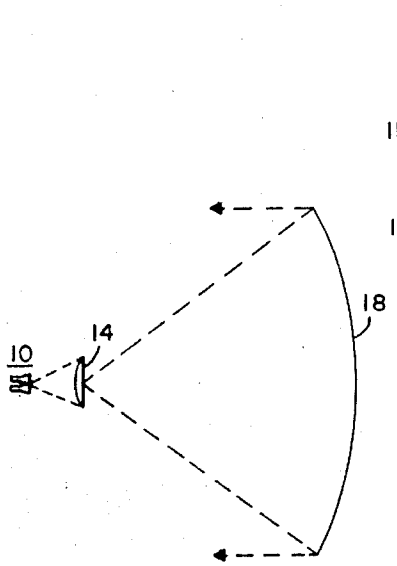


FIG. 1a

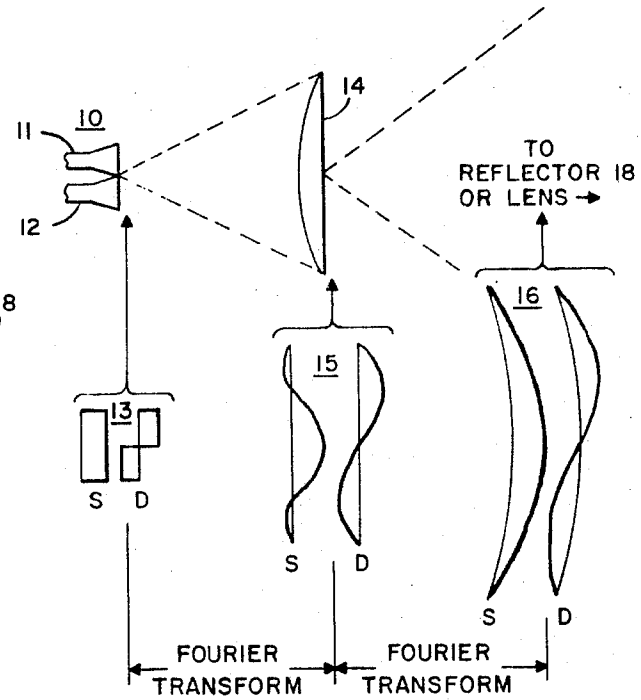


FIG. 1b

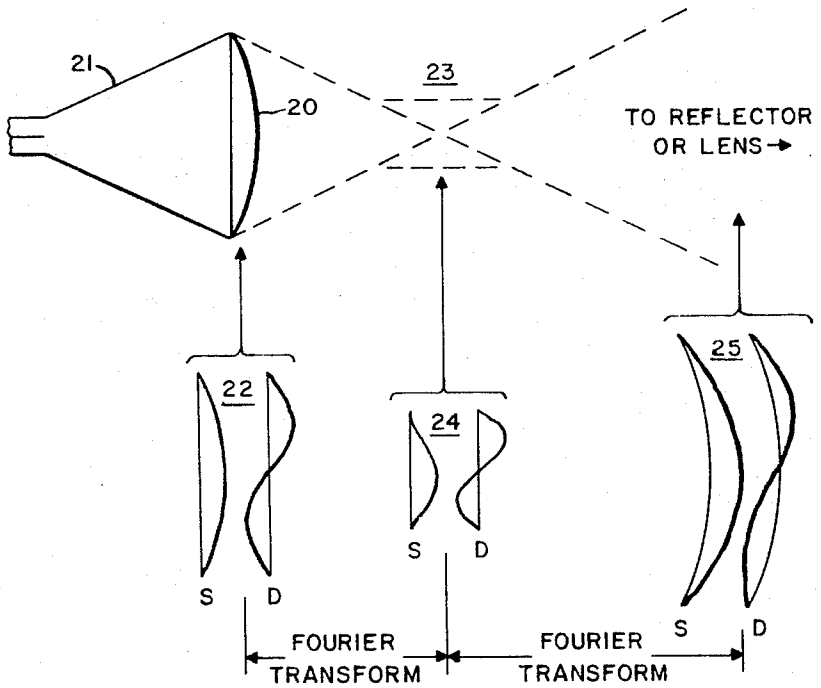


FIG. 2

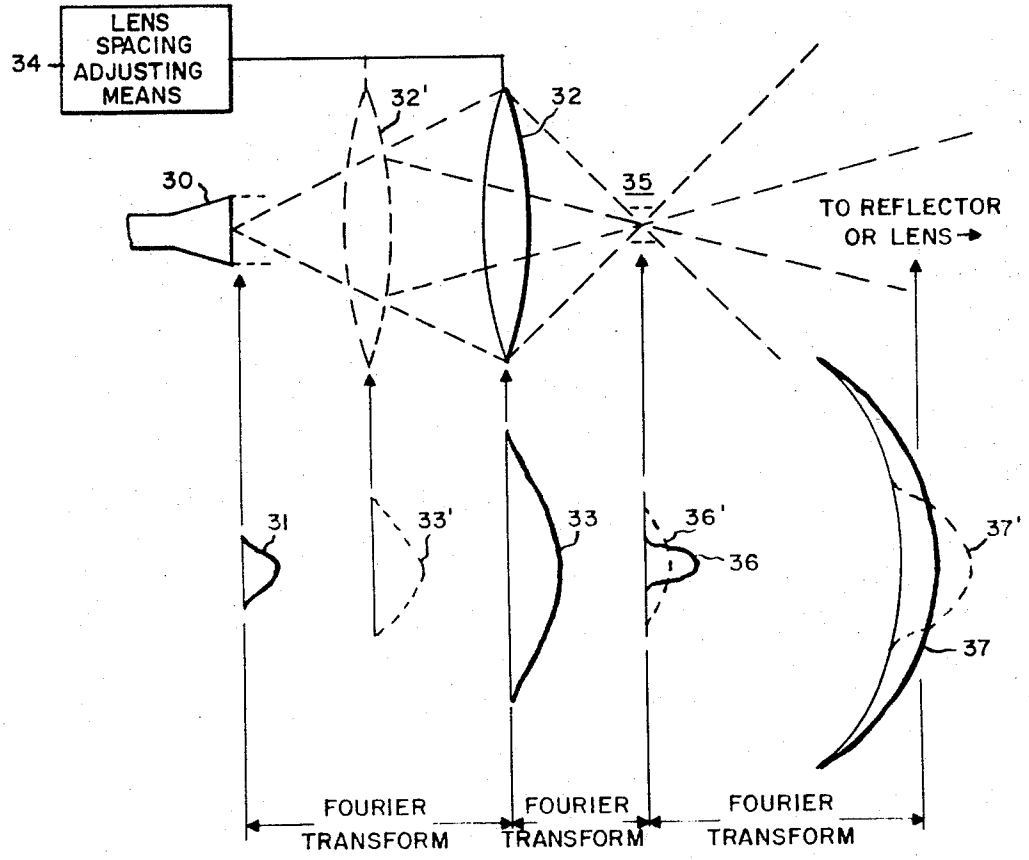

LENS SPACING ADJUSTING MEANS
34
32'
32
30
35
TO REFLECTOR OR LENS
31
33'
33
36'
36
37'
37
FOURIER TRANSFORM
FOURIER TRANSFORM
FOURIER TRANSFORM

FIG. 3

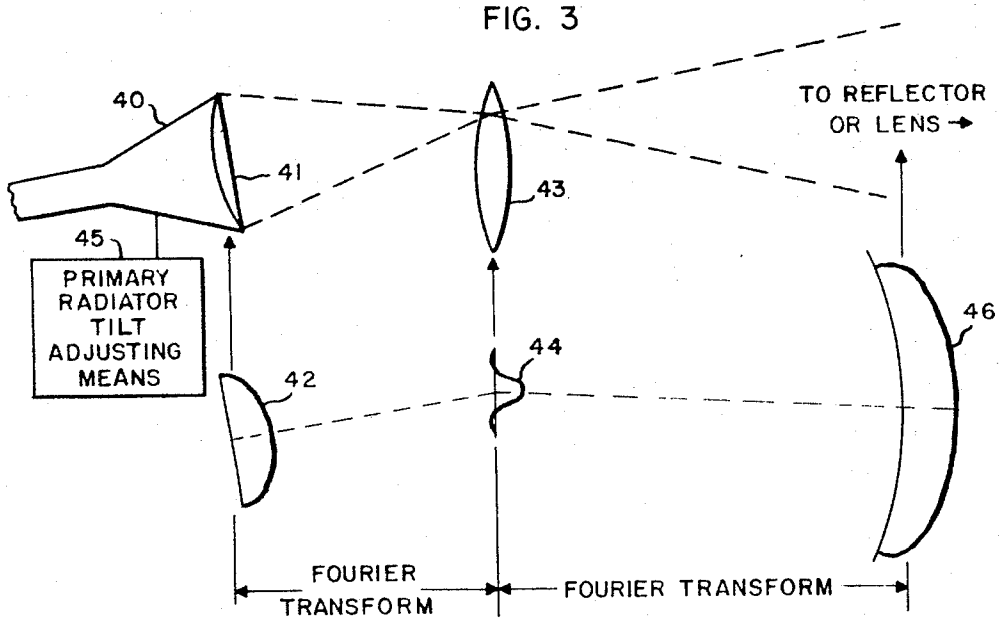

40
41
43
TO REFLECTOR OR LENS
45
PRIMARY RADIATOR TILT ADJUSTING MEANS
42
44
46
FOURIER TRANSFORM
FOURIER TRANSFORM

FIG. 4

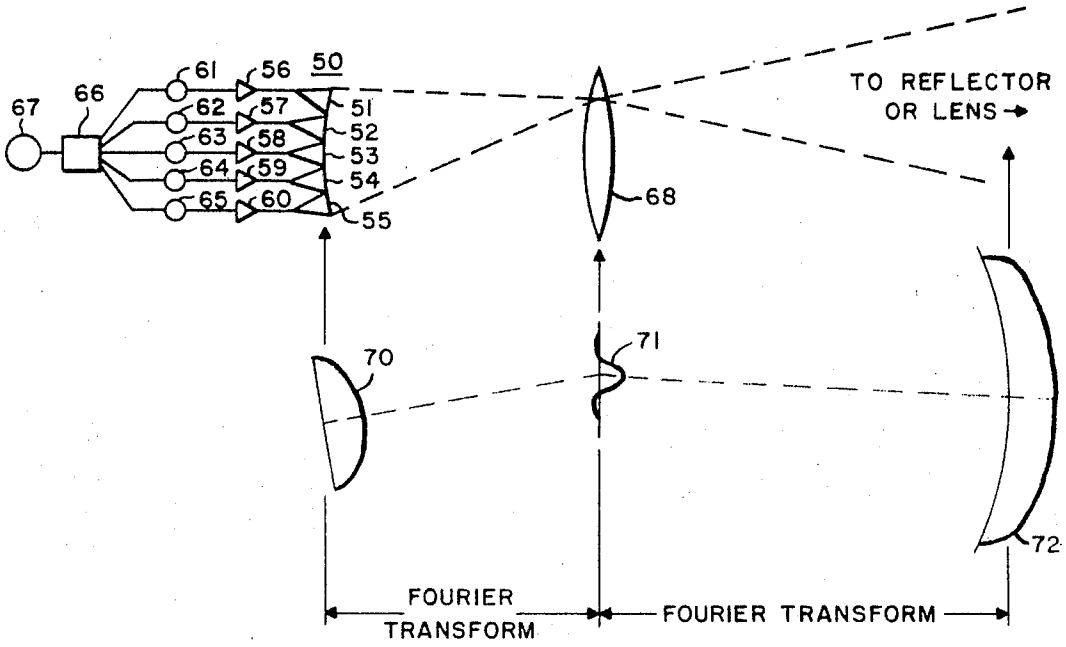


FIG. 5

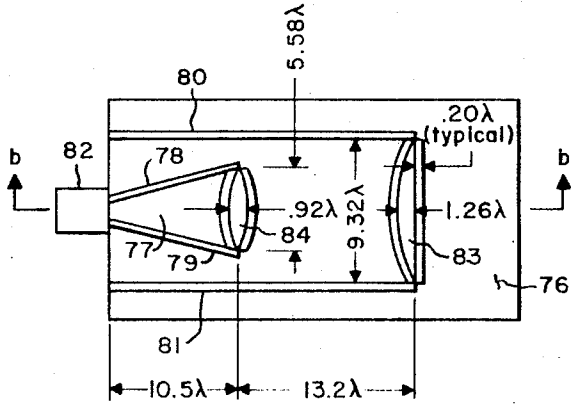


FIG. 6a

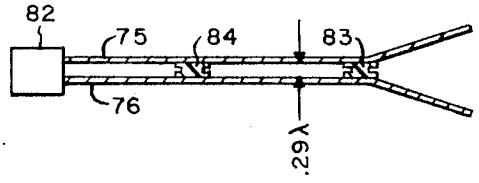


FIG. 6b

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3,456,260

MONOPULSE ANTENNA SYSTEM WITH LENS TO PROVIDE EQUAL ILLUMINATION OF MAIN ANTENNA APERTURE

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Continuation of application Ser. No. 344,068, Feb. 11, 1964. This application Sept. 22, 1967, Ser. No. 669,972
Int. Cl. H01q 19/10
U.S. Cl. 343—755 5 Claims

ABSTRACT OF THE DISCLOSURE

A monopulse antenna system including a focal-transform feed. The focal-transform feed consists of a primary monopulse radiator having equal width aperture field distribution patterns in the sum and difference modes and a focusing element, such as a lens, positioned to produce an additional Fourier transform of the aperture field distribution pattern. The doubly transformed radiation pattern provides equal width illumination of the main antenna aperture or dish.

This is a continuation of application, Ser. No. 344,068, filed on Feb. 11, 1964, now abandoned.

This invention relates to feeds utilized to illuminate a lens or reflector system in a microwave antenna and invention relates to focal-transform feeds able to obtain modified feed radiation patterns which are difficult or impossible to achieve with prior feed design techniques.

One particular well-known problem exists in the design of monopulse antennas which operate in a sum mode and one or more difference modes. The primary radiator commonly used in prior art monopulse systems is a cluster of four horns which are excited with all horns in phase for the sum mode and with two horns out of phase with the other two horns for each difference mode. As is well known, in such an arrangement the field-distribution patterns at the aperture of the horn cluster are equally wide in the sum and difference modes, causing the resulting feed radiation patterns to be twice as wide in the difference modes as in the sum mode. This relation of the sum and difference mode feed radiation patterns leads to inefficient usage of the lens or reflector system, or to large side lobes in the difference mode radiation patterns of the antenna system. This is so because, if the lense or reflector system is positioned for efficient utilization in the difference modes, the sum mode will then utilize only the center portion of the lens or reflector system. On the other hand, if the lens or reflector system is positioned for efficient utilization in the sum mode, then large portions of the difference mode feed radiation patterns will fall outside the limits of the lens or reflector system giving rise to large side lobes in the difference mode radiation patterns of the antenna system.

Objects of this invention are to provide new and improved feeds which avoid one or more disadvantages of prior systems and which provide modified feed radiation patterns. Further objects are to provide antennas using such feeds.

In accordance with the invention there is provided a monopulse antenna system comprising a focal-transform monopulse feed consisting of (a) monopulse radiator means for operating in a sum mode and at least one difference mode and having equal width aperture field-distribution patterns in a given plane which differ for the sum and difference modes; (b) and focusing means for producing in cooperation with the radiator means final feed radiation patterns which are essentially equally wide for the sum and difference modes as a result of two successive Fourier transforms in the given plane of the aperture field-distribution patterns of the radiator means. The system also includes a second main focusing means for providing, in cooperation with the focal-transform feed, an antenna radiation pattern which is essentially the Fourier transform in the given plane of the final feed radiation pattern.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings:

FIG. 1*a* shows a complete antenna constructed in accordance with the invention;

FIG. 1*b* shows in greater detail the focal-transform feed of the FIG. 1*a* antenna which utilizes a lens spaced from a primary radiator in the form of a horn cluster;

FIG. 2 shows a focal-transform feed utilizing a converging lens at the aperture of a horn;

FIG. 3 shows a variable-beamwidth focal-transform feed utilizing a converging lens movably positioned relative to a horn;

FIG. 4 shows a focal-transform feed for beam scanning utilizing a lens spaced from a tiltable horn;

FIG. 5 shows a focal-transform feed for beam scanning utilizing a lens spaced from a scannable beam horn array; and

FIG. 6 shows a specific example of a monopulse antenna utilizing the FIG. 1 concept.

Referring now to FIGS. 1*a* and 1*b*, there is shown an antenna utilizing a focal-transform feed constructed in accordance with the invention. FIG. 1*a* shows the complete antenna and FIG. 1*b* shows in greater detail the feed of the FIG. 1*a* antenna. This feed includes a primary radiator **10** having a predetermined aperture field-distribution pattern as shown at **13**. More particularly, the primary radiator **10** is shown as a monopulse horn cluster, including horns **11** and **12**, for operating in a sum mode and a difference mode and having aperture field-distribution patterns as shown at **13** which differ for the sum (S) and difference (D) modes. The feed also includes focusing means, shown as lens **14**, for producing in cooperation with the radiator **10** a final feed radiation pattern, as shown at **16**, which is essentially the resultant which would be produced by a plurality of successive Fourier transforms of the aperture field-distribution pattern **13**.

The FIG. 1*a* antenna further includes additional focusing means, shown as reflector **18**, which may be a suitable prior art antenna or lens system. Reflector **18** is positioned so as to be illuminated by the final feed radiation pattern **16**. In considering other embodiments of the invention to be discussed below, it will be clear that the various feeds shown and described can be utilized in antennas with reflector systems or lens systems in the manner of FIG. 1*a* and the prior art.

The arrangement of FIGS. 1*a* and 1*b* is such that the lens **14** is in the far field of the primary radiator **10**, and the lens **14** is focused so that the diverging radiation pattern from primary radiator **10** is collimated into essentially a plane wave near the lens. Since the lens is in the far field of the primary radiator, it is well known that the aperture of the lens **14** will have a field-distribution pattern which is essentially the Fourier transform of the aperture field-distribution pattern of the primary radiator **10**. In the example shown in FIGS. 1*a* and 1*b*, the primary radiator is a prior art-type monopulse horn cluster; since its field distribution is equally wide in the sum and difference modes as shown at **13**, its radiation pattern would be essentially twice as wide in the difference mode as in the sum mode as shown at **15**. However, the lens

14 utilizes these radiation patterns for its own field distributions, so that in the far field of the lens, the field distribution will be essentially the Fourier transform of the field distribution across the aperture of the lens. The resulting radiation patterns of the entire feed system will have essentially equal widths in the sum and difference modes as shown at 16. This is the desired condition for the illumination of a reflector or lens system in a monopulse antenna and permits efficient utilization of reflector 18 in the illustrated embodiment.

FIGS. 1*a* and 1*b* can be considered to be either side views or top views of a monopulse feed utilizing a prior art-type four horn cluster for operation in a sum mode and elevation and azimuth difference modes. The only important difference between the two difference modes is the change in coordinates.

In discussing feeds and antennas in accordance with the invention, reliance will be placed largely on terms relating to transmission as is customary in discussing antenna system components. However, reciprocity applies so that the same relations hold true for reception. Thus, in the discussion, terms such as "radiation pattern" are used even though the important monopulse considerations are primarily related to reception and not to radiation of signals.

Referring now to FIG. 2 there is shown an alternative arrangement in which the physical components of the feed system represent only a part of the entire effective feed system. In this case, the focusing means is a large lens 20 positioned at the aperture of a large primary radiator, shown as horn 21, for converging the field-distribution pattern as shown at 22 to a small radiation pattern at area 23 near the primary focus of the primary radiator 21. Since this small radiation pattern is near the focus of the primary radiator system, a small Fraunhofer pattern is developed as shown at 24 which is essentially the Fourier transform of the aperture field distribution of the primary radiator 21. This small radiation pattern 24 acts like the field-distribution pattern of an effective secondary radiator which produces the final feed radiation pattern as shown at 25, which is essentially the Fourier transform of the small radiation pattern 24 and which would then illuminate a large reflector, for example. If the primary radiator is a monopulse feed, a final feed radiation pattern is provided which has desirable properties similar to those previously discussed with reference to FIGS. 1*a* and 1*b*.

Referring now to FIG. 3 there is shown a variable-beamwidth focal-transform feed including a primary radiator 30 focusing means shown as lens 32 and lens spacing adjusting means 34. The primary radiator 30 has a predetermined aperture field-distribution pattern as shown at 31. The lens 32 is positioned so that its aperture field-distribution pattern 33 is essentially the Fourier transform of the aperture field-distribution pattern 31 of the primary radiator. The lens 32 acts to converge the diverging radiation pattern of the primary radiator 30 to a small radiation pattern as shown at 36 which is located in the area 35, near the focus of the system comprising primary radiator 30 and lens 32. The small radiation pattern 36 represents essentially the field-distribution pattern of an effective secondary radiator which produces the final feed radiation pattern as shown at 37.

The small radiation pattern 36 is essentially the Fourier transform of the aperture field-distribution pattern 33 of the lens 32 and the final feed radiation pattern as shown at 37 is essentially the Fourier transform of the small radiation pattern as shown at 36. Thus, there are three transforms involved in the feed system. In this arrangement it is possible to achieve control of the width of the final feed radiation pattern. This is done by varying the location of the lens 32 relative to the radiator 30. For example, if the lens spacing adjusting means 34 is actuated so as to move the lens 32 to the dotted position labeled 32', the small radiation pattern 36 will increase in size as indicated at 36'. Thus, this effective secondary radiator will become more directive and as a result the final feed radiation pattern will be narrower as indicated at 37'. In this way a variation in the beamwidth of a complete antenna can be achieved. Lens spacing adjusting means 34 may be any suitable mechanical arrangement for varying the position of the lens 32.

Referring now to FIG. 4 there is shown a focal-transform feed for beam scanning including a primary radiator 40, a first focusing means shown as lens 41 positioned at the aperture of the primary radiator 40, second focusing means shown as lens 43 and primary radiator tilt adjusting means 45. The combination of the primary radiator 40 and the lens 41 positioned at its aperture provides an aperture field-distribution pattern as shown at 42. The lens 41 acts to converge the radiation pattern of the primary radiator 40 to produce a small radiation pattern 44 which is essentially the Fourier transform of the aperture field-distribution pattern 42 of the primary radiator. The second lens 43 is substantially larger than the small radiation pattern 44 and lens 43 is positioned so that the small pattern 44 occupies a portion of the aperture of this lens 43. Lens 43 acts to produce a final feed radiation pattern shown at 46 which is essentially the Fourier transform of the aperture radiation pattern 44.

The FIG. 4 arrangement is such that the small radiation pattern 44 acts like an effective secondary radiator which, because of the action of the lens 43, is always directed toward the same region and therefore will efficiently illuminate a large reflector. By activating the primary radiator tilt adjusting means 45 to change the tilt of the primary radiator 40, the small radiation pattern 44 can be made to move to a different portion of the aperture of lens 43. This movement, or translation, of the effective secondary radiator (represented by the movement of the small radiation pattern 44) is a very desirable arrangement for the feed of a rapid-scanning antenna because the radiated beam can be scanned without the necessity of having to move the entire antenna. The present invention allows translation of the effective secondary feed by tilting the primary radiator; this will usually be much easier to accomplish than effecting such translation by other arrangements. The primary radiator tilt adjusting means 45 may be any suitable mechanical arrangement for providing the desired change in the tilt of the primary radiator.

Referring now to FIG. 5, there is shown a focal-transform feed for beam scanning which is similar in operation to the FIG. 4 arrangement. The main difference between the feeds of FIGS. 4 and 5 is in the primary radiator and its operation. The FIG. 5 feed includes an array of radiators 50, in the form of horns 51–55, which has a converging scannable radiation pattern. Each of horns 51–55 is fed by a separate amplifier (56–60, respectively) and a separate adjustable phase shifter (61–65, respectively) the complete arrangement being fed from a distribution network 66 and a wave signal source 67. The phasing is first adjusted so that the array of horns 51–55 is focused toward the lens 68. Then by varying the phase shifters to produce a linear phase deviation across the array, the effective secondary feed is translated across the lens 68 as in the FIG. 4 arrangement. Steerable arrays are well known and any suitable types of distribution network 66, phase shifters 61–65, and amplifiers 56–60, may be utilized. As indicated, the field-distribution patterns are similar to those associated with the FIG. 4 feed.

The FIG. 5 system has several significant advantages over the ordinary technique of actually translating a real feed. First, there are no physically moving parts (the phase shifting can be done electronically using prior art techniques). Second, the transmitted power is obtained from a number of amplifiers of relatively low power capability, not just a single high power amplifier. Third, phase shifting is done at low power levels. Fourth, the power level in each amplifier remains constant as scan-

ning takes place. Fifth, the number of amplifiers is moderate, i.e. small compared with the number required in a large scanning array-type of antenna. Thus, this scheme is attractive for a large high-power rapid-scan antenna of limited scan angle.

Referring now to FIGS. 6*a* and 6*b*, there are shown two views of a focal-transform feed in accordance with the invention which was constructed and successfully operated. The feed of FIGS. 6*a* and6*b* is a two-mode monopulse feed basically he same as the feed shown in FIG. 1*b*. The feed of FIGS. 6*a* and 6*b* was constructed between two spaced parallel conductive plates **75** and **76** to minimize the size. FIG. 6*a* is a top view of the feed with plate **75** removed to show the interior construction and FIG. 6*b* is a side sectional view. Horn **77**, which is the primary radiator in the feed of FIGS. 6*a* and 6*b*, is formed by two conductive walls **78** and **79** in combination with a portion of the plates **75** and **76**. Two similar conductive walls **80** and **81** were included primarily for mechanical stability. The walls **80** and **81** are located at the extremities of the active feed region and do not appreciably affect the operation of the feed.

As noted, the feed of FIGS. 6*a* and 6*b* is basically the same as the FIG. 1*b* feed. The feed of FIGS. 6*a* and 6*b* utilizes a single monopulse horn constructed to operate in a sum mode and a single difference in conjunction with the hybrid junction **82**. In FIG. 1*b*, the primary radiator **10** was small compared to the lens **14**; in FIGS. 6*a* and 6*b* the horn **77** is not small compared to the lens **83** and therefore an additional lens **84** was included at the aperture of horn **77** to retain the Fraunhofer pattern at lens **83**. Lens **84** is not important to the basic principles of the invention. The field-distribution and radiation patterns applicable to the feed of FIGS. 6*a* and 6*b* are essentially indentical to those shown in FIG. 1*b* and discussed with reference thereto. The important dimensions of the feed of FIGS. 6*a* and 6*b* as constructed, are given in the drawing in terms of operating wavelengths. The lenses were constructed of a dielectric material having a dielectric constant of approximately 2.6. The hybrid junction **82** is a prior art device suitable for exciting a sum and one difference mode in the horn **77**.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A monopulse antenna system comprising:

a focal-transform monopulse feed consisting of

(a) monopulse radiator means for operating in a sum mode and at least one difference mode and having equal width aperture field-distribution patterns in a given plane which differ for the sum and difference modes;

(b) and focusing means for producing in cooperation with said radiator means final feed radiation patterns which are essentially equally wide for the sum and difference modes as a result of two successive Fourier transforms in said given plane of said aperture field-distribution patterns of said radiator means;

and a second main focusing means for providing, in cooperation with said focal-transform feed, antenna radiation patterns which are essentially the Fourier transform in said given plane of the final feed radiation patterns.

2. An antenna system in accordance with claim **1**, wherein said primary radiator comprises at least one horn and said focusing means comprises at least one lens.

3. A monopulse antenna system comprising:

a focal-transform monopulse feed consisting of

(a) a monopulse horn cluster for operating in a sum mode and at least one difference mode and having equal width aperture field-distribution patterns in a given plane which differ for the sum and difference modes;

(b) and focusing means, positioned at the aperture of said horn cluster, for converging the radiation patterns of the horn cluster to small radiation patterns near the focus of said horn cluster, which said small patterns represent essentially the field-distribution patterns in said given plane of effective secondary radiators which produce the final feed radiation patterns;

the feed being so constructed and arranged that said small radiation patterns are essentially the Fourier transforms in said given plane of said aperture field-distribution patterns of the horn cluster and said final radiation patterns are essentially the Fourier transforms in said given plane of said small radiation patterns and the final feed radiation patterns are essentially equally wide for the sum and difference modes;

and a second main focusing means for providing, in cooperation with said focal-transform feed, antenna radiation patterns which are essentially the Fourier transform of the final feed radiation patterns in said given plane.

4. A monopulse antenna system comprising:

a focal-transform monopulse feed consisting of

(a) a monopulse horn cluster for operating in a sum mode and at least one difference mode and having equal width aperture field-distribution patterns in a given plane which differ for the sum and difference modes;

(b) first focusing means, positioned at the aperture of said horn cluster, for developing Fraunhofer radiation patterns in said given plane not far from said horn cluster;

(c) and second focusing means, positioned so that its aperture field-distribution patterns are essentially the Fourier transforms in said given plane of said aperture field-distribution patterns of said horn cluster, for producing final feed radiation patterns which are essentially the Fourier transforms in said given plane of the aperture field-distribution patterns of said second focusing means;

the feed being so constructed and arranged that the final feed radiation patterns are essentially equally wide for the sum and difference modes;

and a third main focusing means for providing, in cooperation with said focal-transform feed, antenna radiation patterns which are essentially the Fourier transform of the final feed radiation patterns in said given plane.

5. A monopulse antenna system comprising:

a focal-transform monopulse feed consisting of

(a) monopulse radiator means for operating in a sum mode and at least one difference mode and having equal width-aperture field-distribution patterns in a given plane which differ for the sum and difference modes;

(b) and focusing means positioned so that its aperture field-distribution patterns are essentially the Fourier transform of said aperture field-distribution patterns of said primary radiator in said given plane for producing final feed radiation patterns which are essentially the Fourier transform of the aperture field-distribution patterns of said focusing means in said given plane and which are essentially equally wide for the sum and difference modes;

and a second main focusing means for providing, in cooperation with said focal-transform feed, antenna

radiation patterns which are essentially the Fourier transform in said given plane of the final feed radiation patterns.

References Cited

UNITED STATES PATENTS

2,511,610	6/1950	Wheeler	343—909
2,759,154	8/1956	Smith et al.	333—11
3,101,472	8/1963	Goubau	343—909
3,158,862	11/1964	Chisholm	343—909
2,822,541	2/1958	Sichak et al.	343—779

FOREIGN PATENTS

501,429	5/1937	Great Britain.
760,211	10/1956	Great Britain.

OTHER REFERENCES

Hannan; Ire Transactions on Antennas and Propagation, vol. AP–9, 1961, pp. 444–453.

ELI LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

343—779