Virtual Design Review 2
Team 3: Self-Powered Wireless Sensor

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Public Use

Agenda

- Introduction
- Conception Generation
- Target Summary
- Conclusion

Introduction

Introduction: Project Scope

<u>Design</u>, <u>build</u>, and <u>demonstrate</u> a method to power a sensor that will transmit data of a specific variable wirelessly to the Engine Control Module (ECM) in a Cummins' diesel engine.

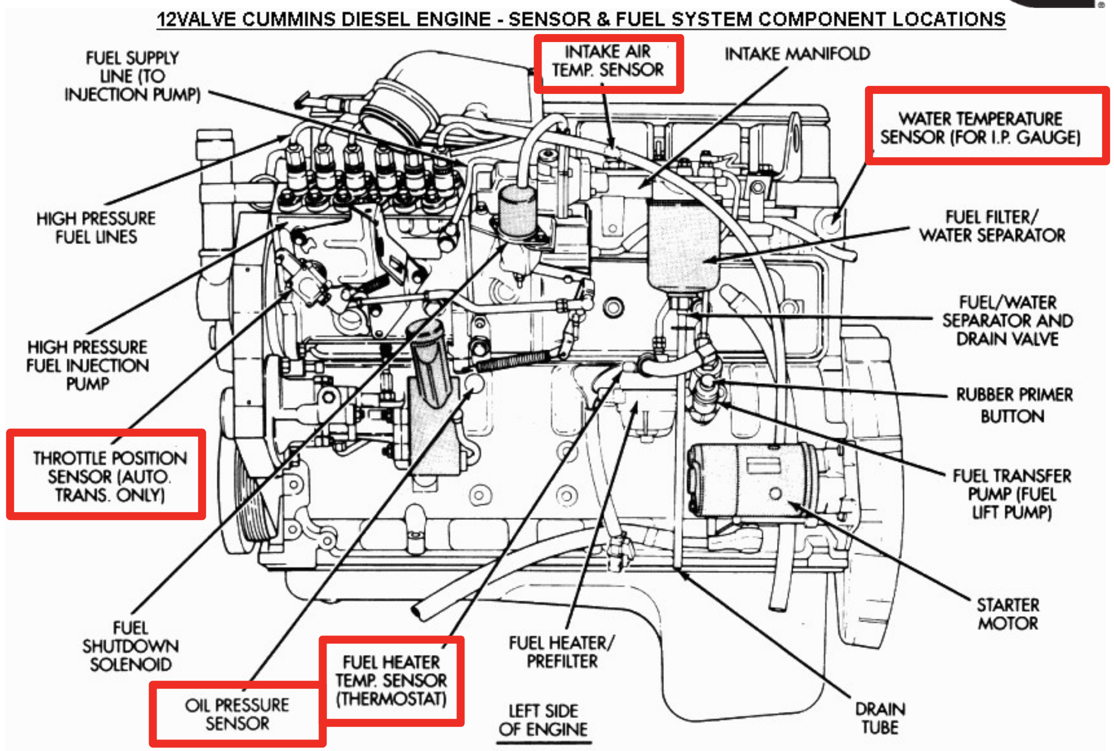
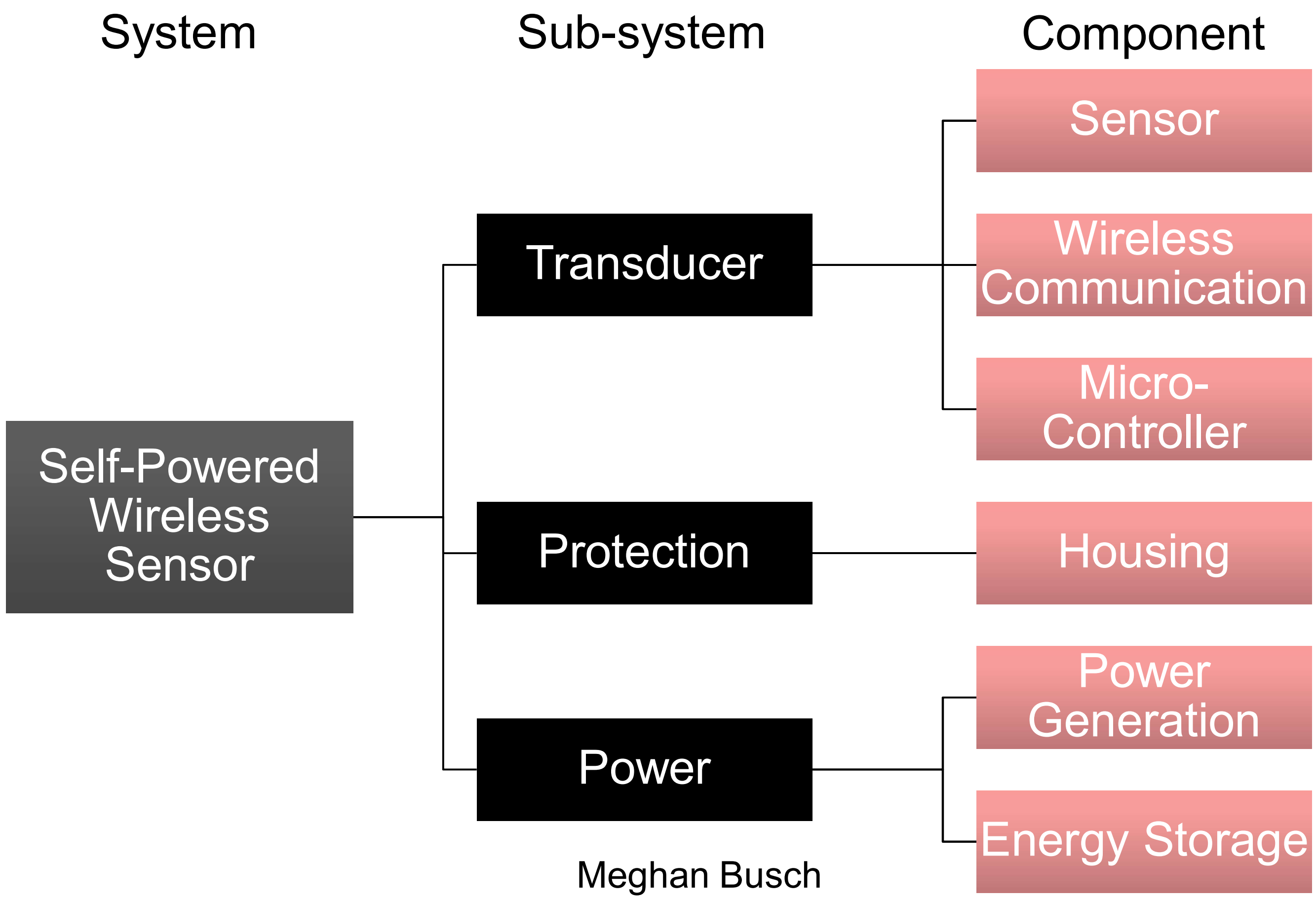


Figure 1. 12V Cummins Diesel Engine illustrating fuel sensor components (Cummins).

Introduction: Customer Needs

- Sensor must be self-powered.
- Communicate to ECM wirelessly.
- Transmit data at a frequency no lower than 1 Hz.
- Power supply must last 36 hours after engine is shut off.
- Transmits signal a distance of at least 5 meters.
- Can utilize any variable in the engine to sense.
- Must operate under harsh conditions.

Introduction: Functional Decomposition



Concept Generation

Transducer Subsystem: Sensor

Important Metrics to Consider:	Concepts to Consider:
• Voltage Supply Requirement • Output Voltage Range • Operating Temperature Range • Resistivity Range • Types of Sensing Variable	• Thermocouples • Thermistor • Pressure Sensor • Mass-Flow Air (Hot-wire) Sensor • Throttle Position Sensor • Oxygen Sensor

Transducer Subsystem: Sensor Concepts

Concept 1: Thermocouple

- Seebeck effect produces voltage across a junction of two different materials at different temperatures.
- Voltage generated is proportional to the temperature difference.
- Has a fast response time but low accuracy.

Concept 2: Thermistor

- A variable resistor with resistance being a function of temperature.
- The temperature is proportional to the voltage drop across the resistor.
- High sensing accuracy.

Concept 3: Manifold Absolute Pressure Sensor

- Used to continuously monitor the manifold pressure.
- Generates an electrical signal as a function of pressure imposed.
- Has a good output to input voltage ratio.

Transducer Subsystem: Sensor Concepts

Concept 4: Mass Flow Air (Hot-Wire) Sensor

- Contains a small electrically heated wire (hot wire) and a small temperature sensor installed close to the hot wire.
- The heating current of the wire is proportional to the mass air flow.
- Low temperature surrounding sensor.

Concept 5: Throttle Position Sensor

- Measures the air to fuel mixture that goes into the engine.
- Located in the butterfly spindle/shaft and monitors the position of the throttle.
- Low resistivity range and low surrounding temperature.

Concept 6: Oxygen Sensor

- Measures the amount of exhaust emissions of the engine.
- Estimated by measuring the amount of oxygen left in the exhaust gases.
- High surrounding temperatures and output to input voltage.

Transducer Subsystem: Wireless Communication

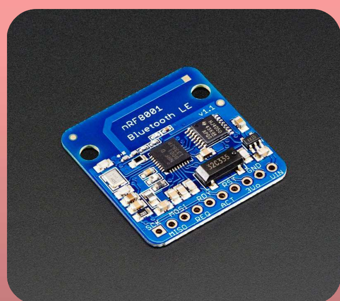
Important Metrics to Consider:

- Size
- Power Consumption
- Communication Distance
- Frequency
- Operating Temperature Range

Concepts to Consider:

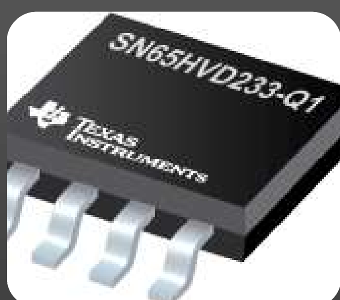
- Active Sensing
  - Wi-fi
  - Bluetooth Low Energy
  - ZigBee
  - High Temperature CAN Bus Transceiver
- Passive Sensing
  - Surface Acoustic Wave
  - Radio Frequency Identification

Transducer Subsystem: Wireless Communication Concepts for Active Sensors



Concept 1: Bluetooth Low Energy (BLE) - nRF8001

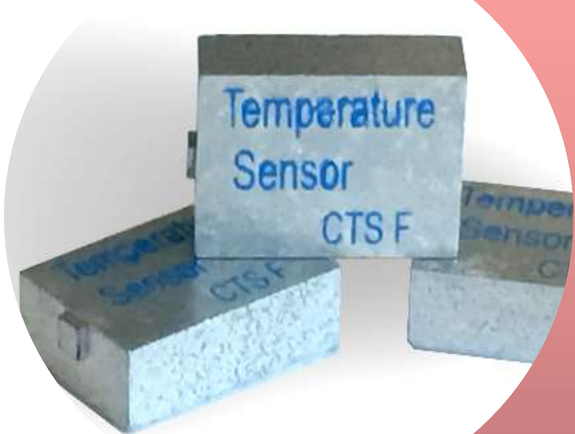
- Requires lowest transmitting power (≈ 0.03 W).
- Is low cost.
- Can withstand temperatures up to 85°C.
- Operates at 2.4 GHz.



Concept 2: Texas Instrument Automotive CAN Bus Transceivers - SN65HVD233-Q1

- Requires a low transmitting power (≈ 0.07 W).
- Can withstand temperatures up to 150°C.
- Operates at 2.4 GHz.

Transducer Subsystem: Wireless Communication Concepts for Passive Sensors



Concept 3: Radio Frequency Identification (RFID) – RFMicron

- Is a hybrid of electrical circuit and RFID.
- Can have a read range up to 19 m.
- Has high temperature alarm at 125°C .
- Is very small and requires no power supply.
- Commercially available through RFMicron.
- Can operate attached to a metal plate with no electromagnetic interference.

Transducer Subsystem: Microcontroller Concepts

Important Metrics to Consider:

- Size
- Power Consumption
- Processing Speed and Memory
- Operating Temperature Range

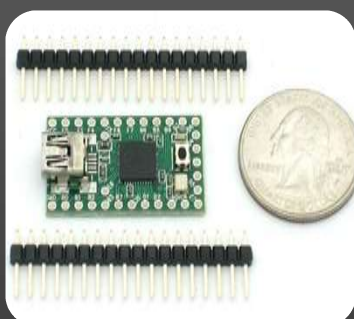
Concepts to Consider:

- Raspberry Pi
- Beagle Bone Black
- Arduino Uno Rev 3
- Teensy 2.0
- Microcontroller Chip PIC24FJ16MC101

Transducer Subsystem: Microcontroller Concepts

Concept 1: Arduino Uno Rev 3

- Is smaller than Beagle Bone and Raspberry Pi.
- Has a slower processer than Beagle Bone and Raspberry Pi.
- Has the smallest program memory.
- Has an average temperature range (up to 85°C).
- Requires 5 V.

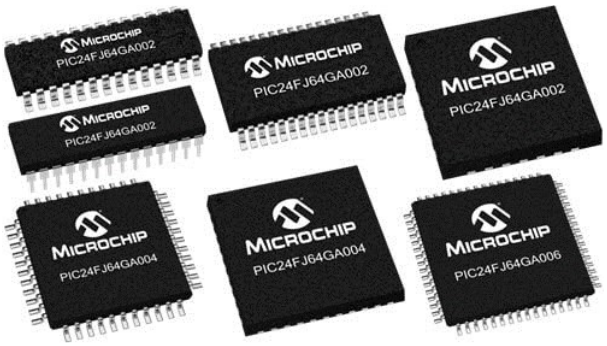


Concept 2: Teensy 2.0

- Is the smallest option.
- Has the same processing chip as Arduino.
- Has the smallest power input range (2.7 - 5.5 V).

Transducer Subsystem: Microcontroller Concepts

- Concept 3: Microcontroller Chip PIC24FJ16MC101



  - A Printed Circuit Board would be fashioned with only the necessary components (transceiver, sensor, microcontroller, and power system).
  - Is more difficult to program, but has the highest temperature range (up to 125°C).
  - Processing power, memory, power consumption, and size are all customizable with this concept.

Protection Subsystem: Housing

Important Metrics to Consider:

- Size and Weight
- Max Allowable Temperature of System
- Electrical Interference

Concepts to Consider:

- Vacuum Casing
- Thermally Isolated Casing

Protection Subsystem: Housing

Concept 1: Vacuumed Casing

- Inside temperature would stay constant since heat cannot travel through a vacuum.
- Vulnerable to a break in the seal.
- Metal vacuumed casing would cause EMI.

Concept 2: Thermally Isolated Casing

- Could utilize a radiation shield or plastic spacers.
- A much cheaper and reliable alternative to a vacuum.
- Would need to be customized for each sensor.

Power Subsystem: Power Generation

Important Metrics to Consider:

- Power demand of system
- Power supplied to system
- Supply voltage
- Capacity factor

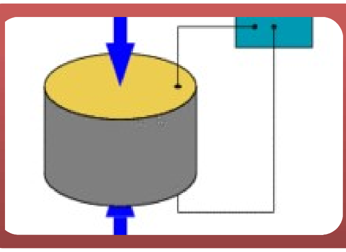
Concepts to Consider:

- Harvest energy from engine
  - Thermoelectric generator
  - Micro-turbine
  - Piezoelectric
  - Pyroelectric
  - Induction
- Zero-power system
  - Passive sensor

Power Subsystem: Power Generation

Thermoelectric Generator

- Generates power from a temperature difference using Seebeck effect.
- Harvest energy from high temperature mediums.



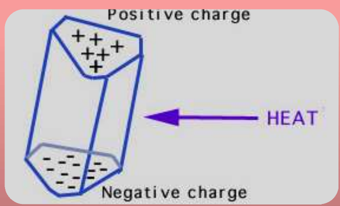
Piezoelectric

- Certain materials such as quartz convert mechanical strain into electrical energy.
- Harvest energy from vibration of the engine.

Micro-Turbine Generator

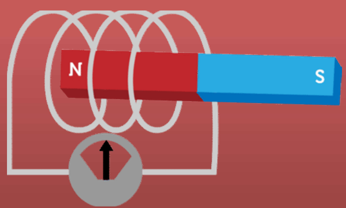
- Convert kinetic energy of fluid flow into electrical energy.
- Harvest energy from flow of exhaust gases, air intake etc.

Power Subsystem: Power Generation



Pyroelectric

- Certain crystals have inherent electric fields and produce a voltage when heated or cooled.
- Harvest energy from high temperatures.



Magnetic Induction

- A magnet in motion will induce an electric current in a wire.
- Harvest energy from engine oscillations.
- Wireless energy transfer via inductive charging.

Ambient Radiation Sources

- Radio and TV broadcasting along with natural radiation sources.
- Harvest energy from ambient or deliberately produced radiation.
- Used in passive RFID technology.

Power Subsystem: Energy Storage

Important Targets to Consider:

- Storage capacity
- Voltage
- Charge and Discharge Rate
- Cycle Life
- Operating Temperature

Concepts to Consider:

- Capacitor
- Supercapacitor
- Battery
  - Lithium-Ion

Power Subsystem: Energy Storage

Lithium Cobalt	• High energy density, high voltage output, and most widely available
Lithium Titanate	• Longest cycle life, safe, and low cost
Lithium Manganese	• High energy density, high voltage output, and high thermal runaway temperature
Lithium Nickel Manganese Cobalt	• High thermal runaway temperature, long cycle life, and high voltage output
Lithium Iron Phosphate	• Highest thermal runaway temperature and has a good cycle life
Lithium Nickel Cobalt Aluminum	• Highest energy density, high voltage output, and low cost

Target Summary

Target Summary

- Complete target catalog changes depending on overall design
- Important Metrics and Targets:
  - Power demand of system: ~10 mW
  - Power supplied to system: ~10 mW
  - Voltage of system: 2 – 5 V
  - Energy storage: 100 – 500 mAh

Conclusion

Conclusion

- Design will depend on type of sensor chosen.
  - Ideal design can be applied to every sensor in engine.
- Design must harvest energy from convenient source.
  - Medium being sensed is often high-energy.
- Active versus passive sensor significantly changes the layout of the design.
- Future Steps: Concept Selection
  - Combining component concepts and measure against our design selection criteria to find the optimal design

Questions?

Appendix A: Concept Parameters

Appendix A: Sensor Concept Parameters

Table 1

Different Type of Sensors and Parameters.

Sensor Type	Sensor Variable	Variable Range	Voltage Supply	Resistivity	Operational Temperature
Engine coolant temperature	Temperature	-40 - 130°C	1.0 - 5.0 V	89 - 46k Ohm	-60 - 180°C
Air temperature	Temperature	-40 - 150°C	5.0 V	46 - 99k Ohm	-60 - 180°C
Barometric pressure/manifold absolute pressure	Pressure	10 to 350 kPa	0.1 - 5.0 V	50 - 50k Ohm	-25 - 110 °C
Mass air flow	Air flow	0 to 450 kg/hr	0.1 - 5.0 V	--	--
Throttle position	Angular Position	0° - 360°	5 V	<1k Ohm	- 45 °C - 125 °C
Oxygen	Oxygen levels	0% - 100% O2	5 V	10 Ohm	--

Appendix A: Microcontroller Concept Parameters

Table 2

Different Type of Microcontrollers and Parameters.

Microcontroller	Voltage Requirement (Volts)	Operating Temperatures	Size	Memory Storage	Processing Performance
Raspberry Pi	5.1 V (Micro USB Supply)	0 to 70 C	85 by 56 mm	1 GB, Can add up to 128 GB with SD card	1.2 GHz
Teensy 2.0	2.7-5.5	-40 to 85 C	35.56 by 17.78 mm	1 KB EEPROM	16 MHz
BeagleBone Black	5v	-40 to 85 C	86.36 by 53.34 mm	4 GB	1 GHz
Arduino Uno Rev 3	5 V	-40 to 85 C	68.6 by 53.4 mm	1 kb EEPROM	16MHz
PIC 24FJ	3-3.6V	-40 to 125 C	12.7 by 12.7 mm	32 kb Flash	7.37 MHz

Appendix A: Transceiver Concept Parameters

Table 3

Different Type of Transceivers and Parameters.

	Wi-fi (ESP8266)	BLE (nRF8001)	Zigbee (Digi XBee® SX 868)	Automotive CAN Bus Transceivers (SN65HVD233-Q1)
Power Consumption (W)	0.24 - 0.288	0.033	0.096 - 0.198	0.005 - 0.07
Voltage Requirement (V)	3 - 3.6	3	2.4 - 3.6	-0.5 - 7
Current Requirement (mA)	80	11	40-55	10
Communication Distance (m)	30-100	10	10-30	--
Frequency (GHz)	2.4	2.4	2.4	2.4
Bandwidth (MHz)	2	--	1	3 - 3000
Temperature Range (℃)	-40 - 125	-40 - 85	-40 - 85	-40 - 150
Size (mm)	25 X 15 X 1	29 X 28 X 0.8	22 X 33.8 X 3	4.9 X 3.91 X 1.58

Appendix A: Power Generation Concept Parameters

Table 4

Different Type of Thermal Electric Generators and Parameters.

	TG12-2.5-01LS POWER GENERATORS (Figure 7a)	EHA-L37AN1-R02-L1 EVERGEN ENERGY HARVESTERS (Figure 7b)	EHA-PA1AN1-R02-L1 EVERGEN ENERGY HARVESTERS (Figure 7c)	EHA-L37L37-R01-L1 EVERGEN ENERGY HARVESTER (Figure 7d)
Description	Generic	Heat Source: Liquid Heat Sink: Air	Heat Source: Surface Heat Sink: Air	Heat Source: Liquid Heat Sink: Liquid
Typical Temp Diff (C)	180	60	10	5
Voltage (V)	5.33	3.3	5	5
Power (W)	2.71	0.0017	0.0003	0.001

Appendix A: Power Generation Concept Parameters

Table 5

Battery Options.

Name of Battery	Type	Energy Density	Volts	Charge Rate	Discharge Rate	Cycle Life	Thermal Runaway	Relative Cost
Li-Cobalt Battery	Li-Ion	110-190 Wh/kg	3 - 4.2V	.7-1C, 4.2V	1C, 2.5V	500-1000	150 C (302 F)	Higher
Li-Titanate	Li-Ion	50-80 Wh/kg	1.8-2.85V	1C, 2.85V	10C, 1.8V	3000-7000	177 C (350.6 F)	Lower
Li-Manganese	Li-Ion	100-150 Wh/kg	3-4.2V	.7-1C, 4.2V	1C, 2.5V	300-700	250 C (482 F)	Higher
Li-Nickel Manganese Cobalt	Li-Ion	150-220 Wh/kg	3-4.2V	.7-1C, 4.2V	1C, 2.5V	1000-2000	210 C (410 F)	Higher
Li-Iron Phosphate	Li-Ion	90-120 Wh/kg	2.5-3.65V	1C, 3.65V	1C, 2.5V	1000-2000	270 C (518 F)	Higher
Li-Nickel Cobalt Al	Li-Ion	200-260 Wh/kg	3-4.2V	.7C, 4.2V	1C, 3V	500	150 C (302 F)	Low

Appendix B: Target Catalog

Appendix B: Target Catalog

Table 6

Target Catalog Before Conception Selection

Subsystem	Target	Value	Units
Power System	Power Generation Capacity	1-5	Milli-Watts
(energy generation and storage)	Generation Voltage	4	Voltage
	Generation Current	0.0001 - 0.001	Amperes
	Generation Capacity Factor	50 - 100	%
	Battery Storage Capacity	0.1 - 0.5	Amp-hours
	Battery Voltage	3 - 5	Voltage
	Battery Current	TBD	Amperes
	Battery Life	300	Cycles
	Standby Time	36	Hours

Appendix B: Target Catalog

Table 6

Target Catalog Before Conception Selection

Transducer System	Sensing Parameter	TBD	Unit of Parameter
(sensor, microcontroller, transceiver)	Sensor Power Requirement	0.001 - 0.01	Milli-Watts
	Sensor Current Requirement	TBD	Amperes
	Sensor Voltage Requirement	3 - 5	Volts
	Sensor Sampling Frequency	1 - 10	Hertz
	Sensor Accuracy (error)	0.1 - 1	%
	Microcontroller Active Power Consumption	0.01-1	Milli-Watts
	Microcontroller Standby Power Consumption	0.001 – 0.01	Milli-Watts
	Microcontroller Voltage Requirement	3 - 5	Volts
	Microcontroller ATD Resolution	16	# of bits
	Microcontroller Amplification	TBD	Decibel
	Microcontroller Filter Range	TBD	Hertz

Appendix B: Target Catalog

Table 6

Target Catalog Before Conception Selection

	Microcontroller Memory Storage	100	Kilo Bytes
	Microcontroller Processing Performance	0.01 - 1	Giga Hertz
	Wireless Transceiver Power Consumption	0.02 - 1	Milli-Watts
	Wireless Transceiver Voltage Requirement	3-5	Volts
	Wireless Transceiver Current Requirement	11-80	Milliamperes
	Wireless Communication Distance	5	Meters
	Wireless Transceiver Frequency	2.4	Gigahertz
	Wireless Transceiver Bandwidth	1 - 2	Megahertz

Appendix B: Target Catalog

Table 6

Target Catalog Before Conception Selection

Protection System	Volume	6	Cubic Inches
(housing and environmental parameters)	Weight	100	Grams
	Maximum Temperature	120	Celsius
	Electrical Noise	0	Hertz