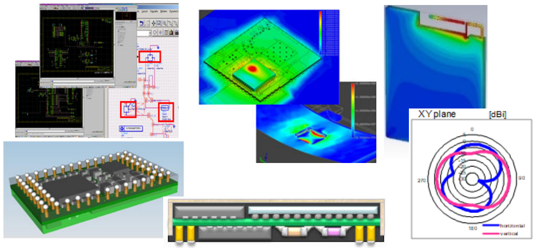
Design Considerations for Wireless Sensor Devices

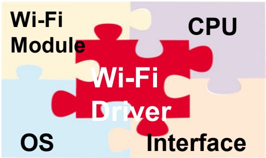
June 2019

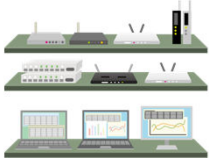
Murata Capabilities

HW / RF Design



SW / Cert. Support



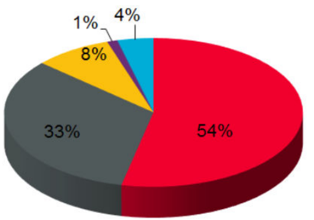


✓Driver Porting
✓Debug w/ System Level

✓Certification supports

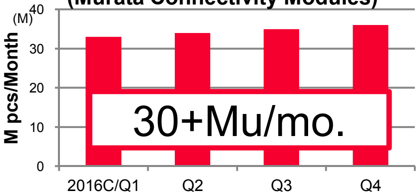
Global Network

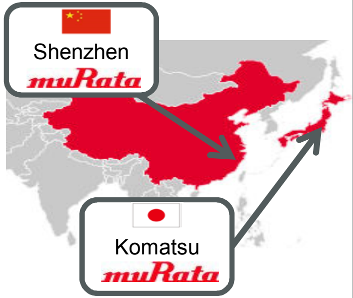
Connectivity Module Market Share
(2017CY - mobile devices)



Market Share

Production Capacity
(Murata Connectivity Modules)





Supply Capability

altair
A Sony Group Company
Qualcomm
ATHEROS
MEDIATEK
NXP
DSP GROUP

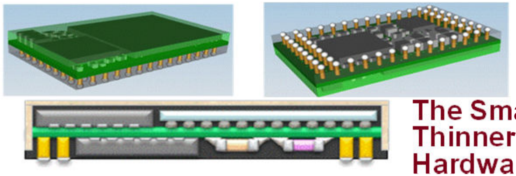
Partnerships

Murata Connectivity Products

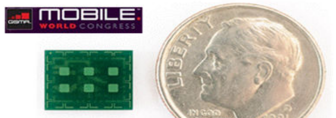
Mobile Market

Smartphone/Tablet /Wearable etc.

Unique Smallest Package
High Performance RF



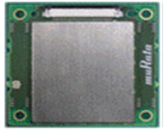
The Smallest
Thinner
Hardware



WiGig Module
60GHz Antenna Embedded

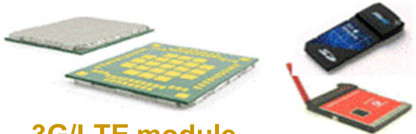
Automotive Market

Automotive Quality
TS16949
Software / Certification



BT/Wi-Fi/GPS
C2X Module

BT/Wi-Fi SW Stack
Miracast Software



3G/LTE module
LGA type / Data Card

IOT Market

Software Embedded Module
Gateway & Sensor Node
Smart System
Connectivity Software Expert
Cloud ~ Mobile application
New Software
- Mesh Network / 6LoWPAN
- Embedded Java / Airplay/
- HomeKit

BLE/Bluetooth 802.15.4 | Wi-Fi | LPWA ISM communications

Driver Soft / Middleware stack

android ITRON

Certification Support

Wi Fi LoRa NB-IoT LTE-M

Gateway
Sensor Node

Smart Lighting System

IoT Module: Target Markets/ Applications

Connected Home

●Product lineup
WiFi/BLE MCU
w/Ant w/o Ant
DECT ULE

●Characteristic
・WiFi driver・TCP/IP
・Radio certified
（FCC/IC/CE/TELEC）
・Cloud
・Serial to WiFi

●IC
Cypress, TI, Marvell,
Qualcomm, DSPG

DSC/AV/PC

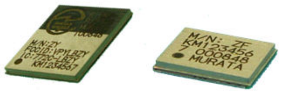
●Product lineup
11ac WiFi module
WiGig module

●Characteristic
・Certified for 120 countries
・Antenna optimization
・Super high throughput
・60GHz antenna (WiGig)

●IC
Cypress, Qualcomm

Healthcare/Wearable

●Product lineup
BLE4.1/4.2 module
（w /Ant w/o Ant）

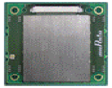


●Characteristic
・Small/Thin
・Low power consumption
・Radio Certified
（FCC/IC/CE/TELEC）
・BLE Profiles

●IC
Dialog Semiconductor
Cypress
Qualcomm
Nordic

Industrial/Commercial

●Product lineup
Wi-Fi/BT
LPWA (LoRa, NBIoT)
SubGHz



●Product
・LPWA
・High reliability
・Industrial temperature
・Mesh network
・SubGHz

IoT

- Iternet connected devices are already in the billions of devices and projected to grow to over 50 billion devices
- Many if not most will be connected wirelessly through one of several technologies – Wi-Fi, Cellular, Bluetooth, LoRa, etc.
- While all designs require tradeoffs, Wireless Sensor devices have some more stringent tradeoffs that need to be considered
- This presentation will look at some general considerations for all the technology options and then drill down on Wi-Fi and Bluetooth with respect to Power, the MCU, RF, and Regulatory considerations

Wireless Technology Options

Wireless Technology Options

Technology	Wi-Fi	Bluetooth	CatM1	LoRa
Range	10s of M	100 M	2000M	10,000M
Infrastructure	Private	Private	Public	Public/Private
Power Consumption	100s of mA peak	10s of mA peak	100s of mA peak	100s of mA peak
Data Rate	100Mbps+	3Mbps	384Kbps	27Kbps
Module Cost	Low - Moderate	Lowest	Moderate	Moderate
Air Time Cost	None	None	~$1 - $2/Mo. for up to 10MB	$0 for private, TBD for public

The ABGs of Wi-Fi

Version	Bands	Max Data Rate	Other
a	5 GHz	54 Mbps	
b	2.4 GHz	11 Mbps	
g	2.4 GHz	54 Mbps	
n	2.4 GHz/5 GHz	72.2/150 Mbps	MIMO; 2.4GHz unless a or ac included
ac	5 GHz	867 Mbps	MU-MIMO; beamforming
ad	60 GHz	6.7 Gbps	WiGig
af	White Space	569 Mbps	Speeds and channels depend on location
ah	Sub-GHz	347 Mbps	
ax	2.4 GHz/5 GHz	10.53 Gbps	MU-MIMO; beamforming
s	N/A	N/A	Mesh

Bluetooth

- BLE is included in Bluetooth 4.0 and later
  - The Bluetooth in Murata's Wi-Fi/BT combo modules is dual mode Bluetooth – Classic BT and BLE
  - Many standalone BLE RFICs and module are BLE only to provide the lowest possible power consumption
- Be careful regarding claims of Bluetooth 5
  - 2x Speed, 4x Range, 8x Data
  - All of the BT5 new features are optional – only 4.2 spec and errata are required to call it BT5
  - BT5 is NOT BLE mesh. BLE mesh can run on BT 4.x devices

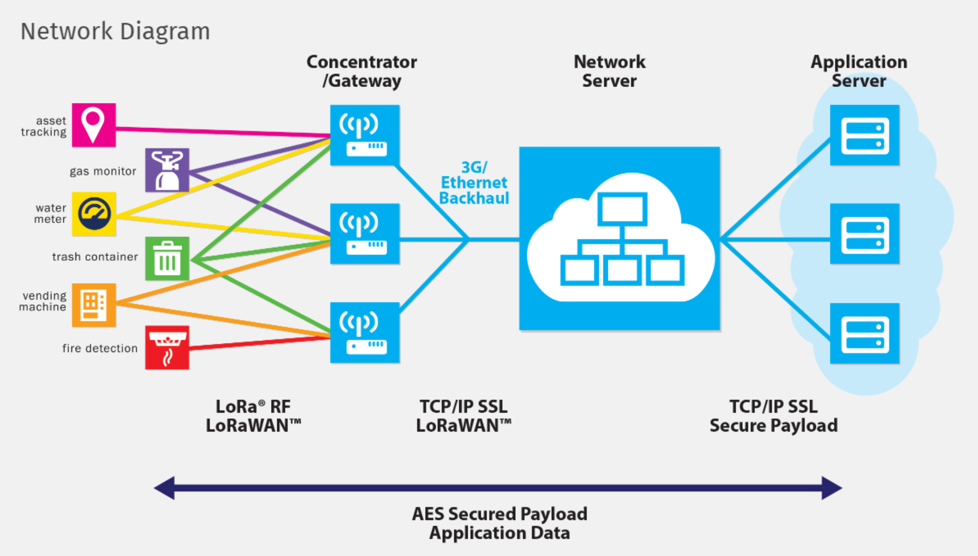
Cellular

	CAT 1	CAT M1	NB-IoT
Bandwidth	1.4 to 20 MHz	1.4 MHz	200 kHz
Duplex Mode	FDD	HD-FDD / FDD / TDD	HD-FDD
Peak Data Rate	10 Mbps Downlink 5 Mbps Uplink	384 kbps HD-FDD	20kbps DL / 60kbps UL
UL Tx Power	23 dBm (Class 3)	23 or 20 dBm (Class 5)	23 dBm
Voice support	Yes	VoLTE	Not supported
Mobility support	Full mobility	Full mobility	No connected mobility (only idle mode reselection)
Rx Antennas	MIMO (carrier required)	Single Antenna	Single Antenna
MCL* 3GPP Spec	140.7 dB	155.7 – 160.7 dB	164 dB
Modulation	16-QAM	QPSK	BPSK
Region	Global	North America, Europe	China, Europe

- Maximum Coupling Loss (transmit power, receiver noise figure, occupied bandwidth, and required SNR)

LoRa

Key Features	
Low Cost	Infrastructure, OpEx, CPE
Standardized	Global compatibility speeding adoption
Lower Power	Up to 20 years on battery
Long Range	> 15Km in non-Urban areas
Secure	End-to-End AES128 encryption
High Capacity	Millions of messages per base station



Connectivity Considerations

- Network Connectivity
  - Must be something to receive the signal
  - Range affects connectivity options
  - Range has power consumption impact
  - Data rate has an impact on range
  - Public versus private infrastructure
  - Wireless technology drives options

Connectivity Considerations

- Security
  - Paramount consideration
  - Encryption
  - Is the device connecting to the right cloud?
  - Is this device supposed to connect to this cloud?
  - Production impact of keys and certificates
  - Make or Buy?

Use Cases

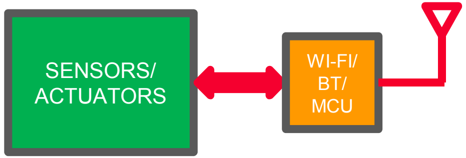
- Know and *Understand* your use cases
  - Battery or mains power?
  - How long must battery last?
  - How much data?
  - What data – all, data outside of a range, alarm?
  - When and How often?
  - Wi-Fi or BT/BLE or both?
  - Security?

The answers to these questions drive the design decisions and many of the tradeoffs

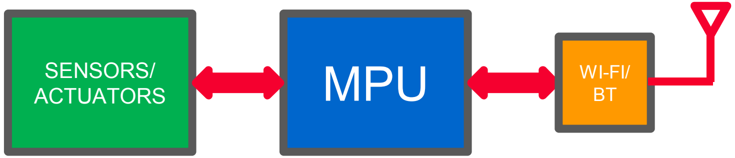
IoT Architectures

1. Discrete ARM-4 MCU running WICED interfaces to sensors and actuators, performs required manipulations of data, and communicates with wireless module. (Effectively the Nebula board with 1DX module)

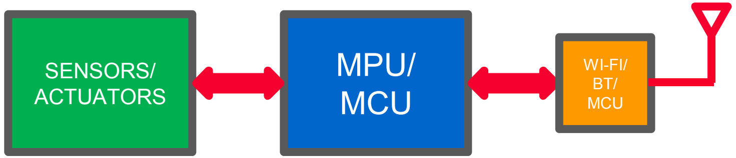
2. ARM-4 MCU in the module running WICED interfaces to sensors and actuators, performs required manipulations of data, and communicates with wireless module. MCU in module may be discrete or part of RFIC



3. A7 MPU running Linux interfaces to sensors and actuators, performs required manipulations of data, and communicates with wireless module. Wi-Fi driver is part of the Linux implementation



4. Discrete MPU/MCU interfaces to sensors and actuators, performs required manipulations of data, and communicates with wireless module running WICED as a serial peripheral device. WICED used to implement serial communications interface for MPU/MCU.



Wi-Fi & Bluetooth Deep Dive

Type 1LV: CYW43012 – 802.11ac-Friendly + BT5.0

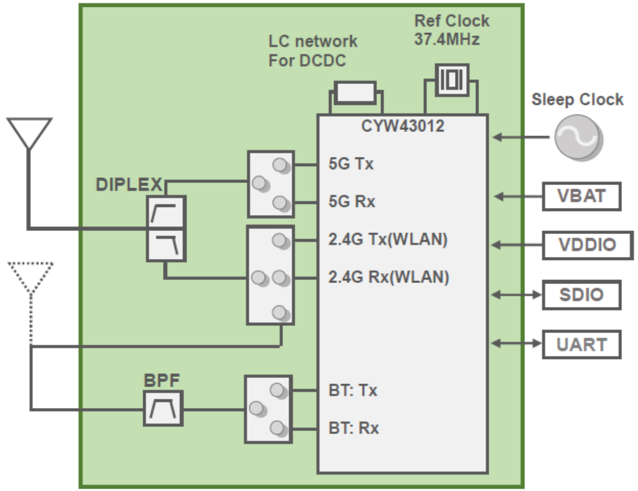
Part Number	
Part Number	LBEE59B1LV-278
Chipset	
WLAN	CYPRESS CYW43012
Features	
WLAN	IEEE802.11a/b/g/n, 11ac-friendly
BT ver.	5.0 (Dual)
Interface	SDIO (WLAN) UART (BT)
Dimensions L x W x H (mm)	10.0 x 7.2 x 1.4
Shield/Mold	Shielded Resin
Operating Temp. (°C)	-20 to +70
Certification	
Bluetooth QDID	125836

<u>*CYW43012 is a 28nm ultra-low power device</u>

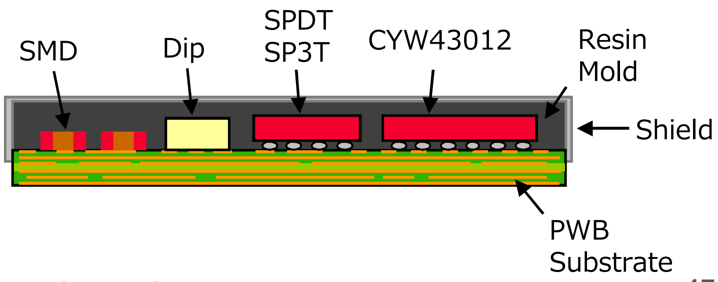
RECEIVE
50% down power consumption
TRANSMIT
25% down power consumption
LOW POWER
80% down Sleep power consumption
50~60% down Idle & Ready Mode power consumption

<u>Than existing 40nm 802.11n products</u>

Block Diagram



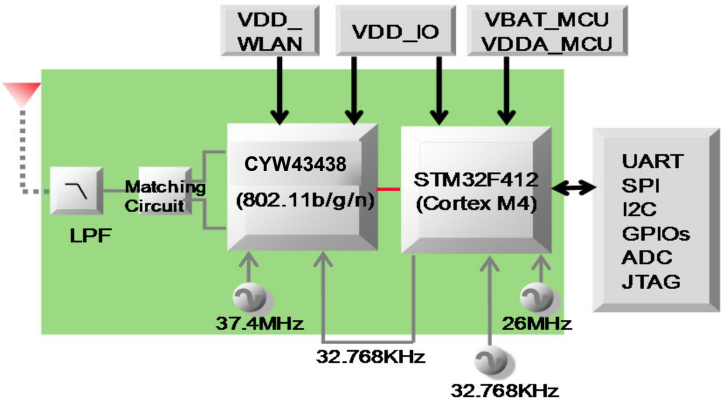
Cross-Sectional Diagram



Type 1LD: CYW43438 - 11b/g/n + BT4.2

Part Number	
Part Number	LBEE5PA1LD-TEMP
Chipset	
WLAN	Cypress CYW43438
MCU	STMicro STM32F412
Features	
WLAN	IEEE802.11b/g/n
BT Version	4.2 (Dual)
Interface	UART/ SPI/ I2C/ GPIO/ JTAG
CPU Core	Cortex-M4
CPU Clock (MHz)	100MHz
ROM/ RAM (KB)	1MB/ 256KB
Software Option	WICED SDK
Dimensions L x W x H (mm)	8.90 x 7.80 x 1.20
Shield/Mold	Shielded Resin
Operating Temp. (°C)	-40 to +85
Certification	
Regulatory	FCC/IC, CE
QDID	119621

Block Diagram



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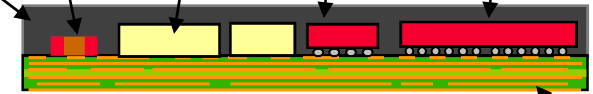
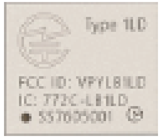
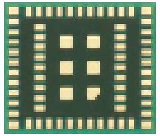


Top View



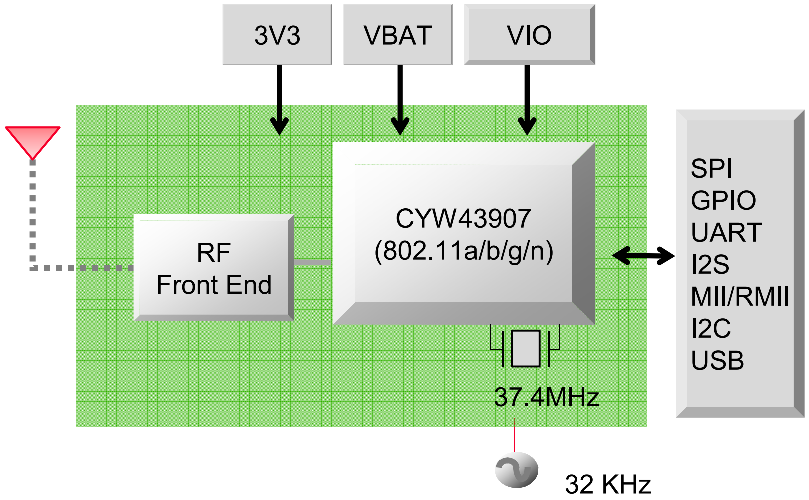
Bottom View



Type 1GC: CYW43907 - 11a/b/g/n

Part Number	
Part Number	LBWA1UZ1GC-958 (WICED) LBWA1UZ1GC-901 (Imp005)
Chipset	
WLAN	Cypress CYW43907
MCU	Cypress CYW43907
Features	
WLAN	IEEE802.11a/b/g/n
Interface	UART/ SPI/ I2C/ I2S/ MII/ RMII/ USB
CPU Core	Cortex-R4
CPU Clock (MHz)	320
ROM/ RAM	External/ 2MB
Software Option	WICED, ElectricImp
Dimensions L x W x H (mm)	10.00 x 10.00 x 1.20 (max.)
Shield/Mold	Shielded Resin
Operating Temp. (°C)	-30 to +85
Certification	
Regulatory	FCC/IC, CE

Block Diagram



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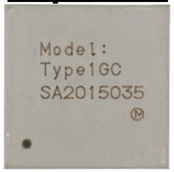
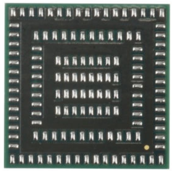


Bottom View



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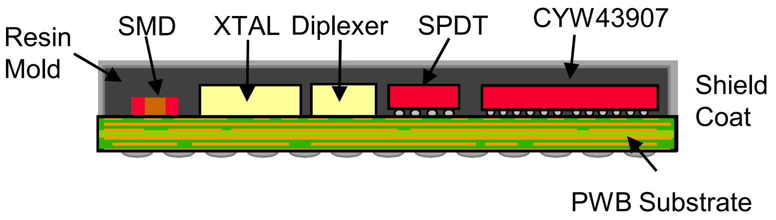
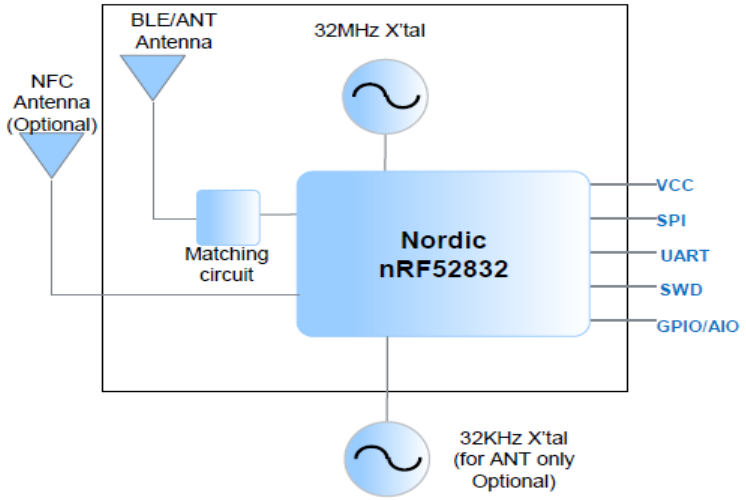


Type MBN: nRF52832 - BT4.2 + ANT + NFC

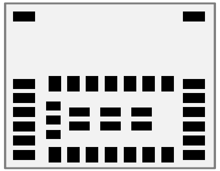
Part Number	
Part Number	WSM-BL241-ADA-008
Chipset	
BLE	Nordic nRF52832 Bluetooth Smart™
Features	
BLE	4.2
Interface	UART/ SPI
CPU Core	ARM Cortex-M4F
CPU Clock (MHz)	32
ROM/ RAM (KB)	512/ 64
Software	nRF5 SDK
Dimensions L x W x H (mm)	7.40 x 7.00 x 1.00 (max.)
Shield/Mold	Shielded Resin
Operating Temp. (°C)	-40 to +85
Certification	
Regulatory	FCC/IC/ETSI *(plan)
Bluetooth QDID	-

Block Diagram

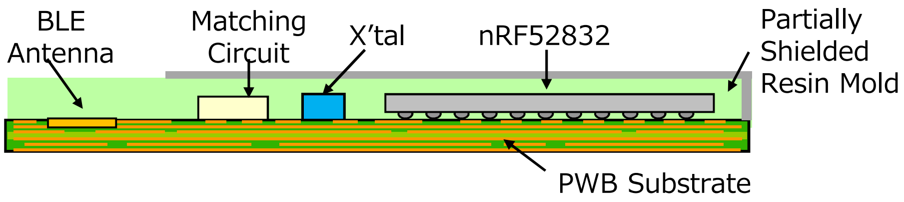


Top View

Bottom View



Cross-Sectional Diagram

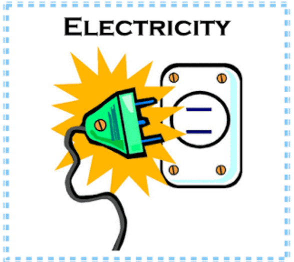


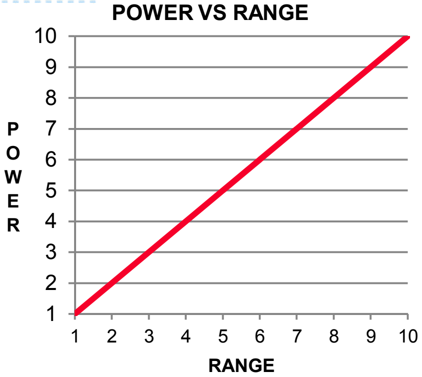
Areas for Consideration

- 4 Key Areas
  1. Power
  2. MCU
  3. RF
  4. Regulatory

Power Considerations

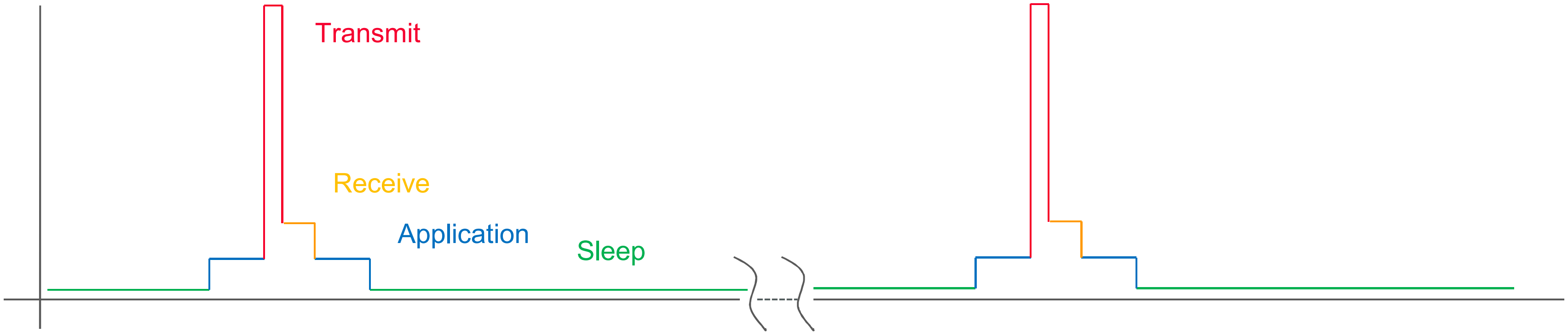
- Power Consumption
  - Critical for battery or alternative energy sources
    - Loss of function/Loss of data
    - Service call/Battery replacement
  - Important for mains powered devices
    - Reducing power consumption is often a key application for IoT products
  - Range and Power Consumption have an positive relationship
  - Data Rate and Range have an inverse relationship
  - Data Rate and Power Consumption can have an inverse relationship





Power

- Average vs Peak
  - Average will define how long your battery will last, peak will help you define which battery (chemistry, capacity) can work
    - Average power is often driven by the sleep or low power number especially when the active duty cycle is low.



Power

Module	Tx (Typ)		Rx (Typ)	Pwr Save Mode (Typ)	
1LD	Wi-Fi:	250 – 300mA	50 - 60mA	DTIM1: DTIM3:	2.2 – 2.8mA 1.1 – 1.5mA
	BT/BLE:	25 - 35mA	25 - 35mA	Sleep*:	156uA
	STM32F412:	10mA	10mA	Stop*:	50uA
1LV	Wi-Fi:	150 – 250mA	15 - 25mA	DTIM1: DTIM3:	0.45 – 0.65mA 0.20 – 0.30mA
	BT/BLE:	20 - 30mA	7 - 13mA	Sleep*:	160uA
1GC	Wi-Fi + MCU:	300 – 500mA	90 - 110mA	DTIM1: DTIM3: Sleep:	1.80 – 2.20mA 0.65 – 0.85mA 170uA
MBN	BLE + MCU:	6 - 8mA	6 - 8mA	Sleep*:	2.90uA

*Sleep and Stop numbers include RAM and register retention as well as RTC operation

Power

- Average Power is simply the arithmetic weighted average:

$$\frac{(\text{Sleep mA x Sleep Time}) + (\text{Application mA x Application Time}) + (\text{Tx mA x Tx Time}) + (\text{Rx mA x Rx Time})}{(\text{Sleep Time} + \text{Application Time} + \text{Tx Time} + \text{Rx Time})}$$

- Example:
  - Application time = 5 ms before and after communication (total 10ms)
  - Tx time for 1000 bytes at 54 Mbps ~ 150us
  - Rx time for 1000 bytes at 54 Mbps ~ 2.5ms (includes turnaround time)
  - One transaction per minute: Sleeping 99.98% of the time
  - One transaction per hour: Sleeping 99.9996% of the time

Power

- Using the example for one per minute, sleeping in between, what are some real numbers?
- MBN Module using 1Mbps PHY (200 bytes since no TCP/IP OH)

$$\frac{(2.9uA \times 59.9843) + (2mA \times 0.010) + (7mA \times 0.0016) + (6mA \times 0.0041)}{60}$$

$$= 4.09uA$$

With a 200mAhr battery you would expect to get:

$$200/0.00409$$

$$= 49{,}000 \text{ hours} = 5.58 \text{ years}$$

Power

- But Wi-Fi isn't quite as straightforward
  - It takes time to establish a connection with an access point and join the network
  - To stay associated, the device must listen to the access point beacons and wake up as required when there is data to receive.
  - To facilitate low power devices, DTIM was developed. It allows a device to only wake up every *n* beacons. Thus DTIM3 will only listen to every third access point beacon
  - DTIM reduces power consumption but increases latency
  - DTIM is set in the access point so your device may or may not be able to take advantage of this feature

Power

- Wi-Fi Security can impact the amount of time it takes to associate with a network
  - Certificate based security requires transmissions of certificates and additional handshaking that burns current
  - Authentication, Authorization and Accounting (RADIUS servers) add additional time to join or re-join a network
  - Changing keys cause additional transmissions during otherwise low power periods
  - You should expect a lot of variability depending on the security environment in which your device is deployed

Power

- Let's look at our example for the Wi-Fi modules assuming they have already associated and joined the network
- 1LD:
  - DTIM1: $\frac{(2.5\text{mA} \times 59.9872) + (10\text{mA} \times 0.01) + (275\text{mA} \times 0.000150) + (55\text{mA} \times 0.00265)}{60}$

    $= 2.5\text{mA}$
  - DTIM3: $\frac{(1.3\text{mA} \times 59.9872) + (10\text{mA} \times 0.01) + (275\text{mA} \times 0.000150) + (55\text{mA} \times 0.00265)}{60}$

    $= 1.3\text{mA}$
  - DTIM1: 200mAhr battery = 80 hours = 3.3 days
  - DTIM3: 200mAhr battery = 153.8 hours = 6.4 days

Power

- Using a similar approach we get the following results for the other Wi-Fi modules:

Module	DTIM	Average Current	Bytes (Tx & Rx)	Transaction Frequency	200mAhr Battery Life
MBN	NA	4.01uA	200	1/min	5.5 yrs
1LD	DTIM1	2.5mA	1000	1/min	3.3 days
	DTIM3	1.3mA	1000	1/min	6.4 days
1LV	DTIM1	0.55mA	1000	1/min	15.1 days
	DTIM3	0.25mA	1000	1/min	33.3 days
1GC	DTIM1	2.01mA	1000	1/min	4.1 days
	DTIM3	0.76mA	1000	1/min	11.0 days

Power

- A Word about Batteries
  - Make sure battery can provide peak current needed
    - Coin cells can’t source Tx currents needed for Wi-Fi
  - Size battery appropriately for needed run-time/life
    - Be aware of pulse discharge, typically for these applications, on rated battery capacity
    - Be aware of ambient temperature effects on capacity and peak current
  - Take care in charge/discharge circuits for rechargeable batteries – especially Lithium-based batteries
    - Charging ICs can provide good performance and safety
    - Consider a battery pack with control built in for multi-cell batteries

Power

- Takeaways
  - BLE has a much lower power profile potentially enabling primary battery solution
  - Wi-Fi power profile will likely require rechargeable battery solution
  - Wi-Fi battery run-time will vary depending on the environment
    - Security used
    - Security settings
    - DTIM access
    - UDP vs TCP

Power

- If Sleeping doesn't meet your battery run-time requirements, you can always turn devices off
  - Requires means to turn them OFF and ON
    - Can turn only parts off, e.g. Wi-Fi, sensors, etc.
    - Something must remained powered to turn the rest of the device back on
  - Power up time increases latency
    - 1LD takes about 1.5 seconds from power on to access point association
  - Device is unreachable when it's off
    - May not be different than when sleeping as with BLE
  - Additional time and power consumption to rejoin the network every time the device wakes up must be factored into the power consumption

MCU Requirements

- MCU must have sufficient compute resources
  - Processor speed
    - Handle incoming data
    - Provide adequate response with required data manipulation, e.g. floating point
  - RAM
    - Data storage, need to store data if communications link goes down
    - Program execution – application, TCP/IP stack, Bluetooth stack
  - Flash
    - XIP Internal and external
    - WLAN firmware, OTA application upgrades

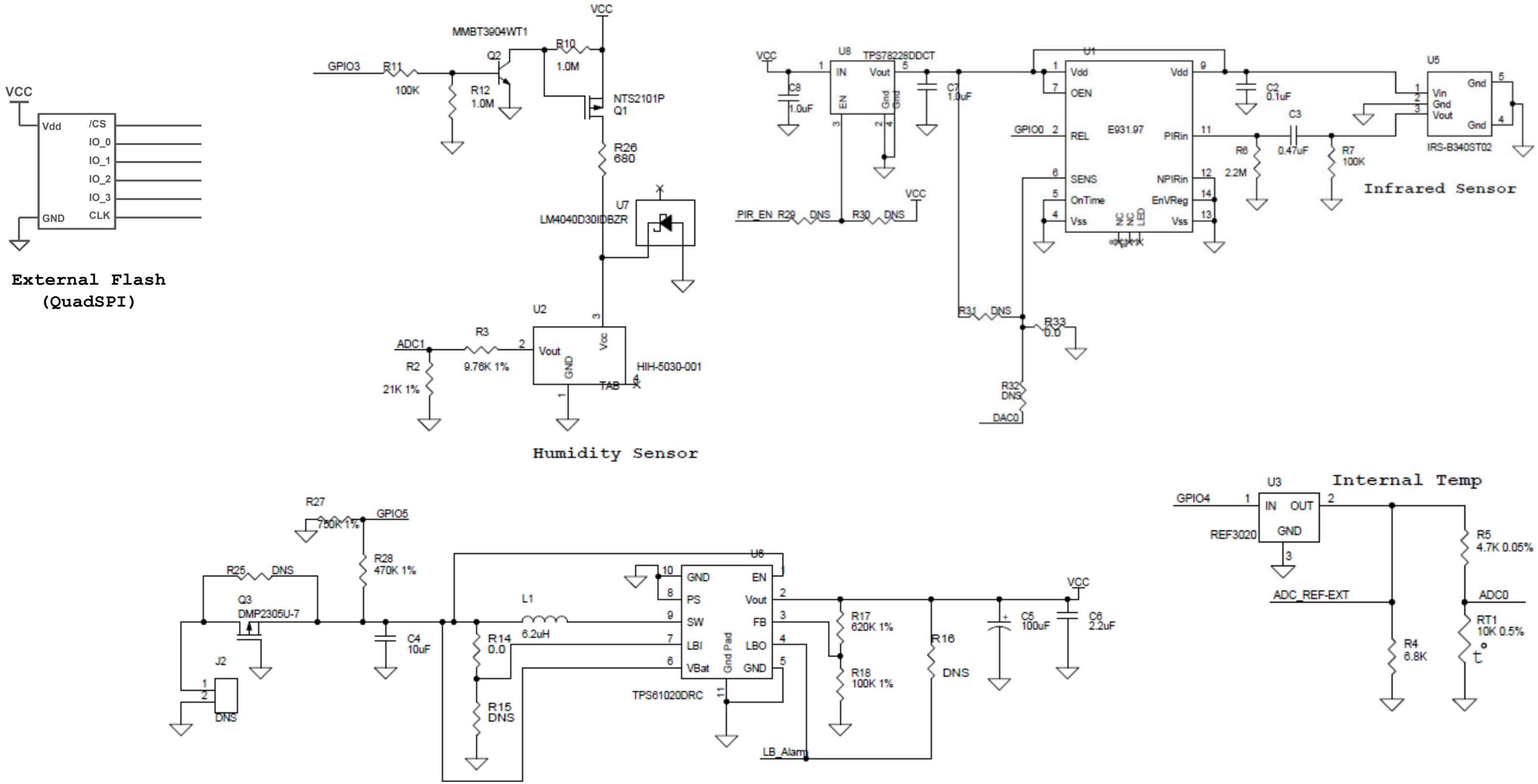
MCU Requirements

- Flash Needs – Wi-Fi
  - WLAN low level firmware that is loaded into RFIC on power up
    - Varies by RFIC but 400K – 500K bytes is fairly typical
  - Wi-Fi/TCP/IP Stack, Bluetooth Stack and Application code
    - 250K for simple TCP/IP application
    - 500K not unusual for complete image
  - 1MB of Flash not unusual for all code
  - For OTA need 3 images so 3MB Flash can be needed
- RAM Needs – Wi-Fi
  - 250K is typically sufficient but be aware of any data storage needs when communications is lost

MCU Requirements

- MCU must have sufficient I/O *that is accessible*
  - Wireless modules with embedded MCUs typically bring out a subset of the MCU's I/O
  - External MCU must be chosen with I/O requirements in mind
  - External Flash support
    - OTA best practice provides room for 3 images – original factory, currently running, and new image being downloaded
    - XIP program execution if needed
  - Sensor/Interface support
    - ADCs and PWMs
    - Sensor activation/granular power supply control

MCU Requirements



MCU Requirements

- Make sure it's the right I/O
  - ADCs, typically 12-bit with 10-bit resolution
  - PWMs
  - Alternate functions of I/O provides flexibility but makes determination of what is available more complicated
- Get an accurate count of what you need
  - Power control to sensors
  - External reference voltages
  - QuadSPI vs SPI needing separate SPI ports
  - Low battery and charging circuit control and monitoring

MCU Examples

Module	MCU Speed	RAM	Flash	IO
1LD	26MHz	250KB	1MB	UART/ SPI/ I2C/ GPIO/ JTAG
1LV	Depends on MCU Selected			
1GC	37.4MHz	2MB	None	UART/ SPI/ /GPIO/ I2S/ I2C/ MII/ RMII/ USB
MBN	32MHz	64KB	512KB	UART/ SPI/ GPIO

RF Considerations

- 2.4GHz, 5GHz, Both?
  - Often decided by what 802.11 modes are required
    - b/g/n will be 2.4GHz only
    - a/b/g/n and a/b/g/n/ac will be both 2.4GHz and 5GHz
  - Even though 11ac only operates in the 5GHz band, the need to support lower data rates, i.e. b/g/n requires the ability to operate in 2.4GHz
- 2.4GHz better propagation characteristics
- 5GHz more spectrum allowing more/wider channels and higher data rates
- Use of 5GHz solution will require dual-band antenna

RF Considerations

- Antennas
  - Give thought to antenna placement
    - Keep away from metal and keep other components and traces out of the area.
    - Follow antenna guidelines on how close plastic enclosure can be
    - Give thought to the enclosure and how the signal can get out of the enclosure for internal antennas
  - For modules without antennas or antenna connectors, be mindful of the need to impedance match the RF trace and the impact that can have on the pcb stackup

RF Considerations

- Antenna Gain
  - Higher gain antennas are more directional – it's how the obtain gain
  - Make sure any antenna gain doesn't exceed FCC limits
    - Various modulation schemes used in Wi-Fi have different power limits so a gain that is okay for one modulation index might not be okay for another
  - For certified modules, if possible, use the antenna that the module was certified with
    - If not, try to use same type, e.g. dipole, pcb trace, etc., with equal or lesser gain – allows Class I Permissive Change – no test report filing with FCC
    - If higher gain or different type Class II Permissive Change may be possible given radiated levels don't exceed limits – requires test report filling with FCC

RF Considerations

- Don’t cut corners when it comes to RF items
  - Having RF work and having it work well are two different things
- If you don’t have RF experience, identify someone who does, and understand the level of support they will provide
  - Antenna manufacturer
  - Module manufacturer
  - Board Layout or Fabricator
- Design the RF with margin
  - Environmental differences can be significant
  - Need to operate reliability in the worst case situation

Regulatory

- Unlicensed doesn’t mean unregulated
  - Every country has regulations on the use of their airwaves and with the proliferation of wireless they are having to be stronger in their enforcement
- Wireless devices are considered “Intentional Radiators”
  - Must meet intentional radiator rules for spectrum of interest
  - Must also meet unintentional radiation limits due to noise generated by clocks and digital signals
  - Both are regulated by the FCC and the same test lab can perform both types of tests
  - Wi-Fi is covered by several different sets of rules so certification testing will include all the relevant tests

Regulatory

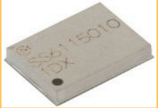
No Certification

- Customer implements antenna as PCB trace, chip, or remote dipole
- Customer works with certified test lab to run full FCC/IC/ETSI tests
- Grant is issued to customer

~$30,000 - $200,000

Reference Certification

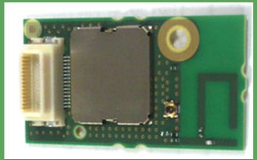
- Module without an antenna or antenna connector certified with a specific pcb trace antenna design
- Customer copies Murata trace design into their design
- Customer files for grant in their name
- Can get other antennas certified as permissive change



~$2000 - $15,000

Full Module Certification

- Module has on-module antenna or antenna connector
- Customer can use on-module antenna or approved antenna
- Customer files for grant in their name



~$2000

Regulatory

RED (ETSI)

- Replaces R&TTE Directive
- Adds additional requirements for performance
- Is part of CE Mark essential requirements
- Doesn't directly address antenna as CE is an end device certification
- Additional testing required by RED has been performed for most modules

Bluetooth Qualification

- QDID required for component/controller subsystem (module), BT stack, and BT application
- Required to gain access to the IP embodied by BT
- Required even if product will be marketed without BT trademarks or the word Bluetooth
- Murata modules have component/controller subsystem QDIDs

Regulatory

- Global Certifications
  - More countries are paying more attention to unlicensed wireless use and are enforcing regulations more
  - FCC & ETSI cover a lot of ground but different countries have different spectrum and power limits
  - Plan your SKU strategy carefully
    - Different SKU for each country?
    - Limited SKUs with a “Rest of World” country code?
    - FCC does not accept 802.11d to determine that a device is in the US or to use location information from the access point
    - Software supports multiple country codes but cannot be set by customer

Regulatory

- FCC Exposure Limits
  - Standard (Mobile) FCC certifications require 20cm of separation from the antenna and human bodies
  - Less than 20cm separation requires a Portable FCC grant – Wearables
  - Depending on RF power and separation distance, obtaining a Portable grant, assuming a mobile grant exists, can be a paperwork exercise
    - FCC Guideline document:
    - RF Exposure Procedures and Equipment Authorization Policies for Mobile and Portable Devices
    - Appendix A and B provide RF power levels by separation distance and frequency below which SAR testing is NOT required (But also see the equations used)

Summary

- Like any design, wireless IoT devices have tradeoffs and considerations that must be taken into account
- All the items discussed are eminently doable
- With proper consideration at the beginning, many foreseeable problems can be avoided
  - Preventing schedule delays
  - Avoiding unnecessary expenses from additional spins

Thank You!