A New Electronic Phase Shifter*

With the imminent feasibility of very large electronically-scanned phased-array antennas, has come the necessity for suitable circuitry for accurately shifting phase of very many elements. A scheme, which is now receiving some attention, was described by the author in February, 1960, in a Mitre memo, which has achieved some circulation in Air Force circles. The basic idea is simple, taking advantage of the fact that the phase of the harmonic of a fundamental frequency is proportional to the harmonic number, viz.,

$$\sin n\omega(t+\tau) = \sin(n\omega t + n\omega\tau)$$
$$= \sin(n\omega t + \psi) \text{ where } \psi = n\omega\tau.$$

If this nth phase-shifted harmonic is beaten with the $(N-n)$th unphase-shifted harmonic, the sum frequency is $\sin(N\omega t+\psi)$ where $\psi = n\omega\tau$, taking advantage of the further fact that phase-shift is invariant with heterodyning. The result is a signal with phase-shift proportional to n, but with a fixed frequency.

The author first considered this idea as the basis of a multiplier in an analog computer using phase-shift as the physical variable, about ten years ago; phase, of course, is the exact variable in which we are interested, in the present application.

A circuit diagram embodying the above principles is shown in Fig. 1. In this example, a pulse is generated at a basic repetition rate such as 1 kc; if one thousand elements of equal phase-shift are desired, the pulse must have components up to 1 Mc, thus specifying a pulse width less than 1 μsec. Passing through the adjustable delay line, the pulse is delayed an amount τ, each harmonic component thus receiving a phase-shift $\psi = n\omega\tau$, where ω is the fundamental radian frequency. These are produced at the right of the diagram. However, each phase-shifted signal is produced at a different frequency. Therefore, the pulse is also sent down the other side, its harmonic components undelayed, to beat with the delayed harmonic components. Thus, if signals at the sum frequencies are selected at the outputs of the mixers in the center column, these signals exist all at the same frequency, in this case 1 Mc, but with the proper phase shifts. If nanosecond pulses are used at a repetition rate of 1 Mc, equiphase-shifted signals can be delivered at 1000 Mc. If these signals are distributed to the successive elements of a linear array, or to the successive rows or columns of the beam-steering matrix of a planar array, there is an equal phase-shift $\Delta\psi = \omega\tau$ between adjacent elements, and the phase shifted, and the beam angle steered, by variation of τ.

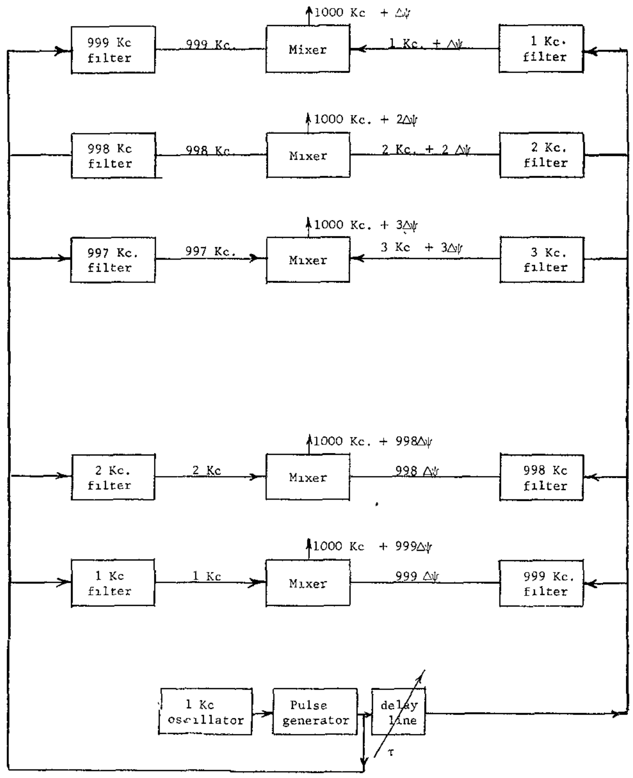

Fig. 1.

In practice, an actual delay line might not be used, but an electronically-switched selector of clock-controlled pulses. In fact, instead of a pulse generator, a sine-wave generator could be used in conjunction with harmonic generators, but to the author this seems the hard way.

There are problems in connection with spurious beats from the mixers. However, the end is not one easily achieved by other means. By this method, if spurious outputs can be controlled, a single delay element, as shown, is essentially repeated one thousand times, without serious correlated error, which is one of the more important criteria in assessing the value of a phase-shifter for a phased-array.

Since the time this phase-shifting circuit was proposed by the author for control of phase in array antennas, it was brought to his attention that Augustin[1] described a similar scheme for measuring phase angles as low as 1/1000°, with a phase meter of only 1° resolution. He uses the difference instead of the sum frequency, and frequency-multiplies by ten, three times in succession, to obtain phase-shift multiplication by 1000, and states that "in a completed setup, it was shown that the stability of the phase multiplied by a factor of 100 exceeded all expectations, so that one even could have considered a further multiplication by 10. . . , if one were to provide for a careful design and electrical stabilization of the direct and heater filament voltage."

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* Received by the PGMTT, November 6, 1961.

[1] E. Augustin, "A phase multiplier," *Hochfrequenztechnik und Elektroakustik*, vol. 67, pp. 84–87; November, 1959.