Networking for Communications Challenged Communities:
Architecture, Test Beds and Innovative Alliances
Contract no: 223994

D6.2 N4C

Point to point communications using multiple antennas technologies

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ABSTRACT (Max 400 word)

Starting in May 2008, N4C is a 36 month research project in the Seventh Framework Programme (www.cordis.lu/fp7). In cooperation between users in northern Sweden and Kočevje region in Slovenian mountain and partners, the project will design and experiment with an architecture, infrastructure and applications in field trials and build two test beds.

This document describes the study of multiple antenna technologies and focuses on one of them which allow increasing the distance in a point to point communication link. It also describes the technical issues of implementing such technology.

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PU = Public	PU
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CO = Confidential, only for members of the consortium (including the Commission Services).	

CONTENT

EXECUTIVE SUMMARY

One of the main objectives of the N4C project is to include the communications challenged regions (CCR) in the global communications networks. The approach selected by the N4C consortium is the use of delay tolerant networks to obtain an economic and sustainable range of applications for these special regions.

These CCRs are characterized by the lack of infrastructure and the need of lower costs than the standard deployments. The N4C consortium has added an extra requirement of nomadity, as there are many communities that move during the year from one place to another.

In the last years, big efforts have been conducted toward the research of multiple antenna techniques. The main reason behind this is that multiple antennas techniques combined with advanced signal processing algorithms can be used to improve the communications in many different ways without increasing the spectrum bandwidth. This is very attractive for the market of mobile services since it permits to best suit the increasing demand of higher data rates. However, our proposal is to take advantage of this technology to increase the distance of the communication link.

This document discusses the employment of multiple antennas technologies and it focuses on one particular technique that allows increasing the point to point link distance and thus it could be used to reduce the cost of the network deployments in CCRs.

The first chapter of this document analyzes the different multiple antenna technologies. They are usually known as smart antennas techniques or MIMO (Multiple Inputs Multiple Outputs) schemes. Depending on the geometric setup, the control algorithms and the signal processing algorithm, they can improve directivity, availability or the capacity of the communication link. Some times they are combined to obtain a trade off solution.

The second chapter deals with the simulations carried out for the adopted MIMO scheme and with the targeted technical solution of this WG (Working Group). The system level simulation shows the improvements of the SNR (Signal to Noise Ratio) achieved with the selected MIMO scheme over a traditional system.

Finally, the last chapter deals with the technical issues of a real implementation of the digital signal processing algorithms for the selected MIMO scheme. It describes the full chain of DSP processing blocks and it concludes with the description of work being done to test the whole system.

Acronyms

ADC	Analog to Digital Converter
ALC	Automatic Level Control
AWGN	Additive White Gaussian Noise.
BB	Base Band
BW	Bandwidth
CCR	Communications Challenged Regions
CINR	Carrier to Interference-plus-Noise Ratio
CP	Cyclic Prefix
DAC	Digital to analog Converter
DDC	Digital Down Converter
DL	Downlink
DSP	Digital Signal Processing
DTN	Delay Tolerant Network
DUC	Digital Up Converter
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FMC	FPGA Mezzanine
FPGA	Field programmable gate array
IEEE	Institute of Electrical and Electronic Engineers
IF	Intermediate Frequency
IFFT	Inverse Fast Fourier Transform
LOS	Line Of Sight
LTE	Long Term Evolution
MAC	Medium Access Control Layer
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output

MMB	MIMO Board
MRC	Maximal Ratio Combining
NCO	Numerically Controlled Oscillator.
NLOS	Non-Line Of Sight
OFDM	Orthogonal Frequency Division Multiplexing
RF	Radio Frequency
RSSI	Receive Signal Strength Indication
RX	Receiver
RXATT	Attenuation on the receiver chain of the equipment.
SM	Spatial Multiplexing.
SS	Subscriber Station
STBC	Space Time Block Code
TDD	Time Division Duplex
TXPOW	Transmitted Power
UE	User Equipment
UL	Uplink
WG	Working Group
WiMAX	Wireless Interoperability for Microwave Access (IEEE 802.16)

1. MIMO TECHNOLOGIES

There are many MIMO schemes under investigation. They are always composed of many antennas. The notation is $N_T \times N_R$, which means N_T antennas at the transmitter and N_R antennas at the receiver.

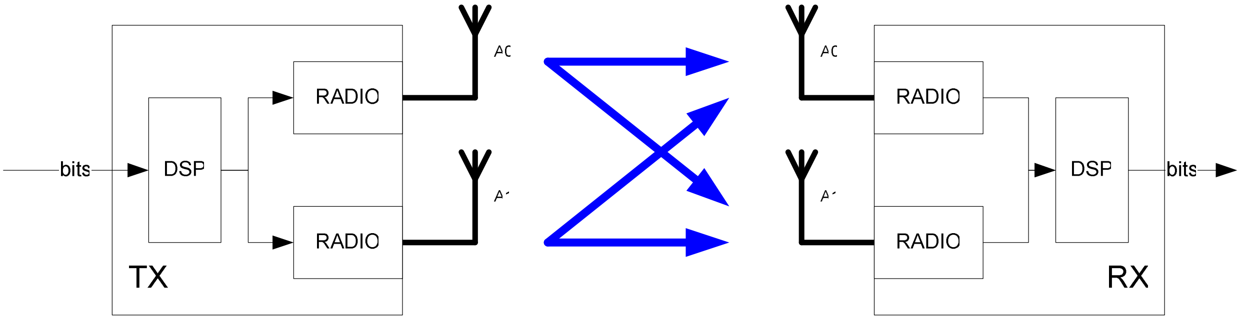


FIGURE 1.1: MIMO 2X2 EXAMPLE

1.1 STATIC ANTENNA ARRAY

The static antenna arrays have been used in communications systems for decades. As an example we can point to the arrays of elements used in mobile phone base stations. Another example is the antenna systems used by satellites which usually is an array of elements that confine the radiation to a specific area on earth. Typically these arrays are characterized by a fixed radiation pattern which can not be changed. The objective pursued of using multiple elements is to achieve some improvement in radiation pattern or gain. In order to precisely confine the beam, the spacing between elements should be narrow.

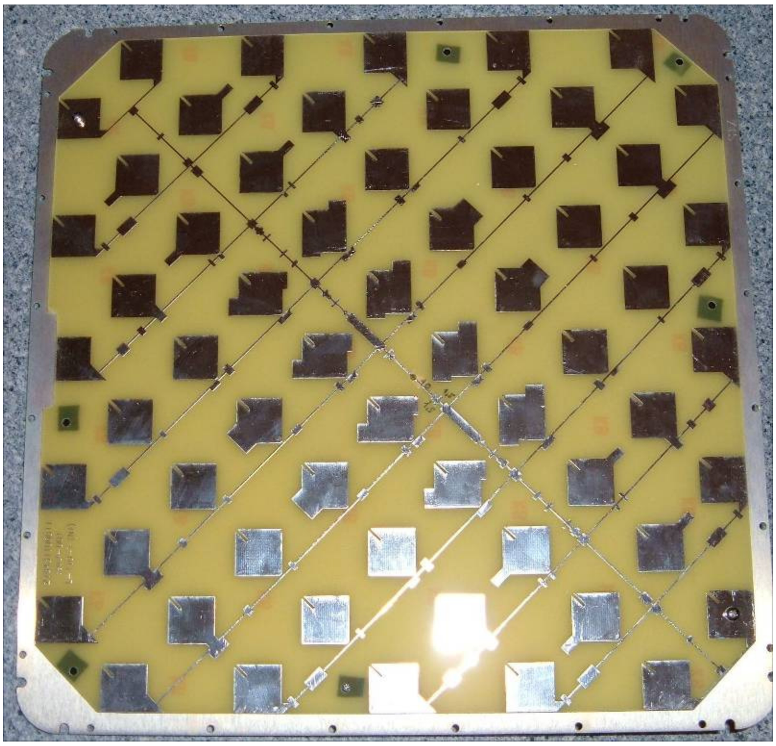


FIGURE 1.2: 5GHZ PANEL ANTENNA MADE OF AN ARRAY OF RADIATING PADS.

1.2 BEAM FORMING CAPABLE ANTENNAS

The idea behind beam forming is to dynamically change the phase and amplitude of the signal radiated by each element with the aim of making the signals add-up constructively on the receiving side. This way the radiation pattern can be changed dynamically.

This technique is well suited for point to multipoint communications systems where the access to the radio resources is separated in time TDD (Time Division Duplexing). This way the beam can be very directive and point all the power to each UE (user equipment) at a time. For the moving UE the control algorithm will be much more complicated since the beam should be tracking the user.

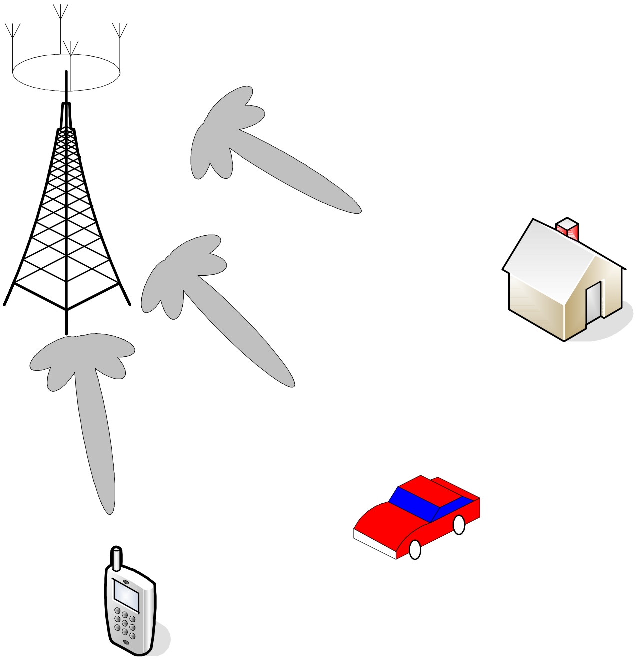


FIGURE 1.3: TDD SYSTEM TAKING ADVANTAGE OF BEAM FORMING

A 4 antenna simplified implementation schematic is show on Figure 1.4. The RF signal coming out from the RF Front-end is split into 4 signals. The signals are routed by the multiplexers through different phase shifter lines up to the antennas. The signal that controls the multiplexers is S0 for channel 0, S1 for channel 1 and so on.

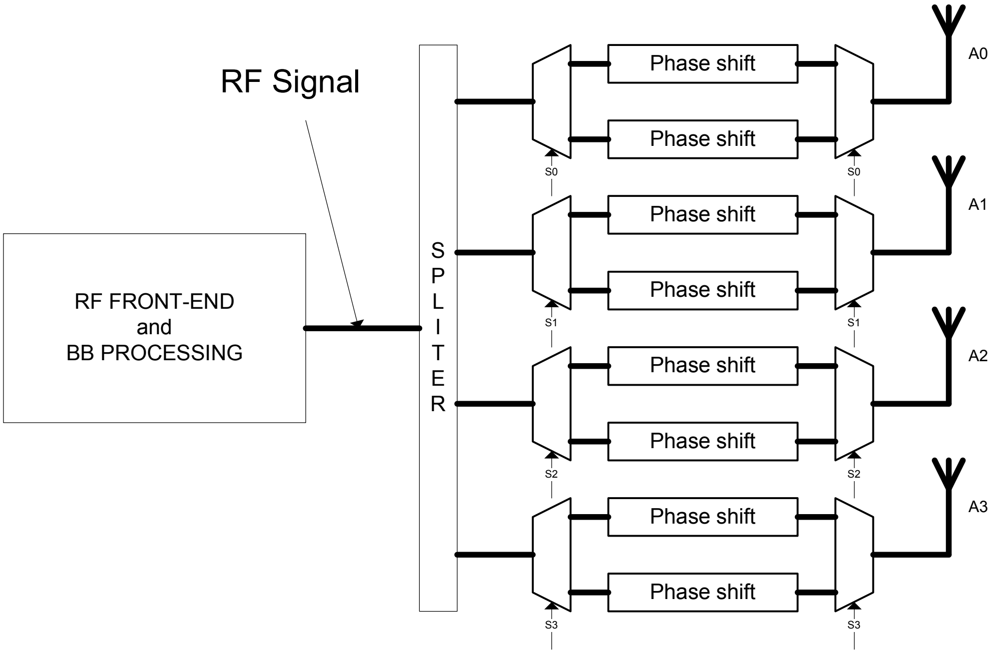


FIGURE 1.4: SIMPLE 4 ANTENNAS BEAM FORMING SCHEME

The signals coming out from the antennas will have different phases which will make them to add-up constructively at different points in space. Therefore, by changing the phase of the signals, the point at which these signals add constructively is changed. This way the directivity of the antenna can be electronically controlled. By the principle of reciprocity, the same behaviour applies when working in RX (receiver mode).

1.2.1 Space Division Multiple Access

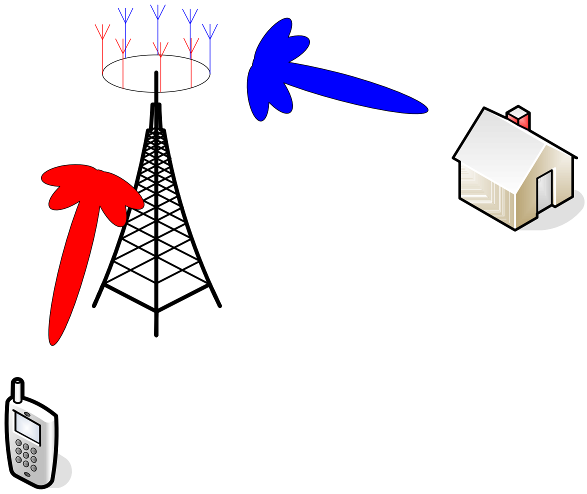


FIGURE 1.5: SDMA ESCENARIO EXAMPLE

Another technique that takes advantage of the beam forming is known as Space Division Multiple Access. It consists mainly in focusing the beams to users that are not geographically close. This way, the base station is able to use the same frequency and transmit to or receive from these users at the same time. This scheme increases the base station capacity per square kilometer.

1.3 RECEIVE DIVERSITY

Within the Receive Diversity scheme group, two techniques can be described

1.3.1 Selection Combining

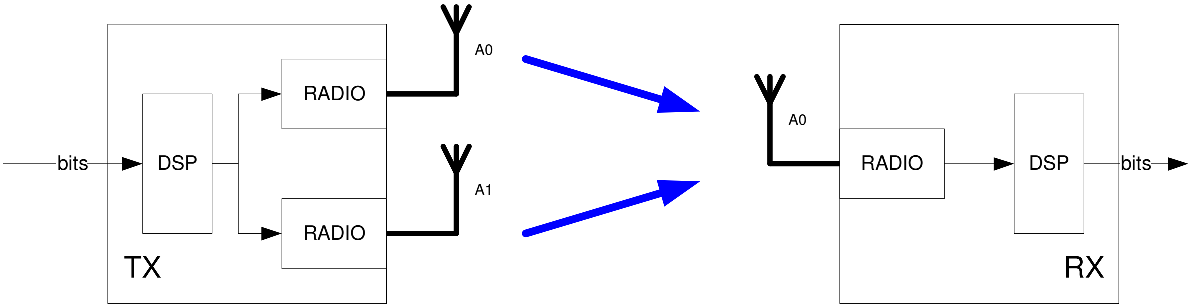
There are N_R antennas at the receiver. The system measures the signal power and quality and then chooses the best signal. The main advantage of this technique is that it is very simple to implement.

1.3.2 Maximal Ratio Combining

MRC significantly improves overall gain, especially in multipath environments. There are N_R antennas at the receiver. In such environments, signals pass through and reflect from various objects so that different signal characteristics reach the receiving antennas. Some frequencies tend to be attenuated at one antenna but not at the other. The received signals are combined coherently which means that the average signal strength increases by $20\log(N_R)$ and the interference signals increases only by $10\log(N_R)$. Thus signal to noise ratio increases 3dB by doubling the number of antennas. This is the kind of scheme that the WG group has selected for implementation. The reasons are given in the next chapter.

1.4 TRANSMIT DIVERSITY

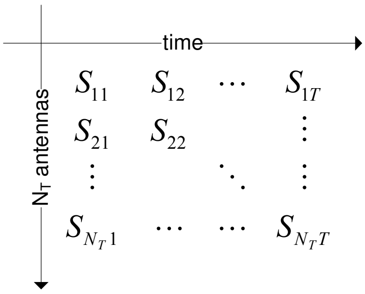
There are N_T antennas at the transmitter. Each antenna transmits a different precoded symbol every time instant. The Figure 1.6 shows an example of MISO (Multiple Input Single Output) transmit diversity. In this example the symbols are precoded with the Alamouti STBC (Space Time Block Code). The symbols to be transmitted by the system should be S_1 at time interval t_1 and S_2 at time interval t_2, however by applying the Alamouti block code, the pair (S_1,S_2) is transmitted at time interval t_1 and $((S_1)^*,-(S_2)^*)$ at time interval t_2 . At the receiver, both signals will superpose. The receiver will take advantage of the orthogonal encoding of the two pairs to optimally recover the information symbols S_1 and S_2 .



A0	s_1	$-(s_2)^*$
A1	s_2	$(s_1)^*$
Time interval	t_0	t_1

FIGURE 1.6: TRANSMIT DIVERSITY 2X1 EXAMPLE

The transmission rank of the MIMO system is defined as the number of independent modulation symbols transmitted per time-frequency resource. The above example can transmit 2 symbols in 2 time intervals, so its rank is $r = \frac{2}{2} = 1$. The Alamouti code is the only orthogonal code that allows rank 1. For a higher number of antennas, it has been shown in [OSTBC] that employing orthogonal codes leads to $r < 1$.



$$\begin{array}{cccc} S_{11} & S_{12} & \cdots & S_{1T} \\ S_{21} & S_{22} & & \vdots \\ \vdots & & \ddots & \vdots \\ S_{N_T 1} & \cdots & \cdots & S_{N_T T} \end{array}$$

FIGURE 1.7: CODE COMPOSITION

Transmit diversity also improves the SNR of the received signal. However if more than 2 antennas are used with orthogonal codes then there is a capacity-coverage trade-off.

1.5 SPATIAL MULTIPLEXING

The MIMO schemes described so far try to improve the SNR of the communication link. These optimizations translate into throughput gains. However this gain saturates as shown in Figure 1.8.

By the use of multiple antennas at both sides of the radio link, multiple parallel channels can be created. These parallel channels share the overall SNR, thus avoiding the above mentioned throughput saturation.

The great interest generated by SM is that the capacity may increase linearly with the number of antennas [IMPNO]; however in practice there is inter-stream interference which means that at the receiver, the signal at each antenna is the combination of the transmitted signals, so in order to have equivalent parallel channels this inter-stream interference should be removed.

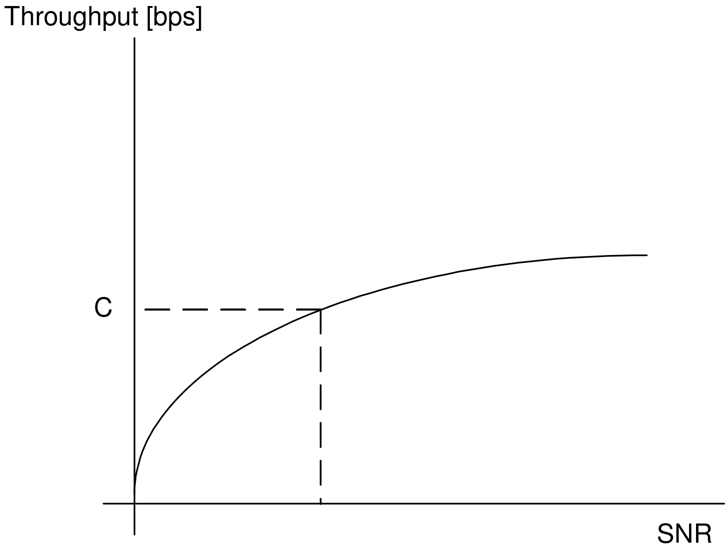


FIGURE 1.8: THROUGHPUT VS SNR FOR ONE CHANNEL

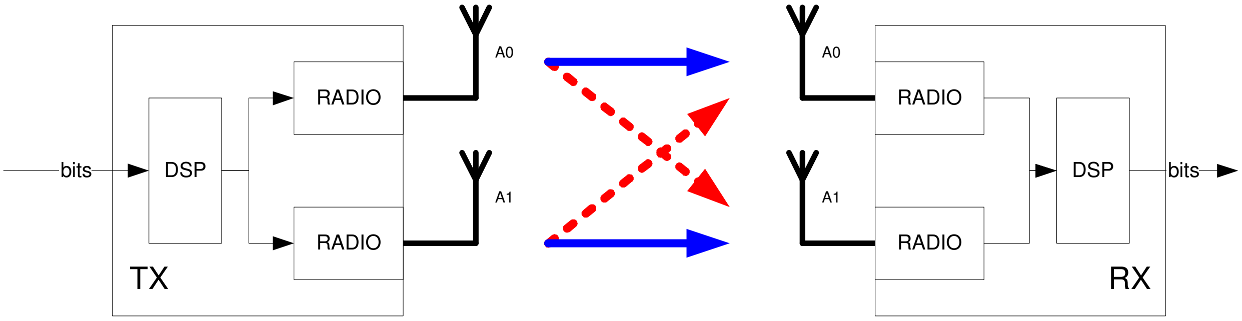


FIGURE 1.9: MIMO SM

In Figure 1.9, the red lines represent the inter-stream interference. For the next generation of mobile phones systems named LTE (Long Term Evolution), the 4x4 SM MIMO scheme allows to transmit 4 streaming as if they were 4 independent channels. LTE will also adjust the scheme dynamically to best suit the channel capacity [MTSLTE]. See Figure 1.10.

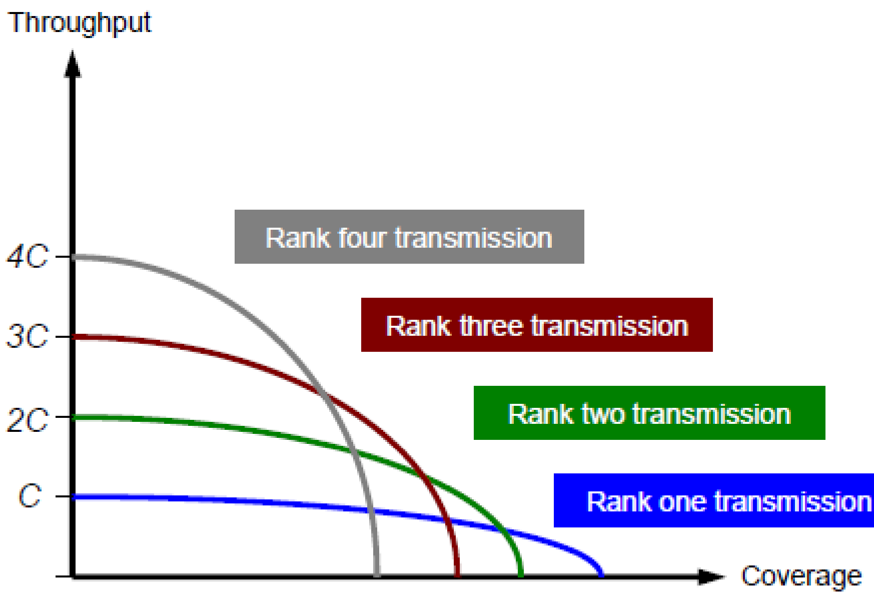


FIGURE 1.10: THROUGHPUT VERSUS COVERAGE FOR A 4X4 MIMO WIRELESS LINK

2. POINT TO POINT MRC MIMO SCHEME ANALYSIS.

The MRC scheme shown in the previous section can improve the SNR of the received signal in $10\log(N_R)$ dB. So just by using 2 antennas at the receiver its sensitivity improves an average of 3dB, which means that the distance in a free-space LOS channel increases by a factor of $\sqrt{2}$.

In order to explain how this scheme works we are going to focus on an OFMD signal which is the modulation used by WiMAX. If we take a look at the point of the constellation that is transmitted at one subcarrier in an OFDM symbol, we can decompose the received subcarrier signal at the antenna A_0 into the transmitted signal $\vec{S}$ and en error signal $\vec{n}_0$. The same applies for the received subcarrier signal $\vec{R}_1$.

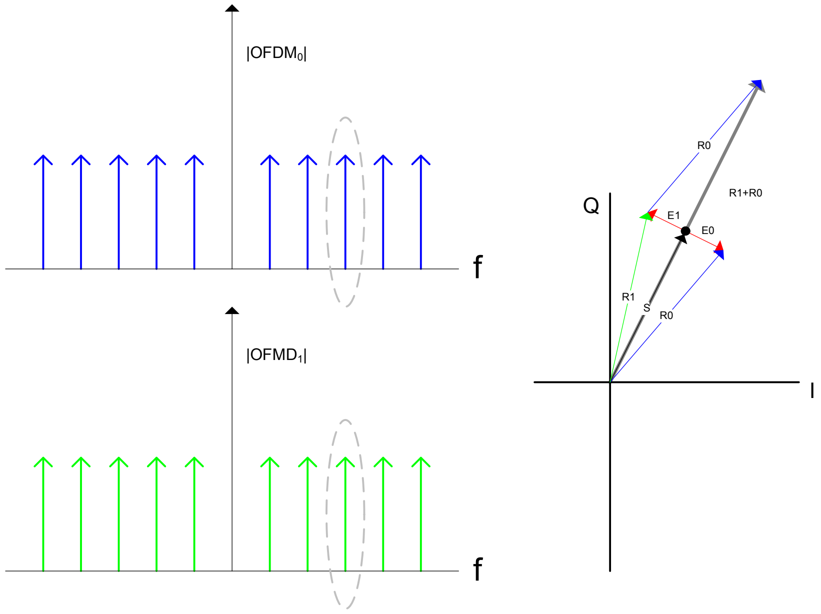


FIGURE 2.1: COMBINATION OF 2 RECEIVED SIGNALS

$$\vec{R}_0 = \vec{S} + \vec{n}_0 \qquad \vec{R}_1 = \vec{S} + \vec{n}_1$$

$$\vec{R} = \vec{R}_0 + \vec{R}_1 = 2\vec{S} + \vec{n}_0 + \vec{n}_1 \Rightarrow SNR_{MRC} = \frac{4|S|^2}{\sigma_0{}^2 + \sigma_1{}^2} = \frac{4|S|^2}{2\sigma^2} = 2\frac{|S|^2}{\sigma^2} = 2SNR,$$

where $\sigma_0{}^2, \sigma_1{}^2$ is the noise power of channel 0 and channel 1 respectively.

When the signals are combined, the amplitude of the received component is doubled; however, the noise component combines differently due to its random nature.

The SNR of the resulting signal is the ratio of the power of the two times amplitude transmitted signal to the sum of the power of noise. We assume that the nature of the noise that affects both channels is the same so the power of the resulting noise is two times the power of the noise of a single channel. This analysis applies for an AWGN channel. When working with fading channels the above gain is only an average gain.

It is important to note that two requisites must be satisfied:

- The signals should be added coherently. It means that the OFDM symbol should be first equalized so the channel response is compensated.
- The two channels should be uncorrelated. If the two received signals were the same there would not be an improvement in SNR. In order to obtain uncorrelated channels, the distance between the two antennas should be very large compared to the signal wavelength.

2.1 MIMO ARCHITECTURE PROPOSAL

The key points that have taken the WG to choose the MRC MIMO scheme are listed below:

- The system complexity is lower than the transmit diversity and SM.
- The complexity resides in only one side of the communication system. This case it is on the receiver.
- Albentia Systems WiMax architecture is composed of two boards (see Figure 2.2, Figure 2.3), a BB (Base Band) processing board and a Radio Interface board. The system can be split apart in the middle and the same strategy than the repeater design can be followed. Two radio boards can be interfaced with the MMB (MIMO board). The MMB samples the signals coming from the two radios. It processes them and delivers the signal to the upper BB board.
- Since there will be two radios, the device will transmit twice the power of a normal device. The overall gain of the system will be 6dB (3dB for TX and 3dB for RX) which translates into double achievable distance. (For space-free LOS link).
- The mechanical design and enclosure developed for the repeater can be reused.

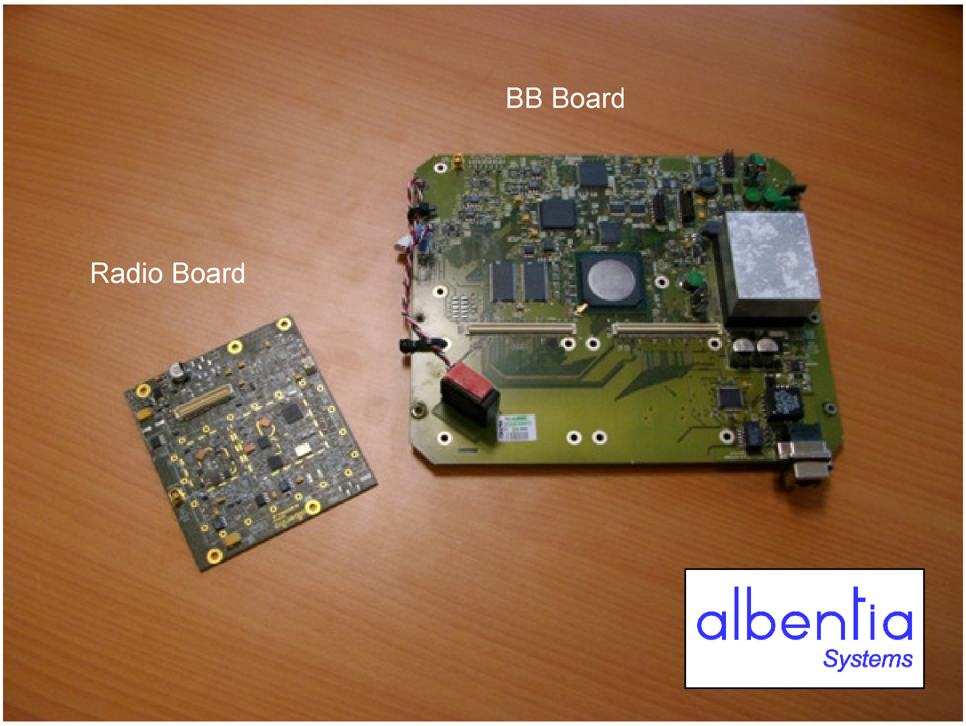


FIGURE 2.2: ALBENTIA SYSTEMS WIMAX SYSTEM PARTITION

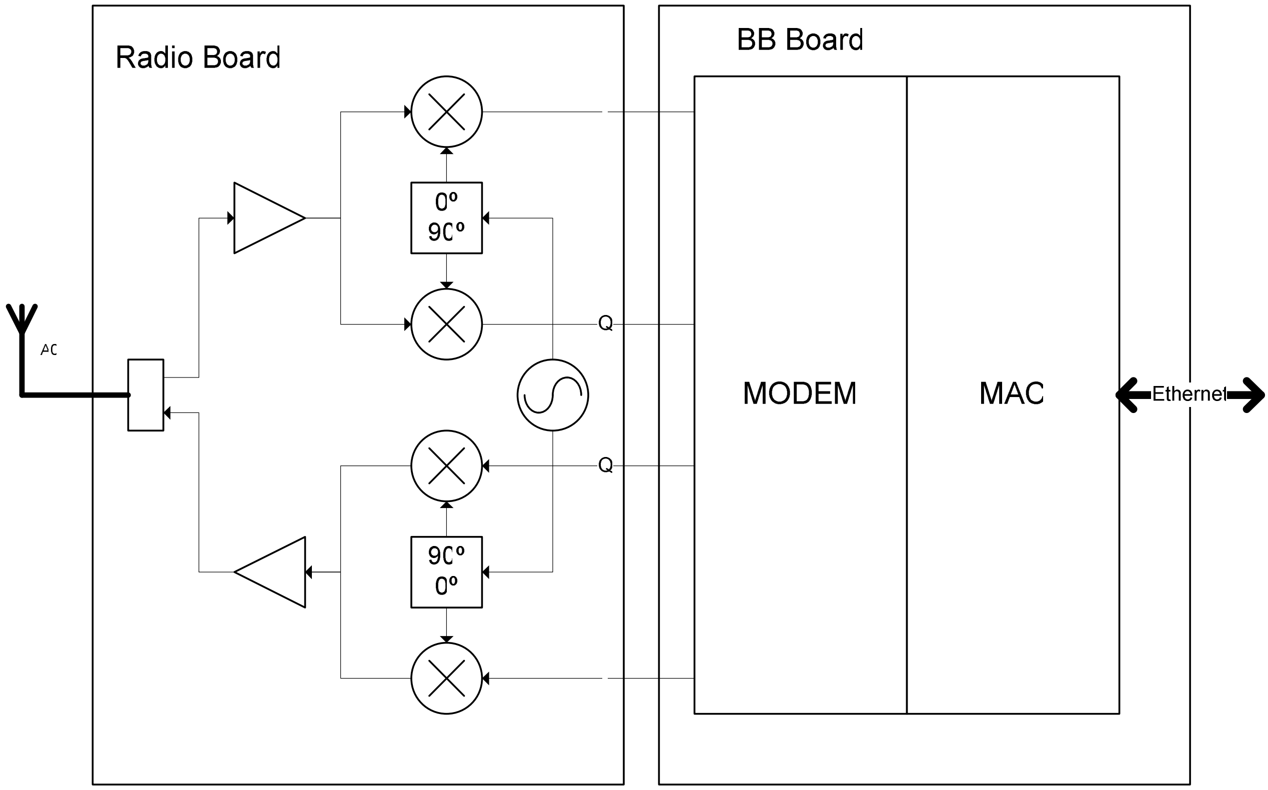


FIGURE 2.3: ALBENTIA SYSTEMS WIMAX SYSTEM SCHEME

Figure 2.4 shows the resulting WiMAX system diagram with the MRC scheme. The MMB will take care of the DSP (Digital Signal Processing) required to synchronize in time and frequency the two symbols received from the antennas.

When the system is transmitting the MMB will only provide the same signal to both radios. This way the same signal will be transmitted to the air and hence a 3dB power boost is achieved.

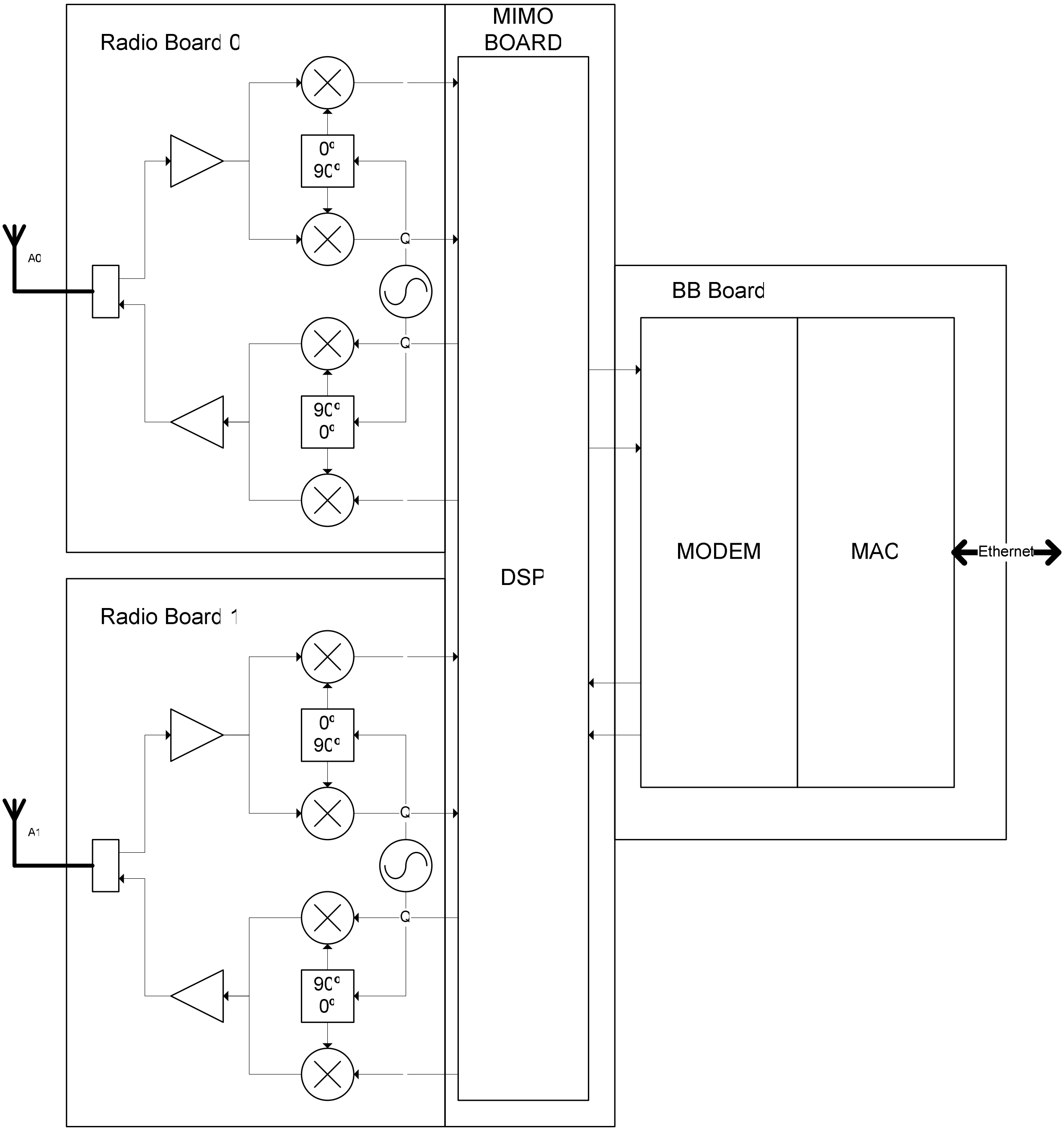


FIGURE 2.4: WIMAX SYSTEM WITH MRC MIMO SCHEME

2.2 SIGNAL LEVEL SYSTEM MODELING

Before getting into the design of the DSP architecture that will perform the MRC combination of the two channels, it is important to carry out a study of the MRC scheme in a WiMAX System. In this subsection we present a simulation of the proposed MIMO technology applied to a WiMAX OFDM receiver. The simulation has been based on the demo model of a WiMAX physical layer interface that comes with the tool Simulink® (from MathWorks). The demonstration only works for a single antenna (see Figure 2.5) therefore we have extended its functionality with the addition of a second communication channel and with the MRC receiver (see Figure 2.6).

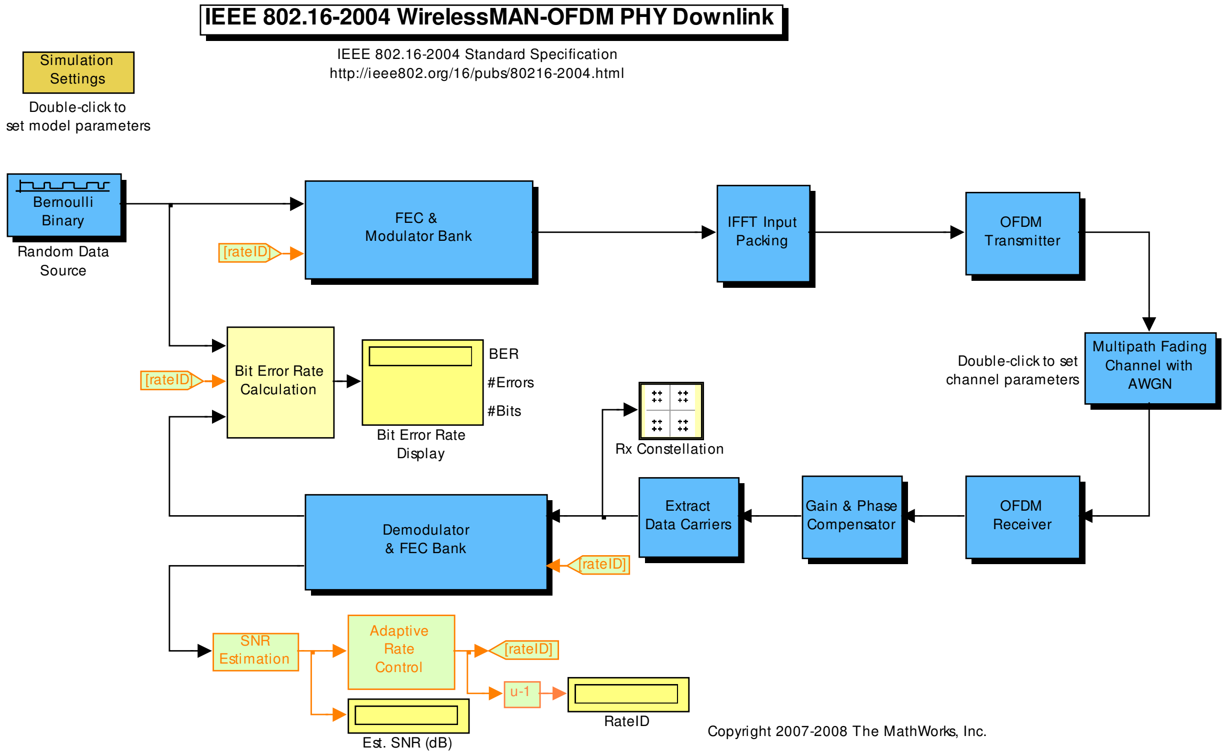


FIGURE 2.5: WIMAX PHY DEMO THAT COMES WITH SIMULINK®.

The Random Data Source block, generates equally probable 0s and 1s. The FEC encoder applies the FEC encoding scheme described in the IEEE802.16-2004 standard and the subcarrier constellation mappings. The FEC encoding scheme is selected according to the “rateID”. At the beginning of the simulation rateID selects the lowest modulation available and if the channel SNR measurements are good, then the modulation order is increased. The IFFT Input Packing block inserts the pilots’ subcarriers. The OFDM transmitter applies the IFFT and inserts the cyclic prefix. The receiver blocks do the counterpart. The Adaptive Rate Control block measures the SNR of the received signal and applies the rateID signal. See Table 1.

Figure 2.6 shows the extended simulation model that includes the MRC receiver and a second uncorrelated channel which simulates the path from the transmitter to the second receiving antenna. Note that the original receiver remains on the extended model. This is useful to compare both results.

Rate ID	Modulation
1	BPSK1/2
2	QPSK1/2
3	QPSK3/4
4	16-QAM1/2
5	16-QAM3/4
6	64-QAM2/3
7	64-QAM3/4

TABLE 1: RATE ID AND MODULATIONS

The simulation parameters are the following:

Parameters	Value
BW	10MHz
CP	1/4

TABLE 2: SIMULATION PARAMETERS

The OFDM MRC receiver is shown in Figure 2.7. Note that it is composed of two OFDM receivers and two Gain & Phase Compensator blocks. After the Gain & Phase Compensator, both signals are coherent then they must be added at this point. Finally the scaling block adjusts the amplitude of the signal before the demodulator.

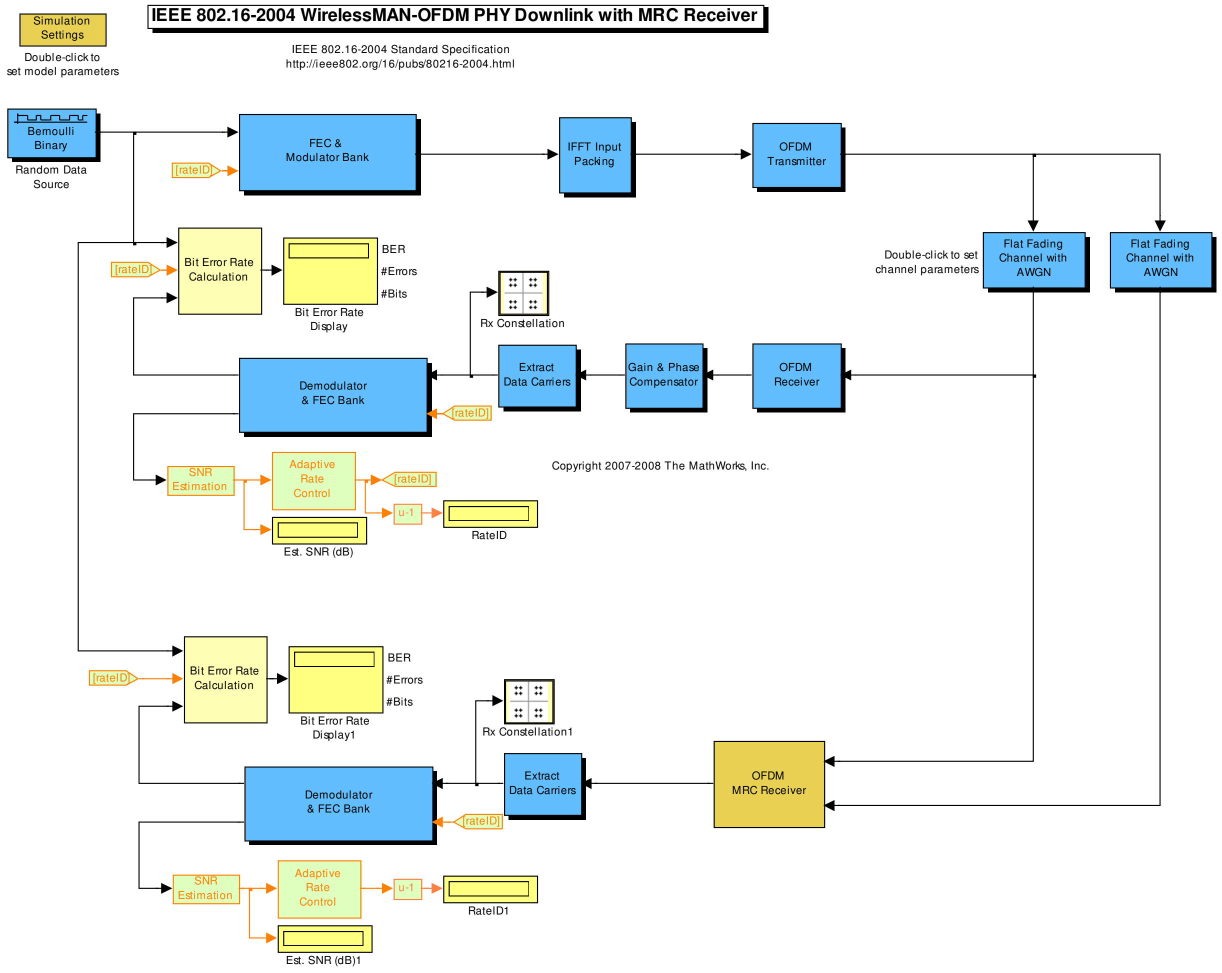


FIGURE 2.6: WIMAX PHY DEMO EXTENDED TO INCLUDE A MRC RECEIVER

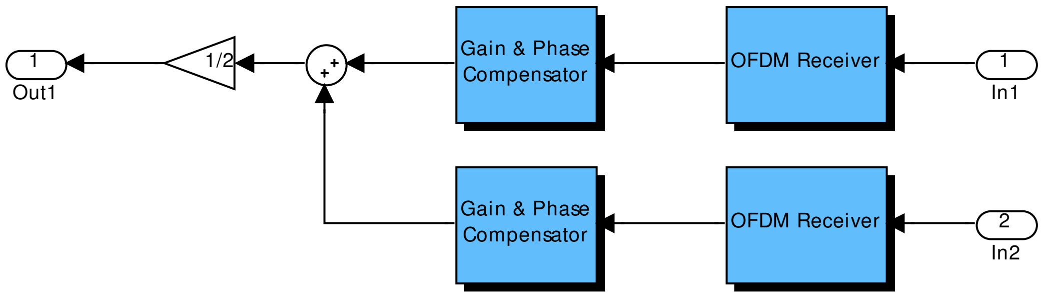


FIGURE 2.7: OFDM MRC RECEIVER

The results of the simulation are listed on Table 3.

Channel Type	**Single Rx** **SNR/RateID**	**MRC Rx** **SNR/RateID**	**Observation**
Frequency selective fading. AWGN 25dB	15.38dB/3	17.1dB/3	This kind of channel is found on indoor environments.
Flat fading channel AWGN 25dB	26dB/5	29dB/6	This kind of channel is found on outdoor LOS environments.
Flat fading channel AWGN 6dB	6.2dB/1	9.4/1	At the lowest SNR allowed, the communication with MRC RX is possible.

TABLE 3: SIMULATION RESULTS

The MRC receiver always outperforms the single receiver. The average gain is about 3dB as expected. Note that since a WiMax communication system selects the modulation level according the SNR of the received signal, when the MRC scheme is used, the threshold for a higher modulation can be reached. Then this scheme could also allow an improvement of the throughput.

3. MRC SCHEME IMPLEMENTATION

3.1 MMB BOARD

Figure 3.1 shows a signal schematic of the MMB board. This board will be composed by the following elements:

- Quadruple ADC (Analog to Digital Converters) for two I-Q signal pairs input.
- An FPGA (Field Programmable Gate Array) for DSP processing.
- Dual DAC (Digital to Analog Converter) for one I-Q signal pair output.
- Signal conditioners and power supply subcircuits.

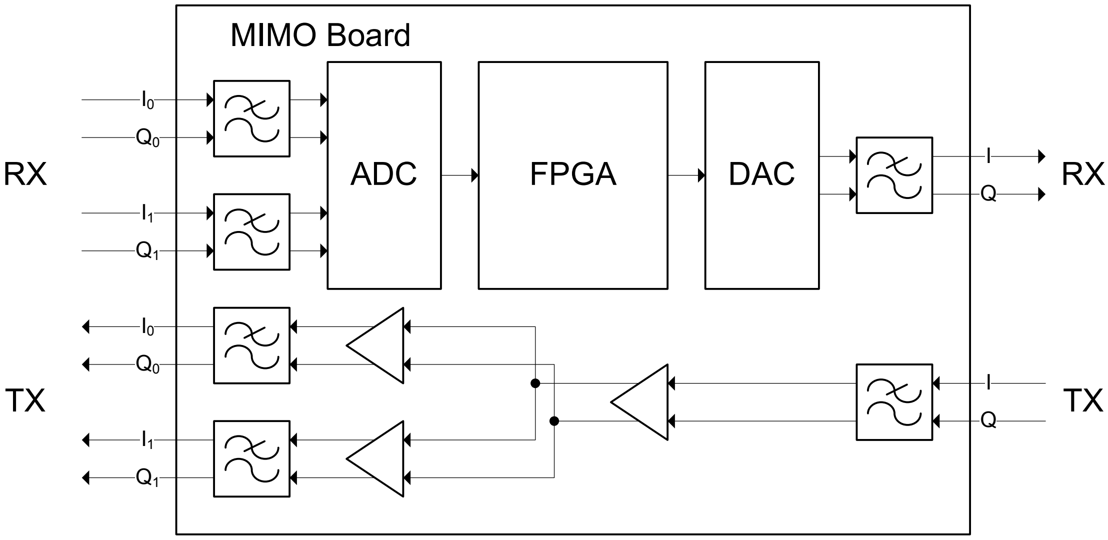


FIGURE 3.1: MIMO BOARD SIGNAL DIAGRAM

Note the DSP processing is only carried out in the receiver branch. On the transmitter branch there are only analog components like differential amplifiers and low pass filters. So from the signal point of view, the MMB will be transparent to the BB board.

The control lines have not been included in MMB diagram; however these signals should be taken into account in a real application. The FPGA will duplicate and buffer the control lines that come from the BB board.

3.2 MRC OFDM RECEIVER IMPLEMENTATION

The most challenging part of the project is to implement the MRC OFDM receiver. The complexity resides on the OFDM receiver and the fixed point quantization profile. The more bits to represent the signals the better results will be achieved. However the FPGA resources used may grow exponentially with the number of bits.

The OFDM receiver is shown in Figure 3.2. It is worth to mention that the MRC receiver must include the DDC (Digital Down Converter) and DUC (Digital Up Converter) blocks because the signal that the BB board handles is not a pure base band signal, instead it is a low IF(Intermediate Frequency) signal which is centered at 10MHz.

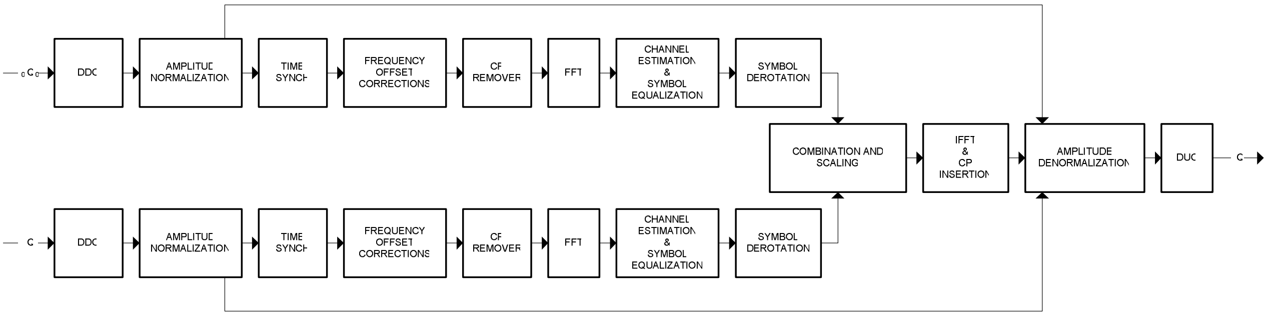


FIGURE 3.2: MRC OFDM RECEIVER

In the following subsections a detailed explanation of the blocas is given:

3.2.1 Digital Down Converter

The DDC block is shown in Figure 3.3. It basically down converts to pure base band as well as it provides decimation.

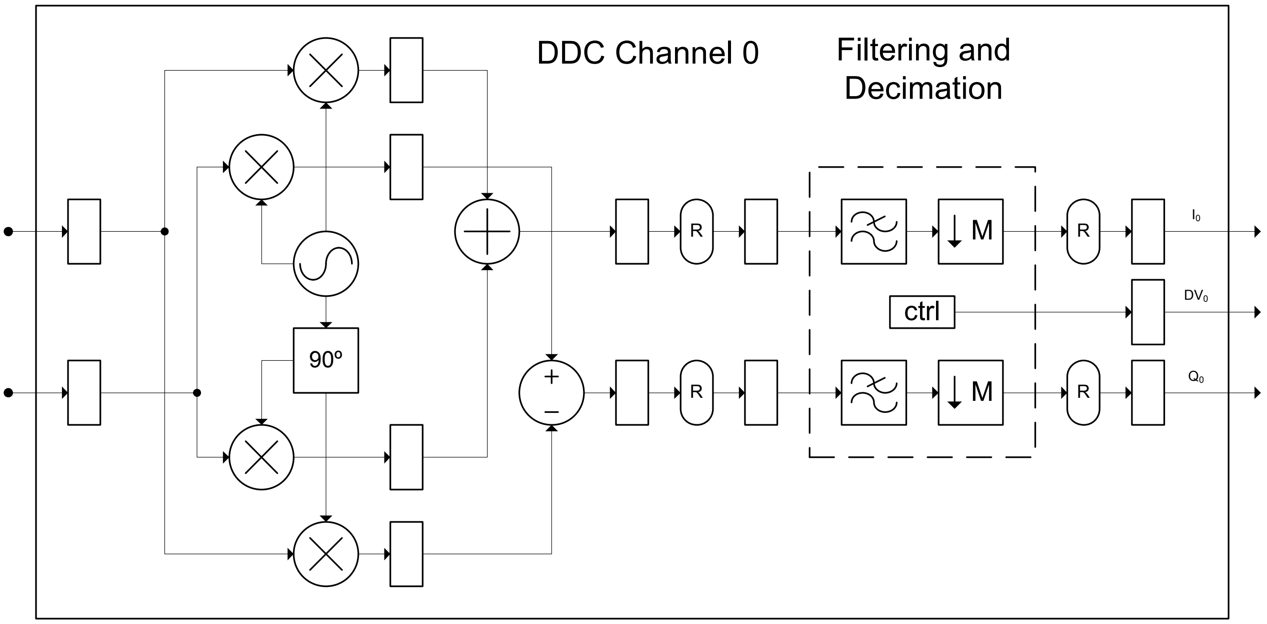


FIGURE 3.3: DDC BLOCK DIAGRAM

3.2.2 Amplitude Normalization Block

The Amplitude Normalization block, scales the received signal so the rest of the blocks always work at the same level. At the end of the processing chain, the amplitude is restored by the Amplitude Denormalization block. This action is needed because a WIMAX system performs ALC (Amplitude Level Control) which means that the BS (Base Station) will measure the amplitude of the received signals and will indicate corrections to the transmitting SS (Subscriber Station) until the amplitude is within the optimum thresholds.

3.2.3 Time Synchronization

A number of approaches to estimate timing and frequency offset in OFDM systems have been presented in the literature. Many of these operate in the time domain (before the FFT) and use the repeating pattern of the preamble [802.16-2004]802.16-2004802.16-2004802.16-2004 (see Figure 3.4, Figure 3.5) or the cycle prefix, or both, to gain information about the symbol timing and frequency offset. The timing is determined by noticing that the correlation of the signal with a delayed version of itself will reach a peak when the repeated pattern is located [LATTICE]. A circuit capable of this is the one proposed by Schmidl and Cox [RFTS]. See Figure 3.7.

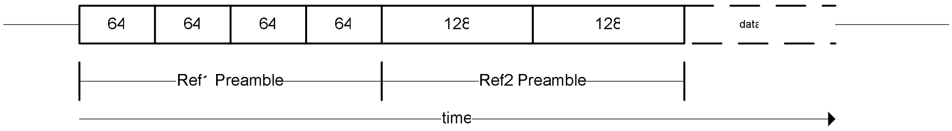


FIGURE 3.4: FRAME START FOR THE DOWNLINK

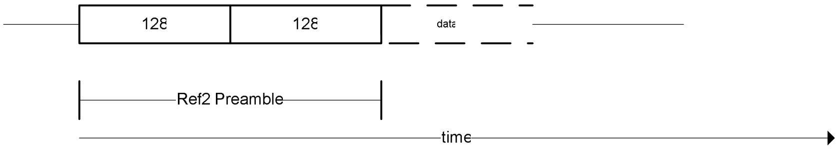


FIGURE 3.5: FRAME START FOR THE UPLINK

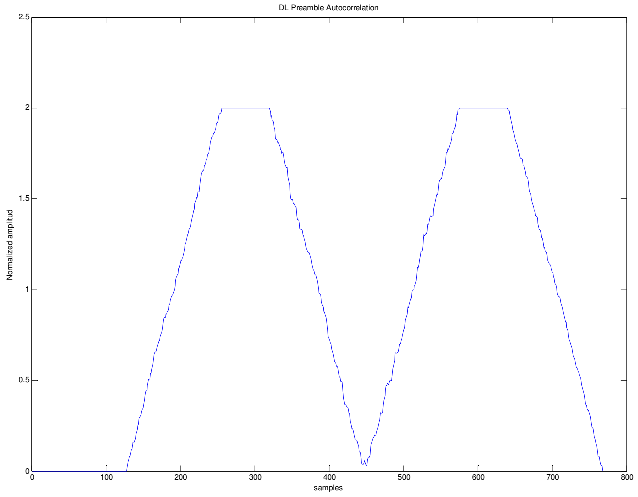


FIGURE 3.6: DL PREAMBLE AUTOCORRELATION

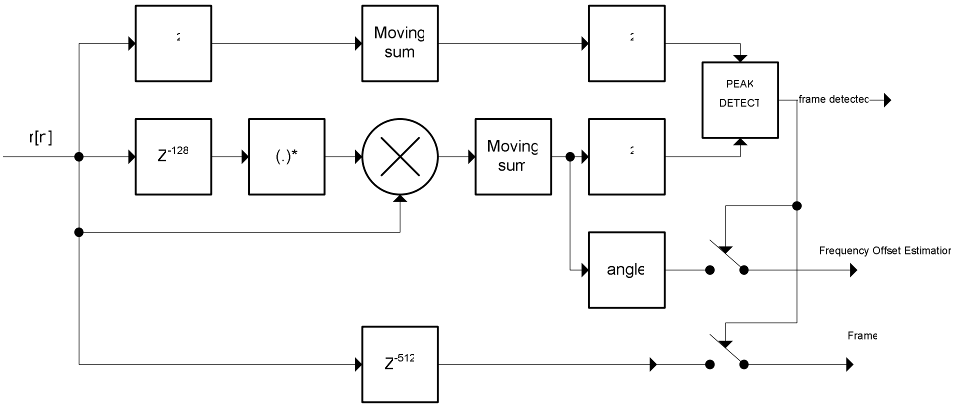


FIGURE 3.7: SCHMIDL AND COX TIME SYNCHRONIZATION ARCHITECTURE.

3.2.4 Frequency Offset Corrections

The frequency offset correction block, takes the frequency offset estimation from the Time Synchronization block and applies the correction. It is very similar as the DDC block; however a NCO (Numerically Controlled Oscillator) is used instead of a fixed oscillator.

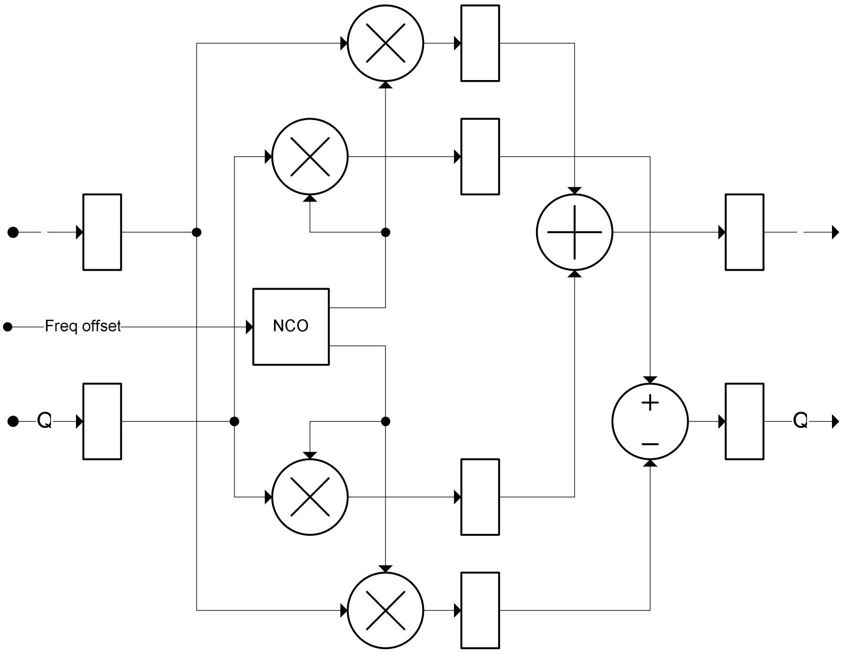


FIGURE 3.8: FREQUENCY OFFSET CORRECTION ARCHITECTURE

3.2.5 CP Remover

The CP remover block removes the cyclic prefix by taking care of the samples indexing. It is out of the scope of this document to do a deeper analysis.

3.2.6 Fast Fourier Transform

The FFT block is composed of two FFT cores. The main reason for this is that the FFT computes the FFT in approximately 14us and when one OFDM symbol is being computed, the other symbol is being loaded into the remaining FFT core. This way, the two FFT cores can handle the FFT computing needs of a 10MHz bandwidth WiMAX frame.

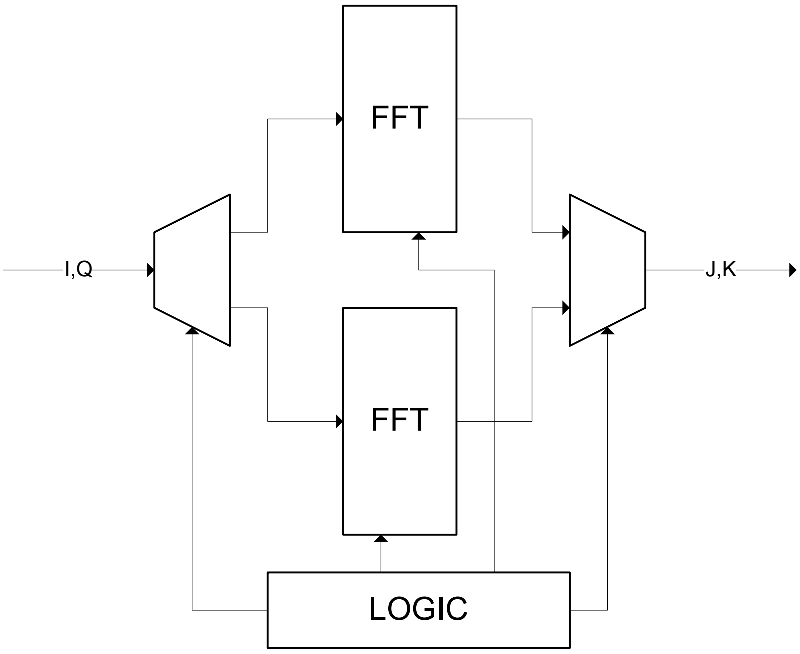


FIGURE 3.9: FFT BLOCK

3.2.7 Channel Estimation

The Channel Estimation and Symbol Equalization block computes the inverse of the channel response. The complex factor is obtained by dividing each subcarrier by the received one. The complex subcarrier channel factor is stored in a dual port ram for later recalling. The control logic will take care of managing the operations in the required order. So when the received symbol is REF2, the control logic will signal to compute the channel estimation, on the other hand when the received symbols are user data, the control logic will signal to compute the symbol equalizations.

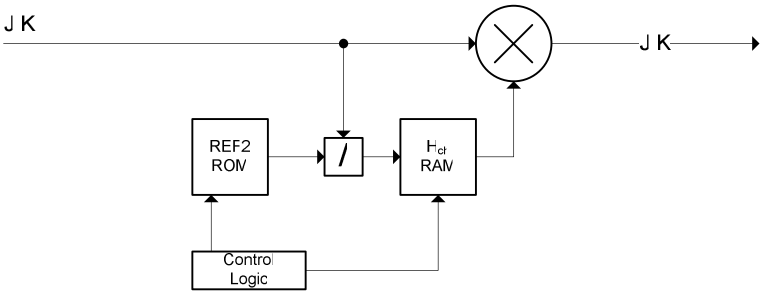


FIGURE 3.10: CHANNEL RESPONSE ESTIMATION BLOCK

3.2.8 Symbol Derotation

The Symbol Derotation Block performs a pilot tracking. It means that any phase variation suffered by the symbols is compensated by this block. It uses the pilot subcarriers to perform the estimation of the variation. The control logic manages the time intervals so that for each symbol, the average phase error of the pilot subcarriers is calculated. Once the average is completed the compensation is applied.

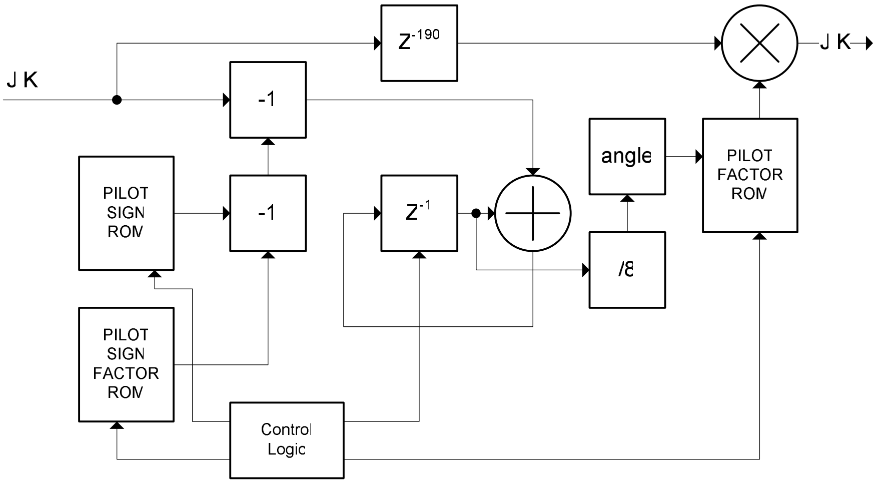


FIGURE 3.11: SYMBOL DEROTATION BLOCK

3.2.9 Channel Combining

Up to this point, the combination of both channels is left. As it has already been stated, the combination has to be coherent. The samples getting into the queues (see Figure 3.12) have already been processed; however before the combination begins, samples from both channels should be already present. The control logic takes care of this, and also handles a timer which establishes the maximum time that both channels have available to come up with samples. Once this point is reached the channel that has an empty queue is ignored for the rest of the frame. If both queues are empty, then the frame has been missed and the system waits for a new preamble. The Channel combining block also handles the preamble insertion. Since the symbols have already been equalized, the frame signals provided to the BB board should carry an ideal preamble. This way the equalization performed by the BB board will not make any difference.

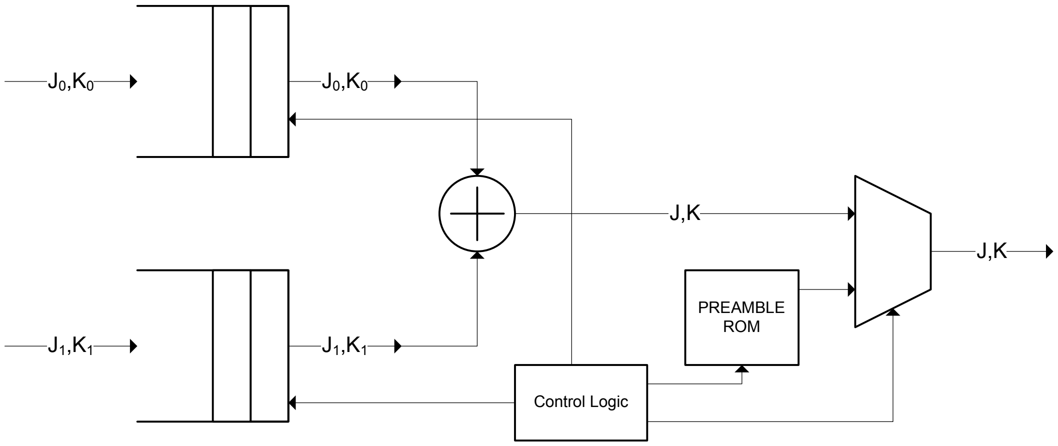


FIGURE 3.12: CHANNEL COMBINING BLOCK

3.2.10 Inverse Fast Fourier Transform

The IFFT block transforms the sucarriers into time samples. The strategy followed by this block is the same than the FFT block. There are two IFFT cores that work in parallel to meet the timing needs of the system. A major difference between the FFT core and the IFFT core is that the later inserts the CP as samples come out of its internal memory.

3.2.11 Amplitude Denormalization

The amplitude measured at the beginning is restored by the Amplitude Denormalization block; however the amplitude restored is the average of the amplitudes measured by both receiving channels. This only applies if both channels were correctly detected. Otherwise only the amplitude of the detected channel is restored.

3.2.12 Digital Up Converter

Finally the DUC Converter block centers the output signal at 10MHz which is the center frequency that the BB board is waiting.

3.3 DSP MODEL SIMULATION RESULTS

A very comprehensive DSP model simulation has been carried out. The simulation model covers from the Time Synchronization block up to the IFFT and CP insertion block. The simulation input signals were signals captured from real BS with a spectrum analyzer, so they were "rich" in timing errors as well as frequency offset errors. The simulations details as well as the results are listed below:

Parameters	Value
BW	10MHz.
CP	1/4

Quantization	**Channel Type**	**SNR**	**MRC RX SNR**	**Observation**
Floating point quantization	Frequency selective fading with AWGN 25dB	14.32dB	16.35dB	This kind of channel is found on indoor environments.
	Flat fading channel with AWGN 25dB	22.6dB	24.3dB	This kind of channel is found on outdoor LOS environments.
	AWGN 6dB	5.8dB	9.4	

The system behaves pretty much the same as the ideal system simulated on section 2.2. The main differences arise for the flat fading channel. This is due to the fact that the signal used for the test is not ideal and it already own errors introduced by the Spectrum Analizer at the time of capturing. The constellation error that the input signal exhibits determines the roof of the achievable SNR in this test.

3.4 TESTING WORK

The design has been concluded successfully and the blocks of the DSP algorithm have been tested independently. For this purpose the WG has used the following development tools provided by Albentia Systems:

- An Spartan 6 development platform
- Quad ADC Evaluation module from Texas Instrument.
- ADC to FMC(FPGA Mezzanine Connector) adapter card.
- Dual DAC Evaluation module from Texas Instrument.
- DAC to FMC adapter card.

Since the FGPA development platform mentioned above only allows interfacing either the ADC or the DAC board; the input stages, output stages and intermediate stages of the DSP algorithm have been tested separately.

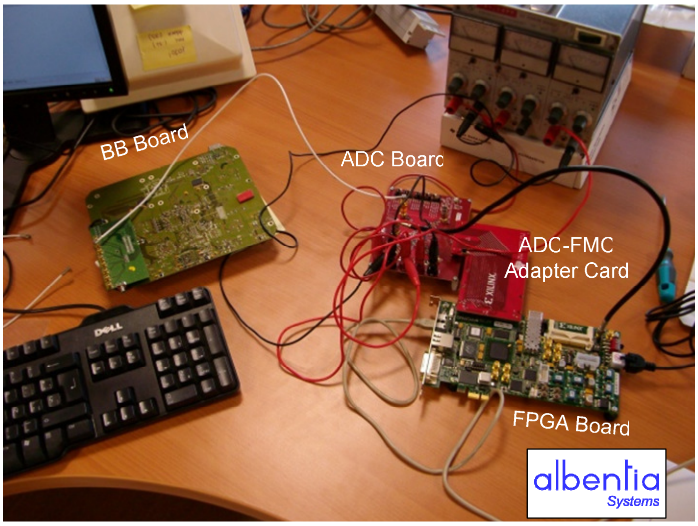


FIGURE 3.13: CURRENT DSP TEST SETUP

In order to perform system tests that will be reported in the future deliverable 6.5 the WG has acquired the following platform:

- FPGA Virtex 6 development platform: EK-V6-ML605-G.

This platform has been selected among others because it has the following required features:

- XC6VLX240T-1FFG1156 Virtex 6 FPGA with 768 DSP48E1 Slices which are very useful for the whole DSP algorithm integration.
- Two FMC interfaces available to allow the simultaneous connection to the ADC and DAC cards
- PCI Express expansion bus which allows the interfacing with a computer for fast data uploading and downloading.

3.5 REFERENCES

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