Noise as a transmitted signal has been used in radar, ultrasonic Doppler flow measurement, and ultrasonic flaw detection. In each of these applications, the unique properties of noise have mainly influenced the design and operation of the signal processing portions of the system in which it was used. Our present work shows that the use of noise as a transmitted signal may also benefit the properties of phased array transducers used in imaging systems.

Some imaging systems excite the transducer array sequentially in several modes. The echoes resulting from each of the transmitted modes are stored separately and then processed together to yield an effective beam pattern which cannot be realized by any elementary mode of the array. Although phased arrays are frequently used to simultaneously receive in a number of modes, it has not, up to now, been possible for an array to transmit more than one mode at a time.

A technique is described which allows several modes to be transmitted simultaneously from a transducer array. This is achieved by exciting each mode with its own independent random signal. The echoes corresponding to each transmitted signal can then be unambiguously identified by correlation with the desired reference signal. This technique generally leads to simplified system design and permits operation in real time.

Preliminary results for a small random signal phased array system will be described.

INTRODUCTION

Noise as a transmitted signal has been used in radar (1) as well as in ultrasound Doppler systems applied to flow measurement (2) and in ultrasonic correlation systems applied to flaw detection. (3) In all these applications the unique properties of noise have mainly influenced the design and operation of the signal processing portions of the systems in which it was used. We have recently shown that the use of noise as a transmitted signal can also benefit the properties of phased or delayed arrays. (4) The term "phased or delayed array" as used here refers to the arrays of antenna elements or electro-acoustic transducers which are used in transmission or reception to sweep and shape beams of electromagnetic or sound radiation.

The reader will recall that phased arrays are used to transmit and receive beams in different configurations or modes and that each of these modes is produced by a unique way of amplifying and delaying or phasing the signals supplied to or received from the various array elements. Although phased arrays are frequently used to simultaneously receive in a number of modes, it has not, up to now, been possible for an array to transmit more than one mode at a time. This limitation is due to the fact that with present techniques, if more than one mode is transmitted simultaneously, it will not be possible to distinguish the echoes of these various transmitted modes from one another. We have shown that a phased array can transmit and receive in many modes simultaneously provided that a separate incoherent noise signal is used for each mode and than an equivalent number of correlation receivers is used to pick out the echoes corresponding to each transmitted beam configuration. (4)

The ability of phased arrays to transmit (as well as receive) many modes simultaneously should lead to significant performance improvements in wide angle scanning, in which the use of noise signals should enable several sectors to be scanned simultaneously. A second application is to methods of side lobe suppression and beam shaping in which different modes are transmitted sequentially with their echoes being stored and processed. (5) In this application the use of noise signals will permit the different modes to be transmitted simultaneously allowing echoes to be processed without intermediate A/D conversion and storage.

A third application is to dynamic focusing in which the focus during reception is shifted in synchronism with the signal. Here the use of noise will allow the focus to be shifted during transmission as well as reception thus squaring the array directivity with respect to current systems. Finally the use of simultaneous noise signals will allow an array to scan with one pattern for imaging while simultaneously keeping another beam fixed in space for Doppler measurements.

Fig. 1. An ultrasonic random signal phased array.

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Our noise array principle can be understood in more detail by reference to the figure. No ise source 1 drives the various elements of the array through a set of delay line shifters and transmits a signal in the direction of beam 1. Similarly noise source 2 transmits a signal along beam 2. The echoes received by the array are distributed to correlators 1 and 2 through two additional sets of phase shifters. Both correlators receive echoes due to both noise sources. Each correlator also receives a delayed version of the transmitted signal of its associated noise source. The variable delay through which it received this reference signal is adjusted depending on the range at which the system is to operate. Even though each correlator receives echoes from the transmitted signals of both noise sources, only that echo which corresponds to the reference signal it receives will produce an output from the correlator. Thus two independent outputs are produced by the system illustrated.

In many applications a single set of delay line phase shifters will be used for transmission and reception of each signal instead of two sets as shown in the figure. Furthermore any number of independent modes can be transmitted by providing a noise source and correlator for each mode. Of course if n independent noise signals are transmitted then each correlator will have a deteriorated signal-to-noise ratio which in the worst case will be of order 1/n. Since we have shown that the resolution of noise correlation systems is independent of the length of the transmitted signal, this degraded signal-to-noise ratio can be improved by lengthening the transmitted pulses. The attractiveness of multi-mode noise operation for a specific application will depend on the degree to which the signal-to-noise ratio can be kept high without sacrifice of operating time.

In this presentation a double noise source, triple transducer system used for beam shaping will be described.

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REFERENCES


DISCUSSION

N. Batra (System Research Lab): I have a question regarding your delay lines. Were the water delay lines that you used the best?

E. S. Furgason (Purdue University): Are you referring to the delay line in this system?

N. Batra: Yes

E. S. Furgason: Yes, we did use a water delay line. Just for convenience, there is nothing magical about a water delay line. It could just as easily be an electronic delay line.