Re: calculating a link budget

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- *From*: Michael <nleahcim@xxxxxxxxx>
- *Date*: Fri, 30 May 2008 12:33:30 −0700 (PDT)

On May 30, 12:49 pm, Jeff Liebermann <je...@xxxxxxxxxx> wrote:

> On Fri, 30 May 2008 08:03:12 −0700 (PDT), Michael <nleah...@xxxxxxxxx>
> wrote:
>
> > Hi there − I'm pretty much RF handicapped. I'm trying to figure out
> > some basic RF things, however. Specifically, I'm trying to figure out
> > how to make a link budget.
>
> Here's an example of how to do it for a wi−fi link:
> <http://wireless.wikia.com/wiki/Wi−Fi#Link_Calculations>
> Note that this makes quite a few simplifications and assumptions. It
> also results in the best case results, which are never the case.

Hi Jeff − So that seems to be exactly how I was calculating it, except that I was using the wrong terms and didn't know that I needed a fade margin. By the way, I'm getting a slightly different number for that calculation:

tx power: +15DbM
TX/RX coax loss: 4dB
distance: 2 miles −> 110.225dB free space loss (36.6 + 20log(2.4E3) +
20log(2))
fade margin: 20dB
RX sensitivity: −84dBm

RX sensitivity <= tx power − tx coax loss + tx antenna gain − free
space loss + rx antenna gain − rx coax loss − fade margin
−84dBm <= 15dBm − 4dB + tx antenna gain − 110.225dB + rx antenna gain
− 4dB − 20dB

−84dBm <= −123.225 + tx antenna gain + rx antenna gain
total antenna gain >= 39.225

The page says you need 21db gain (i'm assuming per antenna) so somehow
our numbers aren't matching. Any idea why?

> > So, for example, let's say I want two Nordic Semiconductor nRF24L01+s (datasheet:http://www.nordicsemi.no/files/Product/data_sheet/nRF24L01Pluss_Preli...) to talk to each other. On page 8 of the datasheet, it says it has a max output power of 0dBm, and −94dBm sensitivity at 250Kbps. So my understanding there is that the max output power is 1mw and the minimum received power is 251fw (10^(−96/10) mw) . Can that even be right? I mean, that seems like an incredibly small amount of power to receive.

> Nope. I'm not sure what you're doing, but the receive sensitivity is −94dBm into 50 ohms. To convert that to watts, use:
> milliWatts = 10^(dBm/10)
> or use a web page based calculator:
> <http://www.aubraux.com/design/dbm−to−milli−watts−calculator.php>
> −94 dBm = 4^−10 milliwatts
> or 400 pico watts. Get used to going between dBm and milliwatts, as it's a very calculation.
> <http://en.wikipedia.org/wiki/DBm>

I accidentally thought it was 96dBm, not 94, hence the wrong number :)

> > OK, next up − so when figuring out a link budget, you first calculate out the link margin

> Nope. It's called "fade margin" or "System Operating Margin". It's (my definition) the amount of signal level you would normally operate expressed in dB over the point where your system craps out and belches unacceptable error levels. It directly correlates to the system reliability:
> SOM dB Reliability % Downtime per year
> 8 90 876 hours
> 18 99 88 hours
> 28 99.9 8.8 hours
> 38 99.99 53 minutes
> 48 99.999 5.3 minutes
> 58 99.9999 32 seconds

Does this table only apply for 802.11 or can it be used for anything?

> The fade margin is not really calculated. You need to determine how reliable your wireless link needs to be. From that, you can obtain a

target value for fade margin. For most Wi−Fi applications, anything less than 10dB fade margin is going to barely work. For some semblance of reliability, aim for about 20dB fade margin. Note that a 10dB increase in fade margin means that your antennas will need to have 10dB more gain which is a HUGE change in antenna size.

> which would be the max output power − minimum input power, or in this case 0 dBm − (−) 94dBm, giving a link margin of 94dB.

Nope. You forgot just about everything that goes between the receiver and the transmitter. There are two antennas with gain (or loss). There are two coax cables to add some losses. There's the all important free space loss, which is a function of distance. See my example at:
<http://wireless.wikia.com/wiki/Wi−Fi#Link_Calculations>
or look at a simple link budget calculator:
<http://www.terabeam.com/support/calculations/som.php>

Not forgetting − just saving for later :)

> Then you just sum up all the losses and gains in between the output and the input. So for example let's say we have a perfect connection from the IC to the antenna. Let's say I use the patch antennas shown here:http://en.wikipedia.org/wiki/Image:Patch_antenna_pattern.gif for both sides of the link. So as long as they are both facing each other I'll have 9dBi gain on both sides of the link. So that means I can now lose 0 dBm − (−)94dBm + 9dBi + 9dBi = 112dB to all other factors (cable, free space/path loss). Let's just say I am also losing another 5db on each side due to connectors, antennas, etc. And let's leave 2db link margin. So that gives me 100db to free space loss. According to wikipedia, free space loss = 32.45 dB + 20*log[frequency(MHz)] + 20*log[distance(km)]. So if I solve for 100 = 32.45 + 20log(2.4E3) + 20log(distance) I find that I can operate at a range of about 1Km.
>
> Did I do that all correctly?

Nope. Let's try it my way. Start with a table of gains and losses starting at one end of the link and going to the other. Some assumptions:
1. This is all at 2.4Ghz.
2. There's coax cable between the devices and the antenna.

3. The manufacturers actually meets their own specs.
4. A receiver sensitivity of −94dBm is at 250Kbits/sec.

So, this is what we know so far.
TX power 0 dBm
TX coax loss −2 dB
TX ant gain 9 dB
Distance unknown
RX ant gain 9 dB
RX coax loss −2 dB
RX sens −94 dBm
Fade Margin 20 dB

Plug that into a link budget calculator and try various ranges until you get the desired 20 dB fade margin.
<http://www.terabeam.com/support/calculations/som.php>
I get 0.15 miles or 240 meters. Again, note that this is the best case and makes quite a few assumptions, such as no Fresnel Zone issues, perfectly aligned antennas, no interference, no atmospheric issues (rain or fog), no folliage attenuation, and no other losses.

I get 249.625 meters. Our numbers are close enough for government work, methinks :)

Now − what about if I were to put an amp on the antenna? Specifically, how about the RF Arrays RWF111 (datasheet: http://www.rfarrays.com/docs/RWF111_datasheetver3.1.1.pdf).

Fair choice. The amp is made to be driven at below about −5 dBm, so you should have enough drive power. If you go for full output power at +22dBm, it will probably go non−linear, belch errors, and never pass FCC Part 19 tests. My guess(tm) is that you can get about +19dBm out of it and meet specs.

I don't
think this is possible as it looks like the nRF24L01+ doesn't have any pin to control the rx/tx switch in the amp, but bear with me anyways :) (or is there a way to do this?).

Wrong. Pins 1 and 15 are TX enable and RX enable. These form the parts of the TX/RX switch.

Sure − but what about on the Nordic part? What would drive the rx/tx enable lines on the RF amp? Doesn't it need to be told whether the

Nordic part is sending or receiving

> > Since this Nordic part is even slower than 802.11b,
> > I think I can assume that I'd get 19dBm or better.

> Adobe reader just crashed on me so I can't look at the original data sheet. There's a difference in modulation density between the various 802.11 speeds, and 802.11g OFDM modes. The result is that the average power output for OFDM is about −2dB less than for 802.11b modes. You'll see this on the various FCC type certification reports, where the power output for 802.11b and 802.11g are different.
>
> Nowever, none of this applies to the Nordic chip, which runs pure FM with no amplitude components. No need to be particularly linear in the power amplfier (except to avoid harmonic generation). No issues with modulation density. My guess(tm) is that with the Nordic chip running FM only, you could get the full +22dBm out of the power amp.

> > Now, I believe that
> > means my output power would be 19dBm, instead of 0dBm before. Now, if the Nordic part had 5dBm output power, instead of 0dBm, I believe I would still have 19dBm output power as they say that the power, not power gain, is 19dBm. Is that right? It says in the transmit path the small signal gain is 28dB, so I guess that means that as long as the inputted transmitter signal had −9dBm (19dBm − 28dB) or greater power it'd output 19dBm. Otherwise it'd output the inputted signal power + 29dB. Is that all right?

> You're describing the effects of overdriving a power amplifier. For a Class C amplifier, that's the way it's done. However, this is a Class A amplifier, that is intended to operate in the linear region of the device, which results in somewhere around −19dBm output. You can overdrive it by 3dB and get the full +22dBm output without any apparent violations of the printed specifications. No clue what it will do if you go over that. As a rule, use the minimum amount of power necessary to get the full output power. Any more is wasted.

So when a power amplifier says that it is a 22dBm amplifier, it means that it's actually adding +22dBm to the strength of the signal, not bringing the signal to 22dBm?

> > Lastly − the small signal gain in the
> > receiver path is 14dB. So without an additional RX amp the Nordic part needed −94dBm. But with this extra amp the received signal could have as low as 108dBm (−94dBm − 14dB).

> Nope. That's not how it works. You can't just add more and more and more gain in front of a receiver to improve the sensitivity. Sensitivity is primarily determined by the NF (noise factor) of the input stage. In this case, it's the NF of the 14dB RF RX amplifier in the power amplifier. In general (a really bad assumption), the NF of the devices inside the amp will be the same as the NF of the devices inside the receiver. If that's true, then the receiver sensitivity will remain at −94dBm for 250Kbits/sec. The main thing the RX amp does is eliminate the losses inherent in the T/R switching and any interconnecting spagetti between the amp and the receiver.

So if the NF of the amp was 5dB worse than the NF of the receiver, the receiver sensitivity would go from −94dBm to −89dBm? Also, are the terms small signal gain and noise factor interchangeable in this context? Also, so the RX part of the amplifier does nothing to boost the signal? That doesn't seem right...

>> Sorry for writing such a book − I wanted to make an example that would illustrate a whole lot of things that I'm unsure about.

> Perahps you should first read a book on the topic instead of writing one?

If there is a good book on the topic, I would be interested! Bear in mind I have a degree in EE, so I'm not a *complete* dolt. (just 80% of one)

>> Thanks so much for anybody that can shed some light on this!

> Rule of thumb:
> − To double the range, you need 4 times the xmit power (+6dB).
> − Double the size of the antenna, and you get 3dB more gain.
> − 6dB of system gain is good for twice the range. 12dB for 4 times the range.
> − Double the data rate is good for a −6dB decrease in RX sensitivity.
>
> Also, everyone lies on their data sheets. For 802.11b/g see:
> <http://802.11junk.com/jeffl/rx−sens/receiver%20sensitivity.htm>
>
> −−
> Jeff Liebermann

Thanks so much for your help,

−Michael

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