APPLICATION NOTE

Extending 2.4 GHz ZigBee® Short-Range Radio Performance with Skyworks SKY65344/SKY65343 Front-End Modules

Introduction

Skyworks SKY65344 and SKY65343 ZigBee Front-End Modules (FEMs) can greatly enhance the performance of a ZigBee radio solution when integrated with any ZigBee low power reference design. Both devices can transmit up to 100 times more power than a typical 0 dBm low power ZigBee radio transmitter and can reduce the level of unwanted spurious emissions to be compliant with the main regulatory standards without the use of external components such as filters.

The SKY65344 also integrates a Low Noise Amplifier (LNA) that enhances the sensitivity of a ZigBee receiver by several dB, a key factor that extends the receiver range. The SKY65344 can also be used to implement high data rate solutions that require high Signal-to-Noise Ratios (SNRs).

This Application Note describes the benefits of using the SKY65344 and SKY65343 FEMs in ZigBee radio systems and details how the devices can contribute to tremendously extending the ZigBee wireless range and throughput.

Transmit Power Improvement

The SKY65344 and SKY65343 FEMs incorporate a highly efficient Power Amplifier (PA) in the transmit path that can deliver up to +20 dBm at the antenna port (see Figure 1). Both modules also provide harmonic filters that guarantee a level of harmonics lower than –44 dBm, which eliminates the need for additional filters in the transmit path to be compliant with regulatory standards (Table 1 summarizes the limits for each standard). This facilitates RF design efficiency, and reduces the Bill of Materials (BOM) count and cost.

Table 1. Conducted Spurious Emission Limits

Regulatory Standard	Effective Isotropically Radiated Power (dBm/MHz)
FCC 15.247	–41.20
EN300 328	–30.00
ARIB STD-T66	–26.02

Receiver Sensitivity

The sensitivity of a receiver is the minimum level of the input signal that it is able to receive and decode successfully with a given error rate. This sensitivity depends on two main factors:

- The SNR ratio at the receiver output that is necessary to ensure the target error rate. The SNR is a function of the energy per bit to the noise density ratio (Eb/No), the data rate (R), and the receive bandwidth (B):

$$SNR = \frac{Eb}{No} \times \frac{R}{B} \qquad (1)$$

- The Noise Figure (NF) of the system, which describes the ability of the system to process a small signal noise-free. The NF is calculated according to the following equation:

$$NF = 10 \times \log \frac{SNR_{in}}{SNR_{out}} = 10 \times \log \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \qquad (2)$$

The minimum sensitivity (measured in dBm) is calculated as:

$$Sensitivity = NF + SNR_{out} + N_{in} \qquad (3)$$

If:

$$N_{in} = 10 \log(k)(T)(B)$$

Where: k = Boltzman's Constant = 1.38 × 10^{-23} Joules/Kelvin

T = absolute temperature = 298 °K

B = noise bandwidth

Then:

$$N_{in} = -174 + 10 \log B$$

And:

$$Sensitivity = N_{in} + NF + SNR_{out} \qquad (4)$$

Where: SNR_{OUT} = Minimum SNR that guarantees the target error rate.

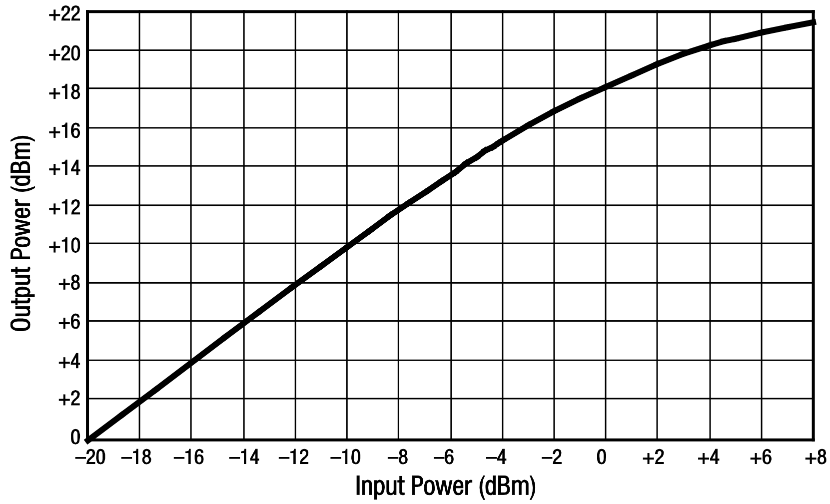

Figure 1. Output Power vs Input Power

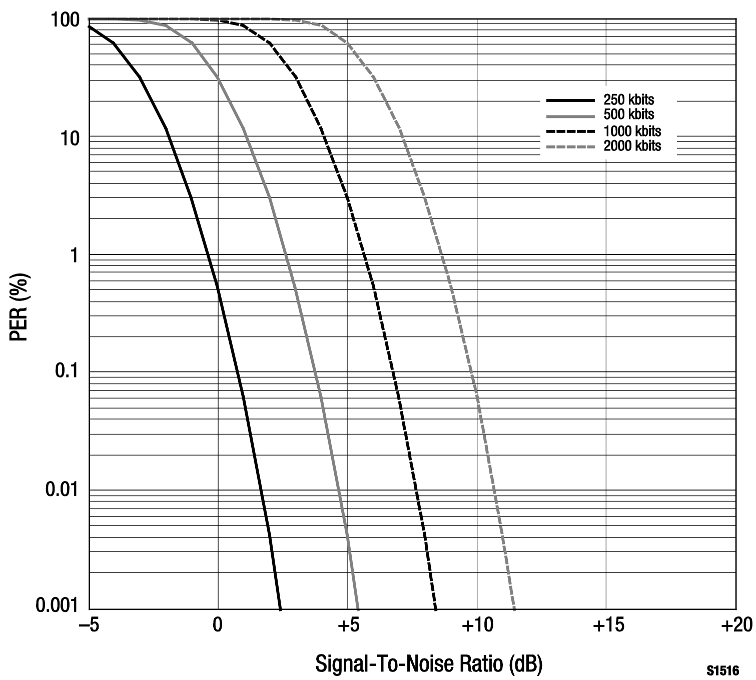

Figure 2. PER Curves for QPSK Modulation vs SNR and Data Rate

The IEEE 802.15.4-2003 standard [1] sets the requirements for the –85 dBm one percent Packet Error Ratio (PER) minimum sensitivity. The 2.4 GHz receiver link uses Offset Quadrature Phase-Shift Keying (O-QPSK) modulation with Direct Sequence Spreading Spectrum (DSSS) techniques. The main benefit of DSSS systems is to provide substantial immunity to narrow band interference because the signal energy is spread over a wide bandwidth. Beyond the IEEE 802.15.4-2003 standard, using different spreading factors (e.g., 8, 4, 2, or 1) can also provide an efficient way to achieve a multi-user configurable data rate system.

Figure 2 shows an example of PER (20 octets) curves for a QPSK signal for different data rates. The spreading gain is demonstrated in this Figure by showing that the highest spread signal (250 kbit/sec data rate with a spreading factor of 8) for a given PER requires the smallest SNR.

Various ZigBee-compliant transceivers are available with reported sensitivities for 250 kbit/sec ranges from –97 to –101 dBm. For the same data rate, ref[2] suggests that the minimum SNR for an actual ZigBee receiver is 3 dB and the receive bandwidth is 1.1 MHz. Typical sensitivity data for the different data rates are calculated according to Equation 4 and summarized in Table 2.

Table 2. Typical Receiver Sensitivity Performance

Data Rate (kbits/sec)	SNR (Note 1) (dB)	NF (dB)	Sensitivity (dBm)
250	3	11.5	–99
500	6	11.5	–96
1000	9	11.5	–93
2000	12	11.5	–90

Note 1: The SNR for higher data rates is calculated from the SNR at 250 kbits/sec and spreading gain reduction.

Improving Sensitivity with the SKY65344 Low Noise Amplifier (LNA)

Equation 4 shows that reducing the system NF improves sensitivity. The cascaded NF of a complex system can be derived from the standalone block level NF and gain as follows (Friis Formula):

$$NF_{total} = 10 \times log(10^{\frac{NF_1}{10}} + \sum_i \frac{10^{\frac{NF_i}{10}} - 1}{10^{\frac{G_{i-1}}{10}}}) \quad (5)$$

The SKY65344 incorporates an LNA in its receive path along with the front-end transmit/receive switch and output RF balun. The device provides a NF of 2.2 dB with a gain of 10 dB. Assuming the ZigBee transceiver (without the RF balun and harmonics filter) NF is 9.5 dB, the cascaded NF is 4 dB compared to the original value of 11.5 dB. Table 3 summarizes the sensitivity of the receiver calculated using Equations 4 and 5. Note that for all data rates, the sensitivity improvement is >7 dB.

Table 3. Sensitivity Comparison Between a Standalone Transceiver and the SKY65344 FEM

Data Rate (kbits/sec)	Standalone Transceiver (dBm)	Sensitivity With SKY65344 (dBm)
250	–99	–106.5
500	–96	–103.5
1000	–93	–100.5
2000	–90	–97.5

RF Signal Propagation Attenuation

Signal propagating from the source or transmitter to the receiver can be attenuated by several different factors:

1. Free space attenuation (the signal “spreads” in space).
2. Signal absorption or shadowing (the signal passes through solid objects like walls or floors).
3. Multipath fading (the signal reflects, refracts, or scatters).

Free space attenuation can be calculated according to the following equation:

$$L_{FreeSpace} = -(20 log\, d + 20 log\, f - 27.5) \quad (6)$$

Where: $L_{FreeSpace}$ = Free space attenuation in dB
d = Distance in meters
f = Frequency in MHz

In the case of a ZigBee frequency of 2.45 GHz, Equation 6 becomes:

$$L_{FreeSpace\_2450MHz} = -(20 log\, d + 40.3) \quad (7)$$

Note that Annex E of ref[1] suggests a different free-space attenuation for 802.15.4-compliant systems:

$$L_{FreeSpace\_2450MHz} = -(33 log \frac{d}{8} + 58.5) \quad (8)$$

Attenuation for signal absorption and multi-path fading are usually derived from Equation 7 with the addition of some empirical factors [3]:

$$L_{2450MHz} = -(10 \times \gamma \times log\, d + L_{FreeSpace\_2450MHz}[1\ meter] + L_{Absorption}) \quad (9)$$

Where: γ = Propagation loss exponent
$L_{Absorption}$ = Attenuation (in dB) of signal passing through walls, doors, floors, etc.

Examples of indoor wall absorption [4] indicate that γ equals 4 and $L_{Absorption}$ equals 10 dB. Using these values, Equation 9 becomes:

$$L_{2450MHz\_Indoor} = -(40 log\, d + 50.3) \quad (10)$$

Comparing Equations 8 and 10 indicates that a ZigBee RF subsystem range is greatly reduced when operating indoors. For example, at 20 meters away from the source, the transmit signal is reduced by more than 100 dB indoors compared to only 72 dB for outdoor free space loss.

Comparing ZigBee System Ranges

The range of the RF system is defined as the maximum distance between the signal source or transmitter and the receiver. Range depends on three factors:

1. Effective transmit power
2. Propagation path loss
3. Minimum sensitivity of the receiver as defined in Equations 1 through 4.

The effective transmit power is the power transmitted by the source in the direction of the receiver. Effective transmit power is derived from adding the transmit antenna gain (G_t) to the total transmit power (P_t). Similarly, receiver antenna gain (G_r) and receiver power (P_r) can be derived from the following equation:

$$P_r = P_t + G_r + G_t + L \tag{11}$$

Where: P_r = Receiver power in dBm

P_t = Transmitter power in dBm

G_r = Receiver antenna gain in dB

G_t = Transmitter antenna gain in dB

L = Attenuation at 2450 MHz in dB

Assuming the antenna gain for both transmitter and receiver is 0 dB, receive power is given by:

$$P_r = P_t - (33 \log \frac{d}{8} + 58.5)$$

for free-space propagation conditions, and by:

$$P_r = P_t - (40 \log d + 50.3)$$

for indoor propagation conditions.

Examples of receive power for two different systems are shown in Figure 3 for free-space propagation conditions. A similar example is shown in Figure 4 for indoor propagation conditions. In both cases, the range is derived from the intersection of the minimum sensitivity level, as calculated in Table 3, and the receive signal strength measured at the receiver input.

Table 4 lists the range for a ZigBee transceiver and the improved ranges by adding the SKY65343 or SKY65344 FEM to the system. The optimum performance is achieved with the SKY65344 because of the improved sensitivity of the receiver.

Table 4. Comparison of Wireless Ranges

System	Indoor Range (m)	Free-Space Range (m)
Transceiver only	16	133
Transceiver with SKY65343	53	543
Transceiver with SKY65344	81	923

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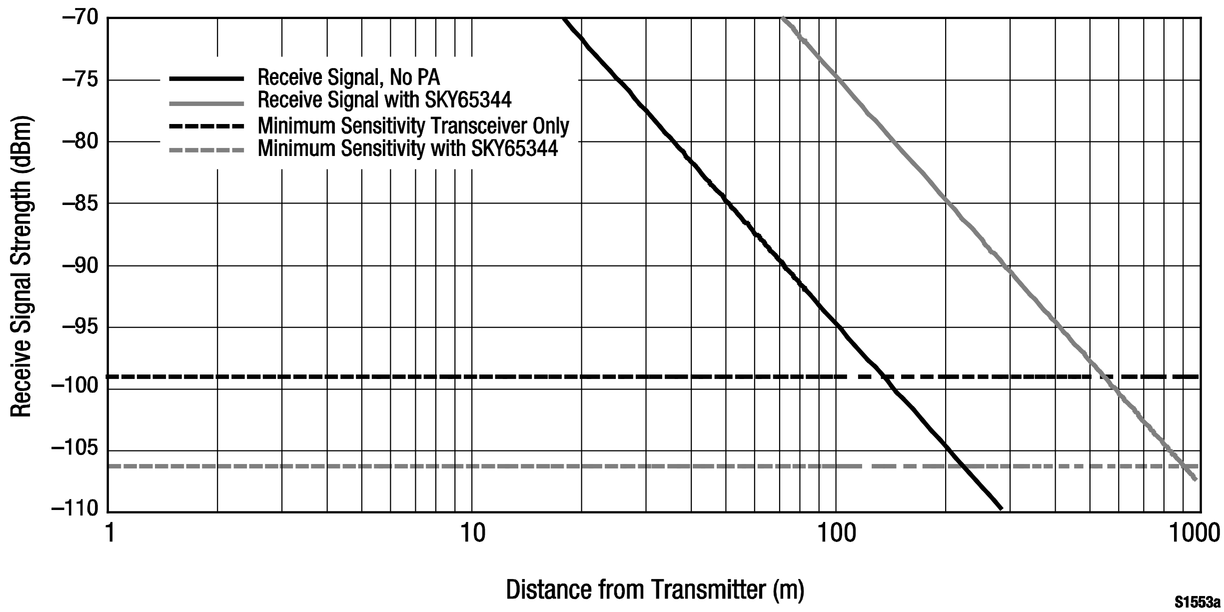

Figure 3. Received Signal Strength at the Receiver Node vs Distance Between Transmitter and Receiver for Low Power 0 dBm and High Power +20 dBm Transmitters (Free-Space Propagation Conditions)

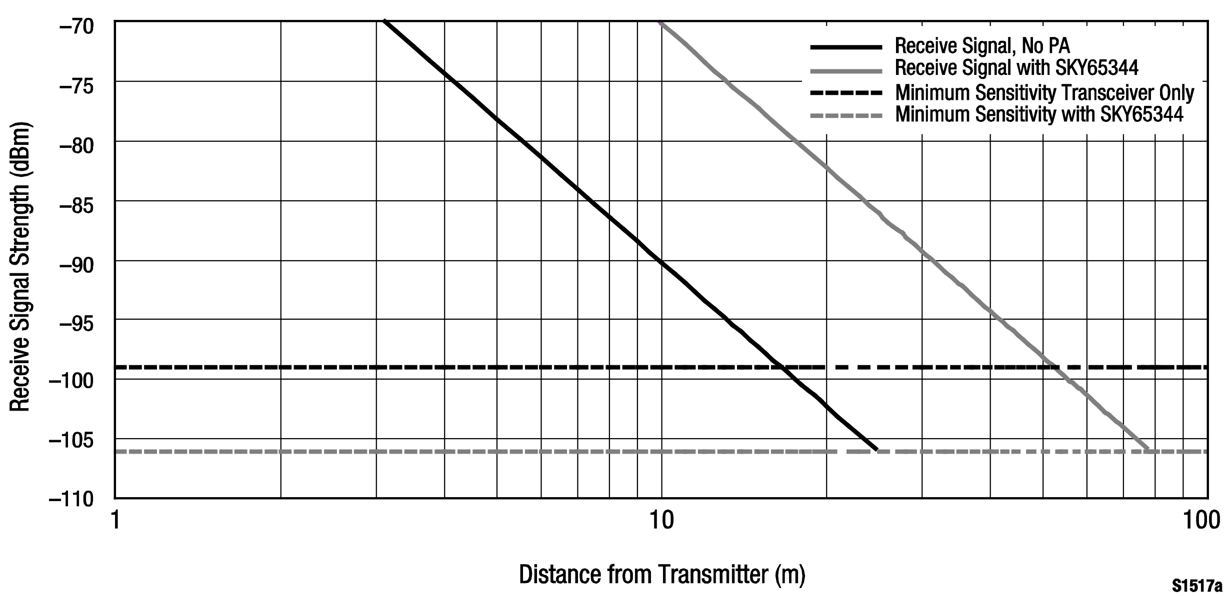

Figure 4. Received Signal Strength at the Receiver Node vs Distance Between Transmitter and Receiver for Low Power 0 dBm and High Power +20 dBm Transmitters (Indoor Propagation Conditions)

Conclusion

The Skyworks SKY65344 and SKY65343 are easy to integrate, highly efficient ZigBee FEMs. Both devices provide a natural, low-cost solution to improve ZigBee wireless network performance whether extending coverage or increasing the available data rate. Refer to the SKY65344 and SKY65343 Data Sheets (document number 201181 and 201125, respectively) for further information.

References

1. IEEE Std 802.15.4-2003, Part 15.4, *Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs)*, 2003.

2. *Adjacent Channel Rejection Measurements for 802.15.4 Radios Application Note 5059*, Ember Corporation, 27 March 2009.

3. Christiano Monti, Antonio Saitto, and Damiano Valletta, *Indoor Radio Channel Models for IEEE 802.15.4 Technology*, Telespazio S.p.A Proceedings of EURASIP Workshop, RFID, 2008.

4. *RF Propagation Basics White Paper*, Sputnik, Inc., April 2004.