A PHASE ALIGNMENT NETWORK FOR SPACE DIVERSITY COMBINING

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ABSTRACT

The design and microstrip implementation of the combination of a quadrant phase stepper and continuously variable phase shifter is described which allows clockwise or counterclockwise phase rotation through an arbitrary number of revolutions.

1. Introduction

In radio communication systems, space diversity reception (i.e. two spacially separated antennas located on the same tower) is frequently used to reduce outage times caused by certain types of path fading. In many cases a switch is used to connect the receiver to either of the two antennas; most switching algorithms use "blind" switching, i.e. reception is transferred between antennas without prior knowledge of received signal level. To avoid this as well as the associated switching transients, the two (coherent) received signals can be continuously combined, thus always taking advantage of the higher received signal. Such a combiner requires a network which can adjust the relative phase between the two signals over an arbitrary number of 2π radians in either a clockwise or counterclockwise direction without introducing large amplitude or phase discontinuities. Limited range phase shifters do not satisfy this requirement since phase tracking is lost past their design limits; in returning to zero, large amplitude fluctuations may occur due to transient phase misalignments.

These problems are avoided by a network which consists of a 90° incremental phase stepper to achieve phase quadrant alignment in either direction of rotation and a continuously variable phase shifter [1] with a range somewhat greater than 90° for adjustment within the selected quadrant. This paper describes the operation and microstrip implementation of this network for use in the 4 GHz common carrier communication band.

2. Network Operation

The two parts of the network are shown schematically in Figure 1, with the diodes operated from negative supplies; heavy lines indicate microwave elements while inductively decoupled dc connections are shown as thin lines. The inset shows the signal vector diagram at the output reference plane of the quadrant phase stepper.

The stepper consists of two 180° phase switches inserted between two 90°, 3 dB hybrid (quadrature) couplers with an additional fixed phase shift of 90° introduced in the lower branch. In each phase switch a set of two PIN diodes is placed behind a quadrature coupler. The diodes present either a microwave open or short circuit, depending on whether each set is unbiased (characterized by a logic type "state": D = "0") or forward biased (D = "1"), respectively. Assume first that D1 = D2 = "0". Then the two signal vectors are 90° out of phase (due to the 90° fixed phase shift introduced in the lower branch) as indicated by the two solid vectors in the inset and the output vector sum is state "00" (45°) of the stepper. For lossless stepper components this represents a 3 dB signal loss with the remaining power dissipated in termination R.

Switching diodes 1 to D1 = "1" causes the sum vector to travel to stepper state "10" (135°) along a path essentially parallel to the D1 axis, experiencing a maximum attenuation increase of 3 dB at the point where the upper branch signal is absorbed by diodes D1. This occurs when, during the switching transient, the PIN diode resistance is matched to the stripline impedance. Rotation of the sum vector into the third quadrant occurs when D2 is switched to D2 = "1" and the fourth quadrant is reached for D1 = "0" and D2 = "1". Therefore, by appropriately switching one diode set at a time, the sum vector can be rotated in either direction by an arbitrary number of 90° increments with a maximum attenuation change of 3 dB during the switching transient.

The continuously variable phase shifter uses two varactor diodes behind a quadrature coupler [2] to introduce phase shifts of at least 90° to precisely align the two signal vectors within a given quadrant. When the phase shifter reaches its upper or lower limit, a phase step is initiated in the appropriate direction to allow phase alignment in the adjacent quadrant.

3. Network Design

The phase shifting network is implemented in microstrip technology on 0.025" thick alumina substrates using the folded Lange coupler [3] as the 3 dB hybrid. To simplify assembly of the circuit no applique components (blocking capacitors, termination resistors, etc.) were used; instead, resistors are formed directly on the substrate using an imbedded resistive layer (50 ohms per square Tantalum) and trimmed, where necessary, using localized anodization. Blocking capacitors are avoided by supplying bias voltages (currents) through microwave resonating elements on the far side of the diodes and inductively decoupled ground returns to the backplane of the substrate. Diode biases are supplied through pads located along the perimeter of the substrate.

The completely assembled substrate (Figure 2) shows the Diversity Antenna Input first going to a phase shifter used as a phase modulator operated at a 10 Hz rate with a peak sinusoidal phase modulation of about 30°. This method allows the sensing of the phase misalignment between the two signals by observing the amplitude modulation in the AGC circuit of the IF amplifier [4]. The output of the modulator feeds the quadrant phase stepper with the two 45° delay line sections in the lower branch. One output of the stepper is terminated, while the desired output, through the variable phase shifter, provides one input to the combining hybrid. The second input is the received signal from the main antenna. When the two signals are properly aligned and arrive at the combining hybrid with equal amplitudes, the combined output signal shows a 3 dB increase over the normally received main antenna signal. In-phase addition also takes place during periods of fading, making this a maximum power combining circuit.

4. Network Performance

Over the 3.7 to 4.2 GHz common carrier communications band the individual 3 dB coupler shows (Figure 3) an insertion loss of 3.3 $\pm$ 0.1 dB between the input port (1) and the two output ports (2) and (4) with a minimum isolation of 30 dB to port (3). The varactor phase shifter produces a minimum phase change of 120° for applied voltages between 0 and -15V, has an average insertion loss of 2 dB with a maximum variation of ± 0.5 dB over any 20 MHz region within the 500 MHz wide band. Each of the two PIN phase switches in Fig. 1 has an average insertion loss of 1.5 dB with a loss change of ± 0.2 dB and a phase change of 180° $\pm$ 5° between the two states.

The phase and loss characteristics of the quadrant phase stepper relative to the "00" state (Figure 4) show phase increments of 90° ± 10° with loss variations of ± 1.4 dB. These variations are due to the dispersion of the (90°) delay line across the 500 MHz band, as well as the loss and phase variations of the phase switches. The time dependence of a typical 90° transition (Figure 5) shows the expected 3 dB loss increase during the switching transient with a smooth phase transition between the two states.

5. Summary

A phase shifting network has been designed which allows phase alignment of two coherent signals through an arbitrary number of revolutions in either a clockwise or counterclockwise direction. Possible cancellation during switching transients is avoided. The quadrant phase stepper and continuously variable phase shifter combination of this network uses PIN diodes and varactor diodes as phase control elements. Except for these diodes, no other applique components are required in the assembly of this microstrip circuit.

REFERENCES

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[3] J. Lange, "Interdigitated Stripline Quadrature Hybrid," IEEE Trans. MTT, Vol. 17, pg 1150, Dec. 1969.

[4] L. Lewin, "Diversity Reception and Automatic Phase Correction", Proc. IEE (London), Vol. 109, Part B, No. 46, pp 295-304, July 1962.

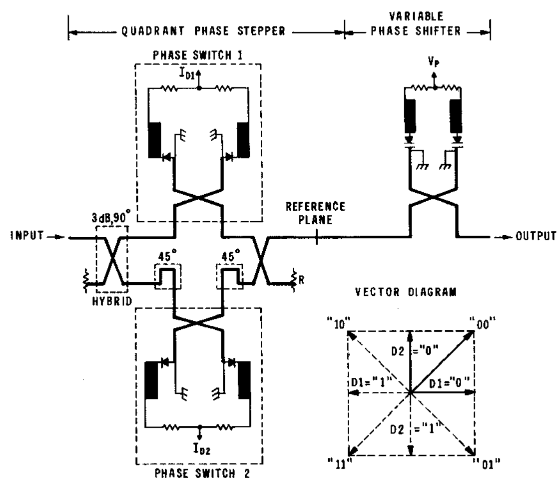

FIGURE 1
SCHEMATIC DIAGRAM OF PHASE ALIGNMENT NETWORK

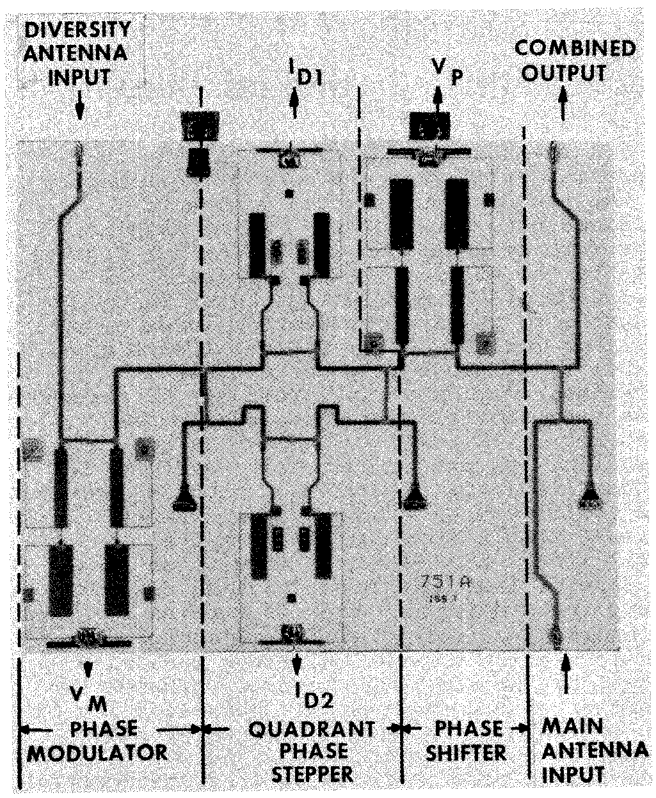

FIGURE 2
MICROSTRIP ASSEMBLY OF PHASE ALIGNMENT NETWORK

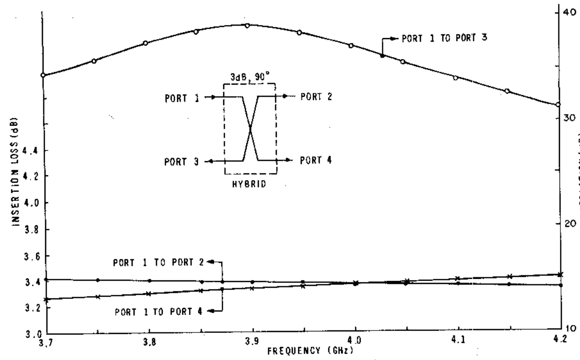

FIGURE 3
FREQUENCY RESPONSE OF 3dB, 90° HYBRID COUPLER

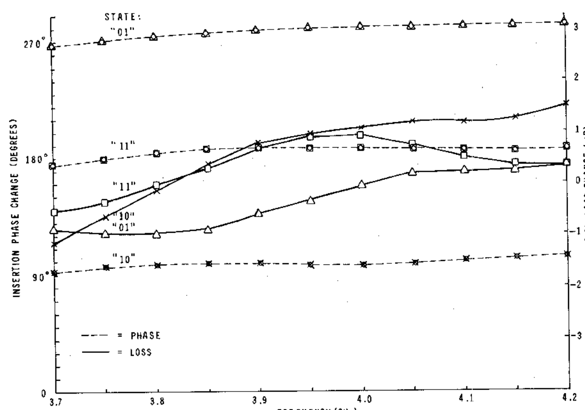

FIGURE 4
FREQUENCY RESPONSE OF PHASE ALIGNMENT NETWORK RELATIVE TO STATE "00"

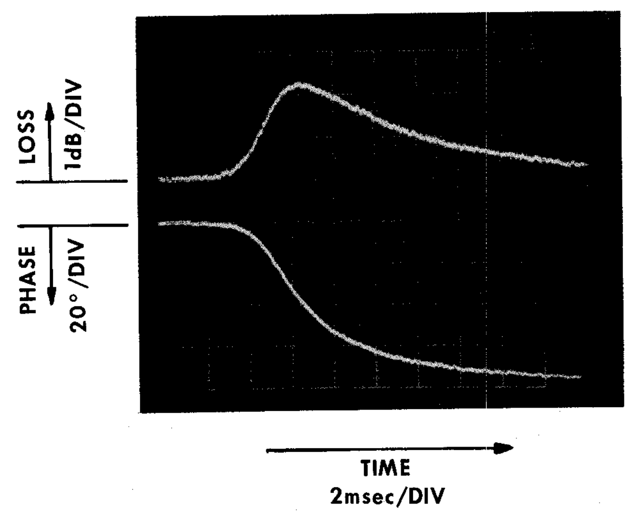

FIGURE 5
LOSS AND PHASE CHANGES DURING SWITCHING TRANSIENT