PSPICE SIMULATION OF TRANSIENT RESPONSES OF TRANSDUCERS AND SPIKE GENERATORS INCLUDED IN E/R ULTRASONIC SYSTEMS

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ABSTRACT

The global performance of ultrasonic emitting-receiving stages is influenced by the behavior of their respective electronic elements. In typical pulsed driving-receiving systems, present in commercial equipment employed in NDE or medical imaging, the electronic components notably condition the characteristics of the mechanical and electrical outputs under different operating conditions.
This paper presents some PSPICE electric diagrams representing the piezoelectric transduction and the spike generation included in E/R ultrasonic systems. The modeling of non-linear driving electronic stages is considered. These diagrams are applied in the computer simulation of different driving, emission and/or reception ultrasonic processes taking into account several working situations. The influence of some reactive and resistive electronic components included in these arrangements and their effects on the driving spike waveforms and the E/R ultrasonic responses, are evaluated.

INTRODUCTION

The whole performance of many practical emitting – receiving ultrasonic systems, employing piezoelectric thickness-mode transducers, is determined by their electrical, mechanical and piezoelectric properties, the interaction of the wave transmitted with the medium, and the driving - receiving electronic stages. Although this driving/receiving electronic have a significative influence on the global response, this fact is often neglected or only considered through very simplified approaches and its interaction on ultrasonic responses are not commonly reported in the literature**.**

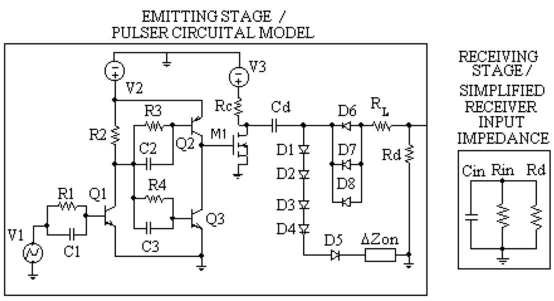
Some specific effects of the electrical driving-receiving stages on ultrasonic systems have been previously discussed [1-8]. In some cases this have been done considering a resistive and CW signal generator [1] or in the case of broadband excitation, with practical driving circuits invariably including some switching network.[2-7].

In pulsed E/R systems, present in commercial equipment employed in NDE or medical imaging, the electronic components notably condition the time and frequency characteristics of the mechanical and electrical outputs. The complex interaction among several electrical components included in the E/R stages, under different operating conditions, make difficult the evaluation of their influence over the global emitter-receiver piezoelectric transduction performance. This is the reason why several aspects involved in the electrical E/R arrangements, such as electrical matching [1-5,7-8], the damping setting [2-4], the loading characteristics of the ultrasonic probe [5] and non-lineal behavior of some components [7] have been analyzed in different papers.

This paper presents some PSPICE (Orcad^{TM}, Beaverton, OR) electrical schemes representing the piezoelectric transduction, the spike generation and a simplified receiving network, which are present in E/R ultrasonic systems. In the first section two models in PSPICE format of the electrical emitting and receiving stages are presented and described. In the same section a pulse-echo model, based on well-known PSPICE implementations [9,10] is shown and described. The second section shows the simulation results in time and frequency domains of the driving and pulse-echo waveforms, for different values of the energy-discharge parameter (Cd) in the pulser, and light or strong damping settings. In addition a parametric analysis of the Cd component influence, was performed. The influence of these pulser settings on a driving characteristic magnitude as the rise time was evaluated.

EMITTING-RECEIVING ELECTRONICS AND PULSE-ECHO MODELING

Figure 1 depicts two electrical models corresponding to emitting-receiving electronic stages, which are employed in this paper for the simulation of practical pulse-echo ultrasonic configurations. A pulsed circuital diagram symbolizing the output stage of a typical ultrasonic wideband excitation system is presented in Figure 1a). This diagram includes a widespread representation of the driving configuration in the input section, allowing a precise simulation of the LV driving pulse in the gate-source port of the MOSFET transistor.



a) b)

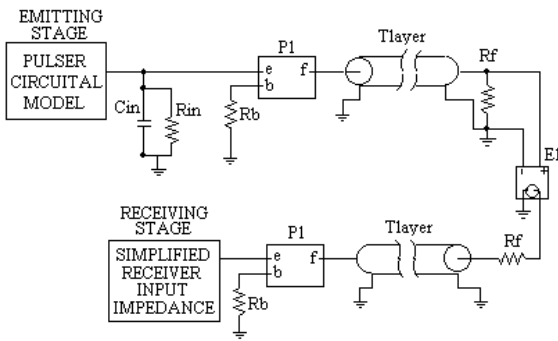


Figure 1. Emitting and Receiving models in PSPICE diagram for the electrical stages
a) Pulser circuital model
b) Simplified receiver input impedance

Figure 2. Pulse-echo configuration in PSPICE diagram

Besides typical loading components (R_d, R_L), some semiconductor devices and their associated non-ideal impedance elements (ΔZon), have been considered in the simulation scheme with the aim of achieving a modeling closer to the practical pulsers functioning [5].

The receiving stage effect has been represented by a simplified receiver input impedance, which is composed by the resistive and capacitive elements (Rin, Cin) associated to the measurement instrumentation and the loading resistive component Rd, also present in reception.

In Figure 2 a PSPICE electric diagram representing a practical pulse-echo ultrasonic configuration is depicted. This scheme, which includes the blocks of Figure 1, was employed to simulate the driving spike and pulse-echo temporal responses, under light and strong damping conditions and for several values of the main parameter conditioning the energy discharge inside the pulser (the reactive component Cd).

In this diagram an ultrasonic probe with acoustic matching layer is symbolized by the two three-port blocks P1, which involve stablished PSPICE piezoelectric models [9,10] and a transmission line (Tlayer). In this backed case, the losses in the acoustic matching were considered negligible and not included in the simulation. The interaction of the wave transmitted with the propagation medium is represented by some resistive components (Rf, Rb) and a dependent voltage source (E1).

The semiconductor elements considered in the pulser circuital diagram were not included as loading in the receiving stage modeling [7]. The reason for doing this is to isolate possible non - linear effects, which could mask the specific modeling aspects explained in this work.

The elements Cin and Rin associated to the measurement instrumentation, were placed also loading the emitting stage, attempting to model a more realistic pulse-echo situation. A more extensive explanation about these simulation details can be found in [7,11]

SIMULATION RESULTS IN TIME AND FREQUENCY DOMAINS

Driving waveforms

Figure 3 shows a comparison of the temporal spike waveforms for different values of the energy-discharge parameter (Cd) in the pulser, considering a light damping condition (Rd = 470 Ohm). In this figure an increment of the spike amplitude for the higher values of Cd as well as certain distortions on the spike waveforms induced from the motional behavior of the piezoelectric load [5] and caused also by the interference of the MOSFET transistor cut-off process, can be clearly appreciated.

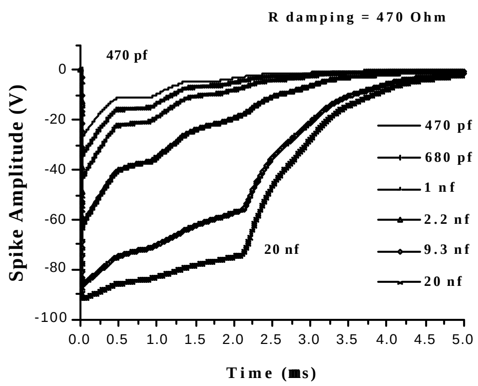


Figure 3.Driving temporal responses for different Cd values and under light damping conditions (Rd = 470 Ohm).

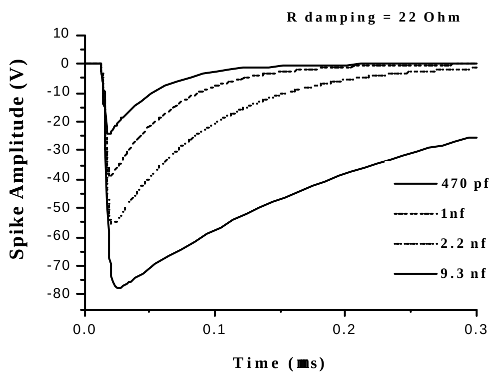
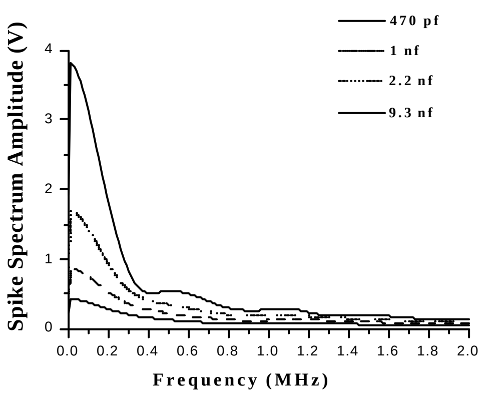


Figure 4. Driving temporal responses for different Cd values and with strong damping conditions (Rd = 22 Ohm).

The distortions due to the motional influence of the piezoelectric load, are more clearly shown for Cd values lower than 2.2 nf. Additionally the influence of the MOSFET transistor cut-off process on the spike waveform is better appreciated for the two higher values of Cd.

The Figure 4 shows the simulated spike temporal waveforms for different values of the energy - discharge parameter, considering a strong damping setting (Rd = 22 Ohm). As in Figure 3, the spike amplitude is increased for higher values of Cd. Nevertheless in this case the distortion on the spike waveforms cannot be observed. This may be due to the influence of the low value of the damping resistor with a strong shortening effect on the rise time of the spike waveforms. In this case, the previously mentioned distortions (with Rd = 470 Ohm) caused by the piezoelectric load and the MOSFET transistor cut-off process, are not present during the spike rise time.

The spike frequency spectra amplitudes, simulated for different values of the energy-discharge parameter Cd and considering light (Rd = 470 Ohm) and strong (Rd = 22 Ohm) damping conditions, are presented in Figures 5 and 6. In Figure 5 an important increment of the spectrum amplitudes for higher values of the analyzed parameter Cd can be appreciated, but this mainly happens for the low frequency range, which impairs the pulse performance of the spike in a broad-band context.



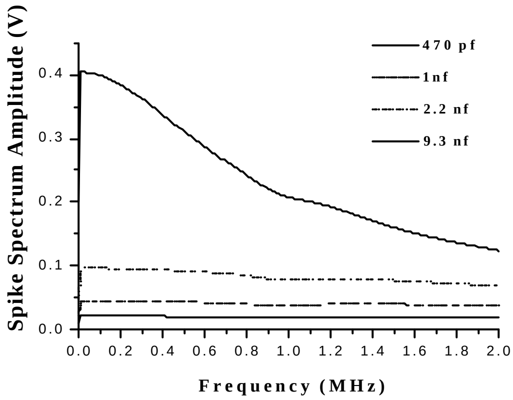


Figure 5. Spike frequency spectra amplitudes for different values of Cd and light damping conditions (Rd = 470 Ohm). Figure

6. Spike frequency spectra amplitudes for different values of Cd and strong damping conditions (Rd = 22 Ohm)

On the other hand, for a strong damping setting (Rd = 22 Ohm) and for Cd values lower than 9.3 nf, the spike spectrum amplitudes are nearly constant in the frequency range analyzed, as appears represented in the Figure 6.

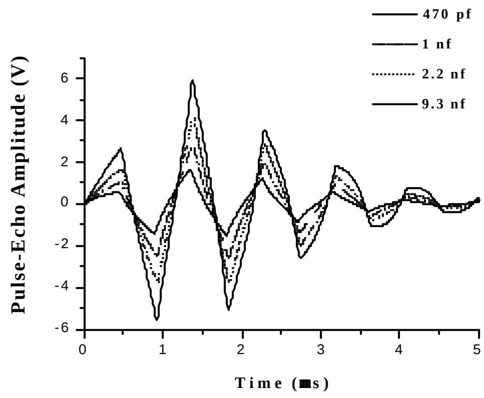
<u>Pulse-echo waveforms</u>

The influence of the pulser energy-discharge parameter on the pulse-echo amplitudes, in the time and frequency domains, including light and strong pulser damping conditions was also simulated.

Figure 7 shows the pulse-echo waveforms for a light damping effect (Rd = 470 Ohm) and several values of the energy-discharge parameter (Cd). In this case, a successive increment of the amplitudes as well as a change in the waveforms can be observed for the respective Cd selected values.

The spike frequency spectrum amplitudes, corresponding to the previous cases of Figure 7, are presented in Figure 8. For this pulser setting, the combined effect of a light damping and the analyzed discharge parameter values, produces bigger spectrum amplitudes for bigger Cd values, but improvements in bandwidths are not clearly observed. For 9.3 nf a low-frequency enhancement appears around 200 Khz.

A parametric analysis of the effect of the Cd component included in the ultrasonic emission stage, was performed considering the same two former damping resistors (22 Ohm and 470 Ohm). The influence of these pulser settings on a spike characteristic magnitude as the rise time, was evaluated. Figure 9 shows the spike rise time as a function of selected Cd values considering two pulser-damping cases. In strong damping conditions (Rd = 22 Ohm), a lineal increment in the spike rise-time for higher discharge parameter values is observed. Although also exists a spike rise-time increment in the light damping case, it is only restricted to Cd values lower than 9.3 nf and present a non-linear behavior. The diminishing of the spike rise time in the last parametric range simulated (10-20 nf), may be originated by the interference of the MOSFET transistor cut-off process, being this in agreement with the time-domain results observed in Figure 3.



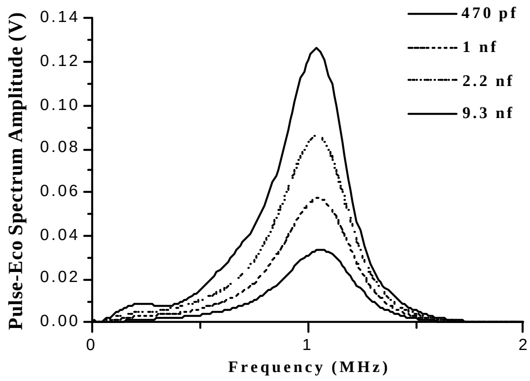


Figure 7. Pulse-Echo temporal responses for different Cd values and light damping conditions (Rd = 470 Ohm).

Figure 8. Pulse-Echo frequency spectrum amplitudes for different Cd values and light damping conditions (Rd = 470 Ohm)

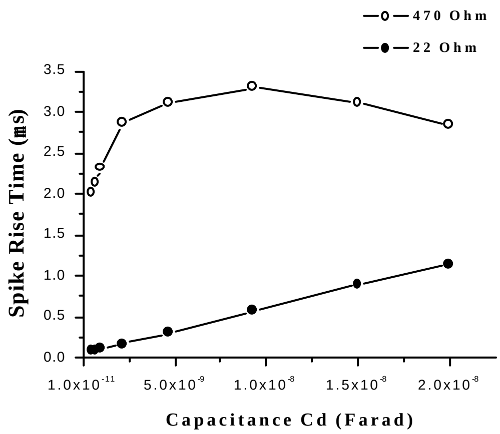


Figure 9. Behavior of the Spike Rise-Time as a function of the parameter Cd and for two different damping conditions: - light pulser damping, ● - strong pulser damping

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