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Low Cost Matching Network for Ultrasonic Transducers

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Abstract

This paper investigates low cost matching network for high impedance ultrasonic transducers. Matching the output transmitter impedance to high impedance transducer is important to maximize the transfer of power and improve the transmitting efficiency of the transducer, and so achieve better signal-to-noise ratio.
In NDT ultrasonic applications based on piezoelectric transducers it is usual to introduce a tuned inductor, normally fitted in an experimental way, in order to cancel out the reactive component of the impedance of the transducer. More elaborated tuning solutions are well known, but in systems employing several transducers, such as arrays, is not feasible to connect all the transducer elements via a transformer or a complex network to their transmitters. Therefore, when the number of components is critical, if the system works in a narrow frequency range, this paper proposes to employ a simple L-C matching network with only one inductor and one capacitor. This topology is evaluated, by means of equivalent circuit analysis, computer simulation, and experimental assessment.

Keywords: impedance; matching network; non-destructive testing; ultrasonic transducer

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1. Introduction

Matching transmitter impedances to high impedance transducer is very important in ultrasound systems with poor signal-to-noise ratio (SNR) 00. The high ultrasonic transducer excitation voltage permits the improvement of SNR, but it is also often needed a matching circuit that maximizes the power delivered to the transducer and transforms it in acoustic waves, because in other case the most of this power will be wasted. Matching networks becomes much less important when using lower impedance transducers because the losses are not so great.

Usually NDE ultrasonic applications based on piezoelectric devices include some tuning circuit at the pulser output. A common procedure is to introduce an inductance in parallel or serial. The objective of this inductor is to compensate the capacitive effect of the transducer. This compensation is available only at a single frequency, which

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for many applications is enough. Nevertheless, only the imaginary part of the impedance is thus compensated and not the real part. This will be a problem when high impedance transducers are employed with low impedance excitation circuits, because the power transfer will be thus far to its maximum. Therefore this work proposes a matching network composed by two reactive components that compensates and matches both imaginary part and real part of the impedance of the transducer 0.

2. Matching network description

Two reactive elements are placed between the transducer and the pulser circuit, in order to maximize the power transfer. To design the matching network, the impedance of the transducer must be known. The first step to be able to describe the matching network is to approximate the ultrasonic transducer by some electrical model.

Around the resonance frequency, an ultrasonic transducer can be described using the Butterworth-Van-Dyke (BVD) model 0. Fig.1 shows this model, where C_o is the equivalent capacitance, R_s represents the radiation and mechanical losses, and L_s and C_s model the resonant performance of the transducer 0. Assuming that mechanical losses are relatively small, the power supplied to R_s can be considered as the acoustic power emitted.

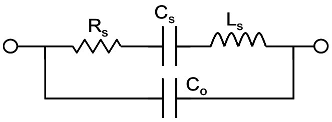


Fig.1 Electrical Butterworth-Van-Dyke model around resonance frequency.

The impedance of transducer can be expressed according to the model parameters and the frequency as given by (1), where ω_s and ω_p are the series and parallel resonance frequencies, respectively:

$$Z_s(\omega) = \frac{1}{\omega C_o} \frac{\left(\omega_s^2 - \omega^2\right) + j\frac{R_s}{L_s}\omega}{-\frac{R_s}{L_s}\omega + j\left(\omega_p^2 - \omega^2\right)} \qquad \omega_s^2 = \frac{1}{L_s C_s} \qquad \omega_p^2 = \frac{C_s + C_o}{L_s C_s C_o} \tag{1}$$

At the series resonance the transducer can be simplified to R_s in parallel with C_o or its equivalent series. Fig.2 shows the connection of excitation pulser to a transducer through a matching network, where v_g is an ideal source, $R_g + jX_g$ represents the output impedance of the source, $R_t + jX_t$ models the transducer impedance at series resonance, and X_1 and X_2 are the components of the matching network. And Z_i is the impedance of the load seen by the source.

Next step is obtaining the equation for X_1 and X_2. The criteria employed will be to maximize the power supplied by the excitation circuit to R_s. The efficiency is optimal when the generator impedance is the complex conjugate of the load 0.

$$R_g = \mathbb{R}\mathrm{e}(Z_i) \quad ; \quad X_g = -\mathbb{I}\mathrm{m}(Z_i) \tag{2}$$

Satisfying this condition (2) the equations for X_1 and X_2 0 are:

$$X_1 = QR_t + X_t \quad ; \quad X_2 = \frac{-\left(R_g^2 - X_g^2\right)}{QR_g + X_g}$$

$$where, \qquad Q = \pm\sqrt{\frac{R_g\left[1+\left(\frac{X_g}{R_g}\right)^2\right]}{R_t}}. \tag{3}$$

Equation (3) can be simplified if the output excitation impedance is assumed to be purely resistive, and considering that the impedance of the transducer is significantly higher than the impedance of the excitation circuit. In this case matching network is a LC network. The configuration can be low pass filter or high-pass filter, both made correctly the matching function. Here, low-pass filter solution is presented because it is preferred to avoid that in nonlinear systems, the transducer may be excited by any harmonic in the driving source. With these considerations the equivalent circuit is shown in Fig.3, and the equations (3) can be expressed as (4).

$$\begin{aligned} L_m &= \frac{R_g}{\omega}\sqrt{\frac{R_s}{R_g}-1} \\ C_m &= \frac{1}{\omega R_s}\sqrt{\frac{R_s}{R_g}-1} - C_o \end{aligned} \tag{4}$$

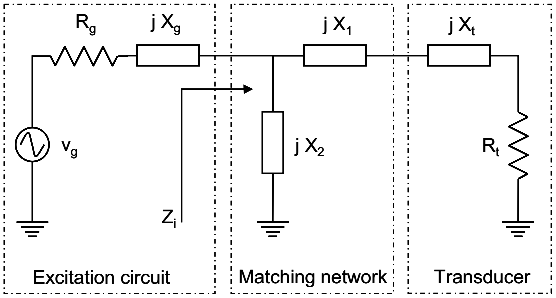


Fig.2 Equivalent circuit at series resonance.

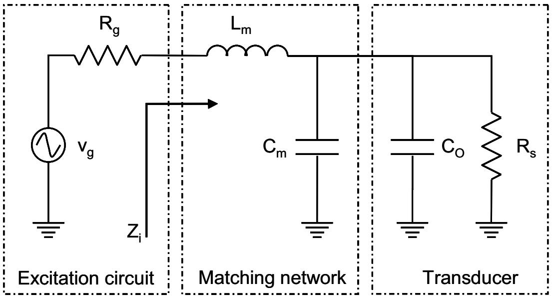


Fig.3 Simplified equivalent circuit at series resonance.

3. Results

To evaluate the improvement in the performance of the transducers using this matching network, first a computer simulation has been done.

The matching network proposed has been also experimentally tested with two different types of transducers: a piezoelectric air coupled ultrasonic transducer with an active surface area of 15 mm^2 and the resonance frequency at 800 kHz that it is used for Lamb wave generation 0 and a shear wave transducer (100 kHz, Panametrics) used in the ultrasound rheology of some food products 0.

For air coupled ultrasonic transducer, the BVD model parameters, measured with Agilent 4294A Precision Impedance Analyzer, are: R_s=1.8 kΩ, L_s=1.6 mH, C_s=26 pF, C_o=65 pF. And using equations (4) the values obtained for LC matching network are: L_m=58.8 μH, C_m=588 pF. And for shear wave transducer the model parameters are: R_s=1.5 kΩ, L_s=8.6 mH, C_s=278 pF, C_o=692 pF and the obtained values for the components of the LC matching network are C_m=5 nF and L_m=430 μH. The excitation impedance is assumed to be 50 Ω.

3.1. Simulation

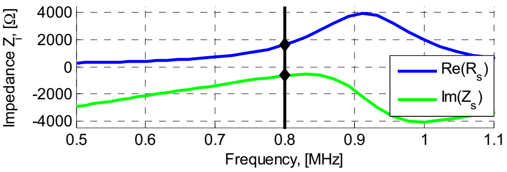
3.1.1. Air coupled ultrasonic transducer

The circuit of Fig.3, with all elements of the BVD model for the transducer, was simulated using SPICE program. The simulations presented correspond to air coupled ultrasonic transducer.

The real and imaginary part of the simulated input impedance Z_i of the transducer is shown in Fig.4 a). The resulting input impedance for Z_i with matching network is also presented in Fig.4 b). In both figures the impedance at working frequency are marked. It should be noted that using matching network the imaginary part is compensated and the real part is matched to 50 Ω, equal to the excitation circuit impedance.

Fig.5 shows the simulated acoustic power emitted for circuit with LC matching network and without matching. As can be seen, the power emitted by the matched transducer at the desired frequency (marked by a point) is more than 9 times higher than the observed for the transducer without matching network.

a) Impedance Z_i without matching network



b) Impedance Z_i with matching network

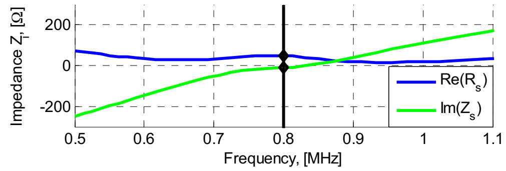


Fig.4 Simulated impedance Z_i.

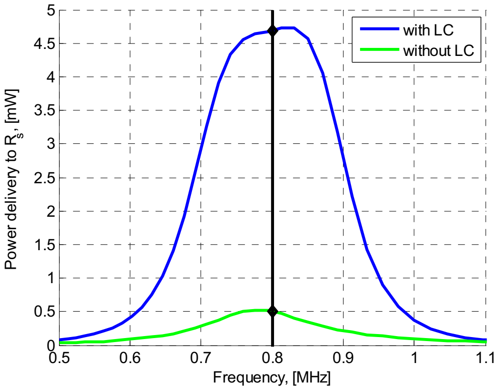


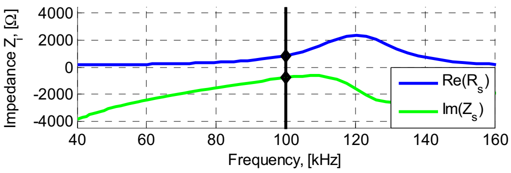
Fig.5 Simulated acoustic power emitted.

3.1.2. Shear wave transducer

Equivalent simulations have been done for shear wave transducers with similar results. Fig.6 shows input impedance Z_i of the transducer with and without matching network where it can be seen how the matching network transforms the impedance into a resistance of ~50 Ω.

Fig.7 shows the acoustic power emitted, with and without LC matching. Also in this case, the power emitted by the matched transducer is almost 9 times higher than the obtained for the transducer without matching network.

a) Impedance Z_i without matching network



b) Impedance Z_i with matching network

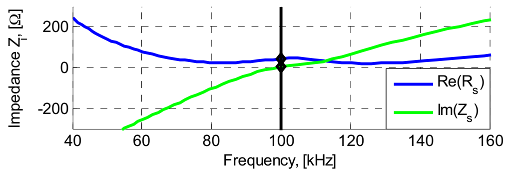


Fig.6 Simulated impedance Z_i.

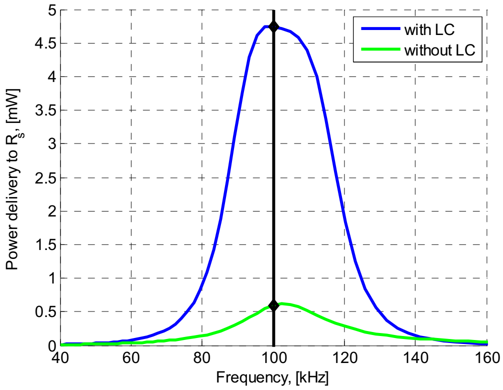


Fig.7 Simulated acoustic power emitted.

3.2. Experimental assessments

3.2.1. Air coupled ultrasonic transducer

The Fig.8 shows the experimental setup implemented to characterize the air coupled ultrasonic transducer response when a LC matching network is used. The commercial values of the matching network components are C_m=560 pF and L_m=56 μH. The transducer is driven by a pulser circuit that generates a square burst signal 0 of 15 cycles, 800 kHz, and 30 V peak to peak. The ultrasonic field is measured by a hydrophone at a distance of 1.7 cm and amplified by 57 dB. The amplified signal is recorded and displayed with a Tektronix TDS 2024B oscilloscope. This measurement was performed two times: with and without the matching network. The signals captured by the oscilloscope in both cases are shown in Fig.9.

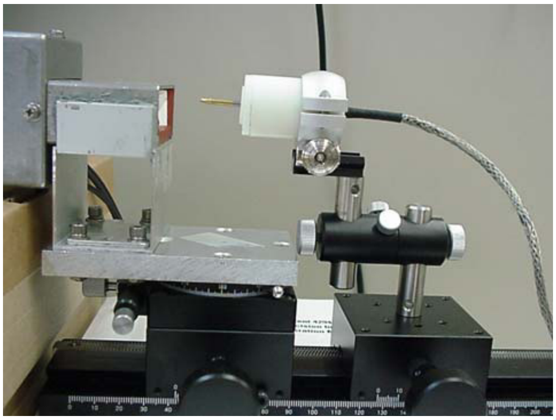


Fig.8 Setup used to measure the emitted signal by the piezoelectric transducer.

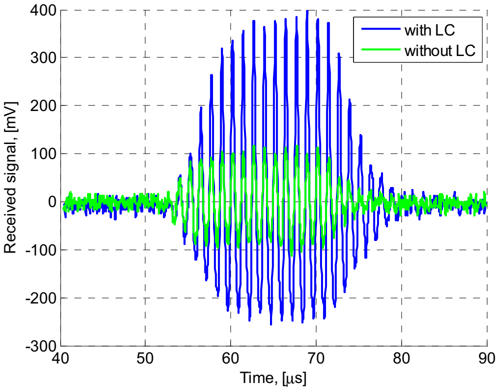


Fig.9 Signal received by hydrophone using matching network and without matching.

It can be seen an improvement of almost 300% in the amplitude of the received signal of the matched transducer with respect to the measured with the unmatched transducer. This agrees with the simulated results shown in previous section, where has been shown an improvement of the power of 900%.

3.2.2. Shear wave transducer

The same network topology has been used to improve the performance of the shear wave transducers. The commercial values of the matching network components are C_m=4.7 nF and L_m=470 µH. Emitter and receiver were joined together using a coupling gel, the emitter was excited with a sine continuous signal of 10 V peak to peak and the signal given by the receiver was measured with a digital oscilloscope. Then, a second measurement inserting the network was carried out. The obtained signals in both cases are shown in Fig.10. As can be seen, a significant improvement of almost 300% in the amplitude of the received signal can be attained.

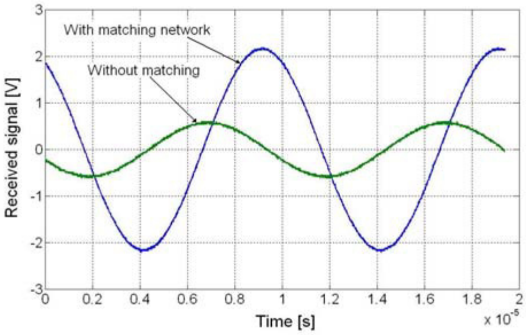


Fig.10 Signal given by the receiver transducer using matching network and without matching.

4. Conclusion

In this work, it has been shown how the initial performance of a high impedance ultrasonic transducer can be improved by means of a simple matching network with only one inductor and one capacitor. The topology has been evaluated by simulation models and experimental measurements with two different type of transducers. Both simulations and experimental results show an excellent agreement. The proposed LC matching network allows matching both real and imaginary part of the transducer impedance, and thus the power is delivered efficiently to R_s and higher levels of signal-to-noise ratio can be achieved. Moreover, the increase in the efficiency of the measurement system that can be attained with the application of a matching network could lead to stronger received signals and thus to obtain better accuracy in the measurements.

Aknowledgements

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References

[1] A. Ramos, J. L. San Emeterio, and P. T. Sanz, "Improvement in transient piezoelectric responses of NDE transceivers using selective damping and tuning networks," Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on, vol. 47, pp. 826-835, 2000.

[2] J. L. S. Emeterio, A. Ramos, P. T. Sanz, and A. Ruiz, "Evaluation of Impedance Matching Schemes for Pulse-Echo Ultrasonic Piezoelectric Transducers," Ferroelectrics, vol. 273, pp. 297-302, 2002.

[3] G. Petersen. “L-matching the output of a RITEC gated amplifier to an arbitrary load”. RITEC Inc., USA. 2006

[4] S. Sherrit, H.D. Wiederick, B.K. Mukherjee and M. Sayer, “An accurate equivalent circuit for the unloaded piezoelectric vibrator in the thickness mode”, Journal of Physic D: Appl. Phys. Vol 30 (1997), pp. 2354–2363.

[5] Y. Yañez, M. J. Garcia-Hernandez, J. Salazar, A. Turo, and J. A. Chavez, "Designing amplifiers with very low output noise for high impedance piezoelectric transducers," NDT & E International, vol. 38, pp. 491-496, 2005.

[6] S. C. Cripps, “Advanced techniques in RF power amplifier design.” Boston: Artech House, 2002.

[7] F. Montero de Espinosa, J.A. Chavez, Y. Yañez, J. Salazar, A. Turo, F.J. Chinchurreta, M.J. Garcia-Hernandez, “Air-Coupled piezoelectric array transducers for NDT applications”, 16th World Conference on Non-destructive Testing, August 30 – September 3, 2004.

[8] J. García-Álvarez, M. Gómez, A. Turó, J.A. Chávez, M.J. García, J. Salazar. “Acquisition of ultrasound signals for flour products testing.” Proceedings of the International Congress on Acoustics ICA 2007 Madrid, Spain.

[9] Y. Yañez, M. Garcia-Rodriguez, M. J. Garcia-Hernandez, J. Salazar, A. Turo, and J. A. Chavez, "Lamb wave generation with an air-coupled piezoelectric concave array using square-wave burst excitation," NDT & E International, vol. 41, pp. 292-299, 2008.