Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 70 (2015) 578 – 581

Physics Procedia

2015 International Congress on Ultrasonics, 2015 ICU Metz

Investigation of pulser-transducer matching networks for power delivery efficiency of spread spectrum signals

Darius Kybartas[a]*, Alberto Rodriguez[b], Linas Svilainis[a] and Andrius Chaziachmetovas[a]

[a]*Kaunas University of Technology, Department of Electronics Engineering, Studentu 50, LT-51368 Kaunas, Lithuania*
[b]*Department of Communications Engineering, Univesidad Muguel Hernandez, Avda, Universidad S/N, 03203 Elche, Spain*

Abstract

Replacement of a single ultrasonic pulse to the spread spectrum signals allows higher energy without losing the bandwidth and it also means higher requirements for energy delivery to test object. Pulser efficiency for single pulse is not essential comparing to high energy signals. Pulser stress is large if power delivery efficiency to transducer is low. In narrowband case the solution is to use the matching network, but matching circuit effect will be different in case of wideband excitation. Aim of the investigation was to evaluate the matching techniques for spread spectrum signals.

Peer-review under responsibility of the Scientific Committee of ICU 2015

Keywords: ultrasonic equipment; ultrasonic transducer; matching networks; wideband excitation; flowmeter.

1. Introduction

Ultrasonic non-destructive testing and other ultrasonic-based measurements use estimation of time-of-flight of acoustical pulse in specimen. Then it can be converted to physical properties of a tested sample, such as localization of defects, elastic properties or inhomogeneity. Ultrasonic time-of-flight measurements are also widely used as non-contact method for estimation of fluid flow. This method perfectly suits for flow and temperature measurement task in heating systems (Fig.1a). Wide frequency bandwidth is essential to attain measurement accuracy and resolution. Short electrical pulses can be used for excitation, ensuring wide bandwidth, but energy of a single pulse is limited.

* Corresponding author. Tel.: +370-37-300532; fax: +370-37-352998.
E-mail address: darius.kybartas@ktu.lt

Peer-review under responsibility of the Scientific Committee of ICU 2015
doi:10.1016/j.phpro.2015.08.025

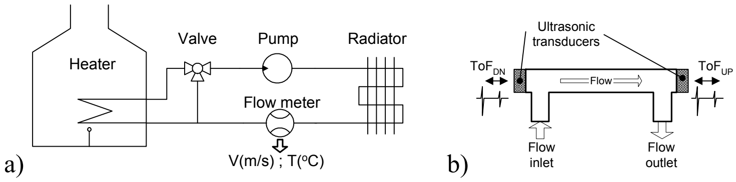

Fig. 1. Flow meter application in heating system (a) and transient flow meter structure (b).

CW tone bursts have high energy but are limited in bandwidth. Energy can be increased without compromising the bandwidth if spread spectrum signals (SS) are used. Svilainis et al. (2012) show that precision can be improved using wideband spread spectrum signals. Transducer limits the bandwidth and the efficiency. Matching networks enhance the transducer response and can be synthesized analytically, e.g., San Emeterio et al. (2002) or using computational optimization as Huang, Paramo (2011). Some authors use transducer equivalent circuit (e.g., An, Zhang (2014)) while others use experimentally measured impedance (e.g., Capineri et al. (1993)). Simulations of the mutual performance of the pulser, matching network, coaxial cable and transducer were used by Ramos et al. (2006). Abovementioned studies did not analyze the matching effect on the final quality of measurements. In this study we suggest to account not only the transducer impedance but also the complex output impedance of the pulser.

2. Investigation techniques

Signal source and load can be analyzed in term of conventional matching and also as efficiency of final measurement result using spread spectrum signals. Power delivery efficiency means ratio of real part of power delivered to load in aspect to real part of total power sent by pulser. Rest of energy is reflected back and it is dissipated on internal resistance of pulser and also in serial and parallel resistances of matching network components. Common criteria of performance can be expressed as transducer power gain (TPG)

$$TPG = \frac{4R_g R_L}{\left(R_g + R_L\right)^2 + \left(X_g + X_L\right)^2}, \tag{1}$$

where R_g, R_L are resistance and X_g, X_L are reactance of pulser (generator) Z_g and load Z_L. Efficiency of matching can be estimated using bandwidth $\Delta BW_{\text{-3dB}}$ of TPG. Effective bandwidth and center frequency f_0 can be obtained using power delivered $P(f)$. Use of mean frequency and total energy E of signal allows calculation of effective bandwidth

$$F_e = \sqrt{\frac{2\int_0^{\infty}(f - f_0)^2 P(f)df}{E} + f_0^2}, f_0 = \frac{2\int_0^{\infty} fP(f)df}{E}. \tag{2}$$

It is used for estimation of lower random error bound σ at known noise power N_0 using Crammer-Rao expression

$$\sigma \geq \frac{1}{2\pi F_e \sqrt{\frac{2E}{N_0}}} \tag{3}$$

Perfect matching of impedances means equal resistances and conjugates reactance of signal source and load: R_g=R_L, X_g=-X_L. Simple circuits such as parallel or serial are used to compensate unmatched imaginary part of impedances (Fig. 2). An L-circuit perfectly matches both real and imaginary parts but it has narrower bandwidth than transformer match. Each circuit has two possible solutions, e.g., Garcia-Rodriguez et al. (2010).

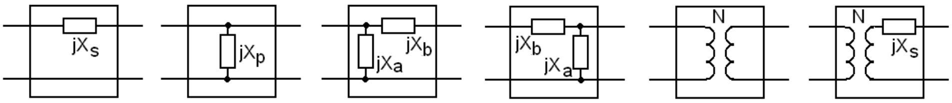

Fig. 2. Matching networks tested (from left to right): serial, parallel, L and reversed L, transformer, transformer with serial compensation.

In our investigation they are marked as L1 and L2. Matching using transformer does not compensate reactance and its lowest frequency is limited due transformer inductance. Serial resistances of winding and parallel inductances of transformer are included in model. Turns ratio for simple transformer was calculated using absolute values of impedance while transformer with serial compensation matches only real parts of Z_g and Z_L.

MATLAB code was developed for calculation and comparison of all matching network performances. Program allows automatic switch from L to reversed L networks according to matching conditions. Searching for best matching over frequency range is performed varying the frequency f_{match} at which reactance is compensated.

3. Results

In many cases transducer and pulser impedances are capacitive (Fig.3). Additional matching circuit is required if transducers are matched to 50 Ω but output impedance of the pulser differs. Matching networks have different performance in terms of TPG and bandwidth. Results for 2 MHz transducer obtained for 50 Ω source show that additional matching network increases energy transfer to transducer (see Fig. 4a) at the price of the reduced bandwidth (Fig. 4b), e.g. resonant circuits such as reactance compensation or L-match reduce the bandwidth. An exception is the transformer which increases the power delivery without losing the bandwidth (Fig. 4b, Fig. 4c).

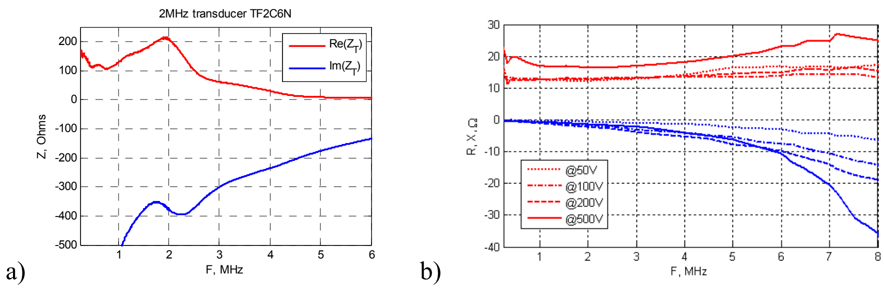

Fig. 3. (a) Input impedance of broadband 2 MHz transducer; (b) output impedance of ultrasonic pulser.

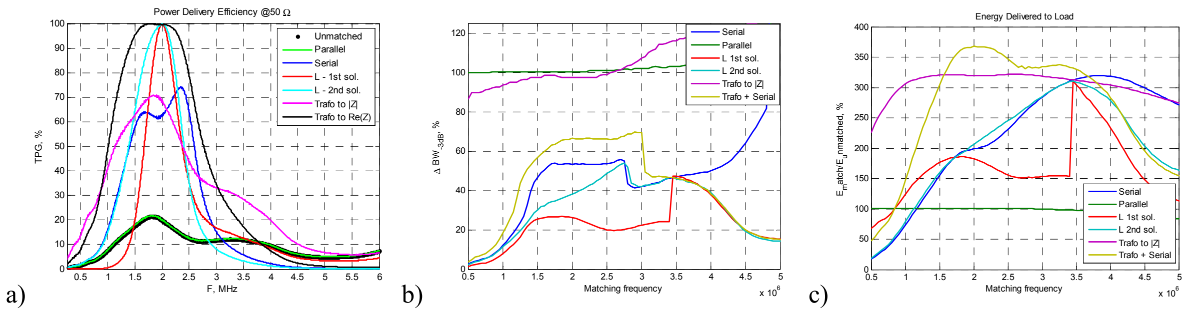

Fig. 4. (a) TPG of broadband 2 MHz transducer using different matching networks; (b) bandwidth with matching networks compared to unmatched transducer, (c) energy delivered to the load with matching networks compared to unmatched transducer.

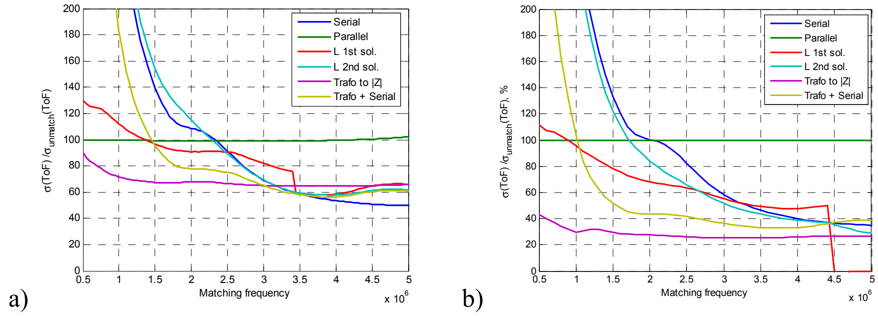

Fig. 5. Lower error bound using matching networks compared to unmatched transducer: (a) 50 Ω source; (b) measured pulser output impedance.

Steps in bandwidth plots are related to the tortuosity of the transfer function. Steps in energy plots are cause by switching between L and reversed-L networks. Matching performance evaluation can be based on Crammer-Rao lower error bound (3) comparison for matched and unmatched transducer (Fig. 5). Random errors decrease (despite the reduced bandwidth) by 30 % if transducer is matched to 50 Ω source and can be suppressed to 50 % or more if transducer is matched to measured pulser impedance despite the lower bandwidth central frequency (2 MHz).

4. Conclusions and discussion

Simple matching circuits can be useful for increasing efficiency of spread spectrum signal in time-of-flight measurements. They are useful when cheap unmatched transducers are used in flow meter with the aim for cost reduction. Final measurement random errors reduction was proposed as an alternative parameter for matching network performance evaluation. Best matching performance was obtained for transformer matching. Further improvement was obtained in some cases when transformer was combined with serial compensation of the transducer reactance. Bandwidth and the accuracy can be improved. More accurate results can be obtained using electro-acoustical transfer function of transducer but for frequencies near resonant proposed method can be applied.

Acknowledgements

This research was funded by a European Social Fund Agency project IN-SMART, grant No. VP1-3.1SMM-10-V-02-012.

References

An J., Zhang S. 2014. A new method of designing electrical impedance matching network for piezoelectric ultrasonic transducer. Journal of Engineering Science and Technology Review. 7(1), 71-75.

Capineri L., Masoti L., Rinieri M., Rocchi S. 1993. Ultrasonic transducers as a black-box: equivalent circuit synthesis and matching network design. IEEE Transaction on Ultrasonics, Ferroelectrics, and Frequency Control. 40(6), 694-702.

Garcia-Rodriguez M., Garcia-Alvarez J., Yanez.Y., Garcia-Hernandez M., Salazar J., Turo A., Chavez J. 2010. Low cost matching network for ultrasonic transducers. Physics Procedia. 3, 1025-1031.

Huang H., Paramo D. 2011. Broadband electrrical impedance matching for piezoelectric ultrasound transducers. IEEE Transaction on Ultrasonics, Ferroelectrics, and Frequency Control. 58(12), 2699-2707.

Ramos A., Ruiz A., San Emeterio J.L., Sanz P.T. 2006. PSpice circuital modelling of ultrasonic imaging transceivers including frequency-dependent acoustic losses and signal distortions in electronic stages. Ultrasonics. 44, 995-1000.

San Emeterio J., Ramos A., Sanz P., Ruiz A. 2002. Evaluation of impedance matching schemes for pulse-echo ultrasonic piezoelectric transducers. Ferroelectrics. 273(1), 297-302.

Svilainis L., Kabisius P., Aleksandrovas A., Chaziachmetovas A. 2012. Excitation signal's influence on ultrasonic transit time flow meter's performance. IOP Conf. Ser.: Mater. Sci. Eng. 42, 012047-1-4.