L.S. RESEARCH
Wireless Product Development

Compliance By Design

Presented By Bob Buczkiewicz

Texas Instruments

Presentation Overview

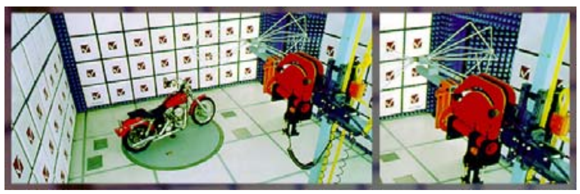
- About LS Research/ LS Compliance
- Regulatory Approval Overview/Guidelines
- Pros and Cons of using RF Modules
- Compliance Risk Mitigation
  - RF Component Selection
  - PCB Layout
  - Compliance Pre-Scans
  - Antenna Radiation Patterns
- Q & A

About LS Research

- Founded in 1980 by Larry Schotz – One of the Premier RF Engineers in FM Receivers.
- Core Competency: Wireless Product Development and EMC Testing
- 18,000 sq. ft. building, 50 Employees
- Locations: Cedarburg and Madison, WI

About LS Compliance

- LSR opened its Compliance division in 1997.
- LS Compliance provides EMC Testing and Radio Certification Services for companies worldwide. We are accredited to ISO / IEC 17025 by A2LA, the American Association for Laboratory Accreditation for EMC and Radio Certification.
- Our staff of EMC and RF Design Engineers is experienced in assisting our customers at all levels of test and problem resolution. From test plan development, to managing the certification process for your radio, LS Research has the experience and the relationships to ensure your products certification.



TEXAS INSTRUMENTS

Regulatory Approval Overview

EMC Testing is known by many titles:

In the United States, it is typically classified as
FCC Part 15 – Radio Frequency Devices

In Canada, it is typically classified as
ICES: Interference - Causing Equipment Standards

In Europe, it is typical defined by its Directives. They are:
EMC Directive 89/336/EEC
RTTE Directive 1999/5/EC
Medical Device Directive 93/42/EEC
Machinery Safety Directive 98/37/EC

In Australia, it is typically classified as
ACMA – Radio Communications Act of 1992

Two Basic Equipment Classes

Intentional Radiator: Radio Transmitters
Unintentional Radiator: Electronic equipment containing signal sources.

ACCREDITED CE FC ACIL USCEL

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Regulatory Approval/Overview

- **EMC Defined: Electromagnetic Compatibility**

- **<u>EMC has two basic branches</u>**
  - **Emissions = Operate equipment measure electrical emissions.**
  - **Immunity = Operate equipment, stress equipment with electrical disturbances, confirm impairment/recovery performance.**

- **<u>Emissions</u>**
  - **Radiated = Measure Electric Field Emission at a distance (3m).**
  - **Conducted=Measure disturbance voltages on power mains.**

- **<u>Immunity</u>**
  - **RF Radiated Immunity: Transmitting antenna generates a calibrated Electric Field as Interferer.**
  - **RF Conducted Immunity: Calibrated voltage/current injected into power mains or other cabling. Simulated power mains disturbances.**
  - **ESD: Electrostatic Discharge.**
  - **Magnetic Field Immunity: Generate calibrated Magnetic field to stress items sensitive to magnetic field: e.g. CRTs.**

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Regulatory Approval/Overview

Radio Approval Process

FCC, Industry Canada, ACA, CE

- **Authorized Frequency Band: 2400-2483.5 MHz**
  - **•Spread Spectrum Operation: FCC 15.247**
  - **• Narrow Band Operation: FCC 15.249, 15.231**
  - **•Spread Spectrum Operation: IC RSS-210**
  - **•Spread Spectrum Operation: EN 300 328**
  - **•Short Range Devices (SRD): EN 300 220,EN 300 440**
- **ACA Radio communications (Low Interference Potential Devices) Class License 2000.**

The Process:

•FCC Registration Number
•FCC Grantee Code
•FCC ID Number
•Emissions Designator Number
•TCB Agreement
•FCC Certification Letter

Modular Filing – FCC PART 15 UNLICENSED MODULAR TRANSMITTER APPROVAL
*If you are marketing your product as a radio module (opposed to discrete design)
Advantage: Limited FCC costs
Disadvantage: Higher manufacturing costs

Regulatory Approval/Overview

Typical Time Frames:

- Test Time: 1 Week
- Test Report: 1 Week after test
- TCB Approval: 1 to 2 weeks after report
- CE Declaration of Conformity: 1 Day after report

Typical Costs:

- FCC: ~$8,000- 10,000
- IC: ~ $2,000 - 3,000
- CE: ~ $10,000- $13,000

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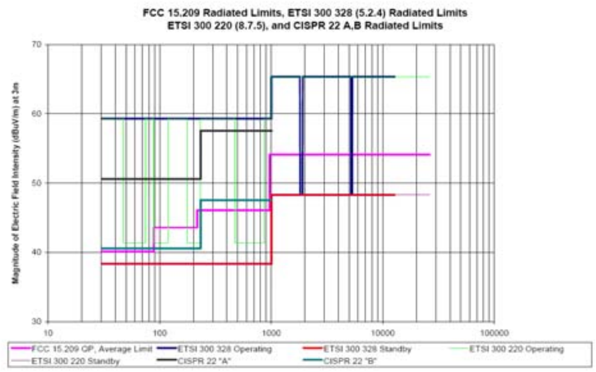
Regulatory Approval/Overview

Know the standards: FCC, ETSI, CISPR…



Pros and Cons of Using RF Modules

LSR Zigbee Ready Modules

Matrix – TI CC2430

Matrix and Matrix HP

Key Features:

- Low Power Consumption - As low as < 3 micro amp
- Impressive Range - Up to 4,500 feet line of sight
- Excellent Sensitivity - Up to -98dBm
- Compact Form Factor - 1.13" X 0.92"
- FCC and CE Certified
- Customizable Design

Pros:

- Low Risk
- Time to Market
- No Certification Fees

Cons:

- Unit Price
- Size

Benefits to Embedded Design:

- Custom, Application Specific.
- Built from components/raw materials: highest gross margin.
- Optimized Antenna Performance
- Host Interface, I/Os Custom

Tradeoffs:

- Cost: RF Design for Performance.
- Cost: RF Design for EMC.
- Cost: Software Development of PHY/MAC.
- Cost: Stabilization of Design over Process.

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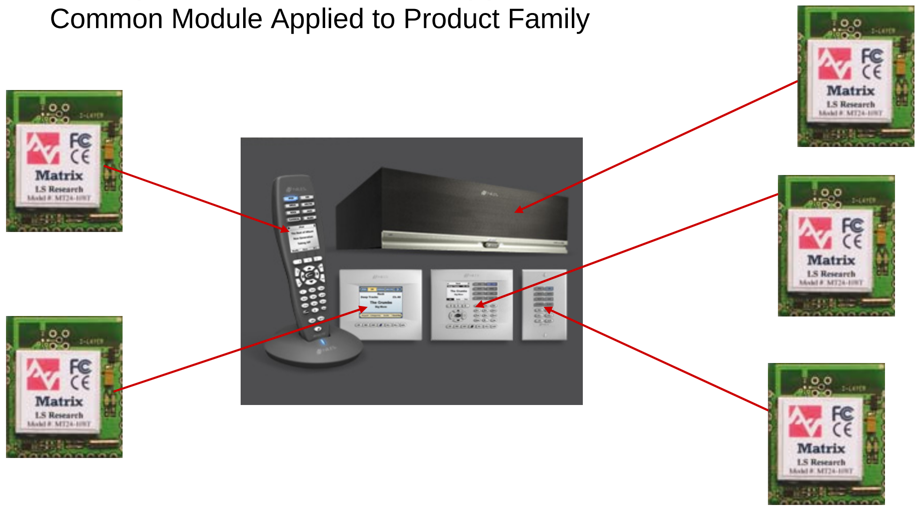
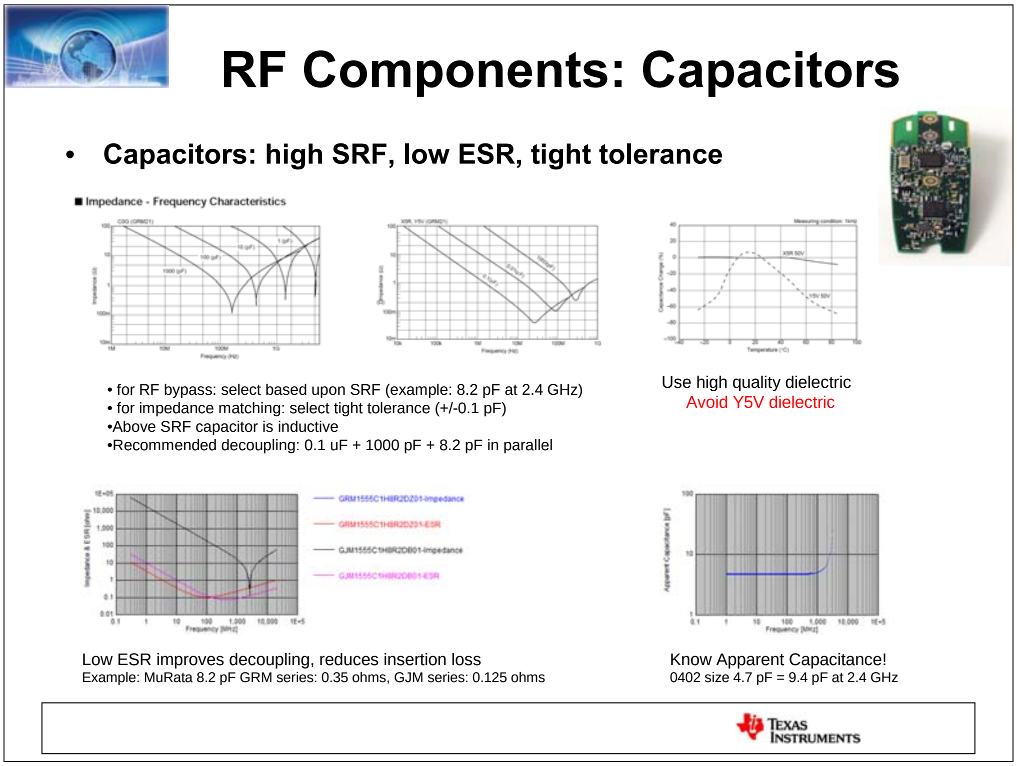
Pros and Cons of Using RF Modules

Example of Radio Module Application -

Common Module Applied to Product Family

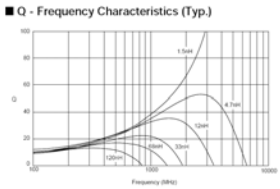




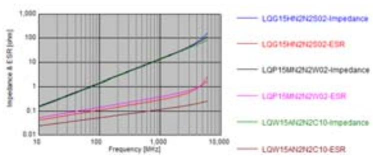
1. Select RF decoupling capacitor based upon SRF to provide lowest impedance at carrier frequency.
2. Sometimes additional harmonic suppression can be achieved by adding additional capacitor that has SRF at harmonic. Place this capacitor closest to IC pin to minimize PCB trace inductance (1 nH per 1/10").
3. PCB vias can add 0.2 nH series inductance and degrade decoupling.
4. Low ESR capacitors provide significant performance improvement for high power amplifiers
5. Avoid Y5V dielectrics, vary with temperature and voltage, shock & vibration can introduce microphonics
6. Tantalum capacitors have high ESR and limited useable range of <100 kHz
7. Each bypass capacitor should have a separate via to ground, don't share vias!
8. MuRata, ATC and AVX provide full S-parameters

RF Components: Inductors

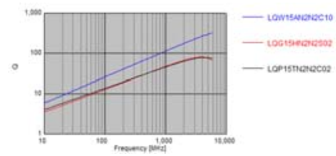
- **Inductors: high SRF, high Q, tight tolerance**



- **Multilayer:** lowest EMI, lowest Q, high inductance (>270 nH), lowest cost [MuRata LQG series $0.028]
- **Film:** tightest tolerance (0.1 nH) low Q, low inductance (<33 nH) [MuRata LQP series $0.047]
- **Wire Wound**: highest SRF & Q, highest current, highest EMI, limited values [MuRata LQW series $0.100]
- Keep PCB traces short: PCB trace can add 1 nH per 100 mil trace length



Low ESR reduces insertion loss



Wire Wound has highest Q!
0402 size 2.2 nH Q >100 at 2.4 GHz

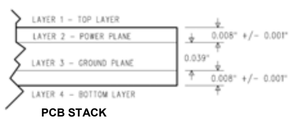
High inductor SRF improves filter frequency response and lowers emissions, tight tolerance and fine component value resolution needed > 1GHz to assure consistent performance, component Q must be >10x circuit Q to keep IL <1dB

Good Practices of PCB Layout

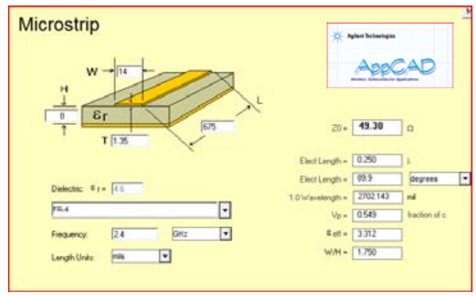
- **Use Microstrip and point-to-point component routing**
  - **Free Microstrip Impedance Calculators:**
    - **Agilent AppCAD: www.agilent.com**
    - **University of Missouri (Rolla) EMC Lab: http://emclab.mst.edu**

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r + 1.41}} \ln\left(\frac{5.98H}{0.8W + T}\right) \text{ ohms}$$

- **Caution: Low cost FR-4 PCB ε_r = 4.5 +/-0.3 at 1 MHz but ε_r = 4.1 - 4.9 at 2.4 GHz**
- **4-layer PCB can provide 5-15 dB less EMI when compared to 2-layer PCB**
- **Avoid microstrip discontinuities: trace width should match component footprints**
  - **Rule-Of-Thumb: PCB trace width (w) is 2x the dielectric thickness (H)**
  - **PCB trace width should be 75% of component footprint width (w = 14 mil for EIA 0402 package)**
- **Ground plane must be continuous pour and located directly below the RF component layer**

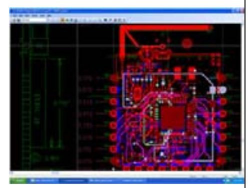


PCB STACK
Layer 1 = digital traces
Layer 2 = power plane
Layer 3 = ground plane
Layer 4 = RF traces

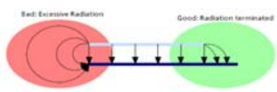


Compliance By Design

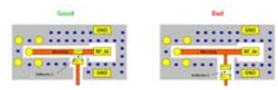
The PCB layout has the biggest impact on compliance (EMI).



- **Plan for a RF shield over the radio portion of the circuit board.**
- **Add RF de-coupling capacitors to <u>every</u> power supply pin.**
  - **Place decoupling capacitors as close to the pin as possible.**
- **Digital I/O: fast rise times increase EMI**
  - **add small value series damping resistor (22-33Ω) and shunt capacitor**
- **Keep RF traces as short as possible (< 1/20 λ)**
- **Don't route RF traces through vias**
- **Partition and isolate RF circuits from digital circuits**
- **Use dedicated digital and analog/RF LDO regulators**
- **Isolate power supplies with chip ferrite beads (Z > 100Ω)**
- **Discontinuities in power or ground planes will act as slot antennas**

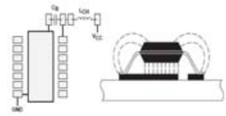


Traces routed near PCB edge can have 20 dB higher EMI



Utilize Point-to-Point Component Connections

Application Notes



TI Application Notes

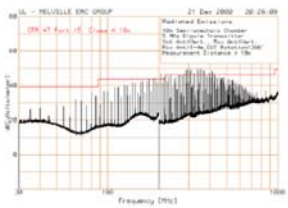
- **PCB Design Guidelines For Reduced EMI: TI SZZA009**
- **PCB Layout for Improved Electromagnetic Compatibility: TI SDYA011**
- **Understanding and Enhancing Sensitivity in Receivers for Wireless Applications: TI SWRA030**

Regulatory

- **SRD regulations for licensed-free transceiver operation in the 2.4 GHz band – Chipcon AN032**
- **Unlicensed Devices General Technical Requirements – FCC TCB Workshop 2005**

Compliance Pre-Scans

- **Over 80% of products fail initial certification tests**
- **Compliance failures can be show stoppers**
- **Don't wait until the design is completed to begin thinking about compliance**
- **Anticipate EMI during the design, PCB layout and packaging stages**
- **Product compliance costs increase exponentially with respect to the product development schedule – most fixes require PCB respin.**
- **Provide "test code" to facilitate testing (CW mode, PN9 packets)**



Prescan the product early in the development cycle

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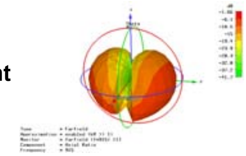
Antenna Selection or Design

Antenna design & location should not be an afterthought!



- **Say NO to metallic enclosures, foil labels and metal flake paint**
- **Bigger is Better!**
- **Just Like Real Estate: “location, location, location…”**
- **Options: ¼ wave whip, chip dielectrically loaded, PCB trace, external**
- **Internal antennas must be optimized for dielectric loading by the enclosure**
- **PCB trace antennas (PIFA) are free and can provide good performance**
- **Ceramic Chip Antennas – narrow BW, directivity & gain determined by PCB**
- **External antennas may require non-standard connector (FCC 15.203)**
- **Antenna Optimization: must have access to a Vector Network Analyzer**

GPS Antenna Hand Loading Effects

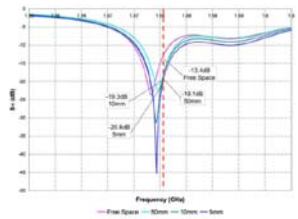
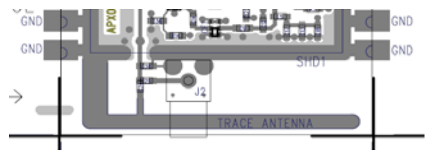


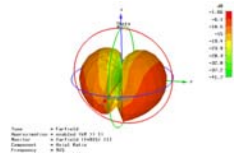
Figure 4: S_{11} plot of passive GeoHelix antenna in free space (blue), hand 10mm away from radiating section (red), and 5mm away (green)



2.4 GHz PIFA

1. FCC 15.203…MMCX, MCX, and reverse polarity SMA, reverse polarity BNC and reverse polarity TNC type antenna connectors are acceptable.
2. Microwave oven can be used to test for RF absorbtion of plastics at 2.4 GHz (if it gets hot, don’t use!)
3. Enclosure dielectric loading is significant if distance to antenna is 5 mm or less

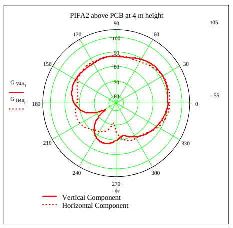
Antenna Radiation Patterns



Critical in assessing hand held and body worn devices

- **LSR uses 3D EM simulation tools from CST Microwave**
- **Antenna patterns measured using proprietary LSR test tool**
- **Antenna performance can not be predicted from data sheet**
- **Radiation pattern dictated by longest dimension of PCB**
- **FCC "free space" emissions do not indicate true antenna performance**
- **Antenna "average" gain or efficiency provides a more accurate prediction of range performance**
- **Portable Devices: "real world" performance should include human body loading (ε_r = 50) and RF absorption (Loss Tangent tan = 0.40)**

Dry Phantom Head used to mimic RF reflection, absorption and dissipation of human body



2441 MHz			
Device Orientation	polarization	Gain [dBi]	
		Max	Avg
(V)	vertical	0.28	-2.79
(V)	horizontal	-3.28	-8.90
(H)	vertical	-7.70	-12.47
(H)	horizontal	2.15	-2.38
(F)	vertical	-0.02	-3.88
(F)	horizontal	-4.45	-9.93
Total Avg. Gain [dBi]		-2.22	

Peak vs. Average Gain
Over 4 dB difference

Q & A

Thank You

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