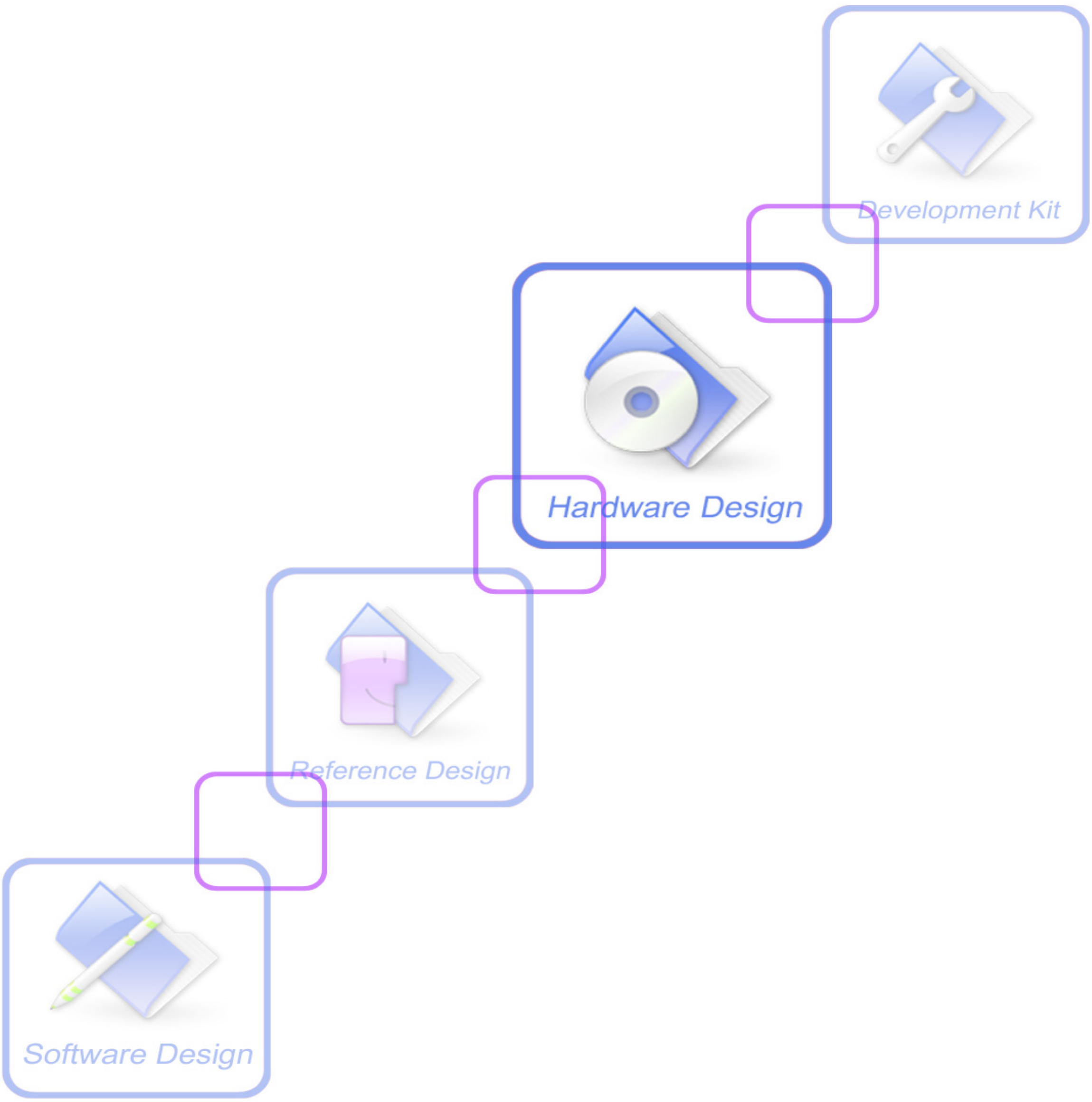
ANTENNA DESIGN GUIDELINES FOR DIVERSITY RECEIVE SYSTEM V1.01



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Version History

Date	Version	Description of change	Author
2014-10-22	1.01	Origin	Li Ya

1 Introduction

This document describes the key antenna performance parameters for mobile receive diversity (MRD) and the necessary steps to evaluate these parameters. Recommended antenna performance specifications are included in this document. Some antenna design examples for typical wireless device form factors are included in this document to demonstrate the feasibility of implementing dual antennas.
This document is intended to assist modem designers with their antenna implementations. By following the guidelines and processes described in this document, successful diversity product developments should improve significantly.

2 Overview

2.1 Antenna system of a device with mobile receiver diversity overview

The antenna system of a device with mobile receiver diversity capability consists of:

- **A primary TX/RX antenna** – similar to antennas of existing non-diversity mobile devices
- **A secondary Rx-only antenna –** typically smaller than the primary antenna

It is shown in the following figure:

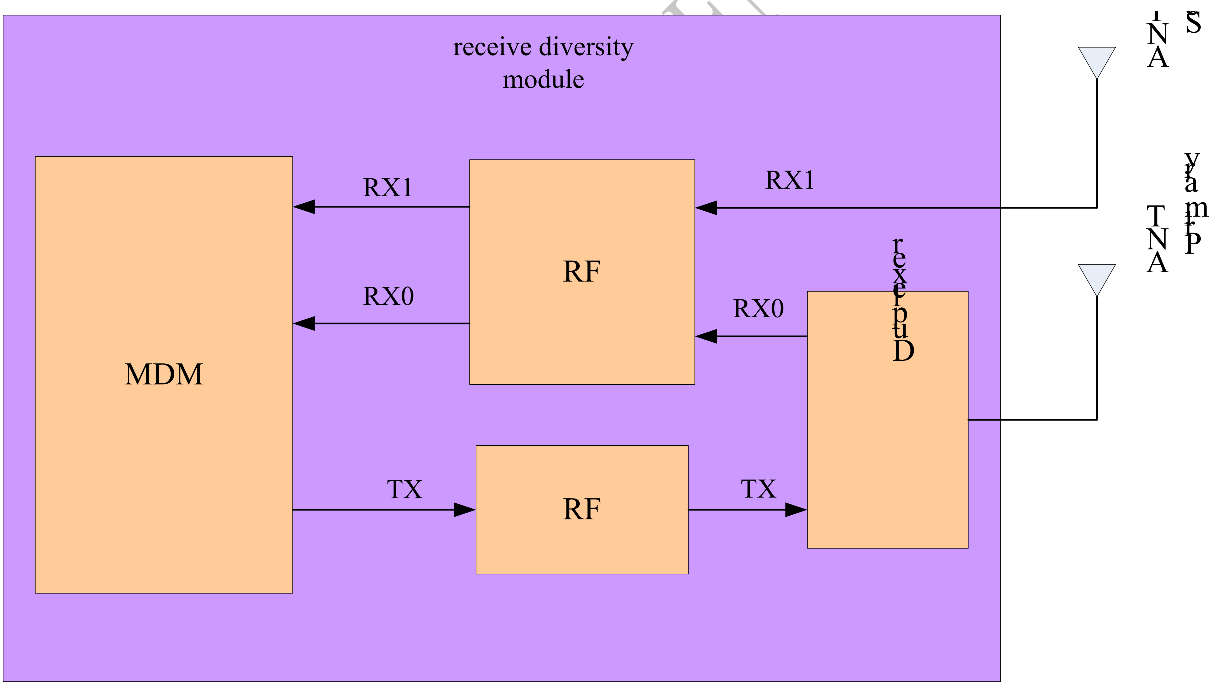


Figure 1: Diversity receive system

System of a device with mobile receiver diversity requires two antenna elements: a primary antenna and a secondary antenna. The primary antenna is connected to the transmitter and the main receiver Rx0 of the modem, while the secondary antenna is routed to the diversity receiver Rx1.

The greatest gains are achieved where they are most needed for receive diversity system. The system can produce the largest gains, reducing the interference of competing sector signals and allowing users to operate at higher data rates or lower forward-traffic powers

The received signals of the two receivers are processed and combined at the baseband using several algorithms to maximize the received signal-to-interference-plus-noise ratio (SINR), It is shown in figure 2.

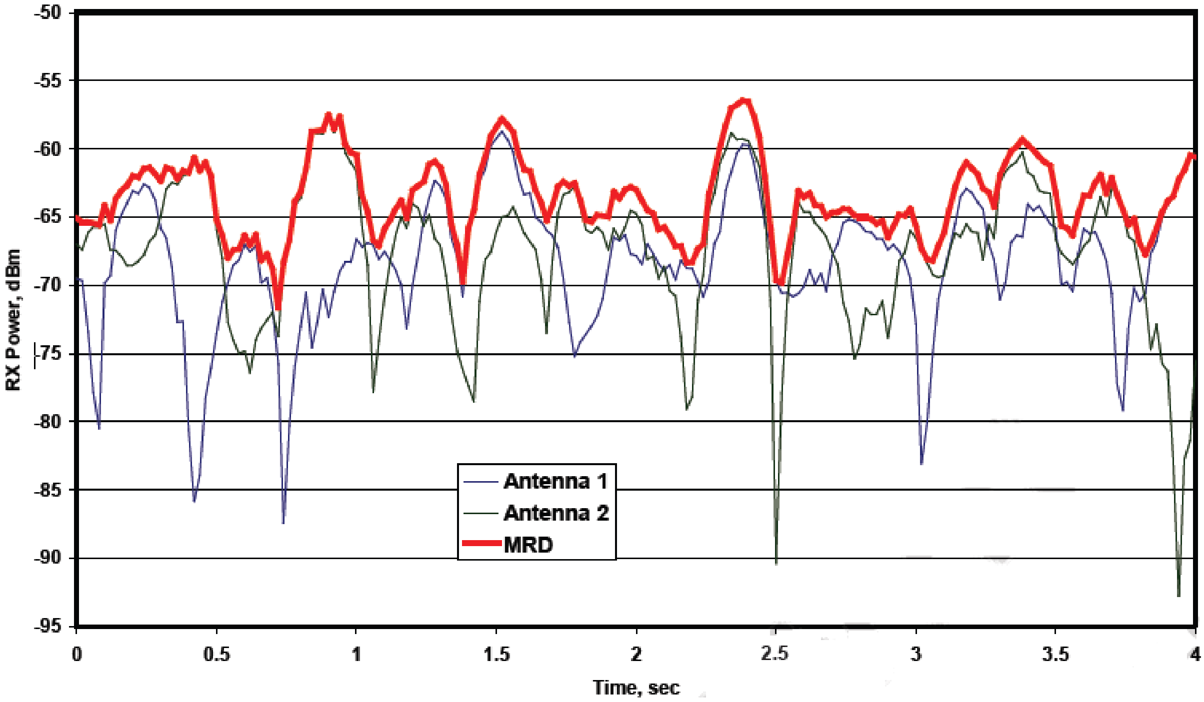


Figure 2: Receive signal strength of antennas with and without diversity

It can be come to a conclusion that , with receiver diversity the forward link power can be reduced to half or less while actually improving FER in voice services. For data services, higher data rates are achieved with MRD while forward traffic power remains the same.
So if the device can support receive diversity, the secondary antenna should be also taken into account. Without the secondary antenna, the system would get worse FER in voice and lower data rates than two antennas.

2.2 Primary and secondary antenna overview

Many compact designs necessitate a diversity antenna that is not identical to the primary, such as external/internal pairs or dual internal antennas of different types. In a multipath environment, the resulting pattern diversity allows two antennas to receive relatively uncorrelated signals despite small separation of their respective phase centers.

2.2.1 Primary antenna

As the minimum, the primary antenna must have the same electrical performance as that of a single-antenna phone. Furthermore, the transmit function of a diversity receiver system relies solely on the primary antenna. The primary antenna can be external or internal type similar to those used in non-diversity receiver phones. External antennas, such as whip or stubby, generally have superior performance compared to the internal ones and require less internal space. However, these external antennas are not compatible aesthetically with the newer thin phones.

In summary, the primary antenna of a diversity receiver system:

1. Should perform the same as the antenna in single-receiver phone
2. Can be an external or an internal antenna
3. Should perform both transmit and receive functions

2.2.2 Secondary antenna

Since the diversity antenna is used only for the receive function, its required bandwidth is typically less than 45% of that of the primary antenna. This allows for the smaller internal antenna types to be used as the secondary antenna. In addition, the 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. Large gain imbalance between the primary and secondary antennas will result in lower diversity gain. In summary, the secondary antenna of a diversity receiver system:

1. Could be an internal type because of aesthetics consideration
2. Performs only the receive function
3. Covers less than 45% of the primary antenna bandwidth
4. Should have efficiency of no more than 6 dB lower than the primary antenna efficiency (and within 3 dB of the primary antenna efficiency as the design goal)

2.2.3 Key antenna performance parameters

There are two main antenna parameters that impact diversity receiver system performance:

1. The gain or efficiency difference between the primary and secondary antennas
2. The envelope (or fading) correlation coefficient between the two antennas

3 Antenna Performance Parameters and placement

3.1 Antenna Performance Parameters

For diversity receiver system, the two antennas have other basic antenna performance parameters that must also be considered to achieve optimum performance. All the relevant antenna performance parameters are listed below:

1. **Antenna efficiency** – How effectively the antenna receives or transmits signals.
2. **Envelope correlation coefficient** – An indicator of pattern similarity between the primary and secondary antennas. This impacts system performance in the field.
3. **Isolation** – Amount of coupling energy between the primary and secondary antenna. Antenna efficiency is affected by isolation.
4. **VSWR**– Antenna input impedance response as function of frequency. This shows the antenna resonances and its bandwidth.
5. **Polarization** – Pointing direction of the electric (E) field of the antenna. For good diversity performance, the primary and secondary antennas should have different polarizations.
6. **Pattern shape** – Distribution of the far-field antenna gain as function of elevation and azimuth angles.

3.1.1 Antenna efficiency

Recommended antenna efficiency is:

- **Primary antenna efficiency > -4 dB (or 40%)**
- **Diversity antenna efficiency > -10 dB (or 10%)**

These antenna efficiency values are recommended for free space condition.

3.1.2 Envelope correlation coefficient

This coefficient is the cross-correlation value of the complex patterns of the primary and secondary antennas. It indicates how similar or how different the magnitude and phase patterns of the two antennas are. For ideal MRD performance, the two patterns should have no similarity or a correlation coefficient value of zero
The recommended value of the envelope correlation coefficient to achieve good diversity performance in the field is:
Correlation coefficient < 0.5
The envelope correlation coefficient value of greater than 0.5 can actually degrade diversity performance.

3.1.3 Isolation

For a wireless device with multiple antennas, such as a diversity receiver system, there is cross- coupling energy between a pair of adjacent antennas. The antenna isolation parameter indicates the amount of coupling and can be measured using a two-port network analyzer.

The recommended primary-to-secondary antenna isolation for is:

Primary-to-secondary antenna isolation > 8 dB for all bands (or |S21| < -8 dB)

For example to the placement, if the antenna is bar antenna or whip antenna 3-a is recommended than 3-b, if the composition is impossible for 3-a, make the two antenna far away some like 3-c

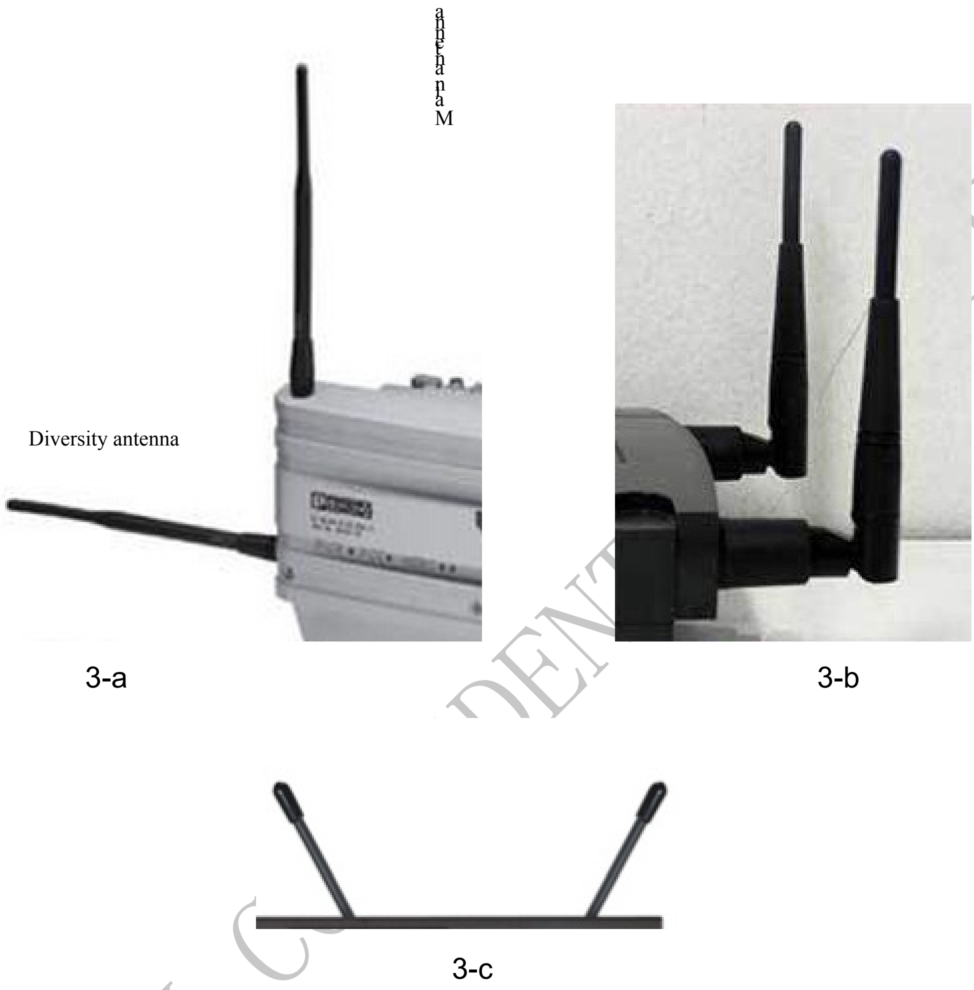


Figure 3: Bar antenna placement

3.1.4 VSWR

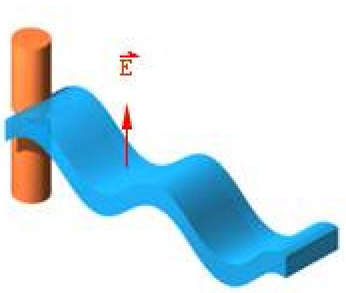
Voltage standing wave ratio (VSWR) is a way of expressing the antenna input impedance relative to 50 Ω as function of frequency
it is important to keep the VSWR level of the antenna in the frequency band of interest at a reasonable recommended level, such as:

- **VSWR of the primary antenna < 3:1 in free space for all bands**
- **VSWR of the secondary antenna < 3:1 in free space for all bands**

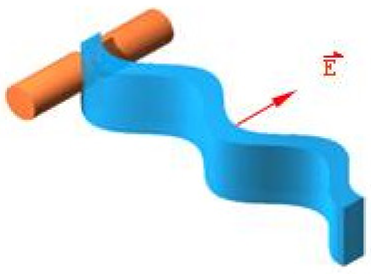
3.1.5 Polarization

For diversity receiver system, 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 MRD antennas are recommended:

- **Primary antenna polarization: predominantly vertical**
- **Diversity antenna polarization: horizontal, vertical, or mixed**



Primary antenna polarization



Diversity antenna polarization

Figure 4: Different polarization of the primary antenna and diversity antenna

3.1.6 Pattern shape

The gain distribution of the antenna as a function of azimuth (φ) and elevation (θ) 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.

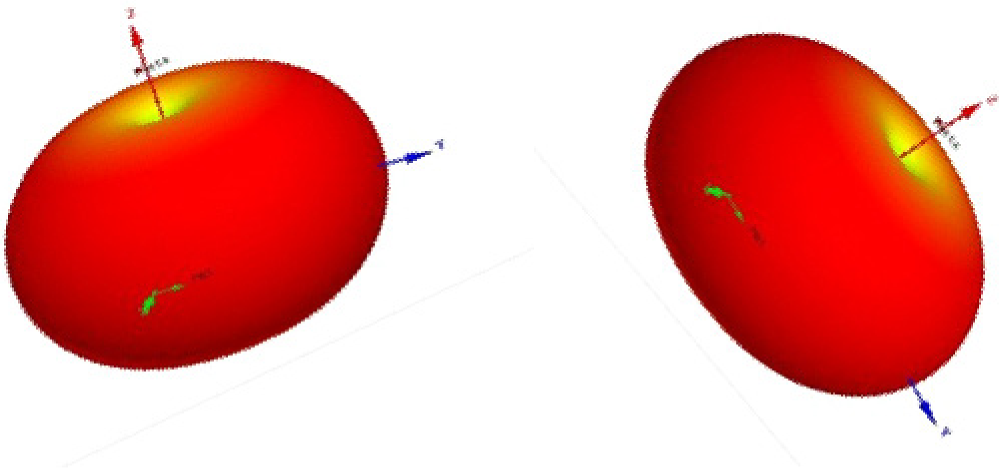


Figure 5: Difference in pattern of the primary antenna and diversity antenna

If the antenna is internal antenna, 6-a is recommended than 6-b

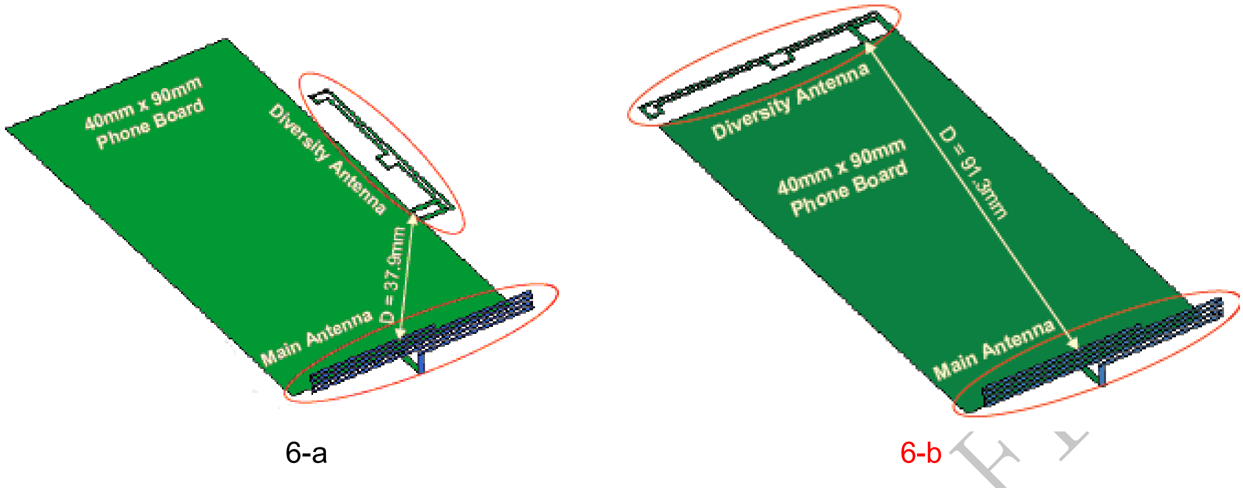


Figure 6: Internal antenna placement

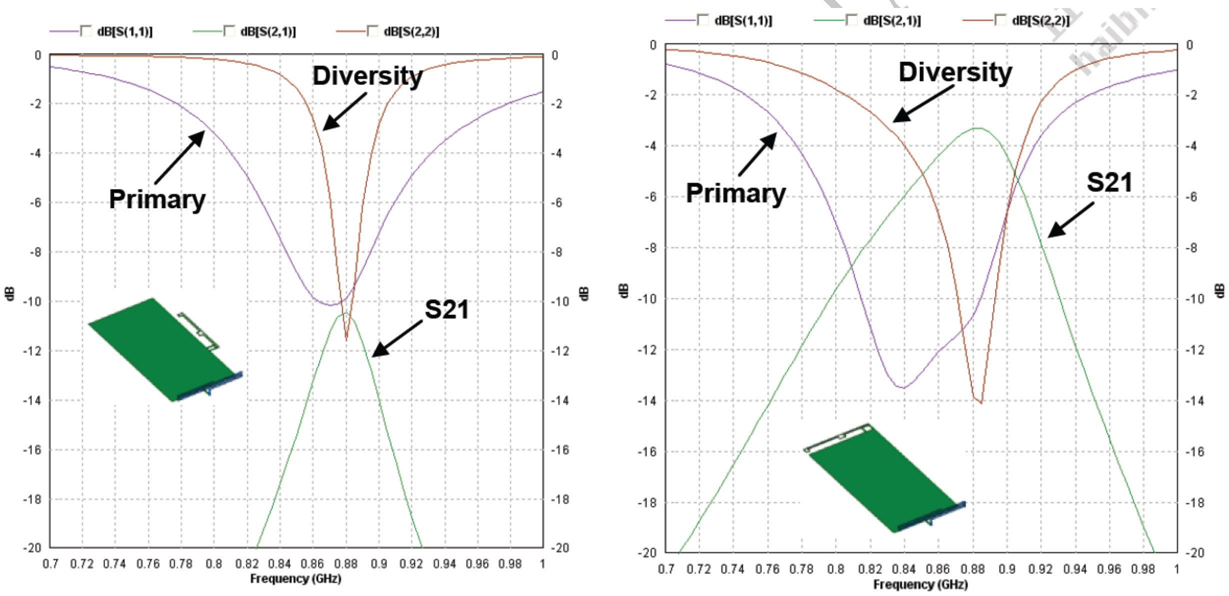


Figure 7: S21 for different placement

S-parameter results from the simulations of the two cases are compared for the case where the two antennas are closer (D = 37.9 mm), the |S21| level is 7.2 dB better than when the two antennas were separated farther apart (D = 91.3 mm).

Placement of the primary antenna and the diversity antenna can make correlation coefficient performance better; place the secondary antenna far away from the primary antenna and other wireless system GPS/WIFI antennas shown as the figure8

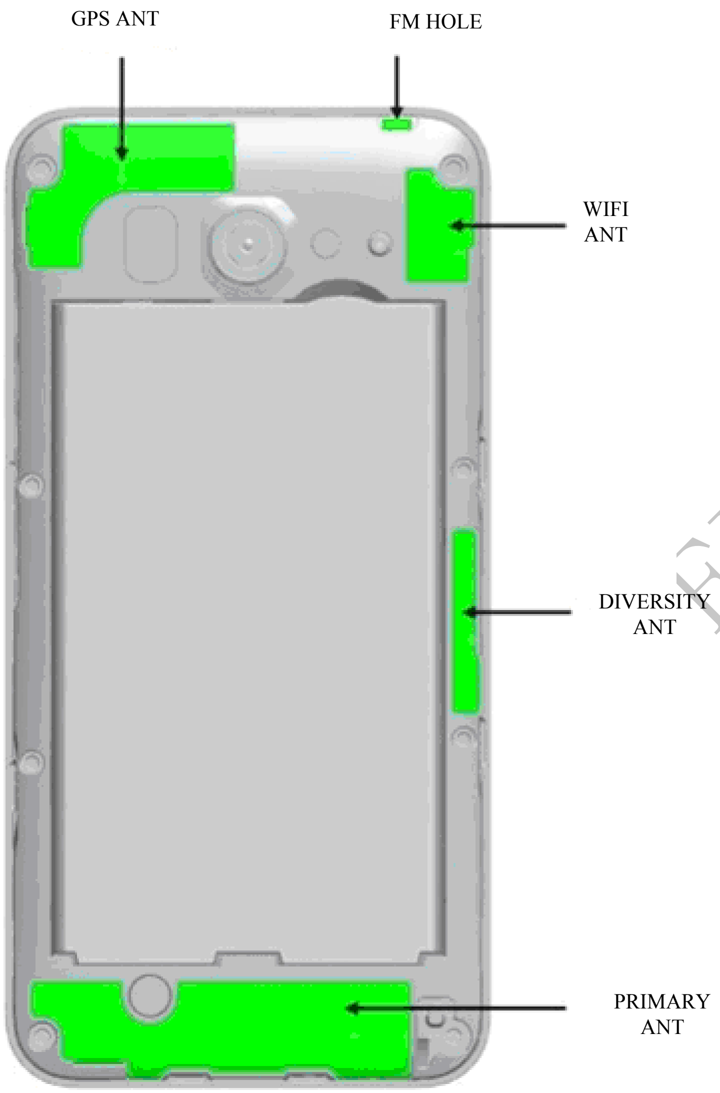


Figure 8: Placement of the primary antenna and diversity antenna

Note:

The mutual coupling effect between antennas that share the same ground plane is very complex and depends on many factors (antenna type, size, orientation, board size, etc.); therefore, it is not possible to generalize isolation and envelope correlation performance as functions of antenna separation. Simulation or measurement should be done to predict the mentioned performance parameters.

It is highly emphasized that antenna tradeoff study in terms of mounting location, antenna type be done early in the product development.

3.2 Recommended antenna performance objectives

The recommended antenna performance goals are summarized in table 1:

Table 1: recommended antenna performance

Parameter	Value	Rationale
Primary antenna		
Functionality	Tx and Rx0	Both transmit and receive functions
Free space peak antenna gain	> 1 dBi	
Free space average gain	> -3 dBi	
Free space antenna efficiency	> -4 dB	
Polarization	> 0 dB	
Input VSWR (relative to 50 Ω)	< 3:1	Free space
Secondary antenna		
Functionality	Rx1	For diversity reception and combining
Free space average gain	> -9 dBi	
Free space antenna efficiency	> -10 dB	
Polarization	> 0 dB	
Input VSWR (relative to 50 Ω)	< 3:1	Free space
Antenna-to-antenna requirements		
isolation	> 8 dB	
correlation coefficient	< 0.5	

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