Rx Diversity/MIMO Antenna Integration

Application Note 57

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Supported Products:	**See** Section 1.1

Contents

0 Document History

Preceding document: AN57: "Rx Diversity/MIMO Antenna Integration", Version 01
New document: AN57: "Rx Diversity/MIMO Antenna Integration", Version **02**

Chapter	What is new
1.1	Updated supported products in the list.
3	Added 600MHz in Table 1 and Table 2.
3.1	Added 1700MHz and 2300MHz.
1.1	Added J variant to Supported Products.

New document: AN57: "Rx Diversity/MIMO Antenna Integration", Version 01

Chapter	What is new
--	Initial document setup.

1 Introduction

Rx diversity/MIMO antenna integration provides for an adaptive method of combining receive signals to enhance link quality and/or throughput.

Rx diversity is especially advantageous if operating at higher data rates (>14,4Mbps), where the higher order modulation technologies (>16QAM) are more susceptible to variations in receive signal strength, e.g., fading.

MIMO is especially advantageous in a stable downlink path environment to maximize throughput by multiplexing data over two or more layers (RF links).

To fully use the benefit of the Rx diversity/MIMO antenna, proper antenna design is essential. The main purpose of this Application Note is to assist wireless application engineers with their antenna implementations.

Following a short introduction to Rx diversity/MIMO (see Chapter 2), the document identifies the key antenna performance parameters for diversity antenna design (see Chapter 3) and gives hints for Rx diversity/MIMO implementation (see Chapter 4).

1.1 Supported Products

This Application Note applies to the following Thales products supporting MIMO (2x2 MIMO):

- Cinterion® PLS63-W Module
- Cinterion® PLS63-EP Module
- Cinterion® PLS63-LA Module
- Cinterion® PLS63-J Module
- Cinterion® PLS63-X Module
- Cinterion® PLS63-X2 Module
- Cinterion® PLS63-X3 Module
- Cinterion® PLS63-X4 Module
- Cinterion® PLS63-I Module
- Cinterion® PLS83-W Module
- Cinterion® PLS83-EP Module
- Cinterion® PLS83-LA Module
- Cinterion® PLS83-J Module
- Cinterion® PLS83-X Module
- Cinterion® PLS83-X2 Module
- Cinterion® PLS83-X3 Module
- Cinterion® PLS83-X4 Module
- Cinterion® PLS83-I Module

Where necessary, a note is made to differentiate between individual product variants.

1.2 Related Documents

[1] Hardware Interface Description provided with your Thales module
[2] AT Command Set provided with your Thales module

1.3 Abbreviations

Abbreviation	Description
EIRP	Effective isotropic radiated power
MIMO	Multiple Input Multiple Output
MRD	Mobile receive diversity
PA	Power amplifier
PCB	Printed Circuit Board
SNR	Signal-to-Noise Ratio
RxD	Receive Diversity
VSWR	Voltage standing wave ratio

2 Overview

The following two sections introduce basic concepts to improve the stability and quality of the downlink path in a multipath environment, and/or to optimize throughput in a stable downlink path environment.

2.1 1x2 Rx Diversity (1x2 RxD)

Note that the term Rx diversity is typically related to LTE/WCDMA and sometimes GSM. Its main purpose is to increase the SNR.

In a multipath environment the base station signal can reach the mobile device directly (vertical polarized signal from the base station) and/or via a reflected signal path (polarization will be changed, most probably not vertical). The signal may as such reach the mobile device from various directions.

The basic diversity idea is to use two different receive Rx antennas simultaneously with one Tx antenna at the mobile network‘s base station (1x2 RxD). The two antennas should have a different radiation pattern and polarization as well as a certain mechanical distance between each other. The mechanical displacement of both antennas helps to avoid signal fading nulls that occur with a spatial distribution. The displacement makes signal fading nulls unlikely to happen at both antenna locations at the same time.

1x2 RxD is therefore applied to even out fading and to rectify receive signal nulls - resulting in a more constant signal level versus time.

Please also note that 1x2 RxD cannot overcome a weak performance of the main antenna. For an overview of RxD performance parameters see Chapter 3.

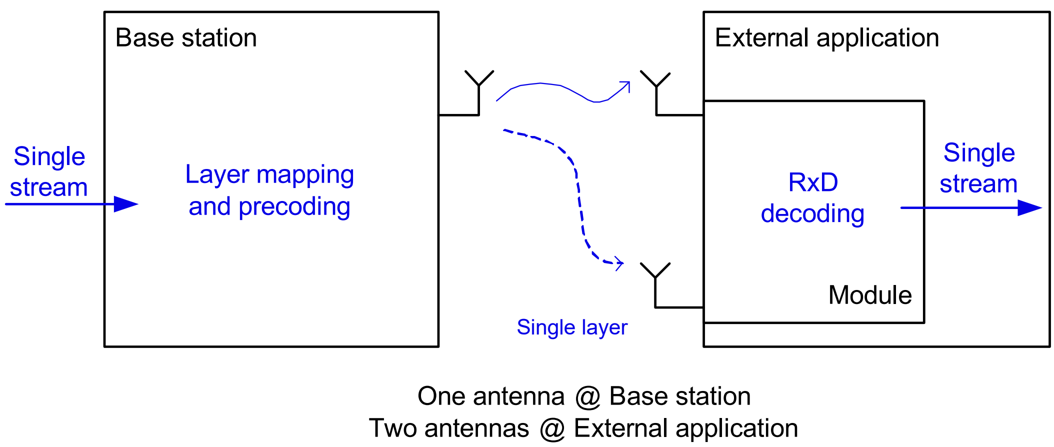

Figure 1: Single stream transmission (1x2 scenario)

2.2 2x2 Multiple Input Multiple Output (2x2 MIMO)

In contrast to the 1x2 RxD setup described in Section 2.1 providing the diversity as well as the signal-to-noise ratio (SNR) gain benefits, a 2x2 multiple input multiple output setup (2x2 MIMO) requires two Tx antennas at the mobile network's base station, and two Rx antennas at the module's application side.

Note that the term MIMO is related to LTE, especially in combination with carrier aggregation, and that its main purpose is to increase data throughput.

Compared with a 1x2 RxD setup, the 2x2 MIMO setup provides the following two enhancements:

- Single-stream transmission: At poor propagation conditions and low SNRs, a single data stream can be sent from both transmit antennas (see Figure 2). This provides transmit diversity and transmit beam-forming gains in addition to the usual 1x2 RxD gains provided by the two Rx diversity antennas of the module's application side.

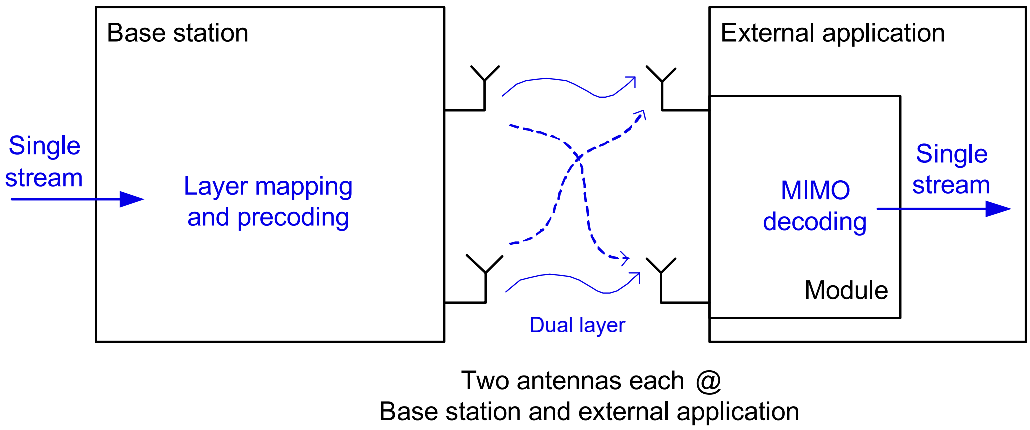

Figure 2: Single stream transmission (2x2 scenario)

- Dual-stream transmission: At good propagation conditions and high SNRs, two data streams can be spatially multiplexed over the 2x2 channel between the Tx and Rx antennas (see Figure 3). When the 2x2 channel is well conditioned, a high data rate can be sent over both these streams, resulting in a possible two-fold increase in data rates.

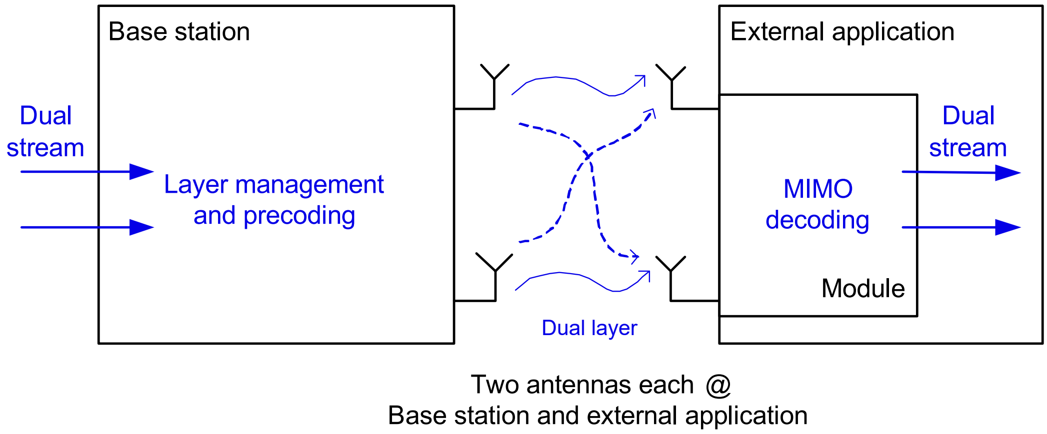

Figure 3: Dual stream transmission (2x2 scenario)

With the antenna performance parameters of imbalance for 1x2 RxD <6dB and for 2x2 MIMO <3dB, and the envelope correlation coefficient <0.5 recommended in Chapter 3 for 1x2 RxD, the 2x2 MIMO enhancements are preserved in most scenarios. Therefore, no tightening of the 1x2 RxD antenna requirements except for antenna imbalance is required. The antenna performance parameters and implementation hints given in Chapter 3 and Chapter 4 for 1x2 RxD apply to 2x2 MIMO as well.

3 Antenna Performance Parameters

For Rx antenna diversity, the two most important antenna performance parameters are:
- (Low) gain difference between the two antennas
- (Low) fading (or envelope) correlation coefficient between the two antennas

However, there are other basic antenna performance parameters that must also be considered to achieve optimum Rx antenna diversity performance:

- Antenna efficiency - An indicator of how effectively the antenna receives or transmit signals (see AT&T requirements as a reference)
- Envelope correlation coefficient - An indicator of pattern similarity between the primary and secondary antennas. This impacts Rx antenna diversity performance in the field.
- Isolation - Amount of coupling energy between the primary and secondary antenna. Antenna efficiency is affected by isolation.
- VSWR (or |S11|)- Antenna input impedance response as function of frequency. This shows the antenna resonances and its bandwidth.
- Polarization - Pointing direction of the electric (E) field of the antenna. For good diversity performance, the primary and secondary antennas should have different polarizations.
- Pattern shape - Distribution of the far-field antenna gain as function of elevation and azimuth angles. Omnidirectional in the azimuth plane is typically preferred for terrestrial type applications.
- Body effect - Antenna efficiency loss due to absorption, blockage and pattern distortion by the head and/or hand of the user

Table 1 summarizes recommended antenna performance parameter values for an optimized Rx antenna integration. Section 3.1 and Section 3.2 describe basic primary and secondary antenna parameters in more detail. Note that in MIMO applications, and especially in combination with carrier aggregation, the usage of the secondary Rx antenna is quite important.

Table 1: Recommended antenna performance parameter values (primary antenna)

Parameter	Value	Description
Primary antenna (A0)		
Functionality	Tx and Rx0	Main antenna. Performs both transmit and receive functions similar to non-MRD antenna
Free space peak antenna gain (max of Gv and Gh)[1]	> 1dBi	Allows for meeting peak EIRP with commercially available PAs
Free space antenna efficiency (radiated vs. port input power)[2] • Low bands (600/700/800/900MHz) • High bands (1710-2690MHz)	> -4dB (40%) > -2dB (60%)	Typical for today's mobile phones
Body loss gain degradation[3] • Low bands (600/700/800/900MHz) • High bands (1710-2690MHz)	-5dB -3dB	Typical for today's mobile phones
Polarization [4] (ratio of average Gv to Gh)	> 0dB	RF environment for cellular tends toward V-polarization

Table 1: Recommended antenna performance parameter values (primary antenna)

Parameter	Value	Description
Input VSWR (relative to 50Ω) • Free space • With body loading	 < 2:1 < 2.5:1	Typical for today's mobile phones
Average power handling	> 2W	Typical for today's mobile phones

1. Gv = gain measured by using a vertically-polarized source antenna; Gh = gain measured using a horizontally-polarized source antenna.
2. Efficiency is the sum of the measured average gain values for the vertical and horizontal polarizations (Gv + Gh), where both Gv and Gh are measured (and averaged) over 0-180° in elevation and 0-360° in azimuth.
3. Head-and-hand losses are assumed to be similar for the primary (A0) and secondary (A1) antennas. If not, the difference in net average gain (free space average gain plus body losses) for A0 and A1 should be less than 6dB.
4. Tested with the handset in its talk position (held at 60° elevation angle and against the head).

Table 2: Recommended antenna performance parameter values (secondary antenna)

Parameter	Value	Description
Secondary antenna (A1)		
Functionality	Rx1	Rx diversity/MIMO antenna. For diversity reception and combining
Free space antenna efficiency (radiated vs. port input power)[1] WCDMA (1x2 RxD): • Low bands (700/800/900 MHz) • High bands (1710-2690 MHz) LTE (2x2 MIMO): • Low bands (600/700/800/900 MHz) • High bands (1710-2690 MHz)	 > -10dB (10%) > -8dB (16%) > -7dB (20%) > -5dB (30%)	Typical for today's mobile phones < 6dB lower than primary < 3dB lower than primary
Body loss gain degradation[2] • Low bands (600/700/800/900 MHz) • High bands (1710-2690 MHz)	 -5dB -3dB	Typical for today's mobile phones
Polarization[3] (ratio of average Gv to Gh)	> 0dB	RF environment tends toward V-polarization
Input VSWR (relative to 50Ω) • Free space • With body loading	 < 3:1 < 3.5:1	Typical for today's mobile phones

1. Efficiency is the sum of the measured average gain values for the vertical and horizontal polarizations (Gv + Gh), where both Gv and Gh are measured (and averaged) over 0-180° in elevation and 0-360° in azimuth.
2. Head-and-hand losses are assumed to be similar for the primary (A0) and secondary (A1) antennas. If not, the difference in net average gain (free space average gain plus body losses) for A0 and A1 should be less than 6dB.
3. Tested with the handset in its talk position (held at 60° elevation angle and against the head).

Table 3: Recommended antenna performance parameter values (antenna-to-antenna)

Parameter	Value	Description
Antenna-to-antenna requirements		
Antenna imbalance: • WCDMA (1x2 RxD) • LTE (2x2 MIMO)	 > -6dB > -3dB	
A0-to-A1 isolation	> 12dB	Improves transmit efficiency; lower isolation could allow secondary impedance mismatch to alter the primary transmit antenna pattern. Reduces possibility of self jamming
Correlation coefficient (ρ_e)[1]	< 0.5	Allows for minimal capacity impact

1. As calculated from measured complex pattern data.

3.1 Primary Antenna

The primary antenna determines the over-the-air performance of the radio system under non-faded propagation conditions. The transmit function of an Rx diversity device relies solely on the primary antenna. Electrical performance parameter can be derived from the OTA requirements applicable for AT&T approval. Key values are:

- Antenna efficiency:
  - >40% (low bands 600/700/800/900MHz)
  - >60% (high bands, 1700/1800/1900/2100/2300/2600MHz)
- Antenna matching: Minimum -10dB reflection loss
- Antenna polarization: Vertical
- Antenna radiation pattern: Omnidirectional

A primary antenna meeting these requirements would be for instance the wide-band SMD antenna PA.710A from Taoglas. For more information and a data sheet see www.taoglas.com.

3.2 Secondary Antenna

Since the Rx diversity antenna is used for the receive function only, its required performance is typically less than 45% of that of the primary antenna. This allows for the smaller internal antenna types to be used as secondary antenna. In addition, the Rx diversity antenna does not have to perform as well as the primary antenna. However, its performance must be good enough so that it can still receive base station signals in most of the coverage areas. A large gain imbalance between the primary and secondary antennas will result in lower diversity gain. In summary, the secondary antenna of an Rx diversity capable device

- performs only the receive function,
- covers less than 45% of the primary antenna performance,
- should have efficiency better than 6 dB for WCDMA (1x2 RxD) and 3 dB for LTE (2x2 MIMO) lower than the primary antenna efficiency (and within 3 dB of the primary antenna efficiency as the design goal).

A secondary antenna meeting these requirements would be for instance the 850/1900MHz Dual Band Diversity RX Ceramic Antenna (W3047A) from Pulse Electronics. For more information and a data sheet see www.pulseelectronics.com.

3.3 Antenna Characteristics

3.3.1 Polarization

The pointing direction of the electric (E) field of an antenna characterizes its polarization.

Antenna polarization can be linear, circular or elliptical. Dipole, monopole and other common phone antennas have linear polarization. For optimum communication between the base station and the mobile phone, the polarization of their antennas should be the same. Most of the existing base station antennas have vertical polarization; therefore, the polarization of the mobile phone antenna should be designed to have vertical polarization. For the case of Rx antenna diversity, the primary antenna should have vertical polarization while the secondary antenna can have horizontal polarization to enhance diversity gain. Indoors, due to scattering, a horizontal component of the base station signals is often generated.

In general, the following polarization characteristics of the Rx diversity antennas are recommended:

- Primary antenna polarization: Predominantly vertical
- Rx diversity antenna polarization: Horizontal or mixed

3.3.2 Pattern Shape

The gain distribution of the antenna as a function of azimuth and elevation angles specifies the shape of the antenna radiation pattern. For a terrestrial application such as cellular phone service, a donut-like pattern shape of a half wavelength dipole is generally preferred for the mobile antenna, since the incident angles of the base station signals are mostly near the horizontal plane. To maximize diversity gain, the pattern shape of the primary and secondary antennas should complement each other. Difference in pattern phase helps to reduce envelope correlation coefficient value.

The following antenna pattern shape is recommended for an Rx diversity device:

- Shape of primary antenna pattern: Near omni in azimuth is preferred
- Shape of the secondary antenna pattern: Complementing the shape of the primary antenna pattern, if possible

In practice, it is difficult to achieve perfectly complementary patterns for the two antennas. However, the calculation of envelope correlation is a good measure of similarity of the patterns. Perfect correlation of one indicates that the patterns are identical, while a correlation of zero means they are perfectly complementary.

3.3.3 Antenna Placement

In general a certain distance between both antennas (main and diversity) is recommended. As a rule of thumb the decoupling (=|S21|) between both antennas will increase with distance. Larger decoupling results in a lower correlation coefficient. However, there are two different cases to consider:

1. Polarization of both antennas is identical. This requires a larger displacement. A quarter wave length at 850Mhz would for example be 9cm as shown in the below figure. A typical application would be a mobile phone with the main antenna on top of the PCB and the diversity antenna on the bottom side.

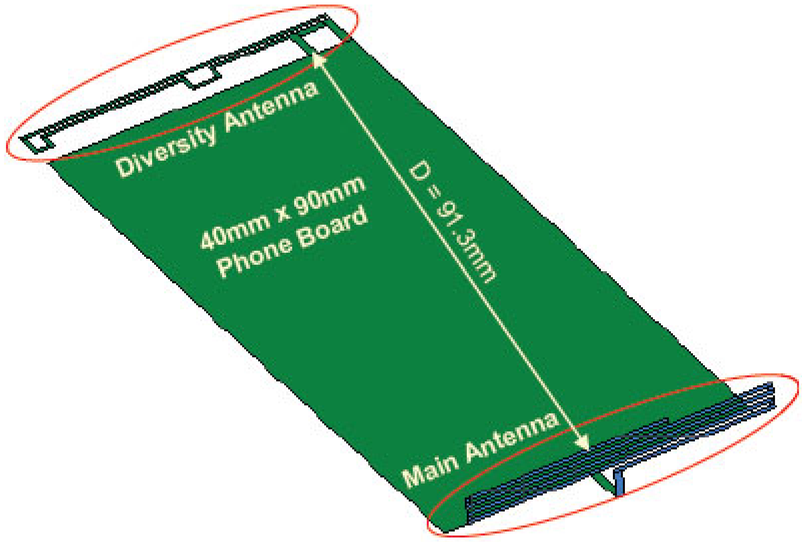

Figure 4: Antenna placement with identical polarization

2. Polarization of both antennas is different, i.e., the main antenna's polarization is vertical and the diversity antenna's polarization is horizontal. This results in a cross polarization decoupling of up to 20dB that is more or less independent of the distance between both antennas.

   This applies for two dipole antennas without common ground. If both antennas are monopol antennas using a common ground plane there is more coupling between them via the ground currents. This way the decoupling of about 20dB is reduced. Increasing the distance between both feeding points might help to compensate for this. As this effect depends on several parameters (layout, component placement, housing) it is difficult to specify a recommended distance between the two antennas. The below figure shows an example.

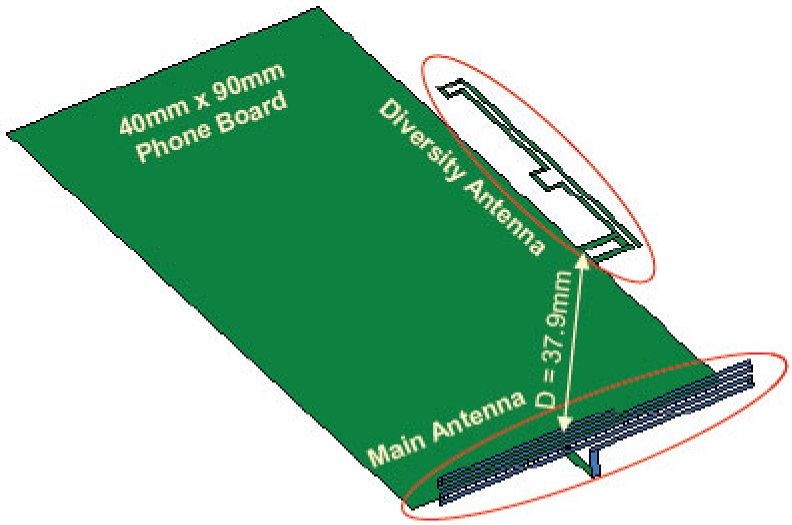

Figure 5: Antenna placement with different polarization

4 Implementation Hints

The following implementation hints should be considered in the development of an Rx antenna diversity system:

- Antenna size
  - The lowest operating frequency band of the antenna determines its minimum size.
  - Lower operating frequencies require larger antenna size for resonance.
  - Using a matching circuit can help to reduce antenna size; however, this often results in lower antenna efficiency due to higher dissipation loss of smaller antenna size (because of higher antenna current density) and insertion loss of the matching components.
- Mounting location
  - Bandwidth, pattern shape, polarization, body effect, and radiated performance of an antenna are influenced by its mounting location.
  - An antenna's bandwidth and efficiency may be reduced if it is installed too close to metal objects such as shield cans, speakers, batteries, camera, or a PCB ground plane.
  - Antenna mounted near display, camera, memory, and other digital components with high clock speeds can pick up RF noise generated by harmonics of these devices, which results in the degradation of receiver performance.
- Antenna isolation (|S21|) and envelope correlation coefficient are not directly related and should be considered separately in the design process and measurements.
  - Good isolation (or low coupling) does not guarantee low envelope correlation coefficient.
  - For unbalanced antennas that share the same ground plane (PCB of the device), larger separation between the primary and secondary antennas might not help to improve the isolation (|S21|) level between them since the coupling can occur over-the-air or through conducted antenna currents on the shared ground plane. However, the envelope correlation coefficient value should improve with the larger separation.

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