Active Impedance Matching for Microwave Acoustic Delay Lines

Abstract—Some experimental results are presented which demonstrate the feasibility of using transistor circuits (of the inverted common-collector type) as elements in impedance-matching networks for microwave acoustic delay lines. This technique is shown to offer the possibility of realizing matched delay lines having both low insertion loss and low spurious triple-transit echo level.

Microwave acoustic (bulk-wave) delay lines that utilize passive (electromagnetic) impedance-matching networks tend to be deficient in two main respects:

1) The insertion loss of such devices is higher than that which can be accounted for by the acoustic propagation loss in the substrate material.

2) Even though the transducers are matched at their electrical terminals, they tend to be mismatched at their acoustical terminals, thus causing spurious reverberations to occur whenever a signal is introduced into the delay line.

Both of these defects are due to one cause: dissipation loss in the transducer (and matching network). Much of this loss can often be associated with the resistance of the transducer electrodes (or the contact to the electrodes). Resistances of only a few tenths of an ohm can produce a significant amount of additional insertion loss. Also, since the dissipation losses in the transducer are not distributed uniformly, it follows that a transducer will not be matched automatically at its acoustical port when it is matched at its electrical port, and vice versa. Thus, if the dissipative losses in the transducer could be eliminated, two of the major problems in microwave acoustic delay lines would be overcome.

It does not appear possible to eliminate these resistances completely using the present state of the art of transducer fabrication. An alternative approach, which is the subject of this correspondence, is to use negative resistances to compensate exactly for the undesired positive resistances in the transducer and matching network at the physical location where they occur. The net result is an effectively lossless transducer and matching network.

Recently, it has been shown1 that an inverted common-collector (ICC) transistor circuit can be used to synthesize an inductance and a negative resistance that is useful at microwave frequencies for realizing filters, matching networks, multiplexers, and other normally passive components. When the base of an ICC transistor circuit is terminated in a suitable impedance, the input impedance at the emitter takes the form of an inductance in series with two resistive elements, one positive and one negative. The synthesized inductive reactance and negative resistance as functions of frequency are shown in Fig. 1. These two synthesized elements tend to depend only on the transistor parameters and are insensitive to the transistor bias current. On the other hand, the positive resistance appears in series with these elements is inversely proportional to the dc emitter current. Thus, the net amount of positive or negative resistance seen at the emitter terminals can be adjusted by varying the emitter current. Two further points concerning this circuit are of practical interest: 1) the inductance that appears in the base of the transistor can be a low-Q inductance, and 2) the presence of the collector-to-base capacity produces a negative resistance minimum, thus providing a very stable point of operation. Techniques for designing ICC circuits to provide a given frequency of negative resistance minimum, inductive reactance, and negative resistance have been published elsewhere.

To demonstrate the feasibility of using an ICC circuit for matching into (and out of) a microwave acoustic delay line, an elementary active matching network was built and coupled to a one-port UHF acoustic delay line. The delay line used a thin-film cadmium sulphide (longitudinal mode) transducer and a ruby substrate. Its pulse-echo response at 575 MHz when matched by a narrow-band passive matching structure is shown in Fig. 2. The relative high insertion loss and spurious echo level should be noted. The untuned (no matching) insertion loss for this delay line was 32 dB at 575 MHz for the first echo.

An equivalent circuit for the delay line and the elementary active matching network is shown in Fig. 3. The capacitor $C_o$ is the "clamped" capacitance of the transducer and $Y_{rad}$ is a "radiation" admittance that is determined by the characteristics of the transducer material, substrate, and delay line termination. In the matching circuit the capacitor $C_2$ is used to transform the impedance level of the load (delay line) to a convenient value. The base impedance $Z_B$ is similar in detail to that shown in Fig. 1. The negative resistance generated by the transistor is used to compensate for the losses in the capacitor $C_1$ and also for the losses associated with the connection to the thin-film transducer (represented by $r_e$). The inductance generated by the transistor is then used to tune out the net capacitance of the load. Finally, the capacitor $C_1$ is used to transform the impedance level of the tuned load to that of the source.

The experimental results obtained with this circuit are shown in Fig. 4. It was found that the (active) matching-network parameters could be adjusted to match the transducer either with respect to the incident pulse [looking into the electromagnetic port, Fig. 4(a)] or with respect to the echo pulse [looking into the acoustic port, Fig. 4(b)], but still not simultaneously for both. It should be noted that the match obtained for either case is very good and that in both cases (even without a simultaneous match at both ports) the insertion loss for the first echo is very low; it is essentially the transmission loss in the 2-cm-long delay line rod.

The reason that this circuit cannot be adjusted to provide a simultaneous impedance match in both directions is that the capacitor $C_1$ also has some losses associated with it. In other words, since the two main sources of electrical dissipation appear in different loops of the circuit, a single transistor will not, in general, precisely compensate for both simultaneously. To compensate for the losses in $C_1$ a second transistor was used to generate a negative resistance in series with $C_1$ [Fig. 5(a)]. The experimental results ob-

---

Manuscript received June 15, 1969.


2. Acoustic matching using multilayer thin films is possible to some extent.

3. This procedure obviously is not the same as cascading the transducer with an amplifier.


tained with this circuit are shown in Fig. 5(b).
It is seen that a very good match has been obtained for both the incident pulse and the first echo. (The entire matching network and transducer are now effectively lossless.) The fact that higher order echoes are not as small as the second echo is believed to be due to off-axis propagation effects.

The active matching networks used to demonstrate feasibility exhibited very narrow bandwidths. (This is the reason that the "ears" appear on some of the pulses in Figs. 4 and 5.) For example, the bandwidth over which the input VSWR is less than 2.0 is only 0.35 percent (the minimum VSWR within this band is less than 1.05). However, the circuit used was not designed for optimum bandwidth. It should be possible to design a broad-band matching network using standard techniques and assuming ideal, lossless circuit elements and transducers. The inductors would then be realized using ICC circuits and the negative resistance would be incorporated to compensate for the losses in the real capacitors and transducers.

In conclusion, the feasibility of using ICC circuits as elements in impedance-matching networks for microwave acoustic delay lines has been demonstrated, and a number of advantages of this technique have also become apparent.

1) For transducers that are effectively two-port, an impedance match can be obtained looking into the (internal) acoustic port, while simultaneously maintaining low insertion loss. Thus, the triple-transit echo can virtually be eliminated without the need for large acoustic diffraction losses. These results open up the practical possibility of cascading such delay lines to form a tapped delay line configuration.

2) Lumped-circuit techniques can be used both for designing and realizing the matching networks. This results in a size for the matching network that is commensurate with the size of the delay line. Also, conveniently variable lumped elements are more easily realized than are variable distributed elements. Lumped-circuit techniques are probably suitable for frequencies well into S-band, especially if integrated-circuit techniques are used.

3) The technique of using a negative resistance to compensate for a positive series resistance in the transducer is also important for transducers having more than two ports, such as surface-wave transducers. In this case, the technique can be used to reduce the insertion loss even though a match at all ports cannot in general be obtained.

In some applications it may be necessary to trade off these advantages against a loss in dynamic range since the input power to the matching circuit is presently limited to less than one milliwatt. The limitation is not one of power dissipation, but rather of nonlinear cross modulation in the transistor. Also, the noise figures obtained with active matching circuits should be comparable to the noise figures that are obtained using the same transistors in an amplifier configuration.

ACKNOWLEDGMENT
The authors would like to thank D. K. Adams and L. Young for many stimulating and informative discussions, W. L. Cornelius and M. DiDomenico, Sr., for their excellent technical assistance in constructing the microwave delay line and transistor circuits, and W. A. Crofut and T. M. Reeder for their critical reading of the manuscript.

R. Y. C. Ho
A. J. Bahr
Stanford Research Inst.
Menlo Park, Calif. 94025

Analog Matched Filter Using Tapped
Acoustic Surface Wave Delay Line

Abstract—VHF experiments are described employing 11- and 50-tap surface acoustic wave delay lines fabricated on crystalline quartz as analog matched filters. Excellent correlation characteristics were observed for a 63-bit maximal length biphase code.

Recent work has resulted in a thorough understanding of the electromagnetic-acoustic...