Application Report
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Antenna Diversity

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ABSTRACT

This application report provides real-world measurement results showing the benefit of antenna diversity. The CC1200 radio transceiver is used as an example in this design note, but the results are applicable for all TI LPRF radios.

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1 Introduction

Multipath is a phenomenon that occurs when electromagnetic waves bounce of surfaces such as floors, ceilings, walls, trees, people walking by, and so forth and arrive at the receiver at different times. When these signals arrive at the receiver out-of-phase, they can result in a form of cancellation termed fading.

Antenna diversity is a technique that can be used to improve radio communication and maximize the chance of a packet getting through at a given time and in a given position between a receiver and transmitter in a non-static environment.

2 Antenna Diversity Implementation

2.1 CC1200 Antenna Diversity

The antenna diversity algorithm used in these tests is based on carrier sense (CS). The received signal level using the first antenna is compared to a programmed CS threshold, and if the CS flag is set, the receiver will stay on this antenna. If the received signal level using antenna 1 (ANT1) is below the programmed CS threshold, CC1200 will check the signal level using antenna 2 (ANT2).

CC120X has two different antenna diversity modes: Single-switch mode and continuous-switch mode [1].

- Single switch mode is useful for very low-power schemes where the device only checks each antenna once for a signal and directly terminates RX if a signal is not detected. If a signal is found on the first antenna checked, it does not check the second antenna.
- Continuous mode is useful when staying in RX for longer intervals. In this case antennas are switched until CS is asserted or RX timeout occurs. Continuous mode is used in this design note. Figure 1 shows a simplified flowchart.

The device supports antenna diversity by controlling an external radio frequency (RF) switch using the ANTENNA_SELECT control signal available on GPIO.

The device will remember the last antenna used (when not entering SLEEP mode) and use the last antenna for the next RX or TX transition. Staying with the same antenna will make sure:

- In RX, that the last antenna used for good reception will be the first one to be checked (minimize time for the next reception)
- In TX, the device will transmit acknowledge with the same antenna that received the packet

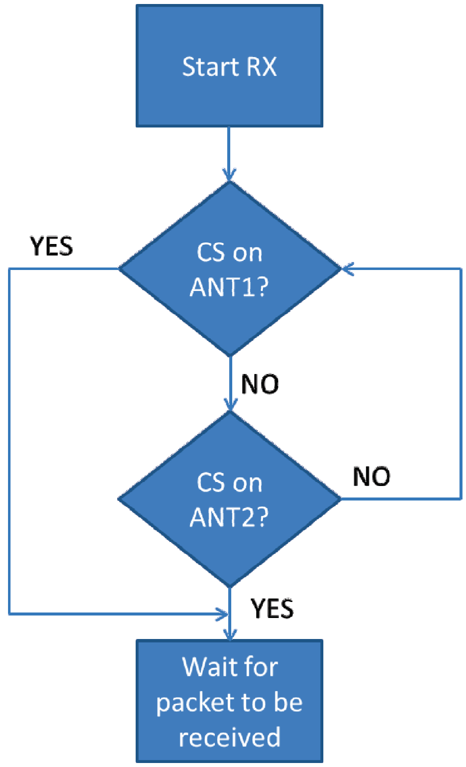

Figure 1. Simplified Flowchart for CC1200-Based Antenna Diversity

2.2 System Parameters

- 2-GFSK modulation
- 50 kbps data rate, ±25 kHz deviation
- 868 MHz
- 12 byte preamble
- 4 byte sync word
- +15 dBm output power
- Carrier sense (CS) threshold set to -105 dBm

2.3 Hardware Setup

In the testing, one transmitter, three receivers, and two antennas (ANT1 and ANT2) were used. The three receivers were in RX mode at the same time. The hardware test setup allows an antenna diversity solution to be compared to a single-antenna solution at the same time and, therefore, under the same fading conditions. Figure 2 shows a block diagram of the test setup and Figure 3 shows the test board.

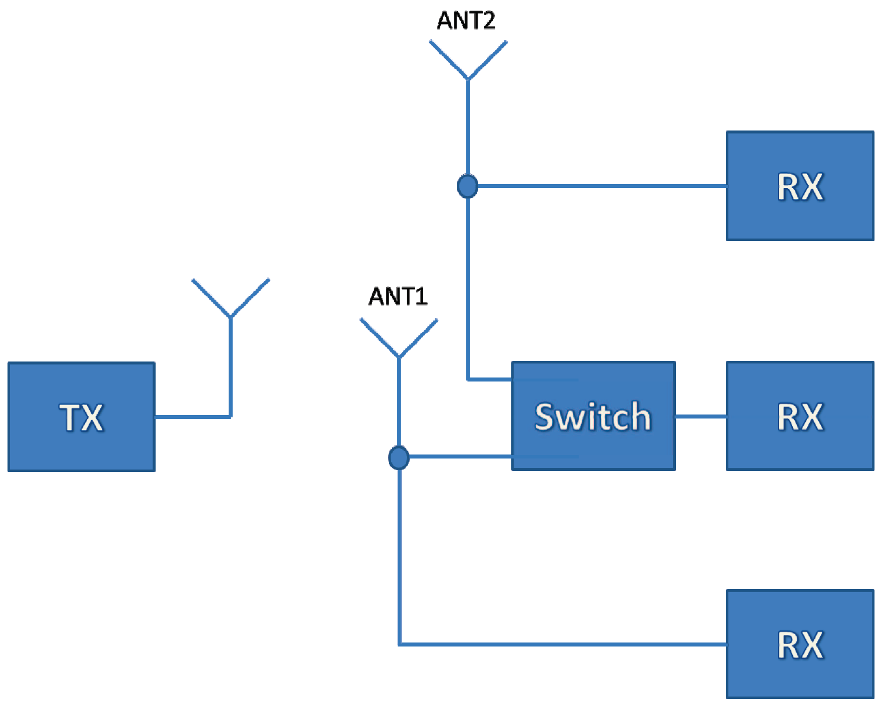

Figure 2. Block Diagram of Antenna Diversity Test Setup

With reference to Figure 3:

- The left TrxEB+CC1200EM is connected to the left antenna (ANT1) through a splitter
- The right TrxEB+CC1200EM is connected to the right antenna (ANT2) through a splitter
- The middle TrxEB+CC1200EM is connected to both antennas (DIV) through a switch and splitters
- A TrxEB+CC1200EM is used as a transmitter
- The antenna feedpoints are placed a distance lambda/4 apart
- The antennas are placed at right angles to each other
- The CC1200 ANTENNA_SELECT control signal and the inverted ANTENNA_SELECT control signal are made available on two of the CC1200 GPIO's and used to select the appropriate antenna through the switch

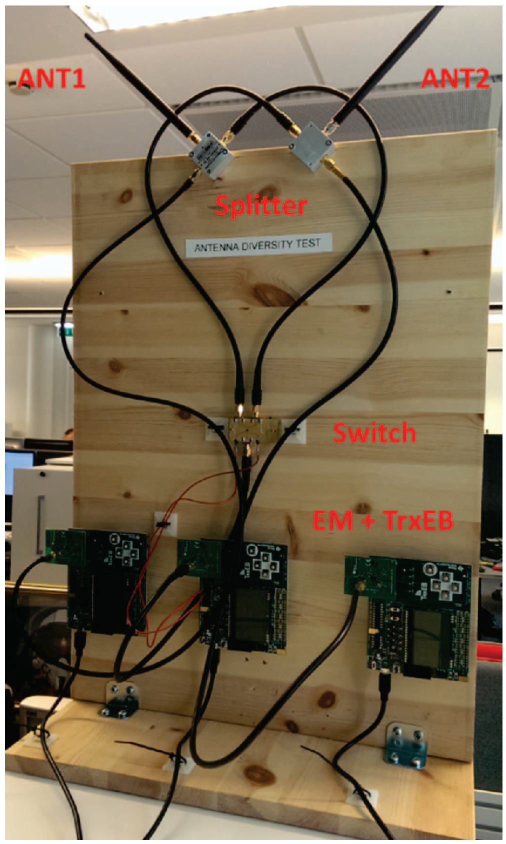

Figure 3. Antenna Diversity Test Board

2.4 Software Implementation

The TrxEB includes an MSP430, which runs the test software.

The transmitter starts sending packets continuously when a button on the TrxEB is pressed. The TX routine is stopped when the button is pressed again. The number of transmitted packets is displayed on the TrxEB display (continuously updated).

The CC1200EM's are put into RX with CS enabled when a button on the TrxEB is pressed. If CS is detected the radio starts looking for a valid sync word. If this is found, the radio will continue in RX to receive the data payload. If the CRC check is OK the number of received packets shown on the TrxEB display is increased by 1. After a packet has been received, RX is re-started. The board running with antenna diversity will be in RX, switching between the two antennas until CS is detected. When CS is asserted it will stay in RX on the current antenna until a packet is received. RX will then be re-started.

By setting the TrxEBs in universal asynchronous receiver/transmitter (UART) mode (see the *SmartRF Transceiver Evaluation Board "TrxEB" User's Guide* (SWRU294) [3]), a standard driver for a virtual COM port over USB is used to communicate with a personal computer (PC) [1] (the configuration used is a baud rate of 57600, 8 data bits, 1 stop bit, and no parity or flow control). Information sent over the virtual COM port is the RSSI level for each packet received together with packet number and which antenna used.

(1) By doing a complete install of SmartRF Studio 7 [4], Windows will recognize the device automatically.

3 Measurement Results

3.1 Test Setup 1

The TX board was put in a fixed location in the TI Oslo office. The RX boards were placed on the same floor with walls between TX and RX boards (fixed obstacles). People were walking between TX and RX boards (obstacles moving in and out). For the TX board a 43 dB attenuator was connected between SMA connector on the CC1200EM and the antenna; transmitted power level of 15 dBm – 43 dB = -28 dBm.

- Test 1: The board using antenna diversity (DIV) and the board connected to ANT2 gave same packet error rate (PER). The EM connected to ANT1 gave significantly higher PER.
- Test 2: Same as Test 1, but the antenna diversity test board was rotated by 90°. The board using DIV and the board connected to ANT2 gave same PER. The EM connected to ANT1 gave significantly higher PER.
- Test 3: Same as Test 1, but the antenna diversity test board was rotated by 180°. The board using DIV and the board connected to ANT1 gave same PER. The EM connected to ANT2 gave significantly higher PER.

Table 1. Packet Error Rate for Boards using ANT1, ANT2, or Diversity (DIV). Test Setup 1

	Antenna	No. of Received Packets	No. of Sent Packets	Packet Error Rate
Test 1	ANT1	30825	38518	20.0 %
	ANT2	38282	38518	0.6 %
	DIV	38234	38518	0.7 %
Test 2	ANT1	33577	41646	19.4 %
	ANT2	41417	41646	0.5 %
	DIV	41446	41646	0.5 %
Test 3	ANT1	36013	36143	0.4 %
	ANT2	32964	36143	8.8 %
	DIV	35976	36143	0.5 %

3.2 Test Setup 2

The TX board was placed in a fixed location on the top floor at the TI office. The RX boards were placed one floor down in the coffee room with people waking in and out. For the TX board, a 16 dB attenuator was connected between SMA connector on the CC1200EM and the antenna (transmitted power level of 15 dBm – 16 dB = -1 dBm).

- Test 4. The board using DIV and the board connected to ANT2 gave same PER. The EM connected to ANT1 gave significantly higher PER.
- Test 5. Same as test 4, but with the antenna diversity test board rotated by 90°. The board using DIV and the board connected to ANT1 gave same PER. The EM connected to ANT2 gave significantly higher PER.

Table 2. Packet Error Rate for Boards using ANT1, ANT2, or diversity (DIV). Test Setup 2

	Antenna	No. of Received Packets	No. of Sent Packets	Packet Error Rate
Test 4	ANT1	18524	27730	33.2 %
	ANT2	22495	27730	18.9 %
	DIV	22197	27730	20.0 %
Test 5	ANT1	16441	16498	0.3 %
	ANT2	13820	16498	16.2 %
	DIV	16390	16498	0.7 %

3.3 Test Setup 3

The TX board was placed in a fixed location on the top floor at the TI office (different location than in test setup 2). The RX boards were placed one floor down in the coffee room with people waking in and out.

Several measurements were done with different output power levels to see how much the power level had to be increased for a system not using antenna diversity to achieve the same PER as a system using antenna diversity. Approximately 42k packets were transmitted for each of the 5 power levels tested.

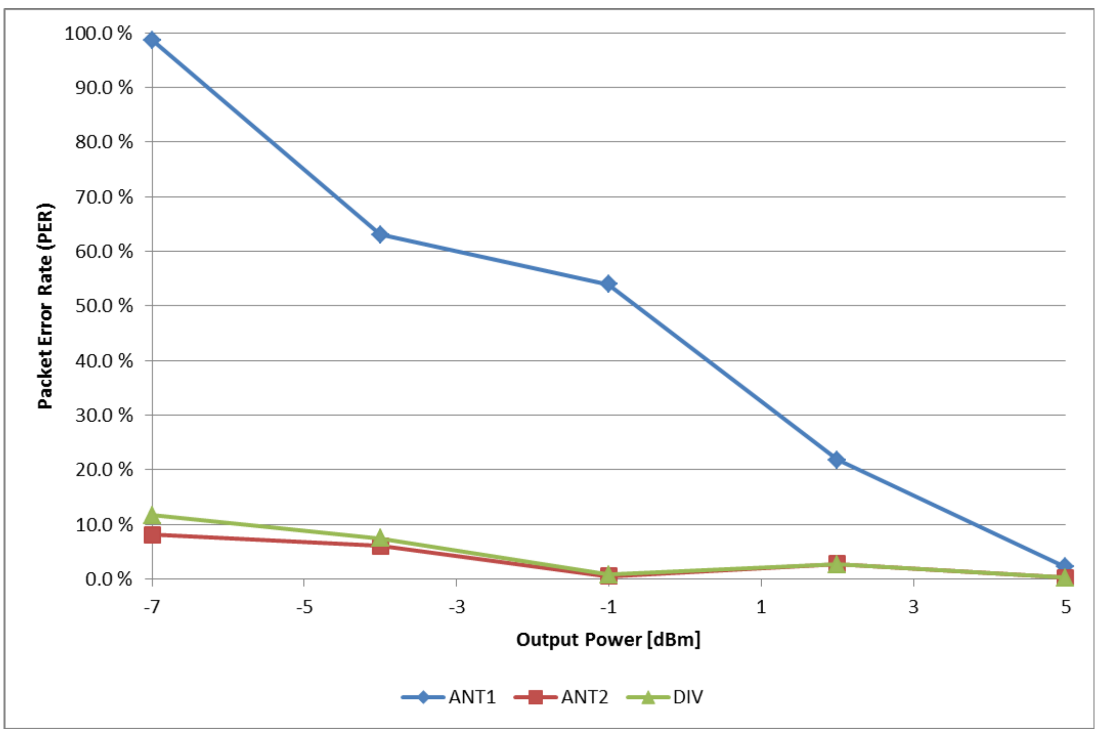

Figure 4. Packet Error Rate vs Output Power. Test Setup 3

In this test approximately 11 dB increase in TX power was required to achieve the same PER for the board connected to ANT1 as for the board using antenna diversity (-+4 dBm vs -7 dBm, respectively).

3.4 Test Setup 4

Same as test setup 3, but the antenna diversity test board was rotated by 90°. Several measurements were done with different output power levels to see how much the power level had to be increased for a system not using antenna diversity to achieve the same PER as a system using antenna diversity. Approximately 30k packets were transmitted for each of the 4 power levels tested.

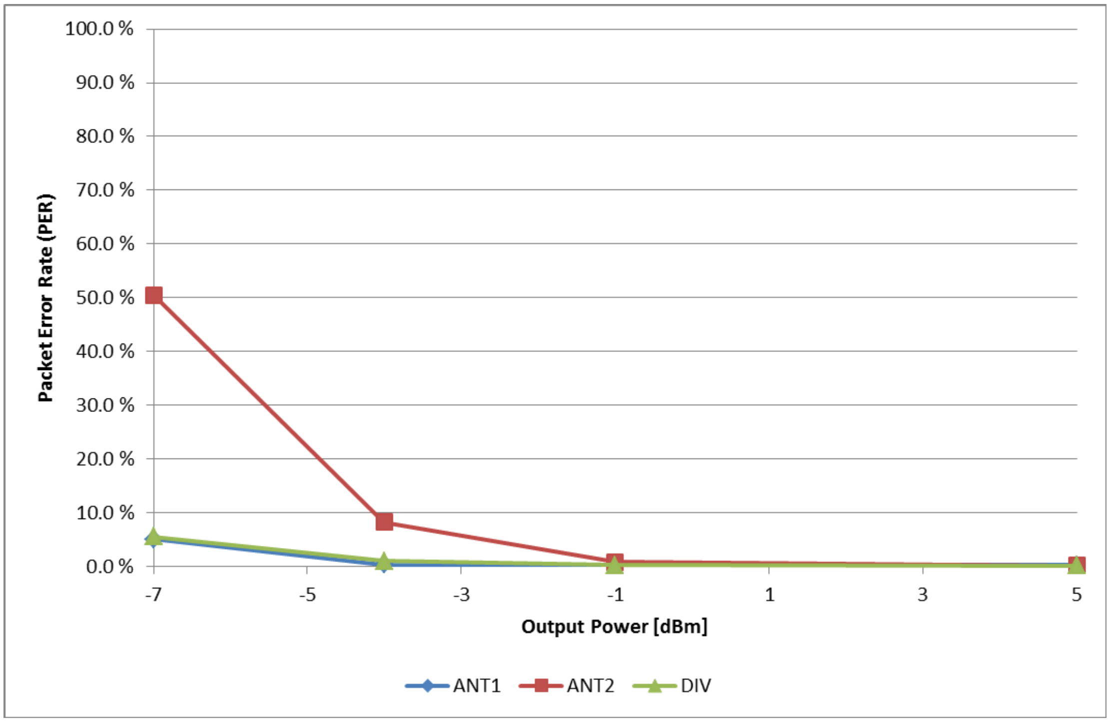

Figure 5. Packet Error Rate vs Output Power. Test Setup 4

In this test, approximately 4 dB increase in TX power was required to achieve the same PER for the board connected to ANT2 as for the board using antenna diversity (- 3 dBm vs -7 dBm, respectively).

3.5 Test Setup 5

A EZ430-Chronos watch [2] was configured as transmitter (see Figure 6). The watch was worn on the wrist and carried around by one of the FAEs in the TI office. Measurements were taken over a 2 day period.

Table 3 shows that ANT1 and ANT2 received 90% of the packets received by DIV in this dynamic multipath fading environment test.

Table 3. Number of Received Packets for Boards Using ANT1, ANT2, or Diversity (DIV). Test Setup 5

Antenna	Day 1	Day 2	Total
ANT1	9038	1371	10409
ANT2	9513	1352	10865
DIV	10376	1509	11885

Figure 6. EZ430-Chronos Watch

4 Conclusion

This application report shows that antenna diversity provides a significant improvement in PER in a dynamic multipath fading environment compared to a solution with one fixed antenna.

5 References

1. *CC120X Low-Power High Performance Sub-1 GHz RF Transceivers User's Guide* (SWRU346)
2. EZ430-Chronos Wiki
3. *SmartRF Transceiver Evaluation Board "TrxEB" User's Guide* (SWRU294)
4. SmartRF Studio 7: http://www.ti.com/lit/zip/swrc176

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