V-8. DESIGN CONSIDERATIONS FOR MICROWAVE ACOUSTIC DELAY DEVICES*

J. R. Yaeger and F. A. Olson

Microwave Electronics Corporation, Palo Alto, California

Recent developments in the field of microwave acoustics have led to the realization of miniature solid state delay devices operating at microwave frequencies. These devices, capable of new functions in terms of length of delay and signal storage time, are finding numerous uses in altimeters, radar, and similar electronic systems. The units are particularly attractive in situations where size and weight are of prime importance.

Acoustic waves are characterized by non-dispersive propagation at velocities in the range of 10^5 cm/sec. This slow propagation immediately suggests the use of these waves to accomplish coherent signal delay. However, a number of unusual features are encountered in attempting to utilize this delay process. The acoustic wavelength at microwave frequencies is comparable to optical wavelengths, thus imposing severe dimensional and surface tolerances on the solids used. The relatively high attenuation per unit length at microwave frequencies also requires careful selection of propagation crystals. The most severe problem, however, has been the development of reasonably efficient transducers for conversion between electromagnetic and acoustic energy. This paper describes the design considerations that have evolved in the development of numerous microwave acoustic delay devices.

Delay Materials. Only single crystals have been found suitable for propagating microwave acoustic waves because of various scattering phenomena associated with microscopic defects in polycrystalline or amorphous solids. The materials listed in Table I are examples of crystals utilized in microwave acoustic delay devices. Some of the more important characteristics of these materials such as velocity, acoustic impedance, attenuation and principle mode are given for acoustic wave propagation at 1.5 gc and room temperature. For minimum insertion-loss delay devices, it is important to choose a propagation material with reasonable acoustic attenuation in the frequency range of interest. Only YIG, sapphire, and rutile appear suitable for operation above 2 gc.

Transducers. The realization of efficient transducers is extremely important to the development of useful microwave acoustic delay devices. Transducers can be rated on the following four factors: (1) efficiency (2) bandwidth (3) saturation level and (4) acoustic bonds. In terms of these factors, thin-film transducers of either ferromagnetic or piezoelectric material are highly rated. The acoustic power density generated by a ferromagnetic film transducer (Reference 1) can be expressed as

$$P_a = \frac{b^2}{2c} v \left(\frac{w}{M}\right)^2 (1 - \cos qd)^2 \qquad (1)$$

where

b = magnetoelastic constant,

c = elastic constant,

v = acoustic velocity,

*This research supported by Air Force Avionics Laboratory, Wright-Patterson Air Force Base under contract No. AF33(615)-1069.

TABLE I

Properties of Important Acoustic Materials

Material	Acoustic Mode	Velocity (cm/sec)	Impedance (Ohms)	Attenuation at 1.5 Gc (db/cm)
X Quartz	Longitudinal	5.60×10^5	14.7×10^6	10.0
Z Quartz	Longitudinal	6.30×10^5	16.7×10^6	5.8
AC Quartz	Shear	3.32×10^5	8.8×10^6	12.0
BC Quartz	Shear	5.04×10^5	13.4×10^6	3.3
Sapphire	Longitudinal	11.2×10^5	43.6×10^6	0.9
Sapphire	Shear	6.1×10^5	23.8×10^6	3.2
Rutile	Longitudinal	10.3×10^5	43.9×10^6	7.0
Rutile	Shear	5.4×10^5	23.0×10^6	1.8
YIG	Longitudinal	7.2×10^5	37.2×10^6	---
YIG	Shear	3.87×10^5	20.0×10^6	0.77

m = rf magnetization,

M = saturation magnetization,

q = wave number, and

d = film thickness.

Similarly, the acoustic power density generated by a piezoelectric film transducer (Reference 2) is given by

$$P_a = \frac{k^2 v}{4} (\epsilon E)^2 (1 - \cos qd)^2, \qquad (2)$$

where

k = electromechanical coupling coefficient,

E = electric field and

ϵ = permitivity.

Maximum acoustic power results when the film thickness is an odd number of half wavelengths thick (qd = 2n + 1). The intrinsic 3 db bandwidth of the film transducer is then given by 73/2n+1 percent. Although these expressions must be practically modified by acoustic impedance ratios, ferromagnetic linewidth factors and similar considerations, they highlight the more important parameters. Single half-wavelength (n = 0) films of materials with large coupling constants are necessary for efficient, broadband transducers. The limitations imposed by factors such as acoustic impedance and ferromagnetic linewidth will be discussed fully in this paper.

Dimensional Considerations. Because the acoustic wavelength is extremely short at microwave frequencies, the surfaces of the propagation crystal must be optically flat and parallel. If an acoustic wave is required to reverberate a long period of time for long-term storage of a pulse signal, the degree of end-face parallelism is critical. For n reflections in a crystal of diameter D and length L, the ends must be parallel to within $2D/n^2L$ radians before the wave collides with the side of the crystal. Five hundred microseconds of storage in a YIG crystal 0.5 inches long and 0.1 inch diameter requires 150 reverberations. Thus the ends must be parallel to better than four seconds of arc

Other Considerations. The usual single pass delay device requires the optimization of the parameters just discussed. In particular, the transducer efficiency must be made as near to unity as possible for a minimum insertion loss device. A reverberating delay device used to obtain very long storage times, however, must have a transducer with an efficiency somewhere between unity (one echo) and zero (no echoes). The number of echoes coupled out of a reverberating device is given by

$$N = \frac{\ln P_N/P_I - 2 \ln \Gamma + 2 \ln (1 - \Gamma) - aL}{2 \ln (1 - \Gamma) - 2aL} \tag{3}$$

when

P_N = power of the Nth echo,

P_I = power into the device,

Γ = the conversion efficiency of the transducer

aL = one-way loss through the propagation crystal.

Figure 1 shows this equation plotted for two representative crystals with one-way losses of one and five decibels and for dynamic ranges (ratio of P_N to P_I) of 80, 100, 120 db. The important point emphasized by these curves is that the conversion efficiency for maximum storage lies on a broad maximum nominally between 10 and 20 db. This is a realizable efficiency for some of the better thin film acoustic transducers. The importance of low loss crystals is also evident.

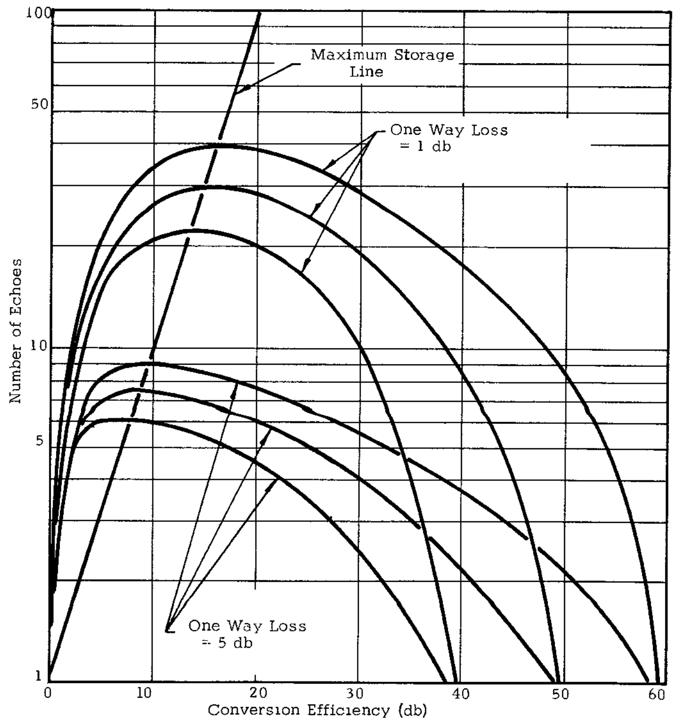

Figure 1.

Performance. Several reverberating units have been built which represent nearly optimum storage time devices for a given acoustic material and dynamic range. The oscillogram shown in Figure 2 shows the 90 microsecond storage capacity of a unit with a one-way loss of about 2.5 db, a transducer with a conversion efficiency of 20 db and a dynamic range of about 120 db. The 20 echoes shown fall on the broad maximum intersected by the maximum storage line. Units of this type have been built to demonstrate the storage capacity of acoustic delay devices from 1 to 4 gc at room temperature.

The considerations outlined here will be discussed in detail in the paper with the emphasis placed on the coordination of efficient broadband acoustic transducers with low loss propagation crystals in the design of practical long-delay devices operating at microwave frequencies and room temperature. More examples will be given to demonstrate the delay properties and capabilities of these devices.

REFERENCES

1. Seavey, M. H., Jr., Ultrasonics Symposium of IRE Professional Group on Ultrasonics Engineering, 1962.

2. Blotekjaer, K., et al, M. L. Report No. 1132, Stanford University, January 1964.

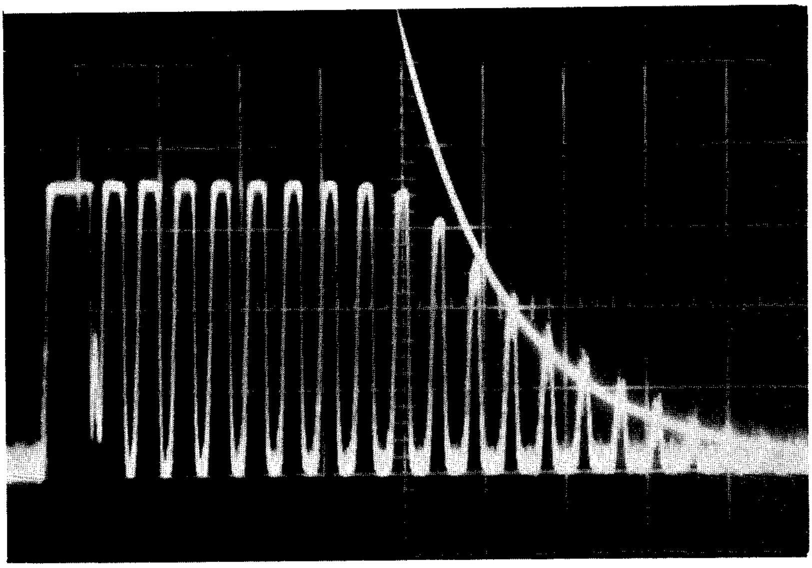

Figure 2.