Technical Budgeting

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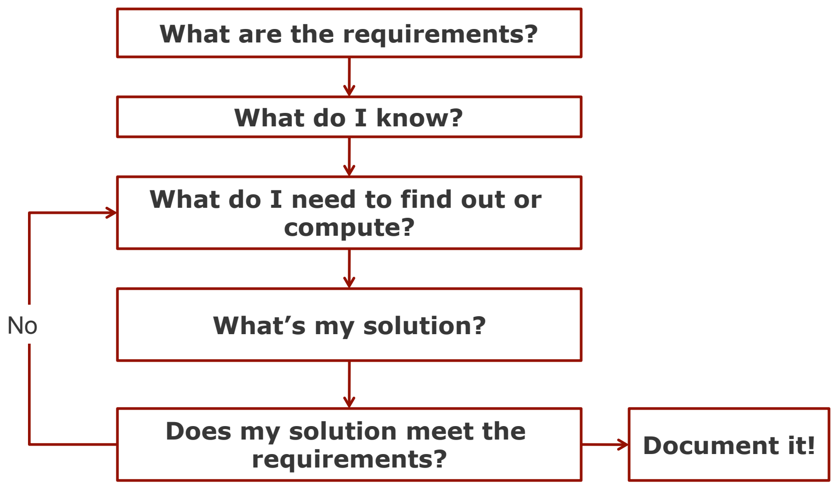
- At some time in our design process, we need to allocate our main requirements
  - How fast?
  - How long?
  - How much?
  - How accurate?
  - How precise?
- The allocation process should not be *ad hoc*!
- The allocation becomes the requirements for sub elements of our design.
- We can mechanize the 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

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

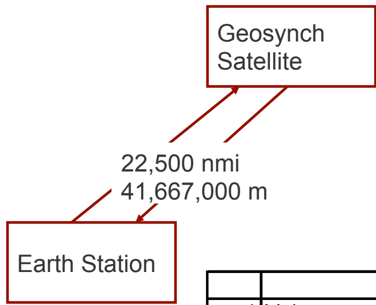
What have we learned?

- **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!**

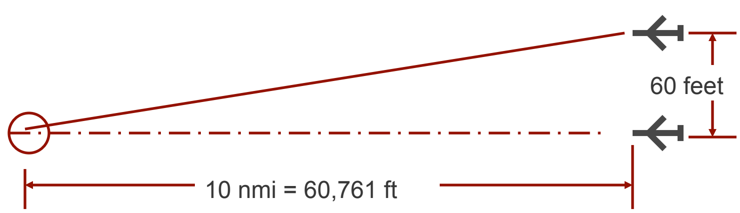
Real world example - Inmarsat voice delay budget



- 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

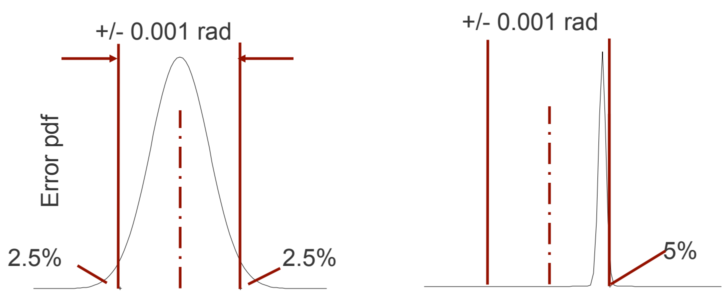
Example 2, PRM angle error Budget



- 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

Large bias, Small noise

Accurate, but not precise

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**

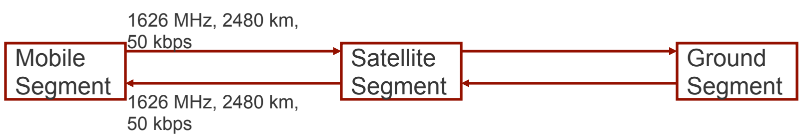
$$\bar{x}_{TOTAL} = \sum_{k=1}^{K} \bar{x}_k \qquad \sigma_{TOTAL} = \sqrt{\sum_{k=1}^{K} \sigma_k^2}$$

- **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