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Tunable ferroelectric impedance matching networks and their impact on digital modulation system performance

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ABSTRACT

In this paper the bit error rate performance and error vector magnitude of a tunable impedance matching network is analyzed assuming QPSK, 16-QAM and 64-QAM digital modulation schemes. The characterized tunable impedance matching network is based on barium–strontium–titanate ferroelectric thick-film varactors. Inherent dispersive behavior is subsumed into the forward transmission of the passive device. Due to this nonlinear phase response, in general to maximize the overall system performance, an agile tuning of the varactor values is demonstrated, taking into account the phase and group delay of s_{21} parameter. Detailed signal simulation results based on measured data of a testbed are presented. The influence of varying matched impedances on the tuning behavior with different modulation bandwidths is discussed at a center frequency of 1.9 GHz.

1. Introduction

In practice, the maximum bandwidth efficiency of a determined radio requires perfect transmission paths, matching networks and filters. Furthermore, diverse portable devices are subject to different environmental scenarios, which lead to a change of their input impedance $Z(f, P_{in}, \text{environment})$. Therefore, its performance such as rejection interference and battery life time is decreased. When a device aims for multiservice purposes, agile systems with tunable components can increase the performance in terms of energy consumption and utilize the spectrum in a more efficient way. Thus, matching networks with tunable components could be used to balance this mismatch of the impedance.

The scope of this work is to show the importance of considering group delay variations, when a tunable matching network fixes the emerging mismatch of the antenna at the receiver side. In this manner, a fundamental enhancement of the same communication system can be achieved by proper adjustment and tuning of those components with the strongest influence on the quality of a signal during its propagation towards the receiver. The signal path represented in Fig. 1 shows a receiver architecture, with RF components such as antenna, matching network, filter, low noise amplifier (LNA), mixer and voltage controlled oscillator (VCO) via IF filter and A/D converter down to the digital baseband.

It is known, that modulation schemes with high spectral efficiency are more vulnerable to system imperfections, arousing other transmission impairments, e.g. intermodulation distortion, echo or crosstalk [1–3]. Hence, in order to clearly show an influence of group delay on the reception side of a reconfigurable frontend, a quadrature amplitude modulation (QAM) scheme with different order has been chosen for evaluation. Among the most important factors dealing with digital phase modulation schemes, group delay variations take an important place regarding bit error rate (BER) degradation and the influence on the error vector magnitude (EVM) [4–7]. Nevertheless, most analyses are performed by considering a response with ideal flat amplitude $|s_{21}| = 1$ for transmission within the available bandwidth at a fixed RF center frequency f_c only.

2. Reconfigurable frontend architecture with tunable impedance matching network

Due to the increase in the demand of services and lack of available spectrum, flexible radios and reconfigurable architectures are required. However, reconfigurable hardware with tunable components, either self-adapted, or controlled by software, still represent a challenge in order to exploit its best performance [8,9].

In many cases when an ideal flatness response of the signal during the transmission of data through a defined signal path is taken

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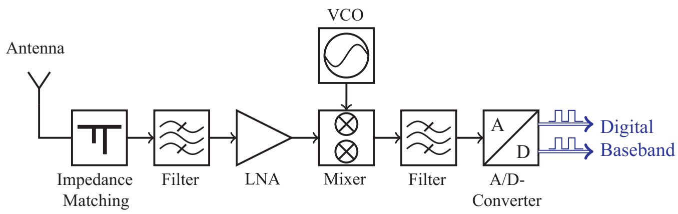

Fig. 1. Receiver architecture of a reconfigurable frontend with different RF components.

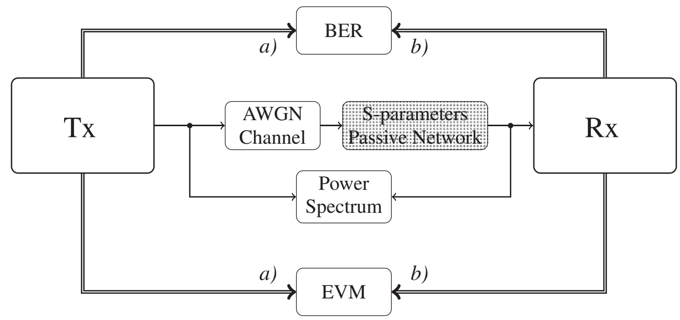

Fig. 2. Communication system testbed with passive matching network under investigation. The chain is modeled in Matlab and Simulink, including deembedded S-parameters measurement of a TMN. Legends: (a) reference signal and (b) recovered signal.

into account, a relation between the BER and EVM can be achieved. In practice, when the BER of the system exceeds defined limits, the given information cannot identify probable sources of signal distortion, and therefore, an EVM analysis is also required [10]. Consequently, more factors have to be taken into account in order to, either, predict the behavior of the system in question, or to provide the most effective performance while the device under test is subject to different conditions. Therefore, to enhance the performance of an adaptive matching by means of agile components within the hardware of a reconfigurable frontend, the complete system can be reconfigured in terms of analog and digital measures.

In the case of the analysis presented in this work, to improve the total efficiency or to recognize the best performance of the antenna according to a defined scenario, different criteria are taken into account:

- S-parameters of RF components at a defined carrier frequency f_c,
- phase linearity of the RF components,
- group delay across overall signal bandwidth,
- RF signal bandwidth,
- SNR level,
- BER level,
- EVM level,
- and defined digital modulation scheme.

Thus, by providing an agile and accurate selection of the varactor values in the tunable impedance matching network (TMN) module, the most suitable system performance for a given scenario can be attained.

3. System design

In the system under investigation, coherent modulation and demodulation of a transmitted QAM signal of the form [11]

$$s_i(t) = \sqrt{\frac{2}{T_s}} g_a(t) \cos 2\pi f_c t + \sqrt{\frac{2}{T_s}} g_b(t) \sin 2\pi f_c t \quad (1)$$

through an additive white Gaussian noise (AWGN) channel is used, where g_a and g_b represent the ith message point at coordinates $a_i\sqrt{\varepsilon}$ and $b_i\sqrt{\varepsilon}$ with energy signal ε. The complete setup is based on a typical digital modulation scheme under the influence of AWGN so that theoretical performance according to [12] can be used for comparison.

3.1. Communication system testbed

Different kinds of testbeds have been developed in recent years by means of simulations, including theoretical models to represent the channel only. They are also used to evaluate new algorithms and robust techniques that may improve the overall performance of a communication system [13–17]. Nevertheless, only little attention has been given to the analysis and evaluation of tunable components that form a reconfigurable RF chain. An individual investigation of these elements is needed to show the impact in the overall system. In this work, the testbed developed in Matlab and Simulink is focused on the analysis of a TMN.

The complete testbed shown in Fig. 2 links Matlab with Simulink to control the proposed designed system by setting up mainly: (a) signal properties of the waveform, such as order modulation scheme, signal bandwidth and determined center carrier frequency, (b) passive network in terms of its reference impedance along with measured S-parameters of the TMN for amplitude, phase linearity and group delay analysis as well as, (c) computation properties for Monte Carlo simulations in terms of the number of bits and errors at a defined SNR level. Thus, a reliable comparison of the figures of merit (FoM) BER and EVM is acquired.

In the aforementioned passive network block, located after the AWGN channel, scattering parameters of the characterized TMN are included as a representation of the receiver chain in the RF domain. Thus, the setup allows to include measured characteristics of an RF signal path and to perform simulations at selected frequencies. Baseband I/Q modulation process, signal power and phase compensation are modeled on the transmitter (Tx) side. The receiver side (Rx) focuses on the demodulation process. Deft handling synchronization of data between discrete reference signal and recovered signal is also carried out to ensure accurate BER and EVM values.

3.2. Modeling of the quadrature modulation

A random signal with uniform distribution is used as a symbol generator. Data is sampled at a time T_{symbol} so that the sampling frequency f_s easily fulfills the Nyquist criteria. Signals with two different RF bandwidths are analyzed, $BW_{RF} = 20$ MHz and $BW_{RF} = 40$ MHz. Modulation and demodulation processes include a QPSK, 16-QAM and 64-QAM baseband schemes with pulse shaping raised cosine filter. It is worth mentioning, that one of the key parts of this setup resides in the passive network module, where S-parameters can be read out at a desired carrier frequency. And thus, signals with different characteristics in terms of bandwidth and modulation scheme, can be efficiently processed to reconfigure the complete system.

4. Tunable impedance matching network based on BST thick-film ferroelectric varactors

In the last years, a variety of materials and processing techniques have been applied to realize agile components. Between the most promising, ferroelectric materials for microwave applications barium–strontium–titanate (BST) thick-film ceramics take a prominent place. Low power consumption, fast tuning and high linearity, i.e. low intermodulation distortions, are one of its main characteristics compared to other technologies [18]. The permittivity of this material can be tuned by applying an external electrostatic field.