WF101:
RF Essentials

Jared Hofhiens
RF Embedded Product Manager

www.digi.com
RF Essentials

- Basic communication system
  - Transmitter & receiver
RF Essentials

- Basic communication system
  - Transmitter & receiver
  - Transmitting antenna
  - Receiving antenna
RF Essentials

- **Basic communication system**
  - Transmitter & receiver
  - Transmitting antenna
  - Receiving antenna
  - Environment
RX Sensitivity

• How low can you go?

– Receiver sensitivity is a measure of how well the receiver performs and is defined as the power of the weakest signal the receiver can detect.
TX Power

• Total net output power of transmitter
• Typically measured in dBm or mW

• **mW**: milliwatts are a measurement of power (1000 mW = 1 Watt).
• **dB**: decibel is a unit for expressing the ratio of two amounts of signal power equal to 10 times the common logarithm of this ratio. So, a power measurement in dB has to be relative to something.
• **dBm**: dB(mW) is power relative to 1 milliwatt (mW to dBm = 10Log_{10}(mW/1000) + 30).
• **dBi**: dB(isotropic) is the forward gain of an antenna compared to the hypothetical isotropic antenna, which uniformly distributes energy in all directions.
• **dBd**: dB(dipole) is the forward gain of an antenna compared to a half-wave dipole antenna.
# dBm to mW Conversion

<table>
<thead>
<tr>
<th>dBm</th>
<th>Watts</th>
<th>dBm</th>
<th>Watts</th>
<th>dBm</th>
<th>Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.0 mW</td>
<td>16</td>
<td>40 mW</td>
<td>32</td>
<td>1.6 W</td>
</tr>
<tr>
<td>1</td>
<td>1.3 mW</td>
<td>17</td>
<td>50 mW</td>
<td>33</td>
<td>2.0 W</td>
</tr>
<tr>
<td>2</td>
<td>1.6 mW</td>
<td>18</td>
<td>63 mW</td>
<td>34</td>
<td>2.5 W</td>
</tr>
<tr>
<td>3</td>
<td>2.0 mW</td>
<td>19</td>
<td>79 mW</td>
<td>35</td>
<td>3.2 W</td>
</tr>
<tr>
<td>4</td>
<td>2.5 mW</td>
<td>20</td>
<td>100 mW</td>
<td>36</td>
<td>4.0 W</td>
</tr>
<tr>
<td>5</td>
<td>3.2 mW</td>
<td>21</td>
<td>126 mW</td>
<td>37</td>
<td>5.0 W</td>
</tr>
<tr>
<td>6</td>
<td>4.0 mW</td>
<td>22</td>
<td>158 mW</td>
<td>38</td>
<td>6.3 W</td>
</tr>
<tr>
<td>7</td>
<td>5.0 mW</td>
<td>23</td>
<td>200 mW</td>
<td>39</td>
<td>8.0 W</td>
</tr>
<tr>
<td>8</td>
<td>6.0 mW</td>
<td>24</td>
<td>250 mW</td>
<td>40</td>
<td>10.0 W</td>
</tr>
<tr>
<td>9</td>
<td>8.0 mW</td>
<td>25</td>
<td>316 mW</td>
<td>41</td>
<td>13.0 W</td>
</tr>
<tr>
<td>10</td>
<td>10.0 mW</td>
<td>26</td>
<td>398 mW</td>
<td>42</td>
<td>16.0 W</td>
</tr>
<tr>
<td>11</td>
<td>13.0 mW</td>
<td>27</td>
<td>500 mW</td>
<td>43</td>
<td>20.0 W</td>
</tr>
<tr>
<td>12</td>
<td>16.0 mW</td>
<td>28</td>
<td>630 mW</td>
<td>44</td>
<td>25.0 W</td>
</tr>
<tr>
<td>13</td>
<td>20.0 mW</td>
<td>29</td>
<td>800 mW</td>
<td>45</td>
<td>32.0 W</td>
</tr>
<tr>
<td>14</td>
<td>25.0 mW</td>
<td>30</td>
<td>1.0 W</td>
<td>46</td>
<td>40.0 W</td>
</tr>
<tr>
<td>15</td>
<td>32.0 mW</td>
<td>31</td>
<td>1.3 W</td>
<td>47</td>
<td>50.0 W</td>
</tr>
</tbody>
</table>
Pop Quiz

0 dBm = ?
Pop Quiz

30 dBm = ?
Pop Quiz

-10 dBm = ?
RF Essentials

• Maximizing range
  – Increase TX (transmit) power
    • Government regulated
    • Low-powered applications
RF Essentials

• Maximizing range
  – Increase TX (transmit) power
  – Improve RX (receive) sensitivity
    • Specified in dBm
    • Every 6 dB doubles RF link’s range (line-of-sight)
    • Every 12 dB doubles RF link’s range in indoor/urban environments
RF Essentials

- Maximizing range
  - Increase TX (transmit) power
  - Improve RX (receive) sensitivity
  - Increase antenna gain
    - More gain means more directionality (good and bad)
    - Antenna cables should be as short as possible
    - Government regulated EIRP (TX pwr + antenna gain)
RF Essentials

• Maximizing range
  – Increase TX (transmit) power
  – Improve RX (receive) sensitivity
  – Increase antenna gain
  – Clear environment of obstructions
    • Visual (linear) line-of-sight vs. RF (radio) line-of-sight

Increase Power
Increase Gain

Environment

Increase Gain
Improve RX Sensitivity
RF Essentials

- Fresnel Zone
  - Football-shaped path
RF Essentials

- **Fresnel Zone**
  - Football-shaped path
  - Acceptable = 60% of Zone 1 + 3 meters

![Fresnel Zones Diagram]
• Fresnel Zone
  – Football-shaped path
  – Acceptable = 60% of Zone 1 + 3 meters
  – Raise antennas to help clear the zone
RF Essentials

• Fresnel Zone
  – Football-shaped path
  – Acceptable = 60% of Zone 1 + 3 meters
  – Raise antennas to help clear the zone
  – Formula - use an online Fresnel Zone calculator

\[ r_n = \sqrt{\frac{n \lambda d_1 d_2}{d_1 + d_2}} \]
RF Essentials

- Fresnel Zone diameters

<table>
<thead>
<tr>
<th>Range Distance</th>
<th>900 MHz Modems Required Fresnel Zone Diameter</th>
<th>2.4 GHz Modems Required Fresnel Zone Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 ft. (300 m)</td>
<td>16 ft. (5 m)</td>
<td>11 ft. (3.4 m)</td>
</tr>
<tr>
<td>1 Mile (1.6 km)</td>
<td>32 ft. (10 m)</td>
<td>21 ft. (6.4 m)</td>
</tr>
<tr>
<td>5 Miles (8 km)</td>
<td>68 ft. (21 m)</td>
<td>43 ft. (13 m)</td>
</tr>
<tr>
<td>10 Miles (16 km)</td>
<td>95 ft. (29 m)</td>
<td>59 ft. (18 m)</td>
</tr>
</tbody>
</table>
Antennas

- Antenna gain
  - Directional antennas FOCUS energy: they DO NOT ADD energy
Antennas

• Antenna Gain
  – Omni-directional antennas FOCUS energy: they DO NOT ADD energy
Antennas

• Antenna Gain
  – Omni-directional antennas FOCUS energy: they DO NOT ADD energy
Conducted Power vs. EIRP

- **Conducted**: the TX Power of the RF module

- **EIRP**: EIRP (Effective Isotropic Radiated Power) is the effective power of radio + antenna

![Image of RF module and antenna]
The Datasheet War

- **TX Power:** Is this conducted or EIRP?

  | Output power (w/ 3dBi antenna) | 5mW-200mW variable | 5mW-1000mW variable |

- **RX Sensitivity:** dB for dB, RX Sensitivity increases range as much as TX Power

  Add TX Power + (-RX Sensitivity) for full link budget

- **Current Draw:** Is this the full TX current draw?

  †Current consumption assumes 50% transmitter on-time.