

Oct. 29, 1968

J. BLASS

3,408,653

ANTENNA SYSTEM COMPENSATING FOR PRISM EFFECT UTILIZING
CONTROL MEANS AT THE SIGNAL FEED

Filed Nov. 12, 1964

5 Sheets-Sheet 1

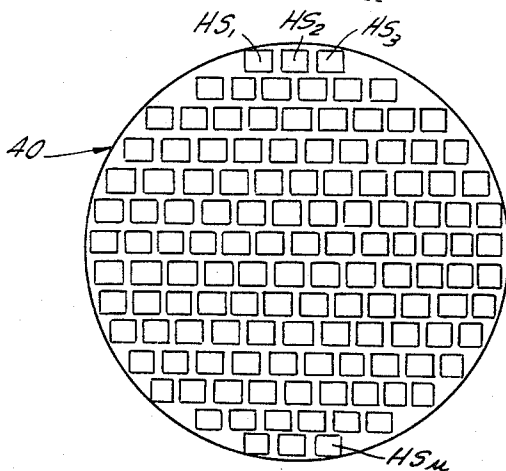
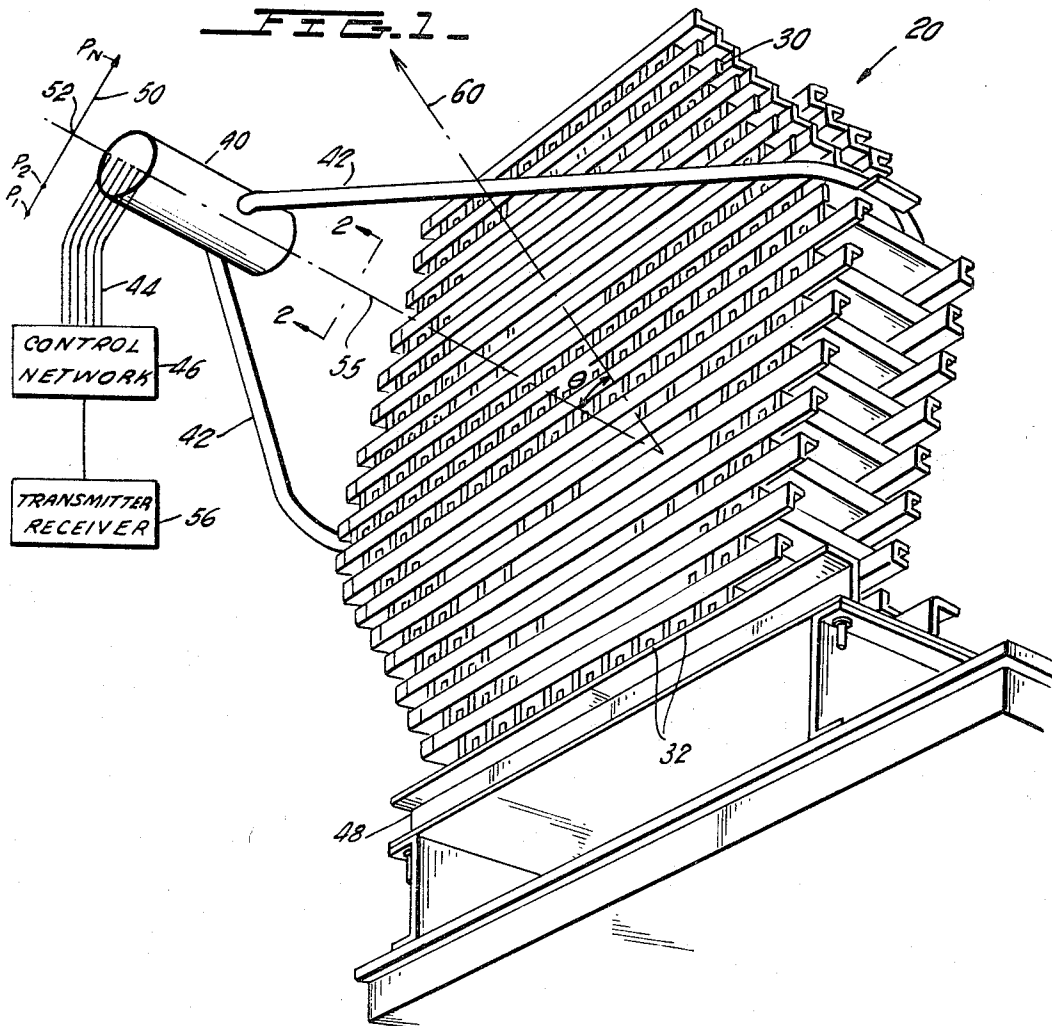


FIG. 2

INVENTOR
JUDD BLASS

BY
OSTROLENK, FABER, GERB & SOFFEN

ATTORNEYS

Oct. 29, 1968

J. BLASS

3,408,653

ANTENNA SYSTEM COMPENSATING FOR PRISM EFFECT UTILIZING
CONTROL MEANS AT THE SIGNAL FEED

Filed Nov. 12, 1964

5 Sheets-Sheet 2

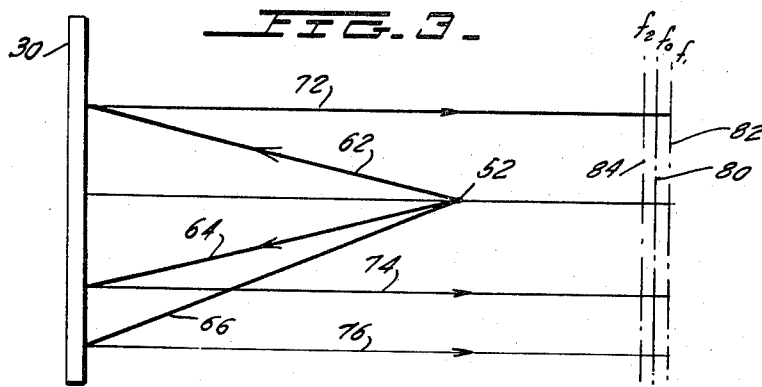


FIG. 5.

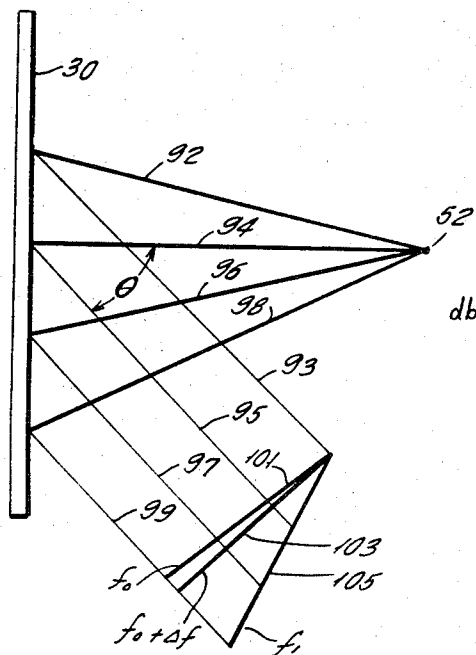
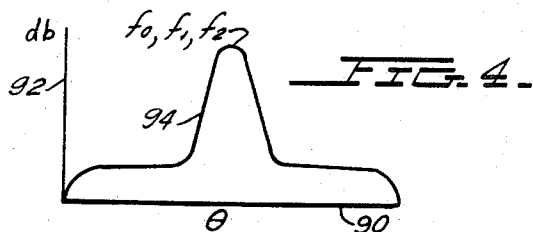
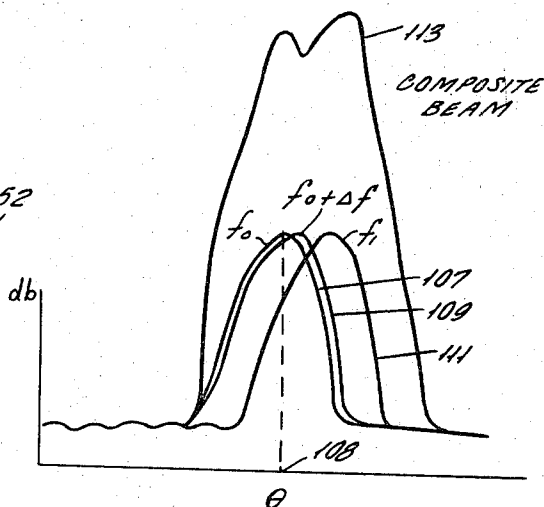


FIG. 6.



INVENTOR
JUDD BLASS

BY
OSTROLENK, FABER, GERB & SOFFEN
ATTORNEYS

Oct. 29, 1968

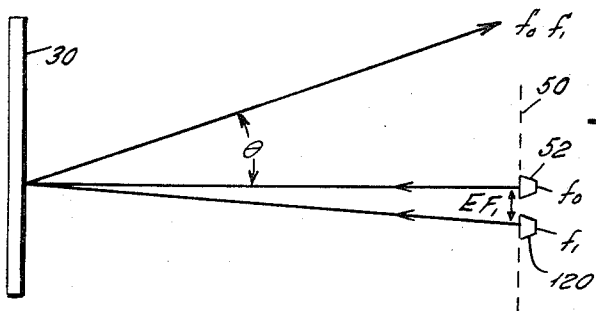
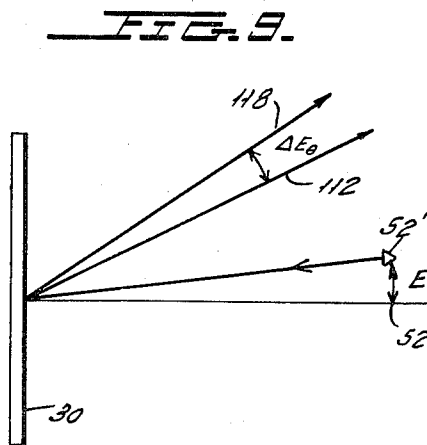
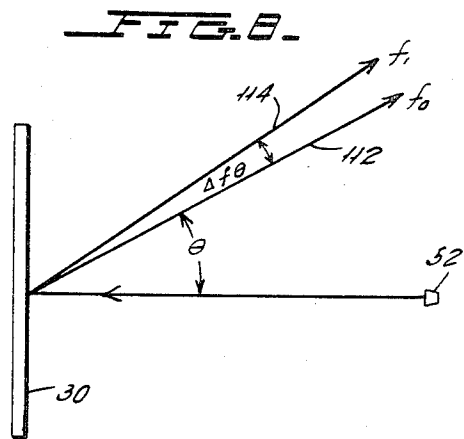
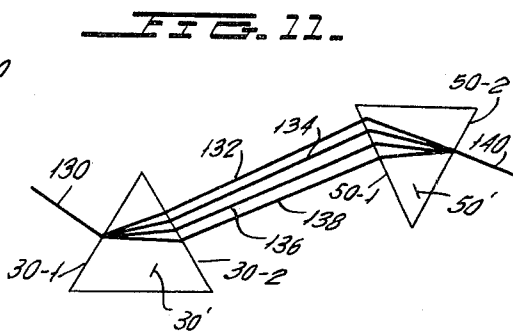
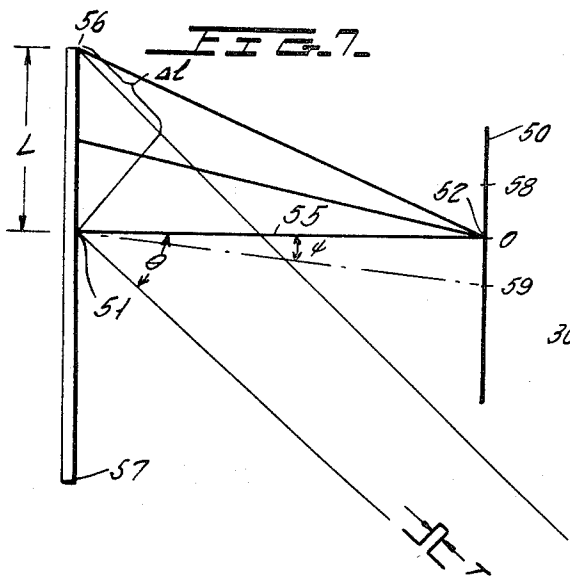
J. BLASS

3,408,653

ANTENNA SYSTEM COMPENSATING FOR PRISM EFFECT UTILIZING
CONTROL MEANS AT THE SIGNAL FEED

Filed Nov. 12, 1964

5 Sheets-Sheet 3



INVENTOR
JUDD BLASS

BY

OSTROLENK, FABER, GERB & SOFFEN

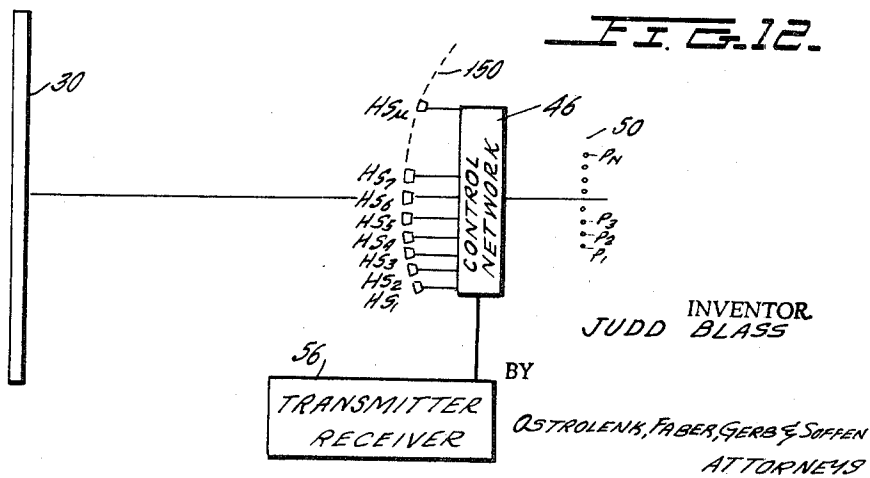
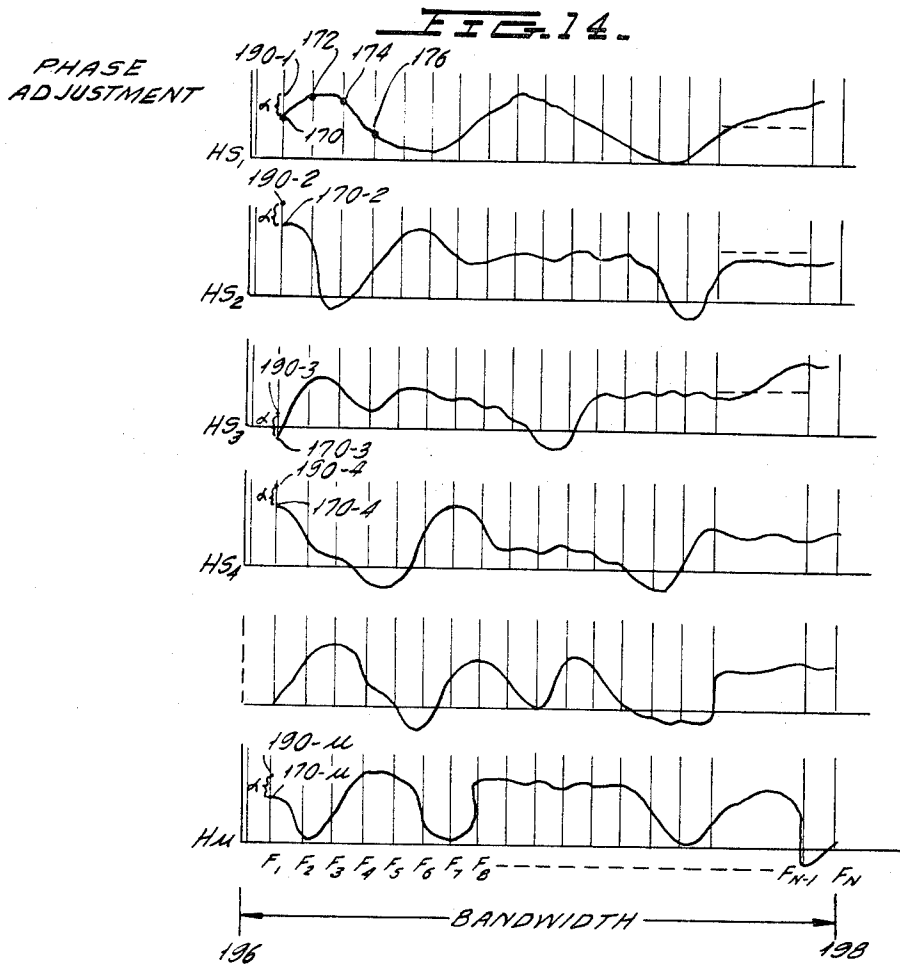
ATTORNEYS

Oct. 29, 1968 J. BLASS 3,408,653
ANTENNA SYSTEM COMPENSATING FOR PRISM EFFECT UTILIZING
CONTROL MEANS AT THE SIGNAL FEED
Filed Nov. 12, 1964 5 Sheets-Sheet 4

ANTENNA SYSTEM COMPENSATING FOR PRISM EFFECT UTILIZING
CONTROL MEANS AT THE SIGNAL FEED

Filed Nov. 12, 1964

5 Sheets-Sheet 4



Oct. 29, 1968

J. BLASS

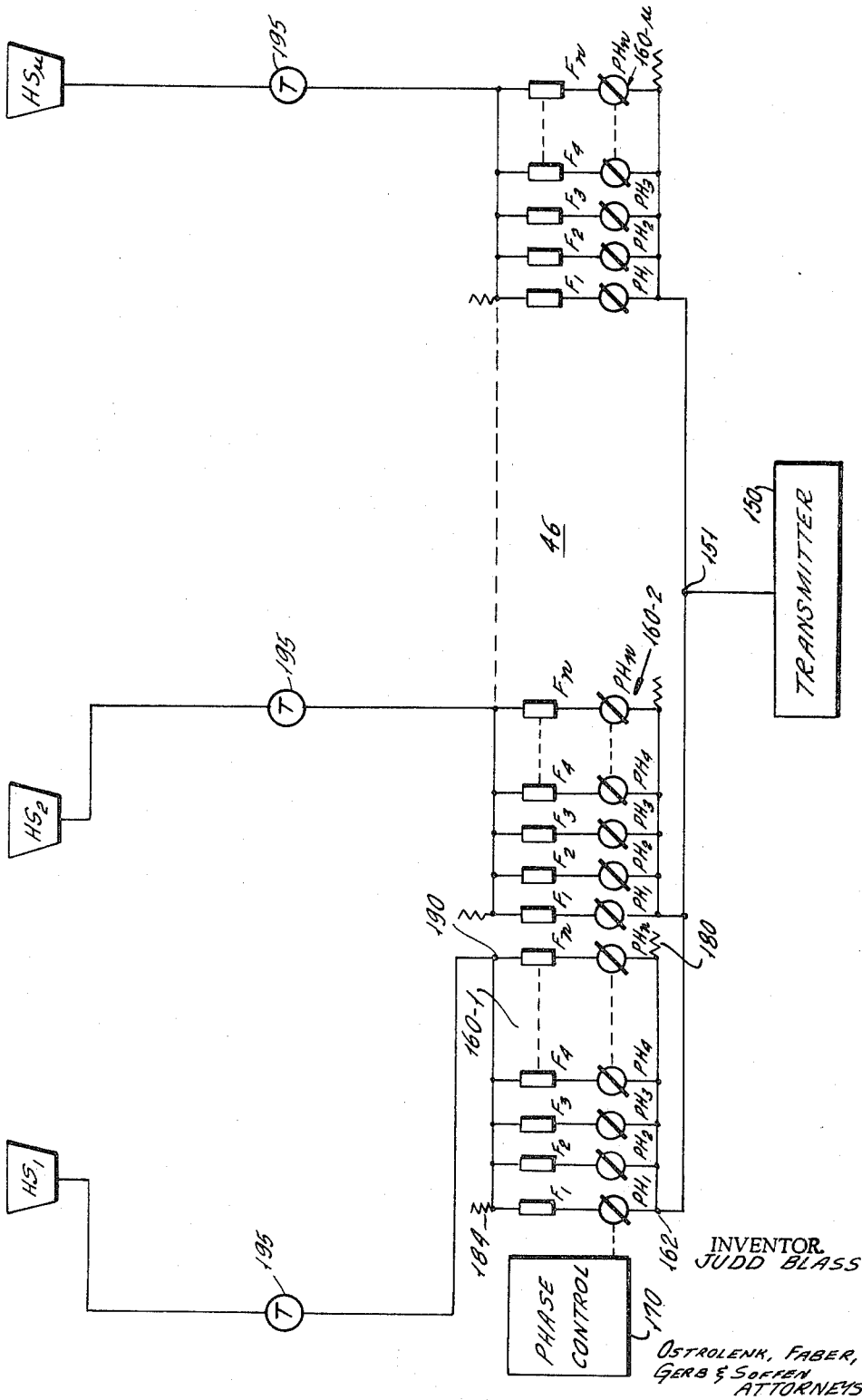
3,408,653

ANTENNA SYSTEM COMPENSATING FOR PRISM EFFECT UTILIZING
CONTROL MEANS AT THE SIGNAL FEED

Filed Nov. 12, 1964

5 Sheets-Sheet 5

FIG. 13.



1

2

3,408,653

ANTENNA SYSTEM COMPENSATING FOR PRISM EFFECT UTILIZING CONTROL MEANS AT THE SIGNAL FEED

Judd Blass, Bayside, N.Y., assignor to Blass Antenna Electronics Corporation, Long Island City, N.Y., a corporation of Delaware

Filed Nov. 12, 1964, Ser. No. 409,905

31 Claims. (Cl. 343—754)

ABSTRACT OF THE DISCLOSURE

An antenna system is provided which includes an energy impinging surface and a feed surface spaced therefrom. In systems of this type non-broadside scanning produces path length variations for the various frequency components comprising the desired bandwidth. By utilizing a plurality of feed points within the focal plane of the energy impinging surface, with the location of each of these feed points determined by the scan angle and associated frequency component, the variations in path length can be compensated for such that bandwidth is materially increased. Because of physical limitations, the required feed point spacing becomes a physical impossibility. However, by the implementation of Huygens' principle, a plurality of feed members can be spaced outside of the focal plane and controlled to produce the necessary feed points within the focal plane of the energy impinging surface.

My invention relates to antenna systems of increased bandwidth capabilities, and more particularly to a novel feed system for maintaining the proper antenna beam scan direction and phase coordination of the various frequency components which combinedly comprise the desired bandwidth of operation.

An antenna may basically be considered as a connecting link between free space and a transmitter or receiver. The antenna surface is designed to direct electromagnetic energy between a desired direction in space and a receiver or transmitter located at its focus. This linking interconnection may, in many cases, be reciprocal; that is, the transmitter located at the focus of the antenna system directs its energy to the antenna surface, with such energy then being formed into an antenna beam of the desired characteristics and having the desired angular orientation, or scan angle, in space. Conversely, the antenna surface may be directed such that a signal source originating within the antenna beam pattern of desired scan angle will be received by that surface and re-directed towards a receiver located at the focus. During the course of the ensuing explanation, certain aspects of the invention will be discussed in conjunction with either a transmit or receiver mode of operation. This, however, will merely be for purposes of simplifying the particular analysis. It is to be understood that analogous conditions prevail for both the transmit and receive mode of operation and my invention is equally adaptable for both of such modes.

In some system applications, it is desired that the direction of the antenna beam be varied in space. Means must, therefore, be provided within the antenna system for changing the antenna scan angle. One well known method for obtaining such antenna beam scanning is to move the reflector mount structure itself to appropriately direct its antenna beam in the desired direction. As the antenna structure is re-orientated corresponding to the desired scan angle, broadside operation is usually maintained. Thus, the path lengths of the signal rays illuminating various portions of the antenna surface will be maintained corresponding to variations of scan angle, and such an-

tenna systems will not be subject to prism effect signal degradation. Such systems have, however, been severely limited in scanning rates and accuracy because of system inertia and other mechanical difficulties encountered with movement of the reflector or feed.

Various electronic scanning techniques are also known for varying the scan angle of the antenna beam without physically moving either the reflector or feed. Some typical prior art systems are more fully discussed in my copending U.S. patent applications Ser. No. 230,358 filed Oct. 15, 1962 now U.S. Patent No. 3,316,553 and Ser. No. 244,089 filed Dec. 12, 1962, now U.S. Patent No. 3,274,601, to which reference is herewith made. As is the subject of my U.S. patent application Ser. No. 244,089, a stationary reflecting surface may be formed of an array of individual, phase control radiating elements. The relative phase of the individual wave signals formed at the reflecting surface may be individually and rapidly controlled (in the order of a few nano-seconds) to electrically form an antenna beam of desired scan angle direction. Further, the phase control circuitry associated with the individual radiating elements forming the array may be modified to reposition its axis of directivity, such that the antenna beam associated with such an array antenna will change its angle of scan in space, without the need to physically move the antenna surface.

Such directive arrays have been previously limited in frequency capabilities because of the variations of path lengths over the surface of the antenna array, corresponding to variations of scan angle. More specifically, as the angle of scan varies in space, the path length traversed by energy incident at the edge of the antenna will vary from the path length of energy incident on the center of the antenna, with such path length variation being proportional to the cosine of the scan angle. Such an actual path length differential, or true time delay, corresponds to a different phase delay at the various frequencies forming the desired bandwidth of operation. This variation of phase with frequency will therefore narrow the bandwidth over which a well defined antenna beam may be maintained. This problem had been recognized in the prior art, and is termed the "prism" effect, because it may be broadly analogized to the dispersive effect of polychromatic light passing through a prism. That is, since the actual path length variation over the surface of the array will correspond to a different number of wavelengths of each of the individual frequency components forming the bandwidth of operation, different ones of the signal components will experience a different phase variation at the antenna surface. The result is analogous to the manner in which a ray of polychromatic light incident on one surface of a prism emerges from the opposite surface of the prism as a fan-shaped beam, separated into its individual monochromatic components.

In the past the solution to the prism effect problem has usually been to provide modifications of the antenna surface to compensate for the path length differential as the angle of scan varies. For example, in a phase back scatter array wherein the signal enters the surface of the antenna, penetrating it to a desired depth and is then reflected out of the surface in the proper phase relationship to establish the requisite beam orientation, additional compensating delay may be introduced about the array surface by varying the depth of signal penetration. This delay will be of an amount which compensates for the additional path lengths resulting from the variation of antenna scan angle. However, the introduction of such delay is extremely complex, difficult to accurately control and would require excessive antenna depths.

A somewhat simplified solution has been to introduce 0° to 360° phase shifters over the surface of the an-

tenna to compensate for the path length variation which exceeds an integral number of full wave lengths. Since this solution does not actually compensate for the true time delay of the prism effect, will only provide compensation over a narrow band of frequencies. Thus, while it will broaden the bandwidth of operation to some extent, it will fail to achieve significantly increased bandwidth of operation, in the order of at least 10% about the mean operating frequency, as is the objective of the instant invention.

My invention avoids the limitations of the prior art systems by the utilization of a novel feed structure wherein the individual signal components comprising the desired bandwidth of operation are phase and frequency coordinated at the feed to compensate for the antenna surface prism effect resulting from scan angle variations. I have found that such compensation may be accurately obtained by establishing a plurality of signal feed points within the focal plane of the antenna systems, which each of the signal feed points corresponding to a different frequency source within the desired bandwidth of system operation. The phase and location of the individual signal feed points are properly coordinated so as to completely eliminate or effectively reduce the prism effect, and its attendant bandwidth limitations. The establishment of such signal feed points may be broadly considered as analogous to an additional prism which dispersively presents the multi-frequency components to the antenna surface in a manner which will compensate for the dispersive effect that is introduced by the antenna surface. The combined effect of the two prisms serves to cancel out the frequency dependent dispersion, thereby resulting in the orientation of the antenna beam pattern in the desired direction in space.

I have, however, determined that the requisite displacement between the individual signal feed points which are to be established within the focal plane may be less than the minimum dimensions of practically realizable elements. Specifically, the feed is usually constructed of horn radiators. As is well known, such feed horns must usually have an aperture dimension in the order of at least a half wavelength, in order to achieve efficient signal transmission and propagation. However, the solution presented by the instant invention may oftentimes require the establishment of individual signal feed points closer together than this half wavelength displacement.

This is solved in an extremely advantageous manner by the utilization of what I term Huygens principle sources. According to this well established principle (see, for example, Optics, Francis Weston Sears; Principles of Physics Series, Addison-Wesley Press, Inc., Cambridge, Mass., Third Edition, 1949, pages 5-6), a point source of wave energy may be considered as a source of small secondary wavelets. Thus, just as Huygens principle permits the construction of the secondary wave front by generating an envelope of wavelets emanating out from the point source, I propose to conversely establish a point source by the proper phase and frequency coordination of a plurality of secondary feed members. Hence, it is seen that the actual feed members which I use to establish the equivalent Huygens sources may be practical members, being displaced by at least a half wavelength from each other, while their equivalent feed points at the focal point may have a considerably closer effective placement. As, for example, such equivalent feed points may be as close as $\frac{1}{10}$ of a wavelength apart.

The feed system includes a coordinated array of individual feed members displaced from the focal plane of the antenna system. Considering one of the frequency components associated with the feed system, the phase of that frequency component at each of the feed members is properly adjusted such that the feed members additively correspond to the wave front of a feed point of that frequency located at the desired point within the focal plane of the antenna system. Likewise, the phase

of the other frequency components, which comprise the desired bandwidth of operation of the antenna system, are similarly adjusted such that they collectively define a plurality of feed points, within the focal plane. The location of these feed points is predetermined to compensate for the prism effects of the antenna surface when operating at a non-broadside condition, in satisfaction of the objectives of my invention. As, for example, the location of the individual frequency point sources is determined to properly coordinate their respective antenna beams, with the antenna scan angle. It is still also required that these phase of the individual frequency components be properly coordinated. This may be achieved by adding or subtracting phase simultaneously to the feed member signals corresponding to the establishment of a particular signal feed point within the focal plane. This will serve to effectively change the phase of the signal emanating from the feed point, with respect to the other feed points, while still maintaining the proper location of that feed point within the focal plane.

The establishment of Huygens sources, in accordance with the preferred objectives of my invention advantageously permits a considerable degree of flexibility as to the relative location and phase of such sources. As the angle of antenna scan varies, the required location of the signal feed points within the focal plane must correspondingly be relocated to properly compensate for the antenna prism effect. The instant invention permits this by changing the phase of the signals associated with each of the Huygens source feed members. That is, the locations of the established feed points, as well as their relative phase, may be changed without necessitating actual physical relocation of the feed members, or any of the other components combinedly defining the antenna system.

In the particular embodiment selected to illustrate the basic concepts of my invention, individual filter-phase networks are provided for each of the Huygen source feed members. The filter-phase network includes a number of branches corresponding to the separation of the desired signal bandwidth into its constituent frequency components. Each of the branches includes a filter, and a phase shifter. The filter-phase networks serve to separate the overall signal frequency bandwidth into individual frequency sub-bands, adjust the relative frequency of each of these sub-bands, and then recombine the signal. The phase adjusted signals will then effectively establish a plurality of feed points within the focal plane. The phase shifters are properly coordinated, in conjunction with the positioning of their associated feed horn members, to effectively establish the focal plane point sources in accordance with Huygens' principle. The position and phase relationship of the feed members are predeterminedly controlled to establish the feed points in a manner which will compensate for the signal narrowing prism effect of the antenna array.

It is therefore seen that the basic concept of my invention resides in providing a novel feed system for improving the bandwidth capabilities, with such improvement being provided by the establishment of a plurality of individual feed points within the antenna focal plane, located to compensate for the bandwidth reducing prism effect resulting from angle of antenna scan path length deviations.

It is therefore a primary object of this invention to provide broad band antenna systems of increased capabilities.

A further object of this invention is to provide an antenna system wherein the prism effect resulting from non-broadside operation thereof is compensated for by an adjustment within the signal feed for introducing an equivalent real time delay.

Another object of this invention is to establish, within an antenna system, a plurality of signal feed points, each associated with different frequencies within the desired bandwidth of operation.

An additional object of this invention is to provide such a feed system, wherein the phase and location of the respective signal feed points corresponding to various ones of the frequency components is adjustably controlled.

Still a further object of this invention is to provide a feed means within such an antenna system, wherein the phase and frequency adjustments are coordinated to compensate and correct for the prism effect of the antenna surface corresponding to non-broadside operation.

Still another object of this invention is to provide signal feed means for establishing a signal feedpoint, with such signal feed means being located remote from the signal feed point and being established in accordance with the Huygens' principle distribution of electromagnetic energy at said signal feed point.

Still an additional object of this invention is to provide, within an antenna system, a plurality of signal feed points at the focal plane thereof, with such feed points being established by a plurality of feed horn radiators displaced from the focal plane and being phase coordinated to establish the equivalent of said feed points within the focal plane in satisfaction of Huygens' principle.

These as well as other objects of the instant invention will readily become apparent after reading the following description of the accompanying drawings, in which:

FIGURE 1 is a perspective view of an antenna system constructed in accordance with the teachings of my invention and shown in conjunction with the phased array antenna surface of my aforementioned U.S. patent application Ser. No. 244,089.

FIGURE 2 is an end view of the novel feed system of the instant invention, shown looking in the direction of the lines 2—2 of FIGURE 1.

FIGURE 3 is a simplified schematic representation showing the manner in which a variation of frequency will change the beam pattern of an antenna system operating at broadside.

FIGURE 4 graphically shows the antenna beam pattern corresponding to FIGURE 3.

FIGURE 5 is a simplified schematic representation, similar to FIGURE 2, but showing the non-broadside operation of the antenna system corresponding to a scan angle θ .

FIGURE 6 graphically shows the beam pattern of the antenna system of FIGURE 5, and illustrates the adverse prism effect on beam directivity.

FIGURE 7 schematically illustrates the manner in which path length differentials corresponding to non-broadside operation of the antenna system array gives rise to the effective frequency narrowing of the antenna beam pattern.

FIGURE 8 schematically shows, in a somewhat simplified manner, the variation of scan angle with frequency, corresponding to a feed located at the antenna focus point.

FIGURE 9 schematically shows the variation of scan angle with the location of the feed source within the focal plane, the frequency of operation remaining constant.

FIGURE 10 schematically shows how the deviations of FIGURES 8 and 9 may be combined in accordance with basic conceptual contribution of the instant invention, to compensate for the antenna prism effect.

FIGURE 11 is an extremely simplified representation, showing the analogy of the instant invention to the dispersion of polychromatic light by a prism, and illustrating the manner in which the instant invention serves to compensate for the prism effect.

FIGURE 12 is a schematic representation illustrating the Huygens' principle establishment of a plurality of feed points within the focal plane of the antenna system, by a plurality of feed horns displaced from the focal plane.

FIGURE 13 is a block schematic indicating the manner in which the individual Huygen's source feed members of the instant invention may be interconnected and coordinated.

FIGURE 14 illustrates the phase relationship between the signal components associated with each of the Huygens' source feed members comprising the novel feed system of the instant invention.

Referring to FIGURE 1, antenna system 20 comprises a reflecting surface 30 and a signal feed 40. Feed 40 is typically shown secured to the reflecting surface 30 by side supports 42.

Considering antenna system 20 in the transmit mode of operation, the wave signal rays emanating from feed 40 will illuminate the entire antenna surface 30, and will be reflected therefrom as a beam of electromagnetic energy 60 directed in the desired angular orientation, θ , in space. The individual rays of the feed signal over the surface of antenna 30 are properly phase controlled such that the additive phase effect of the signals emerging from each of the individual channels 32 will provide a uniform phase front directed in space, in the desired scan angle.

Reflecting surface 30 may be formed of a plurality of adjacently positioned radiating elements 32 mechanically supported by a platform 48. An electrical antenna surface is combinedly formed by adjusting the phase of the signals associated with the radiating elements 32, to additively direct the antenna beam in space along the scan angle θ , as is the subject of and is fully described in my aforementioned U.S. patent application 244,089. It should be recognized, however, that the application of the instant invention is not limited to such an antenna array, and may be practiced in conjunction with numerous other antenna systems.

In accordance with the instant invention, antenna feed 40 is formed of a coordinated array of individual radiating members such as horns, shown as $HS_1, HS_2, HS_3, \dots, HS_n$, as shown in the end view FIGURE 2. These individual horns or feed members are then interconnected by feed lines, generally shown as 44, to a coordinated control network 46. The coordinated control network properly adjusts the signal components associated with each of the individual feed member sources HS_1 through HS_n to remotely establish individual signal feed points, shown as P_1 through P_n . The feed points established by feed 40 are electrically located in the focal plane of the antenna system 20, shown by line 50, with the focus thereof 52 shown at the intersection of focal plane 50 and principal axis 55 of the antenna system. The control network 46 is in turn interconnected to transmitter/receiver 56, to provide operation of the antenna system 20 in either of the transmit or receive modes, or in combined transmit-receive mode. In the latter case, routing of the signals being transmitted and received between the antenna, transmitter and receiver is obtained by conventional devices, including circulators, duplexers, etc. (not shown).

Antenna system 20 is of a type which has the capabilities of electrically re-orientating the direction of its associated antenna beam 60 in space, such that the scan angle θ varies without physically repositioning the reflecting surface 30. This is to be contrasted to the well known scanning antenna system, wherein the reflective surface, typically being a parabola, is physically moved in accordance with the required direction of beam orientation. In antenna systems which physically re-direct the antenna surface, the bandwidth of the system is ideally unlimited, and in practice limited essentially by the bandwidth of the associated signal processing components (e.g., receiver, transmitter, circulators, etc.). Such systems, however, are severely limited in application. Considerably more stringent operating conditions may be met by electrical scanning techniques. In such antenna systems the re-orientation of the scan angle results in non-broadside operation. This causes variations of traversed path lengths of the signal rays over the extremes of the antenna surface, which in turn limits the bandwidth of operation.

To understand the manner in which my invention compensates for this previous bandwidth limitation, and serves to effectively increase the broad band capabilities of an

antenna array, reference is now made to FIGURES 3-11 which will be used in developing the theoretical basis for the operation of the instant invention.

Referring initially to FIGURE 3, consider a signal feed located at the focal point 52 of the antenna surface 30, and shown in the broadside condition. Signal feed 52 will be typically transmitting a signal over a band of frequencies centered at mean frequency F_0 and including higher and lower frequency components F_1 and F_2 respectively. The wave energy emanating from source 52 will illuminate the entire surface of the antenna 30, as typically shown by incident 62, 64, 66. These waves will be reflected from the antenna surface 30 as waves 72, 74, 76, respectively, which will additively determine an antenna beam pattern in the broadside direction. This antenna beam pattern will exhibit a uniform phase front in space, in the desired direction. For example, a zero phase relationship is shown by line 80, corresponding to this condition at the mean frequency F_0 . At frequencies slightly higher and slightly lower than this mean frequency, the beam pattern and its direction will be maintained, with the only result being a variation of the distance along the beam pattern at which zero phase front will be periodically located. Lines 82 and 84 show a typical interrelation of the zero phase front for the frequencies F_1 and F_2 respectively. FIGURE 4 shows the beam pattern of an antenna beam in the broadside direction, as shown in FIGURE 3. The horizontal axis 90 represents angle of scan and the vertical axis 92 represents relative signal strength. It is to be noted that the beam patterns for the individual signal components F_0 , F_1 and F_2 are effectively superimposed and shown as curve 94.

Turning now to FIGURE 5, let us now consider the situation corresponding to non-broadside operation of the antenna array 30. The signal feed is still shown located at the focal point 52. The antenna surface 30 is now, however, adjusted such that the angle of beam orientation will be θ . The plurality of individual rays which illuminate the antenna surface 30 and are reflected therefrom to combinedly form the transmit antenna beam pattern are typically shown as 92, 94, 96 and 98. These rays are, in turn, reflected by the antenna surface 30, as 93, 95, 97 and 99 respectively. Note, however, that the overall path traversed by signal ray 92-93 is substantially greater than the path traversed by a ray such as 94-95 which is incident at the center of the antenna array 30. Similarly, the path lengths 96-97 and 98-99 are progressively shorter. Thus, a path length variation will be effected along the surface of the antenna array, corresponding to a non-broadside condition of operation. This path length variation will serve to introduce a definite time delay to signals which are incident over various portions of the antenna surface. Considering such a time delay with respect to the band of frequencies over which the antenna system is intended to operate, it is recognized that such an actual time delay corresponds to a variation of wavelengths, or phase delay at each of the operating frequencies. This, in turn, will result in a deviation of the angular orientation of the antenna beam corresponding to deviations from the mean frequency F_0 . Typically, the antenna beam at the mean frequency F_0 will have a uniform phase front in the direction shown by line 101. At a frequency slightly differing from the mean frequency F_0 by an amount ΔF , the uniform phase front will be orientated in a slightly different direction as shown by the line 103. At a substantially higher frequency, as for example, F_1 , the angular orientation of the beam pattern will be significantly varied as shown by the uniform phase front represented by line 105.

Reference is now made to FIGURE 6, which shows the beam patterns corresponding to that shown in FIGURE 5. The beam pattern for the mean frequency F_0 is shown by curve 107. It is noted that this curve is centered about the antenna scan angle θ shown as abscissa point 108. The beam pattern for the somewhat higher

frequency $F_0 + \Delta F$ is shown by the curve 109, and is displaced along the X axis a slight amount from the desired scan angle θ . The beam pattern of frequency F_1 which substantially differs from the mean frequency F_0 will be considerably displaced from the scan angle θ , as shown by curve 111. The composite beam characteristics of all the individual frequency components which comprise the intended bandwidth of antenna system operation, and includes such end extreme frequencies as F_1 , is shown by a curve 113. This curve does not have a well defined shape, as is required for accurate antenna operation, and therefor corresponds to an unacceptable condition of signal propagation and target analysis. It is this dispersing out of the beam patterns associated with the individual frequency components, comprising the signal bandwidth, that is known as the prism effect, and has heretofore resulted in a substantial narrowing of the bandwidth capabilities of such antenna systems.

Considering now the magnitude of the prism effect, reference is made to FIGURE 7, wherein the antenna array 30 is shown as extending a length L from the central point 51, along its principal axis 55. Although a linear array 30 is shown, this is merely to simplify the ensuing analysis. It should be recognized that the analogous situation will result upon a full consideration of the planar array, as is shown in FIGURE 1. For purposes of the present analysis of FIGURE 7, it is assumed that the antenna array 30 is directed along the scan angle θ , and is receiving a pulse of energy having a bandwidth T . The propagation of electromagnetic energy in free space is such that one microsecond of pulse width corresponds to 500 feet of radar range. Hence, the narrower the pulse width which may be received and properly processed by the antenna system, the greater the degree of resolution is provided. However, it is also known that the required bandwidth for properly reproducing the pulse is inversely proportional to the pulse duration. At the scan angle θ , corresponding to the non-broadside operation of the antenna system, the difference in distance travelled between a ray directed to the center of the antenna 51, and that directed to an end extreme 56 of the antenna, is given by the relationship

$$\Delta l = L \sin \theta \quad (1)$$

This variation in distance Δl in turn introduces a real time delay in the signal rays incident at the end extremes of the antenna. The antenna bandwidth had to be limited such that the pulse width T is greater than Δl . If this condition were not satisfied, the pulse signal received at the center of the antenna 51 will be terminated prior to the signal being received at the end extreme 56.

One way in which the prior art has suggested remedying this problem is to judiciously change the depth of penetration about the antenna surface 30, and hence provide compensating delay. As, for example, the array element at central point 55 can be modified such that the ray energy incident thereat will be entered an additional amount into the antenna array 30 and reflected therefrom equal to the length Δl . Similarly, the additional length introduced by the antenna array intermediate central point 51 and end extremes 56, 57 progressively decreases, so as to maintain the same effective path length for incident energy over the entire surface of array 30. The modification of the surface 30 to achieve this compensation is extremely difficult, costly and quite space-consuming. Considering a typical antenna system wherein length L corresponds to 10 feet, Δl for a scan angle of 45° will correspond to approximately 7 feet. It is to be further recognized that the required path length differential of the antenna array to introduce the requisite amount of real time delay will be dependent on the particular angle of scan.

As a somewhat simplified and less space-consuming arrangement, it has also been suggested by the prior art that the additional amount of delay introduced in the re-

flexible surface be provided by phase shifters, which compensate for the amount that the path length deviates from an integral number of wave lengths. Such a compensating arrangement, however, will only operate at a particular frequency or narrow band of frequencies, inasmuch as the correlation of path length to wave length is proportional to the frequency of operation.

I have found, however, that the effect of a compensating real time delay may be introduced in a much more simplified, and easily controllable manner, by varying the feed, rather than the antenna array.

It may be mathematically shown that a result of such signal path differentials, the impulse of energy received by the feed located at focal plane 52, corresponding to illumination of the antenna array 30 by a pulse of bandwidth T and of unity amplitude will be reduced in amplitude by the factor and will be spread out in frequency

$$\frac{T}{T + \frac{L}{C} (\sin \theta)} \quad (2)$$

to include a bandwidth as represented by

$$T + \frac{L}{C} (\sin \theta) \quad (3)$$

where: C is the velocity of propagation of the electromagnetic wave.

If, however, additional receiving channels are located along the focal plane of the antenna, as shown at points 58 and 59, and these channels are properly filtered and phase coordinated, it is possible to restore the signal bandwidth and pulse shape even under those conditions where

$$\frac{L}{C \times \sin \theta}$$

is much greater than the pulse width T. Considering the source at 59, lying along the focal plane and angularly separated from the principal axis 55 by the angle p.s.i., its received signal will correspond to that received at focal point 52, except that the frequency of this pulse will be centered at

$$F_0 / (1 + \sin \theta / \sin \theta) \quad (4)$$

This frequency, being a lower frequency than the mean frequency F_0 of the signal impulse received at 52, may be simplified and represented by the expression

$$F_0 - B/2 \quad (\text{where } B \text{ is the signal bandwidth}) \quad (5)$$

Similarly, if a receiver at point 58 equally displaced from focal point 52 as is receiver 59, the output is a rectangular pulse about the center frequency

$$F_0 + B/2 \quad (6)$$

It can be proven that if sufficient receiving channels are placed along the focal plane 50 and properly frequency and phase coordinated, the entire pulse spectrum will be recaptured. In particular, I have determined that the manner of such channels should preferably be equal to

$$\left(T + \frac{L}{C} \sin \theta \right) / T \quad (7)$$

and the bandwidth of each channel is given approximately by

$$T / \left(T + \frac{L}{C} \sin \theta \right) B \quad (8)$$

By proper spatial and frequency filtering, such a feed system will provide the equivalent of a true time delay, to compensate for the prism effect at the array surface 30. Hence, the pulse energy, pulse shape, noise bandwidth and antenna directivity will be preserved, with the bandwidth now being theoretically determined by the associated signal processing components (receiver, transmitter, directional couplers, circulators, etc.).

FIGURES 8-10 represent a simplified analysis of the

solution proposed by my invention, and are herein presented to facilitate the theoretical discussion of the manner in which I achieve prism effect compensation. Referring first to FIGURE 8, a feed located at focal point 52 is shown emitting signal rays corresponding to the mean frequency F_0 and an end frequency F_1 within the bandwidth of desired antenna system operation. According to the prism effect, as theoretically discussed above, the signal at the mean frequency F_0 will be directed out into space in the desired scan angle direction θ , as shown by ray 112. The antenna beam corresponding to frequency F_1 , however, will be directed out into space at a somewhat differing scan angle as shown by the ray 112, with the difference in angular direction of their associated antenna beams being given by the relationship

$$\Delta F \theta = \left(\frac{F_1 - F_0}{F_0} \right) \tan \theta \quad (9)$$

Referring now to FIGURE 9, consider what happens when a signal source 52' displaced from the focal point 52 by an amount E emits a signal at the mean frequency F_0 . The antenna beam pattern will now be in the direction shown by ray 118, with its angular deviation from ray 112 (corresponding to a similar frequency source at the focal point 52) being given by the relationship

$$\Delta E \theta = E \sec \theta \quad (10)$$

In accordance with my invention, it is proposed that the deviation in frequency as shown in FIGURE 8 be compensated for by an appropriate movement of the source corresponding to frequency F_1 , in the focal point, to provide a readjustment of angular direction, as shown by FIGURE 9. That is, referring to FIGURE 10, the source of frequency F_1 shown located at 120 is displaced within the focal plane a distance equal to EF_1 , with EF_1 being obtained by setting Equation 9 equal to Equation 10, resulting in the solution that

$$EF_1 = \sin \theta \left(\frac{F_0 - F_1}{F_0} \right) \quad (11)$$

Thus, it is seen for a particular change in frequency from the mean frequency F_0 , the compensating displacement of its associated feed 120 from the focal point 52 is related to both the angle of antenna scan θ and the deviation from the mean frequency ($F_1 - F_0$).

In accordance with the subject invention, the individual signal components of the antenna system bandwidth of operation are separated into individual sources located along the focal plane 50 of the antenna system, with each of the sources satisfying the relationship expressed by Equation 11. This will serve to insure that all the frequency components are directed in the proper scan angle, and accordingly satisfying the conservation of energy requirements. In addition to satisfying this requirement, it is also necessary that there be a proper phase relationship of the beam pattern associated with each of the individual frequency components. By so insuring proper frequency and phase coordination along the focal plane 50 to compensate for the prism effect of antenna array surface 30, the proposed solution may be analogized to compensating prisms, as shown in FIGURE 11. The prism 30' may be analogized to antenna array surface 30, and the prism 50' to the novel feed means of my invention. Should a ray of multi-frequency signals, as characterized by the pulse shown in FIGURE 7 and represented by the arrow 130, strike the prism side 30-1, it will be separated into individual frequency components and dispersed outward at opposite side 30-2, as shown my rays 132-138. The dispersed rays which are received along surface 50-1 of compensating prism 50' are recombined within that prism and emerge as a singly directed ray 140 at surface 50-2. In effect, the manner in which the plurality of phase and frequency coordinated feed points of the instant invention are located within the focal plane of the antenna

system may be broadly analogized to the compensating effect of prism 50' shown in FIGURE 11.

It has been found, however, that these signal feed points, in order to satisfy the requirements imposed by my solution to the problem of antenna surface prism effect, oftentimes necessitate a placement of one-tenth of a wavelength or even closer between the adjacent signal feed points. As is well known, efficient horn radiators, which will be typically used at the antenna feed, must be at least in the order of a half wavelength across their aperture end. In order to solve this dilemma of having a closer displacement of signal feed points than is feasible with practically realizable components, I have proposed a network of horn radiators displaced from the focal plane and phase and frequency coordinated to establish effective feed point at the focal plane in accordance with a Huygens' principle distribution of their associated frequency components. FIGURE 12 shows the manner in which the plurality of signal feed points $P_1, P_2 \dots P_N$ may be established within the focal plane 50 by remotely located Huygens source horns HS_1-HS_u .

In accordance with Huygens' principle a point source such as P_1 of energy located within the focal plane 50 may be considered as a source of secondary wavelengths, spreading out from that point and having a velocity equal to the velocity of wave propagation. To find the wave front at a later instant, the surface of secondary wave lengths may be constructed lying along the surface defined by the line 150, with this wave constituting the envelope of the wavelets so established by an effective point source P_1 . I now propose that conversely the equivalent phase distribution of such a source at P_1 may be determined and established by individual horn radiators $HS_1 HS_2 \dots HS_u$ lying along surface 150, and having a phase coordination corresponding to that which would have been established by a point source at P_1 . As far as the antenna array 30 is concerned, the energy associated with such secondary sources $HS_1 HS_2 \dots HS_u$ serves to effectively establish a point source at P_1 . Similarly, each of these secondary sources ($HS_1 HS_2 \dots HS_u$), which I term Huygens' sources, are fed the proper phase coordinated frequency components of the individual feed points ($P_1, P_2, P_3 \dots P_N$), which are to be established along the focal point 50, with such phase control being properly coordinated to the desired antenna scan angle θ by control network 46, which in turn is connected to transmitter receiver 56.

Reference is now made to FIGURES 13 and 14, which illustrate the interconnection and control of the Huygens' sources, as well as the frequency phase relationship of the signals associated with each of the Huygen feed source horns. Considering the transmit mode of operation, common transmitter 150 presents an output signal to branch junction 151. Branch junction 151 is in turn connected to the control network 46, comprising filter-phase networks 160-1 160-2 $\dots$ 160- u with one such network being provided for each of the Huygen source horns $HS_1 HS_2 \dots HS_u$ respectively. The filter phase network includes a number of branch arms, corresponding to the frequency division of the signal bandwidth, and shown equal to the desired number of point sources to be established within the antenna focal plane. Each of the branch arms includes a narrow pass band filter $F_1, F_2, F_3 \dots F_N$, as well as a phase adjustor $PH_1, PH_2, PH_3 \dots PH_N$. The phase adjustments of the individual phase controls are interconnected to a phase control unit 170, which provides the necessary phase adjustment, in accordance with the scan angle prism effect compensation, with the phase adjustments being graphically shown in FIGURE 14.

Considering the operation of filter phase network 160-1, its input terminal 162 is connected to branch junction 151. The antenna signal enters input terminal 162. The signal component corresponding to the frequency F_1 will be circuit directed across the branch arm F_1-PH_1 ,

with phase adjustment PH_1 being controlled to provide the relative phase adjustment indicated by point 170 of FIGURE 14. Similarly, the component of frequency F_2 will be circuit directed across the branch arm F_2-PH_2 and receive a relative phase adjustment indicated by point 172 of FIGURE 14. The frequency components F_3 and F_4 of the signal bandwidth are similarly transmitted via their respective branch arms and receive the desired phase adjustments as shown by points 174, 176 of FIGURE 14. The individual signal components travel across their respective branches from input terminal 162 to output terminal 190 in the manner of a travelling wave array, such that all of the signal components will traverse an equal path length within their respective filter-phase networks. Dummy loads 180 and 184 are preferably provided in the filter phase network to dissipate portions of the signal which are not transmitted to output terminal 190 of the filter phase network.

It is understood that the common junction 151 feeds the other filter phaser networks 160-2, 160-3 $\dots$ 160- u corresponding to their respective Huygen sources, with the relative phase adjustments of each of the frequency components of the signals associated with the individual Huygen sources being typically represented by the curves of FIGURE 14. In the establishment of the relative phases, it should be again noted that the phase between respective ones of the same frequency components (e.g. F_1) of the various Huygen sources (as shown by points 170, 170-2, 170-3, 170-4 $\dots$ 170- u) serve to locate its associated feed point (P_1) within the focal plane 50. Once so located, equal phase α may be added to or subtracted from all of the phase shifters of that frequency (as shown by points 190-1, 190-2, 190-3, 190-4 $\dots$ 190- u), thereby serving to change the relative phase of its frequency source P_1 with respect to the other frequency sources, while still maintaining the location of the frequency source within the focal plane 50.

There is a loss of energy resulting from the coupling components and also from the phase shifters and filters of the system which is used to individually adjust the frequencies to each of the feed radiators. This loss of energy should preferably be compensated for by individual transmitter amplifiers 195 associated with each of the feed horns. These transmitter amplifiers 195 naturally will be of the frequency band required of the overall system, as shown by the end extremes 196, 198 of FIGURE 14.

It is therefore seen that by proper phase adjustments of the signal frequency components separated out by filter-phase networks 160, a plurality of signal feed points will be effectively established within the focal plane 50 in a manner which will provide proper direction of the associated antenna beam, as well as maintaining proper phase relationship between the individual signal frequency components. Although I have described one form of my novel invention, it should be naturally understood that many variations and modifications will now be obvious to those skilled in the art. For example, although the embodiment shown has demonstrated significant application in the microwave frequency range, its novel concepts may be practiced in other frequency ranges, and in conjunction with reflection, refraction and transmission type systems. Accordingly, I prefer to be limited not by the specific disclosure herein but only by the appended claims.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows.

1. An antenna system characterized as having the property of selectively directing the orientation of its associated antenna beam in space, the antenna beam formed of a plurality of frequency-separated signal components additively defining a desired bandwidth of antenna system operation; said antenna system comprising: a signal impinging surface; a signal feed operatively positioned

such that the signal components of the antenna beam traverse a path intermediate said signal impinging surface and feed, said signal impinging surface, and the selected direction of space orientation; said signal impinging surface defining an aperture plane, said aperture plane forming an angle with the direction of antenna beam orientation, said angle varying in accordance with the selected beam orientation, the variation of said angle affecting a variation of the paths traversed by individual ones of the frequency-separated signal components, with said path variation serving to narrow the effective bandwidth of the antenna beam, said signal feed including control means for compensating for said path variations.

2. The antenna system as set forth in claim 1, wherein said control means includes means for establishing a plurality of feed points, each associated with different ones of said signal components, and for selectively locating said feed points to compensate for the path variation of its respective signal component.

3. The antenna system as set forth in claim 2, further including means for adjusting the relative phase of the signal components associated with respective ones of said feed points.

4. An antenna system characterized as having the property of selectively directing the orientation of its associated antenna beam in space, the antenna beam formed of a plurality of frequency-separated signal components, additively defining a desired bandwidth of antenna system operation; said antenna system comprising: a signal impinging surface; a signal feed operatively positioned such that the signal components of the antenna beam traverse a path intermediate said signal impinging surface and feed, said signal impinging surface, and the selected direction of space orientation; said signal feed located within a focal plane relative to the beam directing surface formed by said signal impinging surface; said signal impinging surface defining an aperture plane, said aperture plane forming an angle with the direction of antenna beam orientation; said angle varying in accordance with the selected beam orientation; the variation of said angle affecting a variation of the paths traversed by individual ones of the frequency-separated signal components, with said path variation serving to narrow the effective bandwidth of the antenna beam; said signal feed including control means to compensate for said path variations; said control means including means for establishing a plurality of feed points within said focal plane, each associated with different ones of said signal components, and for selectively locating said feed points within said focal plane to compensate for the path variation of its respective signal components; said signal feed means including a plurality of feed members displaced from said focal plane, and operatively associated to combinedly establish said feed points at the focal plane.

5. An antenna system as set forth in claim 4, said signal feed points having a minimum spaced separation corresponding to a first distance, said feed members having a minimum spaced separation corresponding to a second distance, said second distance substantially greater than said first distance.

6. An antenna system, as set forth in claim 4, said signal feed means including phase control means for adjusting the relative phase of the individual ones of said signal components associated with respective ones of said feed members, the relative phase adjustment of said feed members serving to combinedly establish the equivalent of said feed points within said focal plane, in satisfaction of Huygen's principle.

7. An antenna system as set forth in claim 6, wherein the adjustment of the relative phase associated with a particular one of said signal components at each of said signal feeds, establishing a particular location within said focal plane of the signal feed point for said particular component, the adjustment by an equal amount of the phase associated with said particular component, at each

of said signal feeds, maintaining said particular location of its feed point, while varying the phase of said feed point relative to the other feed points corresponding to the others of said signal component, whereby said phase control means provides both proper orientation in space of each of said signal component, and the proper relative phase relationship between said signal components to preserve the characteristics of an antenna beam pattern over said desired bandwidth.

8. An antenna system as set forth in claim 6, wherein said phase control means includes a filter-phase network for each of said feed members; said filter phase network including circuit means to separate said bandwidth into said signal components, and independently adjust the relative phase of its associated signal components.

9. An antenna system as set forth in claim 7, wherein said phase control means includes a filter-phase network for each of said feed members; said filter phase network including circuit means to separate said bandwidth into said signal components, and independently adjust the relative phase of its associated signal components.

10. An antenna system as set forth in claim 8, wherein said filter-phase network including a plurality of parallel branch circuits, each including a filter means for limiting its operation to a particular one of said signal components, and phase adjust means for introducing a predetermined phase variation within the individual branch circuits.

11. An antenna system as set forth in claim 10, further including circuit means coupling first ends of said branch circuits to a first common junction, and second ends of said branch circuits to a second common junction, said first common junction circuit connected to its respective feed member, and said second common junctions of a plurality of said filter-phase networks circuit connected to a signal feed junction.

12. An antenna system characterized as having the property of selectively directing the orientation of its associated antenna beam in space, the antenna beam formed of a plurality of frequency-separated signal components, additively defining a desired bandwidth of antenna system operation, said system including: a signal feed and a signal impinging surface for directing the orientation of the antenna beam, said signal feed located within a focal plane relative to the beam directing surface formed by said signal impinging surface, means for establishing a plurality of feed points within said focal plane, each associated with different ones of said signal components, and for selectively locating said feed points within said focal plane, said signal means including a plurality of feed members displaced from said focal plane, and operatively associated to combinedly establish said feed points at the focal plane.

13. An antenna system as set forth in claim 12, wherein said signal feed points having a minimum spaced separation corresponding to a first distance, said feed members having a minimum spaced separation corresponding to a second distance, said second distance in the order of a half-wave length at the mean operating frequency of said bandwidth, said second distance substantially greater than said first distance.

14. An antenna system characterized as having the property of selectively directing the orientation of its associated antenna beam in space, the antenna beam formed of a plurality of frequency-separated signal components, additively defining a desired bandwidth of antenna system operation, said system including: a signal feed and a signal impinging surface for directing the orientation of the antenna beam, said signal feed located within a focal plane relative to the beam directing surface formed by said signal impinging surface; means for establishing a plurality of feed points within said focal plane, each associated with different ones of said signal components, and for selectively locating said feed points within said focal plane; said signal means including a plurality of feed members displaced from said focal

15

plane; phase control means for adjusting the relative phase of the individual ones of said signal components associated with respective ones of said feed members, the relative phase adjustment of said feed members serving to combinedly establish the equivalent of said feed points within said focal plane, in satisfaction of Huygens' principle.

15. An antenna system as set forth in claim 13, the adjustment of the relative phase associated with a particular one of said signal components at each of said signal components at each of said signal feeds, establishing a particular location within said focal plane of the signal feed point for said particular component, the adjustment by an equal amount of the phase associated with said particular component, at each of said signal feeds, maintaining said particular location of its feed point, while varying the phase of said feed point relative to the other feed points corresponding to the others of said signal component, whereby said phase control means provides both proper orientation in space of each of said signal component, and the proper relative phase relationship between said signal components to preserve the characteristics of an antenna beam pattern over said desired bandwidth.

16. An antenna system including, a signal feed means for establishing at least first and second signal feed points, said first and second signal feed points associated with first and second signal frequencies, respectively; said feed means comprising a plurality of feed members displaced from the location of said signal feed points; means for simultaneously feeding said first and second signals to said plurality of said feed members; phase control means for selectively adjusting the relative phase of said first and second frequencies fed to individual ones of said feed members, the relative phase distribution of the components of said first frequency fed to said plurality of feed members, characterized as combinedly defining the Huygens principle distribution of a source of said first frequency located at said first signal feed point, the relative phase distribution of the components of said second frequency fed to said plurality of feed members characterized as combinedly defining the Huygens principle distribution of a source of said second frequency located at said second signal feed point; a signal impinging surface for directing an antenna beam in space, said signal feed points located within a focal plane relative to the beam directing surface formed by said signal impinging surface, the adjustment of the relative phase of said first and second frequency components at each of said feed members, establishing a particular location within said focal plane of the signal feed point for said frequencies.

17. An antenna system as set forth in claim 16, the adjustment by an equal amount of the phase associated with one of said frequency components, at each of said feed members, maintaining said particular location of its feed point, while varying the signal phase of said feed point relative to the other feed points corresponding to another of said frequencies.

18. An antenna system as set forth in claim 17, said phase control means includes a filter-phase network for each of said feed members; said filter phase network including circuit means to separate said first and second frequency components, and independently adjust the relative phase of its associated signal components.

19. An antenna system as set forth in claim 18, said filter-phase network including a plurality of parallel branch circuits, each including a filter means for limiting its operation to a particular one of said signal components, and phase adjust means for introducing a predetermined phase variation within the individual branch circuits.

20. An antenna system as set forth in claim 19, circuit means coupling first ends of said branch circuits to a first common junction, and second ends of said branch circuits to a second common junction, said first common junction circuit connected to its respective feed member,

16

and said second common junctions of a plurality of said filter-phase networks circuit connected to a signal feed junction.

21. An antenna system, including a stationary array of signal radiating means, combinedly defining an antenna surface; a signal feed remotely positioned from said antenna surface; scanning means for predeterminedly varying the electrical characteristics of said antenna surface, as presented to a signal source associated with said signal feed; a focal plane defined by the electrical characteristics of said antenna surface; said antenna surface operatively directing said signal source between said signal feed and an antenna beam having a predetermined angular orientation in space; said scanning means serving to change said angular orientation; said signal source having a desired bandwidth, about a mean frequency; said antenna surface, while adjusted for a particular angular orientation at said mean frequency, presenting different electrical characteristics to other of its frequency components within said desired bandwidth whereby the effective angular orientation of said antenna surface for said other frequencies differs from said particular angular orientation corresponding to said mean frequency, with said difference tending to reduce the effective bandwidth capabilities of the antenna system; the improvement comprising control means within said signal feed for compensating for said difference such that an antenna beam in said particular direction effectively includes all of the frequency components within said desired bandwidth; said control means including means for establishing a plurality of feed points within said focal plane, each associated with different ones of the frequency components defining said desired bandwidth of signal source operation.

22. An antenna system as set forth in claim 21, said signal feed means including a plurality of feed members displaced from said focal plane, and operatively associated to combinedly establish said feed points at the focal plane.

23. An antenna system as set forth in claim 21, said signal feed means including a plurality of feed members displaced from said focal plane, phase control means for adjusting the relative phase of the individual ones of said signal components associated with respective ones of said feed members; the relative phase adjustment of said feed member serving to combinedly establish the equivalent of said feed points within said focal plane in satisfaction of Huygens' principle.

24. An antenna system as set forth in claim 21, said signal feed points having a minimum spaced separation corresponding to a first distance, said feed members having a minimum spaced separation corresponding to a second distance, said second distance substantially greater than said first distance.

25. An antenna system, as set forth in claim 21, said bandwidth including upper and lower end frequencies; said focal plane having a focal point; said feed points including at least a first, second, and third feed point, corresponding to said mean, lower end and upper end frequencies respectively; said first feed point located at said focal point; said second feed point located within said focal plane, displaced from said focal point a first distance operatively related to said particular angle of antenna orientation and its frequency displacement from said mean frequency; said third feed point located within said focal plane, displaced from said focal point a second distance operatively related to said particular angle of antenna orientation and its frequency displacement from said mean frequency.

26. An antenna system as set forth in claim 25, said first and second distances extending in opposite directions from said focal point, and being of equal magnitude corresponding to equal frequency separation of said upper and lower end frequencies from said mean frequency.

27. An antenna system as set forth in claim 25, said control means further adjusting the relative phase of the

signal component associated with respective ones of said feed points.

28. An antenna system as set forth in claim 25, said signal feed means including a plurality of feed members displaced from said focal plane, phase control means for adjusting the relative phase of the mean frequency, upper end, and lower end frequency component associated with respective ones of said feed members; the relative phase adjustment of said frequency components combinedly establishing the equivalent of said first, second and third feed points in satisfaction of Huygens' principle.

29. An antenna system as set forth in claim 28, the adjustment by an equal amount of the phase associated with one of said frequency components, at each of said feed members, maintaining said particular location of its feed point, while varying the signal phase of said feed point relative to the other feed points corresponding to another of said frequencies, whereby said phase control means provides both proper orientation in space of each of said signal component, and the proper relative phase relationship between said signal components to preserve the characteristics of an antenna beam pattern over said desired bandwidth.

30. An antenna system as set forth in claim 28, said phase control means includes a filter-phase network for each of said feed members; said filter phase network including circuit means to separate said signal source into

said mean frequency, upper end, lower end and other frequency components, and independently adjusting the relative phase of each signal component associated therewith.

31. An antenna system as set forth in claim 30, said filter-phase network including a plurality of parallel branch circuits, each including a filter means for limiting its operation to a particular one of said signal components, and phase adjust means for introducing a predetermined phase variation within the individual branch circuits.

References Cited

UNITED STATES PATENTS

2,975,419	3/1961	Brown	343—754
3,205,501	9/1965	Kuhn	343—778
3,245,081	4/1966	McFarland	343—754
3,259,902	7/1966	Malech	343—777
2,530,580	11/1950	Lindenblad	343—777 X
2,788,440	4/1957	Ramsay et al.	343—756 X

FOREIGN PATENTS

562,602	9/1958	Canada.
1,075,682	2/1960	Germany.

HERMAN KARL SAALBACH, *Primary Examiner*.
PAUL L. GENSLER, *Assistant Examiner*.