

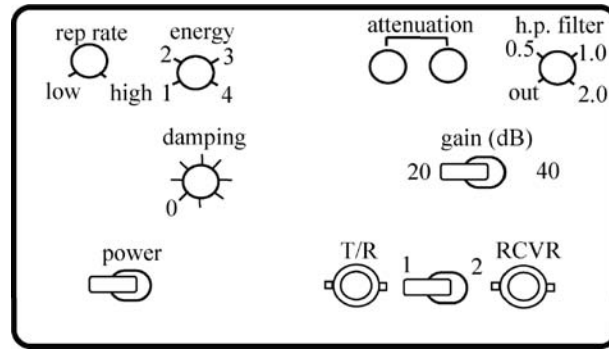
## 2 The Pulser

A pulser/receiver is a complex electrical network that generates the energy that drives the transmitting transducer in an ultrasonic measurement system. The pulser/receiver also amplifies and/or filters the electrical response arriving from the receiving transducer. In this Chapter we will examine only the pulser section of a pulser/receiver and describe some of the important overall characteristics of its output signals and how those signals are affected by instrument setting changes. Simple models that can describe the pulser output are also discussed.

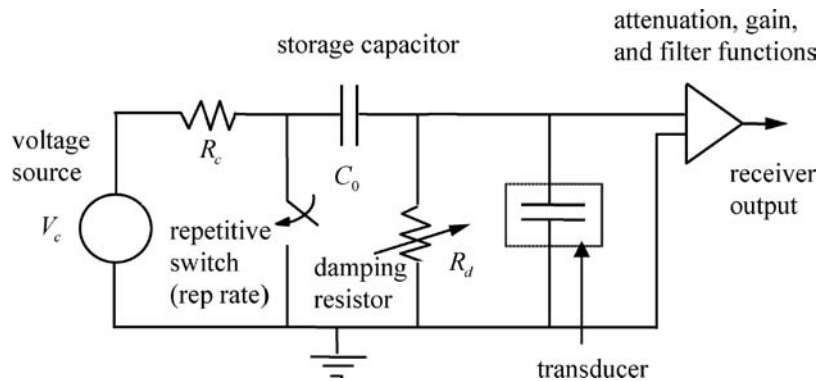
### 2.1 Characteristics of a Pulser

Figure 2.1 shows a sketch of the front panel of a typical laboratory “spike” pulser/receiver while Fig. 2.2 shows a highly idealized circuit schematic of this same instrument. The pulser side of this instrument has three controls. One control is the “energy” setting. The energy setting basically controls the amount of energy stored in the capacitor,  $C_0$ , of Fig. 2.2. This energy is periodically discharged into the sending transducer by closing the switch shown in that figure. The “rep rate” controls the frequency at which this switch is closed, which typically may be varied from several hundred closings/sec to several thousand closings/sec. Generally this rate is set to ensure that the waves traveling in a component have had time to decay in amplitude to very small values before the next discharge occurs. In this case there is no overlapping of the received responses from one closing to the next which, if it occurred, could cause triggering problems when the received signals are displayed on an oscilloscope screen since the oscilloscope is triggered by a signal generated in synchronization with the pulser discharges. The “damping” control on the pulser changes the value of a damping resistance,  $R_d$ , in the pulser/receiver.

In addition to a spike-like pulser, which uses a capacitive discharge to drive a transducer, there are also square wave pulser/receivers like the UTEX 340 shown in Fig. 2.3 which drive a transducer with circuits that produce a rectangular-shaped voltage pulse. This particular pulser has



**Fig. 2.1.** The front panel controls of a typical laboratory “spike” pulser/receiver.

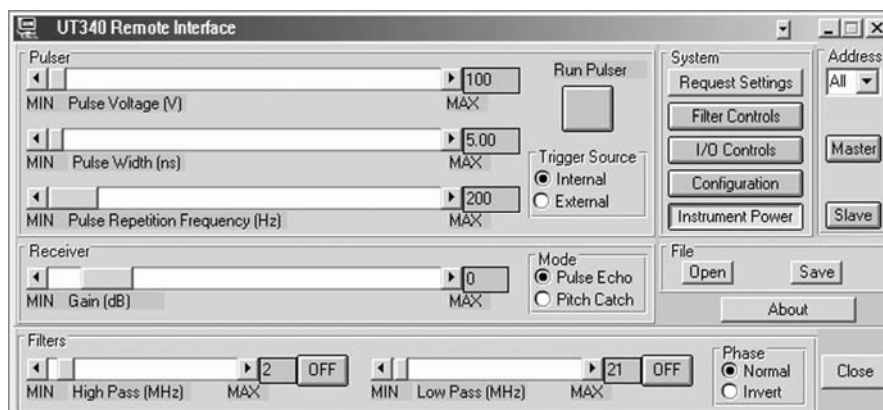


**Fig. 2.2.** A highly simplified circuit representation of a “spike” pulser/receiver.

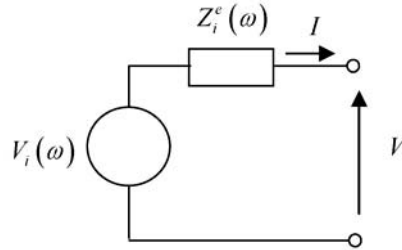
most of its controls also available under computer control. An image of the UTEX 340 computer control panel is shown in Fig. 2.4. It can be seen from that figure that on the pulser side of this instrument there are primarily three settings- the pulse repetition rate, the pulse voltage amplitude (in volts), and the pulse width (in nanoseconds). The energy/damping settings of the spike pulser and the voltage/pulse width settings of the square wave pulser control the amplitude and shape of the voltage and current at the output port of the pulser. In the next section we will show how the output behavior of these pulsers can be described in terms of



**Fig. 2.3.** A UTEX 340 square wave pulser/receiver. Photo courtesy of UTEX Scientific Instruments, Inc. , Mississauga, Ontario, Canada.



**Fig. 2.4.** The control panel of the UTEX 340 pulser/receiver. Photo courtesy of UTEX Scientific Instruments, Inc., Mississauga, Ontario, Canada.

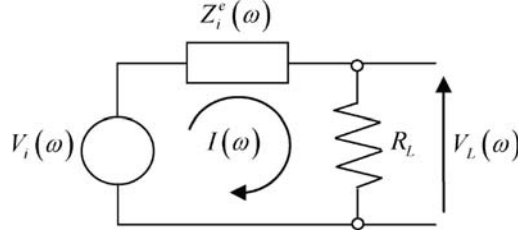


**Fig. 2.5.** The Thévenin equivalent voltage source and impedance for a pulser.

a simple equivalent circuit whose parameters can be obtained with several electrical measurements. The properties of that equivalent circuit, however, are dependent on these pulser settings so that if they are changed, the equivalent parameters will change.

## 2.2 Measurement of the Circuit Parameters of a Pulser

As shown in Appendix B, Thévenin's theorem allows us to replace the pulser, which is a circuit network with sources, with the equivalent voltage source and equivalent impedance of Fig. 2.5 if one assumes that the pulser is a linear device. Several authors have used either the simple model of Fig. 2.5 or other similar equivalent circuits to model both the pulser and receiver circuits [2.1-2.4]. As pointed out in these studies, because of the internal diode protection circuits and other elements present in pulser/receivers, strictly speaking those devices may not act in a linear fashion. However, if the measurement of  $V_i(\omega)$  and  $Z_i^e(\omega)$  are made for a specific set of pulser settings at the same external electrical loading conditions (cabling, transducer) found in the measurement system, then the simple equivalent circuit of Fig. 2.5 can be successfully used to model a given pulser [2.4]. It is relatively easy to measure the Thévenin equivalent voltage source for the pulser,  $V_i(\omega)$ , by measuring the open-circuit voltage,  $V_0(t)$ , at the output terminals of the pulser and then Fourier-transforming this measured voltage to obtain  $V_0(\omega)$ . Since there is no current flowing from the pulser under open-circuit conditions we have  $V_i(\omega) = V_0(\omega)$ .



**Fig. 2.6.** The Thévenin equivalent circuit for a pulser attached to a known external resistance,  $R_L$ , for measuring the impedance,  $Z_i^e(\omega)$ .

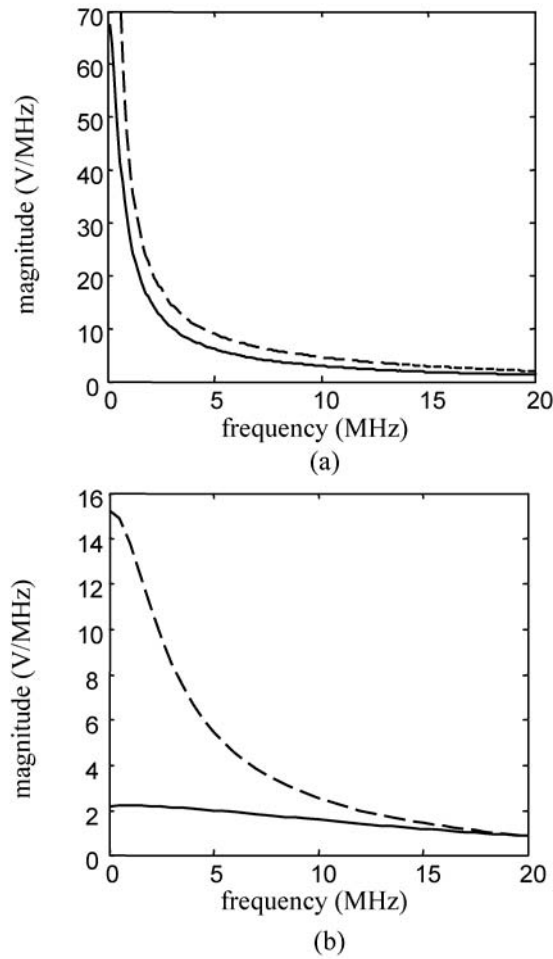
To find the electrical impedance of the pulser we can place a known load resistance,  $R_L$ , at the output terminals of the pulser and measure the voltage,  $V_L(t)$ , across this load. Fourier transforming this voltage then gives  $V_L(\omega)$ . But from the Thévenin equivalent circuit of the pulser shown in Fig. 2.6, we see that

$$\begin{aligned} V_i - V_L &= Z_i^e I \\ V_L &= R_L I. \end{aligned} \quad (2.1)$$

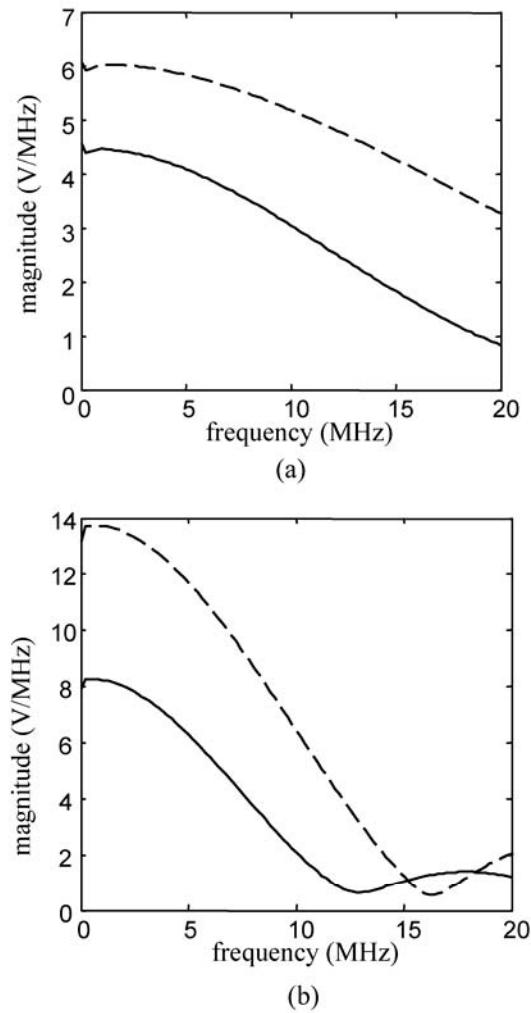
So eliminating the current,  $I$ , we find

$$Z_i^e(\omega) = R_L \left( \frac{V_i(\omega)}{V_L(\omega)} - 1 \right). \quad (2.2)$$

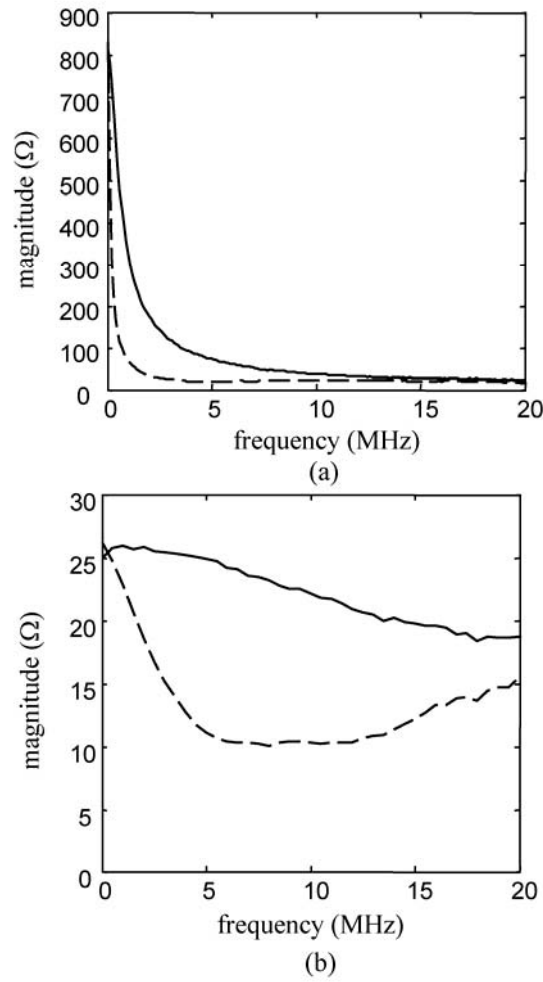
Since the values of the Thévenin equivalent parameters  $(V_i, Z_i^e)$  depend on the instrument settings of the pulser we have shown these parameters at several different settings. Figure 2.7, for example, shows the magnitude of the Thévenin equivalent voltage measured for a Panametrics 5052 PR pulser/receiver (spike pulser) at combinations of two different energy settings and two damping settings. In the same fashion Fig. 2.8 shows the magnitude of the Thévenin equivalent voltage obtained for a UTEX 320 pulser/receiver (square wave pulser) at combinations of two different voltage settings and two pulse width settings. Figures 2.9 and 2.10 show the corresponding dependency of the equivalent impedance of



**Fig. 2.7.** Magnitude of the Thévenin equivalent voltage source versus frequency obtained for a Panametrics 5052PR pulser/receiver for **(a)** damping setting = 0 and energy setting = 1 (solid line) or energy setting = 4 (dashed line), and **(b)** damping setting = 7 and energy setting = 1 (solid line) or energy setting = 4 (dashed line).

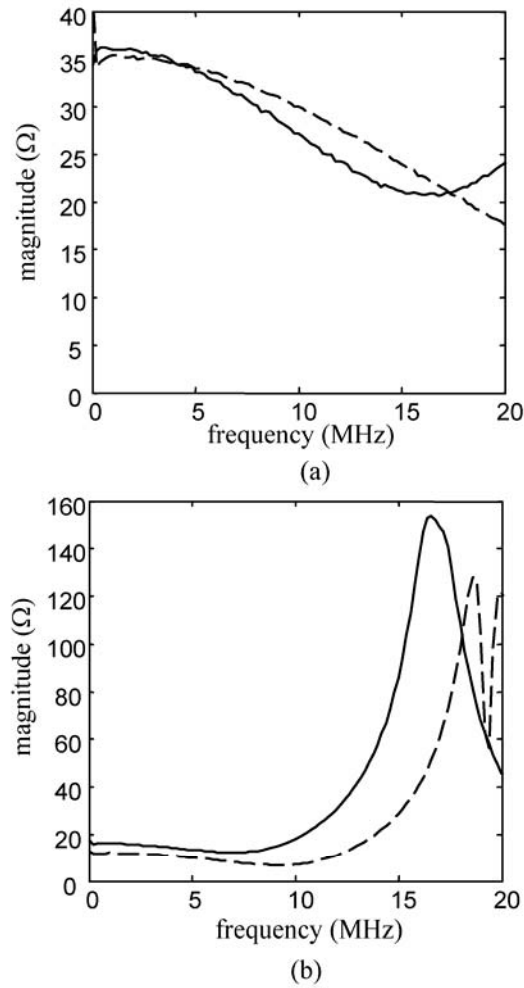


**Fig. 2.8.** Magnitude of the Thévenin equivalent voltage source versus frequency obtained for a UTEX 320 pulser/receiver at: **(a)** pulse width = 10 and voltage = 100V (solid line) or voltage = 200V (dashed line), and **(b)** pulse width = 50 and voltage = 100 V (solid line) or voltage = 200 V (dashed line).



**Fig. 2.9.** Magnitude of the Thévenin equivalent pulser impedance versus frequency obtained for a Panametrics 5052PR pulser/receiver for **(a)** damping setting = 0, energy setting = 1 (solid line), energy setting = 4 (dashed line), and **(b)** damping setting = 7, energy setting = 1 (solid line), energy setting = 4 (dashed line).

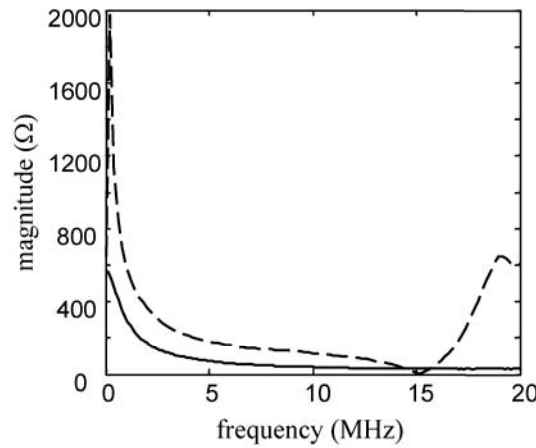




**Fig. 2.10.** Magnitude of the Thévenin equivalent impedance versus frequency for a UTEX 320 pulser/receiver at: **(a)** pulse width = 10, voltage = 100V (solid line), voltage = 200V (dashed line), and **(b)** pulse width = 50, voltage = 100 V (solid line), voltage = 200 V (dashed line).

the pulser at the same pulser settings for these two pulser/receivers. It can be seen that the energy and voltage settings do increase the magnitude of the Thévenin equivalent voltage source for these pulsers, as expected, but that there are also changes in the shape of the voltage source and impedance

with frequency so that the overall behavior of such pulsers is a rather complex function of the pulser settings. Although the resistance,  $R_L$ , appears in Eq. (2.2) the impedance,  $Z_i^e(\omega)$  should not depend on that resistance, as discussed in Appendix B. Pulser impedance measurements made in this fashion with spike and square wave pulsers, however, do show some variations with the load used, possibly due the non-linear elements present in those instruments, as discussed previously. Figure 2.11 shows, for example, the magnitude of the equivalent impedance of the Panametrics 5052 PR pulser obtained when a  $50\Omega$  resistor was used at the pulser output versus the impedance obtained when a transducer and cable were attached to the output port instead. In the latter case the voltage and current were both measured at the output port of the pulser in order to calculate the impedance of the loading induced by the cabling and transducer. The  $R_L$  in Eq. (2.2) was then replaced by that load impedance to calculate the pulser impedance. It can be seen from Fig 2.11 that there are indeed differences in the calculated impedance of the pulser under these different external loads. Similar changes have been observed when calculating the equivalent impedance of square wave pulsers. In general our experience has been that it is best to make these measurements of the pulser impedance under the actual loading conditions that will be found when using the pulser in ultrasonic flaw measurements, but we have also



**Fig. 2.11.** The magnitude of the Thévenin equivalent impedance of a Panametrics 5052 PR pulser/receiver versus frequency found using a 50 ohm resistor loading (solid line) and a loading consisting of a cable and transducer (dashed line).

been successful in using the pulser impedance values measured with Eq. (2.2) and purely resistive loads to simulate the pulser effects in an overall ultrasonic system measurement model of the type discussed in Chapter 7. Thus, while the loading at the pulser output port does change the measured values of the equivalent impedance of the pulser it appears that these loading effects do not significantly affect the measured output voltage in an ultrasonic measurement system, where other parameters, such as transducer sensitivity, play a more important role.

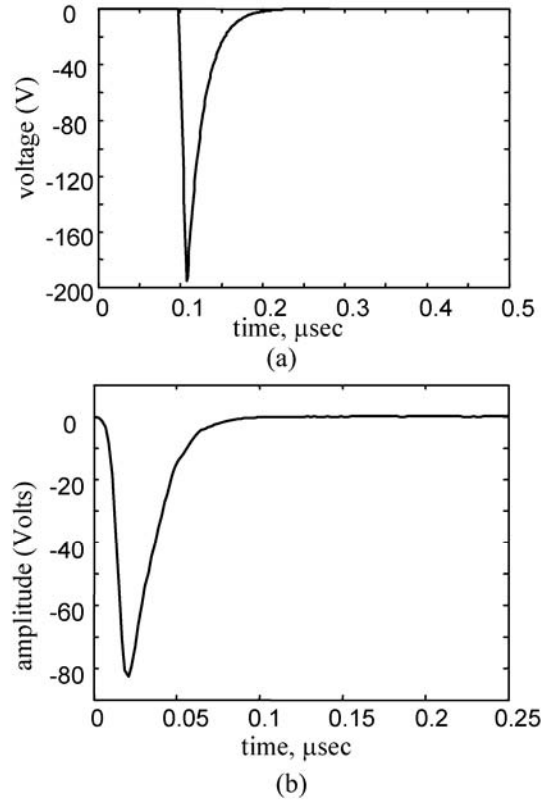
## 2.3 Pulser Models

It is possible to set up a simple model of the open-circuit output voltage of a typical spike or square wave pulser by directly specifying this voltage in the form of a four parameter model given by

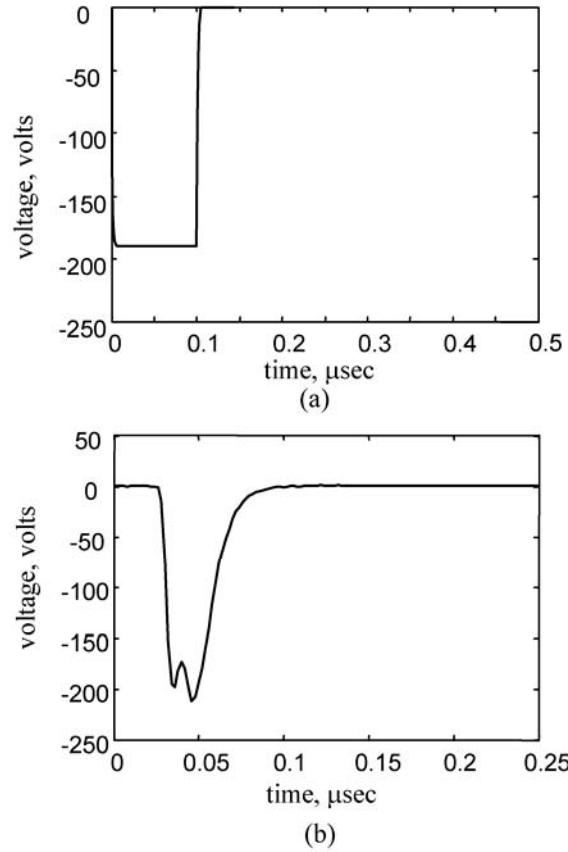
$$V_i(t) = \begin{cases} 0 & t \leq 0 \\ -V_\infty [1 - \exp(-\alpha_1 t)] & 0 \leq t \leq t_0 \\ -V_0 \exp[-\alpha_2 (t - t_0)] & t \geq t_0 \end{cases} \quad (2.3)$$

where  $V_\infty = V_0 / (1 - e^{-\alpha_1 t_0})$  and the four parameters  $(t_0, \alpha_1, \alpha_2, V_0)$  control the amplitude and rise and fall characteristics of the pulse. Figure 2.12 (a) shows a plot of this modeled voltage which is very similar in form to a measured Thévenin equivalent open-circuit voltage from the Panametrics 5052PR pulser/receiver, as shown in Fig. 2.12 (b). This same model, with the appropriate choice of parameters, can also be used to model a square wave pulse output (see Fig. 2.13 (a)). The actual open-circuit output voltage of a UTEX 320 square wave pulser/receiver is shown in Fig. 2.13 (b). The spectrum generated by this simple source model can be obtained from Eq. (2.3) by numerically evaluating the FFT of this time domain response or one can use the explicit Fourier transform of the  $V_i(t)$  of Eq. (2.3), which is given by:

$$V_i(\omega) = \frac{V_\infty \{1 - \exp[-(\alpha_1 - i\omega)t_0]\}}{\alpha_1 - i\omega} + \frac{V_\infty \{1 - \exp[i\omega t_0]\}}{i\omega} - \frac{V_0 \exp[i\omega t_0]}{\alpha_2 - i\omega}. \quad (2.4)$$



**Fig. 2.12. (a)** Voltage pulse (volts) versus time (μsec) obtained from Eq. (2.3) with  $t_0 = 0.01$ ,  $\alpha_1 = 0.2$ ,  $\alpha_2 = 50$ ,  $V_0 = 200$  (shifted for better visualization). **(b)** Measured open-circuit voltage versus time for a Panametrics 5052PR pulser/receiver at energy setting 1, damping setting 5.



**Fig. 2.13.** (a) Voltage pulse (volts) versus time (μsec) obtained from Eq. (2.3) with  $t_0 = 0.1$ ,  $\alpha_1 = 1000$ ,  $\alpha_2 = 1000$ ,  $V_0 = 190$ . (b) Measured open-circuit output voltage versus time for a UTEX 320 pulser/receiver.

It is not as easy to obtain an explicit parametric model of the impedance of a pulser since this impedance changes significantly in both amplitude and shape with the pulser settings and as a function of frequency, as shown in Figs. 2.9 and 2.10. However, one could try to model the pulser impedance by an equivalent RLC circuit whose parameters are adjusted to match the measured impedance values (as a function of frequency) at various damping settings, as done by Brown [2.1]. Brown found that the equivalent RLC parameters obtained for a Panametrics 5052PR did change significantly, particularly at the higher damping settings.

## 2.4 References

- 2.1 Brown LF (2000) Design considerations for piezoelectric polymer ultrasound transducers. IEEE Trans. Ultrasonics, Ferroelectrics, and Frequency Control 47: 1377-1396
- 2.2 Dang CJ, Schmerr LW, Sedov A (2002) Modeling and measuring all the elements of an ultrasonic nondestructive evaluation system. I: Modeling foundations. Research in Nondestructive Evaluation 14: 141-176
- 2.3 Dang CJ, Schmerr LW, Sedov A (2002) Modeling and measuring all the elements of an ultrasonic nondestructive evaluation system. II: Model-based measurements. Research in Nondestructive Evaluation 14: 177-201
- 2.4 Ramos A, San Emterio JL, Sanz PT (2000) Dependence of pulser driving responses on electrical and motional characteristics of NDE ultrasonic probes. Ultrasonics 38: 553-558

## 2.5 Exercises

1. The MATLAB function `model_pulser` takes as inputs an energy setting (energy = 1, 2, 3, 4), a damping setting (damping = 0, 5, 10), a resistance loading, `RL`, (in ohms) across the output terminals of the pulser and returns the sampled voltage, `vt`, across `RL` (in volts) and the sampled time values, `t`, (in  $\mu\text{sec}$ ). The form of the calling sequence of this function is:

```
>> [t , vt] =model_pulser( energy, damping, RL);
```

Use this model pulser at energy = 2, damping = 5 settings for both open circuit conditions ( $RL = \infty$ ) and a given load ( $RL = 250$  ohms) to determine the Thévenin equivalent source voltage (in volts) and impedance (in ohms) of the pulser at these settings as functions of frequency over the range of frequencies from 0-20 MHz and plot the magnitude and phase of these functions over the same frequency range. Use the MATLAB `unwrap` function to eliminate any artificial jumps of  $2\pi$  in the phase plots. Example:

```
>> plot(f, unwrap(angle(Vf)))
```

Show and explain all the steps you used to obtain your answers.

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