Mc/s WAVE ANGLE (FROM Abac Nº 1 - NOT SHOWN) = 20°. STRAIGHT EDGE THROUGH THESE TWO POINTS ON Abac Nº 2 SHOWS ELEMENT LENGTH l TO BE 290 FEET. AS THIS LENGTH IS LESS THAN 750 FEET, USE TILT ANGLE $\phi = 90 - \Delta = 70°$ ON Abac Nº 4 A STRAIGHT EDGE THROUGH $\Delta = 20°$ AND $f = 15$ Mc/s SHOWS HEIGHT H TO BE 48·5 FEET.

EXAMPLE 2 (BROKEN LINE) FREQ - 10 Mc/s WAVE ANGLE (FROM Abac Nº 1 - NOT SHOWN) = 12°. PROCEEDING TO Abac Nº 2 AS IN EXAMPLE 1 THE ELEMENT LENGTH IS SHOWN TO BE LONGER THAN 750 FEET. AS 750 FEET IS THE LONGEST LENGTH ALLOWED, THIS MUST BE USED, AND THE APPROPRIATE TILT ANGLE ϕ FOUND FROM Abac Nº 3. A STRAIGHT EDGE THROUGH $\Delta = 12°$ AND FREQ - 10 Mc/s ON THIS Abac SHOWS ϕ TO BE 73°. THE HEIGHT AS GIVEN BY Abac Nº 4 IN A SIMILAR MANNER IS GREATER THAN 100 FEET. HENCE THIS HEIGHT OF 100 FEET MUST BE USED DUE TO MAST HEIGHT LIMITATION (OR 72 FEET IF THESE ARE THE ONLY MASTS AVAILABLE)

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Fig. 1005 - Use of Abacs

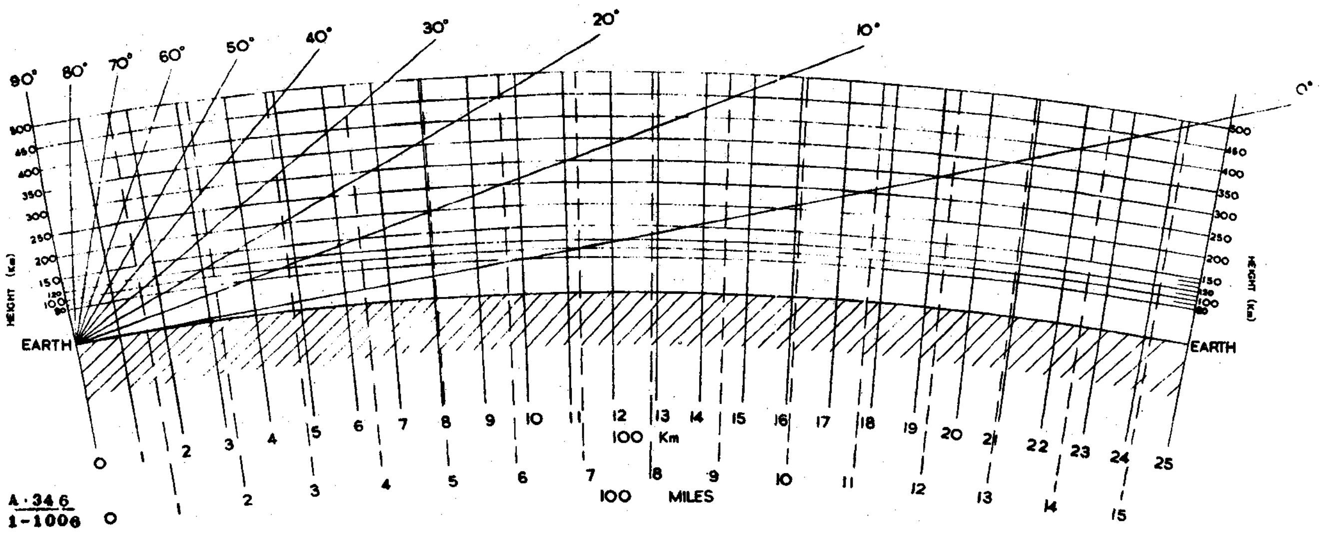

Fig. 1006 - Wave angle chart

The value of Δ when the height of the reflecting layer is approximately known may be found from Fig. 1006. The point of intersection of the lines corresponding to the layer height and the half-distance of the far station (i.e., the distance to the point at which reflection occurs) should be joined to the origin 0. The angle Δ may then be read off from the diagram directly. If a two-hop path is assumed, the true distance of the far station should be divided by 4 in estimating Δ and similarly for multi-hop paths.

Example

Height of reflecting layer.................................350 kilometres
Distance to far station.....................................1,000 miles
∴ distance to point at which reflection occurs is 500 miles.
Reading off $\Delta = 20^\circ$.

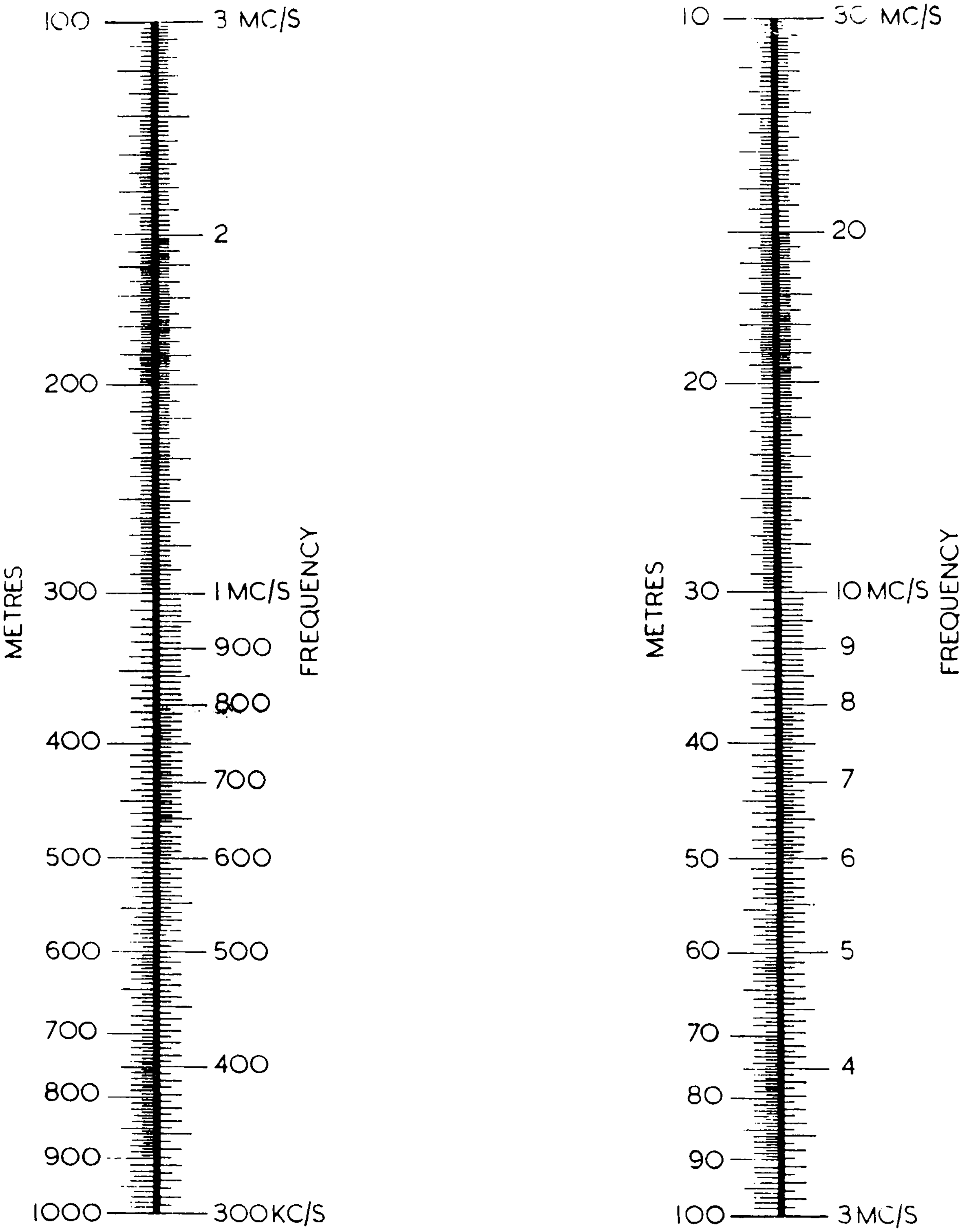

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Fig. 1007 - Abac frequency-wavelength conversion

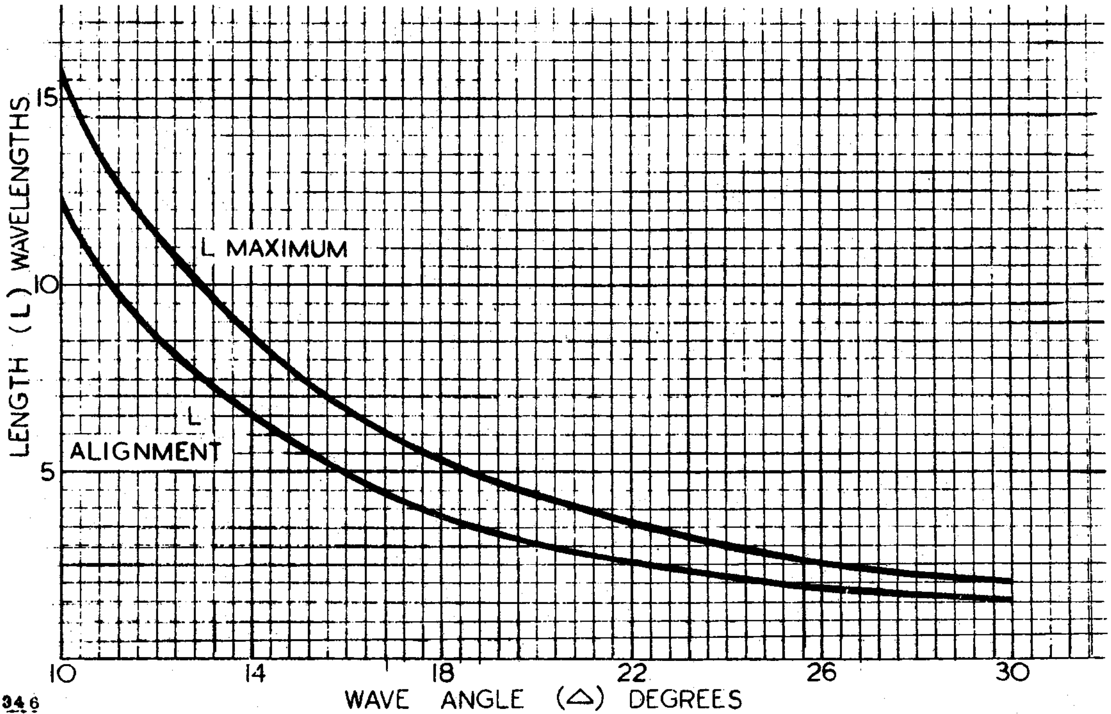

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Fig. 1008 - Maximum and alignment design - value of L

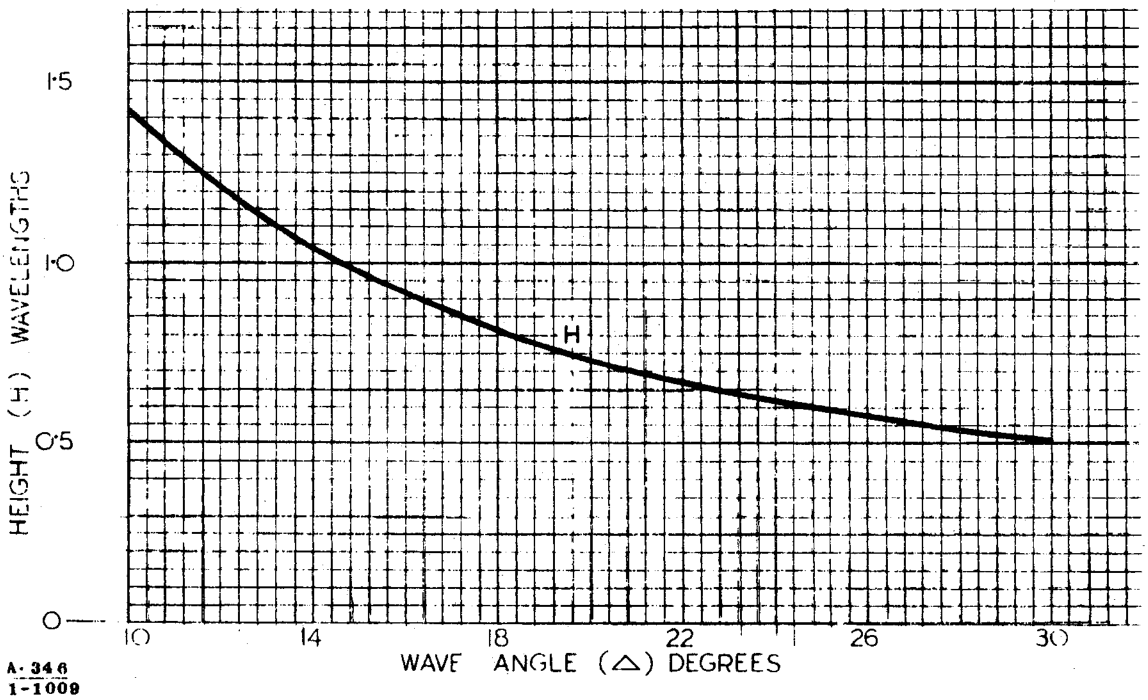

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Fig. 1009 - Maximum and alignment design - value of H

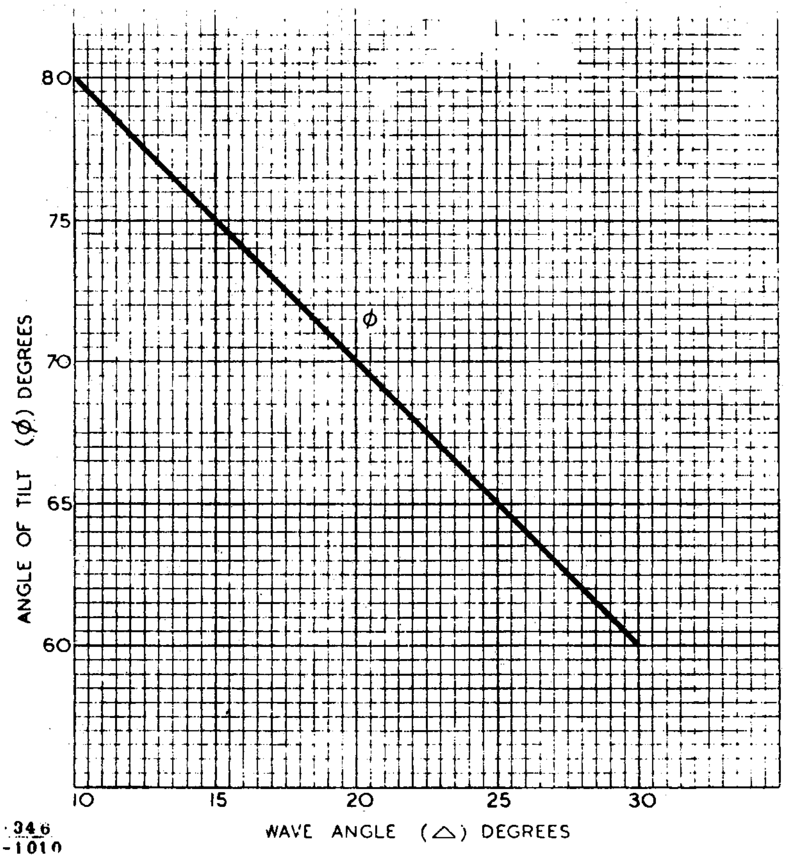

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Fig. 1010 - Maximum and alignment design - value of ϕ

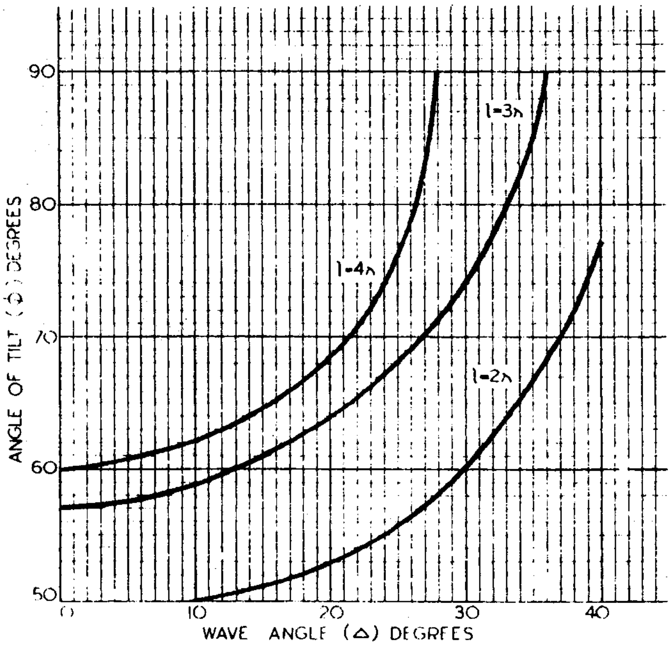

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Fig. 1011 - Economy design - value of ϕ

Note: These pages supersede pages 1009 and 1010, Issue 2. Figures marked ● have been amended.

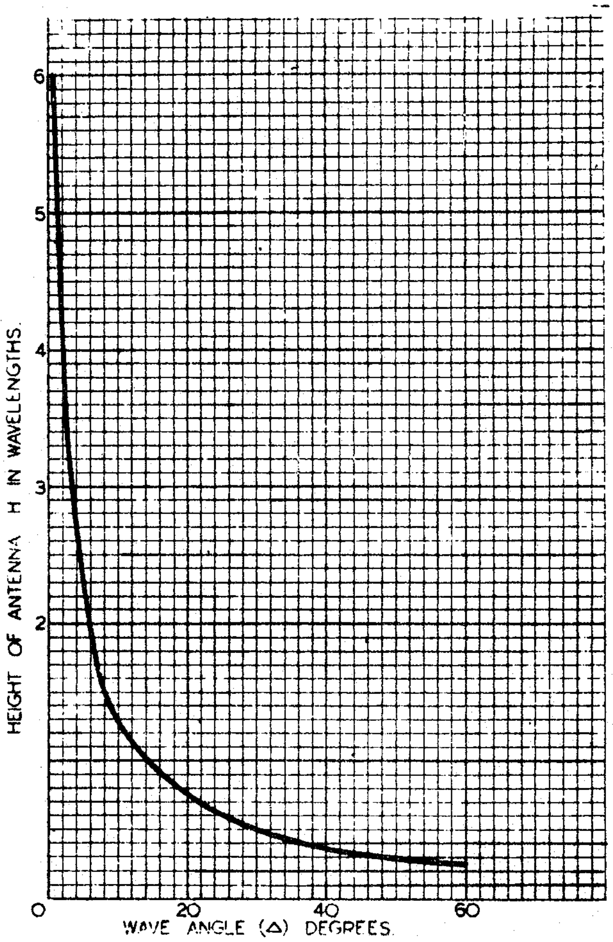

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Fig. 1012 - Economy design - value of H

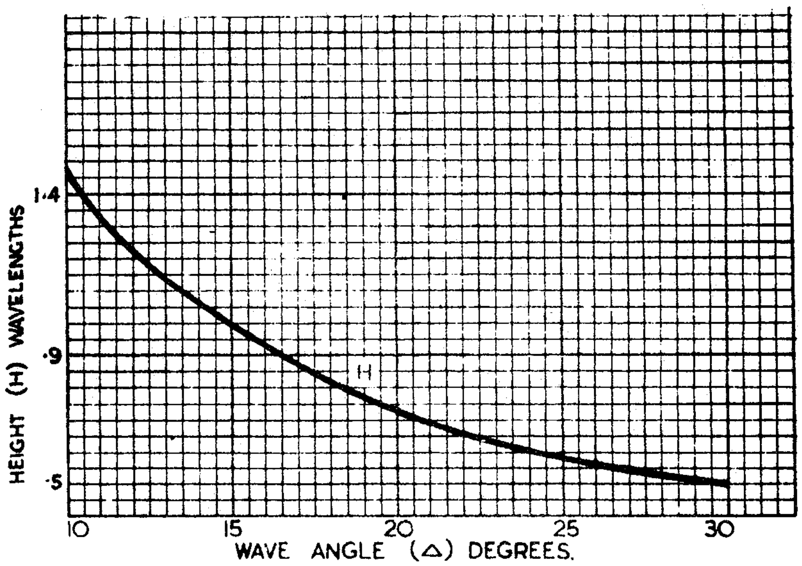

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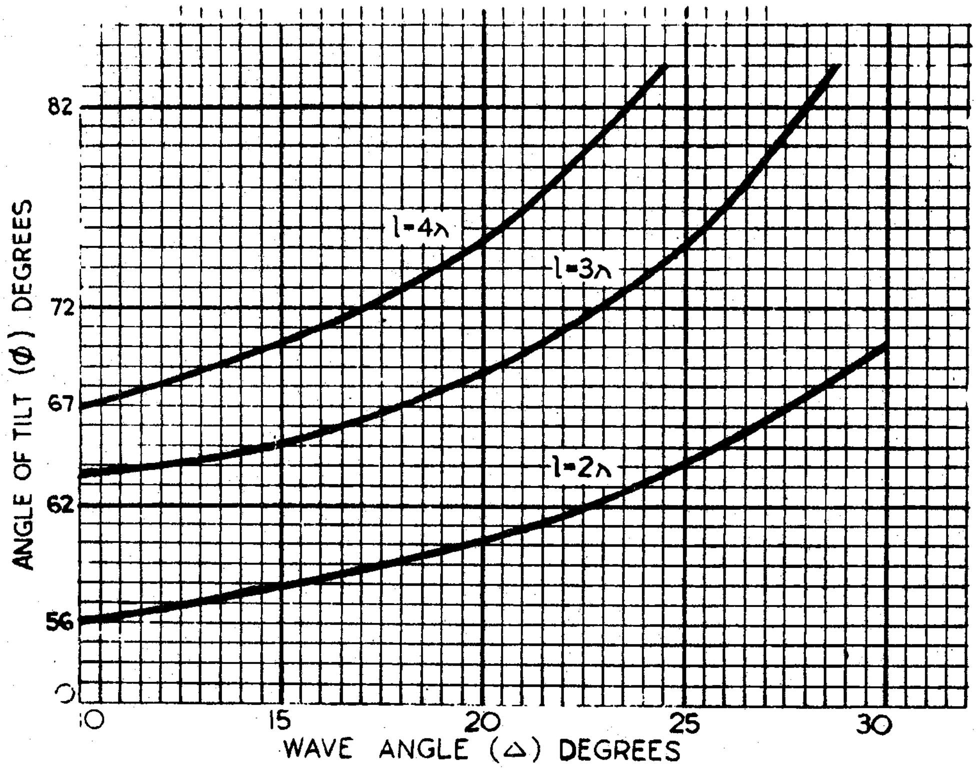
Fig. 1013 - Compromise on sidelength design - value of H



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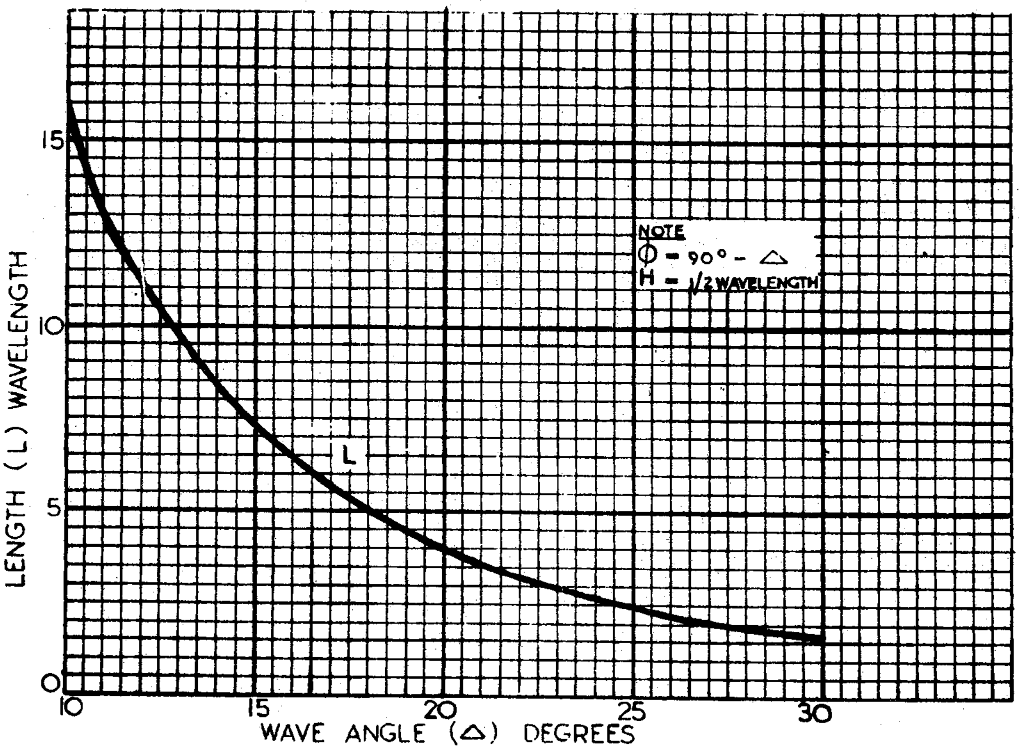
0 Fig. 1014 - Compromise on sidelength design - value of Φ



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