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NORMALIZED TIME RESPONSE FAMILIES FOR THIN DISK TRANSDUCERS

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ABSTRACT

A normalized version of Mason's model is presented which is applicable to the time domain modeling of common transducer configurations. The model consists of a transmission line whose characteristic impedance is 1 ohm and whose delay is 1/2 second, and two capacitors whose values are $1/2k_t^2$. Matching schemes, such as LR electrical matching and quarter wave acoustic matching, can also be normalized. The model is used to produce normalized time response families for switch-driven transducers. These are difficult to obtain using frequency domain models such as KLM because of the time-varying impedance of the driver circuit. Time and frequency response families for basic transducer configurations are easily produced from the normalized model using a circuit analysis program. The normalized time responses can be used as tools for transducer design. An example of backing impedance selection is given for a simple transducer configuration driven by a transistor switch.

1.0 INTRODUCTION

Normalization techniques are used to standardize design and simulation of common transducer configurations. Szabo [1] has applied normalization techniques to transducer design using the KLM model. Kossoff [2] studied the effects of acoustic backing and matching on transducer performance and presented the results as frequency normalized transfer functions. Thurston [3] did similar work studying the effects of shunt and series matching inductors.

In this paper, a normalized equivalent circuit is used to generate time response families for the thin disk transducer. The circuit is derived from a version of Mason's model which lends itself to time domain analysis. This circuit is easily implemented on a circuit analysis program for simulation purposes [4].

Scaling techniques can be applied to obtain normalized versions of common transducer driver and matching schemes. These schemes include resistive-inductive (LR) electrical matching, quarter wave matching and switched drivers, such as transistor pulsers.

Using a normalized transducer circuit, a family of time responses can be generated as a function of some design variable. This family can then be used as a tool to obtain optimum transducer performance. For example, given a family of waveforms as a function of backing impedance, one can select the impedance which gives maximum pulse amplitude yet still satisfies the pulse duration requirements.

The techniques presented here are useful for the design of switch driven transducers because of the emphasis on time domain simulation. Time responses for switch-driven transducers are difficult to obtain using frequency domain models, such as KLM, because of the time varying impedance of the switch.

2.0 NORMALIZED TRANSDUCER CONFIGURATIONS

2.1 Transducer Equivalent Circuit

Figure 1 shows the geometry and port definitions for a thin disk transducer, along with Redwood's version of Mason's model [5]. The circuit parameters are:

$$Z_0 = A\, Z_c = A\, \rho_c \nu^D \qquad (1)$$

$$R_1 = A\, Z_1 = A\, \rho_1 \nu_1 \qquad (2)$$

$$R_2 = A\, Z_2 = A\, \rho_2 \nu_2 \qquad (3)$$

$$\tau = 1/2f_0 = d/\nu^D \qquad (4)$$

$$N = hC_0 \qquad (5)$$

$$C_0 = \frac{\varepsilon^S A}{d} = \frac{N^2}{2k_t^2 f_0 Z_0} \qquad (6)$$

$$k_t^2 = \frac{h^2\, \varepsilon^S}{c^D} \qquad (7)$$

Apply the following four scaling laws to the circuit of Figure 1:

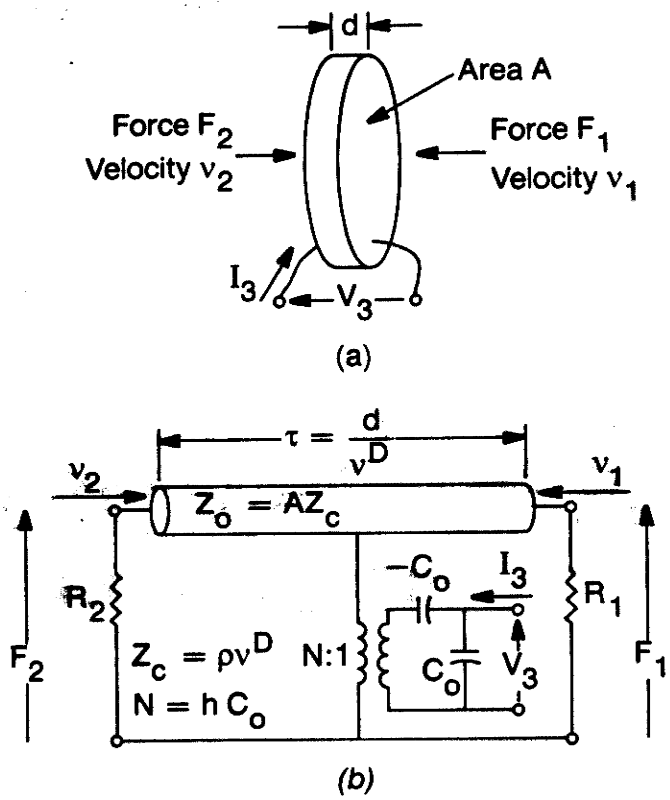

Figure 1 Diagram of thin disk transducer;
(a) geometry and port definitions,
(b) equivalent circuit.

frequency	$f' = f/f_0$	(8)
impedance	$Z' = Z/Z_0$	(9)
current	$I_3' = I_3/N$	(10)
voltage	$V_3' = V_3 N$	(11)

Using Eqs. (1)-(11) yields the normalized circuit of Figure 2.

2.2 Electrical Matching Elements

For electrical matching, two commonly used elements are the resistance R_0 and the series inductance L_0 which are used to obtain a conjugate match to the transducer input impedance at f_0. Solving for the input impedance of Figure 2 gives:

$$R_0' = \frac{R_0\,N^2}{Z_0} = \left(\frac{k_t^2}{\pi}\right)^2 \frac{4}{R_1' + R_2'} \tag{12}$$

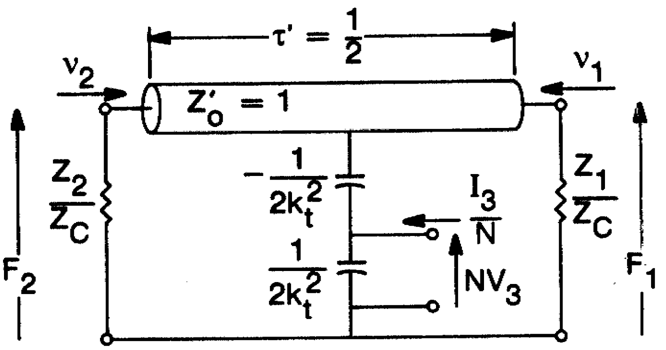

Figure 2 Normalized equivalent circuit.

$$L_0' = \frac{L_0\,N^2\,f_0}{Z_0} = \frac{k_t^2}{2\pi^2} \tag{13}$$

2.3 Quarter Wave Layers

If the quarter wave resonance of a matching layer is chosen to be at f_0, the normalized time delay is:

$$\tau'(\lambda/4) = 1/4 \tag{14}$$

There are several schemes for selecting the impedances of the matching system. The impedance values calculated from each scheme are easily normalized. For example, the single-layer scheme:

$$Z_{m1} = (Z_c\ Z_1)^{1/2} \tag{15}$$

becomes:

$$Z_{m1}' = Z_1'^{1/2} \tag{16}$$

2.4 Switched Drivers

Figure 3 shows a switch-driven transducer configuration. The on and off times of the switch are normalized by using the time transformation:

$$t' = t\ f_0 \tag{17}$$

This configuration is usually driven with:

$$t'\ (\text{on}) = 0 \tag{18}$$

$$t'\ (\text{off}) = 1/2 \tag{19}$$

This corresponds to a drive pulse equal to one-half cycle at f_0.

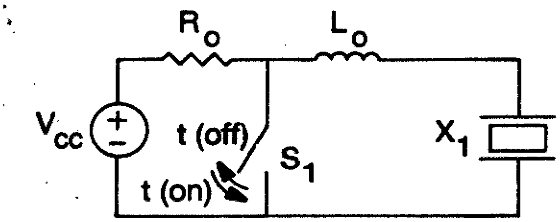

Figure 3 A switch-driven transducer configuration.

3.0 GENERATION OF REFERENCE WAVEFORMS

Using a circuit analysis program, the normalized transducer configurations can be used to generate reference families of waveforms to cover a broad range of transducer problems. The normalized families predict the time and frequency responses of a configuration as a function of some design variable. Using the families, the value of the design variable can be selected to optimize transducer design.

Figures 4 and 5 show families of pulse response waveforms for water loaded PZT-5H and lead metaniobate, respectively, as a function of backing impedance. The waveforms are for pulse-echo response and are excited using a switch as shown in Figure 3. These waveforms can be used to predict transducer time response and select the backing impedance.

4.0 EXAMPLE APPLICATION

Suppose that a 1-in. diameter 500 KHz lead metaniobate transducer is to be designed. The transducer will be water loaded and will have no quarter wave matching. We want to select a backing impedance which gives the best pulse echo amplitude that has a ringdown time of less than 20 µsec.

The normalized ringdown requirement is:

$$\tau_{RD}\, f_0 = 10 \;.$$

Using Figure 5, we estimate the normalized backing impedance should be just greater than 0.1 (2 MRayl) to satisfy the design requirements.

A 500 KHz lead metaniobate transducer was built using a backing of 2.4 MRayl. The parameters f_0, R_0, and L_0 were measured using an impedance meter to be 480 KHz, 760 ohm and 200 µH, respectively. The transducer was driven with a transistor as the switch in Figure 3 using a 780 ohm matching resistor and a 200 µH inductor. The switch was pulsed on for 1 µsec. The pulse echo response, shown in Figure 6, should be compared to the response marked R_B = .1 in Figure 5.

5.0 CONCLUSION

The normalization techniques discussed here allow generic analysis and simulation of common transducer configurations and can be used to estimate time responses of trial transducer designs. The waveform families generated using these techniques are useful for switch-driven transducer designs. Finally, the normalized waveforms can be used as design tools for common transducer configurations.

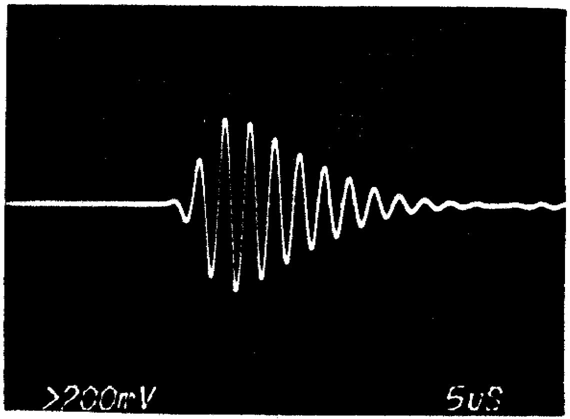

Figure 6 Pulse-echo response of 500 KHz lead metaniobate transducer used as design example.

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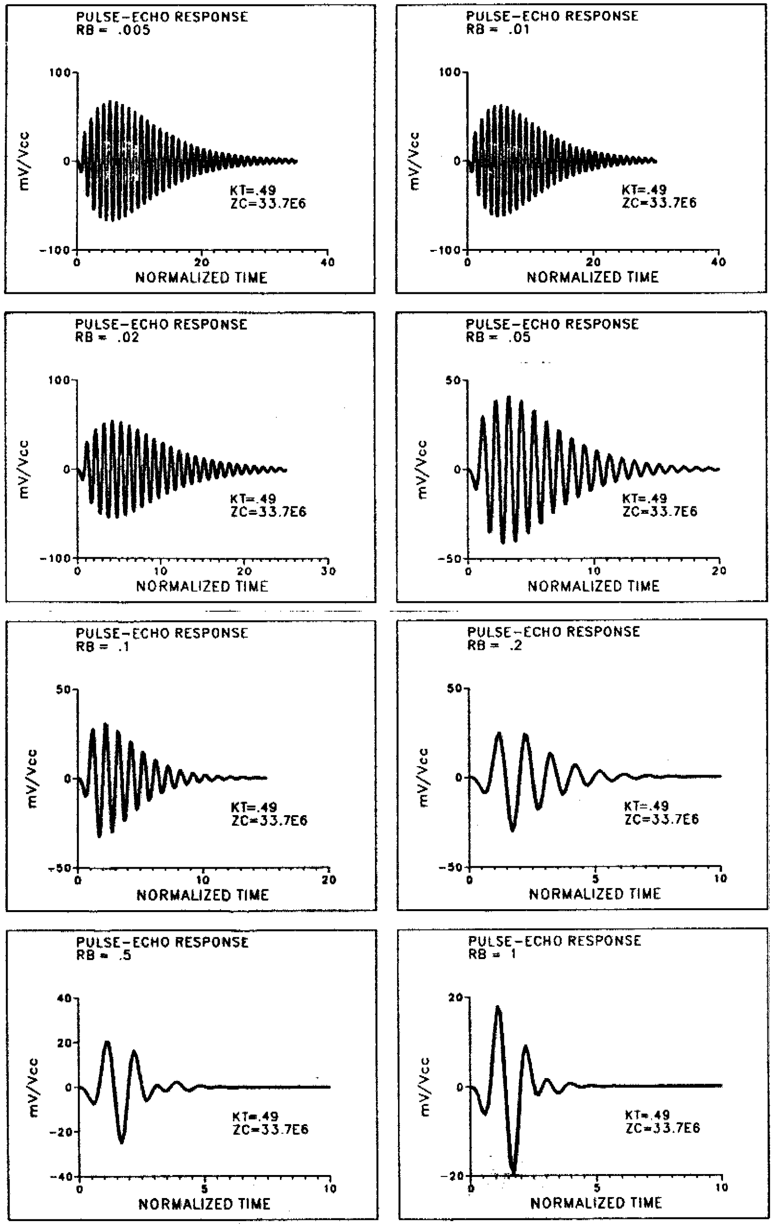

Figure 4 A time response family for PZT-5H as a function of backing impedance. The transducer is water-loaded and driven by the circuit in Figure 3.

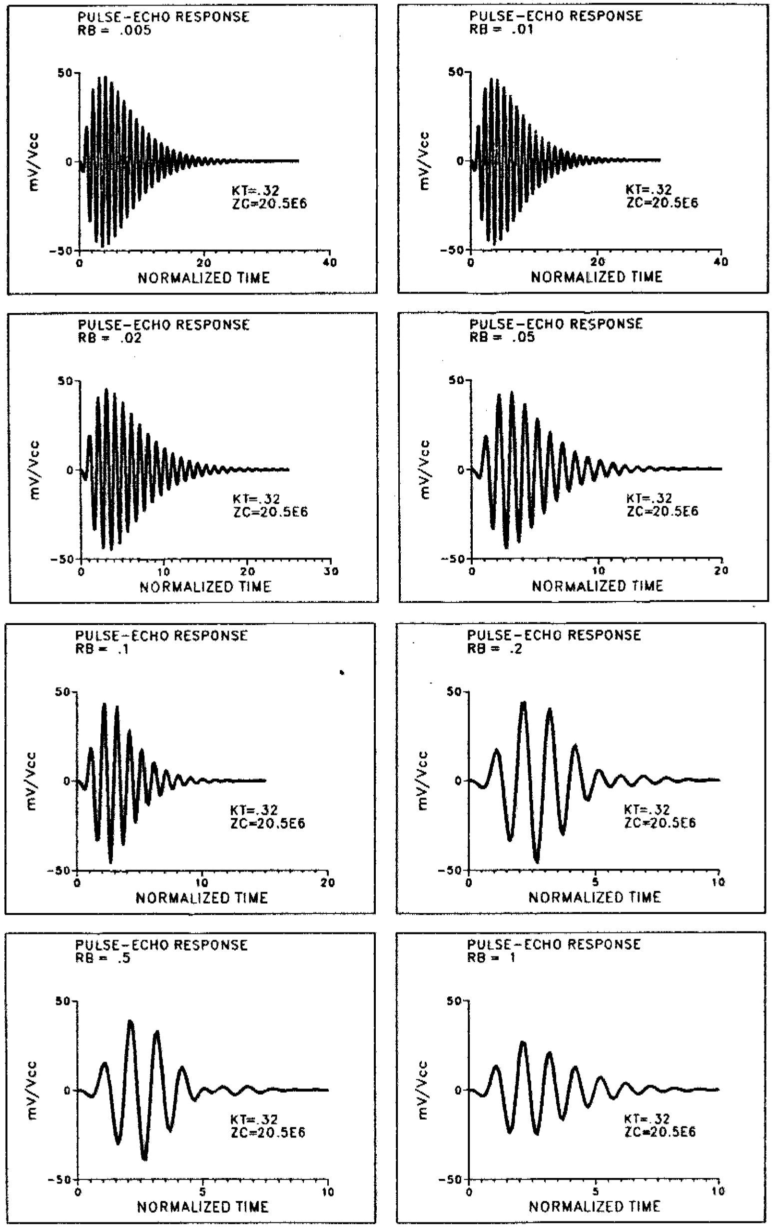

Figure 5 A time response family for lead metaniobate as a function of backing impedance. The transducer is water-loaded and driven by the circuit in Figure 3.