Application Report

MIMO Transceiver with AFE76xx for LTE and 5G Wireless Radio

TEXAS INSTRUMENTS

Ebenezer Dwobeng

ABSTRACT

In this application report, the implementation and performance of a radio transceiver suitable for multiple-input multiple-output (MIMO) wireless communications will be presented. AFE76xx is the main device used for the transceiver design. This device integrates 4 analog-to-digital converters (ADCs), 4 digital-to-analog converters (DACs) and a phase-locked loop (PLL) for sampling clock generation. The main advantage of this MIMO transceiver implementation is the high level of integration, which makes it easier to expand to larger antenna arrays via synchronization of multiple AFE76xx devices. Also the direct RF-sampling based data converters eliminate common analog impairments in radio transceiver design such as local oscillator (LO) leakage and sideband image.

Table of Contents

1 Introduction....2
2 System Overview....4
3 Constellation....8
4 Error Vector Magnitude (EVM)....9
5 Conclusion....10
6 Revision History....10

List of Figures

Figure 1-1. Single-User MIMO in LTE TM4....2
Figure 1-2. Multi-User MIMO in LTE TM5....2
Figure 1-3. Small Cell Network....3
Figure 2-1. Block Diagram of 2x2 MIMO Transceiver....4
Figure 2-2. Transmitter Data Path in AFE76xx....5
Figure 2-3. Receiver Data Path in AFE76xx....6
Figure 2-4. VSA Demodulation Settings for 5-MHz LTE 2x2 MIMO Waveform....7
Figure 2-5. Constellation, Spectrum, EVM vs Carrier Frequency and Error Summary Results After Demodulation....8
Figure 3-1. Received Constellation of 5-MHz LTE 2x2 MU-MIMO Test Pattern....9
Figure 4-1. RMS EVM vs Carrier Frequency for 1 OFDM Symbol....10

List of Tables

Table 2-1. Transceiver System Design Parameters....4
Table 3-1. EVM Performance....8

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

MIMO in wireless communications is a technique that enables the transmission and reception of multiple independent data streams. This helps to increase the maximum data rate at which communications can occur reliably. Some applications of MIMO are described in the following sections.

1.1 MIMO in LTE

In release 12 of the LTE standard, 10 different transmission modes (TM) are specified for the downlink. Among the transmission modes, MIMO is used in TM4 and TM5. TM4 or single user MIMO (SU-MIMO) can support up to 4 antennas to transmit data to the same user equipment (UE) with up to 4 receive antennas. This is shown in Figure 1-1 for the 2x2 SU-MIMO configuration. In TM5 or multi-user MIMO (MU-MIMO), up to 4 antennas can also be supported but the main difference to TM4 is that the data is transmitted to multiple single antenna UE. This is shown in Figure 1-2 for the 2x2 MU-MIMO configuration.

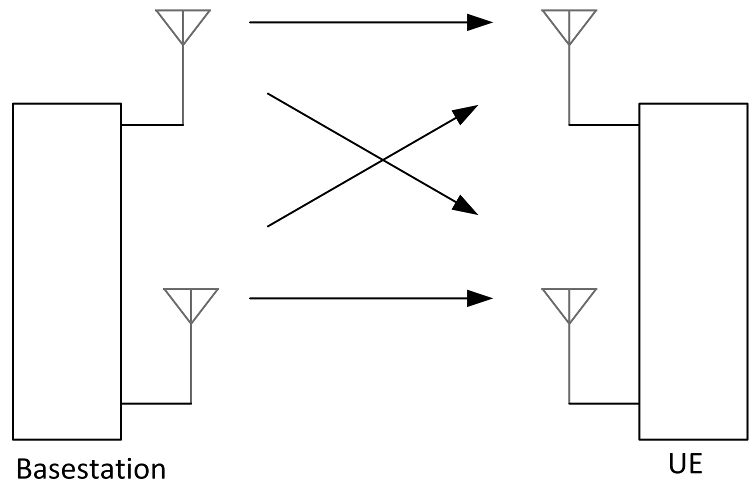

Figure 1-1. Single-User MIMO in LTE TM4

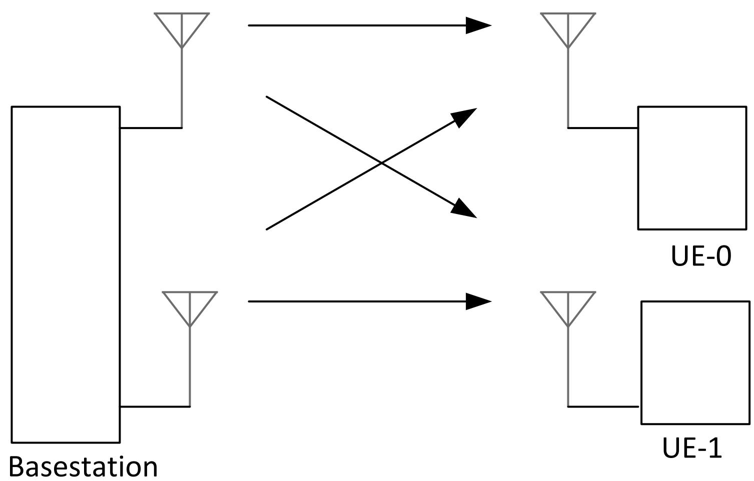

Figure 1-2. Multi-User MIMO in LTE TM5

1.2 MIMO in 5G

In 5G, the requirement for 1000x increase in data rate over existing 4G standards requires large transmission bandwidth which is only available at millimeter wave frequencies (> 24 GHz), but a key challenge with mmWave communications is the high channel attenuation. To counteract this, large antenna arrays are used to boost the antenna gain. This technique, known as Massive MIMO is an integral technology for successful 5G deployment.

1.3 MIMO in Wireless Backhaul

Mobile users at the cell edge of a basestation can experience poor coverage mostly due to interference from neighboring cells. In this scenario, small cells can be deployed to bring the basestation closer to the user and increase coverage. This is shown in Figure 1-3. Small cells are also deployed in areas where there is a large concentration of users to boost the network capacity. Also, with emerging technologies like IoT, more devices will be coming online requiring an increase in the network capacity through the deployment of dense small cell networks. A key challenge with dense deployment of small cells is ensuring effective backhaul communication amongst the small cells and between the small cell and the basestation. To achieve this, wireless backhaul is preferred over using fiber or cable for the backhaul because of the large number of cells involved. MIMO is used in wireless backhaul to increase data rate and also simultaneously communicate with multiple small cells without interference.

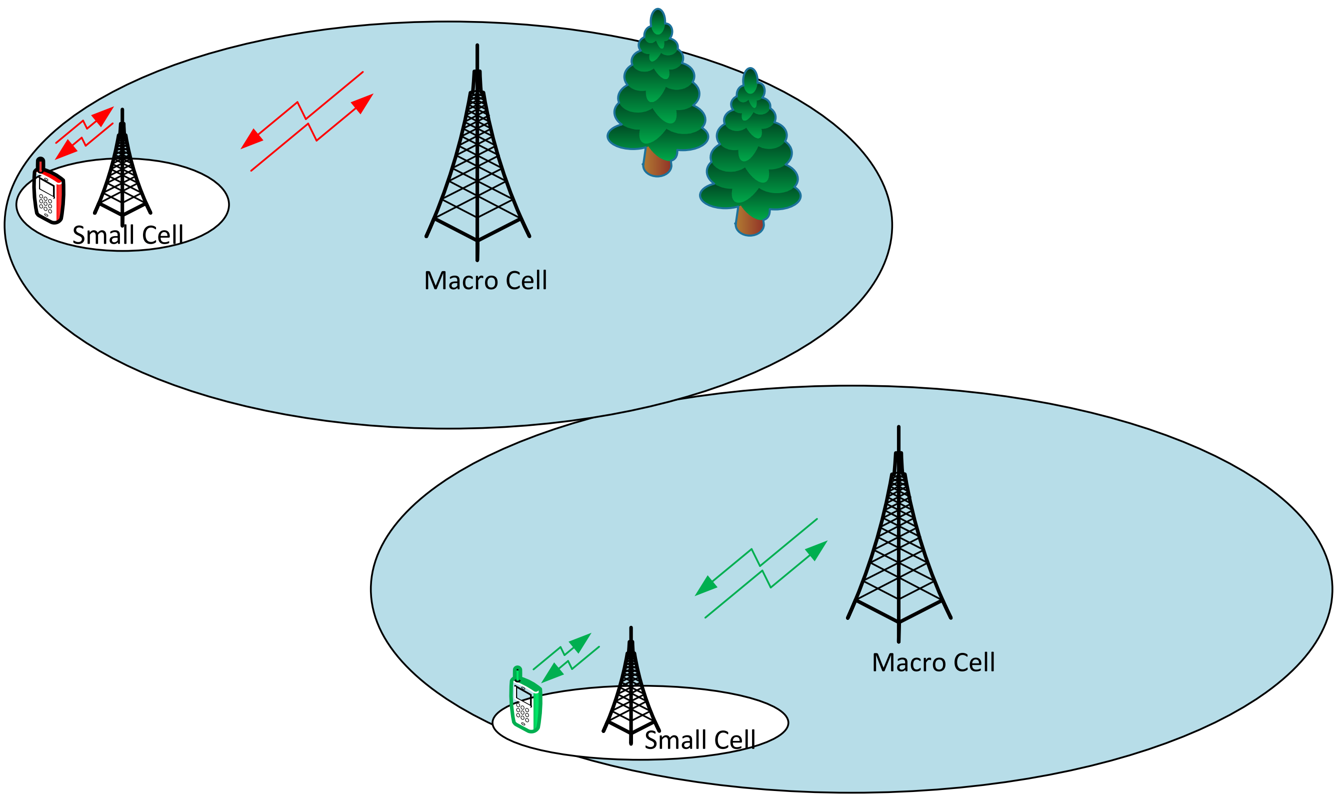

Figure 1-3. Small Cell Network

2 System Overview

2.1 Block Diagram

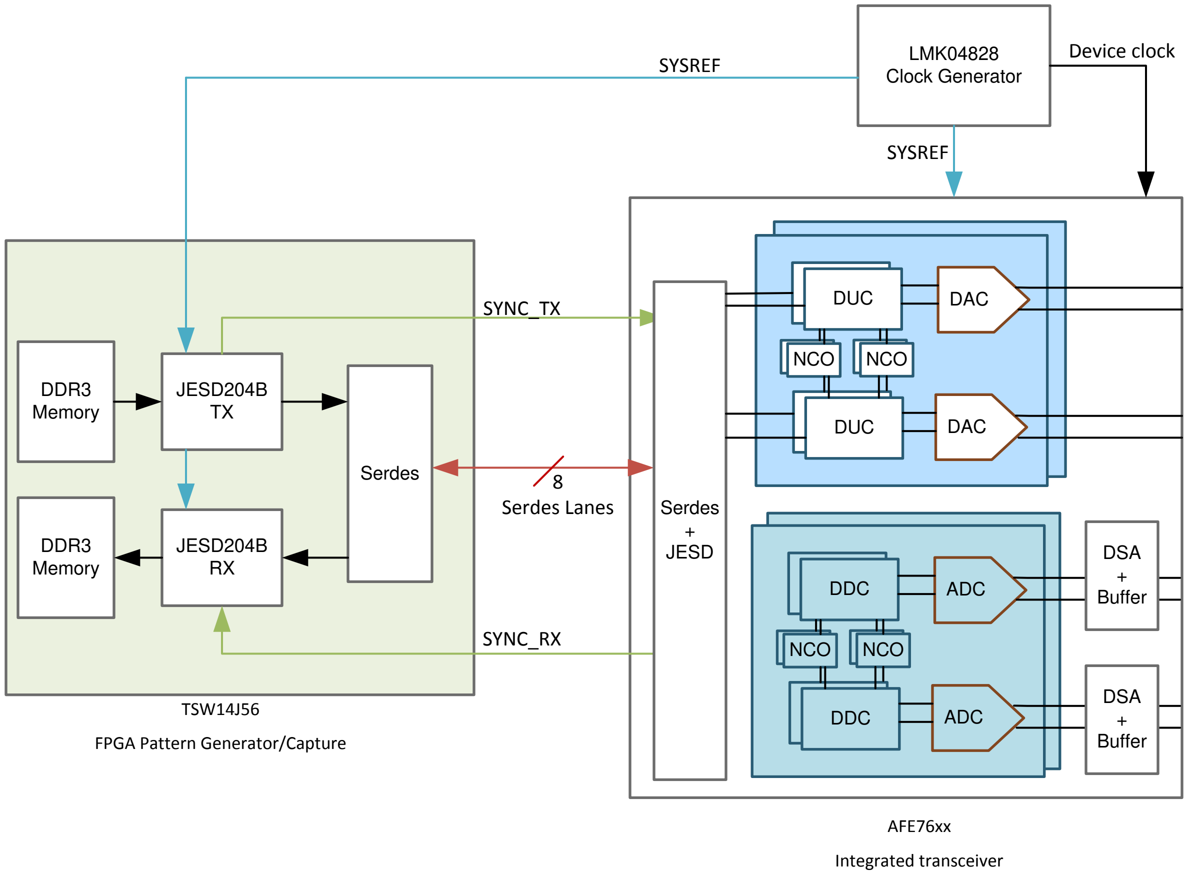

Figure 2-1. Block Diagram of 2x2 MIMO Transceiver

2.2 Design Parameters

Table 2-1. Transceiver System Design Parameters

Function	Parameter	Value
Transmit	Data Rate (MHz)	491.52
	Number of Antennas	2
	Bandwidth (MHz)	>200
	Sampling Rate (MHz)	8847.36
	RF Frequency (GHz)	1.84
	IF Frequency (MHz)	0
Receive	Data Rate (MHz)	491.52
	Number of Antennas	2
	Bandwidth (MHz)	>200
	Sampling Rate (MHz)	2949.12
	RF Frequency (GHz)	1.84
	IF Frequency (MHz)	20

2.3 Hardware Setup

The hardware used to test the transceiver performance consists of TSW14J56EVM (used for data generation to the transmitter and data capture from the receiver) and AFE76xxEVM (used to implement the 2x2 MIMO transceiver). Two equal length coax cables are used to connect the outputs of the transmitter to the input of the receiver through a bandpass filter with a center frequency at 1.84 GHz. The transmitter NCO frequency is set to 1.84 GHz and the receiver NCO frequency is set to 1.82 GHz which results in a 20-MHz IF frequency at the receiver.

2.4 Software Setup

The software used consists of HSDCPRO (used to communicate between PC and TSW14J56EVM for data transfer), AFE76xxEVM GUI (used for configuring the AFE76xxEVM) and Keysight Vector Signal Analyzer (used for creating and analyzing the MIMO test pattern).

2.5 MIMO Test Pattern Generation

The performance of the MIMO transceiver is tested by using a 2x2 MU-MIMO, 5-MHz LTE downlink signal with direct paths only (no cross channel paths). The signal was recorded using Keysight Vector Signal Analyzer (VSA) v 12.0 software and conforms to v8.9.0 (December 2009) of 3GPP LTE standard (TS 36.211).

The recorded file, which has a data rate of 7.68 MHz is interpolated by 64x to 491.52 MHz (the data rate of the MIMO transmitter in Table 2-1) after exporting to Matlab. Also, the interpolated data is converted to 16-bits resolution to match the resolution of the MIMO transmitter.

2.6 Transmitter

After interpolation and 16-bits quantization in Matlab, the test pattern is loaded into the external DDR memory of TSW14J56EVM using the HSDCPRO software. The TSW14J56EVM transmits the data to the AFE76xxEVM over JESD204B interface as shown in Figure 2-1.

Inside the AFE76xx device, the data is processed further with the digital up-converter block (DUC). The DUC filters and up-samples the data by 18x to increase the data rate to 8847.36 MHz. The data clock is generated by the integrated PLL and VCO in this design but can be sourced externally as well. After interpolation, the DUC mixes the data with a carrier generated from the numerically controlled oscillators (NCO). In this design, the frequency of the carrier is set to 1.8 GHz but it can also be set to any frequency between 0 to Nyquist frequency. It is worth noting that there are no sideband images or carrier frequency feedthrough because the mixing is all done in the digital domain.

After the digital processing in the DUC, the data is converted to analog waveform with a DAC running at a sampling rate of 8.847 GHz. Shown in Figure 2-2 is the data path of the transmitter in AFE76xx device.

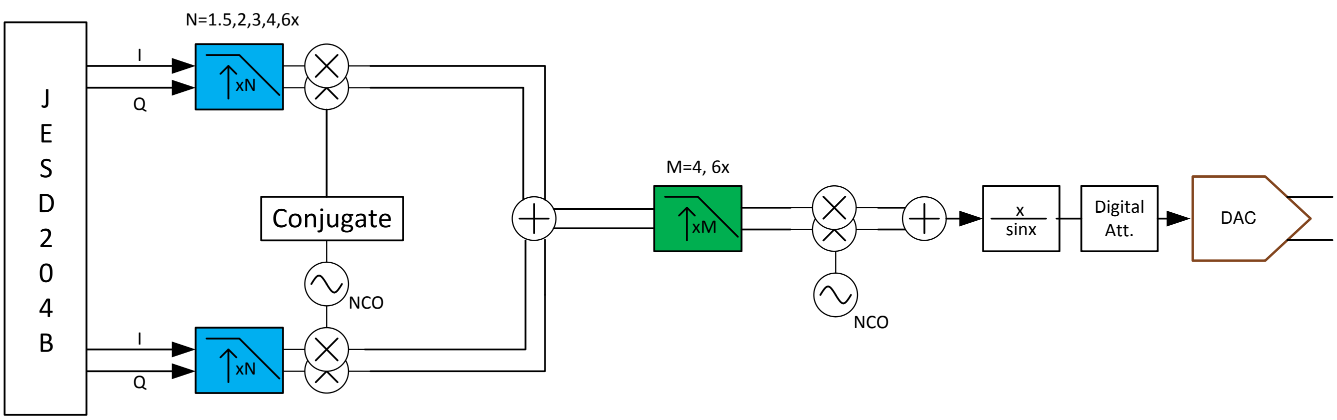

Figure 2-2. Transmitter Data Path in AFE76xx

2.7 Channel

An ideal channel is implemented to remove the effects of the channel on the transceiver performance and examine only the effect of the AFE76xx device. The channel used consisted of matched coax cables and band pass filters with a flat frequency response and 0dB attenuation within the desired bandwidth.

2.8 Receiver

At the receiver, the transmitted waveform is digitized by an ADC running at a sampling rate of 2949.12 MHz. The clock for the ADC is generated by dividing the integrated PLL and VCO output by 3. The digitized data from the

ADC goes to the digital downconverter block (DDC). Inside the DDC, the data is demodulated to IF frequency by mixing with a carrier frequency generated from the NCOs. For this design, the carrier frequency used at the receiver is 1.82 GHz so that the IF frequency is 20 MHz. Inside the DDC, the demodulated data is also filtered and down-sampled by 6x to decrease the data rate to 491.52 MHz.

After the DDC, the decimated data is transmitted to the TSW14J56EVM over the JESD204B interface at a serdes rate of 9.8304 Gbps. The TSW14J56EVM captures and stores the data from the transceiver to its external DDR memory. Shown in Figure 2-3 is the data path of the receiver in AFE76xx device.

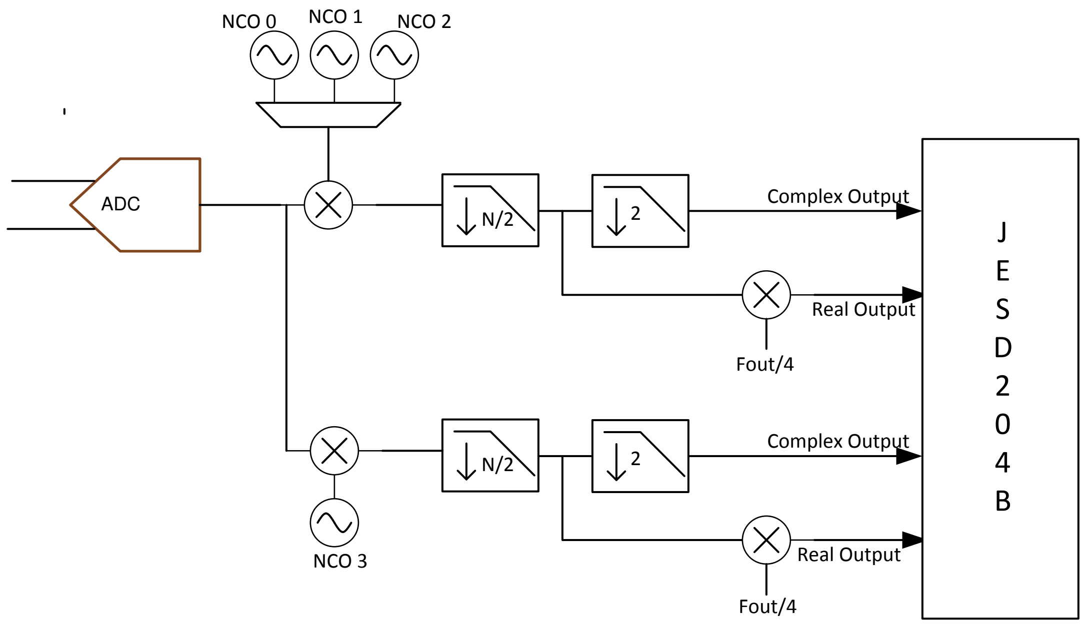

Figure 2-3. Receiver Data Path in AFE76xx

2.9 Captured Data Processing

The captured data will have a data rate of 491.52 MHz at 20-MHz IF frequency and 16-bits resolution. The HSDCPRO software reads the captured data from the DDR memory of the TSW14J56 and saves it to PC. Before loading into the VSA software for analyses, Matlab is used to shift the IF frequency to baseband and also decimate the data by 64x to its original data rate of 7.68 MHz.

2.10 Test Results

The received data is demodulated and analyzed with the VSA software. The analysis results are shown in Figure 2-5 and include received constellation, spectral and error vector magnitude (EVM) performance. The analysis is done on 18 slots or 126 OFDM symbols within an LTE frame. Details of the VSA settings used for the demodulation are shown in Figure 2-4.

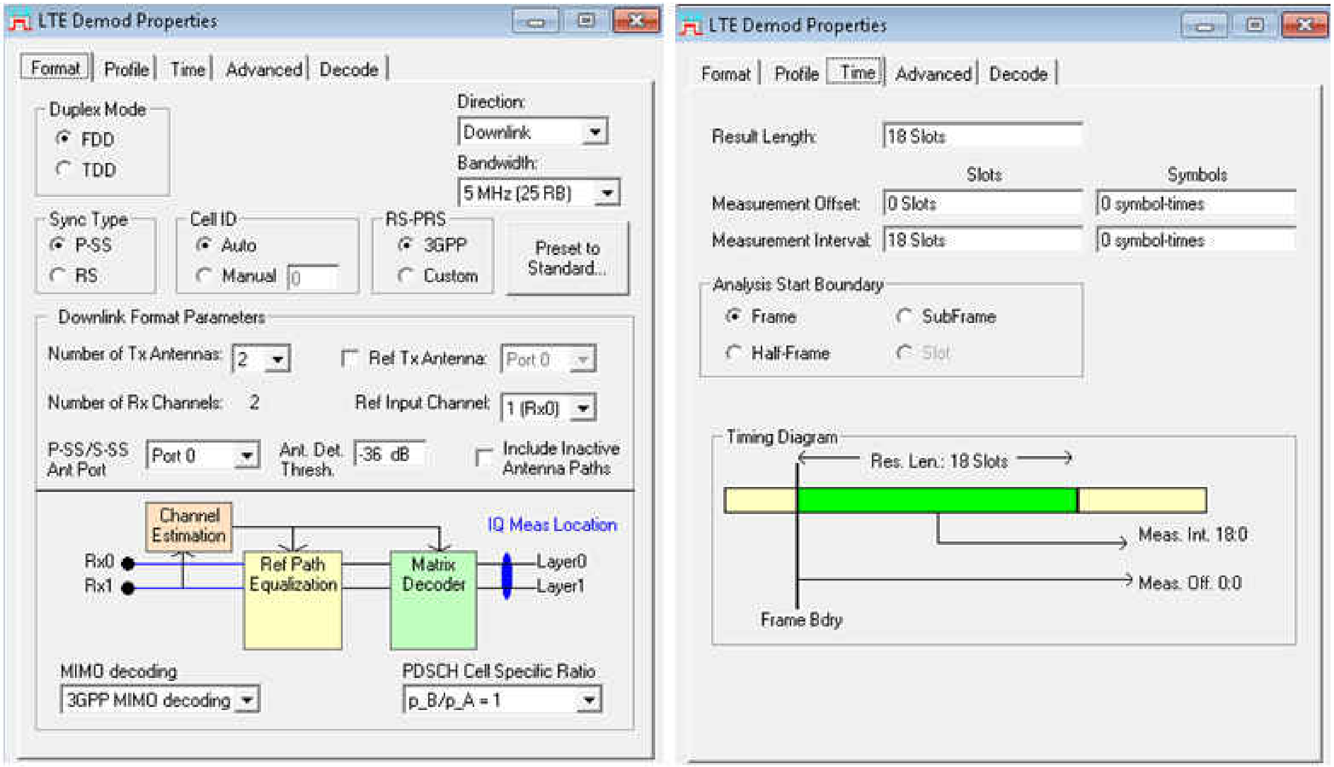

Figure 2-4. VSA Demodulation Settings for 5-MHz LTE 2x2 MIMO Waveform

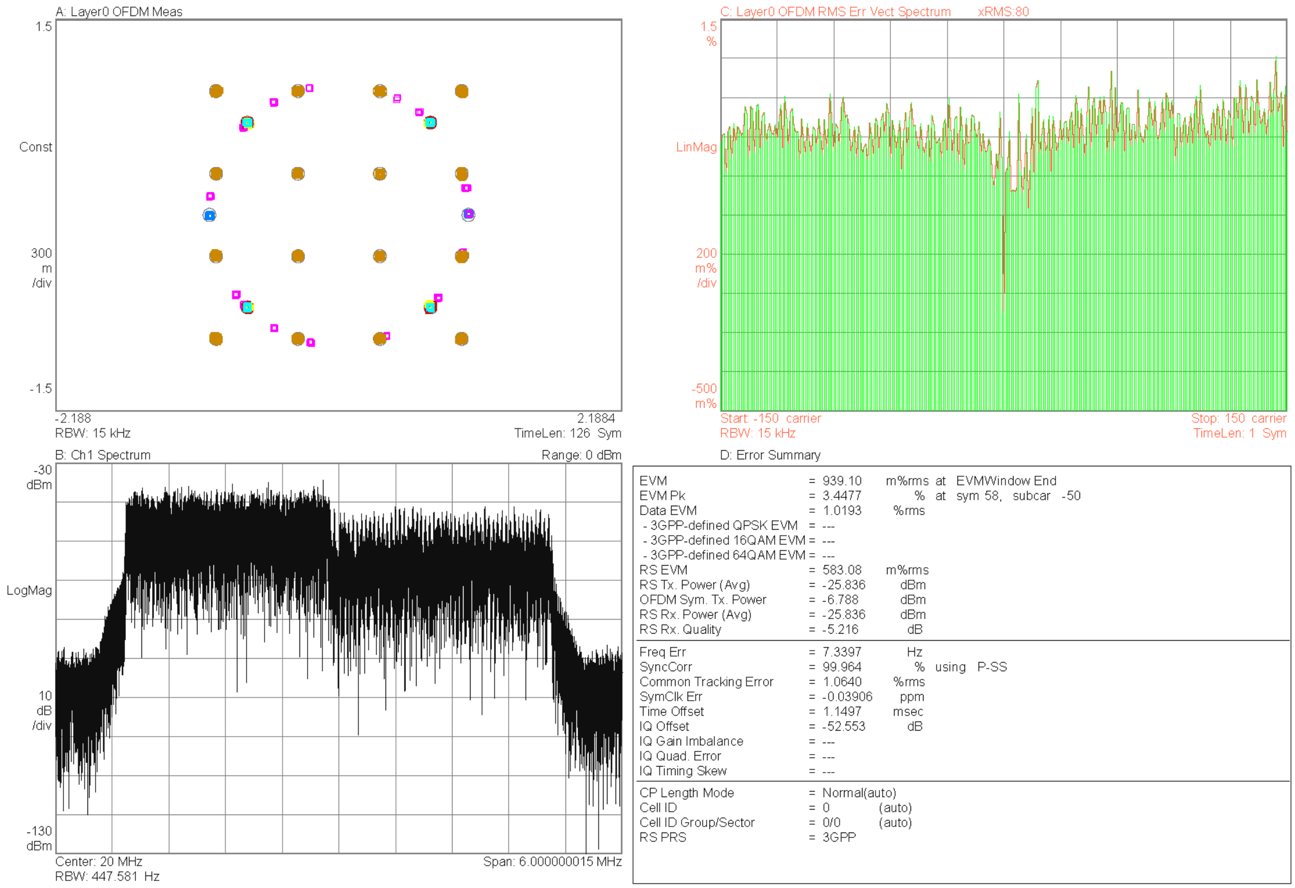

Figure 2-5. Constellation, Spectrum, EVM vs Carrier Frequency and Error Summary Results After Demodulation

3 Constellation

The received constellation is the superposition of various modulation formats including BPSK, QPSK, 16-QAM, and Z-Chu as shown in Figure 3-1. Table 3-1 below summarizes the various channels in the LTE frame, the modulation format used, the measured EVM, and the LTE standard specification.

Table 3-1. EVM Performance

Channel	Modulation	EVM (dB)	Specification
P-SS	Z-Chu	-40.4	
S-SS	BPSK	-39.9	-15dB (or 17.5%)
PDSCH_User01	16-QAM	-40.2	-18dB (or 12.5%)
PDSCH_User02	QPSK	-39.4	-15dB (or 17.5%)

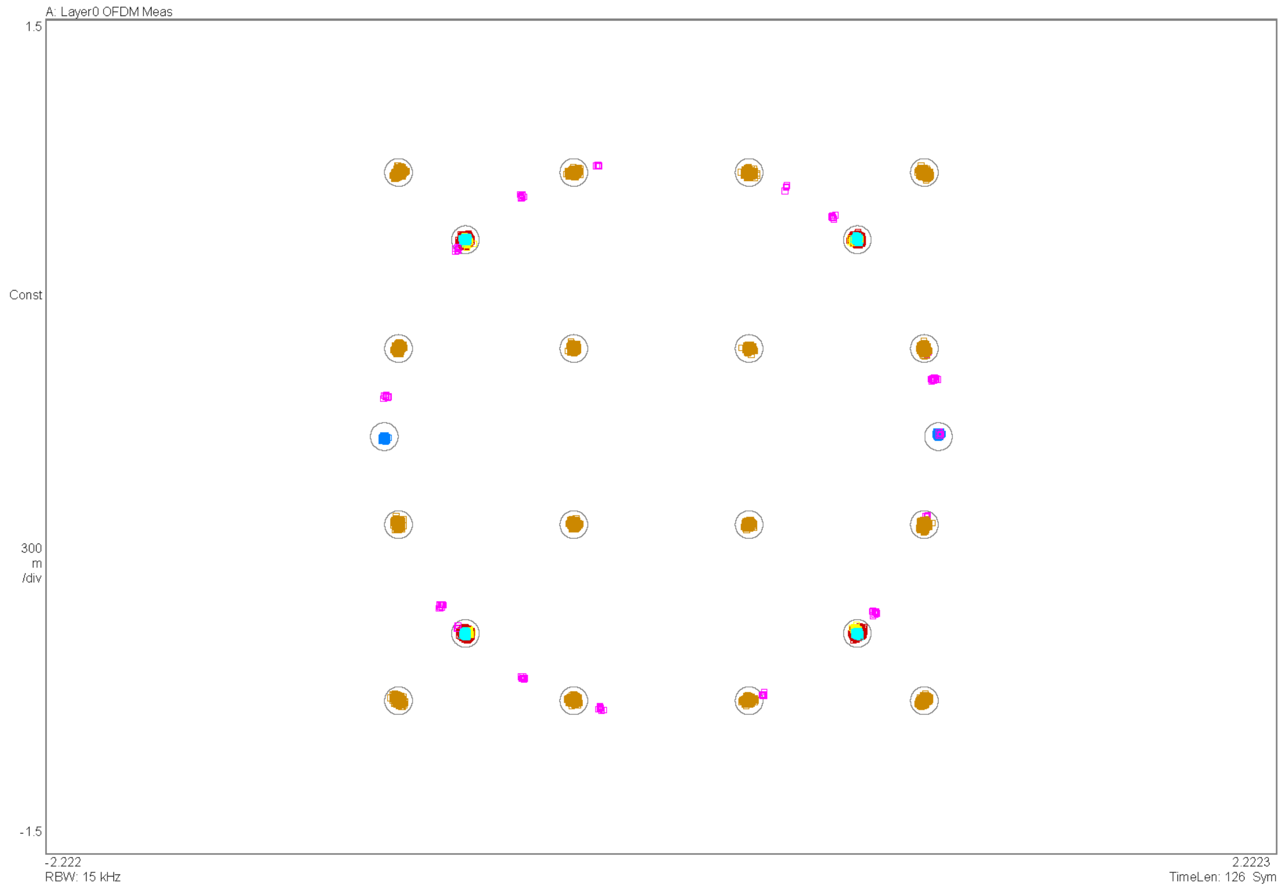

Figure 3-1. Received Constellation of 5-MHz LTE 2x2 MU-MIMO Test Pattern

4 Error Vector Magnitude (EVM)

The EVM measures the extent to which the received constellation deviates from an ideal constellation. Shown in Figure 4-1 is a plot of the RMS EVM for each subcarrier. For 5-MHz LTE each OFDM symbol comprises 300 subcarriers and each subcarrier RMS EVM is calculated by finding the RMS of the EVM for 126 symbols (or 18 slots). This plot is significant to help understand which subcarrier degrades the overall EVM the most and to correct for it if needed. The overall RMS EVM per symbol (the RMS of EVM for each of the 300 subcarriers in a symbol) is 0.939% or -40.5dB.

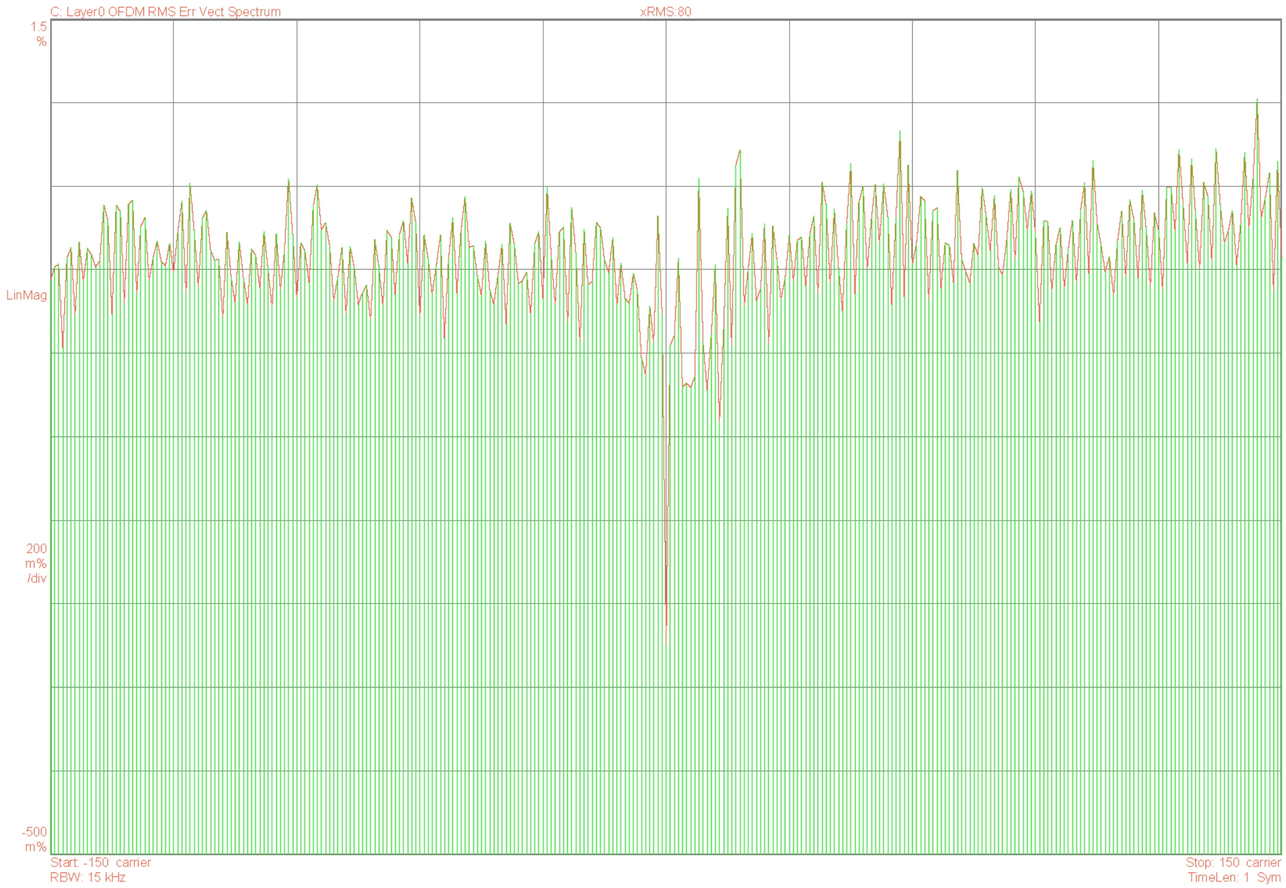

Figure 4-1. RMS EVM vs Carrier Frequency for 1 OFDM Symbol

5 Conclusion

This application report has demonstrated a single chip transceiver solution for implementing 2x2 MIMO with the AFE76xx device. The performance of the transceiver was analyzed with 5-MHz LTE MIMO test pattern and the VSA software. An overall RMS EVM performance of -40.5dB was achieved making it suitable for various applications. The transceiver design can be employed in an LTE eNodeB to implement MIMO transmission modes or can be expanded to a larger array for use in applications such as massive MIMO in 5G.

6 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (September 2018) to Revision A (August 2021)	Page
• Updated the numbering format for tables, figures and cross-references throughout the document..................	1

IMPORTANT NOTICE AND DISCLAIMER