L.S. RESEARCH
Wireless Product Development

Compliance By Design

Presented By Bob Buczkiewicz

Texas Instruments

Bio:

•1st engineer hired by founder, employee #2, 25+ years with LSR

• Previous position Senior Staff Engineer, primarily a RF & hardware engineer with extensive experience in discrete radio designs with emphasis on wireless audio systems.

•As the New Product Development Manager, currently responsible for internal product development which includes LSR intellectual property and licensed reference designs, modules and new technology.

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

TEXAS INSTRUMENTS

• This presentation is not about trying to sell LSR design & compliance services

•More about how to Design for Compliance

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

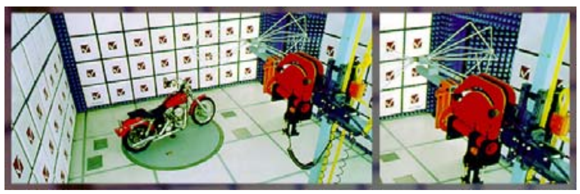
Jen

•Compact cassette adapter

•Also have sales offices on east and west coast

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

•LSR is the only US wireless consulting firm with “on-site” compliance test facility

•3-meter semi-anechoic

•10 meter OATS

•Compact chamber

•LSR is leader in total number of FCC Part 15 Intentional Transmitter filings

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.

USCEL

TEXAS INSTRUMENTS

•How many people have worked on RF or wireless designs?

•How many have experienced compliance testing?

•How many have NEVER failed?

•FCC Part 15 is for “unlicensed” products only, Part 90: licensed band, Part 95: Personal radio Services (CB, FRS, GMRS, Radio Control)

•In most instances, European regulatory requirements are the most stringent so design to meet these requirements

•Canada follows the US and Australia is a hybrid of US and European requirements.

•Unintentional radiators include RF receivers (LO), crystals, high speed clocks.

•Harmonized Standards: http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/reflist/emc.html

Regulatory Approval/Overview

- **EMC Defined: Electromagnetic Compatibility**
- **EMC has two basic branches**
  - Emissions = Operate equipment measure electrical emissions.
  - Immunity = Operate equipment, stress equipment with electrical disturbances, confirm impairment/recovery performance.
- **Emissions**
  - Radiated = Measure Electric Field Emission at a distance (3m).
  - Conducted=Measure disturbance voltages on power mains.
- **Immunity**
  - 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. CRT

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•LSR has Notified Body status for EMC and RTTE directives

•For technical questions: use FCC Knowledge Base website of contact TCB

•FCC Only Requires Transmitters to be Tested

•CE may require receiver testing as well (channel blocking or desensitization)

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

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•Regulations are frequently changed or updated.

•Even within the harmonized bands/standards, many countries have special requirements (i.e. lower output power, less channels)

•See ERC 70-03 appendix

•Regulations can be difficult to interpret or lead to an never ending trail of supporting documents.

•Use LS Research “Testing and Certification Handbook for Radios and Wireless Applications” – available upon request to our customers

 •Includes FCC Form 731 Filing Process plus IC and CE requirements review

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:

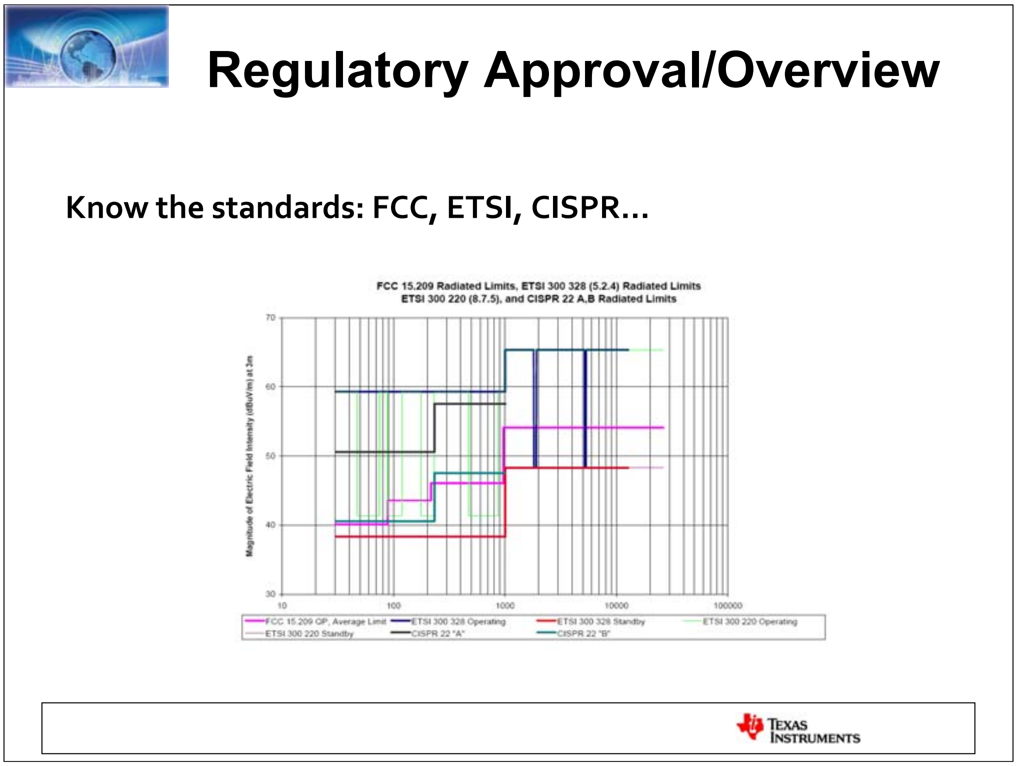
- **FCC: ~$8,000- 10,000**
- **IC: ~ $2,000 - 3,000**
- **CE: ~ $10,000- $13,000**

TEXAS INSTRUMENTS

•Plan early…many labs have a 4-6 week backlog

•Costs are per device so a multiple device system may have higher costs

•Other countries, including non-CE Europe will need to be tested on a per country basis (expensive!)



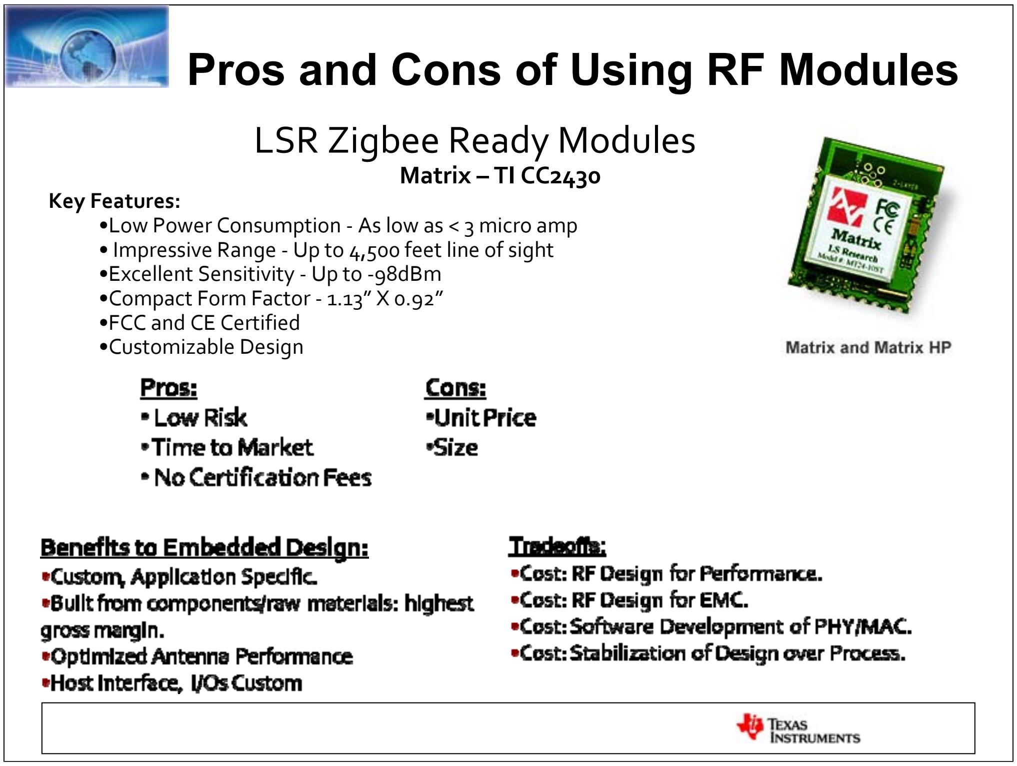
•Be aware of “restricted” bands FCC 15.205 which have tighter emission limits

•FCC Part 15 states: product must accept interference from other devices

- •Understand what other types of standard products share the band (Bluetooth, WiFi, Zigbee, proprietary, RFID, Microwave Ovens)
- •Coexistence a significant issue at 2.4 GHz. Reference IEEE 802.15.2-2003 (ZigBee & WiFi)

•In many bands, Part 15 devices are considered secondary users (to high power Part 90, military and government)…be aware!

- •Example: FCC 15.231 Garage Door Openers used 390 MHz until Homeland Security installed LMRS transmitters



•Modules attractive for standards based products such as Bluetooth, WiFi, ZigBee

•Custom, Proprietary or Application Specific RF Systems are difficult to implement as an OEM module

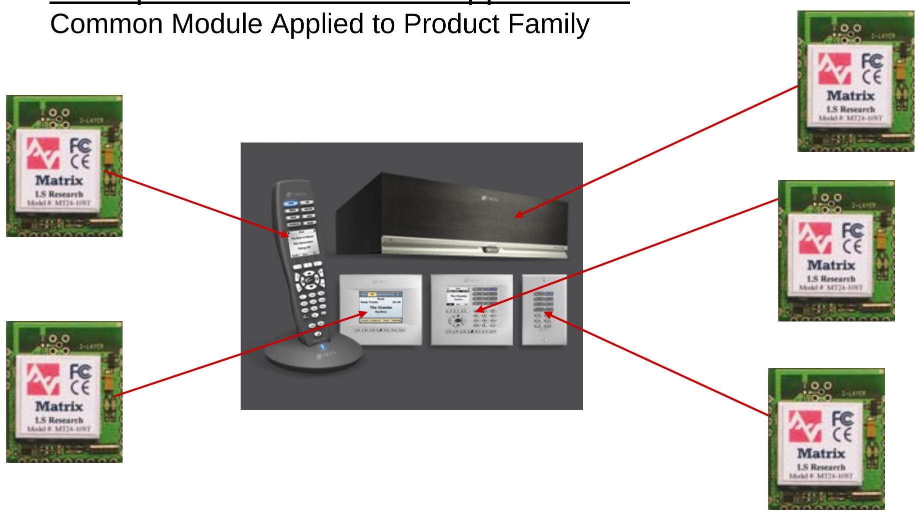
•Standards Based Products (Bluetooth, WiFi, ZigBee) may also require additional qualification to assure inter-operability (in order to use logo)

- •Testing can be more involved and costly than regulatory compliance

Pros and Cons of Using RF Modules

Example of Radio Module Application -

Common Module Applied to Product Family



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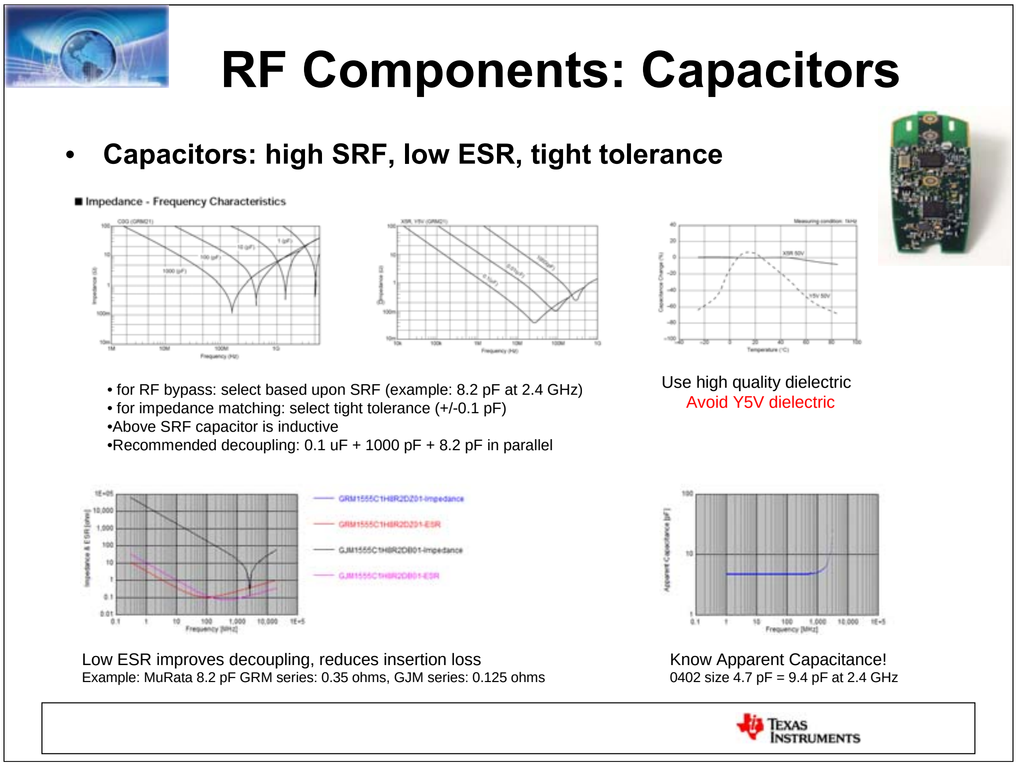
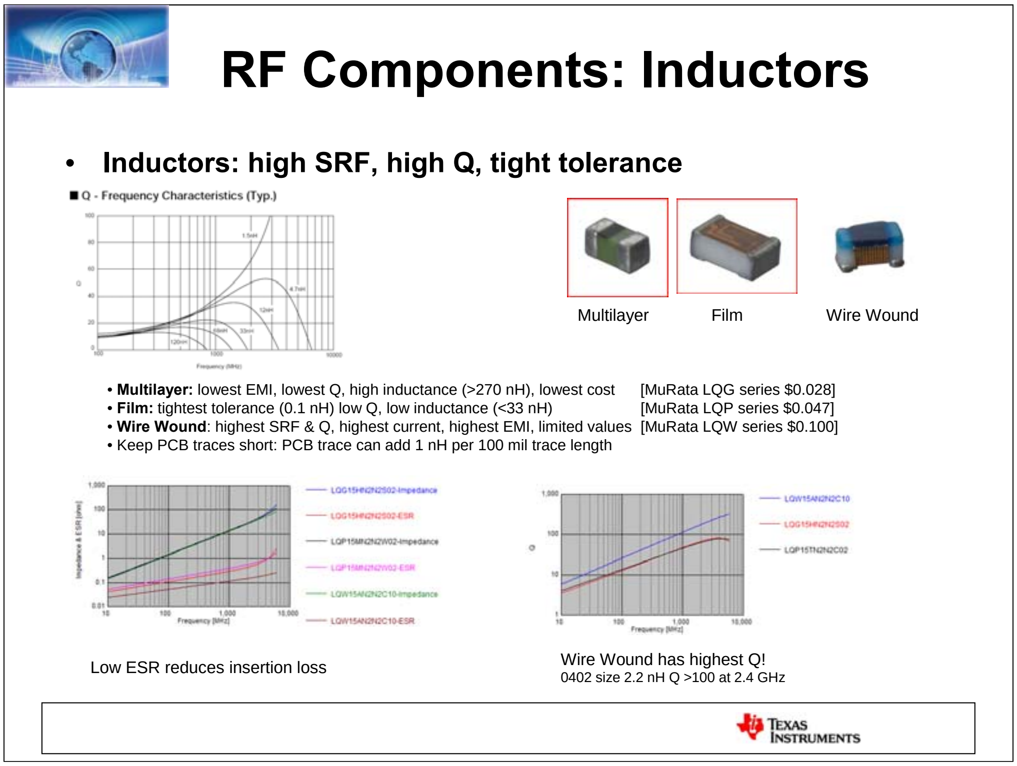
Modules must still address the antenna performance (i.e. plastic enclosure with metalize paint won’t work)



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



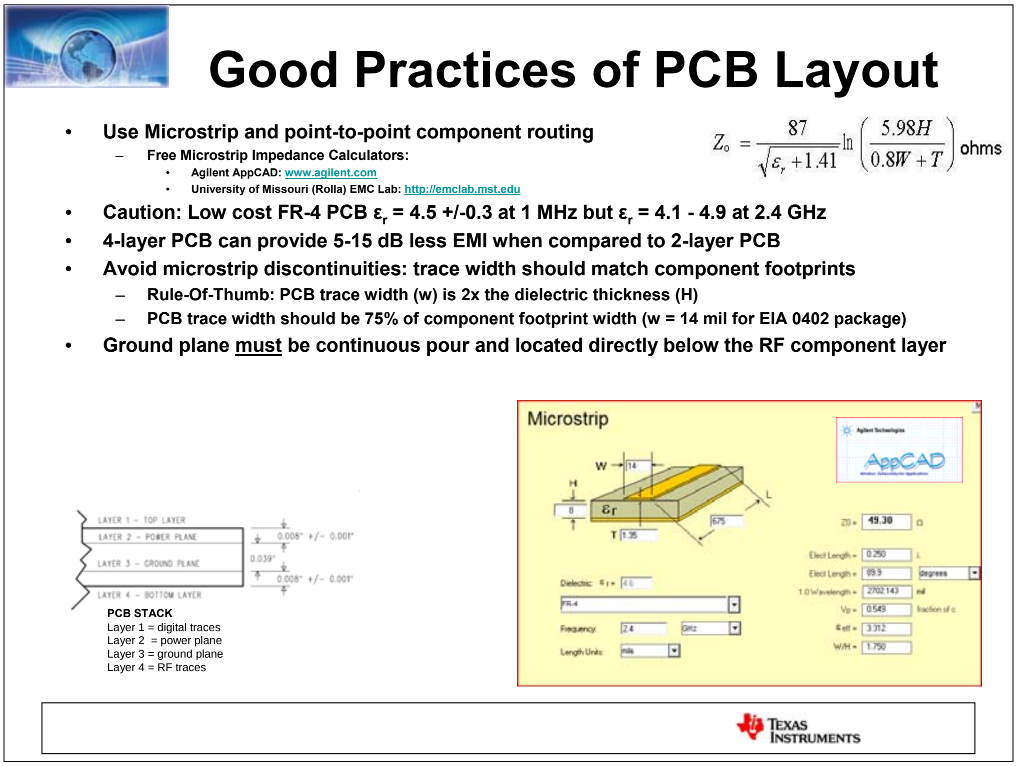
•High inductor SRF improves filter frequency response and lowers emissions

•Tight tolerance and fine component value resolution needed > 1GHz to assure consistent performance

•Component Q must be >10x circuit Q to keep IL <1dB

•Small package (i.e. 0402 size) may not provide performance due to lower Q and limited current capability

•Placement is critical to minimize inductive coupling..orthogonal placement will minimize coupling



•Most single chip transceivers are MCM or SOC so decoupling requirements are less critical

•Follow the device application note or reference design explicitly

•Reference Design: cut & paste is not perfect due to parasitic effects, PCB stack differences etc.

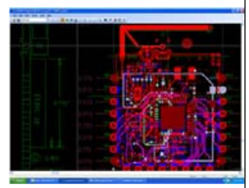
•Top side ground fill can minimize crosstalk but if poorly implemented can cause additional problems

•Rely heavily on good ground stitching vias

•Compartmentalize RF circuit and isolate from digital circuits

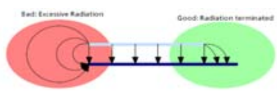
•Allow for key RF TP's via population options and uFL connectors…can be removed or NP in production

Compliance By Design

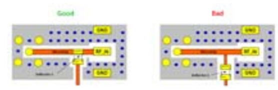


The PCB layout has the biggest impact on compliance (EMI).

- **Plan for a RF shield over the radio portion of the circuit board.**
- **Add RF de-coupling capacitors to every 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

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•PCB layout and routing is critical

•Long traces can act as antennas at higher harmonics

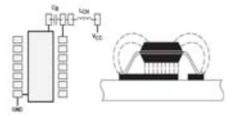
•Decouple all traces to and from radio

•Digital signal lines can inject noise into the RF circuit;;;decouple

•Digital circuits and raise the RF noise floor and desensitize the receiver…FCC does not care about receiver performance

•Locate antenna away from the digital circuits and in an optimal product location (i.e. minimize hand holding or body effects)

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**
- **Testing and Certification Handbook for Radios and other Wireless Applications – LS Research 2006**

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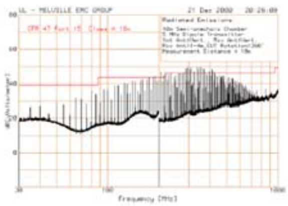
Other good resources are single chip transceiver vendor web sites such as TI, Chipcon, Freescale, Nordic, Analog Devices as well as IEEE Standards

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

TEXAS INSTRUMENTS

•Many single chip transceiver test tools can be used to setup and program a radio prior to digital and firmware being completed

•CW mode tests

•Be cautious of connecting cables such as power supply and programming interfaces…they can increase radiation

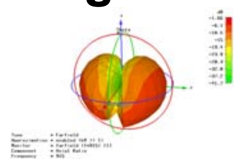
•Test on lowest, middle and highest frequencies

•Be aware of special band edge requirements

•Firmware and/or hardware should allow different circuit blocks to be disabled to help with EMC troubleshooting

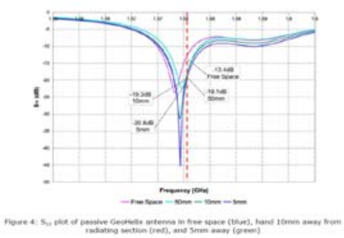
Antenna Selection or Design

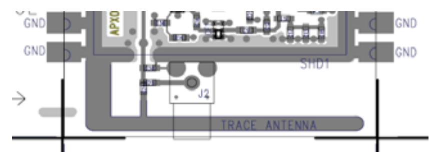
Antenna design & location should not be an afterthought!



- **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





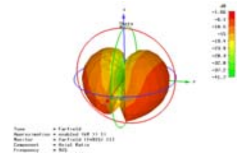
2.4 GHz PIFA

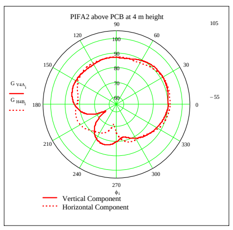
1. Antenna selection & optimization can impact regulatory emissions as well as product range performance
2. A well designed antenna can lower compliance risks (i.e. higher harmonics due to "other" resonances)
3. FCC 15.203…MMCX, MCX, and reverse polarity SMA, reverse polarity BNC and reverse polarity TNC type antenna connectors are acceptable.
4. Microwave oven can be used to test for RF absorption of plastics at 2.4 GHz (if it gets hot, don't use!)
5. Enclosure dielectric loading is significant if distance to antenna is 5 mm or less
6. Very few antennas are Omni-directional. Optimize antenna placement and orientation for maximum range
7. Keep antenna away form large conductive components such as batteries.
8. Magnetic H-field or loop antennas are useful for hand held devices such as remote controls and the human body is transparent to the magnetic field and does not detune he antenna (although it will still absorb it.

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

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•Antenna selection and matching can have significant influence on output power and harmonics

•Antennas are reciprocal, a good TX antenna is a good RX antenna

•Antenna diversity can improve range and minimize fading …not all single chip transceivers support diversity control

Q & A

•Range Extender: add PA, LNA for 15.247 devices…such as new Chipcon part

•Single chip transceivers can be overloaded with the addition of an external LNA, review compression point and AGC characteristics

•External high power PA can introduce additional compliance risks (power spectral density, ramp PA turn on, power supply decoupling, radiated feedback into VCO)

Thank You

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