IMPINJ® Whitepaper

RFID Link Budget Overview

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Overview

The RFID system relies on exchange of power and information between the reader and the tag. The reader provides power and communicates with the tag over the RF link then the tag communicates back to the reader with its data by backscattering the signal from the reader. If any aspect of the communication fails, the RFID link fails. Historically, powering the tag through the RF signal (forward link) has been the challenge. With recent improvement on **tag sensitivity** (ability to harvest power), the reverse link (backscattered signal detection) is starting to cause failures. This paper will describe the physics behind overall RFID link and describe how to determine where link failure can occur from hardware specifications.

Link Budget

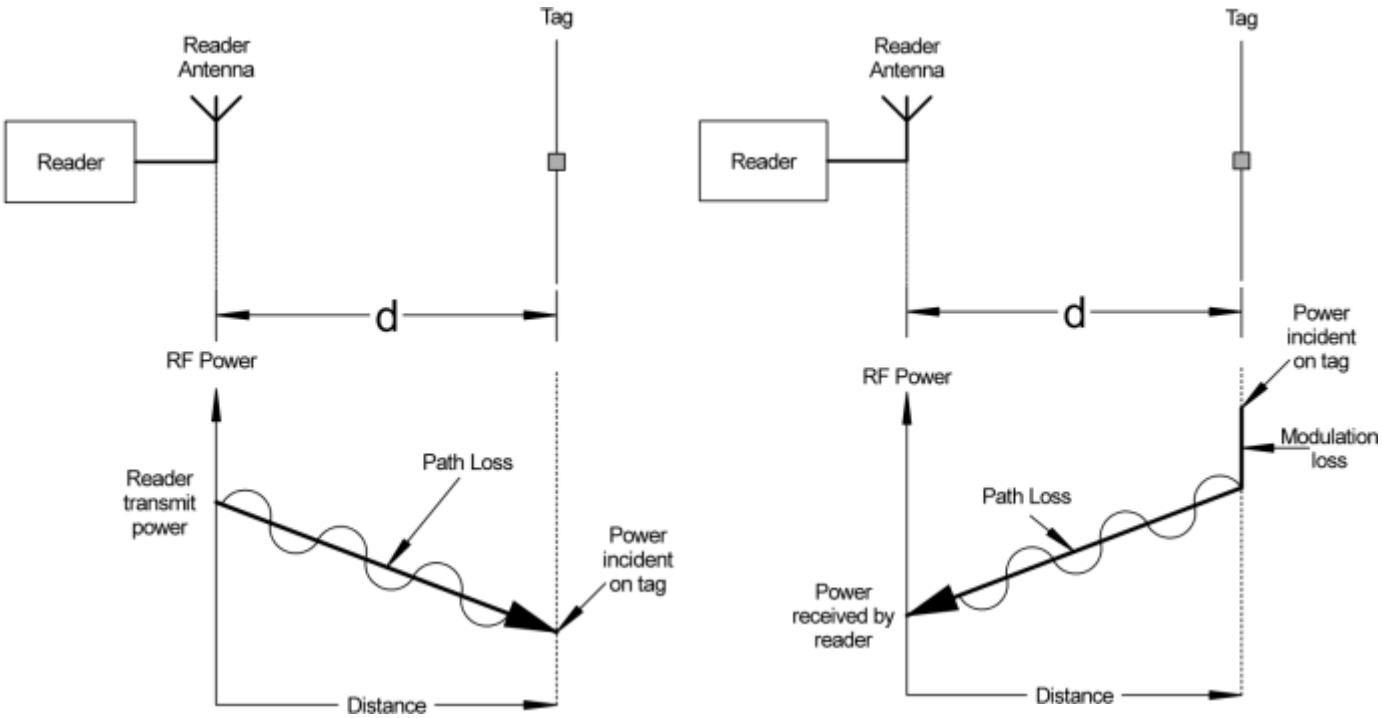
The **link budget** is a calculation of all losses and gains in an RF system. The link budget determines RF power level at each point in the system. This calculation can locate point of failure and determine margin in system performance. Figure 1 shows the link budget diagram of a **monostatic RFID link** where the same reader antenna is used to transmit and receive. The forward link is the transmission from the reader out to the tag in the field. The power received by the tag chip is determined by the reader output power and the distance between reader antenna and tag. The reverse link is the tag's backscattered signal reaching the reader. The signal received by the reader goes through the same loss/gain component of the forward link plus the modulation loss.

Reader Receive Sensitivity

The **reader receive sensitivity** is the minimum power required at the reader port in order to successfully detect the incoming signal. For example, a reader with -60 dBm receive sensitivity cannot detect an incoming signal at -65 dBm. Typically, a fixed reader has better receive sensitivity than a hand-held reader.

Modulation Loss

Modulation loss is the relationship between forward link power and backscatter power. The chip switches between a short and another impedance value and this change in chip impedance is how the tag modulates the reader signal back to the reader. Typically, the modulation loss is -6 dB or worse and is a function of antenna design. Generally smaller tags have higher modulations loss than larger tags. Modulation loss is also dependent on how much RF power is present at the tag. As an example, tags close to a handheld reader transmitting full power may exhibit substantial modulation loss because they are overdriven. Overdriving in some instances can lead to substantial loss of backscatter signal strength leading to reverse link failure.



a) Forward link diagram b) Reverse link diagram

Figure 1: RFID link diagram

Example Link Budget Calculation

An example link budget calculation will be carried out in this section to show what the important parameters are and how they apply to the actual RFID application.

Important parameters:

Reader transmit power = 30 dBm

Path Loss = -39 dB

Tag sensitivity = -12 dBm[1]

Modulation loss = -12 dB

Reader receive sensitivity = -70 dBm[1]

The equation for forward link calculation:

$$\text{Power incident on tag} = \text{Reader transmit power} + \text{Path Loss}$$

$$-9\ \text{dBm} = 30\ \text{dBm} - 39\ \text{dB}$$

The calculation shows that -9 dBm of power arrives at tag meaning forward link has enough RF power to power on the chip.

[1] *Note that lower tag sensitivity signifies a more sensitive tag and a lower reader receive sensitivity number signifies a more sensitive reader.*

The equation for reverse link calculation:

$$\text{Power received by reader} = \text{Power incident on tag} + \text{Modulation Loss} + \text{Path Loss}$$

$$-60\ \text{dBm} = -9\ \text{dBm} - 12\ \text{dBm} - 39\ \text{dBm}$$

The backscatter signal arriving at reader is -60 dBm of power, meaning the reader can detect the incoming signal.

This link budget calculation shows that with the given system parameters, the RFID reader and tag will have no issue communicating. If the **tag sensitivity** was higher than -9 dBm, such as -8 dBm instead of -12 dBm, the forward link would fail. If the **reader receive sensitivity** was higher than -60 dBm, such as -59 dBm instead of -70 dBm, the reverse link would fail.

How to Plan

The success of RFID link depends on many parameters. Only by analyzing all the key components in the system carefully can the application work as intended. Here are a few key factors to analyze:

1. Tag Parameters

Typically, the tag size is the first consideration. Once a suitable size is determined, the tag sensitivity and backscatter power on the intended item for tagging are the important parameters to request from tag vendors. Keep in mind that these quantities are not a single number but a function of frequency. The tag sensitivity will determine if the forward link will be cause of failure while the backscatter power will determine if the reverse link will cause failure.

2. Reader Parameters

The reader itself has two key parameters: maximum output power and receive sensitivity. The first parameter determines forward link success while the latter parameter determines reverse link success. One other important parameter for fixed readers is the reader antenna gain. Most of the reader antennas on the market have 6 dBi gain but if, for any reason, a different gain antenna is used, that becomes an important system parameter for both forward and reverse link.

3. Physical Application Space

The actual application space also contributes to system performance. Primarily the distance from the reader antenna determines the path loss in the system. Also, any metal near the tag or high tag population in a small space can drastically alter tag sensitivity leading to failures. The only way to prepare for the application space is to conduct thorough testing in a similar environment.

Summary

RFID system failure can happen in many ways. The only way to ensure successful RFID system deployment is to study the entire system carefully. First obtain all the tag and reader specifications. Then put those specification numbers in the application space and carry out link budget calculations. The calculation should determine if the chosen components will be good candidates for the application.

Notices: