Computer-Controllable Phase Shifter

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A voltage-variable phase shifter having a linear voltage-to-phase characteristic has been built and tested. The design uses a phase detector in a feedback loop configuration to linearize an RC phase shifter. The phase-shift characteristic is 72 degrees/volt operable over the range of 0 to 5 volts. Linearity is within ±1.5%. The design technique can be applied over frequencies extending from the audio range up to greater than 100 MHz.

In the era of Block IV pertormance specifications, it will be necessary to operate the ground stations by remote control. System configuration, failure analysis, and fault isolation will be controlled by computers. To facilitate automatic operation, it is first necessary to develop the capability to control certain functions remotely. One of the items to be automated is that of phase control. Several methods have been previously reported in Refs. 1 and 2.

Another approach to phase control is to build a nonlinear voltage-variable phase shifter and then linearize it by feedback. Figure 1 shows that the output of the nonlinear voltage-variable phase shifter is compared with its input in a phase detector. The error, which is the difference between the phase detector output and the control input, is then applied to the voltage-controlled phase shifter.

The implementation shown in Fig. 1 is incapable of operation over a full 360-deg range since the phase characteristic of the detector changes slope during that range. One of these slopes will place the loop in a positive feedback mode causing it to run away. By dividing the input/output frequency by two, it would be possible to achieve stable 360-deg operation; however, it is possible that under that configuration the phase characteristic might be slightly nonlinear due to end effects in the phase detector. Hence, it is recommended that division by at least four be used. Figure 2 shows the phase shifter utilizing this divide scheme.

It is possible to be in one of four regions of the phase detector characteristic since the divide chains are capable of starting up in different phases. In order to assure that the dividers are in the proper phase, it is necessary to monitor the feedback. The monitor circuitry compares the feedback voltage to preset limits and resynchronizes the dividers if out-of-range is detected. The monitor will guarantee proper phasing upon removal and reapplication of either dc or RF power.

A breadboard and a production prototype phase shifter have been built using the block diagram of Fig. 2. A buffer amplifier is used at the 10-MHz input and a limiting amplifier is incorporated as part of the voltage-variable phase shifter in order to restore losses. The voltage-variable phase shifter is a transformer-coupled RC phase shifter with low-frequency PIN diodes serving as variable resistors.

Test results indicate that the phase shift versus control voltage deviates from a straight line (0 to $+5\,V = 360$ deg) by less than $\pm 1.5\%$. Maximum phase shift is greater than 430 deg. Output level versus phase is within ± 0.8 dB and $\pm 5\%$ power supply variations change the output level by less than ± 1 dB. Phase stability versus $\pm 5\%$ power supply variation is less than 1 deg. Phase stability measurements over $\pm 10°C$ temperature range show that the phase characteristic remains within $\pm 1.5\%$.

The phase shifter described above provides a linear phase versus control characteristic. However, the cost is evident in the size. The production prototype is built on three printed circuit boards. Two of the boards contain the voltage-variable phase shifter and its attendant amplifiers. The third board contains the divider chain, operational amplifiers, and monitor circuits. The entire circuit requires about 20 square inches of circuit board.

The primary advantages of this approach are its frequency capability and linearity. Linearity has proven to be very good (within 1.5%) and repeatable, unit to unit. The basic concept, that is, comparison of output and input in a phase detector, is applicable to any frequency. It is only necessary that a voltage-variable phase shifter and frequency dividers be built at that frequency. The upper frequency range is limited by the divider chain and is in the neighborhood of 150 MHz. The lower range, which can be extended into the audio frequencies, is limited by the design of reasonable size voltage-variable phase shifters.

References

1. Johns, C. E., "Digital Phase Shifter," in *The Deep Space Network*, Space Programs Summary 37-58, Vol. II, pp. 121–122. Jet Propulsion Laboratory, Pasadena, Calif., July 31, 1969.
2. Coffin, R. C., "Binary Digital Phase Shifter," in *The Deep Space Network*, Space Programs Summary 37-61, Vol. II, pp. 100–103. Jet Propulsion Laboratory, Pasadena, Calif., Jan. 31, 1970.

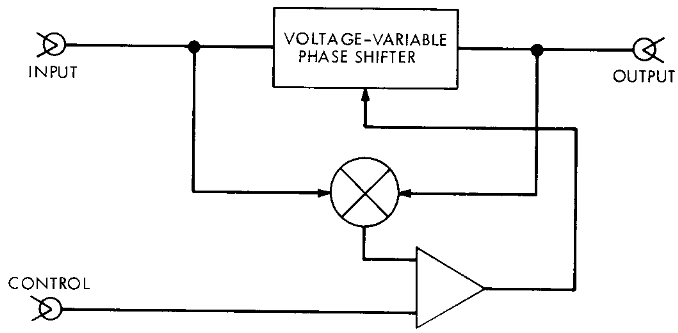

Fig. 1. Conceptual linear phase shifter

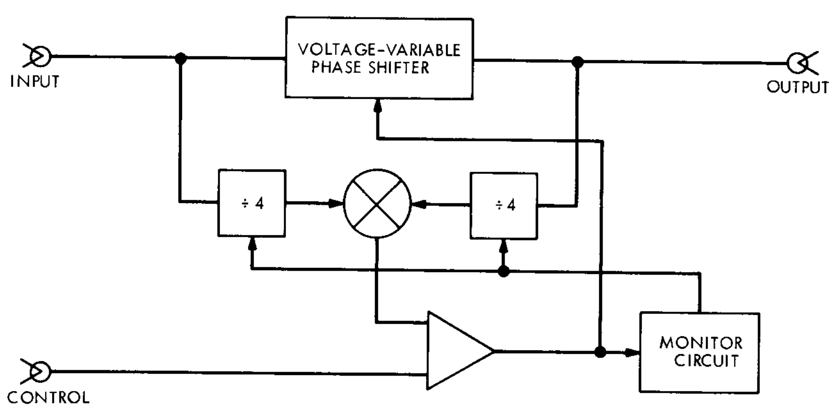

Fig. 2. Linear phase shifter