Noise Investigation of an Active Non-Foster Matching Network for Small Antennas

Christian Stedler, Volker Wienstroer and Rainer Kronberger
High Frequency Laboratory, Cologne University of Applied Sciences, Betzdorfer Str. 2, D 50679 Koeln, Germany

***Abstract* - Matching networks with Non-Foster elements seem to be useful for the matching of small antennas. This paper presents the advantages and disadvantages of such a non-Foster matching network with active elements. Therefore a comparison with a conventional matching network regarding signal performance only and in addition regarding signal-to noise (SNR) performance for automotive application in the FM frequency range is made. In contrast to other publications a severe SNR disadvantage of the non-Foster network results.**

***Index Terms* — Small Antennas, Matching, Non-Foster, Negative Impedance Converter.**

I. Introduction

In the past a variety of publications on the subject of antenna matching with negative-impedance converters and non-Foster elements were made. In non-Foster matching networks, impedances violate Foster's theorem, which says that reactance-versus-frequency slope is always positive in LC-networks. Typically, non-Foster matching networks are based on negative capacitors and negative inductors which are realized by active circuit topologies, named negative-impedance converters (NICs)[1]. Indeed, there is a big need of such devices as they theoretically enable a broadband matching of short antennas ([2], [3]). In this context the signal-to-noise ratio (SNR) at the output of the matching network has to be considered carefully. As the NIC matching element consists of active devices (transistors, etc.) additional electronic noise is generated inside, which contributes to the overall system noise and which degrades the SNR of the antenna system. The principle of an active antenna is often applied to small automotive monopole antennas for FM-radio. High requirements regarding antenna performance, noise and linearity are given. Therefore, investigations were made to show whether non-Foster matching networks with NICs can provide further advantages to small monopoles.

II. Non-Foster Matching Network for Small Antennas

To evaluate and compare the performance of a NIC-matched antenna a short monopole (25 cm) was used. As the length of the monopole is small compared to the wavelength the impedance is highly capacitive (ca. 5 pF) with a small resistive part of approximately 4 – 5 Ohm representing the radiation resistance and losses. To compensate the inapplicable impedance of the monopole a negative series capacitor of –5 pF, realized by means of a NIC-circuit and a conventional parallel capacitor was used. The realized NIC-circuit for the non-Foster elements is a Linville Open Circuit Stable (OCS) structure [4] and was created by means of two low noise transistors BFP760 from Infineon. The simulations were performed in such a way, that the antenna impedance was taken as source impedance and a matching network was connected behind with a load impedance of 50 Ohm. The forward transfer function S21 in Fig. 1 shows the matching performance of the network at the output to the load. As expected, the NIC-network provides a very good matching to 50 Ohms over the entire FM-radio frequency range 87.5 – 108 MHz (red curve) and it is close to the network with the ideal non-Foster element (black curve). By using a conventional matching network, with a bandwidth optimized series inductor and a parallel resonance circuit the blue curve could be achieved. An overall mismatch of 5 – 12 dB results over the entire FM-band which is not satisfactory for practical application. But compared to the unmatched case (Fig. 1, green line) it seems to be that a significant improvement could be achieved by using a NIC as non-Foster element with – 5pF in the matching network of a short monopole antenna. So far, similar results were published by other authors ([5]), who confirmed the advantage of such elements.

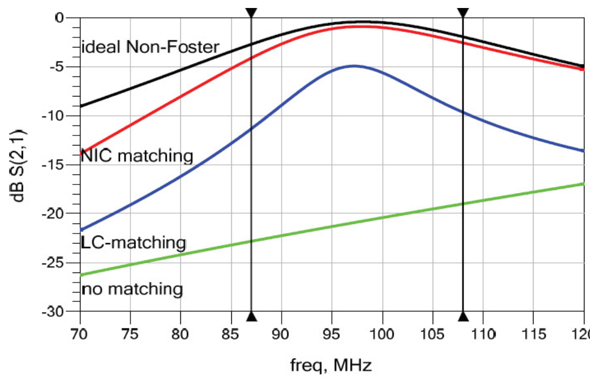

Fig. 1. Forward transfer function respectively matching losses of the three different networks related to a load impedance of 50 Ohm.

III. Noise Simulations

As the NIC-circuit is an active circuit, consisting of at least two transistors, noise considerations have to be made in the same way as they have to be performed with any other active antenna system. The result has to be compared to the conventional passive system and represents then the effective SNR advantage or disadvantage of the whole antenna system. Therefore noise simulations were performed with the above given circuits. The noise voltage at the output port of each matching network was calculated with ADS (noise power density (NsPwrRefBW). With active antennas for automotive applications the output noise should not exceed -5 dBµV (@120 kHz) on a 50 Ohm load impedance. The results of such simulations are displayed in Fig. 2. Now a severe difference between the ideal non-Foster element and

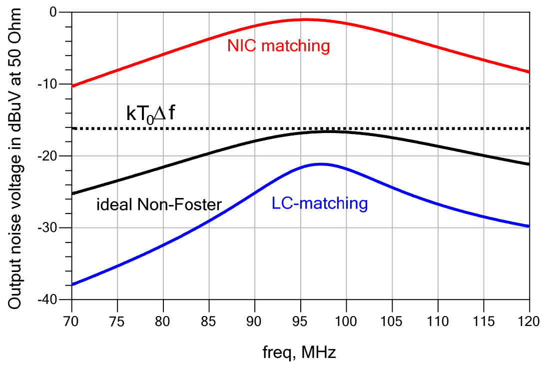

Fig. 2. Calculated output noise voltage (ref. to 120 kHz) for the three different matching networks.

the network with the active NIC matching network (red line) can be seen. This is compared to the minimum noise power at T_0. The ideal non-Foster element and the ideal LC-network provide noise voltages below this level due to mismatch losses. Surprisingly, the output noise voltage of the NIC matching network is far above the ideal noise level. This means, that the NIC matching network significantly provides electronic noise from the inner circuit to the load impedance. To prove this behavior the noise parameters of the NIC circuit were determined. The minimum noise figure F_{min} is 0.14 dB, the optimum source impedance results as $\underline{Z}_{opt}$ = (277 - j1946) Ohm and the equivalent noise resistor is R_N = 227 Ohm (all values calculated for 95 MHz). Out of the noise parameters constant input noise curves (similar to noise circles in the Smith-Diagram) for the NIC-element can be calculated (see Fig. 3). It can be seen that the antenna impedance totally lies beside the 10 dB noise curve. Thus a noise figure of higher than 10 dB would result from the NIC matching circuit already. So far no other active elements or amplifiers are considered here. Main problem for this high

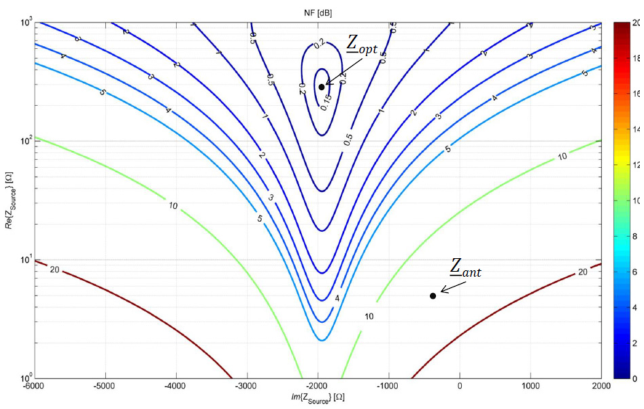

Fig. 3. NIC noise curves at 95 MHz and monopol impedance $\underline{Z}_{Ant}$

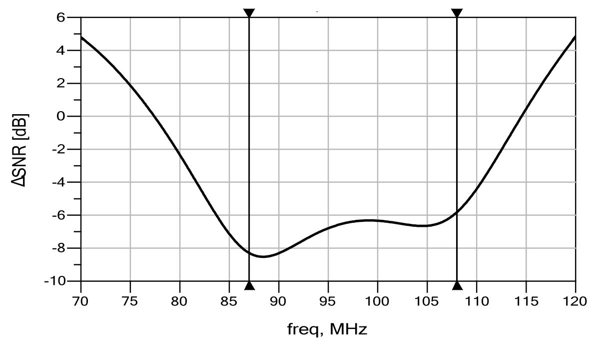

Fig. 4. SNR degradation of the NIC circuit versus the conventional system (NIC is followed by an LNA NF 1dB)

noise seems to be the high value of the real part of the optimum noise impedance of the NIC. The imaginary part of $\underline{Z}_{opt}$ is not so far away from the antenna impedance $\underline{Z}_{Ant}$ however the real part cannot be reached. Therefore, a NIC-circuit as matching element for short active car antennas would degrade the overall SNR performance, compared to a conventional active antenna system. This is displayed in Fig. 4. A disadvantage of 6 – 8 dB in SNR of the NIC-circuit results in comparison with a conventional active antenna.

IV. Conclusions

In this paper a critical investigation of the usability of negative impedance converters for antenna matching networks was made. As in a variety of other publications before the advantage of non-Foster elements for antenna matching regarding the signal level only seems to be obvious. As those non-Foster elements are realized with transistorized negative impedance converters the noise behavior at the output of the matching network has to be taken into account under all circumstances. Therefore a noise analysis of the NIC-element was made and a system comparison between a NIC-matching network and a conventional active system with short monopole antenna for automotive application was performed. With equal gain of both systems the NIC-system provides a significant higher output noise voltage resulting from its unfavorable noise impedance and provides a severe degradation of the SNR at the output. This shows that for the efficient design of small active antennas with non-Foster matching networks realized with NICs a careful noise investigation has always to be performed.

References

[1] J. G. Linvill, “Transistor Negative-Impedance Converters,“ Proc. IRE, Bd. 41, pp. 725-729, 1953.

[2] S. Sussman-Fort, R. Rudish, “Non-Foster Impedance Matching of Electrically-Small Antennas,“ IEEE Transactions On Antennas And Propagation, Bd. 57, Nr. 8, pp. 2230-2241, August 2009

[3] O. Tade, P. Gardner and P. S. Hall, “Negative Impedance Converters for Broadband Antenna Matching,“ Microwave Conference (EuMC), 2012 42nd European, pp. 613, 616, 29 Oct. 2012.

[4] S. Stefanopoulos and S. Koulouridis, “Realizing Non-Foster circuits for antennas,” Antennas and Propagation Symposiom (AP-S), 2013, pp. 1960-1961, 2013.

[5] Aberle, J.T., "Two-Port Representation of an Antenna With Application to Non-Foster Matching Networks," Antennas and Propagation, IEEE Transactions on , vol.56, no.5, pp.1218,1222, May2008.