United States Patent [19]

Thomas

[11] **3,710,281**

[45] **Jan. 9, 1973**

[54] **LOSSLESS N-PORT FREQUENCY MULTIPLEXER**

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[22] Filed: **Dec. 10, 1970**

[21] Appl. No.: **96,911**

[52] **U.S. Cl.** **333/6**, 333/10, 343/854
[51] **Int. Cl.** **H01p 5/12**
[58] **Field of Search**............343/854; 333/6, 11, 31 C

[56] **References Cited**

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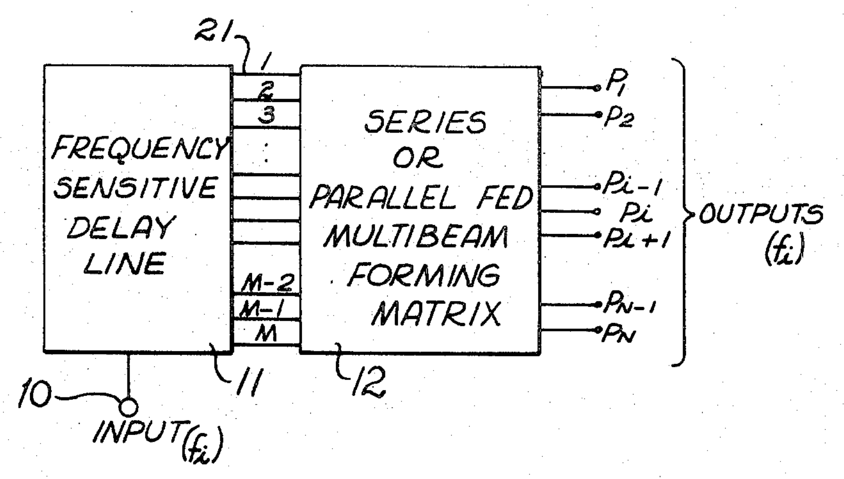
[57] **ABSTRACT**

An N-port multiplexer for separating a single input signal into N distinct isolated frequency components on discrete output terminals. The device is adapted to accomplish this function in a reciprocal, passive, lossless manner, in respect to an arbitrarily large number of such components. The multiplexer basically comprises two known microwave circuit devices uniquely combined. One of these is a frequency sensitive delay line with a plurality of taps and the other is a beam-forming matrix, such as a Butler matrix, or the so-called equal-path-length cross-line matrix. In a receiving mode, the delay line input is the signal to be separated and the taps are fed to the radiating element terminals of the beam-forming matrix. The matrix output terminals then provide the discrete frequency output lines.

7 Claims, 6 Drawing Figures



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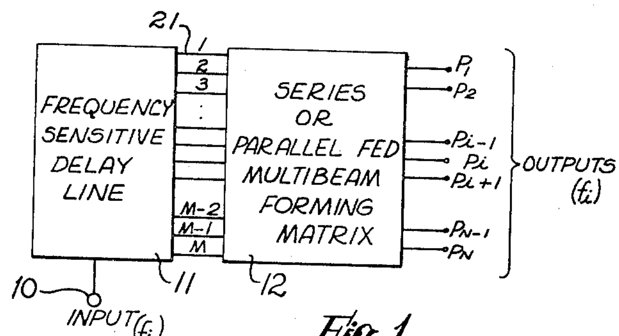
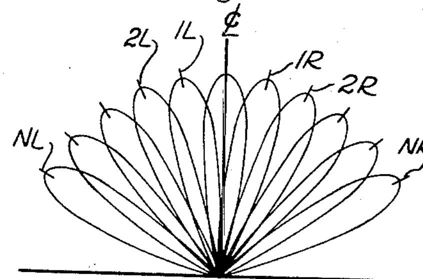


Fig. 1.

Fig. 2.



TYPICAL BEAM PATTERNS

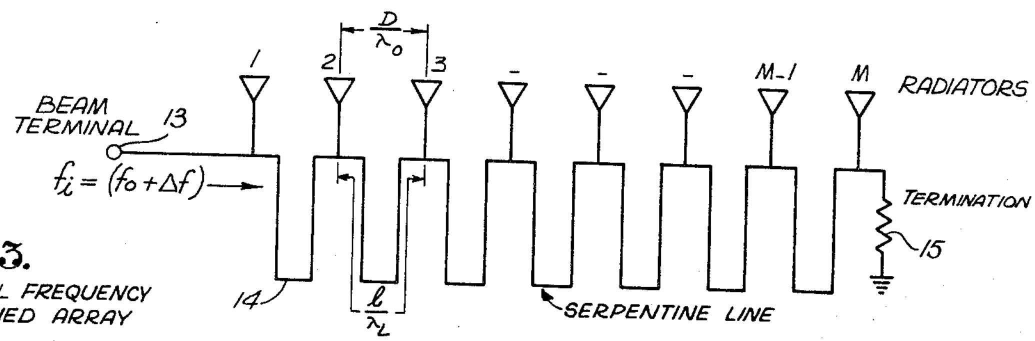


Fig. 3.
TYPICAL FREQUENCY SCANNED ARRAY

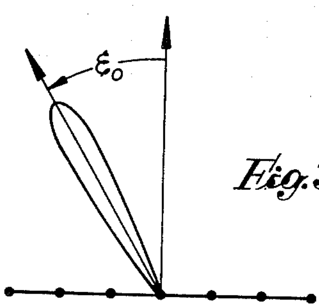
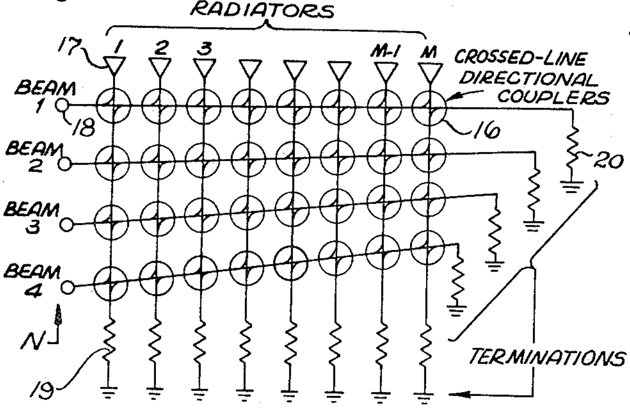


Fig. 3a.

$$\frac{D}{\lambda_0} \sin \xi_0 = \frac{\ell}{\lambda_L} \frac{\Delta f}{f_0}$$

Fig. 4. EQUAL PATH-LENGTH BEAM-FORMING MATRIX



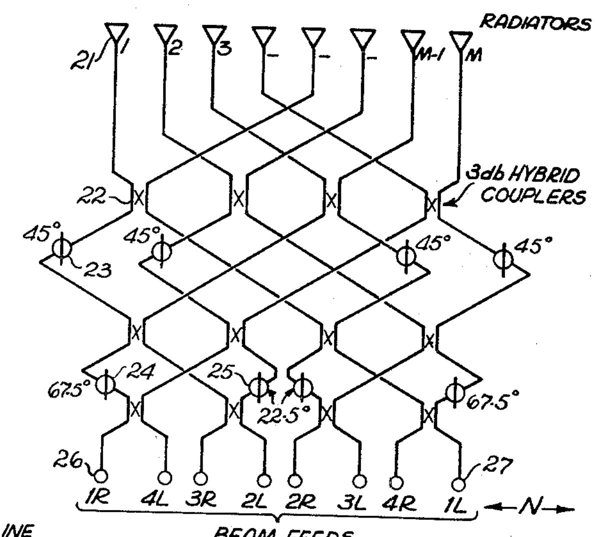


Fig. 5. PARALLEL FED MULTI-BEAM MATRIX

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LOSSLESS N-PORT FREQUENCY MULTIPLEXER

BACKGROUND OF THE INVENTION

1. Field of The Invention

The present invention relates to frequency multiplexing, particularly in microwave systems.

Description of The Prior Art

In the prior and present art an N-port multiplexer is definable as a device which separates one signal input into N distinct isolated frequency components at discrete output terminals. In the prior art, this type of multiplexing has been carried on by various devices generically categorized as filters. Inherently, such prior art devices were lossy, and/or not adapted to instantaneous operation.

It will be realized, of course, that active component systems for the general purpose have been instrumented but are inherently less reliable and more complex than passive devices.

Accordingly, the need clearly existed for a device that will provide frequency separation into an arbitrarily large number of components in a reciprocal, passive, lossless manner.

Since the present invention is primarily concerned with microwave instrumentation, an excellent and comprehensive review of the prior art in general, is presented in "Radar Handbook" by Merrill I. Skolnik, a McGraw Hill book, (1970). In fact, the two principal system components which are uniquely related in the present invention to produce the novel results obtained, are of themselves described in other system context in the aforementioned reference. In particular, in Chapter 11, Page 11–66, two forms of beam-forming networks or matrices, are shown.

The manner in which the present invention accomplishes its objective in a unique manner and the structure for utilizing the aforementioned prior art system components in the present combination will be understood as this description proceeds.

SUMMARY

It may be said to have been the objective of the present invention to produce an N-port frequency multiplexer which (in a receiving mode) will separate an incoming microwave signal into an arbitrarily large number of components in a reciprocal, passive, and lossless manner. The device of the present invention is particularly useful in electronic reconnaissance and electronic countermeasures applications and also will be recognized as useful in various antenna beam scanning and frequency jump radar instrumentations.

The device, according to the present invention, comprises essentially two known microwave system subassemblies combined in a unique manner. The first of these is an M-port delay line of the type employed in frequency scanning systems. The outputs of such a delay line, M, produce a constant progressive phase delay, the slope of which depends on the input frequency in a predetermined manner.

The second discrete building block subassembly is a multibeam-forming matrix of M first ports and N second ports. This particular device is designed such that a different linear progressive phase front is established or received along the terminals M, as each of the individual inputs N is excited in the respective direction.

Joining the two aforementioned devices along the interface at each of the M-ports results in a device which has a single input signal terminal and N beam feeds or output terminals. Accordingly, the discrete frequencies present at the said input terminal are divided among the N beam feed terminals discretely.

The details of operation of the present invention and the complete description of the structure follows hereinafter, along with an appropriate discussion and illustration of alternatives falling within the concepts of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of the overall system of the present invention.

FIG. **2** illustrates typical beam patterns corresponding to the beam angle variations or discrete angles available from excitation of the various N beam feeds.

FIG. **3** depicts a typical frequency-scanned array capable of providing the frequency sensitive delay line for the present invention.

FIG. **3***a* depicts the beam angle mathematical relationships for FIG. **3**.

FIG. **4** shows one form of a beam-forming matrix useful in the combination of the present invention and is identified as an equal path length beam-forming matrix.

FIG. **5** depicts a parallel fed multibeam matrix also adapted for use in the combination of the present invention in lieu of the matrix of FIG. **4**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In describing the present invention, the system will be assumed to be a receiving arrangement, since this is a particularly useful application of the invention; although, since the components comprising the present system are reciprocal, it could also be used in reverse as a transmitting system in which the receiving input becomes a transmitting output and in which the receiving utilization devices would be replaced by sources of microwave energy.

In accordance with the foregoing, and referring now to FIG. **1**, the input terminal **10** will be regarded as a received microwave frequency signal which it is desired to separate into discrete signal outputs according to frequency. The frequency sensitive delay line **11** is shown with generalized outputs **1** through M (typically **21**), which also comprise the inputs of the series or parallel fed multibeam-forming matrix **12**. The said matrix **12**, in turn, has generalized outputs P_1 through P_n. As has been indicated previously, the microwave circuit **11** is a tapped frequency-sensitive delay line, such as illustrated at FIG. **3** and as otherwise commonly used in connection with frequency scanned arrays.

Continuing with FIG. **1**, the output signals of **11** are equivalent to signals representing the phase characteristics of an arriving beam if these M inputs of the microwave circuit **12** were array connected (as will later be seen in FIG. **3**). The angle at which the said beam arrives therefore affects the relative phase of excitation of the inputs of **12** (considered as a separate component) and it is an inherent characteristic of the device **12** to provide an output on one of its P terminals discretely, as a function of the aforementioned M terminal phase relationships.

Referring now to FIG. 2, a generalized set of typical beam patterns is identified by number, right or left of the boresite or center-line of an array. Although FIG. 2 is illustrated with more beams than the arbitrarily selected eight beams of which the illustrated instrumentation is capable, it is to be understood that the actual number of beams is a matter of design. Each beam identified on FIG. 2 corresponds to an input phase distribution along the M terminals of 12 from among the individual (radiator) M signals from 11. A more complete understanding of the foregoing will follow as this description proceeds in connection with the remaining figures.

Referring now to FIG. 3, a typical frequency-scan array arrangement is shown. This array is completely reciprocal and, when fed at 13, with a frequency f_i, produces a beam in space at an angle which is related to f_i in accordance with the self-explanatory mathematical relationships depicted at FIG. 3*a*. In a transmitting radar arrangement, such as FIG. 3 per se, would normally be implemented in waveguide and would resemble the arrangement of FIG. 13*a* in Chapter 13 of the aforementioned "Radar Handbook" reference text. For application in the system of the present invention it could also be as represented at FIG. 26 of Chapter 13 in the same reference, the difference being in the tap arrangement. The serpentine line of FIG. 3, although in waveguide with plural bends (typically as at 14) may also be instrumented in any common travelling wave transmission line configuration used in the microwave arts, such as, for example, strip-line coaxial lime, rigid waveguide, etc. Particularly, since the present invention is being described as a receiving system, the said serpentine line might well be replaced by a strip-line, possibly of the meander type, since large power handling capability would not be a factor in that case. A termination 15 is provided commonly and its selection is made in accordance with well known criteria.

It is known that the energy phase distribution as a function of frequency, present along the taps of the serpentine line of FIG. 3, will excite the radiators in such a way as to cause formation of a beam in the plane of the array. If, as is also known, the frequency of f_i is varied, the corresponding serpentine line (delay line) phase distribution along the taps, is changed and the angle of the beam formed changes correspondingly. Stated in other words, this is the relationship depicted at FIG. 3*a*.

Before describing the specific arrangement and function of the device of FIG. 3 as used at 11 in FIG. 1, it is desirable to discuss the nature of element 12 per se in FIG. 1 in somewhat more detail.

Referring now to FIG. 4, one type of beam-forming network suitable for element 12 in FIG. 1, is illustrated. It is the inherent function of the device of FIG. 4 to place received energy (or substantially all of the received energy), at one of the "N" beam terminals (of which 18 is typical) for each corresponding discrete beam arrival angle at the M terminal radiators (typically 17). The device of FIG. 4 which has horizontal line terminations, typically 20, and also vertical line terminations, typically 19, is based on an equal path length beam-forming concept. Each of the line crossovers includes a crossed-line directional coupler, typically 16. It will be noted that in lieu of the radiators at the M terminals, if the same signal information (in respect to its phase distribution) were supplied to these M terminals by means other than through the radiators receiving a beam at a discrete angle, the result would be separation of all or most of this energy into the appropriate beam (N) terminal, as a function of the aforementioned phase distribution.

If the radiators at the M terminals on the device of FIG. 4 and also those in FIG. 3 are removed and these terminals connected together, line for line, the configuration of FIG. 1 will have been instrumented. Accordingly, the input 10 on FIG. 1 becomes that of 13 on FIG. 3 and the beam 1 through beam N terminals (of which 18 is typical) of FIG. 4, comprise the P_1 through P_n outputs of FIG. 1.

It will be understood that these P outputs from FIG. 1 may be supplied to utilization devices of any type appropriate for a particular application. Thus the energy on any of these P terminals may be simply used, as for example, to light an indicator lamp, or may be detected and amplified for another purpose.

In addition to the reciprocity of the combination of FIG. 1, the general concept of superposition also applies, and accordingly, two discrete frequency signals present at 10 can be contemporaneously present at appropriate (different) P terminals. Referring now to FIG. 5, a so-called "Butler Matrix" is shown. In its usual form, the Butler matrix is connected to a series of radiators in a linear array at its M terminals. Radiator 21 is typical of these connections. A combination 3db hybrid couplers, typically 22, with an arrangement of 45° phase shifters (typically 23) and 67 178° phase shifters (typically 24) is employed. Also, a pair of 22 ½ phase shifters (typically 25) are employed, and the N terminals comparable to the N terminals of the configuration of FIG. 4 run between 26 and 27. Inclusion of this matrix with its M terminals connected to those of the delay line of FIG. 3, produces an alternate instrumentation of the combination of the present invention. The P terminals from FIG. 1 are then generated at the N terminals of the device of FIG. 5.

It is a characteristic of the circuit of FIG. 5 that the beam-feeds or N terminals representing each beam pattern (as, for example, illustrated on FIG. 2) are somewhat intermixed, as illustrated. This is, of course, readily accounted for in making the connections between 11 and 12.

From the foregoing, the operation of the composite circuit, according to the present invention, will be apparent. An input excitation within the circuit operating band applied at terminal 10 will be coupled from the frequency-scan array, operating as a frequency sensitive delay line, into the multibeam matrix with an interelement progressive phase shift, which is dependent upon the input signal frequency. This progressive phase shift will be such that the coupled input signal at frequency f_i will add through a beam-forming array and appear without loss (except I^{2R} losses) at the appropriate beam terminal or port P_i. Similarly, a second input signal at frequency f_j, either contemporaneously or at another time, will couple from the serpentine into the beam-forming matrix with a progressive phase shift characteristic of its own frequency, such that the signal is also coupled in a lossless manner to beam-port P_j, etc., for the N beam ports. In principal, any number, up to (N) of these signals, may be multiplexed in this manner contemporaneously.

It will be evident that the output "granularity" depends on the number of beam outputs, N. Thus, the value of N in a particular design may be determined by knowing the number of increments required within a given frequency band in order to meet a particular design objective. Similarly, it is evident that the resolution between the various output frequencies is a function of the serpentine array length. From the foregoing information, a minimum value of M may be determined for a particular design.

Theoretically, $M \geq N$ for a lossless beam-forming circuit. Moreover, the system sensitivity ($\Delta f/\Delta m$) is dependent on the frequency-sensitive delay line factor, $\Delta\phi/\Delta f$. Dynamic range of the system will depend on the isolation (sidelobe tolerance) between the various ports. Control of this factor, as well as the parameter of beamshape, can be realized in a lossless manner, by providing an amplitude-phase distribution taper along the delay line taps or along the beam-forming couplers.

Modifications and variations falling within the spirit of the present invention will suggest themselves to those skilled in this art. Accordingly, it is not intended that the present invention should be considered limited by the drawings and this description, these being typical and illustrative only.

What is claimed is:

1. An N-port frequency multiplexer comprising:

a frequency sensitive delay line having an input terminal and a plurality of spaced taps for generating a set of output signals along said taps exhibiting a phase distribution which is a predetermined function of the frequency of the signal at said input terminal;

a beam-forming matrix, of the type including the Butler matrix and the series fed multi-beam matrix, having a plurality of first terminals and a plurality of second terminals for converting each set of signals at said first terminals having a predetermined phase distribution into a corresponding output signal from a discrete one of said second terminals, said plural first and second terminals being the set of antenna radiator and beam terminals, respectively, of said-beam forming matrix;

and means interconnecting said delay line taps discretely with corresponding ones of said first terminals of said beam-forming matrix, whereby the location of each output signal among said second terminals is a function of each corresponding signal at said input terminal of said delay line.

2. Apparatus according to claim 1 in which said beam-forming matrix is a Butler matrix.

3. Apparatus according to claim 1 in which said beam-forming matrix is a series-fed multi-beam matrix.

4. The invention set forth in claim 3 further defined in that said frequency sensitive delay line is of the general class of tapped travelling-wave lines.

5. Apparatus according to claim 4 in which said taps are equally spaced in terms of electrical line length between successive taps.

6. Apparatus according to claim 3 in which said beam-forming matrix is further defined as comprising a first plurality of transmission lines within which each line is connected to a corresponding one of said first terminals, a second plurality of transmission lines within which each line is connected to a corresponding one of said second terminals, and coupling means are included for cross-coupling said first and second transmission lines in an intersecting grid pattern having predetermined spacings in each coordinate.

7. Apparatus according to claim 6 in which said cross-coupling means between intersections of lines of said first and second sets comprises a crossed-line directional coupler at each intersection of each of said line with a line of the other set.

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