EVE Link Budget C&C

11 March 2025 Review

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Where to find this document?

https://github.com/OpenResearchInstitute/documents/blob/master/Engineering/Link_Budget/Link_Budget_Modeling.ipynb

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Dr. Daniel Estévez

https://destevez.net

- Context: we took out *adverse margin* in the budget until we could agree on where and how much, since it makes a big difference to detection.

- "A 0dB SNR is far from enough for detection. Since you need to look at many detection hypotheses (for instance one for each delay of the ZC sequence), the chances that the hypothesis with larger detection metric is a wrong one are rather high at 0dB SNR. As ballpark, you need 10dB"

- This falls into the 10-13 dB range from the IEEE paper that Thomas requested and that we have used to help construct the link budget.

Gary Lauterbach, K6MG

San Bernardino Microwave Society, experienced RF engineer, technologist

- One other correction: "What can we do? There's three things we can look at. First, we can do multiple non-coherent integrations (e.g., 10 non-coherent integrations would add ~10 dB" This should say "would add ~5db" [comment is valid and caught an uncorrected 10 to 5 dB text comment]
- Why do you say the coherent integration period is limited by the changing doppler shift? You clearly state the use of doppler tracking both within a PN sequence as well as between PN sequences. [addressed by Lee Blanton WA8YBT - it is because we don't know if there is any closed loop tracking at all at any of these dishes, we have assumed corrections for Doppler between sequences only and the dish is motionless otherwise]

Gary Lauterbach, K6MG

San Bernardino Microwave Society, experienced RF engineer, technologist

- You have not considered Temporal Spread. This is 12e6/3e8 = 40ms. With a chip period of 2e-7 a total of 40e-3/2e-7=2e5 PN sequences need to be summed to collect all of the returned energy.
- Given a 6000Km diameter for Venus the returned energy gets spread over a 12e6/3e8 = 40ms window. This dual temporal/spectral spreading presents a challenge to coherently summing the returned energy to detect a weak signal. OTOH it provides astronomers the mechanism to do planetary surface mapping by pixellating the surface into delay-doppler regions.

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- It looks to me like the bandwidths used in the CNR/SNR calculation for the various modes are not the coherent integration BW's of each mode but the occupied spectrum for a full message. If I understand your goal correctly it is not to send and receive a full message ala Q65,FT8 … (~77 bits) but just a single bit: EVE detected.

- The coherent integration period for the various WSJT modes is the symbol time, the corresponding coherent BW being 1/symbol period. Using the coherency BW will increase the impact of doppler spreading. **[Thomas was correct in pointing out that the SNR numbers for "JT" modes are all given at 2500 Hz and not the listed signal bandwidths. We switched to using SNR numbers at the normalized bandwidths, and stopped using what we might could call the occupied bandwidths of the signals.]**

Gary Lauterbach, K6MG

San Bernardino Microwave Society, experienced RF engineer, technologist

- Mention was made of OTFS possibly being a method to address the delay-doppler spreading, I think this is a very likely possibility. The reflection can be viewed as a highly multi-path environment but with reflection paths that can be pre-calculated so there is no need for dynamic channel characterization.

Gary Lauterbach, K6MG

San Bernardino Microwave Society, experienced RF engineer, technologist

- BER curves all make the assumption that a signal is present and then show the probability of a flipped bit. The model that is generally used is Gaussian noise with a zero mean and the 0/1 decision threshold placed at 0.

- To be sure that a signal is present however one needs to examine the statistics of the bit stream with no signal present. With no signal there is a 50/50 probability of a bit being in the expected state. **[We see this in Opulent Voice lab work]** The question is then how many bits are required to reduce the false positive probability to a desired value.

Gary Lauterbach, K6MG

San Bernardino Microwave Society, experienced RF engineer, technologist

- First, check this lecture out: https://www.youtube.com/watch?v=hwX5oc9yv4M
- If we take the example from this MIT lecture of a 10e-6 probability of a false detect (equivalent to an acceptable bit error rate in information theory) then a bit stream with a 50/50 bit probability would need to be 20 bits long to achieve the one in a million false positive rate (0.5^20 ~= 1e-6).
- 10 log (20) = 13 db, which is the energy increase required to reduce the false positive error rate to 1e-6. So I would say pick your probability of false positives and false negatives and the SNR will drop out.
- This is a solid information theory result and is probably why the IEEE paper says 10-**13** dB. We have two very different people reinforcing the same idea.

Gary Lauterbach, K6MG

San Bernardino Microwave Society, experienced RF engineer, technologist

- Gary has been studying the area of delay-doppler spreading in planetary radar for the last 3 years in the hope of finding a scheme to enable coherent integration in the presence of spreading. The application he is most interested in is mm-wave EME. In this case the spreading is far worse.

- Maybe we can support his work and help him out here, because this sounds like a really cool thing to do.

WTF is Delay Doppler Spreading?

- Delay-Doppler Spreading: The Basics

- Traditional RF engineers understand that things happen primarily in the time domain (delay spread) or frequency domain (Doppler spread! See, you already know this). The delay-doppler domain represents both effects simultaneously in a unified framework.

- In a wireless channel, signals are affected by:
  Delay spread - Different signal paths arrive at different times due to reflections
  Doppler spread - Frequency shifts occur due to relative movement between transmitter, receiver, and reflectors

WTF is Delay Doppler Spreading?

- The Value of the Delay-Doppler Channel: Advantages

- Sparsity - While traditional time-frequency channels might appear “smeared”, and we have all seen this happen, the delay-doppler representation often has a sparse, concentrated structure.

- Stability - The channel representation in delay-doppler remains relatively stable even in high-mobility scenarios, making it easier to estimate and track. If you have high mobility (and we do here) then this is a good model to consider using.

- Separability - Delay and Doppler components can be handled more independently, simplifying equalization. Equalization is super useful.

WTF is Delay Doppler Spreading?

- OTFS: Leveraging the Delay-Doppler Domain

- OTFS modulation specifically exploits these benefits by:

  Spreading each data symbol over the entire time-frequency grid, making it resilient to localized fading

  Transforming the time-frequency domain into the delay-doppler domain where the channel is more structured

  Converting time-varying channels into quasi-static channels in the delay-doppler domain

WTF is Delay Doppler Spreading?

- Analogy time!

- Imagine traditional modulation schemes like OFDM as trying to have a conversation in a large, echoing cathedral where your words bounce around and arrive at different times (delay spread), **and** you're walking around while talking (causing Doppler shifts).

- OTFS is like having that same conversation but with **specialized glasses** that let you see exactly where and how your voice is bouncing, and a **special receiver microphone** that can precisely focus on just those specific reflection points, effectively turning a complex chaotic environment into a structured, manageable one.

WTF is Delay Doppler Spreading?

- Analogy time!

- The "Special Glasses" (Channel Estimation in Delay-Doppler) like Zadoff-Chu (or other sequences) are carefully designed reference signals that help in accurately estimating the delay-Doppler channel.

- Or, they can be 2D Symplectic Fourier Transforms. These are mathematical operations that convert the time-frequency representation to delay-Doppler representation (ugh)

- Matched Filtering and Channel Estimation Algorithms: Specialized processing that extracts the sparse delay-Doppler channel profile “the hard way”

- Delay-Doppler Channel Sounders (similar to OFDM style pilots) Physical layer functions that are designed to measure the delay-Doppler characteristics of a channel on the regular

WTF is Delay Doppler Spreading?

- Analogy time!

- The "Special Microphones" are signal processing done in the receiver's microphone.

- Delay-Doppler Domain Equalizers: Mathematical operations that invert the channel effects based on the estimated delay-Doppler profile.

- ISFFT (Inverse Symplectic Fast Fourier Transform) - do this in Hardware. They are specialized digital signal processing hardware that can efficiently implement the required transformations. It's something that can be offloaded.

- Any circuit that can efficiently detect and process signals in the delay-Doppler domain can help here!

Lee Blanton WA8YBT

Radar engineer

- 1. Tracking error
- We probably only need to be concerned with open-loop pointing error, not tracking error, since we're not doing closed-loop tracking. Tracking error is generally SNR-dependent and also depends on the tracker design.

Lee Blanton WA8YBT

Radar engineer

- 2. Venus radar cross section

- The radar cross section of Venus is defined as (projected Venus cross-sectional area) * (Venus backscatter coefficient, i.e., albedo)

- This physical cross-sectional area is reduced by the backscatter coefficient to obtain an effective area called the radar cross section. It should be kept in mind that both the physical cross sectional area and the radar cross section are the projected areas of spherical reflectors.

Lee Blanton WA8YBT

Radar engineer

- The equation for the radar cross section (RCS) of a flat plate isRCS = 4 * pi * (area**2 / wavelength**2)

Lee Blanton WA8YBT

Radar engineer

- 3. “Billboard gain”

- The term “billboard gain” is misleading since it implies a reflection from a planar surface. Since Venus is a sphere it scatters the incident power isotropically (approximately). The radar cross section isn’t really a “gain” but is rather just an equivalent cross sectional area in square meters.

- On p. 18 the following appears:

- # Billboard gain
  gain = 4 * np.pi * (effective_area / (self.wavelength**2))
  This is the equation for the radar cross section of a flat plate at normal incidence (see the Radar Cross Section Handbook, pp. 513 and 523). This equation is not applicable to Venus since Venus is a sphere. If this equation is used the SNR will be over-estimated.

Lee Blanton WA8YBT

Radar engineer

- 4. Pointing loss
- The pointing loss is approximated by: pointing_loss = -12 * (error_angle / beamwidth)**2
- This is a fairly good parabolic model for the mainlobe shape, with the loss expressed in decibels. This model appears to be very accurate within the 3-dB beamwidth (i.e., within +/- ½ beamwidth from the mainlobe peak) for a circular reflector antenna.

Lee Blanton WA8YBT

Radar engineer

- 5. Libration

- Libration should have no effect on the cross-sectional area of Venus. Libration can cause fluctuation (fading) of echoes due to cancellation and/or reinforcement of returns from multiple scatterers on the planet surface. Libration fading can either enhance or degrade the SNR at different times. Libration effects should probably not be included in the link budget but can instead be dealt with operationally.

Lee Blanton WA8YBT

Radar engineer

- 6. Venus atmospheric loss

- Published values of the Venus backscatter coefficient (albedo) should already include the effect of two-way Venus atmospheric loss. For this reason the Venus atmospheric loss may not need to be included as a separate loss term.

Lee Blanton WA8YBT

Radar engineer

- 7. Earth weather effects
- At path elevation angles greater than 5 degrees above the horizon a rain rate of 4 mm/hr has a negligible effect (< 0.01 dB) on the total path absorption. (A rain rate of 4 mm/hr, which is light rain, is a standard benchmark frequently used for system design.) We probably won't be operating in rain heavier than about 10 mm/hr (moderate rain) although very heavy rain (e.g., an intense thunderstorm) only adds ~0.15 dB one-way loss at 5 degrees elevation. Clouds and fog have no effect at L-band (1.3 GHz) or S-band (2.45 GHz).

Lee Blanton WA8YBT

Radar engineer

- 8. Main beam efficiency

- Main beam efficiency is the ratio of the power received through the mainlobe to the total power received through the full antenna pattern (mainlobe + sidelobes). The mainlobe is generally defined as the region bounded by the first nulls although it can be defined using other angular limits. Main beam efficiency is infrequently used since it is difficult to calculate. It can be relevant in radiometers that make use of power received through the entire main lobe. It isn't as relevant for the E-V-E link budget SNR calculation since Venus subtends only a small fraction of the main beam and we are more interested in the antenna gain.

- Aperture efficiency depends on the aperture illumination function, the reflector surface losses and the spillover loss. Aperture efficiency is relevant to E-V-E operation since it reduces the antenna gain.

Action Items

Discussion

- Update adverse margin?
- Adjust the mode evaluator with respect to SNR and bandwidths?
- Revise any beam width and antenna efficiency numbers or policies?
- Many items pointed out have been fixed, but careful review for the all feedback will happen today and tomorrow.