WIDEBAND MICROWAVE ACOUSTIC DELAY LINE WITH EXCEPTIONALLY SMOOTH PHASE AND LOSS RESPONSE*

W.R. Sperry and E.K. Kirchner
Teledyne MEC
Palo Alto, California 94304

and

T.M. Reeder
Stanford University
Stanford, California 94305

Abstract

Design techniques for high performance microwave delay lines which have superior bandwidth, phase linearity and spurious echo characteristics are presented. Utilization of these techniques to realize a 4 μs L-band unit which has insertion loss of 30 ± 0.5 dB over the 500 MHz band centered at 1.7 GHz, with triple-transit suppression greater than 45 dB and phase deviation from linearity of less than ± 2.5°, are described.

Summary

Microwave acoustic delay lines, because of their potentially wide bandwidth and relatively low insertion loss[1], have long been proposed as high data rate, signal storage devices. Until very recently, however, technological problems have resulted in devices which fell far short of the predicted bandwidth and loss. This paper describes a design approach which allows the bandwidth, phase linearity and spurious signal suppression to be optimized. The design of a high performance, 4 μs unit operating at L-band is used to illustrate the techniques.

Design of microwave acoustic delay lines can be divided into five areas:

- Selection of an acoustic delay medium consistent with the requirements of signal delay, maximum insertion loss and minimum spurious signal suppression.
- Design of efficient, acoustically broadband transducers for acoustoelectric conversion.
- Realization of electromagnetic tuning and coupling networks to provide broadband transducer operation with minimum insertion loss.
- Design of the delay medium and transducer geometry to enhance the suppression of spurious signals.
- Construction of a package to provide stable mechanical and temperature environment, the latter being important for phase stability.

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For an L-band delay line using longitudinal acoustic waves, a sapphire delay medium with propagation along the C-axis is a good choice for signal delay in the 0.1 to 10 μs range. Sapphire has relatively low acoustic loss and can be readily obtained in lengths required for long signal delay. A crystal length of 4.48 cm is required for 4 μs delay.

For efficient acoustoelectric conversion over a broad frequency range, the piezoelectric film transducer[2] has been found most suitable for microwave delay line operation. This type of transducer consists of metal and piezoelectric thin films which are vacuum deposited directly onto each end of the delay medium. For broadband operation, the piezoelectric layer should have an acoustic impedance (Z_T') just slightly less than that of the acoustic delay medium[3]. Piezoelectric ZnO films are a good choice for sapphire delay lines, not only because of their appropriate acoustic impedance, but also because of their high piezoelectric activity leading to low conversion loss[4].

The electrical input impedance of the thin-film transducer imposes a severe problem in achieving broadband operation. The transducer electrical equivalent circuit consists of a series combination of geometrical capacitance (C_o), a radiation resistance (R_a) and electrode conduction resistance (R_c). The problem is that the Q of this circuit, for typical transducers, is on the order of 10. To achieve low loss operation, tuning elements are needed to resonate this highly reactive impedance. One finds a compromise between network insertion loss and bandwidth for bandwidths greater than 1/Q[5,6]. Although standard network design techniques[7] have been successfully applied to the design of broadband transducer matching networks[3,8] these methods typically used a multi-element transmission line circuit which in practice is difficult to fabricate. A somewhat simpler approach has been developed, consisting of shunt resonators coupled by quarter-wavelength transmission lines. By choice of the network impedance level, a maximally flat or small ripple response can be obtained with a 3 dB fractional bandwidth appreciably greater than 1/Q.

The suppression of spurious echoes in a volume-wave delay line poses another design problem. For wideband operation, the thin-film transducers present a high reflection boundary condition. Thus, the signal pulse may be reflected many times within the delay medium unless appreciable propagation loss exists or geometrical loss is created. In the development of the L-band unit described herein, a combination of propagation loss, diffraction loss and delay path geometrical design was used to optimize the suppression of triple-transit signals. Propagation loss for the sapphire delay medium provides only a small amount of triple-transit suppression (TTS) since only 2 dB of loss is incurred in mid L-band for 4 μs of delay. By proper choice of the transducer aperture, another 9.55 dB of TTS is obtained through diffraction loss. Hence for the L-band unit, the largest contribution to TTS was provided using geometrical loss as explained below.

TTS can be enhanced by using an angled (beveled) end face. The angle is chosen to place the null in the radiation pattern of the triple-transit signal, launched at the input transducer aperture, at the position of the output transducer aperture. The null location is frequency dependent; thus the angle is determined at the center operating frequency. Theory for propagation along the C-axis of sapphire (including the anisotropy) predicts that 33 dB TTS can be achieved over a 33.2 percent bandwidth using this geometrical loss technique. For the 4 μs delay line, with a bevel angle of 43.2 minutes, TTS in excess of 46 dB is achieved over the 500 MHz centered at 1.7 GHz.

The beveled end face, however, increases the loss of the desired delay signal and causes a loss slope with frequency. For the 4 μs delay line with a 43.2-minute angle the additional loss incurred due to the angle is 6 dB at 1.45 GHz and 13 dB at 1.95 GHz. This loss slope plus the slight increase in slope due to the propagation loss dependence on frequency is compensated by the diffraction loss due to the input transducer aperture plus tuning. The insertion loss of this unit, which averages 30 dB, is flat within 0.5 dB over the 500 MHz bandwidth centered at 1.7 GHz.

Since the delay medium is nondispersive, the phase characteristic of a microwave acoustic delay line would be linear except for phase ripple caused by the acoustoelectric transducers and associated coupling networks, or, in CW operation, by the presence of a triple-transit signal. The phase ripple of a passive network is low if the insertion loss is close to a maximally flat response[9]. For TTS greater than 45 dB, the phase ripple in CW operation due to the triple-transit signal is less than 0.5^{o}. Tuning the matching network for maximally flat response yielded a phase ripple, for the 4 μs delay line, of less than $\pm 2.5^{o}$ from linearity.

If it is to be useful in microwave systems, a delay line must be packaged with a suitably stable mechanical and thermal environment. The package must also provide shielding to suppress unwanted electromagnetic feedthrough. To determine the necessary thermal environment, CW phase measurements were made on the 4 μs delay line when enclosed in an oven with temperature stability of $0.01^{o}C$. The test frequency was stabilized to one part in 10^9 and measured to better than one part in 10^7. Phase was measured with a network analyzer to $\pm$ 0.6 degree. For the 4 μs delay line, which has a path length of approximately 2.4×10^6 degrees, it was found that an oven stability within $0.01^{o}C$ was necessary to limit the insertion phase drift to $\pm 1^{o}$.

Thus, wideband microwave acoustic delay lines with exceptionally smooth phase and loss responses can be achieved by careful attention to the design techniques described here. These techniques were utilized in achieving 4 μs delay lines with insertion loss of 30 $\pm$ 0.5 dB over the 500 MHz band centered at 1.7 GHz, with triple-transit suppression greater than 45 dB, and with phase deviation from linearity of less than $\pm 2.5^{o}$.

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