FLEXIBLE RADIO FREQUENCY HARDWARE FOR A SOFTWARE DEFINABLE CHANNEL EMULATOR

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Abstract

In this paper we describe the development of RF-transmitters, RF-receivers and their essential local oscillators (LOs) and present their measured performance. First we describe the potentials of the combination of the programmable channel emulator called SmartSim [1][2] from ARC Seibersdorf research GmbH [3] with the RF hardware developed. This combination leads to a powerful platform which can be used for a multitude of different tasks like measurements and simulations as well as in the field of development and prototyping. Furthermore the concepts of the RF-transmitter, the RF-receiver and of the local oscillators are explained in detail. As an example, measurement results are presented of a 2,6GHz transmitter and its first LO at a frequency of 1087,5MHz.

Keywords
Radio Frequency, Software Definable Radio, MIMO

1. Introduction

The demand on higher data rates grows rapidly, also in the field of wireless communications. Researchers are working on new ideas in theory as well as in practice to satisfy this demand. Some results are new digital modulation schemes, new channel models or new transmission techniques. The way from a perfect simulation result to a measurement often is impractical due to the lack of available RF hardware, in particular for MIMO (Multiple Input Multiple Output) transmission techniques with multiple transmitters and receivers. In Figure 1 a possible setup for an 8×8 MIMO environment is shown. With this arrangement of a powerful base band processing unit and the RF front end, RF transmission experiments as well as base band simulations are possible with the same equipment. An overview about requirements

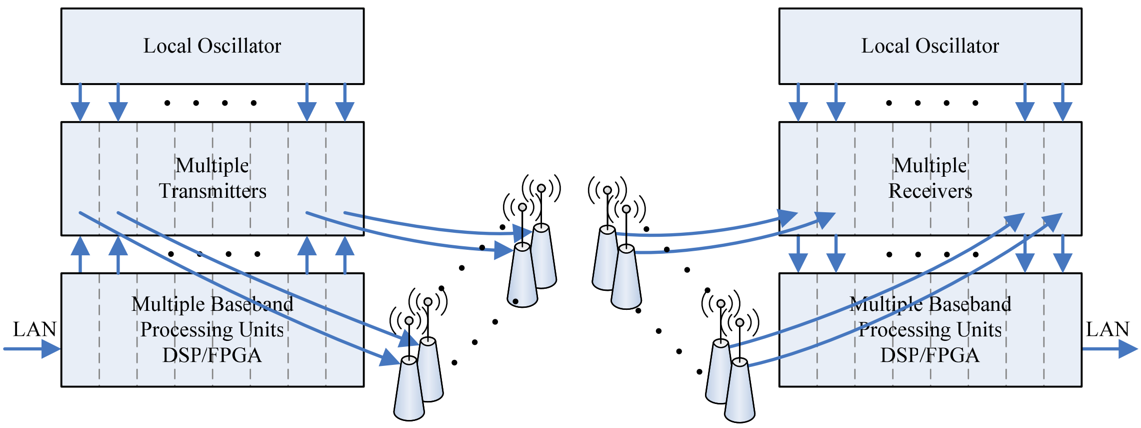

Fig. 1. 8×8 MIMO setup.

and challenges for MIMO platforms is given in [4]. In following we focus on the RF hardware with a low IF (Intermediate Frequency) to RF concept and a double heterodyne frequency conversion at the transmitter side and also the receiver side. This concept is based on a first low IF at 140MHz. This IF signal with a maximum bandwidth of 50MHz can be generated by any signal source at the transmitter and accordingly can by received by any suitable receiver. In our case this will be – on both sides – the digital base band units from the channel emulator SmartSim. Each RF board is connected to its own base band processing unit and each of the base band units is equipped with the same DSP (Digital Signal Processor) and FPGA (Field Programmable Gate Array). Also the DACs (Digital to Analog Converters) and the ADCs (Analog to Digital Converters) are part of the base band units.

2. RF-Transmitter

Based on the experience with the RF front end of the Vienna MIMO-Testbed [5] we decided to perform the frequency conversion in two steps. The transmitter as well as the receiver is separated into two PCBs (Printed Circuit Boards). At the transmitter the low IF to second IF conversion takes place on the Main-PCB. The final frequency conversion to the transmit frequency is implemented on a smaller RF-PCB mounted on the Main-PCB. This constellation allows for the development of different RF-PCBs for different frequency bands suitable for one Main-PCB in parallel. In Figure 2 this is illustrated for the transmitter. As shown in the figure there are several inputs for the LOs, the low IF signal and two RF outputs called transmitter mode and test mode. This outputs differ in maximum output power (+13dBm for the transmitter mode and −10dBm for the test mode) and the available attenuation range (54dB for the transmitter mode and 81dB for the test mode). Power adjustment is obtained by voltage controlled

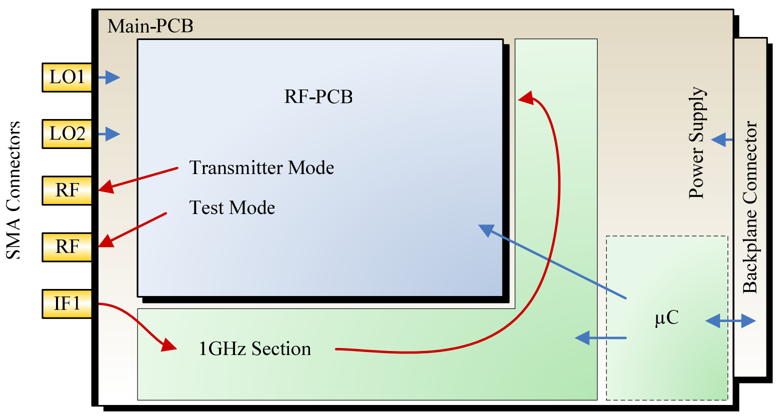

Fig. 2. Single transmitter board with exchangeable RF-PCB.

attenuators in the transmitter chain which can be adjusted via a serial interface and an onboard controller. All RF inputs and outputs have 50Ω impedance and standard SMA (Sub Miniature version A) connectors. A block diagram of the transmitter with its two frequency conversion stages and its two outputs is given in Figure 3. At the input (IF1) the first element is a high quality band pass filter at 140MHz with a 3dB

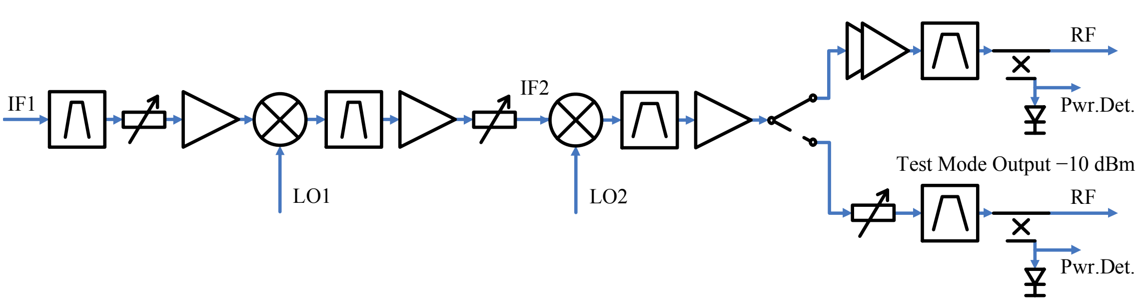

Fig. 3. Block diagram of the transmitter.

bandwidth of 56MHz. This filter protects the following stages from undesired signal components which are generated by the DAC. Then one of the programmable attenuators and an amplifier follow. After the first mixer a second band pass filter attenuates the undesired side band and the crosstalk from LO1 by 50dB. An amplifier and the second programmable attenuator are placed in front of the second frequency conversion. The output of the second mixer is filtered and amplified before it is switched either to the power amplifier in the upper branch of Figure 3 or to the third attenuator in the lower branch of Figure 3.

In both branches the signal is filtered again and the output power is measured. The measured power level can be read out via the serial interface of the onboard controller.

3. RF-Receiver

The concept for the RF-receiver is similar to the transmitter concept. An exchangeable RF-PCB contains an LNA (Low Noise Amplifier) section and the first frequency conversion stage and the Main-PCB contains all other functional blocks. Figure 4 shows a block diagram of the receiver. At the input of the receiver the signal is filtered and amplified before the first frequency conversion takes place. Before and after the second mixer stage the received signal is filtered and amplified again. Additionally, in the

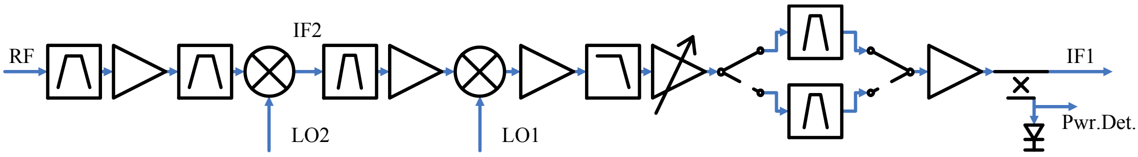

Fig. 4. Block diagram of the receiver.

140MHz IF stage the system bandwidth can be selected as 50MHz or 24MHz. At the IF1 output the power is measured. This allows in combination with a VGA (Variable Gain Amplifier) the adjustment of the output power to an optimum with respect to a following ADC. Bandwidth selection and VGA adjustment is controlled via a serial interface and an onboard controller. The nominal noise figure is 5dB which is compliant with for example 3G UMTS and WiMAX. The system stays linear up to a input level of −10dBm which allows for direct connection to the test mode output. The absolute maximum rating is +13dBm which is the power level of the transmitter mode output.

4. Local Oscillator

Each transmitter board and each receiver board needs two LO signals for the mixing process. For a system as shown in Figure 1, altogether 4 LOs with 8 output ports each are required. The LOs were implemented as frequency synthesizers. For flexibility in frequency step size a fractional-N PLL (Phase Locked Loop) concept was chosen [6]. 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 and programmable step sizes [7] with the same reference frequency. If a new RF-PCB for a new frequency band is developed, only the second synthesizer has to be adapted. Figure 5 shows a block diagram of such a synthesizer. An 8-way splitter provides the desired LO outputs. It is also possible to use an external RF source with

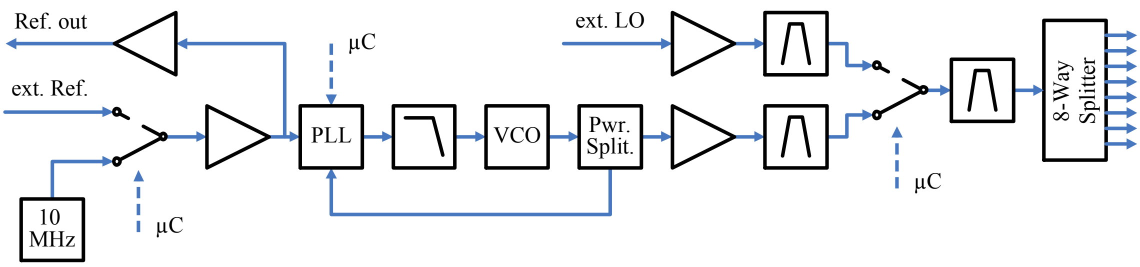

Fig. 5. Synthesizer block diagram.

moderate power instead of the internal synthesizer and utilize the built in amplifier and power splitter to generate the eight LO outputs. As reference source for the PLL a 10MHz oven controlled crystal oscillator is used. With the external 10MHz reference input and the external 10MHz reference output synchronisation to measurement devices or other LO units can be realised. The PLL-IC we use is the ADF4153 from Analog Devices. With this chip, synthesizers up to a frequency of 4GHz can be directly implemented as shown in Figure 5. For frequencies above 4GHz an additional divider is used in the loop from the VCO back to the PLL-IC. Programming and controlling of the synthesizers is done by an external micro-controller and a three wire interface. To minimize noise the power supply of the synthesizer units is a linear regulated one without switching converters. Each synthesizer is mounted into a shielding box and two synthesizers – LO1 and LO2 – are assembled into one 19" housing.

5. Measurement Results

As mentioned in the previous sections the RF front end can be adapted for different frequency bands by changing the respective RF-PCB. In this chapter we show representative measurement results of an implemented transmitter board at 2,6GHz and of its LO1 synthesizer at 1087,5MHz.

5.1 Transmitter

Transmitter boards for 2,6GHz have been implemented and characterized. The selectable output frequency is in the range of ±100MHz around the centre frequency at 2,6GHz. Figure 6 shows a 19" housing with four slots with transmitter cards inserted and four free slots. A linear regulated power supply (without switching converters) finds also place in the housing. A four port network analyzer and an additional frequency source were used in Figure 6 for a scalar mixer measurement. In Figure 7 a composed frequency response is shown for the whole output frequency range of 200MHz. The blue curve

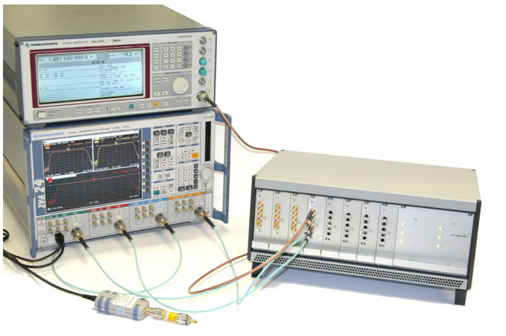

Fig. 6. Characterisation of a 2,6GHz transmitter.

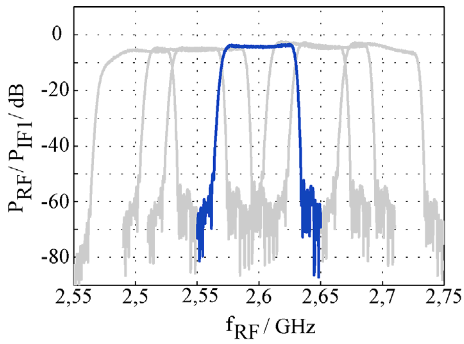

Fig. 7. Composed frequency response.

represents a single measurement in the middle of the transmit band while the light grey curves are shifted in transmit frequency to visualise the characteristic of the available transmit band. In Table 1 the typical gain values G and their maximum variations Δ in the desired measurement band for different

	BW = 20MHz		BW = 40MHz		BW = 50MHz	
f /MHz	G/dB	Δ/dB	G/dB	Δ/dB	G/dB	Δ/dB
2470 - 2570	−6,1	0,7	−6,1	0,9	−6,1	0,9
2490 - 2590	−5,8	0,4	−5,7	0,6	−5,7	0,7
2510 - 2610	−5,3	0,6	−5,3	0,6	−5,3	0,6
2530 - 2630	−5,1	0,9	−5,1	1,1	−5,0	1,2
2550 - 2650	−4,8	0,3	−4,7	0,6	−4,7	0,7
2570 - 2670	−4,3	0,9	−4,4	1,2	−4,4	1,3
2590 - 2690	−4,7	1,5	−4,6	2,0	−4,6	2,2
2610 - 2710	−4,9	0,7	−4,8	1,2	−4,7	1,5
2630 - 2730	−4,6	0,8	−4,7	1,2	−4,7	1,8

Table 1. Gain and flatness at different frequencies and bandwidths.

measurement bandwidths and different transmit frequencies are listed. This measurement was performed at the test mode output at its nominal −10dBm output power. To prove usability for modern digital modulation schemes a vector signal generator as signal source for the transmitter and a vector signal analyzer as a receiver were used for an EVM (Error Vector Magnitude) measurement. As signal a standardized WiMAX signal with a bandwidth of 7MHz has been chosen. The EVM degradation is used as quality indicator of the RF transmitter. Values of lower than 1% EVM have been measured.

5.2. Synthesizers

Synthesizers are implemented for the 2,6GHz system at both LO frequencies f_{LO1} = 1087,5MHz and f_{LO2} = 1652,5MHz. For LO2 the programmed step size is 125kHz and the tuning range is ±100MHz. Figure 8 shows the developed PCB of the LO1 synthesizer. At the upper left corner of the PCB the output connector can be seen. At the upper right corner the external LO input is located. Beneath the external LO input a filtered Sub-D connector is placed which is used for power supply and as programming and controlling interface. A phase noise measurement at 1087,5MHz for this synthesizer is shown in Figure 9. The noise floor is below −80dBc between 100Hz and 10kHz. Some discrete spurs come up to −65dBc. These spurs are inside the bandwidth of the loop filter.

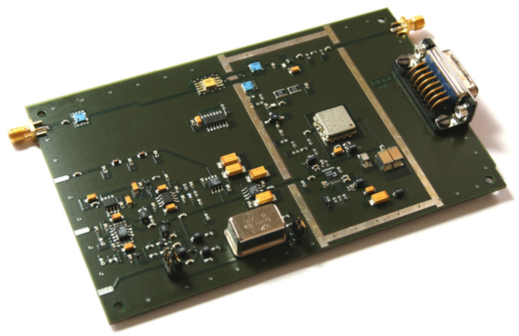

Fig. 8. LO1 synthesizer board.

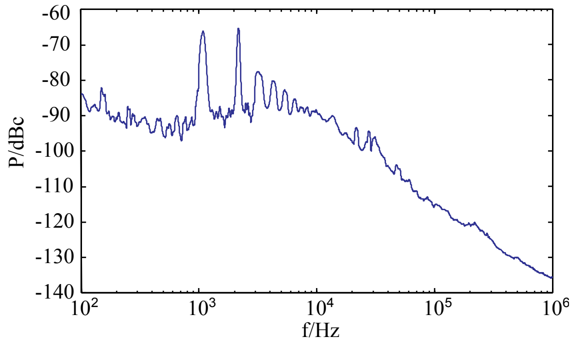

Fig. 9. Phase noise measurement of the LO1 synthesizer.

6. Summary

The combination of a programmable channel emulator with RF equipment leads to a highly flexible instrument. With this instrument simulations can be performed as well as RF transmission experiments for verification. Some of the developed RF modules – transmitters, receivers and local oscillators – for such a software definable channel emulator with MIMO capability were shown in detail. For the transmitter and the first LO we have also presented measurement results. For all realisations off the shelf components have been used.

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