Telecommunications Link Design
DESCANSO Seminar Talk

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Telecomm Link Design - Agenda

- Why do we care?
- History – Sum of the Adverse Tolerances, 1960-1975
- Statistical Approach – Fall 1975, Joseph Yuen
- Restatement of Policy – 1999 to present
- Project S/C to DSN Telecom Link Design
- Application to System Contracted projects

Telecomm Link Design – Why do we care?

- Early 1960's found JPL working RANGER – a series of Lunar Impact missions to take photographs on approach.
- Also, Mariner Venus 1962 was first Planetary Mission.
- Missions were highly visible. Engineering commitments were very important.
- Distances were much greater than Earth Orbit.
- How should telecom links be designed?

Telecomm Link Design – First link Design Policy

- The Flight project is responsible for communications link design and performance. The DSN (DSIF, at the time) is responsible for assuring that network performance parameters are correctly used.
- Each parameter is characterized by a design value, which contains all known variations short of failure, and favorable and adverse values representing design uncertainties as well as measurement errors.
- The telecom link design is captured in a table containing the design values and tolerances along with the name of the engineer cognizant of each value.
- The SNR design value shall provide the required performance by the minimum margin needed to cover design uncertainties.
- That criterion is met when the design value exceeds the required value by the sum of the negative tolerances.

Telecomm Link Design – How well did it work?

- Rangers 1-9 (mission success on only 7, 8, 9)
- Mariner Venus 1962
- Mariner Mars 1964
- Mariner Venus 1967
- Mariner 6&7, Mars 1969
- Mariner 9, Mars Orbiter 1971
- Mariner 10, Venus and Mercury 1973

- Missions were very successful. However, Project Managers and Scientists were disgruntled, because there was substantial unused link margin. Higher data rates could have been used.

Telecomm Link Design – Barriers to Statistical Approach

- Planetary communication was still pretty new.
- Significant elements were procured by system contract.
- A contractor could mess up more than one parameter – hence, several variables could be correlated.
- That effect would effect the resultant distribution.

- By the mid 70's, however, there was a fairly significant body of experience going back a decade.
- The desire to exploit the unused margin was increasing;
- And, flight qualified electronics progress allowed more sophisticated designs to include multiple data modes.

Telecomm Link Design – Development of Statistical Approach

- In 1973, Joe Yuen got the task of developing a probabilistic or statistical approach.
- He examined the design data and measured performances of the previous projects and proposed the current method.
- The new policy took effect in the Fall of 1975 as a memorandum prepared by RPMathison and signed by William Bailey, Assistant Laboratory Director for Telecommunications and Data Acquisition; Robert Parks, ALD for Flight Projects; and, Fred Feldberg, ALD for Technical Divisions.
- The Viking Project was designed according to the old policy, but extra data rates were designed in so as to take advantage of actual performance. And, the statistical approach was applied during the mission.

Telecomm Link Design – Statistical Approach

- The Flight project is responsible for communications link performance.
- The DSN is responsible from assuring that performance parameters are properly used.
- Each parameter is characterized by a design value, which contains all known variations short of failure, and probability distributions for the favorable and adverse tolerances representing design uncertainties as well as measurement errors.
- The telecom link design is captured in a table containing the design values, tolerances, and their probability distributions.
- The Telecom Cognizant Engineer is responsible for the table.
- The system shall meet the performance required by the project by the minimum margin necessary to cover design uncertainties.
- The criterion is met when the expected value of the link Eb/No exceeds the required value by a Project selected multiple of the standard deviation yielding the desired probability of success.

Telecomm Link Design – Gaussian Approximation

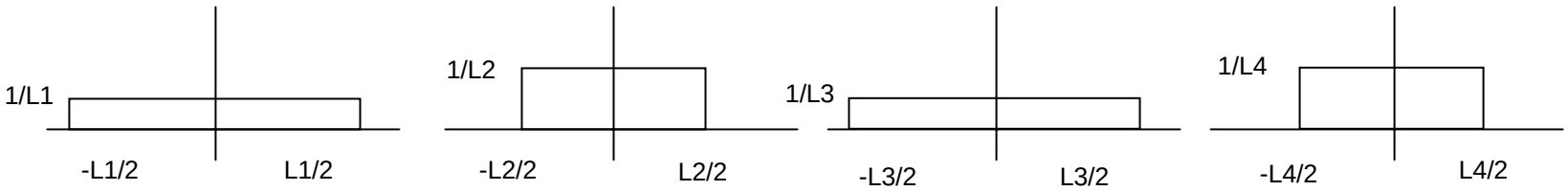
- Language “multiple of standard deviation” assumes Gaussian distribution.
- True: if there are a “large number” of parameters - Central Limit Theorem
- Actual Distribution only approaches Gaussian as N gets large.
- How big N needs to be depends on distributions, relative spreads, and correlation.

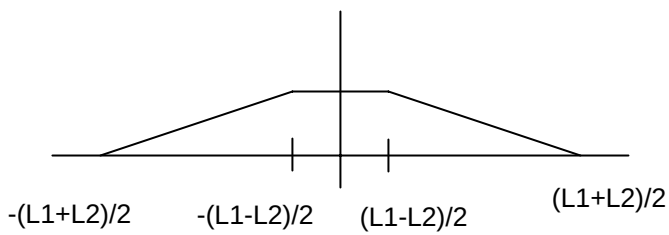
Let’s try a simple example, a 4 parameter link.

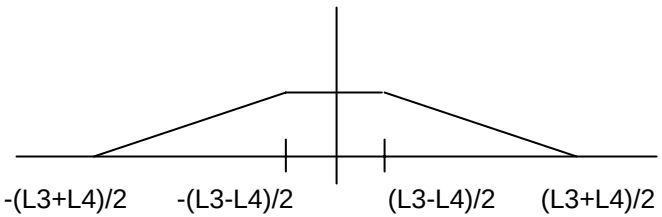
Telecomm Link Design – An example

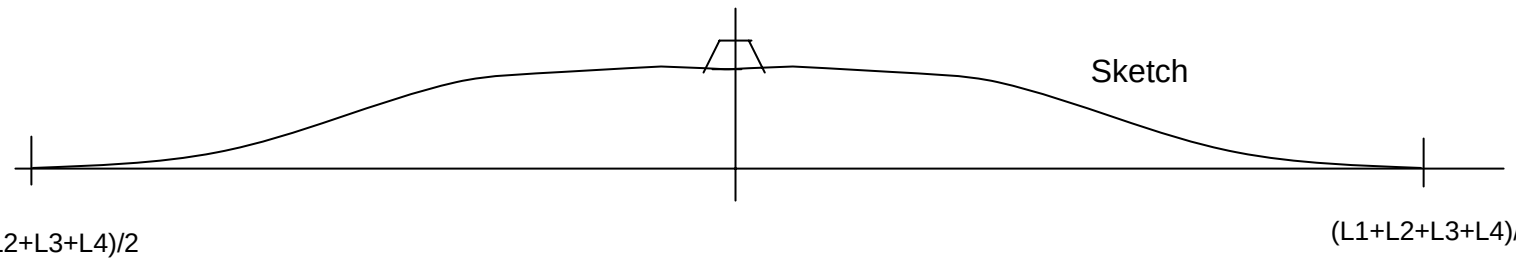
- Pt is transmitter power, tolerances +-L1/2
- Gt is transmitting gain, tolerances +-L2/2
- Gr is receiving gain, tolerances +-L3/2
- N_o is the noise spectral density, tolerances +-L4/2
- Assume uniform densities for simplicity, also reasonable as they represent mostly measurement error.
- Density of E_b/N_o is convolution of the above 4 densities.

Telecom Link Design – Example continued









Telecom Link Design – Example continued

- The density function is finite. That is, it is non zero only over a finite domain. It therefore can not be Gaussian. Gaussian is non-zero every where.
- Notice the left most point at -(L1+L2+L3+L4)/2.
- That is our old friend “The sum of the adverse tolerances”.
- This is really “worst case”; the folks 40+ years ago did not think in probability terms, but “worst case” does mean that 100% of the probability space yields better performance. They are equivalent.

Telecomm Link Design – So What's new?

- Many years have gone by.
- Many new people.
- Many missions at one time.
- Many management fads – FADE, TQM, Reengineering, Process Based Management…
- JPL Rules, Flight Project Practices, Design Principles.
- No home for the 1975 Policy

- Modernize statement and place it appropriately in the JPL Requirements hierarchy.
- Associate Director for Flight and Mission Assurance.

Telecomm link Design – Restatement

- Multiple of the standard deviation replaces “multiple of the variance” – a simple mis-statement.
- Restates the space to space or space to/from Earth link criterion.
- Adds consideration of Orbiter to/from atmosphere entry vehicle.
- Adds consideration of Orbiter to/from Landed vehicle.
- Adds consideration of Landed vehicle to/from another or a Rover.
- Encourages “Thinking” in any case not exactly described by the above listed examples.

Telecom Link Design – Space to Space, Space to/from Earth

- There is usually no dominant link parameter uncertainty.
- A possible exception is an LGA link at high aspect angle.
- A rotating S/C will complicate the ‘nominal’ or design value designation.
- As measured values are accumulated, uncertainties can be reduced, thereby decreasing necessary margin for a given confidence level.

Telecom Link Design – Orbiter to/from Atmospheric Entry Vehicle

- Link will have large transient fades, 10 db may be typical.
- There may be an ionization “blackout” period where link disappears entirely.
- The link may not have a forward link to work a retransmission protocol.
- Fades may be accommodated by margin and multiple transmission of critical data.

Telecom Link Design – Orbiter to/from Lander on Surface

- This link will often be two way.
- The link will have large fades induced by vehicle dynamics. 10 db could be typical.
- The link should be designed to accommodate the fades by a combination of margin and retransmission protocols.

Telecom Link Design – Lander to/from Lander or Rover on Surface

- This link will have large fades associated with movement around or behind large features.
- Fades a large as 20 or 30 db may occur.
- Operating margin should be sufficient to allow basic data to be exchanged. For example: 10bps may work when 10kbps does not.
- Circumstances may occur that preclude such margin.
- In such a case, a Rover should have fault protection that retraces movement until communication is restored.

Telecom link Design – Other Possibilities

- Various features of all the above may exist.
- Or, some circumstance totally new.
- Entry vehicle direct to Earth is an example, as in MER.

  Large transient fades, losses with large uncertainties, very low Eb/No.

Solution was a sequence of tones triggered by specific events. Each tone lasted 10 seconds. The expectation was that some would be missed. However, the known nominal sequence allowed recognition of correct process. And, it allowed for partial reconstruction had bad things occurred.

As it happened, both entries were “observed” flawlessly throughout.

Moral: there is no substitute for **thinking**.

Telecom Link Design – Telecomm Division Objectives

- Improving the accuracy of the expected value specifying link performance, particularly during the design phase of a project.
- Reducing the tolerances of link parameters.
- Reducing the number of link elements with separately assigned tolerances.
- Meeting the design-value as opposed to adverse tolerance performance.
- Taking advantage of link performance which exceeds the adverse tolerance value (by multiple data rate or other multi-mode designs).
- Separate specification of the spacecraft and ground portions of the link.