THEORETICAL CONSIDERATIONS OF ULTRA - HIGH - FREQUENCY TWO - COURSE SIMULTANEOUS RADIO RANGES

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Technical Development Note No 44
March 1947

U S DEPARTMENT OF COMMERCE

CIVIL AERONAUTICS ADMINISTRATION

WASHINGTON, D C

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INFORMATION
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THEORETICAL CONSIDERATIONS OF UHF TWO-COURSE SIMULTANEOUS RADIO RANGES

INTRODUCTION

The problem of adding simultaneous voice communication to the two-course visual and aural UHF radio range has been solved in five different ways described in this Note Before the several solutions are described, it is believed useful to enumerate the most important requirements for the simultaneous system These requirements may be stated as follows

a) Adequate performance involving
   1) Sufficient and steady deflection of the visual indicator, and sufficient and uniform aural signals when flying off course in a straight line or in a turn Steady zero deflection on course
   2) No pushing of course as it is approached from any angle
   3) No reversals of courses, no multiple courses and no bends in course
   4) Proper course sharpness to make it easily flyable for the average pilot
   5) Sufficient distance range.
   6) Adequate clearance between the aural and visual signals off-course.
   7) Adequate voice intelligibility in any direction from the station to the limits of the service area, for any heading of the plane
   8) Voice should not interfere with the aural on-course signals or the visual indications
   9) The aural and visual range signals should not interfere with the voice reception

b) Equipment in the plane must be as light, compact, and simple to operate as is feasible The plane antenna must offer small wind resistance and must not interfere with flying characteristics of the plane

c) Equipment on the ground must be of the utmost reliability
   1) Shifting of courses and changes in course-sharpness and clearance due to partial failure or aging of tubes or equipment should be avoided From a safety, standpoint it is preferable to have no course at all than a false course
   2) The visual course should be independent of failure of aural and/or voice circuits
   3) The ground equipment should be so engineered that available personnel can service and readjust it properly without the help of experts and complex laboratory equipment

FUNDAMENTAL CONSIDERATIONS PERTAINING TO THE UHF SIMULTANEOUS TWO-COURSE RANGE

The antenna system consists of 5 horizontal loop antennas located in a plane $\frac{1}{2}$ wavelength above an elevated counterpoise Four of the loops are located at the corners of a square, and the fifth in its center Two diagonally opposite loops in conjunction with the center loop produce the visual course, the remaining side-loops and the center loop radiate the aural course

The equation for the relative intensity of the radiation field produced by two diagonal side loops and the center loop, in terms of the maximum intensity, is

$$(1)\quad F(\varphi) = \frac{k + 2 \sin (2\pi S/\lambda \sin \varphi)}{k + 2}$$

In deriving equation (1), it is assumed that the phase of the current in the two side loops is +90° and -90°, respectively, with respect to the current in the center loop The symbols are defined as follows

φ = angle (measured in horizontal plane) between line through center loop and reference point, and vertical plane through center loop at right angles to line connecting the 3 loops

k = ratio of current in center loop to current in each side loop.

S = spacing between center loop and side loops

λ = wavelength

For the useful range of values of k and S, the plot of $F(\varphi)$ has the shape of a bean. In addition to the bean pattern one or more minor lobes may occur. Figure 1 gives the field pattern for current ratio $k = 2$ and spacing $S = \lambda/3$

If the phase of the current in each side loop is changed 180°, equation (1) is changed to

$$(2)\quad F'(\varphi) = \frac{k - 2 \sin (2\pi S/\lambda \sin \varphi)}{k + 2}$$

Applied to the case shown in figure 1, equation (1) refers to the curves in solid lines, and equation (2) to the dashed curves

If $F(\varphi)$ in equation (1) represents the visual signal modulated by 90 cyles, and $F'(\varphi)$ in equation (2) represents the signal modulated by 150 cycles, visual courses are obtained where $F(\varphi)$ $F'(\varphi)$, i e , for $\varphi = 0$ and $\varphi = \pi$ The 180° phase shift between 90 cycle and 150 cycle modulated current in the visual side loops is obtained by the cross-over in RF bridge 2, in figures 2, 3, 4, and 5.

Since a vertical plane through the aural antennas is at right angles to that through the "visual" antennas, the aural range pattern is shifted 90° in space with respect to the visual range pattern The aural courses are, therefore, at $\varphi = \pi/2$ and $\varphi = 3\pi/2$ if φ is referred to the visual course.

The keyer in the leads to the aural loops reverses the phase of the loop currents 180° every time it operates One bean pattern is keyed with the letter D, while the other bean pattern is keyed with the letter U. A pilot flying a visual course on one side of the station hears a predominant D signal; whereas, a pilot flying the visual course on the other side of the station hears a predominant U signal The ratio of the intensities of the D and U signals depends on the clearance of the aural patterns The aural range in conjunction with the visual range permits quadrant identification.

In summarizing, it may be said that aural and visual range patterns have the same characteristics in space, except that they are shifted 90° with respect to each other, and their time of operation is different In the visual range the solid and dashed bean patterns of figure 1 are present simultaneously, whereas, in the aural range, either the dashed or the solid bean pattern is radiated, but not both at the same time

The relative signal strength on course, F (0), is independent of the antenna spacing S and depends only on the current distribution k between center and side antennas.

$$(3)\quad F\ (0) = \frac{k}{k + 2}$$

The maximum relative field strength is unity and is in the directions

$$(4)\quad \varphi = \sin^{-1} \frac{(\lambda)}{(4S)}$$

CLEARANCE OF THE VISUAL AND AURAL RANGE

The clearance C of a range is defined as the ratio of the desired to the undesired radiated signal at an arbitrary point in the horizontal plane at angle φ off course. In other words, C is the ratio of the intensity at an angle φ off course, of the stronger to the weaker of two associated bean patterns. C usually is expressed in db.

$$(5)\quad C = \frac{k + 2 \sin (2\pi S/\lambda \ \ \sin \varphi)}{k - 2 \sin (2\pi S/\lambda \ \ \sin \varphi)}$$

for $0 < \varphi < \pi$ $\qquad C > 1$

On course $\varphi = 0$ or π

$C\ (0) = 1 = C$ min.

At right angles to course $\varphi = \pi/2$

$$(5.1)\quad C \left(\frac{\pi}{2}\right) = \frac{k + 2 \sin (2\pi S/\lambda)}{k - 2 \sin (2\pi S/\lambda)}$$

For $0<k<2$ there exist angles φ, for which $C\ (\varphi) = \infty$. They are given by

$$(5.2)\quad \sin \varphi = \pi \frac{1}{2\pi S/\lambda} \quad \sin^{-1} \left(\frac{k}{2}\right)$$

and

$$\sin \varphi = \frac{1}{2\pi S/\lambda} \left[\sin^{-1} \left(\frac{k}{2}\right) - \pi \right]$$

For $k>2$

$$(5.3)\quad C \text{ max.} = \frac{k + 2}{k - 2} \quad \text{with } \varphi = \sin^{-1} \left(\frac{\lambda}{4S}\right)$$

For $0<k<2$ a secondary minimum of clearance exists

$$(5\ 4)\quad C \text{ sec min.} = \frac{2 + k}{2 - k}$$

with

$$(5.5)\quad \varphi = \sin^{-1} \frac{(\ \lambda\ )}{(\ 4S\ )}$$

Angles φ and $(180 - \varphi)$ are identical with those given in equation (4) for maximum field strength

SHARPNESS OF COURSES

The course-sharpness N is defined as the clearance at $1\frac{1}{2}°$ off course

Entering equation (5) above with

$$\varphi = \Delta\varphi = 1\tfrac{1}{2}° = 0.0262 \text{ radian}$$

$$\sin \Delta\varphi = \Delta\varphi$$

$$\sin \left(2\pi S/\lambda \quad \sin\Delta\varphi\right) = 2\pi S/\lambda$$

gives

$$(6) \quad N = \frac{k + 0.33\ S/\lambda}{k - 0.33\ S/\lambda}$$

MODULATION OF THE UHF TWO-COURSE RANGE

In the types of ranges considered here the carrier is radiated from the center antenna only The circular carrier field pattern thus obtained makes the most efficient use of carrier power in all directions.

The shape of the modulation envelope of two associated beam patterns for the visual course will now be examined If the two patterns were of the same frequency, equations (1) and (2) could be added algebraically, giving a resulting circular field of relative intensity

$$(7) \quad M(\varphi) = \frac{2k}{k + 2} = M(0)$$

The aural patterns each have the same aural frequency, but the system does not emit both conjugate patterns simultaneously

In case of unequal pattern frequencies the absolute magnitudes of equations (1) and (2) must be added to obtain the modulation envelope.

In the range of values of φ where $F'(\varphi)$ in equations (2) becomes negative the resulting relative modulation envelope is given by

$$(8) \quad M'(\varphi) = \frac{4}{k + 2} \sin\left(2\pi S/\lambda \quad \sin\varphi\right)$$

The limiting angles φ_0 separating the regions where equations (7) and (8) hold are found by letting $M(\varphi) = M'(\varphi)$

$$(9) \quad \varphi_0 = \sin^{-1}\left[\frac{1}{2\pi S/\lambda} \sin^{-1}\left(\frac{k}{2}\right)\right]$$

$$(9.1) \quad \varphi_0 = \sin^{-1}\left[\frac{1}{2\pi S/\lambda} \left\{\pi - \sin^{-1}\left(\frac{k}{2}\right)\right\}\right]$$

Equation (8) is applicable for values of k

$$0 < k < 2$$

For values of φ leaving $F'(\varphi)$ positive, equation (7) must be used. The modulation envelope on course has the value $M(0)$ given in equation (7)

In the range of angles φ where equation (8) holds the modulation in terms of the modulation on course is given by

$$(10) \quad M'(\varphi) = M(0)\ \frac{2}{k}\ \sin\left(2\pi S/\lambda \quad \sin\varphi\right)$$

In the Type C Range $M(0)$ is 40%, as the modulation factor for each pattern of the visual course is 20%

In figure 6 $M(\varphi)$ versus φ is plotted with k as parameter, for $M(0) = 40\%$ It follows that for best utilization of a circular carrier field the antenna current ratio k should be

$$k \geq 2$$

There are also considerations of course-sharpness and minimum clearance entering the choice of k Referring to figure 7 it will be observed that for maximum clearance in any direction (equal right-angle and minor lobe clearance) k should be 1.6, with $2\pi S/\lambda = 140°$

$$C_{sec\ min} = 19 \text{ db}$$

$$N = 1.45 \text{ db}$$

Figures 8 and 9 show clearance curves versus current ratio over a narrower range of k for antenna spacing of 120° and 140°, respectively

The choice of a suitable antenna spacing and current ratio therefore, is a compromise between course-sharpness, clearance, and modulation envelope In the Type C range, a current ratio k = 2.0 with an antenna spacing of 120° was chosen This is a very satisfactory compromise which gives a circular modulation envelope, a high average clearance in any direction and keeps the course-sharpness sufficiently high In figure 10 the clearance in any direction is shown with k = 2.0 and antenna spacing 120° and 140°, respectively

A comparative table showing the degrees of modulation for the several types of UHF ranges is given below

TABLE I

Percent Modulation of U H F. Simultaneous Two-Course Ranges

Frequency	Type A-1	Type A-2	Type B	Type C	Type D
90 cps	25	25	17.5	20	17
150 "	25	25	17.5	20	17
1020 "	6	6	10		8
Voice	25		20		32
1020 " on 12 kc				14.5	
Voice on 20 kc		13		33	

EFFECT OF MAGNITUDE OF CURRENT IN CENTER ANTENNA ON HORIZONTAL FIELD PATTERN

Under operating conditions changes of the current in the center antenna involve, in general, both magnitude and phase. For purposes of studying the field patterns under various conditions, it is advantageous to consider magnitude and phase changes as occurring both separately and simultaneously. Under this heading the phase angle of the current in the center antenna is assumed to be 0°, and that in the two side antennas ±90°, respectively. Using equations (3) and (6), the relative field strength on-course and the course-sharpness are plotted in figure 11 for values of current ratio k between 0.1 and 10. While for practical two-course radio ranges the limiting values of k are, approximately, between 1 and 2.5, much wider limits of k may accidentally occur in systems where center and side antennas are fed from different amplifiers. Wide variations of the ratio k occur if the vacuum tubes of either amplifier lose emission. A large k makes the course extremely broad, and a small k makes it very sharp. For 140° antenna spacing the course sharpness becomes infinite for $k = 0.128$. The relative signal strength on course increases with k and reaches unity asymptotically. The clearance, given by equation (5), has minima in the direction of the minor lobes. For $2\pi S/\lambda = 140°$ these minima are at $\varphi = 40°$ and 140° given by equation (4). Minor lobe clearance and clearance at right angles to course versus k are plotted in figure 7. For certain values of k the above clearances are infinite and decrease as k is varied in either direction from these critical values. For a satisfactory field pattern the minimum clearance off course should be over 20 db. Figures 12 to 22, inclusive, show horizontal field patterns for various values of k, for 140° and 120° antenna spacing.

EFFECT OF PHASE OF CURRENT IN CENTER ANTENNA ON HORIZONTAL FIELD PATTERN

Assuming unit current in the side antennas whose phase angle differ 180° from each other, and current k in the center antenna whose phase is $(90 + \epsilon)$ and $-(90 - \epsilon)$ with respect to the side antennas, the relative magnitude of the horizontal field pattern in the direction φ is given by

$$(11)\quad F(\varphi) = 2\left[\sin^2\left(2\pi S/\lambda \; \sin\varphi\right) + \frac{k^2}{4} + k\cos\epsilon \, \sin\left(2\pi S/\lambda \; \sin\varphi\right)\right]^{\frac{1}{2}}$$

For antenna spacings of 140° and $k = 1.5$ these field patterns have been drawn for $\epsilon = 0°$, 45°, 80°, 90° and are shown in figures 23 to 26, inclusive. It will be observed that course-sharpness and clearance decrease with increasing angles ϵ.

To further illustrate the effect of the phase angle of the current in the center antenna on clearance, course sharpness and relative signal strength on course, the curves in figure 27 are presented. For phase angles which are not too large, the course-sharpness decreases but little, whereas clearance at right angles to the course, and minor lobe clearance decrease rapidly.

It is important to note that for phase shifts between 90° and 180°, the desired signal off course is weaker than the undesired one, i.e., the courses are reversed. For 100° phase shift, for example, the patterns are similar to those for 80°, except for the reversal.

The effect of simultaneous changes of magnitude and phase of the current in the center antenna is shown in figures 28 to 31, inclusive.

It will be observed that the clearance in any direction becomes insufficient if k is very large or very small, or if ϵ is close to 90°.

If k is small, the course sharpness is large, and the relative signal strength on course weak. The opposite holds true if k is large.

Insufficient clearance may confuse the pilot since he may believe he is approaching a course when he is actually flying away from the course.

In Table II the effect of magnitude and phase of the current in the center antenna on course-sharpness, clearance and relative signal strength on course are given.

THE QUESTION OF COURSE STABILITY

Changing magnitude and phase of the current in the center-antenna does not shift the course, but it changes course-sharpness and clearance.

In order to shift the course, the two associated bean patterns must differ in size and/or shape. Reviewing figure 2 we find that for a symmetrical layout, balanced to ground, and with proper initial adjustment, the patterns of both visual and aural ranges must be symmetrical on either side of the course. Operation of the controls in the transmitter and side-band generator does not affect the stability of the course since both patterns remain symmetrical. The same reasoning also holds for Type B, Type C and Type D ranges.

TABLE II

Antenna Spacing = 140°

(A) Variation of Magnitude k of Current in Center Antenna

k (ratio)	ϵ (degrees)	Course Sharpness (db)	Clearance at 40° (db)	Clearance at 90° (db)	(On Course) (Max. Signal) (%)
0.1	0	18.2	0.87	1.35	4.7
0.8	0	2.85	7.4	13	28.5
1.5	0	1.5	16.9	22.3	43
3	0	0.75	14	7.98	60
10	0	0.24	3.5	2.22	83

(B) Variation of Phase ϵ of Current in Center Antenna

k (ratio)	ϵ (degrees)	Course Sharpness (db)	Clearance at 40° (db)	Clearance at 90° (db)	(On Course) (Max. Signal) (%)
1.5	0	1.5	16.9	22.3	43
1.5	45	1.03	7.2	7.5	46.5
1.5	80	0.257	1.45	1.5	56
1.5	90	0	0	0	60

(C) Simultaneous Variation of k and ϵ

k (ratio)	ϵ (degrees)	Course Sharpness (db)	Clearance at 40° (db)	Clearance at 90° (db)	(On Course) (Max. Signal) (%)
5	45	0.3	4.63	-3.08	76
0.2	45	4.44	1.21	1.87	9.3
5	80	0.069	1.06	0.75	88
0.2	80	1.97	0.30	0.44	9.8

COURSE SHIFTS PRODUCED BY ARTIFICIAL MEANS

As there are cases where it may be desirable not to have the two courses in a straight line but at an angle to each other, the following is of more than academic interest.

The first of two methods for shifting courses described below makes use of two similar bean patterns of unequal size. Such patterns can be produced if the degree of modulation at 90 and 150 cycles is made unequal (visual course), and in case of aural ranges of Types A-1, A-2, and C, if resistance is introduced in the line between aural side-band generator and RF bridge 4 in figures 2 to 4, inclusive. This resistance has to be switched into the line in rhythm with the D or U keying. To obtain similar aural bean patterns of unequal size in the Type B range, the 1020 cycle oscillator output must be reduced in rhythm with the D or U keying.

In figure 32 the course shift φ' versus scale factor y by which the two bean patterns differ, is plotted for antenna current ratios $K = 1$ and $k = 2$, and for an antenna spacing of 120°. Each course is shifted φ' degrees.

The course shift is found from the equation

$$\text{(12)} \quad \sin \varphi' = \frac{1}{2\pi S/\lambda} \sin^{-1}\left[\frac{k}{2} \frac{(1-y)}{(1+y)}\right]$$

and is towards the smaller of the two patterns.

Calculation of the course sharpness of the shifted courses gives the result that for the range of values of k and y given in figure 32 the sharpness changes only a few percent.

The clearance off course between the two patterns is proportional to the scale factor y or to $1/y$, depending on which side of the course it is measured.

The reduction in clearance restricts the values which may be given to the scale factor. The maximum practicable course shift which may be realized with this method is below 5° for each course.

The second method for shifting of courses is as follows. The current in the side antennas is left normal (unity), but the current, for one bean pattern, in the center antenna is made equal to ky, whereas that for the other bean pattern is left equal to k.

The course-shift φ' is given by

$$\text{(13)} \quad \sin\varphi' = \frac{1}{2\pi S/\lambda} \sin^{-1}\left[\frac{k}{4}(y-1)\right]$$

Course shift versus factor y is plotted in figure 33, for $k = 1$ and $k = 2$, and antenna spacing 120°. Appreciable course shifts can be obtained in this way, however, the course sharpness is reduced. For example, for a course-shift of $\varphi' = 14.5°$; $k = 2$, $y = 2$ the course-sharpness is reduced to $N = 0.53$ db compared to $N = 0.9$ db for $y = 1$. Minimum clearance is reduced too, as can readily be shown. Therefore, course-shifts of over 7° for each course appear impractical with this scheme.

Artificial course-shifts should be avoided whenever possible since the overall performance of the range is reduced. The clearance becomes less and the course sharpness becomes less.

DESCRIPTION OF TYPE A-1, A-2 AND C RANGES, USING MECHANICAL MODULATOR AND RF BRIDGES

Inspection of figures 2, 3, and 4 shows range systems using four r f bridges and the mechanical modulator. The function of these five components is identical in Types A-1, A-2 and C

The r f. bridges and connecting circuits consist of 2-wire (balanced) shielded line. The length of the bridge arms is 0 152 λ and is designed to match the characteristic impedance of the connecting lines at the corners of the bridge in bridges 2, 3, and 4. The length of the bridge arms of bridge 1 is $\frac{\lambda}{4}$ and is designed to give minimum reaction on the transmitter Consider r f bridge 1, figure 2 The unmodulated carrier enters at A, divides equally and leaves the bridge at B and C As far as voltage of carrier frequency f_c is concerned, point D in r f bridge 1 constitutes a short-circuit, since the voltages coming from B and C are equal in magnitude and opposite in phase (due to the cross-over) at D The reason for introducing r.f bridges 1 and 2 is to make the 90 and 150 cycle modulation non-interacting, thus avoiding the use of separate transmitters and separate antennas Any change in carrier output of the transmitter affects both 90 and 150 cycle bean-patterns equally, and no course-shift occurs The 150 cycle modulation introduced in line C-H does not enter line B-F It is readily seen that due to the cross-over in arm C-D, the effect of 150 cycle modulation, for example, does not transmit itself from C to B because voltages of equal magnitude and opposite phase arrive at B via A and D, respectively This is only possible, of course, if the impedance looking from A into the transmitter equals that looking from D into the box (Z_1) The impedance looking from A into the transmitter is practically purely reactive, therefore, no power is lost in Z_1.

Similar reasoning holds for r f bridge 2 In this bridge the impedance looking from G towards the visual loops and from E towards r f bridge 3 equals the characteristic impedance Z_0 of the line The frequencies indicated in the various parts of the figures 2 to 4, inclusive, are helpful for the understanding of the bridges and their associated circuits

Besides preventing interaction of the 90 and 150 cycle modulation, the cross-over in r f. bridge 2 also serves to produce 180° phase shift between the 90 and 150 cycle modulated sidebands fed to the visual antennas (equations 1 and 2), thus giving rise to the two bean-patterns in figure 1. The cross-over in the lead to one of the visual (and aural) antennas produces the required 180° phase shift between the current in two diagonally opposite loops Adjustment of the current phase in the center antenna to ±90° with respect to the current in the side-loops is accomplished by a phasing network consisting of a U-shaped variable length of line

The mechanical modulator is of the absorption type It does not furnish any power The mechanical modulator consists of two 2-wire transmission lines, one for 90 cycle and one for 150 cycle modulation, short-circuited at one end and capacitively loaded at the other These transmission lines are inductively coupled to lines B-F and C-H and absorb maximum carrier power when they are tuned to resonance, and, of course, minimum power when tuned farthest off resonance Tuning variations of the modulator frames are obtained by varying their loading capacities toothed discs ("paddle wheels") are rotated between the plates of the loading condensers. The design is such that the frames resonate when the loading capacities are minimum The paddle wheels are on the shaft extensions of an 1800 r p m synchronous motor and have 3 and 5 teeth, respectively. The paddles are so oriented with respect to each other that maximum absorption of power does not occur simultaneously on the 90 and 150 cycle side. Adjustment of the percentage modulation is readily monitored with the oscilloscope.

From the above description it follows that the mechanical modulator has a high degree of reliability since the possibility of course-shift is practically eliminated

R f bridge 3 serves to isolate bridges 2 and 4 from each other. Since the impedance looking from K (bridge 3) into the center antenna equals the characteristic impedance Z_0 (resistive) the same impedance must be present looking from L into Z_3.

Fifty percent of the power entering bridge 3 is, therefore, lost in Z_3

R f bridge 4 separates voice and aural side-bands, and in Z_4 half the power entering bridge 4 is lost The power-loss in bridges 3 and 4 is a disadvantage of Types A-1, A-2, and C ranges Further study has led to a solution which is less wasteful of power than these types It is called the Type D range and is described later

The sideband generators shown diagrammatically in figures 2 to 4, inclusive, are all of the same fundamental design The grids of the two tubes in the output stage of the sideband generator are connected in parallel and excited at carrier frequency The plates of these tubes are connected, as far as the carrier frequency is concerned, to a push-pull circuit The modulation voltage is applied to each of the plate circuits separately and no d c. plate voltage supply is used Each tube passes current during alternate half-cycles of modulation frequency only, and it can be shown that sidebands, but no carrier, are present in the output tank circuit For proper functioning of the range, the suppressed carrier frequency at the sideband generator must, of course, be equal to the carrier frequency of the transmitter Further, the sideband currents must be so phased with respect to the carrier in the center antenna that if the carrier of the sideband generators were not suppressed it would be in phase with the carrier in the center antenna since improper phasing produces distortion With linear detection and phase shift ϕ, the desired signal decreases as $\cos \phi$, and the most important distortion terms increase proportional to $\sin^2 \phi$

The Type A-1 UHF simultaneous two-course range has a radiated frequency spectrum as shown in figure 34. The carrier f_c is modulated by 90, 150, and 1020 cycles, and by voice In order to separate the aural range signal and voice, a combination 1020 cycle band pass, band-rejection filter has to be used with the receiver. The 90 and 150 cycle components are attenuated in the grid circuit of the audio output stage by a resistor-capacitor high pass filter

The Type A-2 and C ranges make use of double modulation The principles of double modulation are well established and are used in carrier telephony over wires, and in radio The carrier is modulated by sub-carriers which in turn are modulated by voice or code At the receiving end, the sub-carriers are separated from each other and de-modulated in order to extract the message In this range, the voice modulated a 20 kc sub-carrier which in turn modulates the voice sideband generators Figure 34 shows the radiated frequency spectrum The voice spectrum can be fully utilized, i e , no voice frequencies are lost and no band pass, band-rejection filters are required

The Type C range has both voice and aural range signals on sub-carrier frequencies which are 20 kc and 12 kc, respectively. The frequency spectrum is also shown in figure 34

While the frequency band is greater in Type A-2 and Type C ranges than in the Type A-1, B and D ranges, little additional equipment is required to produce the sub-carriers, and this equipment is of conventional design

The main advantage of the Types A-1, A-2, C and D ranges is that this distribution of power to center and side antennas takes place at radio frequencies over passive linear networks Changes in transmitter or sideband generator output do not affect the distribution of power between center and side antennas Thus a high degree of stability in course-sharpness and clearance is obtained

DESCRIPTION OF TYPE B UHF TWO-COURSE RANGE USING HYBRID COIL

A schematic diagram of this range is given in figure 35 It will be observed that the same frequencies are radiated by Types A-1 and B, but no r f bridges and no mechanical modulator are used In the Type B range, sideband generators are used to produce both the visual and the aural courses

In contrast with the other ranges, the Type B range uses conventional plate circuit modulation in the output stage of the transmitter The output stage is coupled to the center antenna only and is modulated by voice, 1020, 150, and 90 cycles The 90 and 150 cycle frequencies are produced by two alternators driven by a synchronous motor and are fed through a hybrid coil to the visual sideband generator which feeds the visual side-loops The function of the hybrid coil is to introduce 90 and 150 cycle power into center antenna and visual side antennas without interfering with the voice and 1020 cycle circuits which also deliver power to the center antenna The hybrid coil which consists of four transformers takes the place of the r f bridges in Type A-1, A-2, C and D ranges The equivalent of the cross-over in arm C-H of r f bridge 2 of Type A-1 range is obtained by feeding 150 and 90 cycle voltage into the primary and secondary, respectively, of one of the transformers of the hybrid coil Due to current division, half of the power fed into the hybrid coil is lost, but the amount of power lost is small Keying, i e , reversing the 1020 cycle voltage in Type B range, which is fed into the aural sideband generator, changes the phase of the sideband voltages 180° and thereby reverses the aural field pattern. R f phasing networks are required in the leads to the visual and aural side antennas since phasing between carrier and sidebands cannot be accomplished in the audio frequency circuits

DESCRIPTION OF TYPE D UHF TWO-COURSE RANGE USING MECHANICAL MODULATOR AND RF BRIDGES

Figure 5 shows a schematic diagram of the Type D range The circuits connecting r f bridges 1, 2, and 3 are identical with those of Types A-1, A-2, and C The connections to r f bridges 4, however, are different

Two identical Class C amplifiers are excited in parallel and fed to opposite corners of bridge 4. Both Class C amplifiers are plate modulated with voice, while only one Class C amplifier is plate modulated with 1020 cycles Voice sidebands and carrier are fed to bridge 3, but not to the aural loops In bridge 3 the carrier voltages coming from bridges 2 and 4 feed the center loop and oppose each other in resistance Z_3 If the magnitude of the two carriers is made equal and their phase adjusted properly, no carrier power is lost in Z_3 Half the sideband power entering bridge 3, however, is lost in Z_3 In order to produce the aural course, only one of the voice modulated amplifiers feeding bridge 4 is modulated by 1020 cycles; thus, the 1020 cycle sideband currents enter the aural loops and the center loop

If the two voice modulated carriers entering bridge 4 are not equal in magnitude and phase, some voice sideband and carrier power is fed to the aural side loops and keyed in the rhythm of the D-U signals Tests have shown that as large an unbalance as 2.1 in magnitude of voice sidebands does not produce an objectionable amount of keyed voice

One feature of the Type D range which should not be overlooked is the use of modulated r f amplifiers instead of sideband generators In an amplifier the sidebands are inherently in proper phase relation with respect to the carrier If a properly phased carrier of amplitude A_1 is combined with an improperly phased carrier A_2 with a phase shift ϵ_2 the resulting carrier has a phase shift of but $1/2\ \epsilon_2$, if $A_1 = A_2$ This condition can be obtained for the Type D range The reduction in undesired phase shift between carrier and sidebands thus realized is very noticeable in improved voice quality

An advantage of the Type D range over the Type A-1, A-2, and C ranges is that the overall efficiency is more than doubled thus making it nearly equal to the Type B range. This results in an increased distance range of the three separate services

RECEIVER CONSIDERATIONS

The receiver, Type RUM, is a superheterodyne type with an I F of 10 Mc (carrier-frequency = 125 Mc) For Types A-1, B and D ranges, the receiver is identical By means of the conventional 1020 cycle bandpass, band-rejection filter, the voice and range frequencies are separated

In ranges of Types A-2 and C where double modulation is employed, the filters used for separation of the 12 kc and 20 kc subcarriers may be made relatively light and small However, a separate detector is required for each subcarrier which necessarily complicates the receiver

Results so far obtained with double modulation with a single voice channel show that this system of modulation is not sufficiently different in performance to single modulation as to recommend its use. However, if more than one voice channel is required, it will be necessary to use double modulation with the attendant complication in receiver design.

SYSTEM SELECTED

After reviewing the merits of the various systems the Civil Aeronautics Administration has selected the Type B system for installation since it is the most efficient system and is the simplest to install and adjust

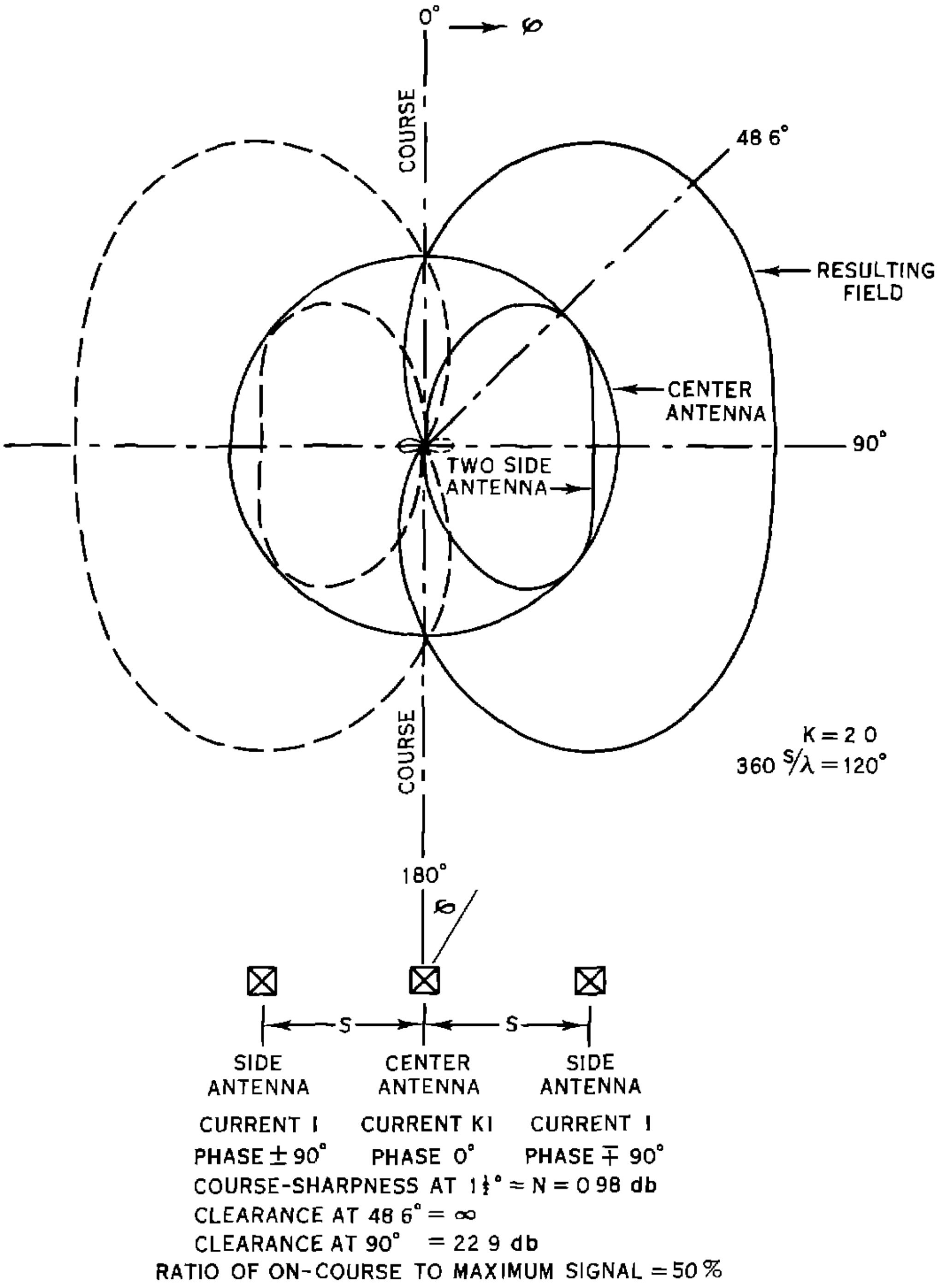


Figure 1 UHF Two Course Radio Range Horizontal Field Pattern

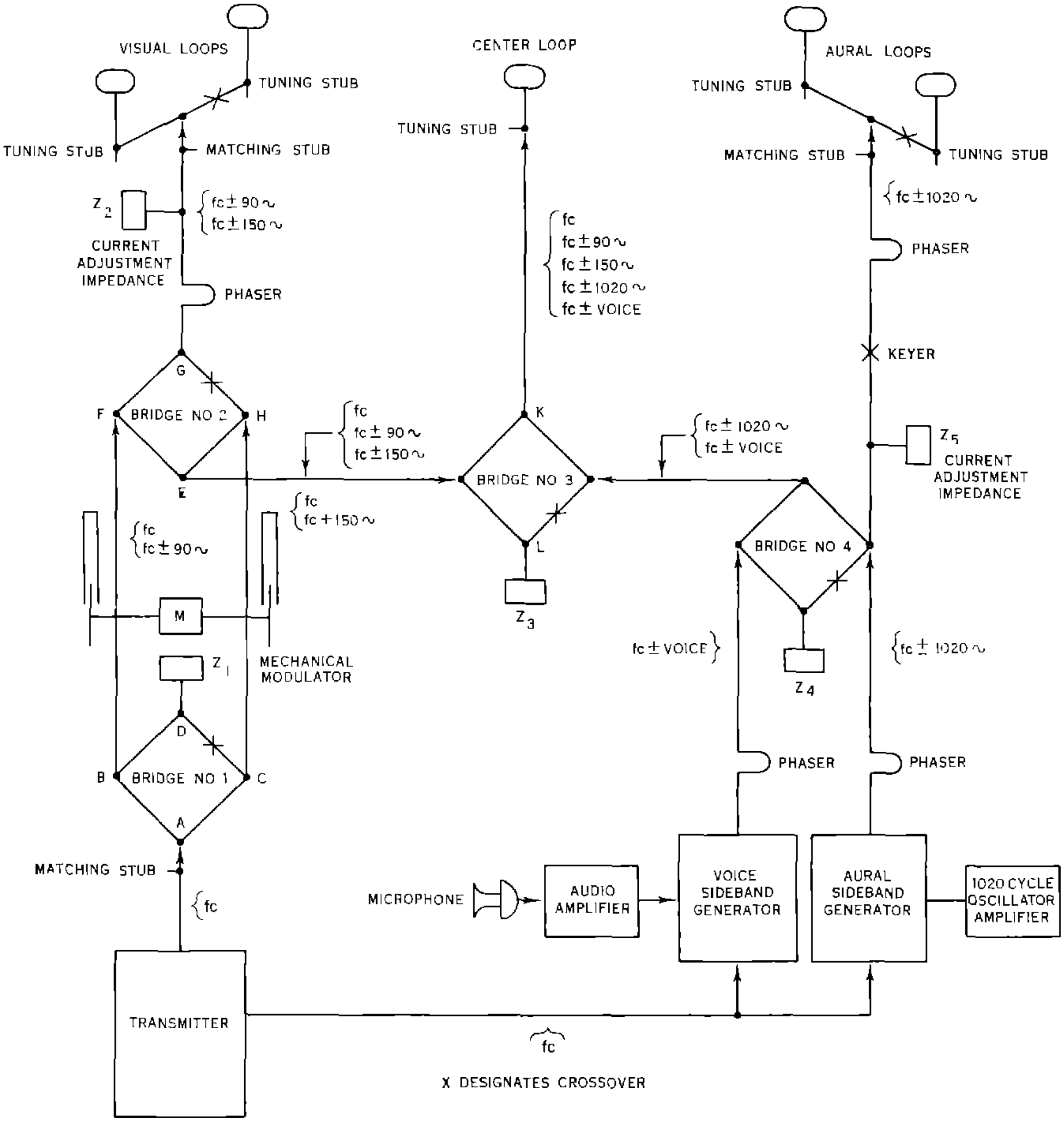


Figure 2 Type A-1 Range Block Diagram

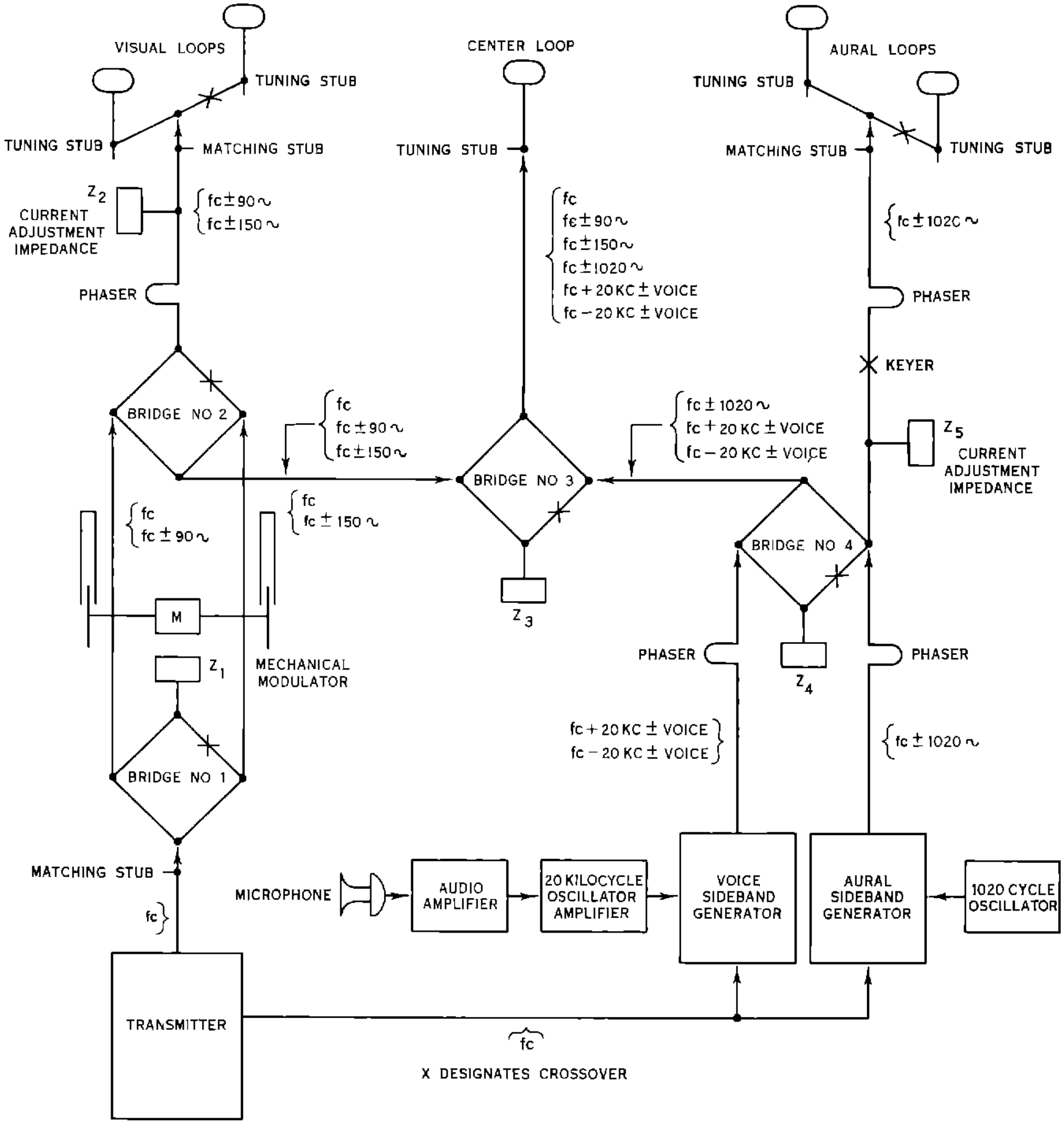


Figure 3 Type A-2 Range Block Diagram

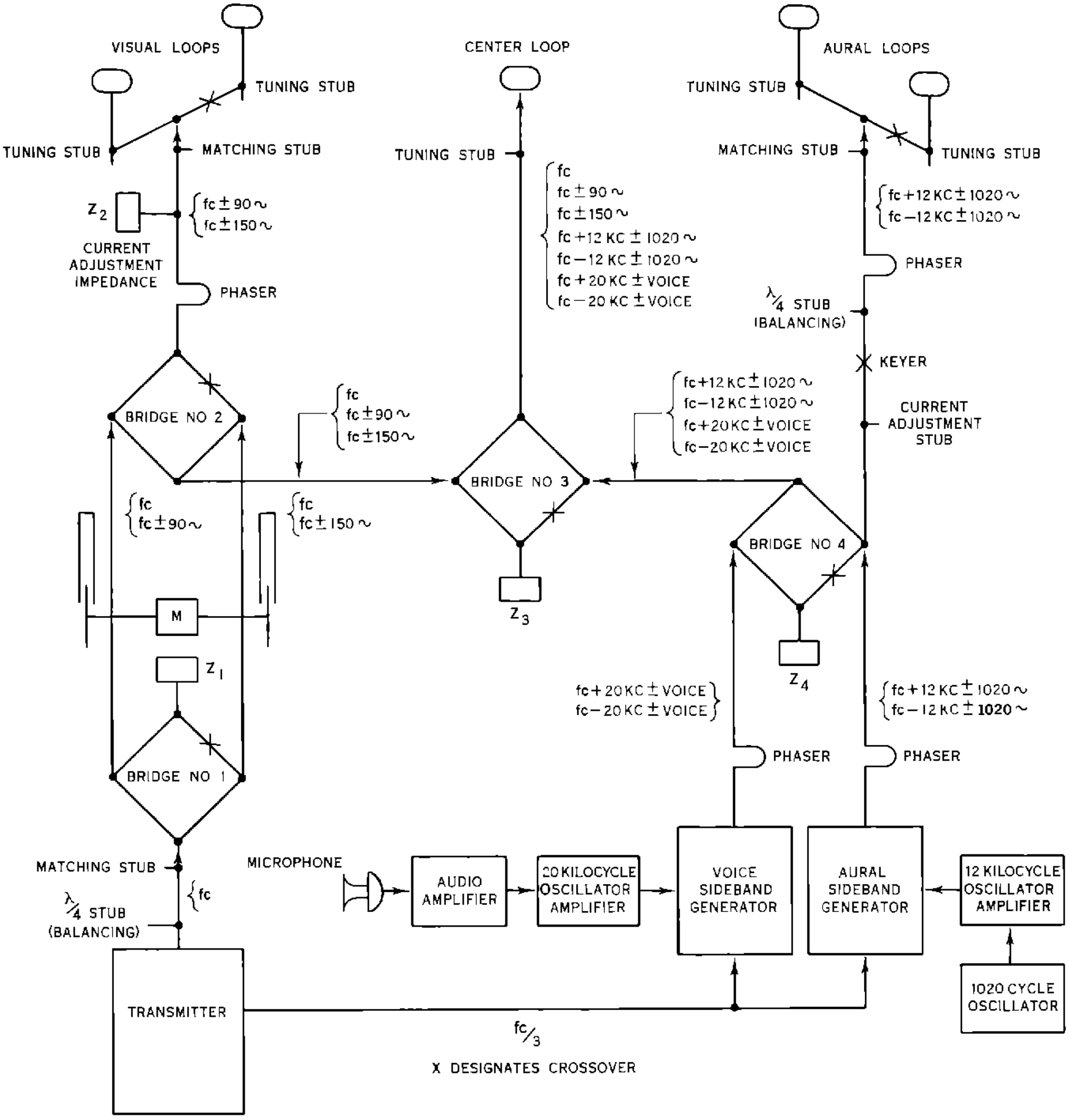


Figure 4 Type C Range Block Diagram

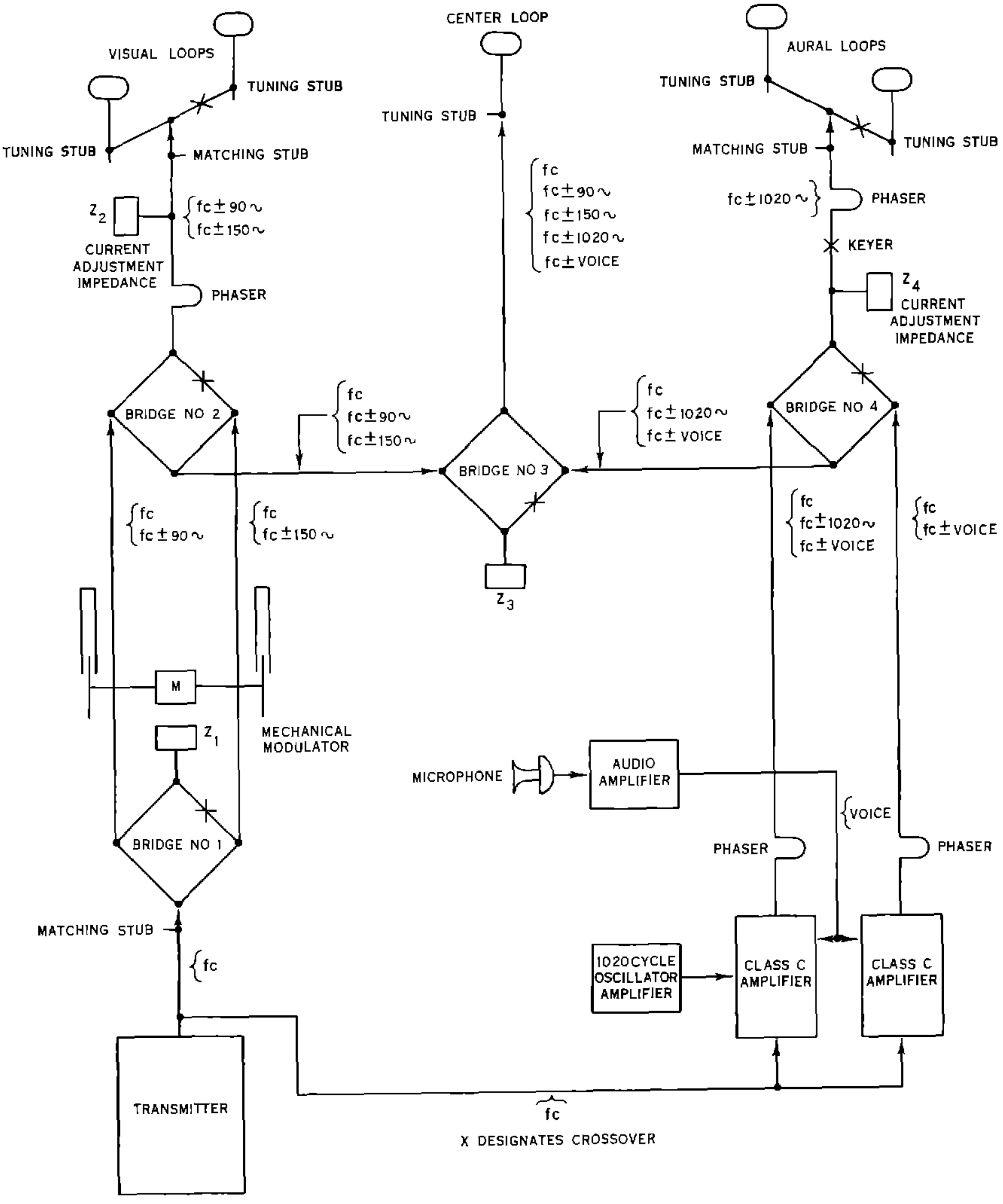


Figure 5 Type D Range Block Diagram

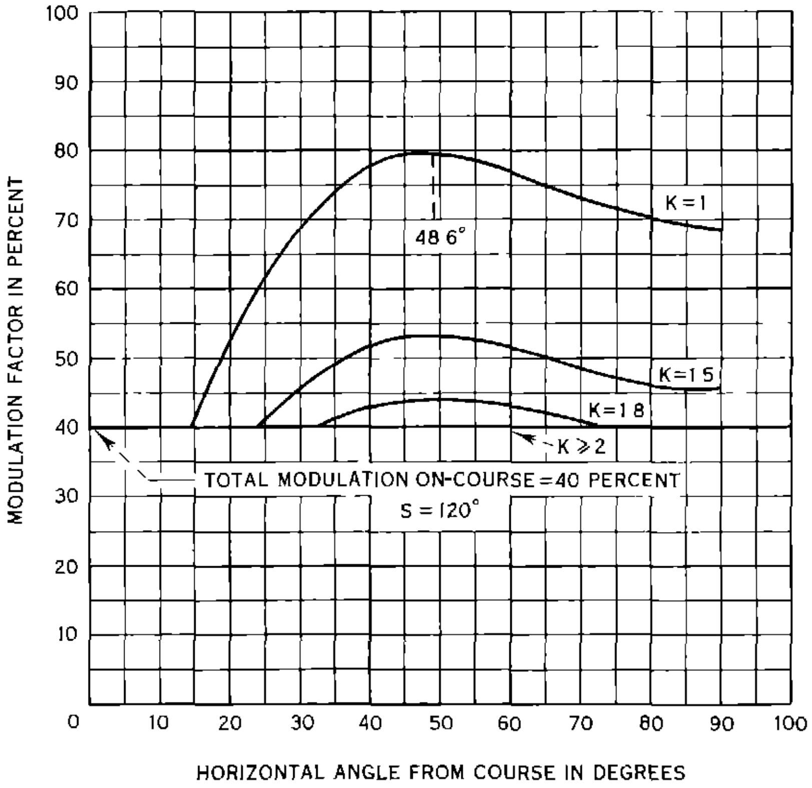


Figure 6 UHF Two-Course Range Modulation Percentage Versus Horizontal Angle from the Course

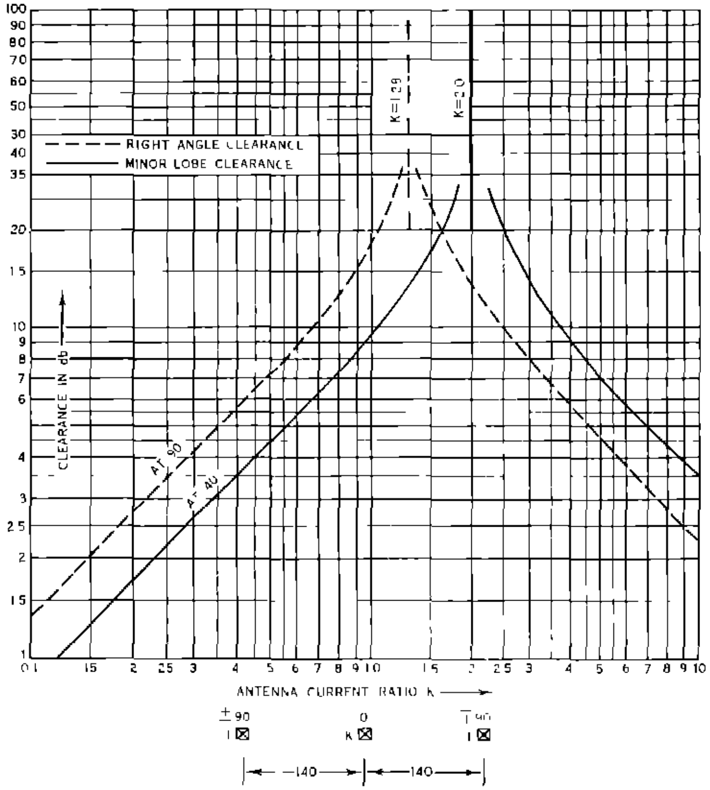


Figure 7 Effect of Current in Center Antenna on Clearance

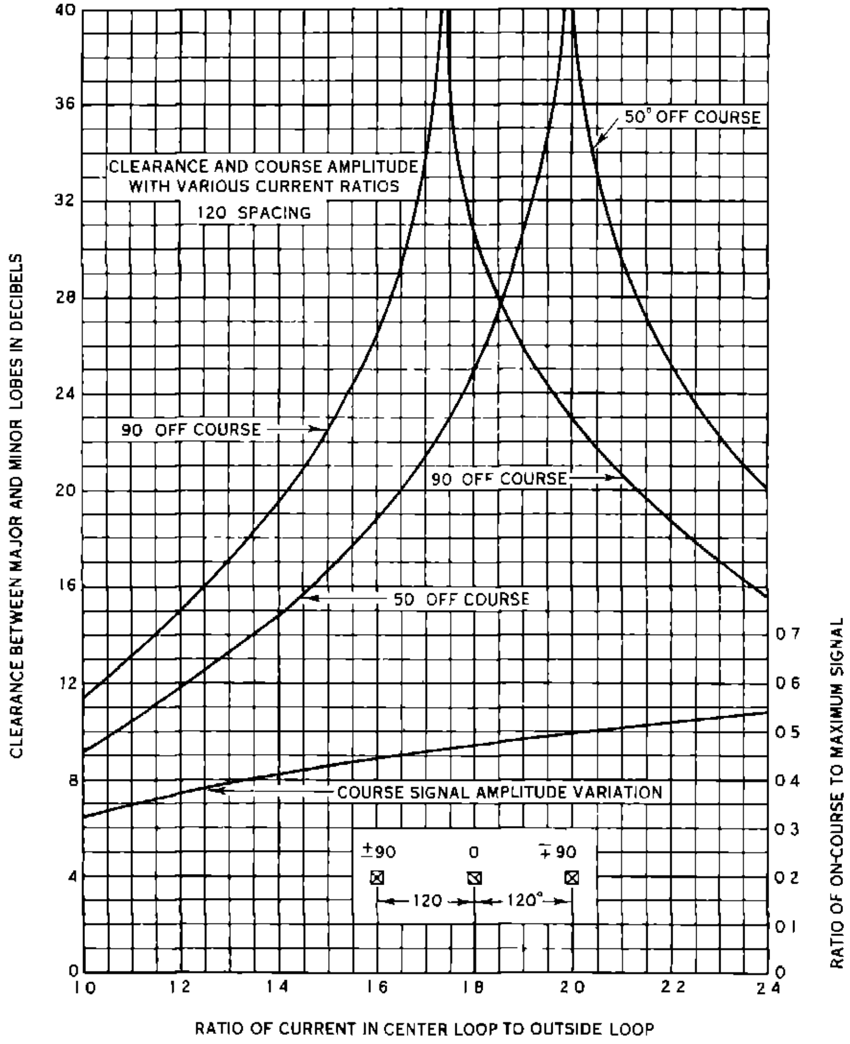


Figure 8 Clearance and Course Amplitude with Various Current Ratios, Antenna Spacing 120°

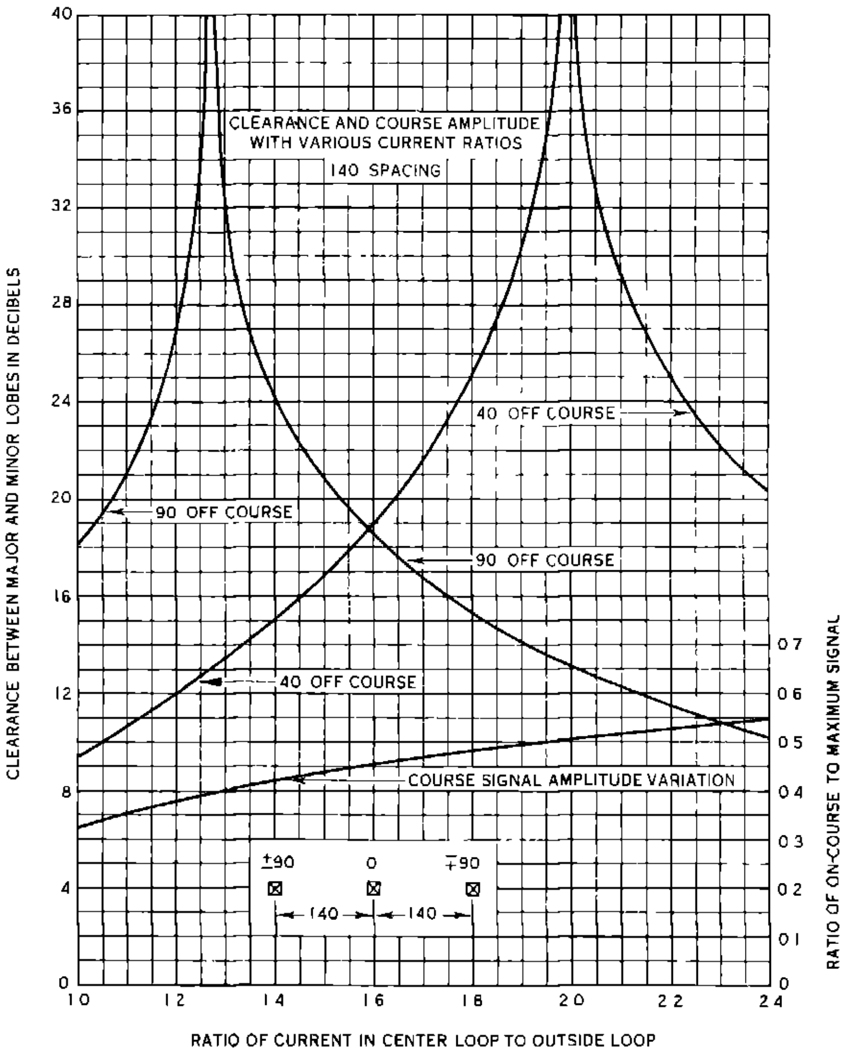


Figure 9 Clearance and Course Amplitude with Various Current Ratios, Antenna Spacing 140°

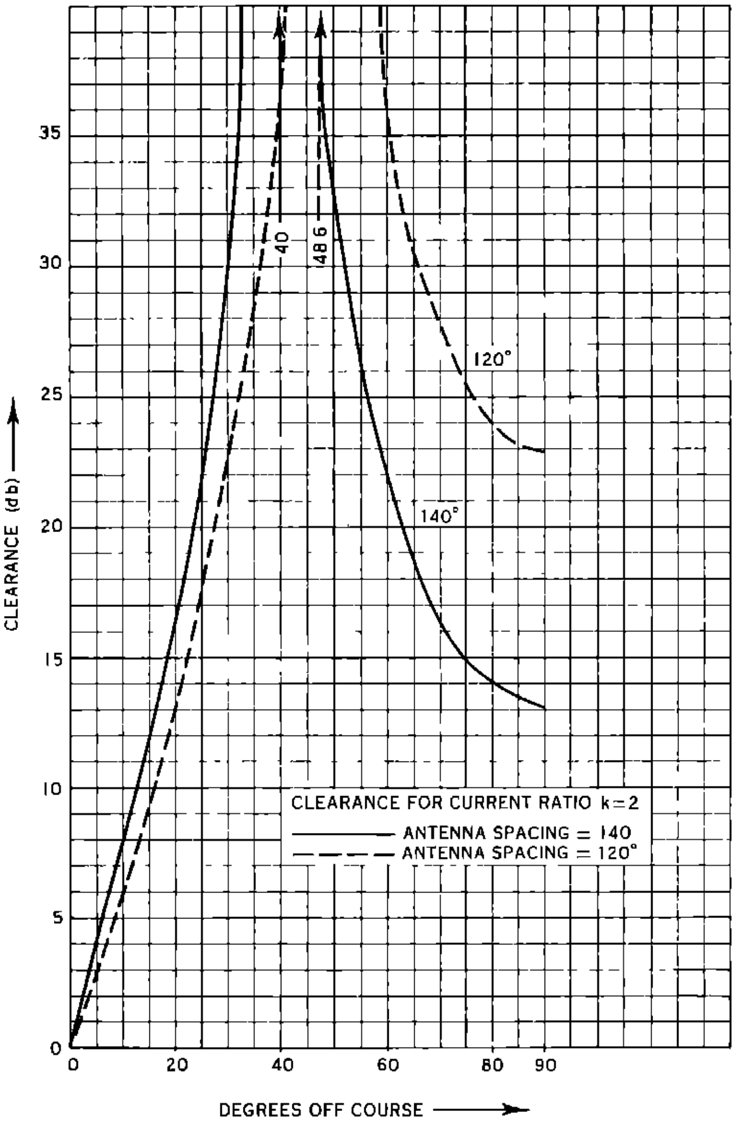


Figure 10 Clearance for Current Ratio of Two

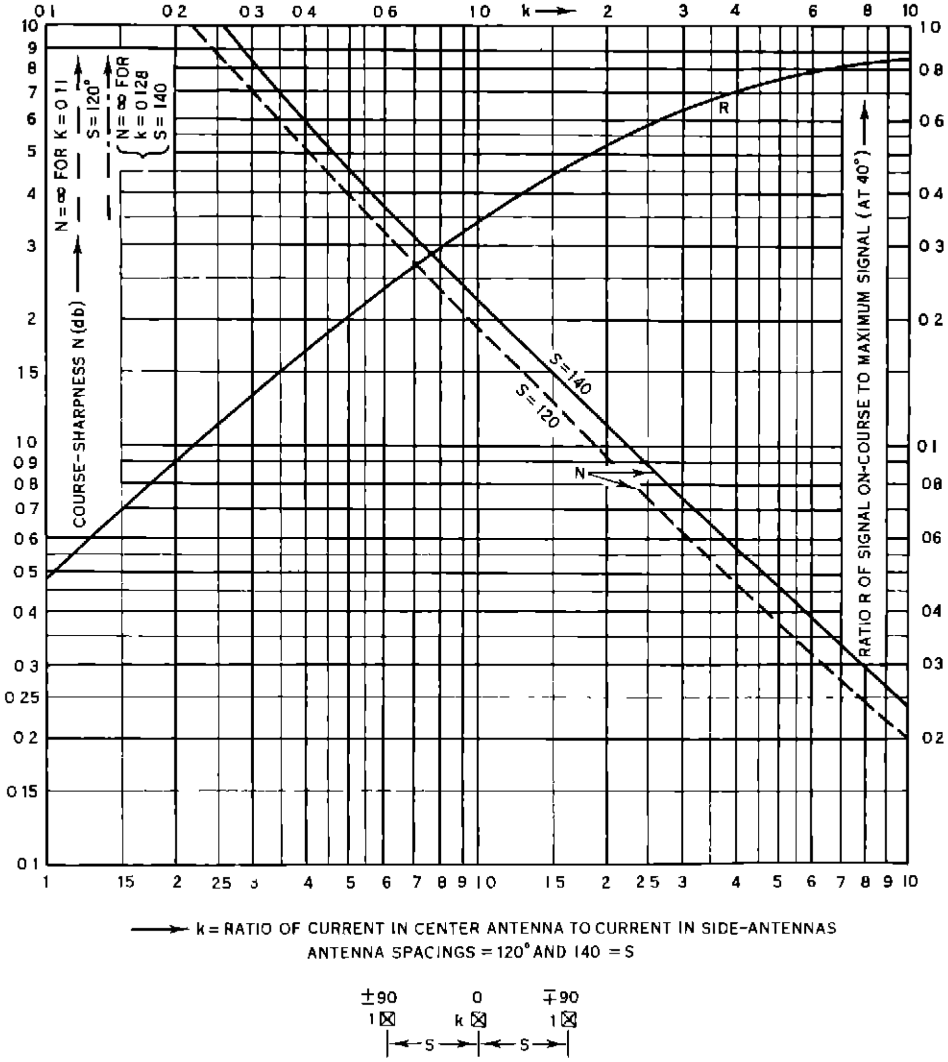
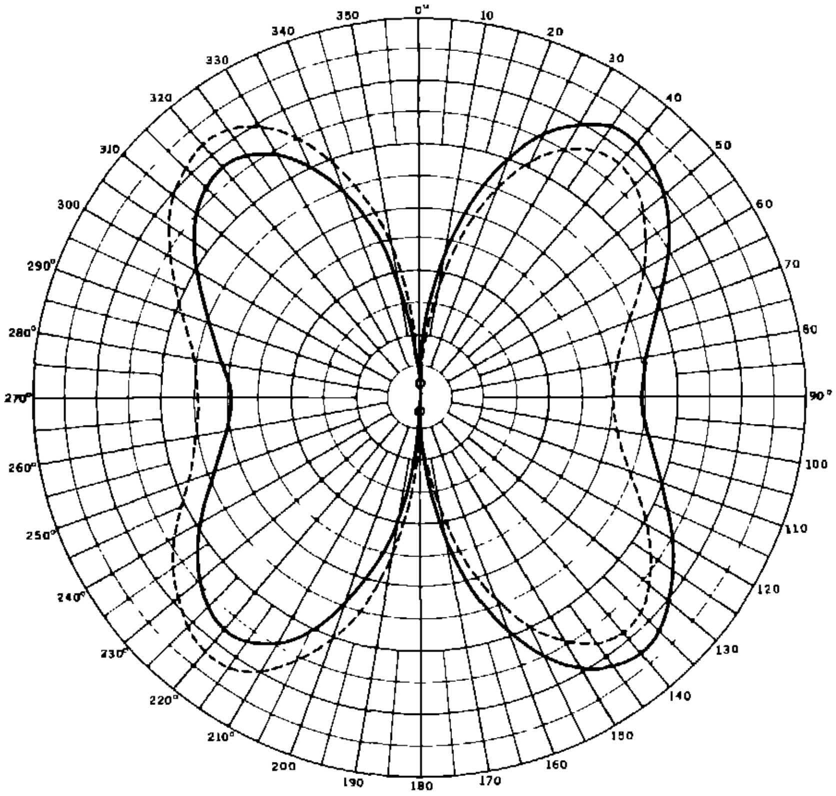


Figure 11 Effect of Current in Center Antenna on Course-Sharpness and On Relative Signal Strength on Course



K = 0 1

±90° 0° ∓90

1 ⊠ 0 1 ⊠ 1 ⊠

|←140°→|←140°→|

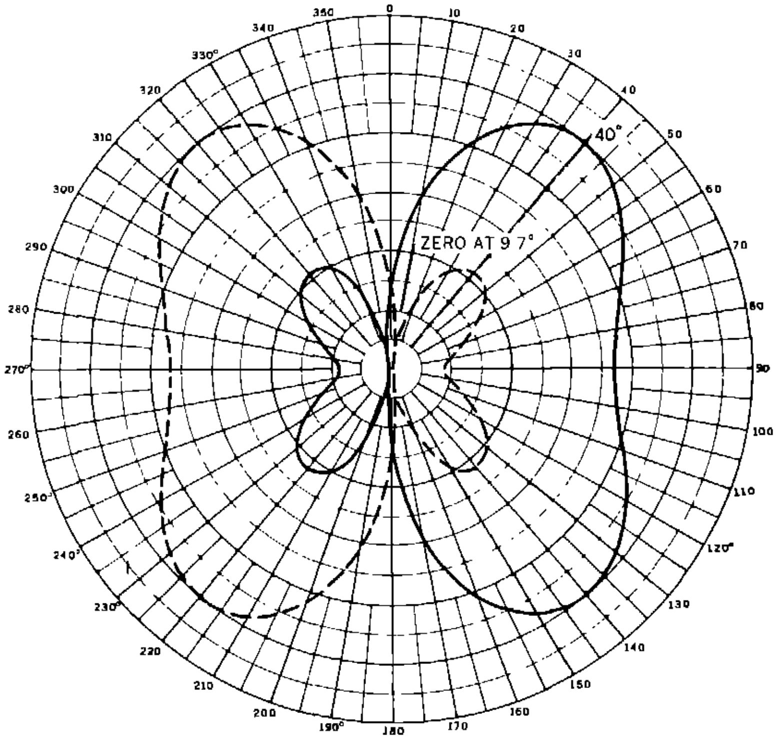
COURSE SHARPNESS = 18 2 db

CLEARANCE AT 90° = 1 35 db

CLEARANCE AT 40° = 0 87 db

ON COURSE TO MAXIMUM SIGNAL = 0 47

Figure 12 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 0 10, Antenna Spacing 140°.



k = 0 8

± 90 0 ∓ 90

1 ⊠ 0 8 ⊠ 1 ⊠

|←140°→|←140°→|

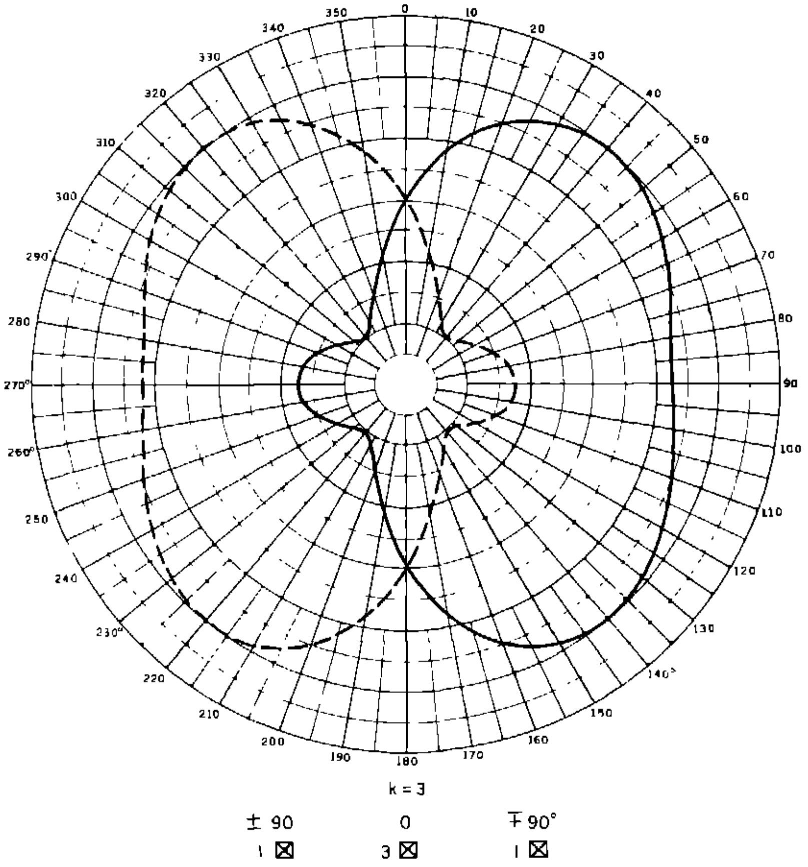
COURSE – SHARPNESS = 2 85 db

CLEARANCE AT 90 = 13 db

CLEARANCE AT 40 = 7 4 db

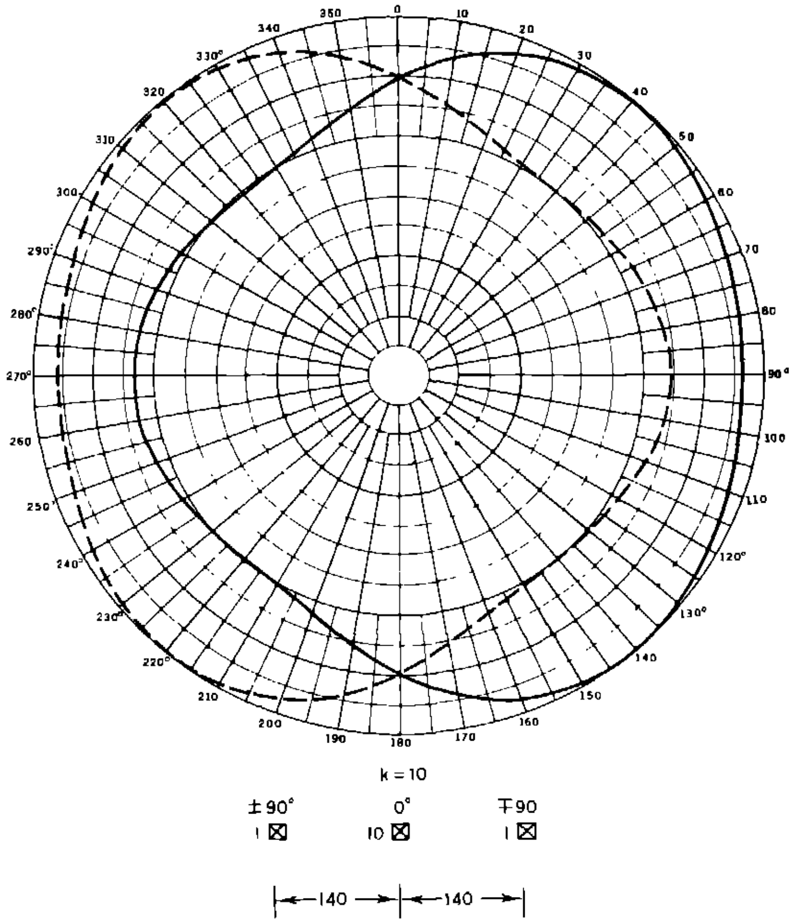
ON-COURSE TO MAXIMUM SIGNAL = 0 285

Figure 13 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 0 8, Antenna Spacing 140°



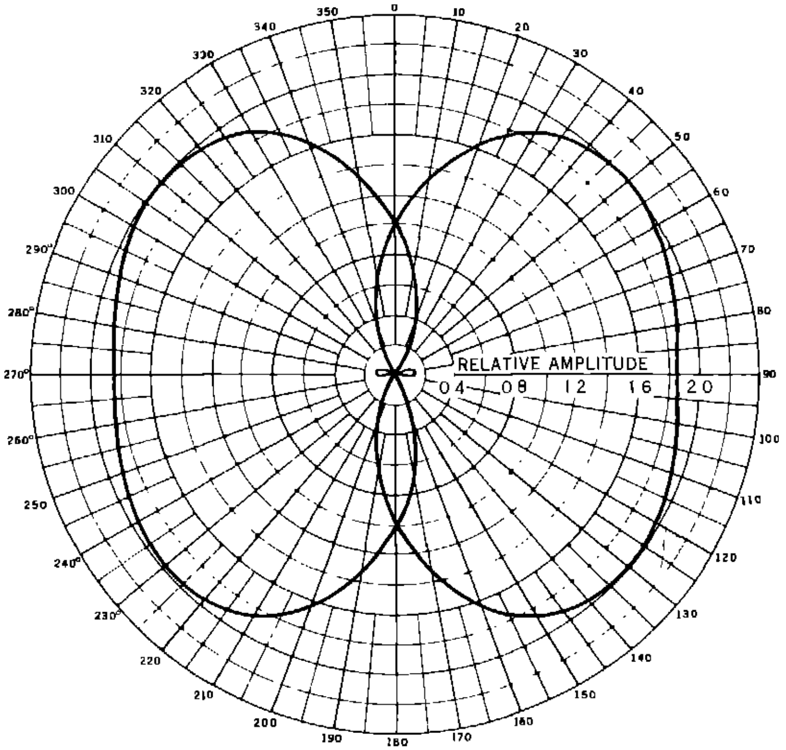
COURSE-SHARPNESS = 0 75 db
CLEARANCE AT 90 = 7 98 db
CLEARANCE AT 40° = 14 db
ON-COURSE TO MAXIMUM SIGNAL - 0 6

Figure 14 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 3, Antenna Spacing 140°



COURSE-SHARPNESS = 0 24 db
CLEARANCE AT 90 = 2 22 db
CLEARANCE AT 40 = 3 52 db
ON-COURSE TO MAXIMUM SIGNAL = 0 83

Figure 15 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 10, Antenna Spacing 140°



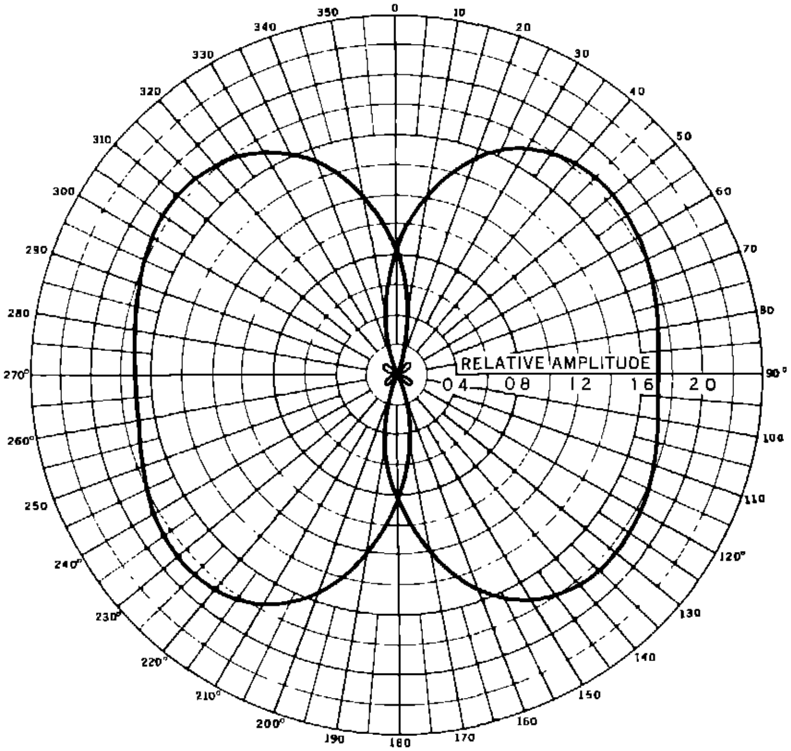
HORIZONTAL FIELD PATTERN

±90 0" ∓90°
1 ☒ 2 ☒ 1 ☒

|←120→|←120→|

COURSE-SHARPNESS AT 1 5 = 0 984 db
MINOR LOBE CLEARANCE = 22 8 db
ON-COURSE TO MAXIMUM SIGNAL = 6 0 db

Figure 16 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 2, Antenna Spacing 120°



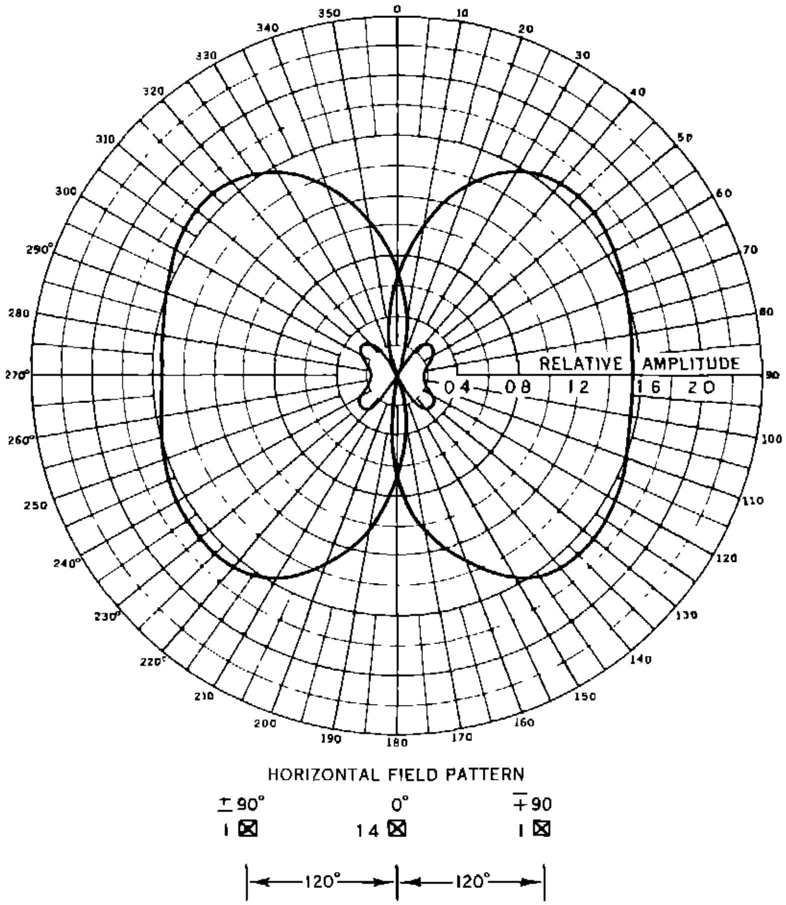
HORIZONTAL FIELD PATTERN

±90 0 ∓90
1 ☒ 1 73 ☒ 1 ☒

|←120→|←120°→|

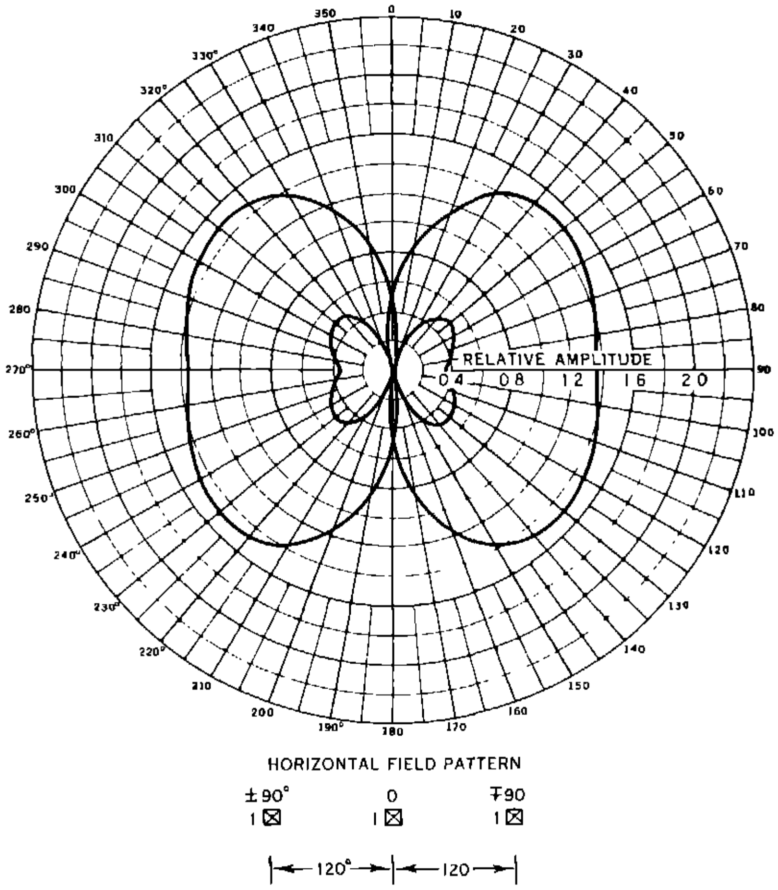
COURSE-SHARPNESS AT 1 5° = 1 14 db
MINOR LOBE CLEARANCE = 22 8 db
ON-COURSE / MAXIMUM SIGNAL = 6 69 db

Figure 17 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 1 73, Antenna Spacing 120°



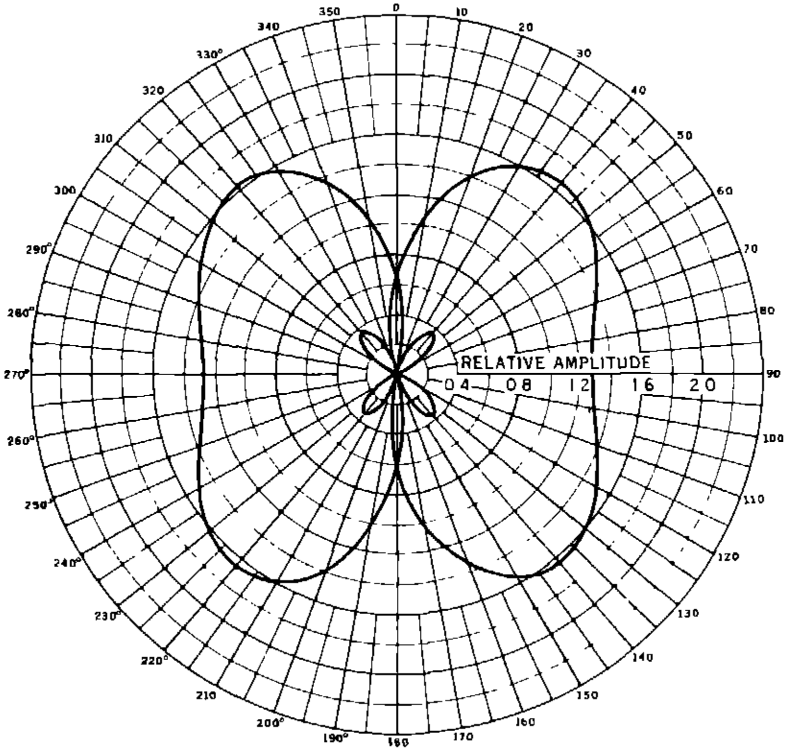
COURSE SHARPNESS AT 1 5° = 1 36 db
MINOR LOBE CLEARANCE (48 6) = 15 1 db
ON COURSE TO MAXIMUM SIGNAL = 7 71 db

Figure 18 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 1 4, Antenna Spacing 120°



COURSE-SHARPNESS AT 1 5 = 1 94 db
MINOR LOBE CLEARANCE (48 6°) = 9 54 db
ON COURSE / MAXIMUM SIGNAL = 9 54 db

Figure 19 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 1, Antenna Spacing 120°



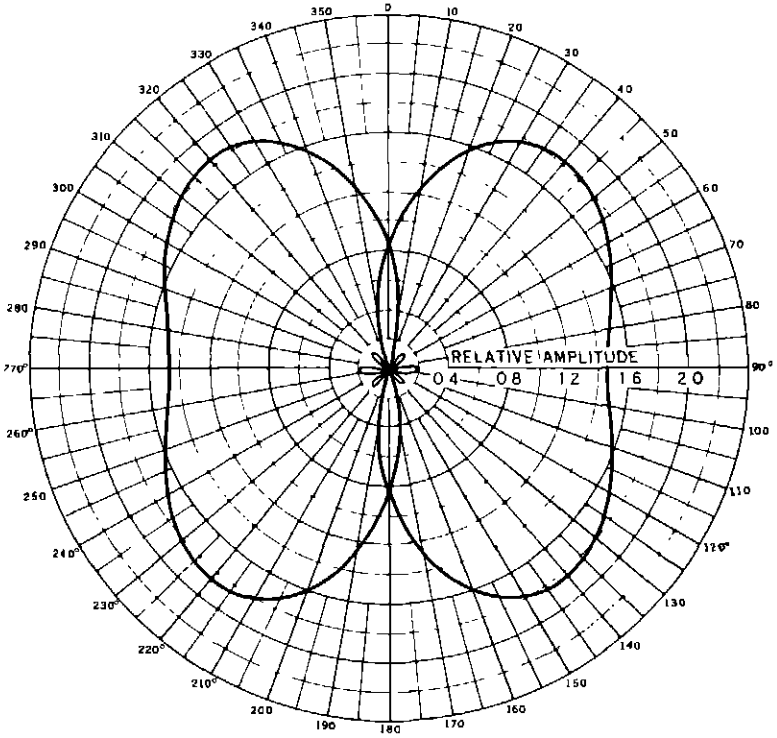
HORIZONTAL FIELD PATTERN

±90°	0°	∓90
1 ⊠	1.28 ⊠	1 ⊠

|←140°→|←140°→|

COURSE-SHARPNESS AT 1.5° = 1.73 db
MINOR LOBE CLEARANCE = 13.16 db
ON COURSE / MAXIMUM SIGNAL = 8.17 db

Figure 20 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 1.28, Antenna Spacing 140°



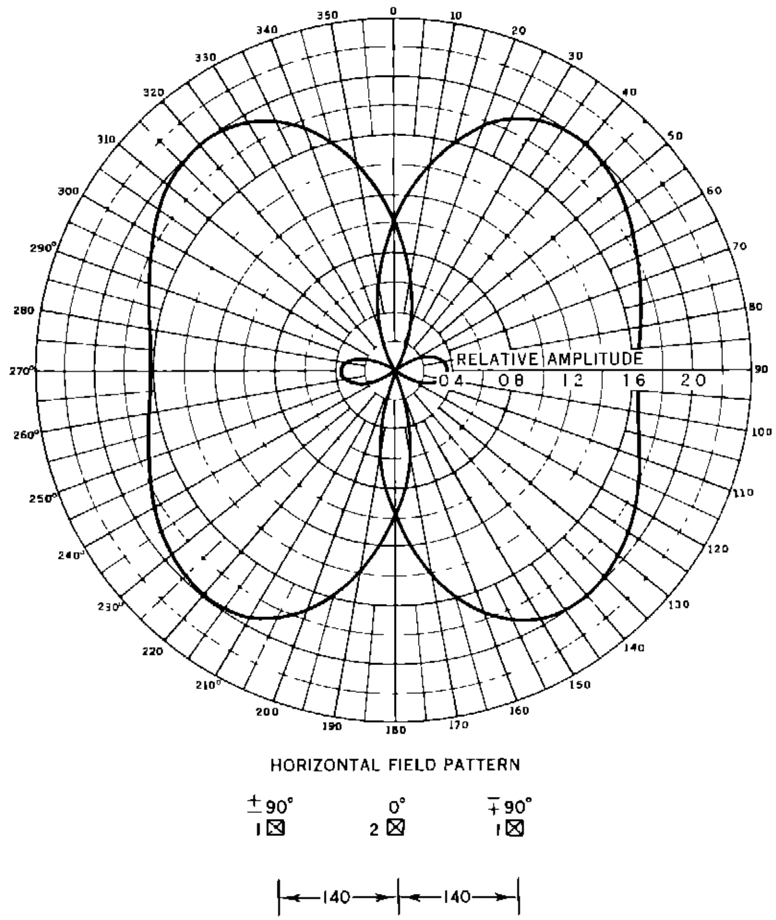
HORIZONTAL FIELD PATTERN

±90	0	∓90
1 ⊠	1.68 ⊠	1 ⊠

|←140°→|←140→|

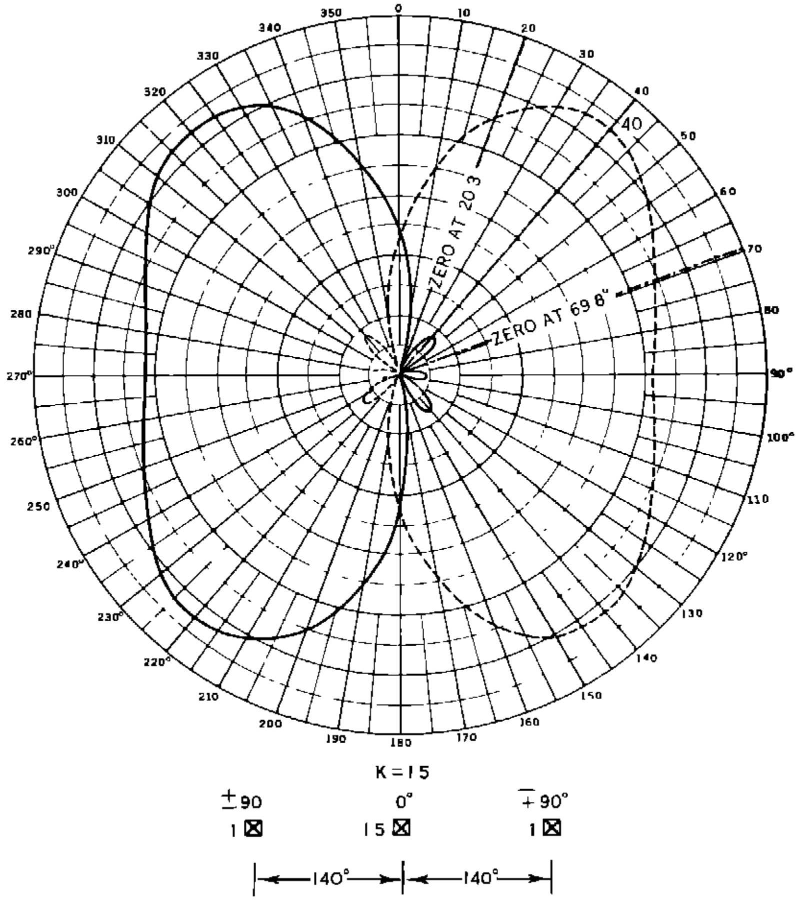
COURSE-SHARPNESS AT 1.5 = 1.33 db
MINOR LOBE CLEARANCE (90°) = 17.52 db
ON-COURSE / MAXIMUM SIGNAL = 6.81 db

Figure 21 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 1.68, Antenna Spacing 140°



COURSE-SHARPNESS AT 1.5 = 11.2 db
MINOR LOBE CLEARANCE = 13.26 db
ON-COURSE / MAXIMUM SIGNAL = 6.0 db

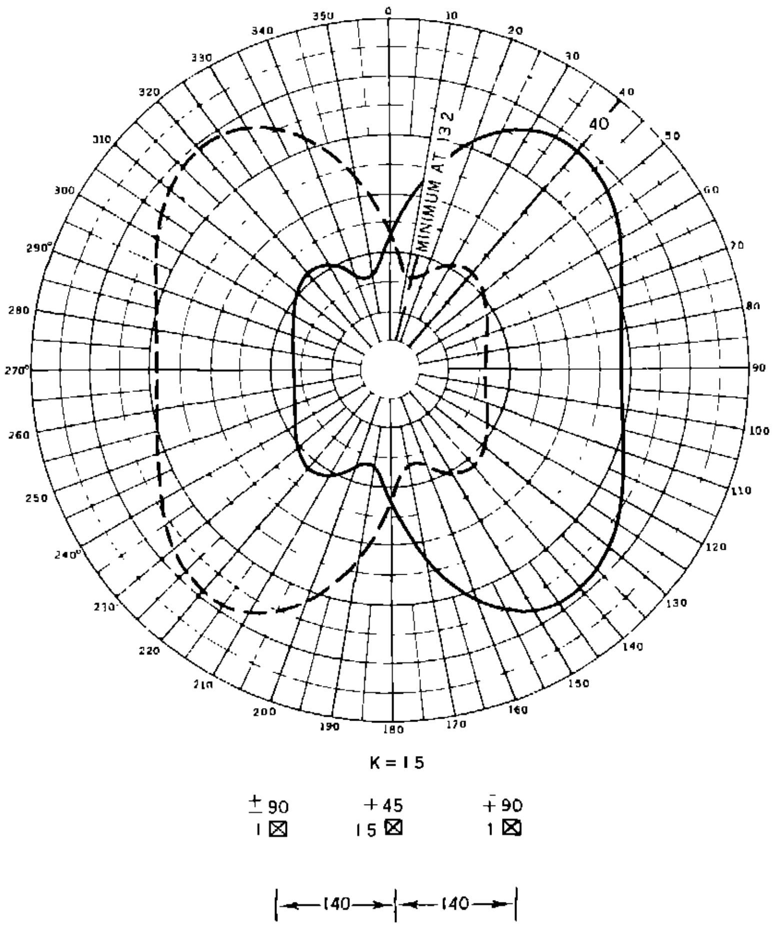
Figure 22 Effect of Antenna Current Ratio on the Horizontal Field Pattern, K = 2, Antenna Spacing 140°



(CORRECT PHASING)

COURSE SHARPNESS = 1.5 db
CLEARANCE AT 40° = 16.9 db
CLEARANCE AT 90 = 22.3 db
ON COURSE TO MAXIMUM SIGNAL = 0.43

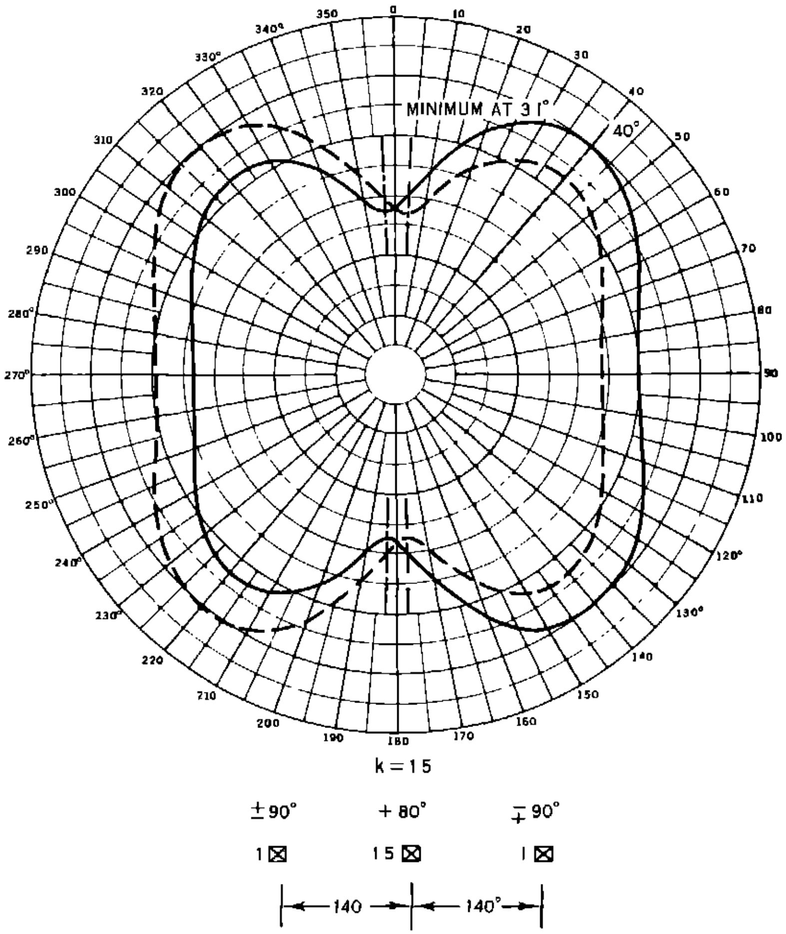
Figure 23 Effect of Phase of Current in Center Antenna on the Horizontal Field Pattern, Center Antenna Phase 0°



COURSE SHARPNESS – 1 03 db
CLEARANCE AT 40 = 7 2 db
CLEARANCE AT 90 = 7 5 db

ON COURSE TO MAXIMUM SIGNAL – 0 46

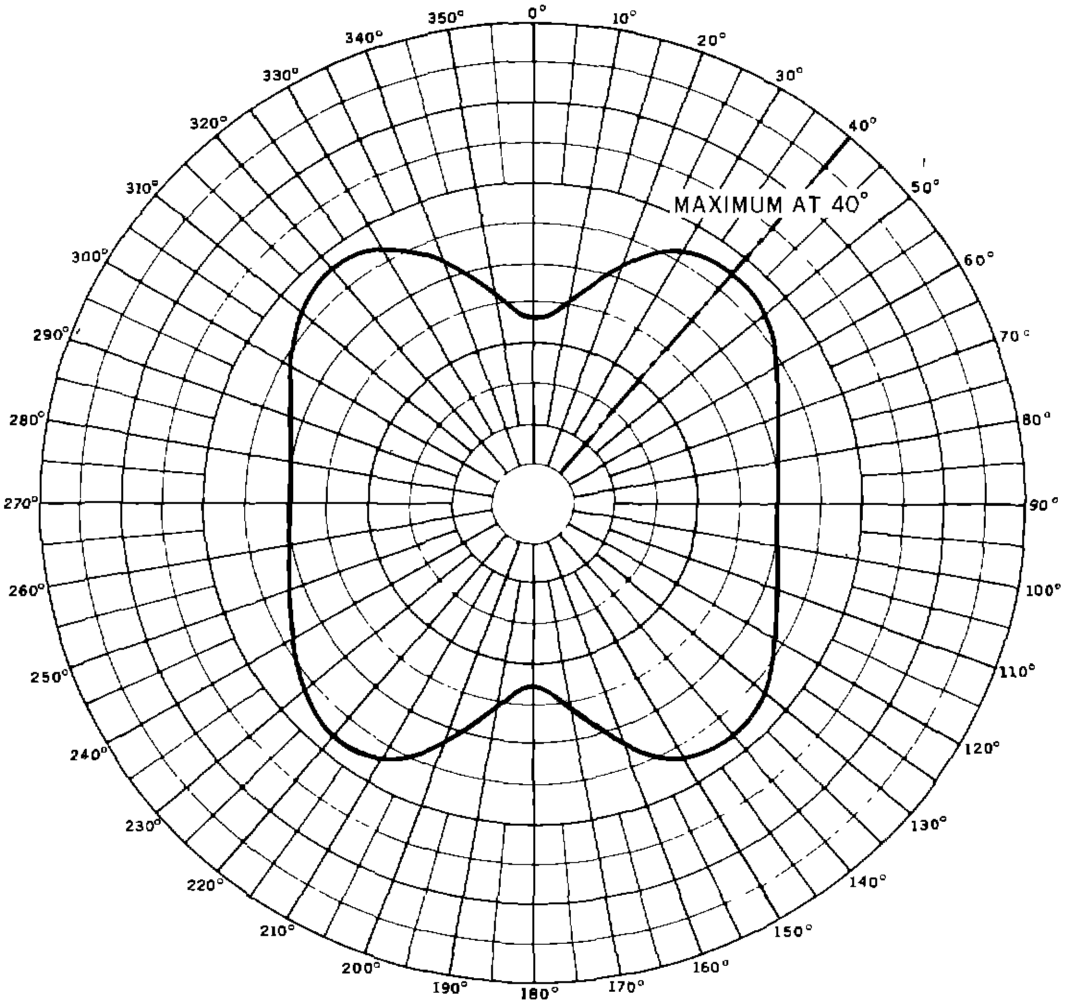
Figure 24 Effect of Phase of Current in Center Antenna on the Horizontal Field Pattern, Center Antenna Phase 45°



COURSE – SHARPNESS ≈ 0 26 db
CLEARANCE AT 40 ≈ 1 45 db
CLEARANCE AT 90° ≈ 1 5 db

ON-COURSE TO MAXIMUM SIGNAL = 0 56

Figure 25 Effect of Phase of Current in Center Antenna on the Horizontal Field Pattern, Center Antenna Phase 80°



K = 1 5

± 90°	+ 90°	∓ 90°
1 ☒	1 5 ☒	1 ☒

|←140°→|←140°→|

(BOTH PATTERNS COINCIDE)
COURSE-SHARPNESS = 0 db
ON-COURSE TO MAXIMUM SIGNAL = 0 6

Figure 26 Effect of Phase of Current in Center Antenna on the Horizontal Field Pattern. Center Antenna Phase 90°

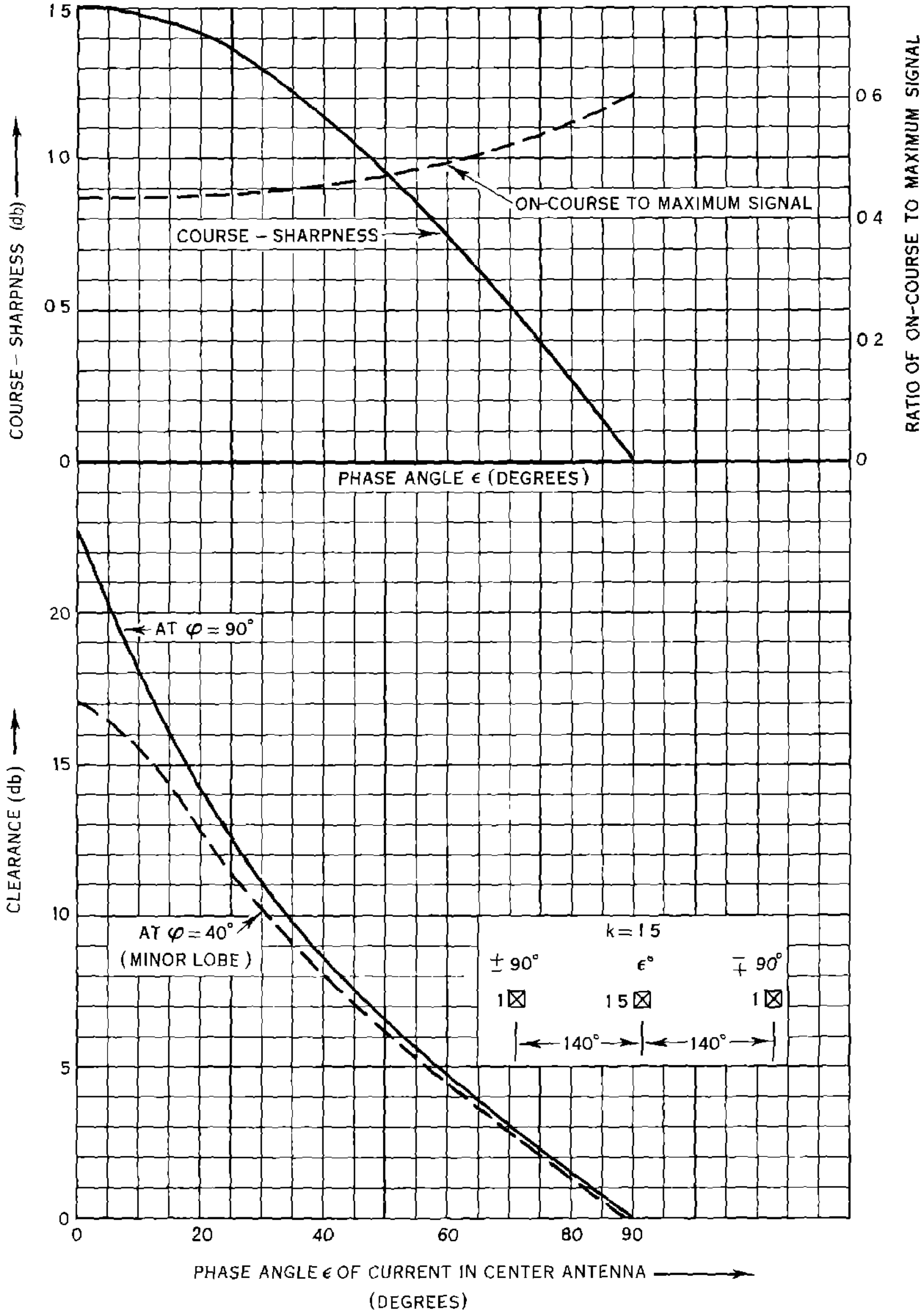
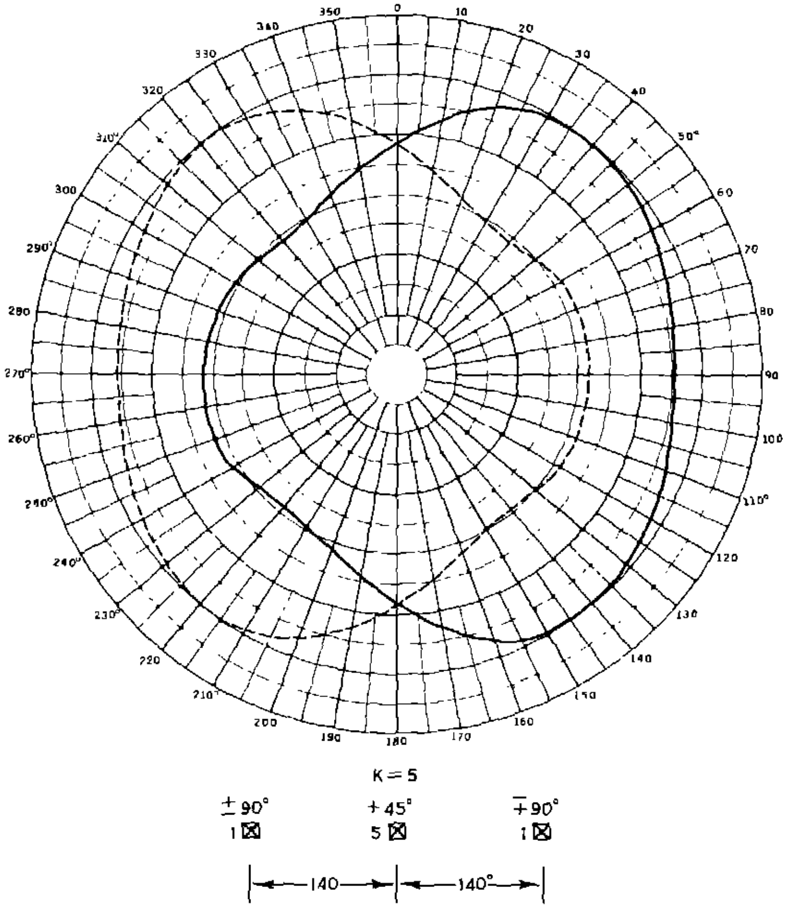
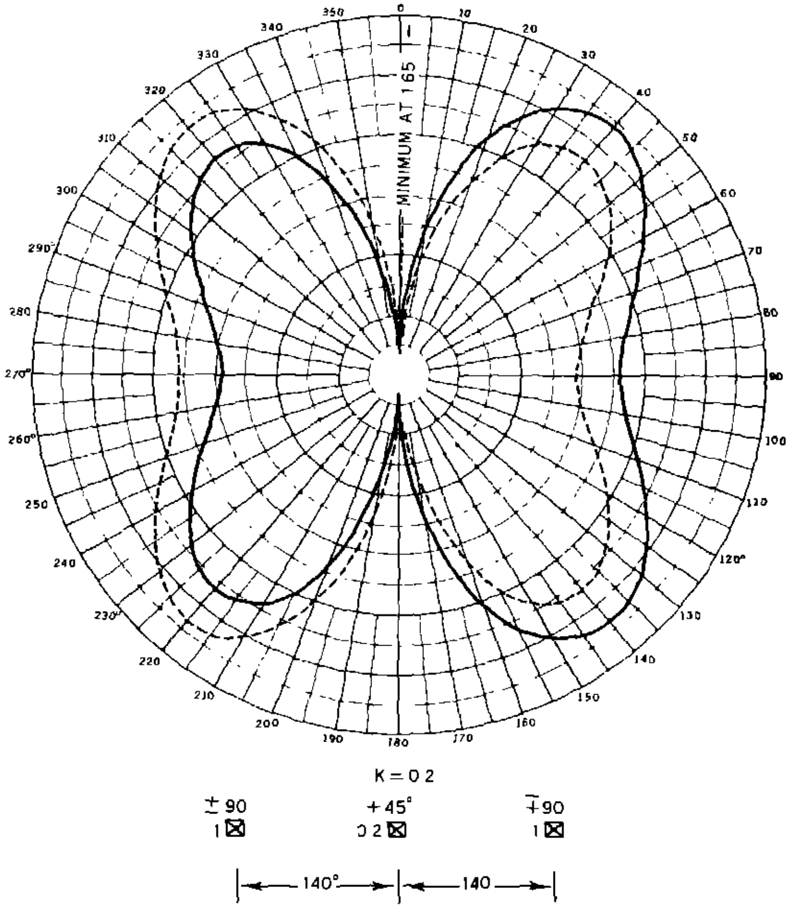


Figure 27 Effect of Phase Angle of Current in Center Antenna on Clearance, Course-Sharpness and Relative Signal Strength on Course



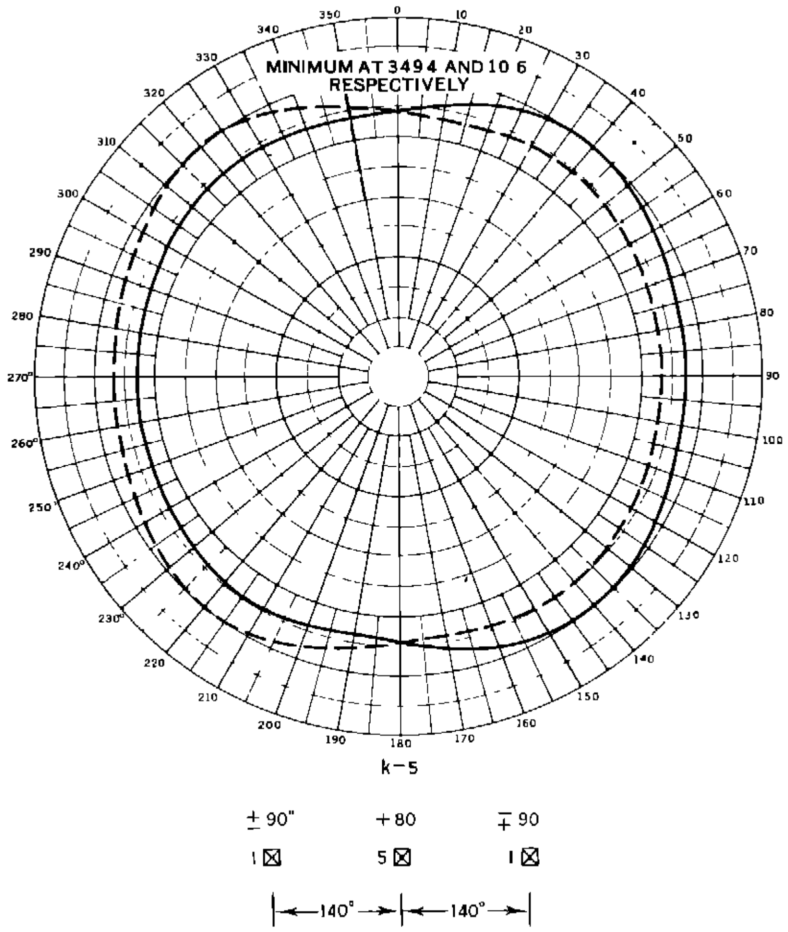
COURSE SHARPNESS = 0 3 db
CLEARANCE AT 90 ≐ 3 08 db
CLEARANCE AT 40 = 4 63 db
ON COURSE TO MAXIMUM SIGNAL ≐ 76%

Figure 28 Effect of Magnitude and Phase of Current in Center Antenna on Horizontal Field Pattern, K=5, Center Antenna 45°



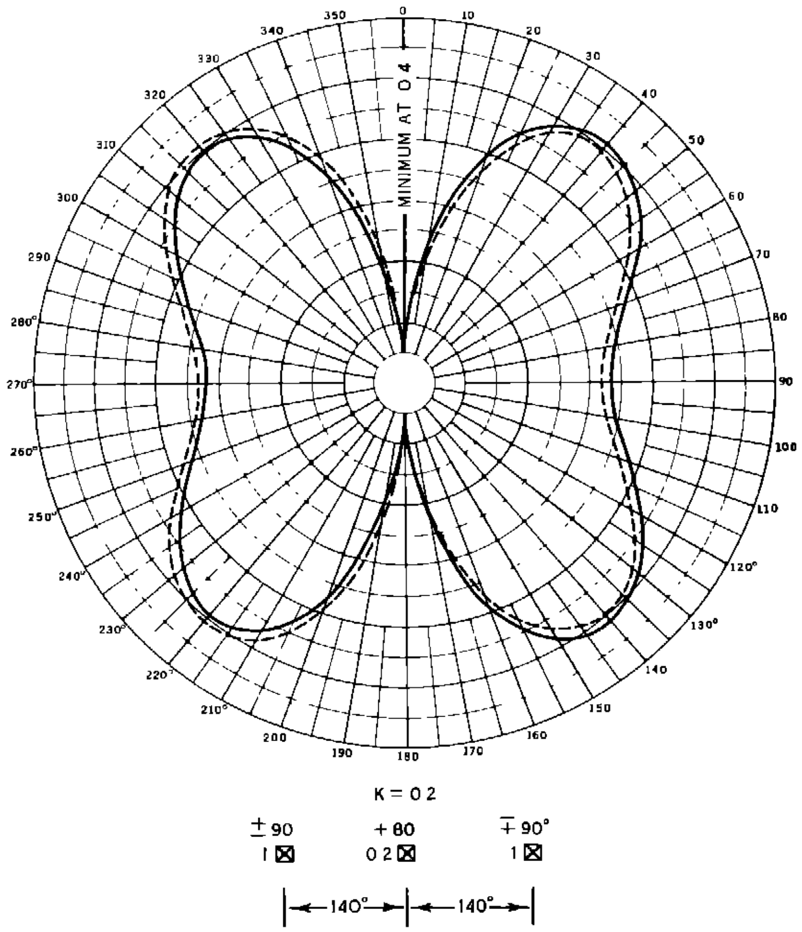
COURSE SHARPNESS = 4 44 db
CLEARANCE AT 90 = 1 87 db
CLEARANCE AT 40 = 1 21 db
ON COURSE TO MAXIMUM SIGNAL ≐ 9 3%

Figure 29 Effect of Magnitude and Phase of Current in Center Antenna on Horizontal Field Pattern, K = 0 2, Center Antenna 45°



COURSE – SHARPNESS – 0 069 db
CLEARANCE AT 90 = 0 75 db
CLEARANCE AT 40 – 1 06 db
ON-COURSE TO MAXIMUM SIGNAL = 88%

Figure 30 Effect of Magnitude and Phase of Current in Center Antenna on Horizontal Field Pattern, K=5, Center Antenna 80°



COURSE SHARPNESS = 1 97 db
CLEARANCE AT 90 = 44 db
CLEARANCE AT 40 = 30 db
ON COURSE TO MAXIMUM SIGNAL = 9 8%

Figure 31 Effect of Magnitude and Phase of Current in Center Antenna on Horizontal Field Pattern, K=0 2, Center Antenna 45°

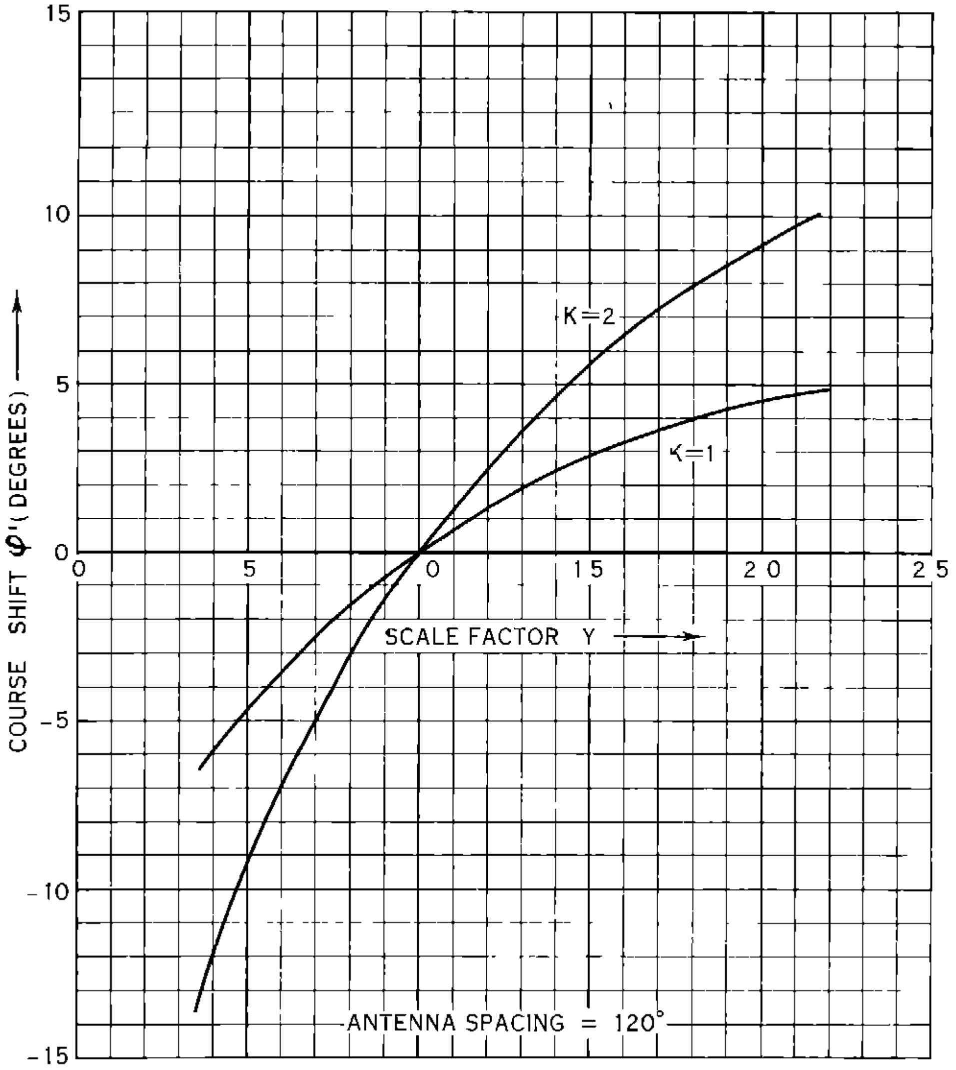


Figure 32 Course Shift Obtained with Two Similar Beam Patterns Differing by Scale Factor Y

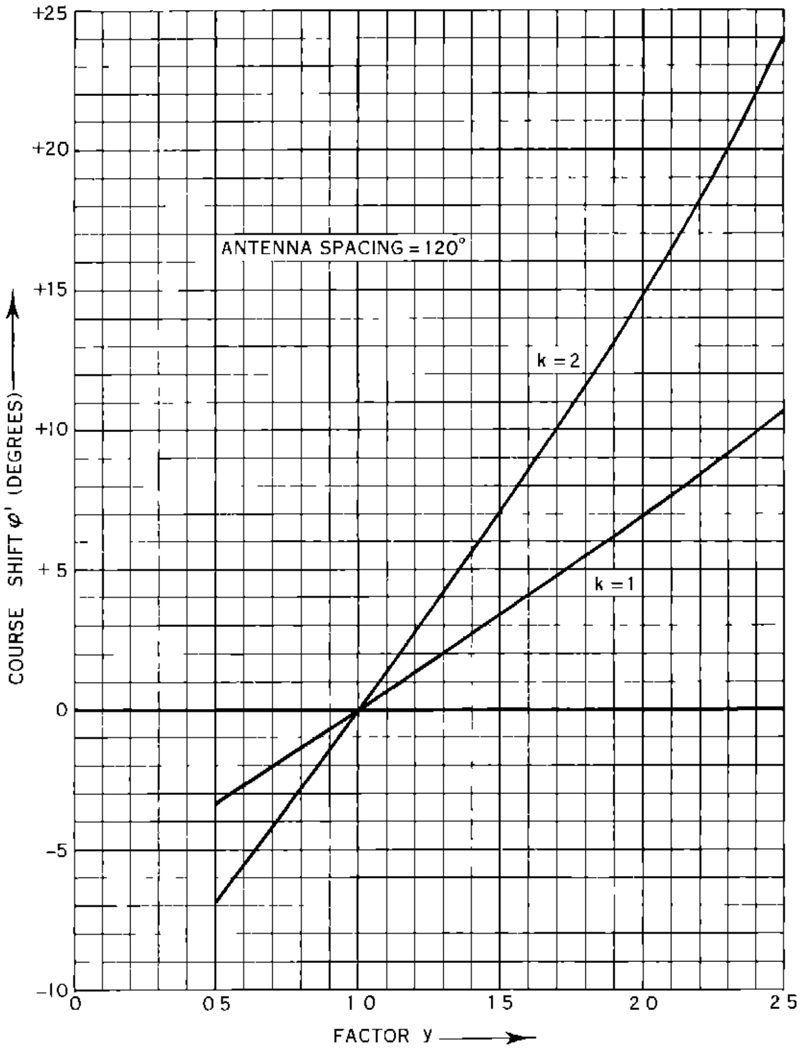


Figure 33 Course-Shift Obtained if Current in Center Antenna of One Beam Pattern is Multiplied by Factor Y

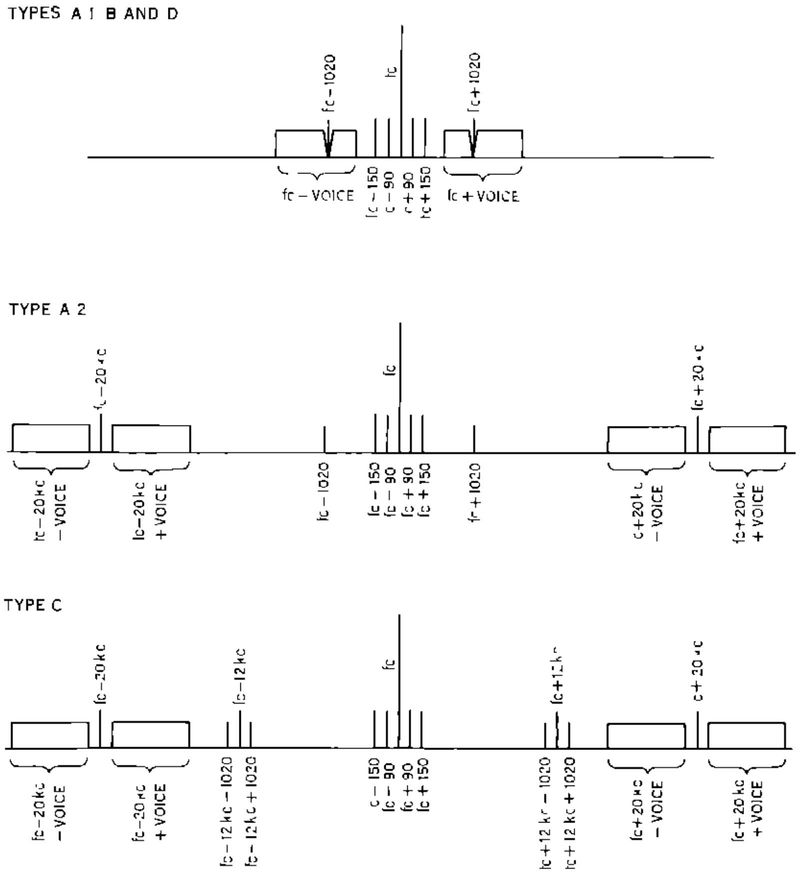


Figure 34 Radiated Frequency Spectra of UHF Simultaneous Ranges

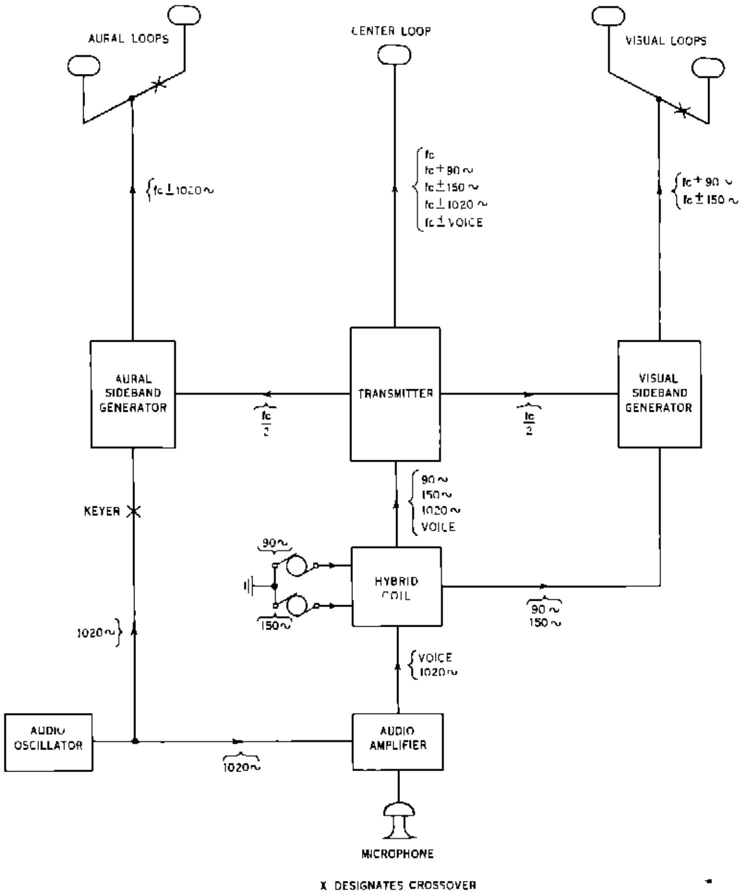


Figure 35 Schematic Diagram of UHF Simultaneous Range Type B