ULTRA BROADBAND PHASE SHIFTERS

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ABSTRACT

A method is shown wherein the resonance effects on three types of PIN diode phase shifters may be completely eliminated, thereby increasing the bandwidth and reducing phase shift limitations. By employing this method, multi-octave phase shifters have been constructed.

INTRODUCTION

Four types of diode phase shifters are generally well known; the switched line [1,2], reflection [3,4], loaded line [5,6], and high-pass low-pass [7,8]. Garver [9] presents an excellent discussion of these four common types of phase shift circuits. According to Garver, "Although many versions of these phase shifters have been designed, none of the designs has exploited the full bandwidth possibilities of these circuits. Most designs to date," (5 May 1972) "have a maximum bandwidth of about 10%, but most of the circuits have a maximum potential bandwidth of an octave."

Historically, the bandwidths and maximum phase shifts of the switched line, reflection, and switched high-pass low-pass types of phase shifters have been limited by resonance effects which cause notches in the amplitude response and large errors in the phase response of these phase shifters. By eliminating the resonance effects, ultrabroadband phase shifters with very large amounts of phase shift become possible.

IMPROVED SWITCHED LINE PHASE SHIFTERS

The ordinary type of switched line phase shifter is shown at the top left hand column of Figure 1. It is based on a very simple concept. As can be seen from Figure 1, the switched line phase shifter consists of two SPDT switches and two transmission lines of different lengths. By alternately switching in one line and then the other, the switched line phase shifter yields a time delay that is a constant function of the frequency, and a phase shift that is a linear function of the frequency.

This simple version of a switched line phase shifter has a serious problem, however. When either of the two lines has an electrical length of a half wavelength, or an integral number of half wavelengths, it forms a high Q resonator when it is the "switched out" line. The open contacts of the PIN diode switches are lightly coupled to this resonant line, as shown in the equivalent circuit for the switched line phase shifter (Figure 1). This coupling to the resonant line causes a sharp insertion loss notch in the amplitude response at the resonant frequency, and large phase errors near resonance.

Podell [10] has suggested a method of completely eliminating these undesired resonance effects. Podell's method is shown at the top right hand column of Figure 1. By using two transfer switches in place of the two SPDT switches of the ordinary switched line phase shifter, the switched out line may be terminated on both ends in its characteristic impedance. Since the line is now properly terminated on both ends, no resonance can occur. Podell's technique effectively eliminates all of the undesired resonance effects. Elimination of the resonance effects makes it possible to construct multi-octave phase shifters with virtually any desired amount of phase shift. With the resonance problems removed, the only limitations to bandwidth and the amount of phase shift are the RF properties of the diodes, and the DC bias circuits.

Reflection upon why the transfer switch idea works reveals many useful variations of the same idea. It turns out that any method of spoiling the Q of the potentially resonant line, without loading the remainder of the circuit, will provide the desired results. Since the coupling coefficient to a resonant line is approximately proportional to the unloaded Q of the resonator (Ginzton [11]) the coupling may be decreased by decreasing the unloaded Q. As the unloaded Q of the resonator becomes lower, less power is coupled to the resonator.

Two other versions of loaded switched line phase shifters are shown in Figure 1. The singly loaded switched line phase shifter is terminated at only one end in its characteristic impedance. By loading the line at one end in its characteristic impedance, the line no longer has a natural resonant frequency.

The other type of switched line phase shifter shown in Figure 1 has only one switched line. This version is a special case of the switched line phase shifter in which the short line length is essentially zero and the distance between the ends of the long line is an insignificant portion of a wavelength along the short line. The short line is assumed to be too short to cause resonant problems. When the long line is the switched out line, RF energy will be coupled onto the open ends of the line in approximately the same phase. Since the two ends of the transmission line are fed in the same phase (in parallel) they may be replaced by a single equivalent transmission line of half the impedance and half the length of the real line. If the end of this equivalent line (middle of the real line) is open circuited, it will form a resonantor at integral multiples of half wavelength (a wavelength for the real line). This causes resonance notches in the phase shifters' amplitude response and phase errors near resonance. However, if the equivalent line is terminated in its characteristic impedance (half the real characteristic impedance or 25 Ohms in a 50 Ohm system), the small amount of energy coupled to the line through the open switches will all be absorbed in the load rather than being reflected back and causing resonant problems. The proper position for the load in the real line is, of course, halfway around from one end of the line, and the proper terminating impedance is one half of the characteristic impednace.

IMPROVED REFLECTION PHASE SHIFTER

One type of reflection phase shifter is shown in Figure 1, along with its equivalent circuit. The problem with this circuit is that when the diode switch is closed, the small inductance of the diode acts as an auto-transformer, coupling a small amount of energy onto the portion of the line beyond the diode. When the electrical length of this portion of the line becomes an integral number of half wavelengths long, the line will become a high Q resonator. A resonance absorption occurs, causing a notch in the amplitude response and large phase errors near resonance.

A method of avoiding the resonance problem, which is appliciable to other types of reflection phase shifters as well, is shown in the right hand column of the reflection type of phase shifter (Figure 1). In this version, only one of the switches is closed at a time. The small amount of RF power that is coupled onto the transmission line beyond the shorted diode is all absorbed by the load at the end of the line. This prevents the energy from reflecting from the end of the line and causing resonance absorption problems.

This technique allows freedom in the placement of the shunt diodes on the line. As many diodes as desired could be distributed along the transmission line at whatever positions are desired.

IMPROVED SWITCHED FILTER PHASE SHIFTER

In the switched line and reflection types of phase shifters, the lines were considered to be nondispersive, leading to a constant time delay and linear phase shift type of phase shifter, which would be applicable to phase array type of uses. Dispersive lines, such as the Schiffman section [12], can be used in the switched line type of phase shifter to yield a constant phase shift type of phase shifter, which would be applicable to phase modulators and serrodyne type doppler offset generators.

The phase characteristics of various forms of filters can be used to obtain both constant phase shift and constant time delay types of phase shifters by switching from one filter to another (as shown at the bottom left of Figure 1). This form of phase shifter, however, suffers from the same type of resonance problem as the switched line phase shifter when the phase delay through one filter is an integral multiple of 180°. Therefore, the number of filter sections that can be used in the filters is severely limited unless some form of resistive loading of the switched out filter is provided. One method of loading the filters (by terminating one end in its characteristic impedance) is shown at the bottom left of Figure 1. This configuration gives freedom of choice of the filter types that can be used. The high-pass low-pass [7,8] (constant phase), low-pass low-pass [13] (constant time delay), or a low-pass band-pass (constant phase) are all useful. The low-pass sections can often be replaced by a section of transmission line.

EXPERIMENTAL RESULTS

A singly loaded switched line phase shifter (as shown in Figure 1) was constructed on an alumina substrate using microstrip transmission lines. This circuit was constructed with overly long transmission lines to invite resonance problems if present. The insertion loss and phase shift of this device from 2 GHz are shown in Figures 2 and 3 respectively. Note the extremely linear phase response and the fact that the phase doubled as the frequency doubled, as it should for non-dispersive lines. The phase and amplitude were also measured from 1 GHz to 2 GHz with similar results.

The phase and amplitude of the switched line phase shifter, with the diodes which were used to switch the terminations onto the "switched out" lines removed, are shown in Figures 4 and 5 respectively. Note the notches in the amplitude response, and the errors in the phase response caused by the resonance of the "switched out" lines.

SUMMARY

Methods were shown which offer the designer great flexibility in the design of switched line, reflection, and switched filter types of phase shifters. By using the techniques presented, phase shifters of both the constant time delay and constant phase shift with greater bandwidth and phase shift range than previously possible can be constructed. Data was presented on one phase shifter which operated over a two octave range.

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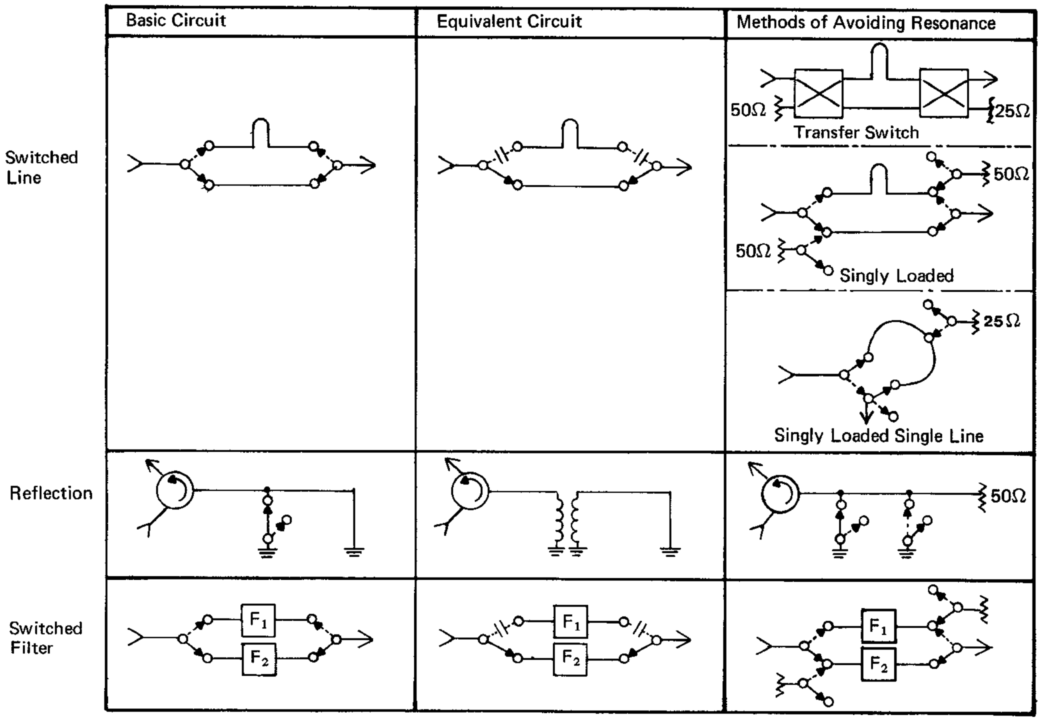

Figure 1 Three Basic Types of PIN Diode Phase Shift Circuits, an Equivalent Circuit of Each, and the Methods of Avoiding Resonance Problems

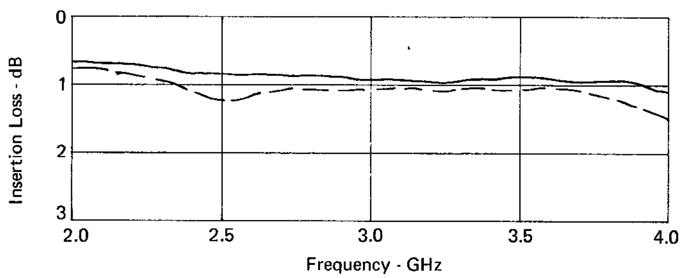

Figure 2 Insertion Loss of the Loaded Switched Line Phase Shifter

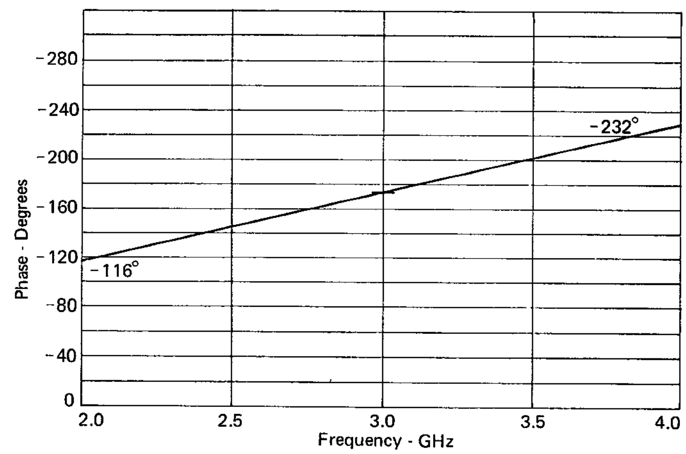

Figure 3 Phase Shift of the Loaded Switched Line Phase Shifter

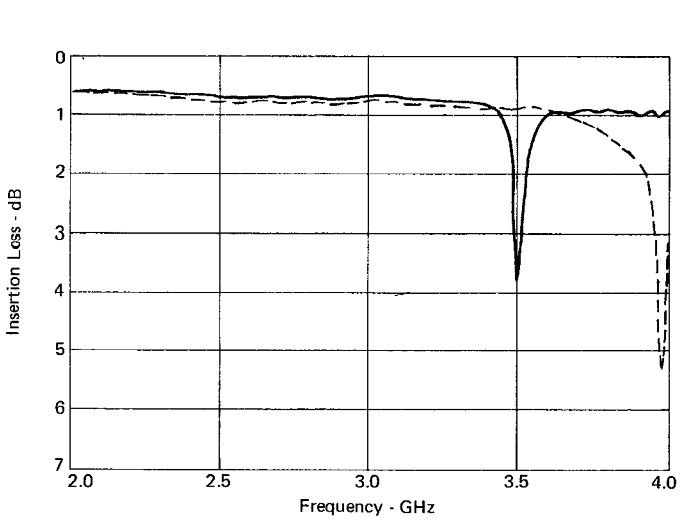

Figure 4 Insertion Loss of the Switched Line Phase Shifter Without Loading

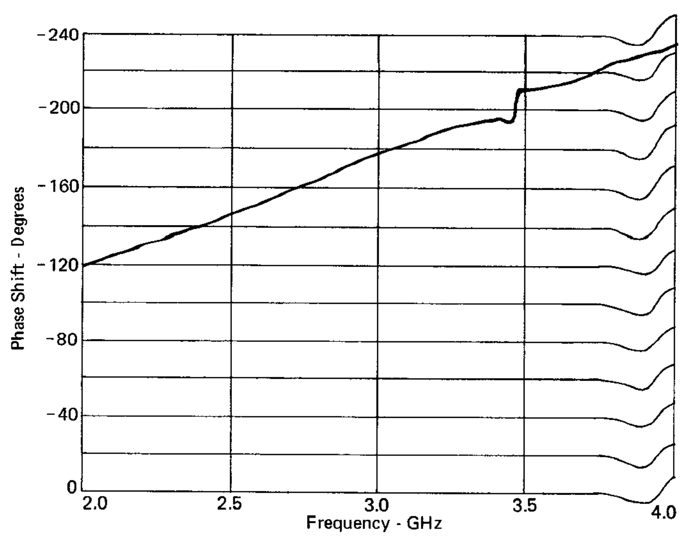

Figure 5 Phase Shift of Switched Line Phase Shifter with Loading Removed