Technical Budgeting

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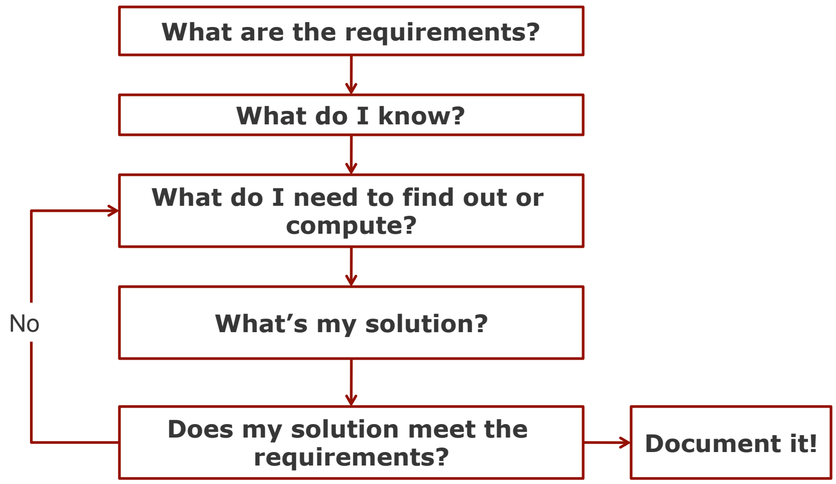
- **At some time in our design process, we need to allocate our main requirements**
  - **How fast?**
  - **How long?**
  - **How much?**
  - **How accurate?**
  - **How precise?**
- **The allocation process should not be *ad hoc*!**
- **The allocation becomes the requirements for sub elements of our design.**
- **We can mechanize the process by means of technical budgets…**
- **…and the easiest way to do this is to use Excel**

LaBerge's Law #3

- Every engineering problem is a **design** problem.
- In fact *designing solutions* is what engineering do!



What's my solution?

- A large part in determining the solution is the process of allocation…
- …that is, how much of a requirement is accomplished by individual elements of your design.
- For example
- A laptop manufacturer requires a battery life of 5 hours under full load…
- …and the power supply engineers tell us that 85 W-Hr is the best energy storage possible in the allowed volume.
- What are the design requirements for the processor, memory board, peripherals, screen, disk drive and other components?

What are the requirements? → 5 hours battery life

What do I know? → 85 W-hrs of energy

What do I need to find out or compute? → How is the energy divided? What's reasonable for each element? Do I need a *margin*!?

What's my solution? → My allocation becomes the next designer's requirement

Does my solution meet the requirements? → Document it!

No → What do I need to find out or compute?

Write the specs for the subsystems
Write a tech note to capture the allocation

How to proceed?

- **I (you) don't know!**
- **…yes, this happens in the real world!**
- **LaBerge's Law #1: Ambiguity!**
- **Careful consideration of units can point the way**

$$85\text{W-Hr to last 5 hr}$$

$$E = PT \left(\text{actually } E = \int p(t)\,dt,\ \text{but that's later!}\right)$$

$$P = \frac{E}{T} = \frac{85\ \text{W-Hr}}{5\ \text{Hr}} = 17\ \text{W}$$

- **That has to be our "bottom line"…**
- **…the power consumption has to be less than 17 W.**

What is reasonable?

- Experience might tell us
  - Your experience on similar designs
  - Your co-workers' experience on similar designs
- Research might be needed
  - Look it up
    - Search the web … be careful of what you find!
  - Take a similar product and measure it
  - Reverse engineer something that works
- When you start out, you don't have experience, so you're forced to research!

First draft DC power budget

DC Power Budget for Laptop				
Item	**Description**	**Value**	**Units**	**Source/Comments**
1	Battery Capacity	85	W-Hrs	Dell Latitude 830 battery specification
2	Desired battery life	5	Hrs	User requirement
3	Average power	17	W	Computation item 1/Item 2
4	Motherboard	20	W	engineering est
5	Disk drive	18	W	engineering est
6	DVD drive	14	W	Dell DVD+/-RW specification
7	SVGA LCD screen	15	W	engineering est
8	WiFi	10	W	engineering est
9	Total load	77	W	Sum(item4..item8)
10	Design margin	-60	W	Computation item 3-item 9
11	Effective time	1.104	Hrs	Computation item 1/Item 9
12	Surplus(Shortfall)	(3.90)	Hrs	Computation item 2-item 11

So this doesn't look so good!

- **What might be wrong?**
  - **There are a lot of "engineering estimates"**
  - **All of the values assume constant operation**
- **What else might we need to know**
  - **How about some duty cycles?** $\tau = \dfrac{\text{on time}}{\text{total time}}$
  - **For example**
    - **Hard drive 5%?**
    - **CDROM 10%?**
    - **Processor 20%**
    - **LCD Screen 75%**
    - **WiFi 15%**

DC Power Budget for Laptop					
Item	**Description**	**Value**	**τ**		**Units**
1	Battery Capacity	85		85	W-Hrs
2	Desired battery life	5		5	Hrs
3	Average power			17	W
4	CPU	20	20%	4	W
5	Disk drive	18	5%	0.9	W
6	DVD drive	14	10%	1.4	W
7	SVGA LCD screen	15	75%	11.25	W
8	WiFi	10	20%	2	W
9	Total load			19.55	W
10	Design margin			-2.55	W
11	Effective time			4.348	Hrs
12	Surplus(Shortfall)			(0.65)	Hrs

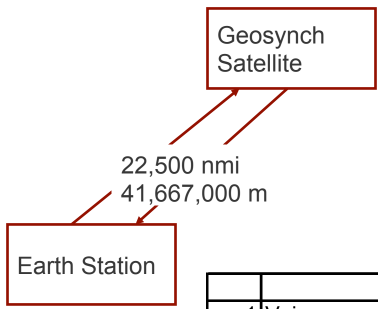
What have we learned?

- We're not far from the goal!
- …and we might reach it for some users!
- Big draw is Display
  - Can it be reduced?
  - How much will THAT cost?
- 100 W Battery would solve the problem!
  - How much will THAT cost?
  - How big will it be?
- We (I) learned all of this for the investment of about 30 minutes!
- Suggesting that technical budgeting is very effective means of developing our design requirements

Technical budgeting gives system insight

- View of all quantitative parameters
- Technical budget is a plan and a tool
- Link budgets for all wireless communications links within the system
- Error budgets for all (sub)systems involving precision measurement
- Timing budgets for all time-critical applications
- Weight budgets for physical subsystems
- DC power or power dissipation budgets for all physical subsystems
- Mass or reaction budgets for chemical processes
- When done well it is self-documenting!

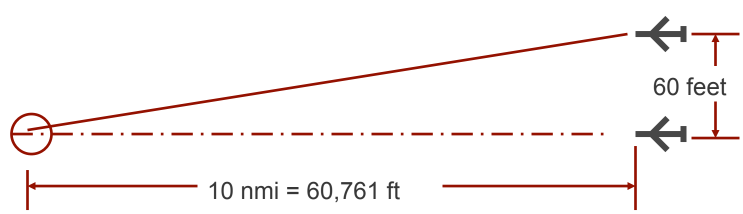
Real world example - Inmarsat voice delay budget



- **Inmarsat voice uses an interleaver of N points at 21,000 bps**
- **Geosync satellite is a bent pipe**

		Bias	Units
1	Voice encoder delay	20.00	ms
2	Voice interleaver depth	1000.00	bits
3	Interleaver delay	47.62	ms
4	Earth-to-Satellite Propagation	138.89	ms
5	Satellite Processing delay	1.00	ms
6	Satellite to Earth Propagation	138.89	ms
7	Receiver interleaver delay	47.62	
8	Voice decoder delay	10.00	ms
9	Total delay	404.02	ms

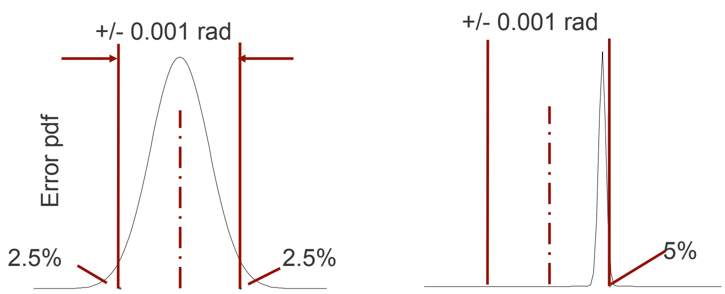
Example 2, PRM angle error Budget



- **Electronically scanned antenna**
- **Monopulse receivers**
- **Requirement 60 feet separation at 10 nmi with 95% confidence**

Random components in error budget

- **Must consider both bias (long term) and noise (short term) errors**



Small bias, large noise — Accurate, but not precise

Large bias, Small noise — Precise, but not accurate

PRM angle error budget

- **Bias (mean) components ADD**
- **Noise components (standard deviations) combined in root sum square manner, i.e., by ADDING VARIANCES**

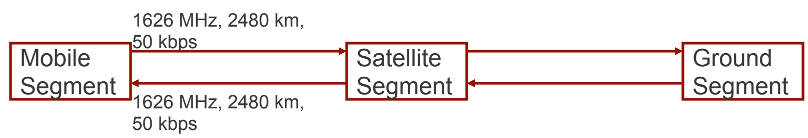
$$\bar{x}_{TOTAL} = \sum_{k=1}^{K} \bar{x}_k \qquad \sigma_{TOTAL} = \sqrt{\sum_{k=1}^{K} \sigma_k^2}$$

- **For Gaussian assumption** $x_{95} \approx \bar{x}_{TOTAL} \pm 2\sigma_{TOTAL}$

		Bias	1 sigma Noise	Units
1	Physical antenna alignment	0.15	0.010	mrad
2	Beam steering error	0.20	0.050	mrad
3	Wind motion	0.00	0.100	mrad
4	Monopulse error	0.05	0.200	mrad
5	Monitor error limit	0.25	0.010	mrad
6	Output quantization	0.00	0.014	mrad
7	PRM System Error	0.65	0.230	mrad
8	95th percentile error (assume Gaussian)	1.11		

Complicated Iridium S/E link budget

- **Iridium is a constellation of low-earth-orbit satellites for cell-phone-like communications**
- **From constellation orbital parameters, we know the following**
  - **The minimum elevation angle from the user to the satellite is 8 degrees**
  - **The maximum distance from the user to any satellite is 2.48 x 10^6 meters**
  - **The channel data rate is 50,000 bps**
  - **The channel operates at 1610-1626.5 MHz**



Example 1, cont'd

	Item	Value	Units
1	Transmitter power	13.0	W
2	Transmitter Power	41.1	dBm
3	Transmitter Cable Loss	2.0	dB
4	Transmitter Antenna Gain	24.0	dBi
5	EIRP	63.1	dBm
6	Operating Frequency	1626.5	MHz
7	Receiver Range	1339.5	nmi
8	Free Space Path Loss	164.6	dB
9	Polarization Loss	0.0	dB
10	Excess Propagation Loss	1.2	dB
11	Power at Isotropic Antenna	-102.6	dBm
12	Receive Antenna Gain	0.0	dBi
13	Receive Cable Loss	0.0	dB
14	Power at Receiver Input	-102.6	dBm
15	Receiver Noise Figure	4.4	dB
16	Boltzmann's constant	-198.6	dBm/(K Hz)
17	Receiver T	24.6	dB-K
18	Receiver N0	-169.6	dBm/Hz
19	Receiver IF Bandwidth	25000.0	Hz
20	IF Carrier-to-Noise Ratio	23.0	dB
21	Symbol rate	25000.0	symbols per second
22	Es/N0	23.0	dB
23	Bits per symbol	2.0	
24	Eb/N0	20.0	dB
25	Interference Power Density	-158.0	dBm/Hz
26	N0+I0	-157.7	dBm/Hz
27	Es/(N0+I0)	11.1	dB
28	Eb/(N0+I0)	8.1	dB