Abstract - The purpose of this work is to explore the loss mechanism in piezoceramic material. This is done by combining the acoustic viscosity constants of the material with the elastic constant and forming a complex elastic constant. Then the one dimensional differential equations are solved with this as the elastic constant. The complex elastic coefficient suggests that the device has a complex resonant frequency. An experiment has been set up to apply a complex frequency to the device in the form of a decaying sine wave, and some preliminary results are presented. Equivalent circuit modeling of the device using transmission lines and controlled sources are used to simulate the device with a decaying sine wave as the excitation. Results are presented from these simulations.

INTRODUCTION

Piezoelectric resonators and filters are important components in many military and commercial communication systems. Standard piezoelectric materials such as quartz have low coupling values and are quite expensive to fabricate. Newer materials like piezoceramics have been developed that are cheaper, have higher values of coupling constant but can be considerably more lossy than single-crystal materials. The manufacture of these ferroelectric ceramics often leads to unacceptable process deviations from batch to batch. By gaining a better understanding of the material loss mechanisms involved, and equivalent networks to characterize resonators made of these materials, it should be possible to improve the situation in two regards. First, the circuit values can be accurately interpreted in terms of the physical properties to provide better feedback to the factory. Second, the circuit parameters of the ceramic can be "impedance-matched" to the using circuit in a manner which will make the best use of the acoustic device.

The purpose of this work is to explore loss mechanisms through the use of complex elastic coefficients in the piezoelectric constitutive relations and the differential equations for a simple one-dimensional resonator.

There has been some work using a complex coupling constant to show that the resonant point of the device does not lie on the jo axis, but in the complex plane. This implies a complex frequency as the resonant frequency. This complex frequency can be represented by an exponentially decaying sinusoid, since the Laplace transform of this signal shows that the device has poles with a real and imaginary component. Knowing this it should be possible to mitigate the loss in the device by applying this type of waveform. The 1-dimensional differential equation was solved including the loss term. The D.E. is a bit more complicated due the mix of derivatives involving the loss term. This solution implies a resonance in the complex plane, so if a lossy device is characterized in a standard manner on a network analyzer, the proper resonance for the device will not be found. This is a result of the network analyzer using a pure sinusoidal signal for device characterization. An experiment has been designed to apply a complex signal to a lossy device to properly identify its complex resonance point. Equivalent circuit models of the device have been set up using Pspice and simulate this behavior using this complex frequency to excite the device.

Experimental Setup

...The experiment to characterize the piezoceramic resonators consists of three parts. The first step is to characterize the device using an HP4952A RF Impedance Analyzer. This unit has a frequency range from 1 MHz up to 1 GHz. It can measure the magnitude of the impedance, the magnitude of the admittance, the phase, resistance, reactance...
conductance, susceptance, and \( Q \) and then display these quantities as functions of frequency. A pulse technique was used to measure the loss constant of the material. An HP8114A pulse generator transmitted an approximately 10 ns pulse through a 50 \( \Omega \) coaxial cable with an approximate length of 60 cm. The resonator was connected between the center conductor and the shield of the cable. The voltage was measured across the device using a 10:1 voltage probe with a 1M \( \Omega \) input impedance, which is connected to a Lecroy 7100A 1Gs/s digitizing oscilloscope. The last part consists of a signal source with the frequencies being manually swept and the voltage and current data being acquired on an HP 54503A 500 MHz four channel oscilloscope. The voltage was measured with a 10:1 voltage probe and the current through the device was measured with a Pearson 4727 10:1 current transformer. An Analogic arbitrary waveform generator with a maximum frequency of 3.125 MHz is used to generate the exponentially decaying sine wave. The data was acquired, stored and plotted using Hewlett-Packard Visual Engineering Environment (VEE). VEE uses the GPIB interface to communicate with data acquisition instruments. An HP8560E spectrum analyzer was used to measure the frequency components of the current through the device. The waveforms of the current, voltage, and spectrum information are plotted and saved using HPVEE. The piezoceramic material that is used in these tests is PZT. Table I lists the material parameters supplied by Channel Industries. The material chosen has a velocity of 4220 m/s. TE mode devices were ordered of varying frequencies, although only results for a 1 MHz device will be presented. The device under test had a resonant frequency of approximately 1.07 MHz and an anti-resonant frequency of 1.185 MHz. Figure 1 shows plots of the admittance and impedance waveforms from the RF impedance analyzer. The capacitance ratio, \( r \), for this device is 5.108 which leads to a coupling value of 49.15%. The device is 2mm thick and has a radius of 20 mm. The radius was chosen to be this large so there would only be TE modes in the device. The acoustic velocity of this material and mode is 4220 m/s. Using the resonance information acquired from the RF impedance analyzer, the arbitrary waveform synthesizer was programmed to generate an exponentially decaying sine wave. The voltage across the device was measured with a high impedance voltage probe and the current was measured with the current transformer. The data are taken for each decay value at a specific frequency and then repeated for different frequency values. With CW sinusoidal excitation at resonance, the voltage across the device is at a minimum and the current is at its maximum value. That has not been the case when applying the complex frequency to the device. Figure 2 is voltage and current plots of the device at the resonant frequency, with an exponential decay of .016 Hz. For a decay time of .9e6 Hz, at the same frequency the voltage and current waveforms are shown in figure 3. The difference at these decay times can be seen in the current waveforms. At the smaller

![Admittance and Impedance vs Frequency](image)

Figure 1. Admittance and Impedance Curves for 1 MHz PZT device.

**DISCUSSION**

The main thrust of this work is to explore the loss mechanisms using a decaying sinusoid. The RF impedance analyzer was used to find the resonant and anti-resonant frequencies of the device along with impedance, admittance, phase and related quantities.
Figure 2. Voltage and current waveforms of device for a decay time of 0.01e6 Hz.

decay constant the current waveforms grows in amplitude for a few cycles and then decreases again. The voltage waveform decreases in amplitude with the exponential decay constant. At the higher decay constant, the current follows the exponential decay, while the voltage drops quickly and then slightly grow and decreases again. An interesting effect is that the measured frequency is different than that set at the source. When the period of the waveforms is measured on a cycle to cycle basis, the calculations of the periods yield different values. It seems that the device is modulating the applied waveform. It appears the decaying sine wave is having an effect on the device performance. More work needs to be done to accurately interpret the data to see if this method of excitation truly stimulates the complex resonant point of the device.

Figure 3. Voltage and current waveforms for a decay time of 0.9e6 Hz.

Equivalent Circuit Modeling

A transmission line model of the PZT device has been set up using a version of Pspice called Microcap V. There have been many models based on transmission lines. Unfortunately the circuit simulator has a difficult time dealing with the negative capacitor in the model and the ideal transformer that represents the piezoelectric effect. Morris and Hutchens in their article get around these problems using controlled sources to represent the negative capacitor and the transformer. This is the model chosen to be used in this work. It is intended to use the lossy transmission line model to represent the lossy device. The model was set up in this new version of Pspice and recreated their results successfully. A schematic of the model is shown in figure 4.

Figure 4. Equivalent Circuit Model.

An AC analysis was performed on the device model for impedance, resistance and reactance to insure that these quantities had the correct form. Figure 5 shows these curves. The AC analysis mode of the simulator only uses a constant amplitude frequency sweep, so to simulate a decaying sine wave the analysis has to be performed in the time domain using the transient simulator. A nice feature of the simulator is the ability to change values of devices during the simulation. What was done was to step through the source frequency and the decay constant during the simulation to see what effect these values had on the model. The impedance in the time domain is not a simple division of the voltage on the device by the current thought the device. The voltage on the device is a convolution of the current and the impedance of the device. What was done in this simulation was to take the time derivatives of the current and the voltage and then perform the division.
be artifacts from the simulation. The simulation is being carried further to use a lossy line to represent device, with the resistance of the line as the loss in the device. Some preliminary work has been done to set up the model, but no data has been generated yet to see how the resistance affects the impedance curves.

**CONCLUSION**

Results were presented from the experiment showing that a decaying sine wave does cause the device to behave differently. The circuit model is showing results but more work needs to be done to include the loss in the device.

**REFERENCES**


