PRODUCT & SYSTEM DESIGN

PERSPECTIVES FROM A DESIGN ENGINEER

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02.27.24

Introduction

> 25 years of product development experience

- Naval Undersea Warfare Center
  - Mechanical Design Engineer/Analyst
    - Exercise Torpedos / Countermeasure sub-systems / Shock&Vibration
- Bose Corporation
  - Mechanical Design Engineer
  - Program Manager
  - Product Architect / Lead System Engineer
  - Research Team Leader (ANR Sub-System)
  - Category Lead System Engineer

BSME University of Rhode Island
MSME Worcester Polytechnic Institute – Dynamics and Vibrations

A Few Product Examples

Banded Headphones

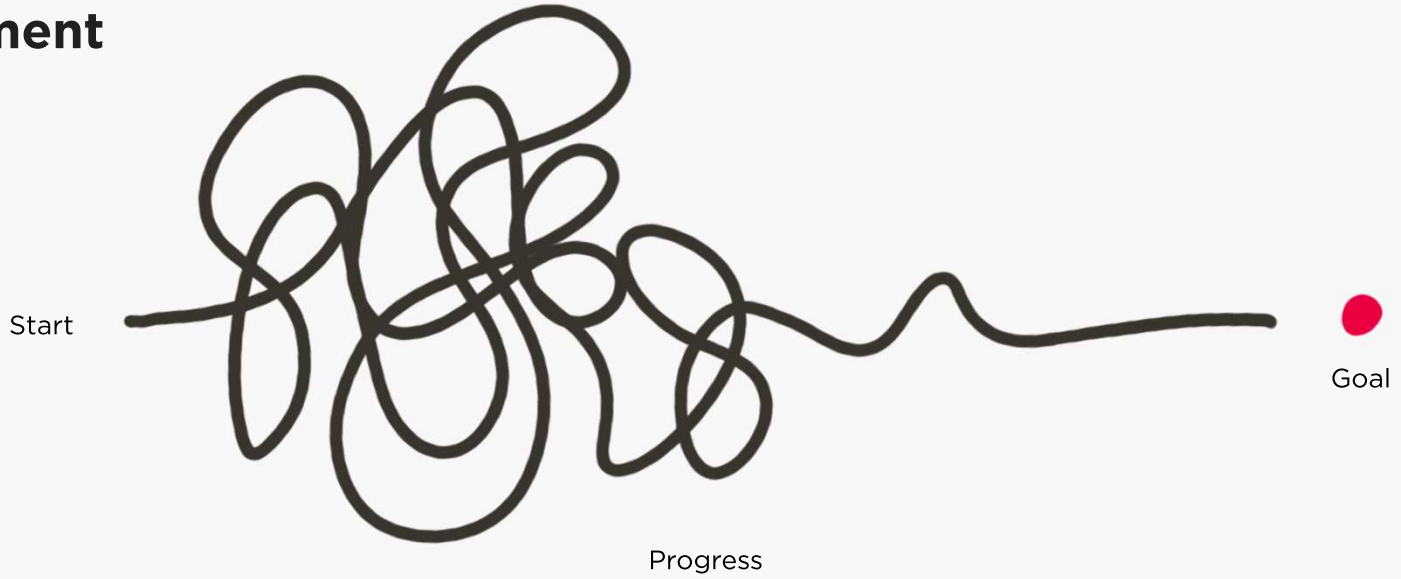
A Few Product Examples

Product Development

Expectation

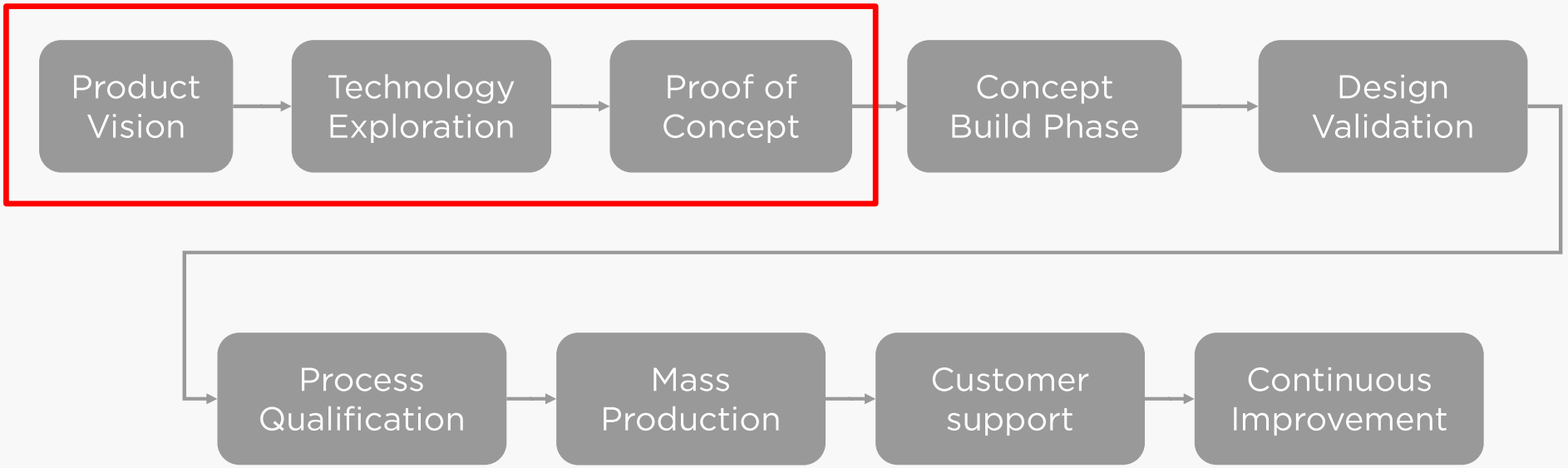
Product Development

Reality



Basic Development Process

Product and System Design Fundamentals to Help
Get off to a good start !



Product and System Design Fundamentals

01 | Requirements Management

Understand What Customer is Asking for
Convert to Engineering Requirements (System and Component)
Map out “How to Know When You’ve Succeeded” (How/What to Measure)
Track It !

02 | Design Approach – Getting Started

System Partitioning
Develop Integration Plans (Dependencies, What comes first/second)
Execution Cycles (Design, Build, Test)

03 | Tradeoffs

Identify Conflicts / Possible Friction Points
Best Practices
Decision Tools
Examples

04 | Real Life Examples

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01 Requirements Management

High Level Customer Facing Needs / Goals (THE WHAT)

Make sure you understand what is desired
Understand Priorities (Need vs Would Like)
Write Them Down !!

MITOS	Sentimet	Miami-Dade
1. It should measure the local weather, at least temperature and humidity and ideally also sun exposure and ground surface temperature and air pressure, all with dynamics appropriate for the use case.***	1. It should measure the "heat experience" at each bus stop, at least temperature and humidity, but also could include air quality, all with dynamics appropriate to the use case.***	
2. It should be able to measure how many people are in the area passing through (e.g., foot traffic) and lingering.***	2. It should be able to measure how many people are waiting, and for how long.***	
3. It should operate without being connected to line voltage. ***	3. It should operate without being connected to line voltage. ***	
4. It should be portable and able to be set up by an average person in a variety of outdoor environments on the MIT campus, including on a tripod or attached to poles of various dimensions.***	4. It should be installable by a technician, and should be easy to set up.***	
5. It should be able to be physically attached to a HOBO MX2302A data logger.*		
6. It should report faults, such as battery failure, falling, vandalism, etc.**	5. It should report faults, such as battery failure, falling, vandalism, etc.**	
7. It should be as inexpensive as possible. *	6. It should be as inexpensive as possible. *	
8. Data from a sensor node should be able to be tied to a location.***	7. Data from a sensor node should be able to be tied to a location.***	
9. It should maintain privacy. ***	8. It should maintain privacy. ***	
10. It should operate independently without user intervention for 2+ weeks.***	9. It should operate independently without user intervention for at least a month.***	
11. It should be rugged and able to withstand a summertime Boston-area environment (heat, rain, wind and curious people). ***	10. It should be rugged and able to withstand shipping, setup, and operation in the Miami-Dade environment. ***	
12. Multiple systems should be able to be used simultaneously. ***	11. Multiple systems should be able to be used simultaneously. ***	
13. The system should present the information on a dashboard (with real-time data outputs to a dashboard if possible), and also allow downloading of raw data.***	12. The system should incorporate data from Swift.ly and present that information to the operator in a useful way. ***	

Mostly the same…could make one overall system, or two slightly different systems

Control Module Requirements:

1. Size <= AHX
2. Dual Volume Control
   a. Thumb Wheels – analog potentiometers
   b. Independent L & R
   c. 12dB range (same as AHX)
   d. By-pass controls and set volume to max when no power (passive)
   e. Knobs need to be protected from inadvertent operation
   f. Knobs need to be able to be used in tandem or independently (closer together than AHX)
   g. There needs to be visual indication of volume level of each channel (numbers on wheels, ramp/wedge)
3. Auto-off is required (same method as current AHX)
4. Indication of battery life (fuel gage)
   a. Similar to AHX – 3 levels minimum
   b. Colors, # of lights, placement are TBD but WL can copy AHX for now.
5. Dual Power supply
   a. Install version will be able to be powered from either batteries or panel.
6. Aux jack for audio only – no cell
   a. Only for headphone interface
   b. Inactive in no-power mode – make it prohibitive
7. Prioritization
   a. ICS over audio jack
   b. Over-ride switch – location TBD (UI) Dip or on main control
   c. No priority for blue tooth
8. Auto-sense stereo / mono
   a. Need override switch
   b. Need traditional switch as well for passive operation and when overiride is on

01 Requirements Management

Convert to Engineering Requirements (THE HOW)

Customer Need:

Best-in-Class Audio Quality

Engineering/System Requirements:

1. Frequency Response matches Bose target within 2dB
2. Maximum Loudness must be 97dBA-100dBA
3. Noise Floor must be less than 28dBA
4. Linear THD levels must be less than -40dB
5. Non-linear THD levels must be less than -20dB
6. No noise greater than -60dB during frequency sweep
7. No audible pop or click during state changes

Component Req Speaker:

1. 40mm diameter speaker
2. R=32+/1 Ohms
3. Sensitivity 110 +/- 3 dBSPL/V
4. THD < 1%

...

Component Req Output Amplifier :

1. Ripple/Noise <
2. THD <
3. Output Voltage

...

01 Requirements Management

Convert to Engineering Requirements (THE HOW)

Customer Need:

What happens when it's something new / no clear line to engineering requirements ?

Use Benchmarking

Find products doing something similar – even if it is for a different purpose or function

Use them in the real world and characterize what you can in the lab
- Develop a sense for what may be important
- Develop your own ideas for other objective measurements

Plan on less conventional metrics for success
- Field testing, Subjective Evaluations to tie back to objective measurements

01 Requirements Management

Define How you Measure Success (THE HOW cont.)

Engineering/System Requirements:

1. Frequency Response matches Bose target within 2dB
2. Maximum Loudness must be 97dBA-100dBA
3. Noise Floor must be less than 28dBA

...

Engineering/System Requirements:

1. Frequency Response matches Bose target within 2dB
    a. Raw Acoustic Measurements on Fixture XXX plus EQ Simulation
    b. Full system measurements on Fixture XXX
    c. Subjective Evaluation
2. Maximum Loudness must be 97dBA-100dBA
    a. Simulated system output using acoustic model with speaker specification
    b. Full system measurements on Fixture XXX per EU Standard YYY
3. Noise Floor must be less than 28dBA
    a. Subjective evaluation of bread-board prototype vs benchmark
    b. Full system measurements on Fixture ZZZ per procedure 123

01 Requirements Management

Define How you Measure Success (THE HOW cont.)

Engineering/System Requirements:

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2. Maximum Loudness must be 97dBA-100dBA
3. Noise Floor must be less than 28dBA

Engineering/System Requirements:

More on this in a later Bose visit / lecture

lus EQ Simulation

el with speaker specification

r EU Standard YYY

3. Noise Floor must be less than 28dBA
    a. Subjective evaluation of bread-board prototype vs benchmark
    b. Full system measurements on Fixture ZZZ per procedure 123

01 Requirements Management

Track it! (THE HOW cont.)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1				Compliance			Method				Documented		
2	Req. Para. #	Requirement	Insp. Para. #	Pass	Fail	Unkn	FAT	Engr	Sim	Insp	Yes	No	Notes
3	3.	REQUIREMENTS	N/A										
121		The talk-through circuit shall provide at least 240 hours transmission in a 90 dB, 1 KHz noise field using a fresh battery.		X			X				X		
122	3.2.4	Acoustical Characteristics	N/A										
123	3.2.4.1	Frequency Response	4.2.3.4.1.1										
124		In the Intercom or Low Power Mode, with the headset mounted on a simulated real head fixture (mannequin), the headset at 22°C, 50% RH shall produce an acoustic frequency response that fits within the limits identified in Figure 1 of PRFA3261202 when driven by a -10 dBV input audio signal when measured in 1/3 octave frequencies between 300 Hz and 4500Hz and corrected for the diffuse field response of the fixture.		X				X	X	X	X		Test method similar to FAT methods, but different equipment used
125		In the Unpowered Mode, the headset at 22°C, 50% RH shall produce an acoustic frequency response that fits within the limits identified in Figure 1 of PRFA3261202 when driven by a -10 dBV input audio signal when measured in one octave frequencies between 300 Hz and 4500Hz and corrected for the diffuse field response of the			X			X			X		Test method similar to FAT methods, but different equipment used
126	3.2.4.2	Output Level	4.2.3.4.1.2										
127		The headset at 22°C, 50% RH shall produce an output level of 106 ± 3dB SPL corrected for the diffuse field response of the fixture for a 0 ± 0.1 dBV input audio signal at 500Hz when in either the Intercom or Low Power Mode.		X		X		X	X		X		Test method similar to FAT methods, but different equipment used
128		With the headset in the Unpowered Mode, the output level shall be 94 ± 4 dB SPL corrected for the diffuse field response of the fixture in the octave around 500 Hz for a 0 ± 0.1 dBV input audio signal.		X		X		X	X		X		Test method similar to FAT methods, but different equipment used
129	3.2.4.3	Harmonic Distortion	4.2.3.4.1.3										
130		The harmonic distortion of the earphone assembly in Low Power and Intercom Modes shall not exceed 5% for a 0 ± 0.1dBV input at 500 Hz and it shall not exceed 10% with the input adjusted for an output of 100 dB SPL at 500 Hz and then swept from 300 Hz to 4500Hz.		X			X	X	X		X		
131		The harmonic distortion of the earphone assembly in Unpowered Mode shall not exceed 5% for a -6 ± 0.1dBV input at 500 Hz and it shall not exceed 10% with the input adjusted for an output of 94 dB SPL at 500 Hz and then swept from 300 Hz to 4500Hz.		X			X	X	X		X		
132	3.2.4.4	Earphone Linearity	4.2.3.4.2.4										
133		From an initial output of 85dB SPL, the output shall remain linear to within ± 2dB for an increase in input of 10 ± 0.1dB and ±3dB for an increase in input of 20 ± 0.1dB.		X		X			X				Design analysis based on prior art

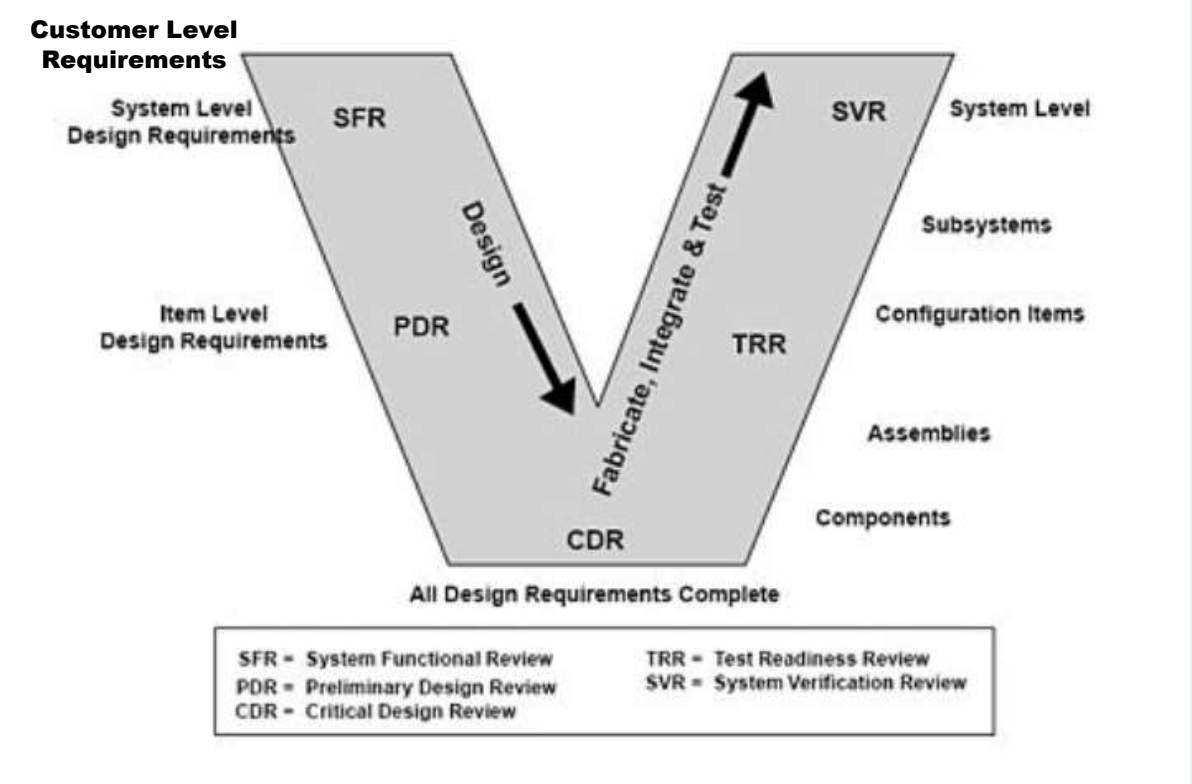
Compliance:
- Pass
- Fail
- Unknown

Method:
- Formal Test
- Eng Eval
- Simulation/Analysis
- Inspection / Subjective

Documented:
- Yes
- No

01 Requirements Management

V Model



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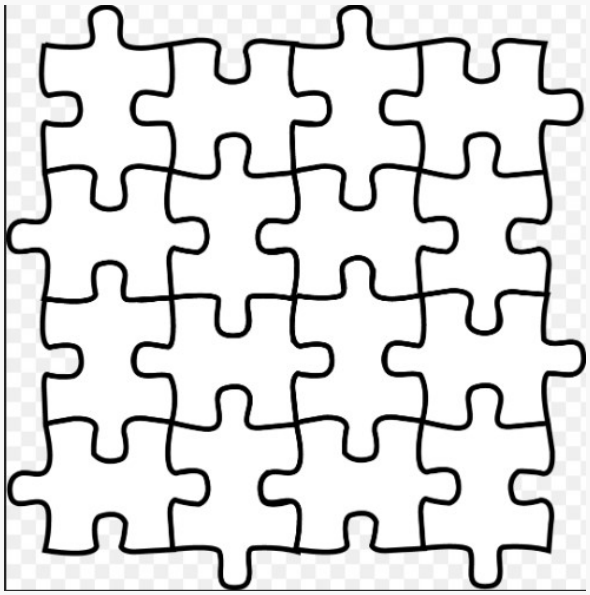
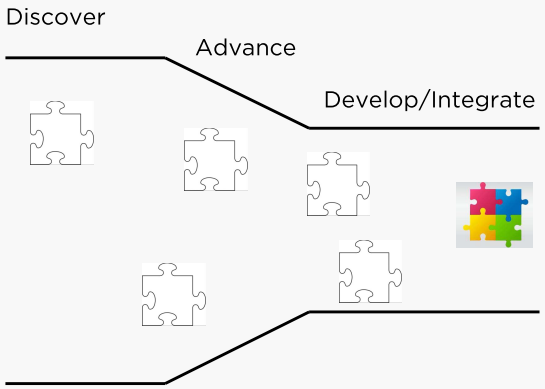
02 Design Approach

System Partitioning



Break into Pieces

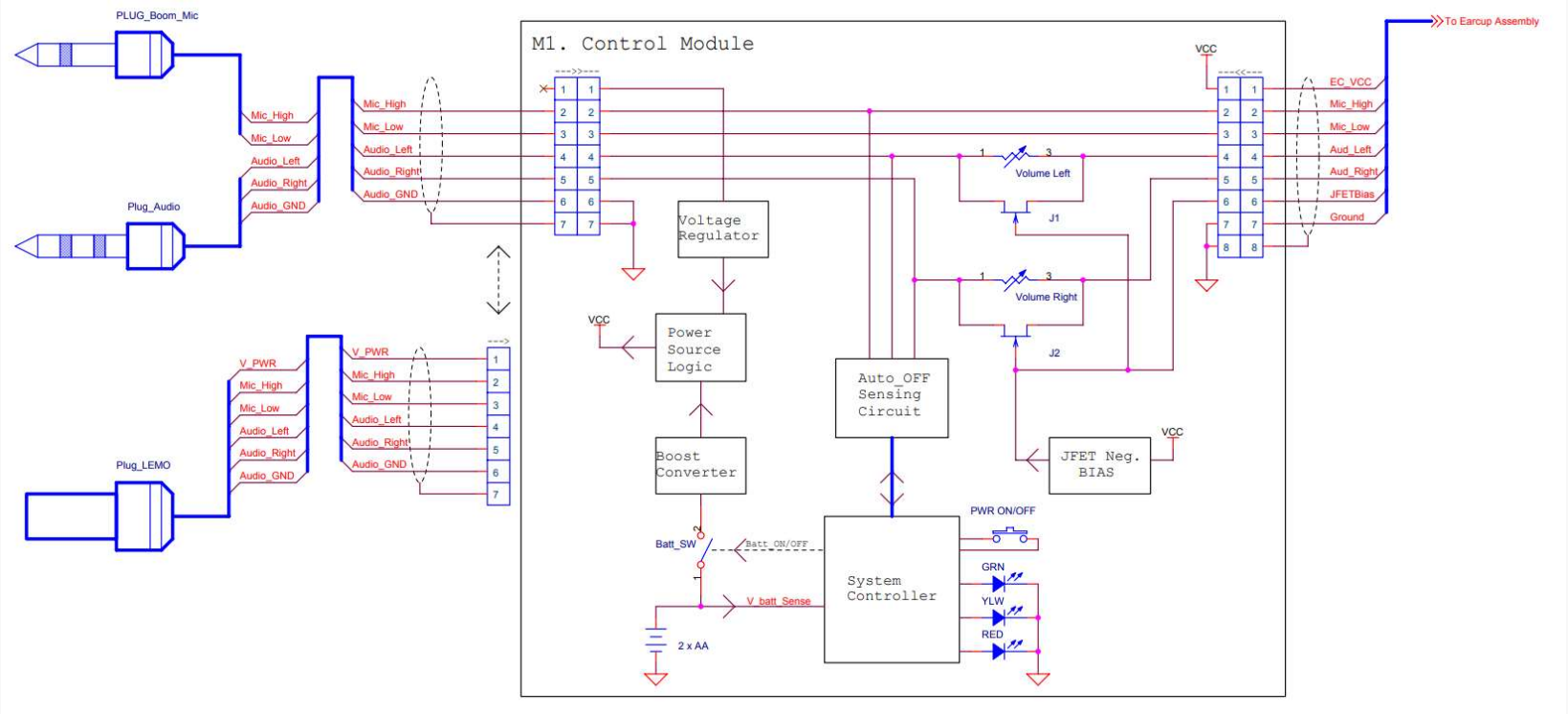


Mature Individual Elements

Put it all Together

02 Design Approach

System Partitioning



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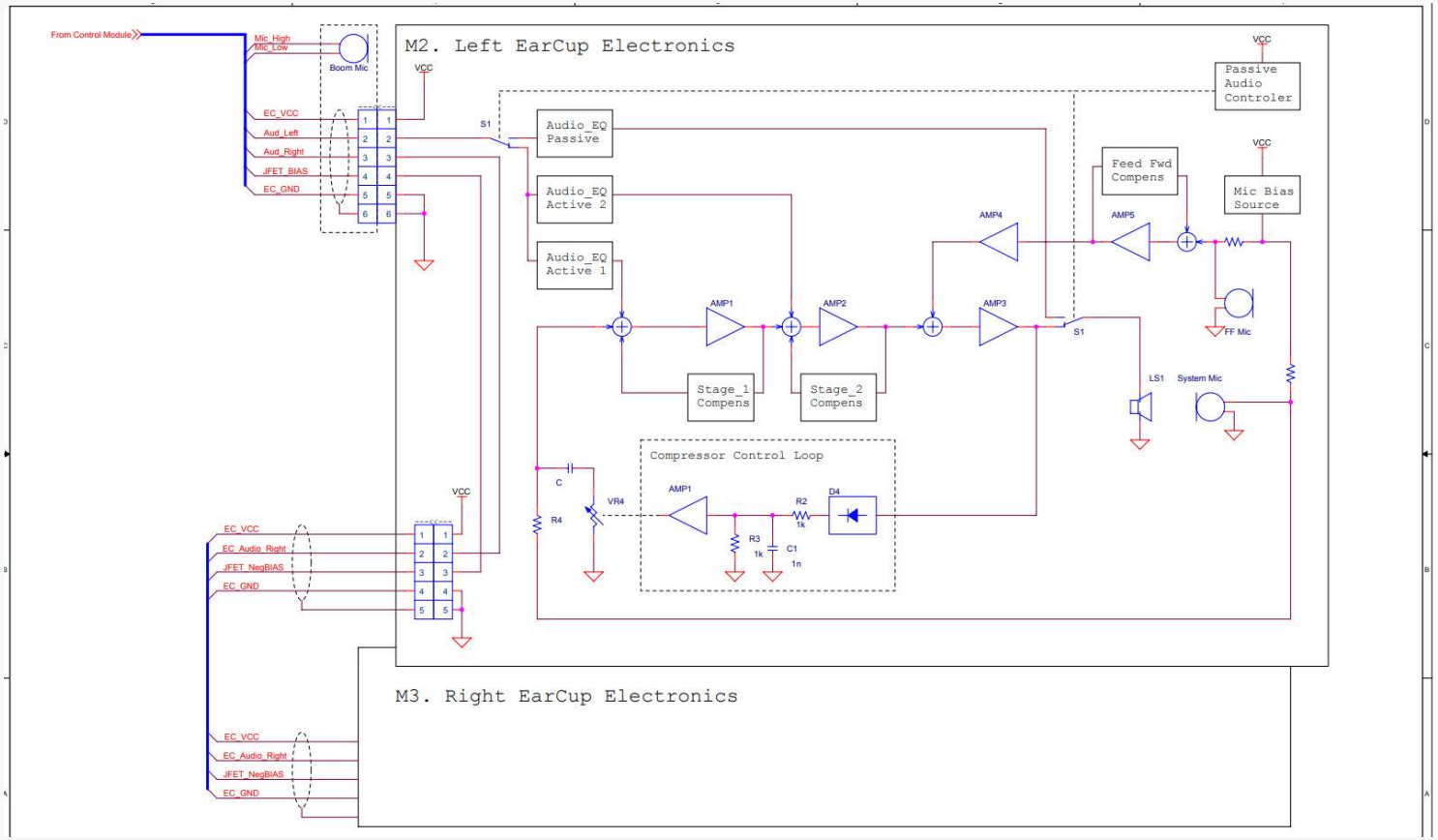
System Partitioning



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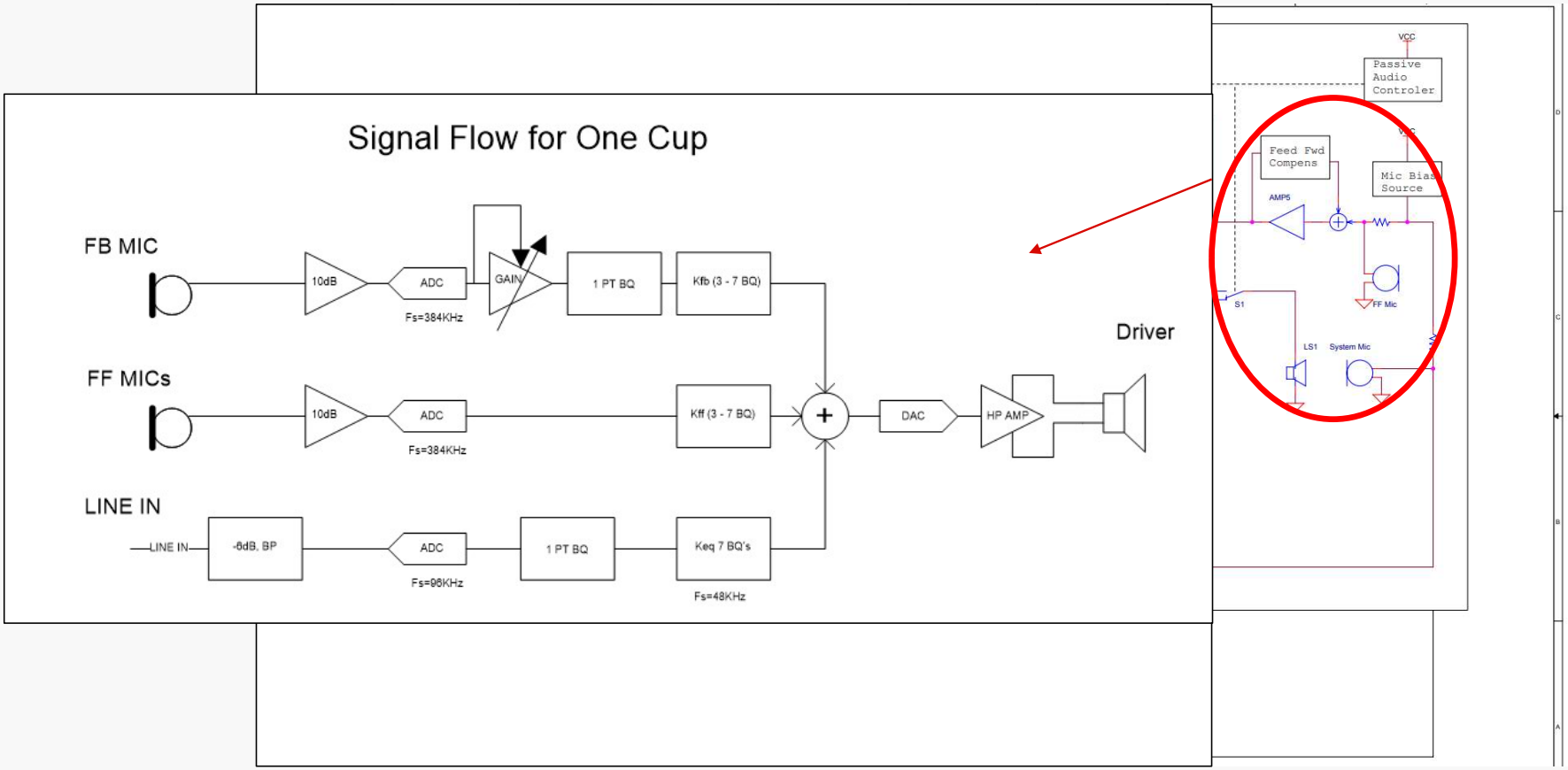

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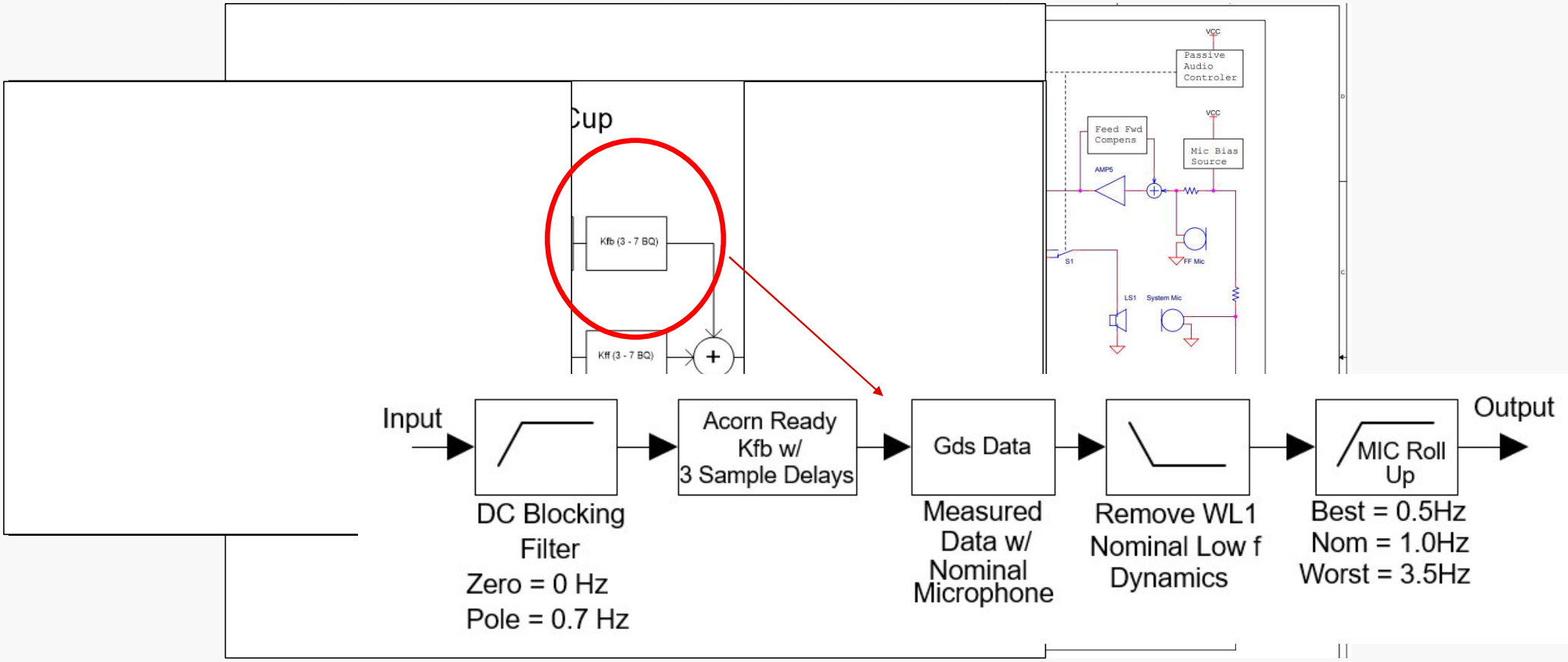


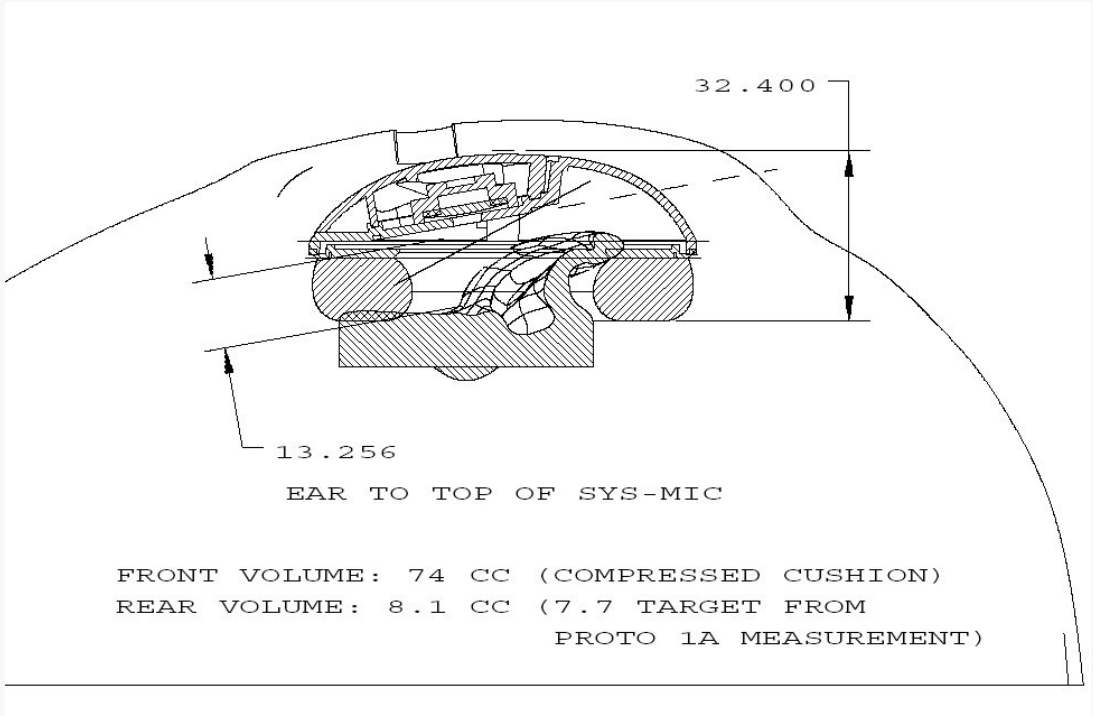
02 Design Approach

Design Sequence – What Comes First ?

OR

02 Design Approach

Design Sequence



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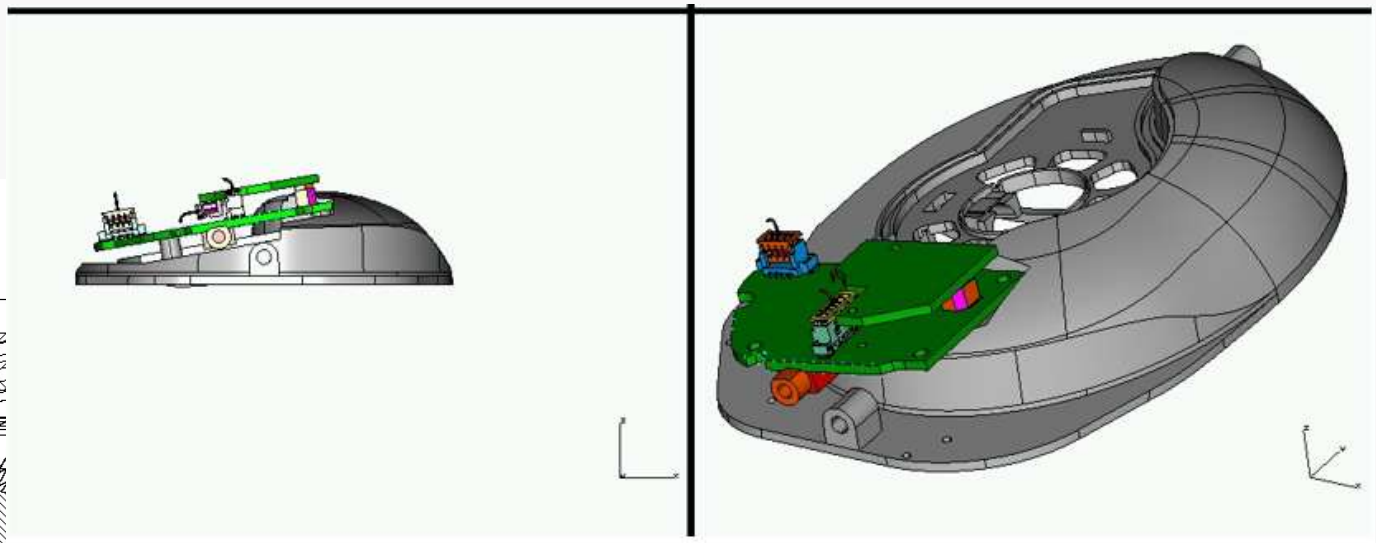
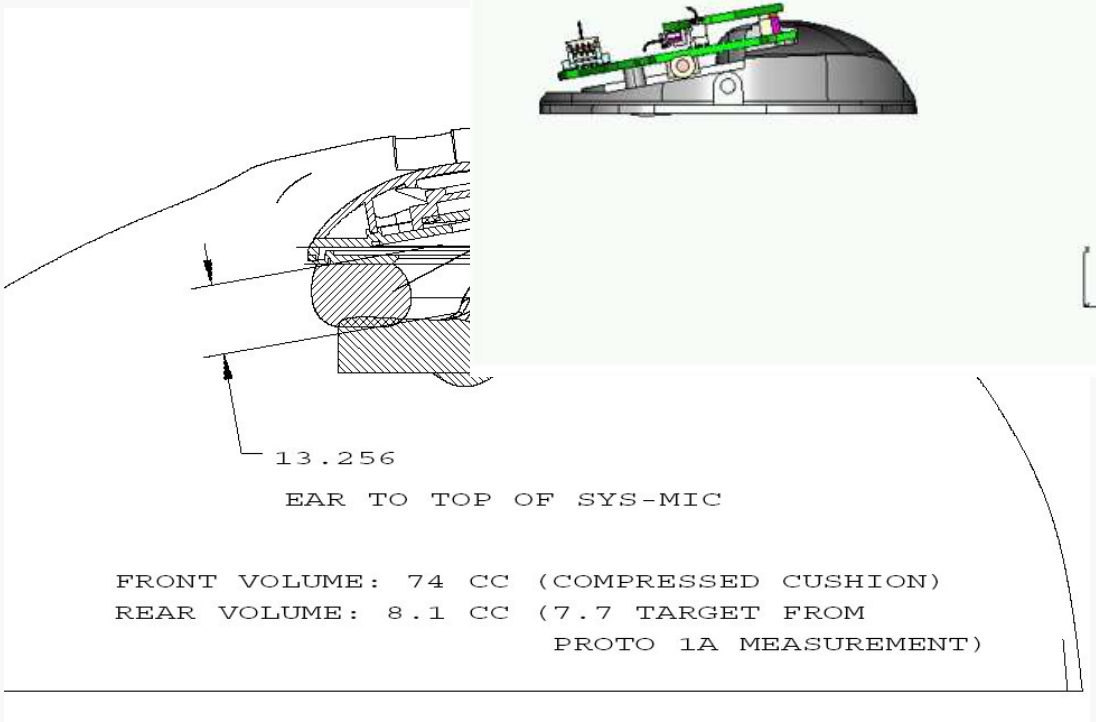
Design Sequence





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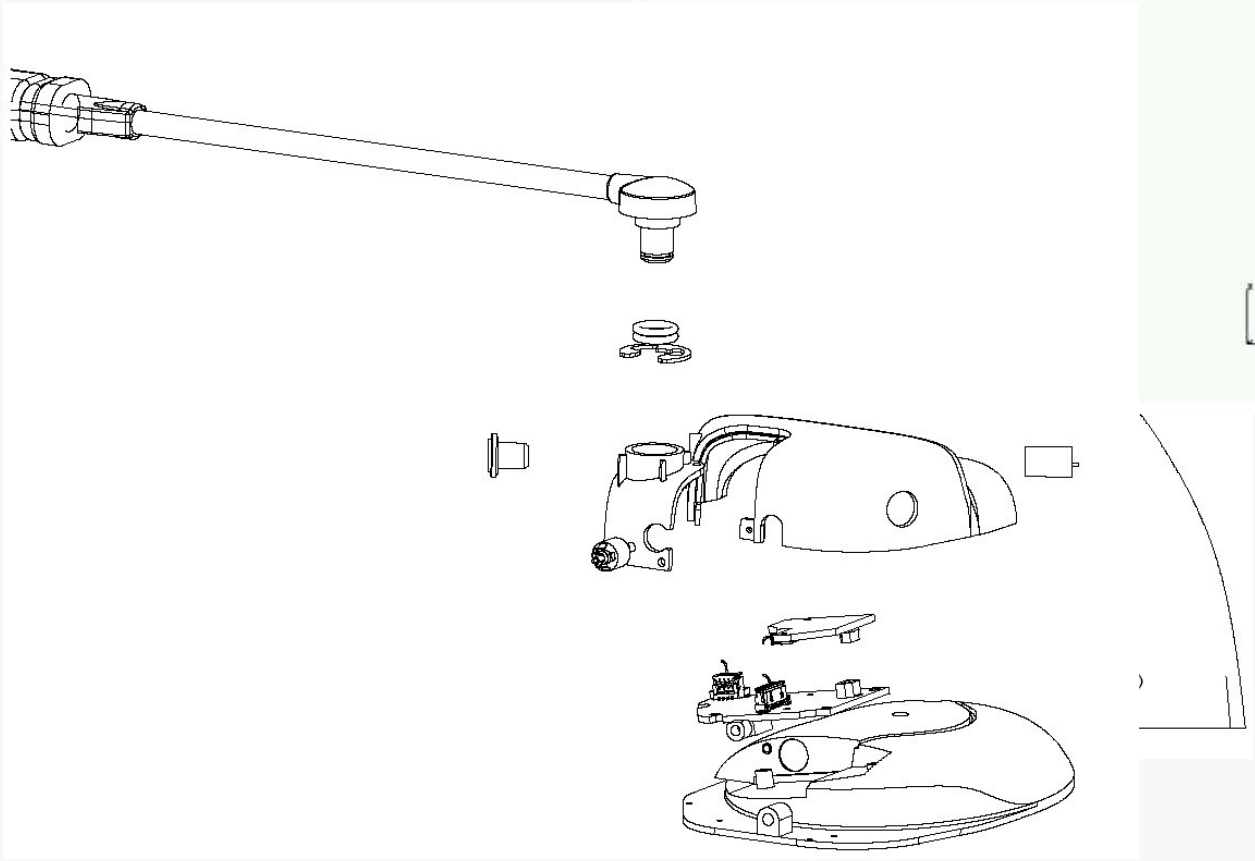
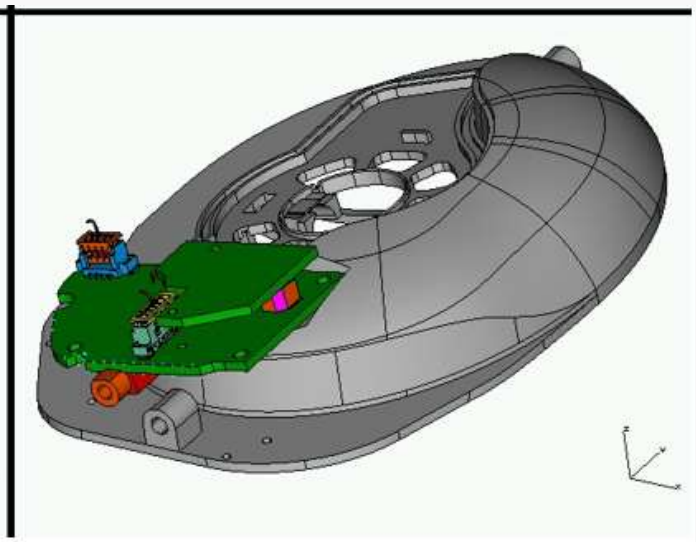
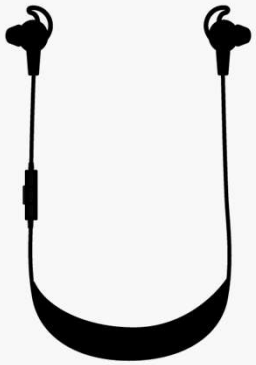




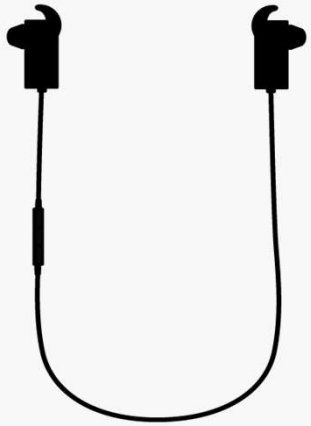
02 Design Approach

Design Sequence and Integration Plans

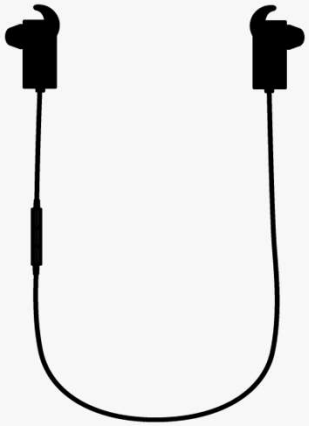
Challenge:
3 Products in parallel, 1 team, share common core parts and algorithms



ANR, Continuous Use
Communting/At Work
Light Activity



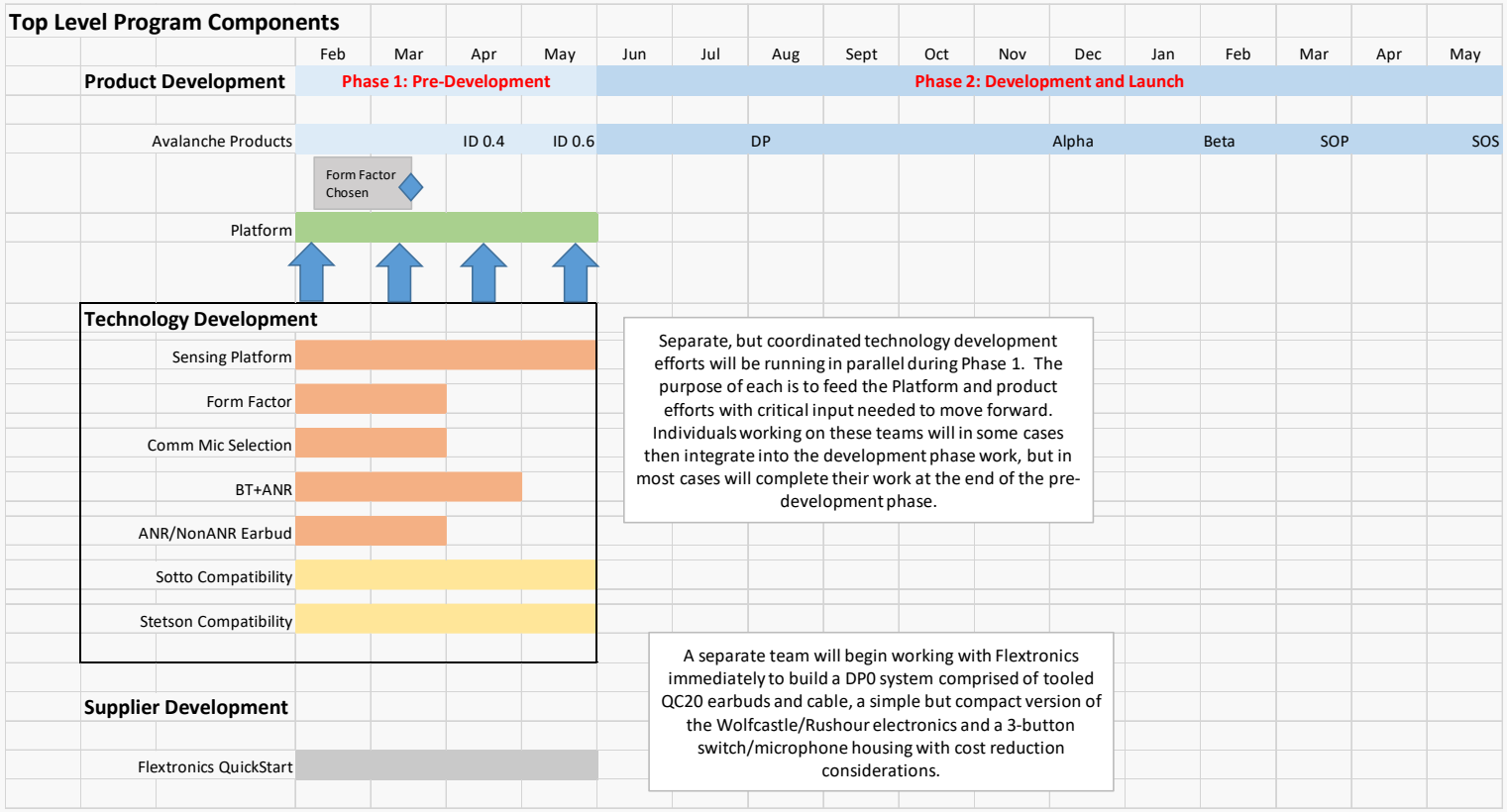
Non-ANR, Espisodic
Music On-The-Go
Moderate Activity



Non-ANR, HR Sensor Espisodic
Sports Enthusiast
High Activity

02 Design Approach

Design Sequence and Integration Plans



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03 Tradeoffs

Identify

Experience Helps – But what if I don't have that ?

Study Full Requirements – Sometimes need to hunt
Create Block Diagrams and Sketches – think through the whole problem
Use Common Sense
Trust your instincts
Don't Forget Cost and Time
Ask and challenge your teammates and colleagues

Common Asked for Conflicts at Bose:

- Long Battery Life / Small Size
- Heavy Re-design / Low Cost
- More ANR Performance / Better Comfort
- New Components / Cost and Effort

03 Tradeoffs

Best Practices – Avoid Guessing or “Opinioneering”

Gather Information – Objectively!
Understand Goals and Priorities from Stakeholders

Quantify!!!
What are the Benefits? (Customer and Company)
What are the negative consequences?

Always include Cost and Time

03 Tradeoffs

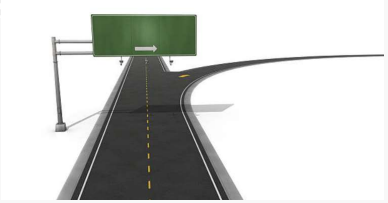
Best Practices – Make Robust Decisions

Use severity and likelihood
To weigh benefits / costs accordingly

		LIKELIHOOD		
		VERY LIKELY	POSSIBLE	UNLIKLEY
		3	2	1
SEVERITY	MAJOR INJURY 3	9	6	3
	MINOR INJURY 2	6	4	2
	TRIVIAL 1	3	2	1

Project the full scenario(s) into the future
What happens if it goes as planned
What if it doesn't?

Create contingency plans in advance!!



If "X" happens, I will do "Y"

Maintain a "Plan of Record" …
Allow structured disruption
Document your rationale !!

03 Tradeoffs

Decision Tools: Simple Tables and Scoring Matrices

Leading Options for Delivering Roadmap

	Meets needs
	Some risk
	Plausible with significant risk
	Does not meet requirements

Primary Considerations	Option 1 Product A & Product B Spring CY15, TWIE/TWOE16 Product A = BTSOC1 + ANR2 Product B = BTSOC1 + ANR1 + ANR2 TWIE16 & TWOE16 = BTSOC2 (ANR TBD)		Option 2 Product A Spring CY15, Product B Fall CY15,TWIE/TW Product 1 = BTSOC1 + ANR1 Product 2 = BTSOC2 + ANR1 TWIE16 & TWOE16 = BTSOC2 (ANR TBD)	
Delivers Key Features and Experiences	Product A Product B TWIE/TWOE26	Adequate Smart Features (non-ML) from ANR1 and BTSOC1 (Mercury Analsis) - new ML smart features like Speakeasy enabled for Product B Enhanced spatial audio and enhanced (Arbgs) voice enabled for Product B. 2025 TWIE: Cardiff is adequate spatial audio, Arbgs Lite on BTSOC1 or other incremental voice improvements are adequate	Product A Product B TWIE/TWOE26	Need to finish work assessing BTSOC2 HiFi4+ML capability vs algos. 2025 TWIE: Adequate Smart Features (non-ML) from ANR1 and BTSOC1, Cardiff is adequate spatial audio, Arby's on BTSOC1 or other incremental voice improvements are adequate.
Time and Resource Constraints Plausible path to delivery within current/expected GR&D resource and skill set constraints	Product A Product B TWIE/TWOE26	Reqs simultaneous work on ANR2, ANR1, and BTSOC2	Product A Product B (risky meeting Oct 1). Banded has timing flexibility TWIE/TWOE26	Re-prioritize new work on ANR1 and BTSOC2. Much of the BTSOC2 code will be derived from BTSOC1 code. [RFC]
Cost/Size/Power Ability to deliver key product requirements	Product A Product B TWIE/TWOE26	Setup for TWIE/TWOE in 2026 could significantly reduce Size and Cost IF BTSOC2 is acceptable for TWIE ANR. The opportunity for reduced quiescent ANR on one chip improved in 2027 with	Product A Product B TWIE/TWOE26	BTSOC2 costing coming March of 2023. Expecting BTSOC2 to cost more than BTSOC1 but less than
Silicon Readiness Production timing/status vs Bose development schedule	Product A Product B TWIE/TWOE26	ANR2 is about 6 months ahead of BTSOC2. BTSOC1 is is well established. ANR1 ready March 2023. [RFC]	Product A Product B TWIE/TWOE26	BTSOC2 silicon timing vs. Product B C0/C1 (Timing risk is for M0! [RFC]) Timing risk of Product B delay is understood by product office
Supply Chain and Support Risk associated with path to Production Ramp and sustaining	Product A Product B TWIE/TWOE26	New supplier for ANR2	Product A Product B TWIE/TWOE26	Both BTSOC and ANR chip suppliers are well positioned to support
"One Bose Platform" Extensibility towards desired LRV and GR&D Goals		Does not align with "One Bose Platform". [RFC] Working to minimize number of permutations in the platform roadmap and maximize SW/HW reuse.		Takes us towards reduced number of compute platforms, and opens up the possibility of a single-IC solution for TWIE/TWOE

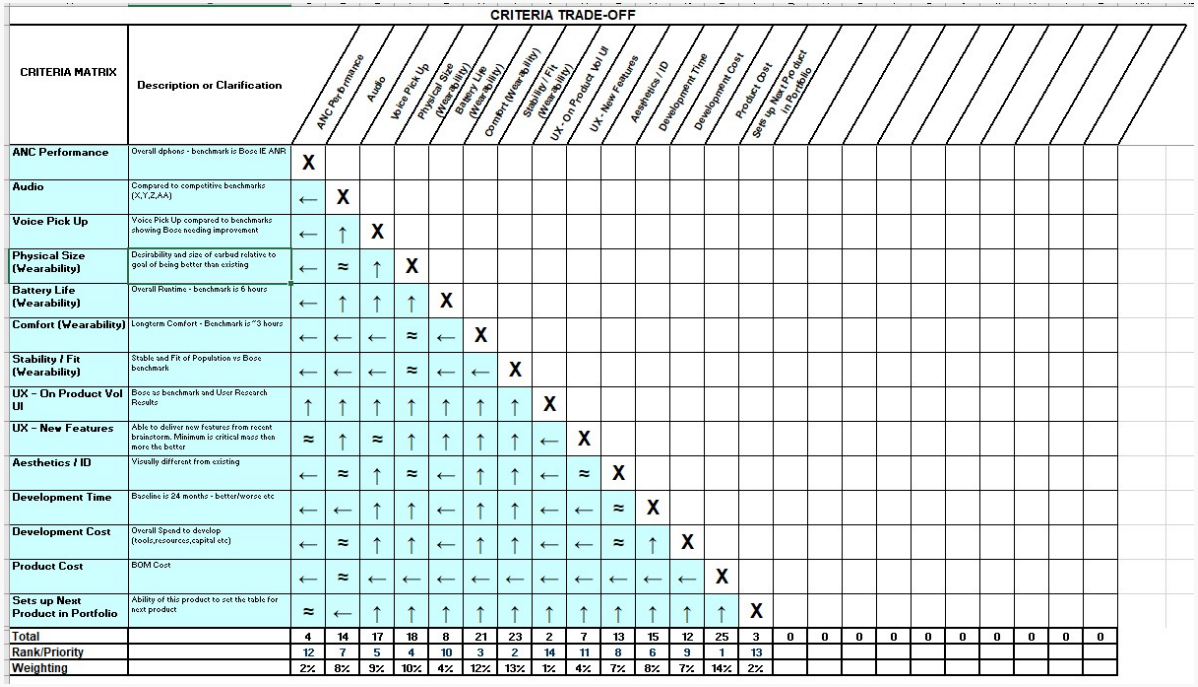
Attribute

Overall: The ability to attract interest (perception)

Criterea	Variant	Small		Large	Small	Medium	Large	Small	Medium	Large
	Appeal (avg)	2.0		1.3	2.7	2.8	2.3	3.0	3.5	3.0
	Comfort (avg)	3.3		2.6	3.3	3.2	2.9	3.5	3.5	3.1
	Sport Stability (avg)	2.8		1.9	3.4	3.6	3.3	3.9	4.0	3.3
	Ease of Use (avg)	3.0		3.0	3.0	3.0	3.0	3.0	3.5	2.9
	Scalability (avg)	2.0			3.2			3.4		
										
		Chorus			Dogtag - Split			Dogtag - Single		
	Form Factor Avg	2.4			3.0			3.3		

03 Tradeoffs

Decision Tools: More Complex – Step 1/3 Work Through Priorities



CRITERIA TRADE-OFF

CRITERIA MATRIX	Description or Clarification	ANC Performance	Audio	Voice Pick Up	Physical Size (Wearability)	Battery Life (Wearability)	Comfort (Wearability)	Stability / Fit (Wearability)	UX - On Product Vol UI	UX - New Features	Aesthetics / ID	Development Time	Development Cost	Product Cost	Sets up Next Product in Portfolio
ANC Performance	Overall dphone - benchmark is Bose IE ANR	X													
Audio	Compared to competitive benchmarks (X,Y,Z,AA)	←	X												
Voice Pick Up	Voice Pick Up compared to benchmarks showing Bose needing improvement	←	↑	X											
Physical Size (Wearability)	Desirability and size of earbud relative to goal of being better than existing	←	≈	↑	X										
Battery Life (Wearability)	Overall Runtime - benchmark is 6 hours	←	↑	↑	↑	X									
Comfort (Wearability)	Longterm Comfort - Benchmark is ~3 hours	←	←	←	≈	←	X								
Stability / Fit (Wearability)	Stable and Fit of Population vs Bose benchmark	←	←	←	≈	←	←	X							
UX - On Product Vol UI	Bose as benchmark and User Research Results	↑	↑	↑	↑	↑	↑	↑	X						
UX - New Features	Able to deliver new features from recent brainstorm. Minimum is critical mass then more the better	≈	↑	≈	↑	↑	↑	↑	←	X					
Aesthetics / ID	Visually different from existing	←	≈	↑	≈	←	↑	↑	←	≈	X				
Development Time	Baseline is 24 months - better/worse etc	←	←	↑	↑	←	↑	↑	←	←	≈	X			
Development Cost	Overall Spend to develop (tools,resources,capital etc)	←	≈	↑	↑	←	↑	↑	←	←	≈	↑	X		
Product Cost	BOM Cost	←	≈	←	←	←	←	←	←	←	←	←	←	X	
Sets up Next Product in Portfolio	Ability of this product to set the table for next product	≈	←	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	X
Total		4	14	17	18	8	21	23	2	7	13	15	12	25	3
Rank/Priority		12	7	5	4	10	3	2	14	11	8	6	9	1	13
Weighting		2%	8%	9%	10%	4%	12%	13%	1%	4%	7%	8%	7%	14%	2%

03 Tradeoffs

Decision Tools: More Complex – Step 2/3 Develop Scoring Definitions

Attributes Ranking Definitions						
Criteria	Definition	Ranking Division				
		5	4	3	2 (Discretionary)	1
		Better Than	Equivalent / Comparable	Competitive but worse		Worse Than
ANC Performance	Overall dphons - benchmark is Bose IE ANR	>= +3 dphons (Noticeably better than Bose A)	+/- 2dphons (Comprable to Bose A)	- 3-4 dphons (Comparable to Competitor B)		More than -4dphons (Worse than Comp)
Audio	Compared to competitive benchmarks (X,Y,Z,AA)	Obvious preference for Bose	Most customers don't notice any difference	Many customers prefer competition and can say why		Obvious preference for competition
Voice Pick Up	Voice Pick Up compared to benchmarks showing Bose needing improvement	Among Best at noise rejection AND among best at voice artifacts	Among best at noise rejection, voice artifacts present but non-distracting	Distracting background noise OR distracting voice artifacts		Distracting background noise AND distracting voice artifacts

03 Tradeoffs

Decision Tools: More Complex – Step 3/3 Pugh Matrix

Criteria	ANC Performance	**Audio**	Voice Pick Up	**Physical Size (Wearability)**	Battery Life (Wearability)	**Comfort (Wearability)**	Stability / Fit (Wearability)	UX - On Product Vol UI	UX - New Features	**Aesthetics / ID**	**Development Time**	**Development Cost**	**Product Cost**	Sets up Next Product in Portfolio	Total Score	Total Weighted Score	non-weighted rank	Weighted Rank
Priority	12	7	5	**4**	10	**3**	2	14	11	**8**	**6**	**9**	**1**	13				
Idea / Weight	2%	8%	9%	**10%**	4%	**12%**	13%	1%	4%	**7%**	**8%**	**7%**	**14%**	2%				
Concept A Form 1260 battery New Stability Feature Platform=BTSOC1+ANR2	4	4	4	**3**	4	**3**	4	4	5	**3**	**4**	**3**	**4**	4	53	3.69	1	**1**
Concept A Form 1260 battery New Stability Feature Platform=BTSOC1+ANR3	3	4	4	**3**	4	**3**	4	4	3	**3**	**5**	**3**	**4**	3	50	3.65	3	**3**
Concept C Form 10XX battery New Stability Feature Platform=BTSOC1+ANR4	3	4	4	**4**	5	**5**	5	4	3	**5**	**1**	**3**	**1**	1	48	3.52	4	**5**
Concept D Form 1260 battery, New driver New Stability Feature Platform BTSOC1+ANR2	3	4	4	**3**	4	**4**	5	4	5	**3**	**1**	**3**	**4**	4	51	3.66	2	**2**
Simone Concept E 1260 battery, New driver New Stability Feature Platform BTSOC1+ANR4	3	4	4	**3**	4	**4**	5	4	3	**3**	**1**	**3**	**4**	3	48	3.57	4	**4**

Product and System Design Fundamentals

01 | Requirements Management

Understand What Customer is Asking for
Convert to Engineering Requirements (System and Component)
Map out “How to Know When You’ve Succeeded” (How/What to Measure)
Track It !

02 | Design Approach – Getting Started

System Partitioning
Develop Integration Plans (Dependencies, What comes first/second)
Execution Cycles (Design, Build, Test)

03 | Tradeoffs

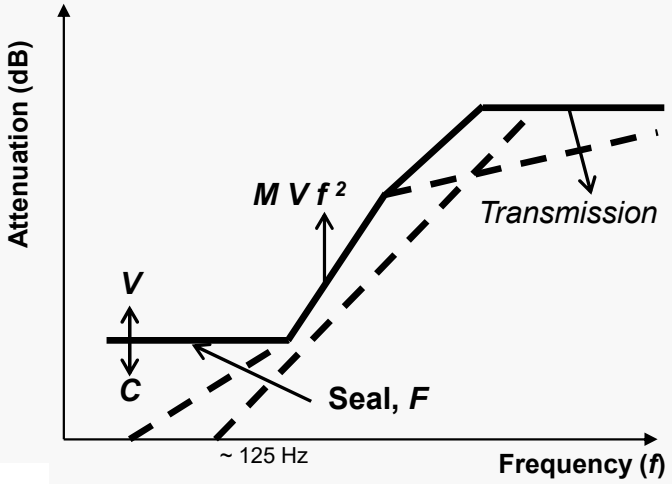
Identify Conflicts / Possible Friction Points
Best Practices
Decision Tools
Examples

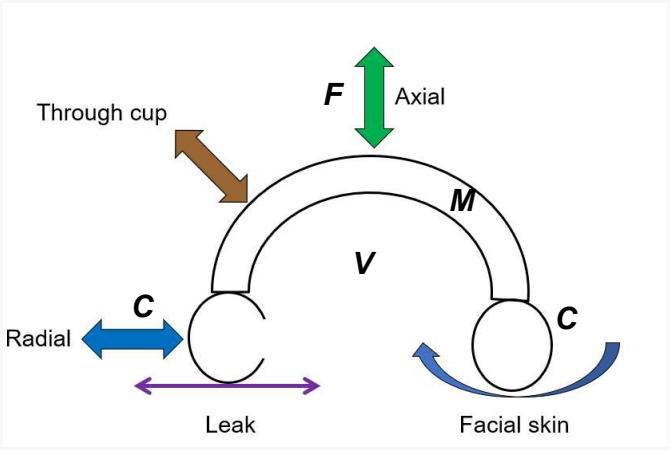
04 | Real Life Examples

04 Tradeoff Example – Comfort & Noise Cancellation

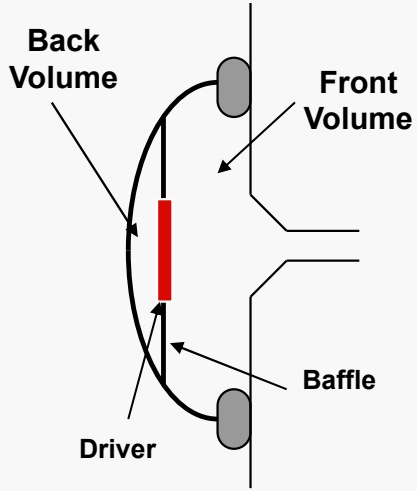
Main parameters

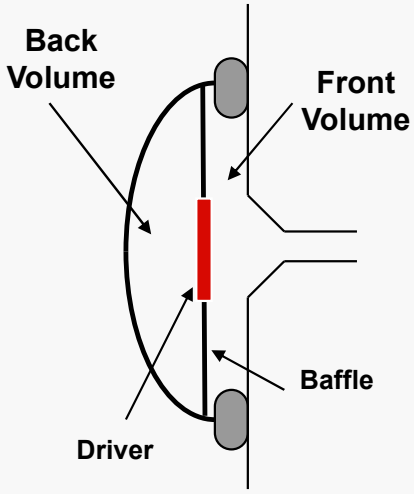
- Cup volume *V*
- Cup mass *M*
- Combined cushion & flesh compliance *C*
- Seal
  - Clamp force *F* & cushion design
  - Shape of the head (leaks)
  - Transmission through cushion
- Transmission through cup

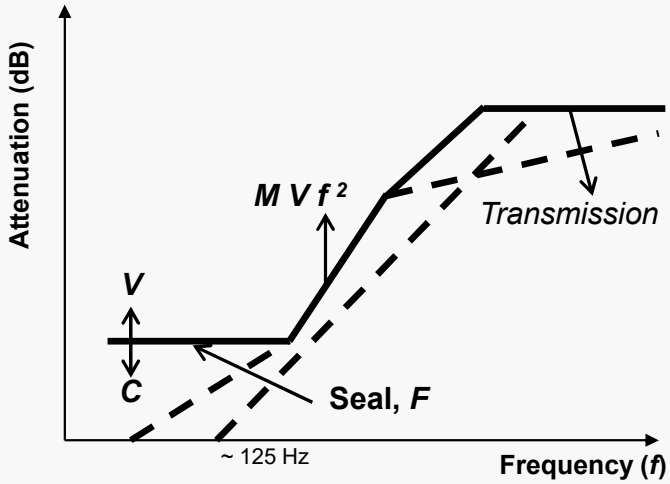




04 Tradeoff Example – Comfort & Noise Cancellation







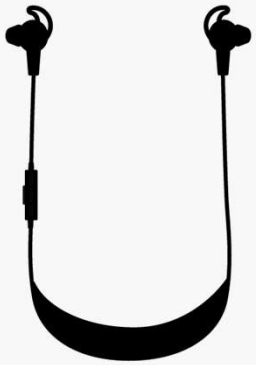
- ⬆ Passive Attenuation
- ⬇ Active Attenuation
- ⬆ Clamping Force
- ⬇ Comfort

- ⬇ Passive Attenuation
- ⬆ Active Attenuation
- ⬇ Clamping Force
- ⬆ Comfort

04 Tradeoff Example – Cost/Time vs Performance

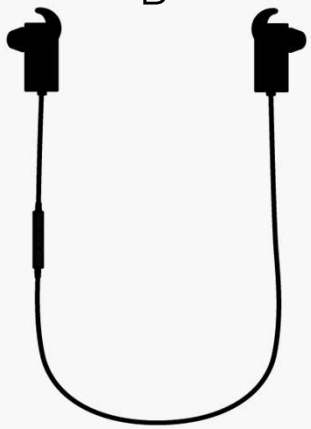
Challenge:
3 Products in parallel, 3 core use cases
1 team, share common core parts and algorithms

A



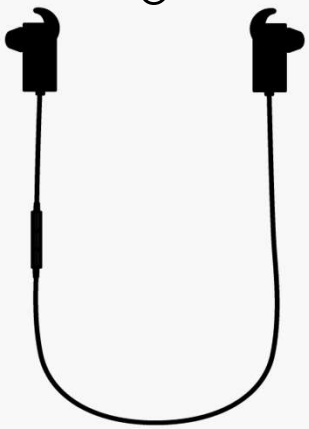
ANR, Continuous Use
Communting/At Work
Light Activity

B



Non-ANR, Espisodic
Music On-The-Go
Moderate Activity

C



Non-ANR, HR Sensor Espisodic
Sports Enthusiast
High Activity

04 Tradeoff Example – Cost/Time vs Performance

Everything at the Ear

A	B	C	
🟢	🟢	🟢	Time / Cost / Sharing
🔴	🟢	🟢	Battery Life
🔴	🟢	🟡	Comfort
🔴	🟡	🟡	Stability

Smallest Earbuds

A	B	C	
🟡	🟡	🟡	Time / Cost / Sharing
🟢	🟢	🟢	Battery Life
🟢	🟡	🔴	Comfort
🟡	🔴	🔴	Stability

04 Tradeoff Example – Cost/Time vs Performance

Everything at the Ear

A	B	C	
🟢	🟢	🟢	Time / Cost / Sharing
🔴	🟢	🟢	Battery Life
🔴	🟢	🟡	Comfort
🔴	🟡	🟡	Stability

This approach for B&C

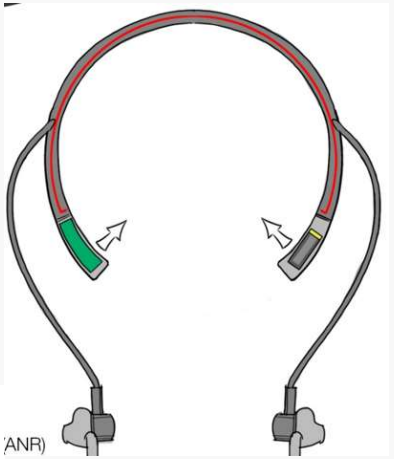
Smallest Earbuds

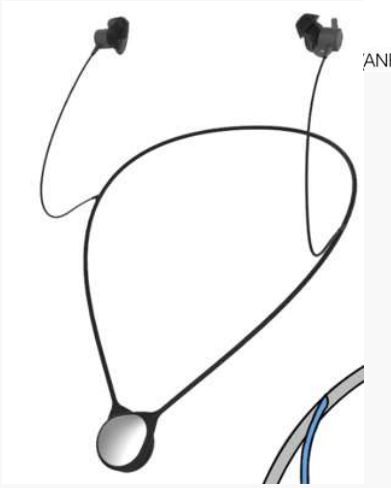
A	B	C	
🟡	🟡	🟡	Time / Cost / Sharing
🟢	🟢	🟢	Battery Life
🟢	🟡	🔴	Comfort
🟡	🔴	🔴	Stability

This approach for A

04 Tradeoff Example – Cost/Time vs Performance

Smallest Earbuds – Where does everything else go?





04 Tradeoff Example – Cost/Time vs Performance

Attribute | Benchmark | Scale 1-5

Overall: The ability to attract interest (perception)

Variant	Small		Large	Small	Medium	Large	Small	Medium	Large	Small		Large		"Large"	"XL"	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Appeal (avg)	2.0		1.3	2.7	2.8	2.3	3.0	3.5	3.0	3.2		2.8		2.4	1.2	2.0	2.0	1.8	3.0	3.3	2.5	4.0	2.4	3.3
Comfort (avg)	3.3		2.6	3.3	3.2	2.9	3.5	3.5	3.1	2.9		2.6		2.8	2.5	2.6	2.8	2.7	3.1	3.8	3.3	4.3	3.0	3.3
Sport Stability (avg)	2.8		1.9	3.4	3.6	3.3	3.9	4.0	3.3	2.0		1.9		1.8	1.5	2.6	2.4	2.6	3.1	3.5	3.1	4.0	2.6	1.8
Ease of Use (avg)	3.0		3.0	3.0	3.0	3.0	3.0	3.5	2.9	3.4		3.4		3.0	2.9	1.6	1.6	1.6	2.9	3.3	2.7	4.5	4.3	3.8
Scalability (avg)	2.0			3.2			3.4			3.2				2.7		3.2			3.2			3.0		3.0
																								
	Chorus			Dogtag - Split			Dogtag - Single			Lester				Pendant		Uber Pendant			Uber Clip			At Ear		W/ Neck
Form Factor Avg	2.4			3.0			3.3			2.8				2.3		2.3			3.1			3.4		3.0
Average per Size	2.8		2.2	3.1	3.1	2.9	3.3	3.6	3.1	2.9		2.7		2.5	2.0	2.2	2.2	2.2	3.0	3.4	2.9	4.2	3.1	3.0

04 Tradeoff Example – Cost/Time vs Performance

A

ANR, Continuous Use
Communting/At Work
Light Activity

B

Non-ANR, Espisodic
Music On-The-Go
Moderate Activity

C

Non-ANR, HR Sensor Espisodic
Sports Enthusiast
High Activity


Q&A
BOSE