

# Antenna Placement Guidelines For 2×2 MIMO WLAN

Associated Part Family: **CYW435X**

This document provides guidelines for placing Wi-Fi antennas in tablets or smartphones that include a Cypress MIMO WLAN chip from the CYW435X family of chips (CYW4354, CYW4356, and CYW4358), or other Cypress chips that support MIMO WLAN. It is intended for OEMs and engineers who are implementing 2×2 MIMO WLAN in their mobile device designs.

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## 1 About This Document

### 1.1 Purpose and Audience

This document provides guidelines for placing Wi-Fi antennas in tablets or smartphones that include a Cypress MIMO WLAN chip from the CYW435X family of chips (CYW4354, CYW4356, and CYW4358), or other Cypress chips that support MIMO WLAN. It is intended for OEMs and engineers who are implementing 2×2 MIMO WLAN in their mobile device designs.

### 1.2 Cypress part numbering scheme

Cypress is converting the acquired IoT part numbers from Broadcom to the Cypress part numbering scheme. Due to this conversion, there is no change in form, fit, or function as a result of offering the device with Cypress part number marking. The table provides Cypress ordering part number that matches an existing IoT part number.

Table 1. Mapping Table for Part Number between Broadcom and Cypress

Broadcom Part Number	Cypress Part Number
BCM4354	CYW4354
BCM4356	CYW4356
BCM4358	CYW4358

### 1.3 Acronyms and Abbreviations

In most cases, acronyms and abbreviations are defined on first use.

### 1.4 Document Conventions

The following conventions may be used in this document:

Convention	Description
<b>Bold</b>	User input and actions: for example, type <b>exit</b> , click <b>OK</b> , press <b>Alt+C</b>

Convention	Description
Monospace	Code: #include <iostream> HTML: <td rowspan = 3> Command line commands and parameters: w1 [-1] <command>
< >	Placeholders for <i>required</i> elements: enter your <username> or w1 <command>
[ ]	Indicates <i>optional</i> command-line parameters: w1 [-1] Indicates bit and byte ranges (inclusive): [0:3] or [7:0]

## 1.5 References

The references in this section may be used in conjunction with this document.

For Cypress documents, replace the “xx” in the document number with the largest number available in the repository to ensure that you have the most current version of the document.

Document (or Item) Name	Number	Source
<b>Cypress Items</b>		
[1] <i>Single-Chip 5G Wi-Fi IEEE 802.11ac 2x2 MAC/Baseband/Radio with Integrated Bluetooth 4.1, FM Receiver</i>	4354-DS1xx-R	CSP
[2] <i>RF Performance Measurements</i>	4354-T11xx-R	CSP

## 2 Technical Support

Cypress provides customer access to a wide range of information, including technical documentation, schematic diagrams, product bill of materials, PCB layout information, and software updates through its customer support portal (<https://community.cypress.com>).

### 3 Overview

The adoption of Wi-Fi in smart phones and tablets has exploded over the last few years. Robust internet connectivity is a key feature in today's mobile devices, driven by a rapidly increasing use of wireless Internet to download music, videos, and games, to support social networking applications, and more.

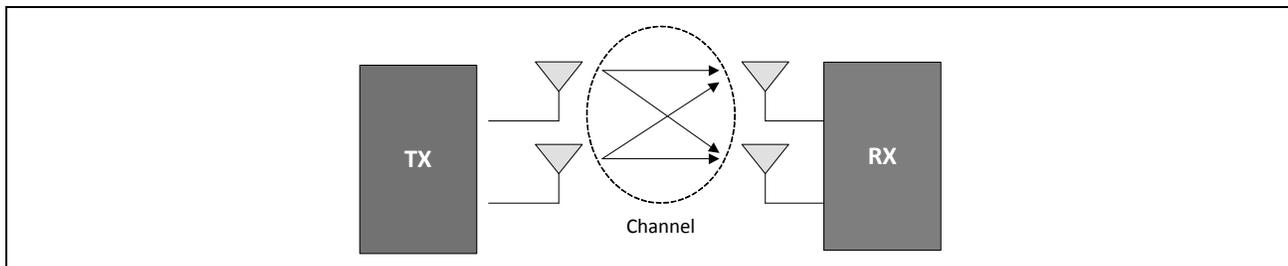
The 802.11ac specification has helped significantly on this front by providing more dense modulation schemes. Moving from Single Input Single Output (SISO) transmission to dual-stream 2x2 MIMO nearly doubles the throughput while improving overall coverage. This application note explains how a 2x2 MIMO WLAN transceiver provides superior performance compared with a SISO system and also provides guidelines for correctly placing the MIMO antennas in a smart phone.

### 4 2x2 MIMO System

As shown in Figure 1, a 2x2 MIMO system comprises a transmitter and a receiver that communicate through a propagation channel. The transmitter has two parallel chains. Each chain is attached to a separate antenna so that it can send two independent data streams simultaneously. Likewise, there are two parallel chains in the receiver with separate antennas to process the two incoming data streams.

A common characteristic of a real propagation channel is that it produces multipath for the transmit signal as it travels through the channel due to reflections from various objects in its path. A sufficiently rich scattering environment creates multiple spatially-decorrelated subchannels. Each subchannel can carry an independent data stream within the same frequency band as the other subchannels. The capacity for each (measured in b/s/Hz) can be predicted by the Shannon-Hartley theorem. Two ideal subchannels have no correlation between them and therefore result in double the overall capacity or data throughput. The correlation between the subchannels can also be compromised by the antenna-to-antenna mutual coupling at the transmitter, at the receiver, or both. This correlation can be minimized by increasing the distance between antennas, changing antenna radiation patterns, or ensuring that the polarization is different for each antenna in the pair.

Figure 1. 2x2 MIMO System



There is a physical limit on how far apart the two antennas that make up a pair can be in a portable terminal. A separation distance of a half-wavelength or closer can achieve reasonable performance. If each antenna in the pair points to a different direction in space, the radiation patterns have less overlap, which reduces coupling. Coupling can also be minimized if one of the antennas is vertically polarized and the other is horizontally polarized.

Ground current in the PCB that runs between the two antennas can also cause coupling if the antennas rely on the ground for propagation (as is the case for monopole antennas.)

### 5 Advantages of 2x2 MIMO over SISO

A 2x2 MIMO chip such as the BCM435X operates in dual-stream or single-stream mode depending on channel conditions or user requirements. In either case, it provides superior performance compared to a single-antenna SISO system.

#### 5.1 Single-Stream Transmission

Although single-stream transmission works just like SISO, MIMO is more effective by virtue of having two transmit/receive chains and two antennas. The main advantages of a 2x2 MIMO chip are due to the following techniques:

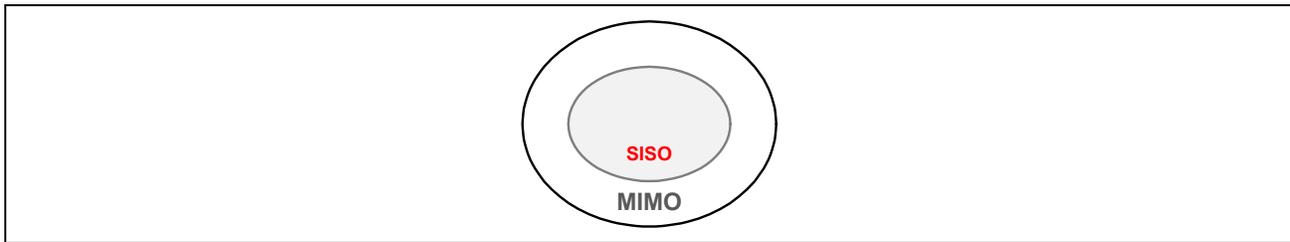
- Receiver Maximal-Ratio Combining (MRC): Under optimal conditions, when a receiver with two chains receives single-stream data with equal power levels at both antennas, it can combine the signals (through

MRC) to increase the SNR by as much as 3 dB. The actual SNR increase is likely to be somewhat lower in under real-world conditions.

- **Antenna diversity:** In the receiver, one antenna may be in a deep fade state while the other is operating normally due to the relative distance between them. Antenna diversity refers to the scheme in which the receiver selects the stronger antenna to process the signal. Antenna diversity works both ways; that is, the same antenna chosen to process the incoming signal would also be used to reply to the sender.
- **Transmit beam-forming:** This steers the transmit energy in the direction of the intended receiver to improve SNR. This both produces a higher data rate for the link and also reduces interference to other receivers in the vicinity.
- **Space Time Block Coding (STBC):** In the STBC scheme, two specially coded (orthogonal) copies of the same data stream are transmitted by two transmit chains/antennas and are recovered by a single-chain (or dual-chain) receiver that supports STBC. This results in some improvement in overall system performance in single-stream 802.11n mode.
- **Cyclic Delay Diversity (CDD):** This is another transmit diversity option (used in 802.11a or 11g) where the same data stream is transmitted by two antennas after passing through a pseudorandom scrambler and relative delay. This prevents correlation between the waves being transmitted from both antennas. On the receive end, the waves can be processed by one or two chains.

In summary, when a 2x2 MIMO system is used in a single-stream data link, the overall effect is increased coverage area as illustrated in [Figure 2](#).

Figure 2. Coverage Area of a 2x2 MIMO System Compared to a SISO System



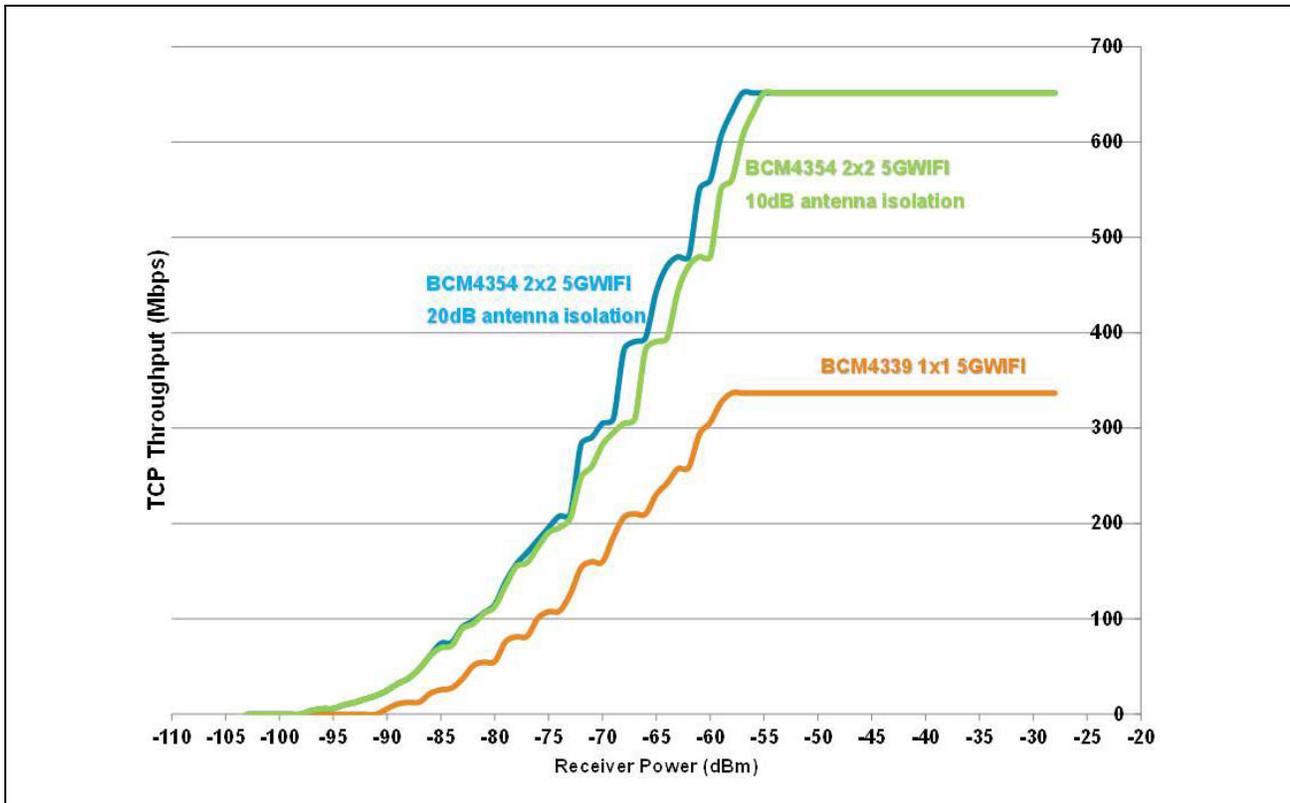
## 5.2 Dual-Stream Transmission

Dual-stream MIMO mode offers spatial multiplexing gain and up to double the throughput. Multiplexing gain stems from having two separate data streams transmitted through the channel, which results in doubling the channel capacity or the throughput.

## 6 Antenna Placement

The main goal of antenna placement in a 2x2 MIMO system is to reduce coupling (that is, to maximize isolation) between any pair of antennas. As illustrated in [Figure 3](#), MIMO throughput drops as isolation decreases.

Figure 3. MIMO Throughput Versus SISO Throughput Versus Antenna Isolation

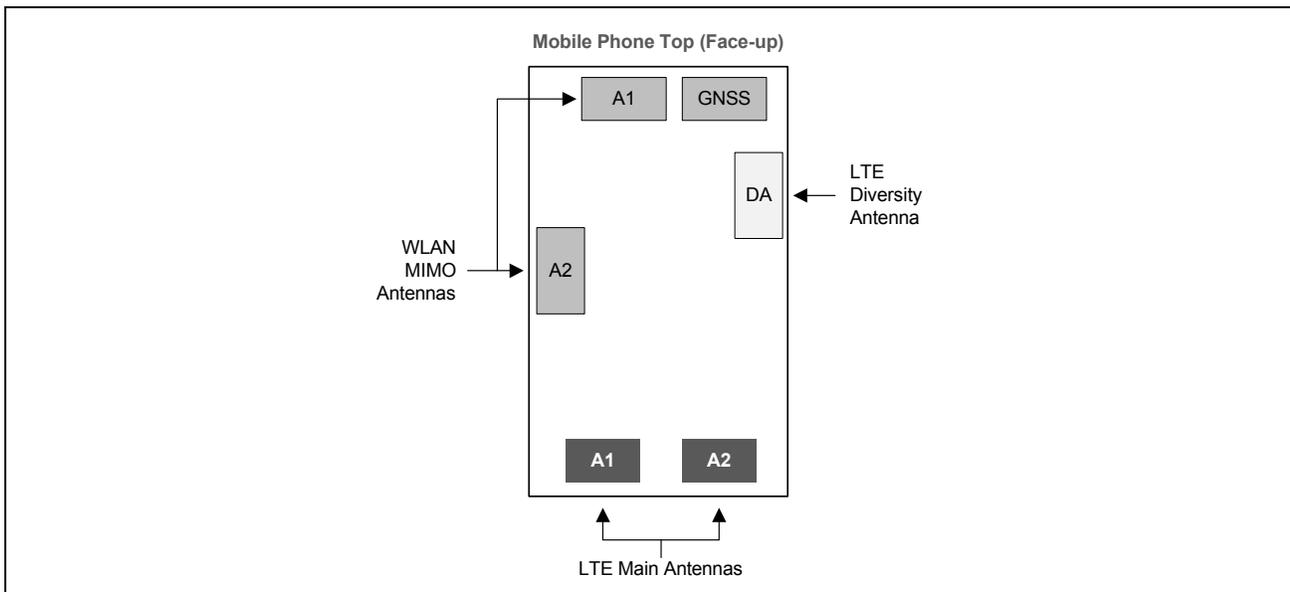


Cypress engineers recommend 15 dB isolation between the two MIMO antennas, but the performance of a MIMO system does not degrade significantly with isolation as low as 8 dB. For LTE devices, the goal is to get 15 dB of isolation between an LTE antenna (Bands 7, 38, 40, and 41) and either of the two WLAN MIMO antennas.

**Note:** Antenna to antenna isolation is determined by measuring the S21 parameter with a network analyzer.

There are a number of ways antennas can be placed inside a smart phone. An arrangement recommended by Cypress engineers is illustrated in Figure 4.

Figure 4. Mobile Terminal Antenna Placement Example



A few observations on this design shown in [Figure 4 on page 5](#):

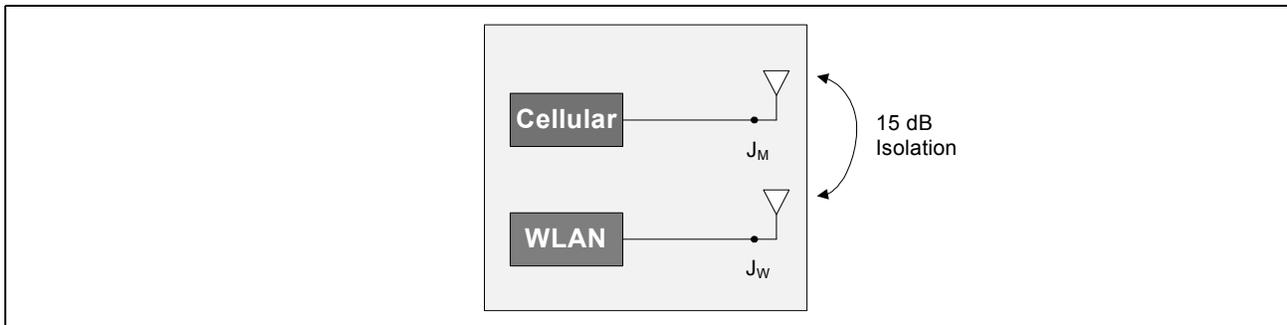
- The main LTE antennas are placed at the bottom of the phone to reduce the obstructive impact of the user's hand and head, and are placed in opposite corners to reduce coupling. For designs with a single LTE antenna, the antenna should be placed in the LTE A1 position. The LTE antennas transmit the most power (24 dBm), so these spatial arrangements keep the power farther away from the user's brain.
- The LTE diversity antenna is placed away from the main LTE antennas for spatial diversity. The polarization of the LTE diversity antenna should also differ from the polarization of each antenna in the LTE pair. It should be placed along one side of the phone toward the top. The side on which it is installed should be the one that provides the greatest spatial diversity.
- The Global Navigation Satellite System (GNSS) antenna is placed on top right corner. It may be shared with WLAN antenna A1 using a triband diplexer.
- The second WLAN antenna can be placed on the side as shown to optimize the spatial and polarization diversity.

## A. Appendix

### A.1 Cellular/WLAN Coexistence

This appendix defines the isolation specifications used to optimize coexistence between cellular and WLAN transceivers. In [Figure 5](#), assume that the cellular is transmitting  $P_M = 24$  dBm power through its own antenna ( $J_M$ ) at 2505 MHz (LTE Band 7).

Figure 5. Cellular and WLAN Transceivers Inside a Smartphone



The cellular transmit power, after being reduced by the antenna-to-antenna isolation, appears at the WLAN receiver input  $J_W$  at level  $P_W = (P_M - \text{Isolation})$ . Although the cellular signal is not in the WLAN band, it is still very strong and acts as a blocker to the WLAN receiver.

**Note:** A blocker is a high-powered interference signal present at the input port of a receiver.

The WLAN receiver must be able to tolerate some blocker interference, but an excessive amount can cause receiver compression, which leads to desensitization. A typical blocker specification could be  $P_B = -45$  dBm, with a maximum 3 dB of desensitization allowed. This means a total attenuation of 69 dB ( $P_M - P_B$ ) is required. Although some of it is obtained through isolation, a filter must be added at the WLAN front-end receive path to provide the additional 54 dB of attenuation (see [Figure 6](#)).

Figure 6. Cellular and WLAN Coexistence—WLAN RX Filtering

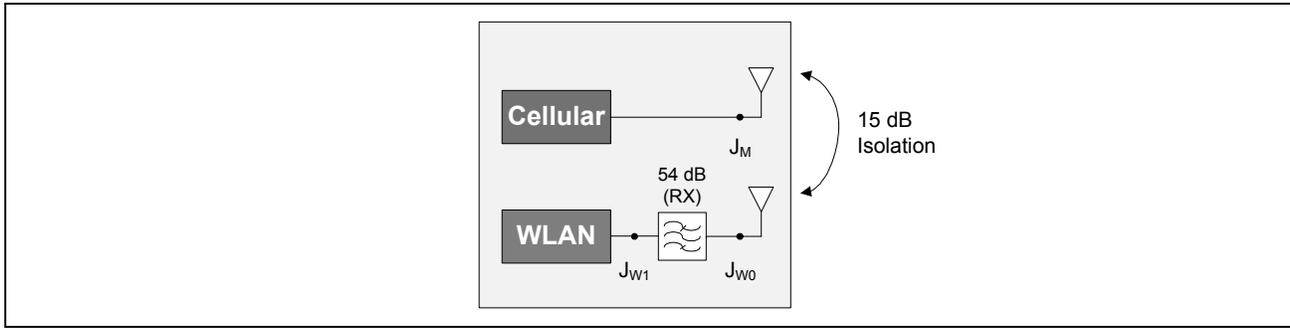
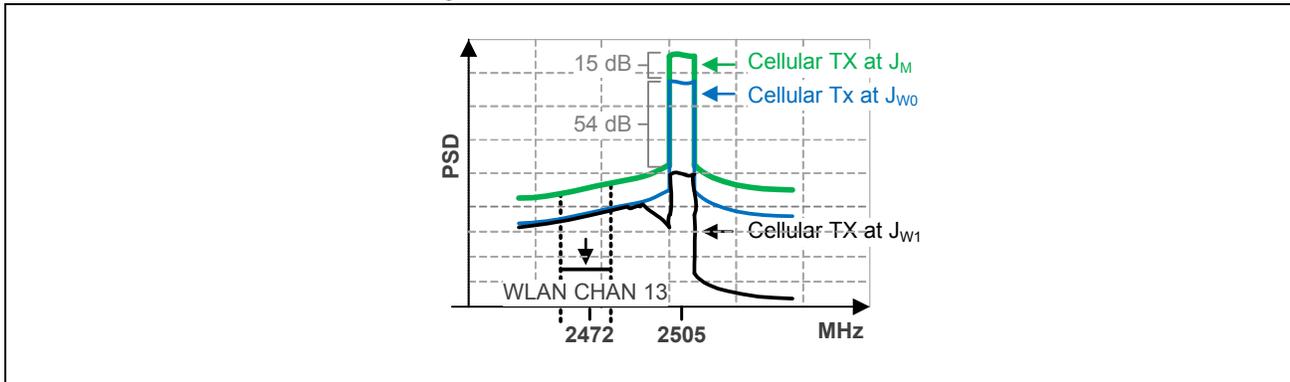


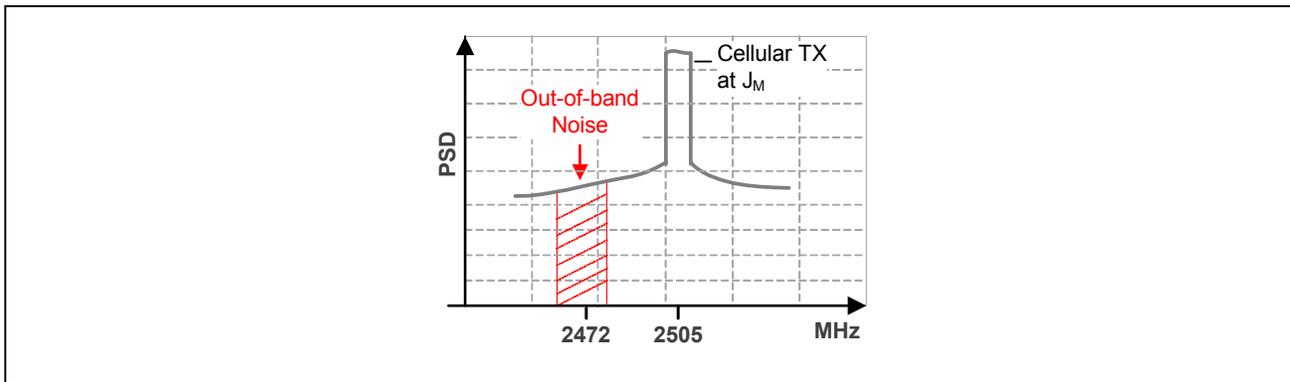
Figure 7 illustrates the cellular transmit spectra at various points based on the architecture in Figure 6 on page 7. The green graph represents the cellular TX at the cellular antenna port ( $J_M$ ). The blue graph represents the cellular TX at WLAN antenna port  $J_{W0}$ . The high point of the blue graph is lower due to 15 dB of antenna-to-antenna isolation. The black graph represents the cellular TX after passing through the filter ( $J_{W1}$ ), at which point the cellular blocker has been attenuated by an additional 54 dB. By the time the cellular TX reaches the WLAN chip port, the cellular TX blocker has been attenuated by 69 dB (54 dB +15 dB).

Figure 7. Cellular Blocker at Various Points



When the cellular transceiver is transmitting, it also emits out-of-band noise ( $N_M$ ) that falls within the WLAN receive channel, as illustrated in Figure 8.

Figure 8. Cellular Transmit Frequency Spectrum



Based on the architecture illustrated in Figure 6 on page 7, assume  $N_M = -105$  dBm/Hz at  $J_M$  or  $-120$  dBm/Hz at  $J_{W0}$ , again with 15 dB of antenna-to-antenna isolation. Because this noise is in the WLAN band, it must be filtered at the source. Placing a 54 dB filter (174 dBm/Hz – 120 dB/Hz) at the cellular front-end transmit path provides the required amount of attenuation (see Figure 9).

Figure 9. Cellular and WLAN Coexistence—Cellular Transmit Filtering

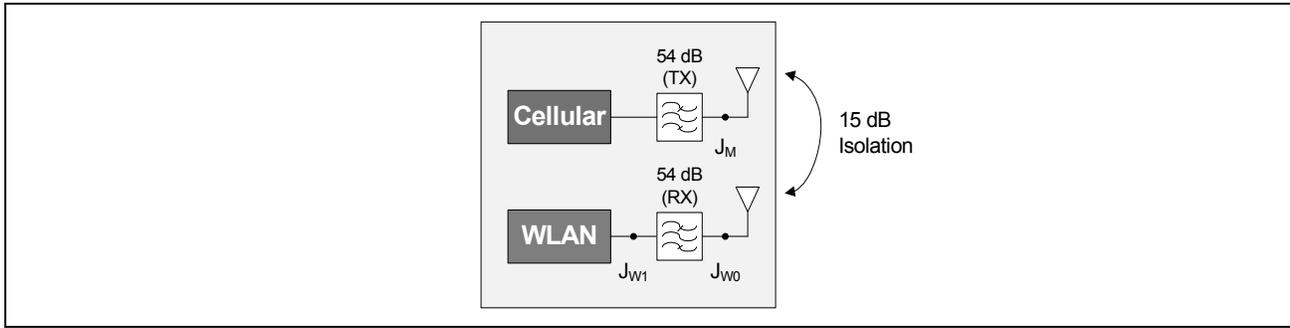
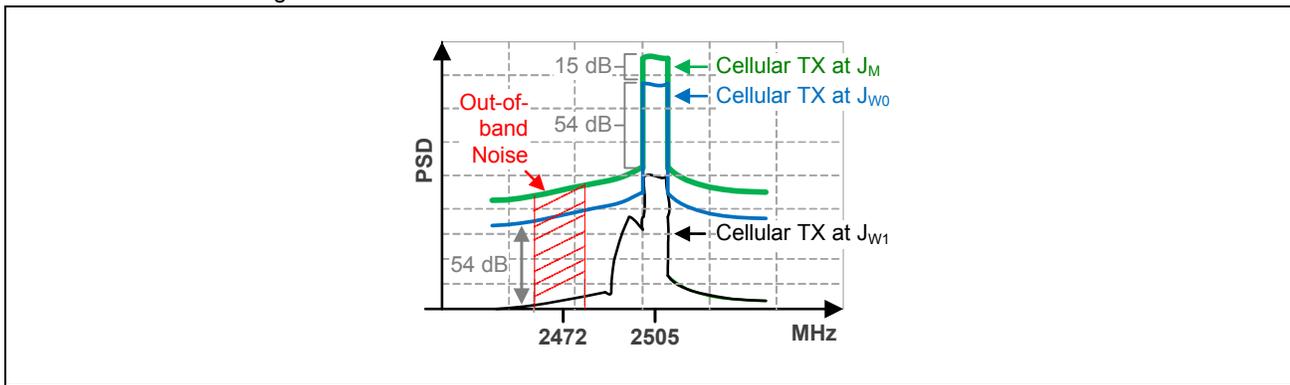


Figure 10 illustrates the cellular transmit spectra at various points based on the architecture in Figure 9, which has filters in both the cellular TX path and the WLAN RX path. The black graph in Figure 10 is the spectrum of the cellular TX after it passes through both filters and the air (antenna-to-antenna) isolation, showing the total reduction of the cellular blocker and the final level of the cellular broadband noise. The WLAN receiver is expected to tolerate this level of interference in order to coexist with the cellular transmitter.

Figure 10. Cellular Blocker and Cellular Broadband Noise at Various Points

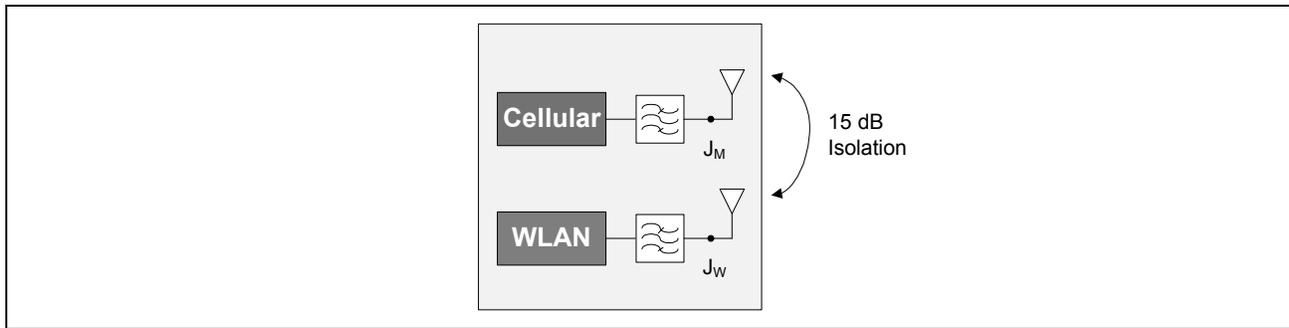


In the previous scenario, the cellular transceiver is transmitting and the WLAN transceiver is receiving. The transmit signal of the cellular becomes a blocker to the WLAN receiver, and the out-of-band noise from the cellular becomes in-band interference to WLAN. The solution discussed so far requires adding 54 dB of attenuation to the cellular transmit path and 54 dB of attenuation to the WLAN receive path. But what happens when the cellular transceiver becomes a receiver and the WLAN transceiver becomes a transmitter?

The same discussion applies, except that the power of the WLAN transmitter is several decibels lower than that of the cellular (typically 16 dBm instead of 24 dBm). This suggests that a filter should be placed in the cellular receive path with somewhat reduced attenuation, depending on the cellular blocker specs (the calculation can be done the same way as discussed on page 7). The solution for this case is to put a filter in the receive path of the cellular transceiver (a 54 dB filter was placed in the transmit path of the cellular transceiver in Figure 9 on page 8). However, to save space and cost, Cypress engineers recommend placing a single filter that meets both requirements in the common RX/TX path of the cellular transceiver (see Figure 11).

The WLAN out-of-band noise is typically around  $-110$  dBm/Hz when operating on channel 13 (2472 MHz). This dictates a filter in the WLAN transmitter path with around 49 dB attenuation, assuming 15 dB antenna isolation. Because the WLAN filter values are similar for both the transmit (49 dB) and receive (54 dB) chains, they are generally placed in the common path leading to the antenna port, as shown in Figure 11.

Figure 11. Cellular and WLAN Coexistence—Final Solution



Filtering requirements become more relaxed as the gap between the operating frequencies of the cellular transceiver and WLAN transceiver increases. The system designer must also consider the spurs or harmonics that might be generated by either transceiver and check whether adequate filtering is in place to compensate for those conditions.

## Document History Page

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**	–	UTSV	06/04/2014	Initial release
*A	5445321	UTSV	09/22/2016	Updated to Cypress template Added Cypress part numbering scheme
*B	5803912	AESATP12	07/07/2017	Updated logo and copyright.

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