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RAPID PROTOTYPING FOR RF-TRANSMITTERS AND RECEIVERS

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ABSTRACT
This paper describes a concept of an RFDP (Radio Frequency Development Platform) for RF-transmitters and RF-receivers. With this platform the time effort for the development process can be reduced and prototypes for different communications standards which are defined at different frequencies can be built faster. Also modifications, e.g. if new analog components are available, can be implemented in short time. A first realization of a transmitter built with off-the-shelf components is shown. The concept for transmitter and receiver uses a double heterodyne principle for the frequency conversion and the therefore essentially double LO (Local Oscillator) is also part of the RFDP and described in concept. The transmitter, receiver and oscillator modules are cascadeable for MIMO (Multiple Input Multiple Output) applications and can be used for closed circuits or via air transmission experiments. The RFDP concept was developed and optimized for a dedicated baseband hardware from ARC Seibersdorf research GmbH [1].

KEY WORDS
Telecommunication Technology, RF-Engineering, MIMO, Prototyping

1 Introduction

Transmission experiments over a real physical channel require an analog radio-front-end. This analog radio-front-end should be very flexible to allow for a multitude of experiments. To allow for meaningful comparison of theory with actual radio transmission experiments the components of the radio-front-end have to perform as good as possible. Linear and nonlinear distortions as well as noise have to be reduced to the minimum technical feasible. In addition to classical communication systems with one transmitter and one receiver transmission experiments with MIMO communication systems with $n_{\mathrm{T}} \times m_{\mathrm{R}}$ transmitters and receivers are of high interest. The primary application of the radio-front-end is in the field of rapid prototyping [2].

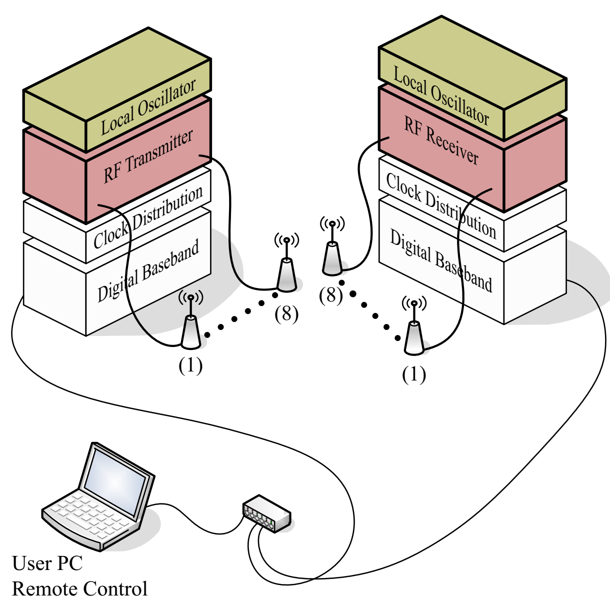


Figure 1. Prototyping system.

Figure 1 gives a schematic overview of the rapid prototyping system which combines RF-transmitters, RF-receivers, local oscillators and digital signal processing units [3]. As implied in the figure with eight antennas on both transmitter and receiver sites, this prototyping system has the capability for MIMO experiments. With this configuration a multitude of SISO (Single Input Single Output) and MIMO transmission experiments and simulations can be performed.

2 The RFDP Concept

The aim of the RFDP is to develop a series of high performance transmitters and receivers at different frequency bands in a flexible way. Each time a new frequency band is discussed for mobile communications one will have difficulties to find suitable and integrated RF components for this new band. To wait until first components are available on market means loss of time. Therefore, we have chosen to use components off-the-shelf wherever it is possible. A component search for different frequency bands has shown that filters are the most critical components at this early stage of development.

2.1 Low IF to RF

Due to our experiences with the Vienna MIMO Testbed [4] we designed our transmitter for an input signal at a low IF and perform the frequency conversion from this IF (Intermediate Frequency) to the desired transmit frequency. Similarly, at the receiver the received signal will be down converted to the same IF at the output. In order to reduce redesign effort because of new or different frequency bands of interest we chose to perform the frequency conversion from the IF in two steps and implemented these two frequency conversion stages on separated PCBs (Printed Circuit Board). In Figure 2 this is illustrated for the transmitter. For the receiver the concept is similar. The lower IF

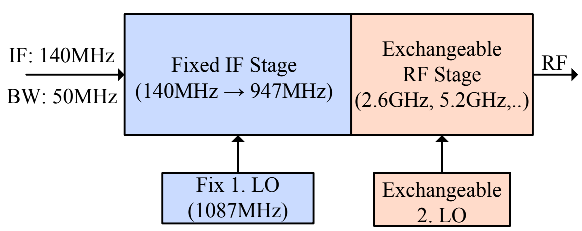
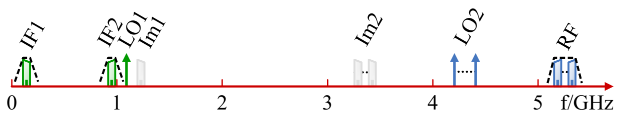


Figure 2. Low IF to RF concept for the RFDP.

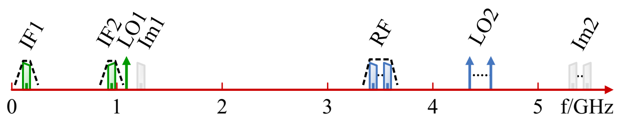
(f_{IF_1}) was set to 140 MHz and the second IF (f_{IF_2}) was chosen at 947.5 MHz. The PCB for the first frequency conversion stage from f_{IF_1} to f_{IF_2} is designed once while the second stage from f_{IF_2} to f_{RF} will be redesigned for different frequency bands. This RF stage is fastened onto the Main-PCB of the first mixing stage. Also the design of the local oscillator for the first frequency upconversion is fixed at a frequency of 1087.5 MHz and the second LO is exchangeable.

2.2 Multi Band Frequency Planning

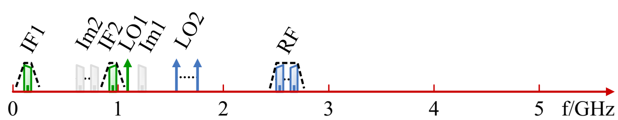
This approach with a fixed IF stage and its exchangeable RF boards for different frequency bands needs a well considered frequency planning. The major difference to a conventional transmission system is given through absence of one dedicated frequency band. The aim of a frequency plan is to avoid undesired sidebands from mixing and mixing artefacts like crosstalk and harmonics falling into the desired IF and RF bands of the radio [5]. In Figures 3(a) to 3(c) such a frequency planning for three frequency bands is shown graphically.



(a) Low IF to 5.2 GHz. f_{LO_2} = 4302.5 MHz, f_{RF} = 5250 MHz



(b) Low IF to 3.5 GHz. f_{LO_2} = 4447.5 MHz, f_{RF} = 3500 MHz



(c) Low IF to 2.6 GHz. f_{LO_2} = 1652.5 MHz, f_{RF} = 2600 MHz

Figure 3. Frequency plan for multiple exchangeable RF stages.

The three frequency bands are 5.15 GHz to 5.35 GHz (WLAN), 3.4 GHz to 3.6 GHz (WiMAX) and 2.5 GHz to 2.7 GHz (WiMAX). For all plans f_{IF_1}, f_{IF_2}, f_{Im_1} and f_{LO_1} are identical due to the fixed first IF stage as explained in the last section. The harmonics of the first LO are at the frequencies 2175 MHz, 3267.5 MHz, 4350 MHz and 5437.5 MHz and outside the desired RF bands. The harmonics of all three different second LOs are at higher frequencies as the according RF band, also the undesired images of the RF bands do not fall into the desired bands.

3 RF Transmitter Units for 2.6 GHz

The Main-PCB, an exchangeable 2.6 GHz RF PCB, an exchangeable 5.2 GHz RF PCB and the Local Oscillators were implemented following the concept as described above.

3.1 Main-PCB

In addition to its main task of the frequency conversion to the second IF this PCB serves as a carrier board for different RF PCBs. The space where the RF stage is mounted on is reserved at the Main-PCB for later direct integration of the RF stage into the carrier board if desired. Figure 4 shows a simplified block diagram of the RF functionality for this Main-PCB. The first component is an SAW (Surface Acoustic Wave) bandpass filter with a 3 dB bandwidth of 56 MHz. This guarantees a bandlimited input signal which is necessary to avoid undesired spectral components. The filter is followed by a variable attenuator which has an attenuation range of 27 dB. A second attenuator can be found at the higher IF at the output of the Main-PCB. Total attenuation range is given by these two attenuators with 54 dB. Note that separation of those attenuators in the frequency domain avoids crosstalk from the attenuators input to the output at high attenuations levels. An amplifier is placed at the input of the following mixer to decouple the circuits and to bring the signal strength to a suitable value for the mixer. After upconversion a ceramic filter with the same bandwidth of 56 MHz as the SAW filter, filters the desired sideband and gives furthermore additional suppression to LO crosstalk, IF crosstalk and LO harmonics. An amplifier brings the output power to -12 dBm.

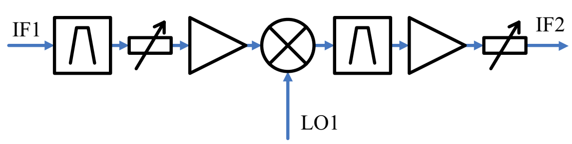


Figure 4. Block diagram of the Main-PCB.

3.2 Exchangeable 2.6 GHz Stage

The RF2600 section performs the second upconversion from the second intermediate frequency f_{IF2} to its final output frequency f_{RF}. The other task is to provide a variable – but precisely leveled – output power. An overview is given in Figure 5.

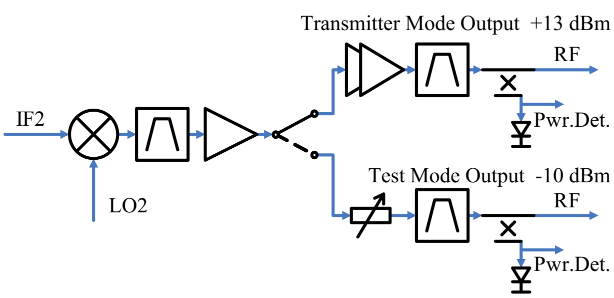


Figure 5. Block diagram of the RF2600 section.

The mixer obtains its input at the second intermediate frequency f_{IF_2} of 947.5 MHz with a nominal bandwidth of 50 MHz. While the center of this input band is fixed, the local oscillator is variable in a 200 MHz range. Accordingly, the output frequency can be chosen in this range minus half the input bandwidth. As mixer a monolithic double balanced type was chosen. The LO input power needed is ranged from -15 dBm to -3 dBm. After the mixer a bandpass filter suppresses the image frequency as well as the various harmonics from IF and LO. Multipole ceramic filters are used for this task. They have a small outline and low insertion loss. To achieve the output power level of -10 dBm for the test mode output there is a buffer amplifier right afterwards. By means of an RF switch one of two outputs can be selected. It consists of several GaAs MESFETs integrated into a single device. An external driving circuit allows for logic input voltage from a micro controller. The upper path in Figure 5 leads to the transmitter mode output. In this path there is a power amplifier. The amplifier can be switched off if the test mode output is selected. Next there is a second bandpass filter. It further increases the suppression of unwanted image frequencies and harmonics. Directly before the output there is a directional coupler which branches off some fraction of the output power. This is measured by a power detector and sampled via a micro controller. The micro controller then controls the variable attenuators on this and the Main-PCB. The output has an impedance of 50 Ω and a maximum power level of +13 dBm. At the other side of the switch there is another voltage variable attenuator. This allows for further variation of the output power of the test mode output. As in the upper branch a second bandpass filter is implemented and the output is again accomplished with a directional coupler and a power detector. It has a maximal output power level of -10 dBm.

3.3 Composed 2.6 GHz Transmitter Card

The smaller 2.6 GHz PCB is fixed onto the Main-PCB and all RF inputs and outputs are connected with semi-rigid cables to a common front panel. In Figure 6 such a composed transmitter card is shown. The Main-PCB is designed to be plugged into a 19” housing where the DC power is distributed via a backplane. Opposite to the front panel the backplane PCB connector can be seen. Only linear regulated analogue power supplies are used.

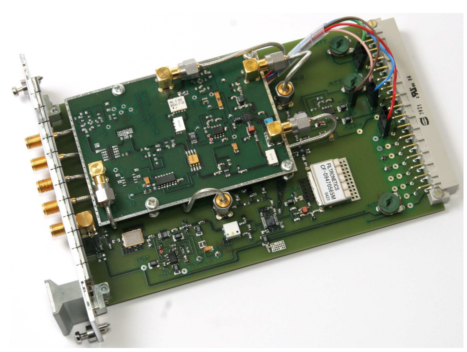


Figure 6. 2.6 GHz single transmitter board.

3.4 Local Oscillator

For each mixer a local oscillator is necessary. One is fixed to 1087.5 MHz as explained before and the second LO can be redesigned for different operating frequencies. Figure 7 shows the basic design for all LOs as synthesizers.

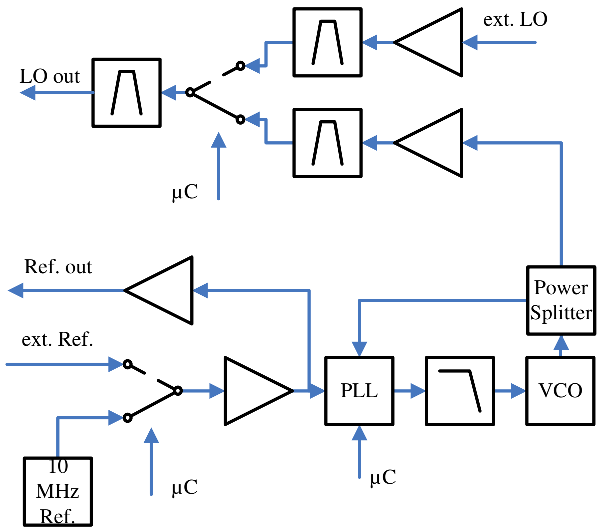


Figure 7. Block diagram of the synthesizer.

For flexibility in frequency step size a fractional N-PLL (Phase Locked Loop) concept was chosen. In comparison to an integer N-PLL where the minimal step size is limited by the reference frequency the fractional N-PLL allows for much smaller frequency steps [6]. As reference source for the PLL an oven controlled crystal oscillator at a frequency of 10 MHz is used. Also an external 10 MHz reference source can be connected to the external reference input. The reference output provides either the internal 10 MHz reference source or the external reference source. The PLL-IC chosen is directly suitable for frequencies in the band of 500 MHz to 4 GHz. Using an additional external frequency divider in the feedback loop the frequency range can be expanded. For the loop filter of the synthesizer a simple passive first order low pass filter was designed. The following voltage controlled oscillator (VCO) is a dedicated device for each LO frequency. With a resistive power splitter the output signal of the VCO is divided into two paths. One for the feedback to the PLL-IC and the second for the LO signal. Next, the LO signal is filtered and amplified to reach the desired power level. At this point also an external LO source can be selected via a switch. All switches and the PLL-IC can be set via a micro controller. For a MIMO scenario as shown in Figure 1, a set of 32 LO signals (2×8 LOs at the transmitter and 2×8 LOs at the receiver) is needed. Therefore eight way power splitters are used to generate multiple LO signal outputs from the synthesizers.

4 Measurement Results

This chapter contains a summary of the measurement results, including a 2.6 GHz transmitter and a 5.2 GHz transmitter as well as a local oscillator.

4.1 2.6 GHz Transmitter

Transmitter cards for 2.6 GHz have been implemented and characterized. The selectable output frequency is in the range of ±100 MHz around the center frequency at 2.6 GHz. Due to the fact that mostly digital modulation schemes are used in wireless communication we do not present traditional power compression and intermodulation measurements. We performed an EVM (Error Vector Magnitude) measurement and used the EVM degradation as quality indicator of the RF transmitter. A vector signal generator as signal source for the transmitter and a vector signal analyzer as a receiver were used for this EVM measurement. A standardized WiMAX signal with a bandwidth of 7 MHz was used. In Figure 8 the received spectrum is shown. In Figure 9 the received signal constellation diagram is shown. For better readability the 16 QAM (Quadrature Amplitude Modulation) signal points were left out in the figure. The 64 QAM, 4 QAM and the 2 PAM (Puls Amplitude Modulation) are shown. Values below 1 % EVM which have been measured, indicate excellent linearity.

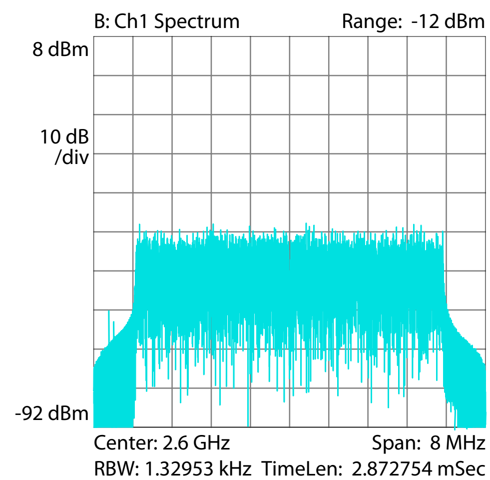


Figure 8. Received WiMAX spectrum at 2.6 GHz.

4.2 5.2 GHz Transmitter

Also a 5.2 GHz RF PCB has been developed and characterized. The selectable output frequency is in the band of 5.15 GHz to 5.35 GHz. For this board a 64 QAM test signal with 10 MSymbol/s was used for the EVM measurement. The measured EVM value in this case is also below 1 %.

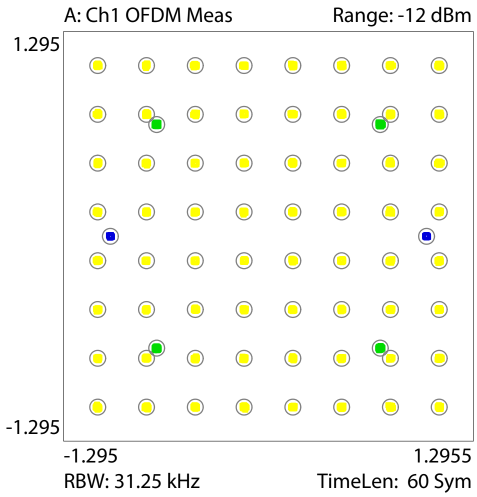


Figure 9. Received signal constellation.

4.3 First LO

For the first LO at 1087.5 GHz its noise floor at offsets from the fundamental frequency of up to ±25 kHz was measured with a spectrum analyzer. The step size of the synthesizer was programmed to 125 kHz. At a distance of 25 kHz the noise was measured as -95 dBc/Hz. Figure 10 shows the spectrum of the synthesizer measured with a spectrum analyzer resolution bandwidth of 100 Hz.

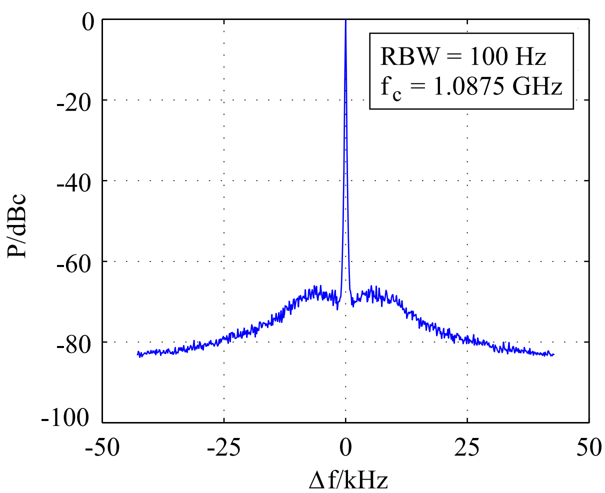


Figure 10. Output spectrum of the fixed LO.

5 Conclusion

In this paper we described a fast way to develop RF transmitters and receivers for different frequency bands. The effort for redesigns was reduced due to our concept which splits the transmitter and the receiver into two PCBs each, a Main-PCB and an exchangeable RF PCB. We showed a frequency planning for three frequency bands for our RFDP and presented measurements of two transmitters, one at 2.6 GHz and the second at 5.2 GHz, and of a local oscillator at a frequency of 1087.5 MHz.

Acknowledgment

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