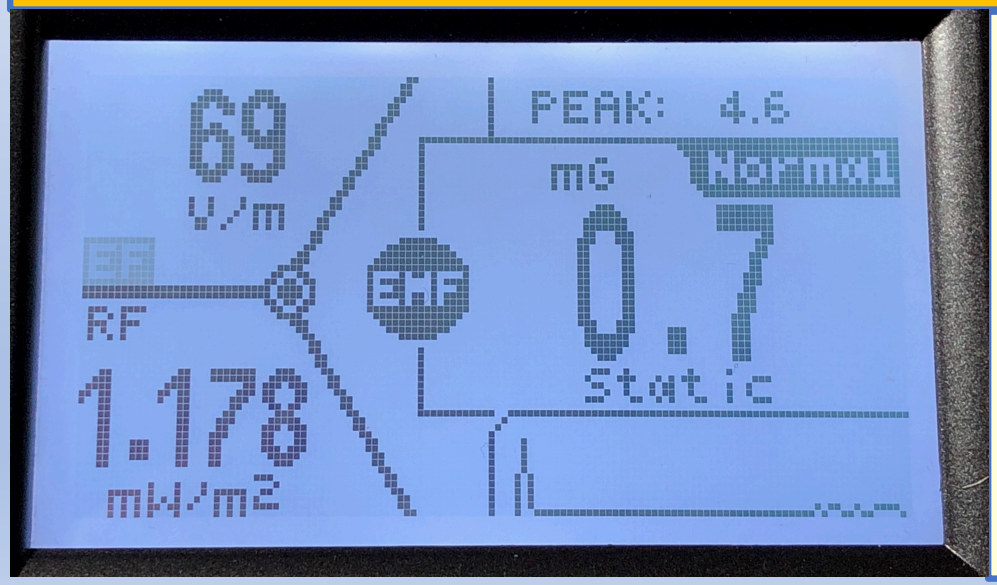
Understanding, identifying sources, and resolving EMI (RFI) problems



Hamfesters Radio Club
February 7, 2020 Presentation

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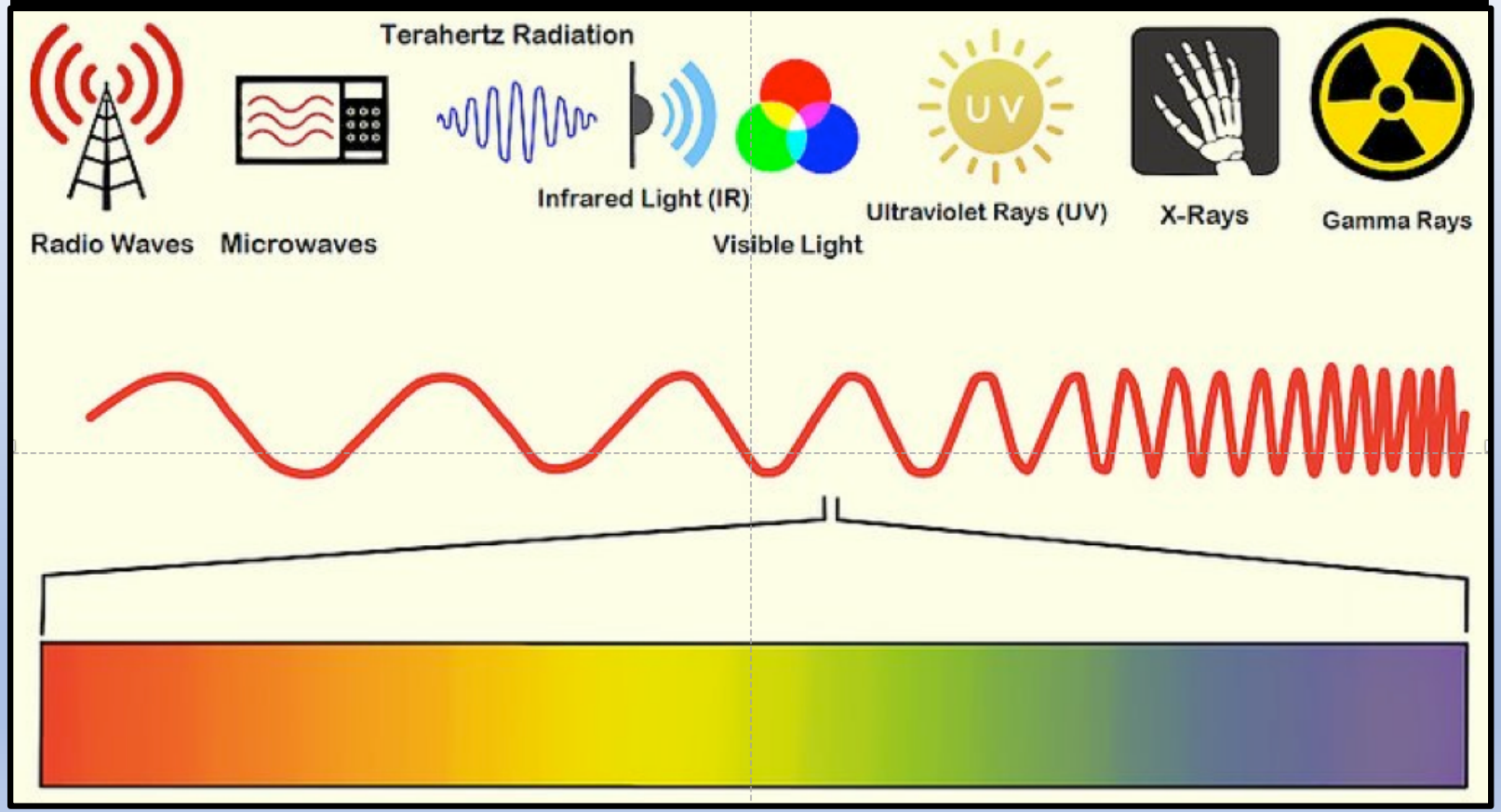
What we will cover

- What is **Electromagnetic** (EMI) and **Radio Frequency Interference** (RFI)?
- What is **Electromagnetic Compatibility** (EMC)?
- What agencies and laws exist to regulate, provide oversight of, enforce **E**lectro**m**agnetic **C**ompatibility (EMC) compliance?
- Who is responsible for resolving EMI (RFI) issues?
- What methods, technologies, and resources are available to assist you in identifying and resolving EMI (RFI) problems.
- What can you do to mitigate EMI (RFI).
- What strategies can you use to work with neighbors, utility companies, and manufacturers to remedy EMI problems.
- Suggested resources to help you learn more about EMI (RFI).

The Electromagnetic Spectrum



EMI (RFI) are a growing World problem

- **Today's environment is filled with EMI.**
- Radio transmitters, cell phones, microwave ovens, Bluetooth, WIFI, Zigbee, Z-Wave, … permeate the air around us with intentional electromagnetic waves and unintentioncal EMI noise.
- **Solar activity and other natural sources of EMI can create significant electromagnetic interference.**
- As devices become smaller, they are increasingly more vulnerable to EMI.

Note: *Especially when the distance between circuits are less than one wavelength (1λ).*

- This creates a challenging environment for electrical engineers, end-users, and manufacturers.

NOTE: *The lowercase version of the Greek letter "lambda" (λ) is the standard symbol used to represent wavelength in physics and mathematics.*

What is Electromagnetic Interference (EMI)?

- EMI is a disturbance generated by an external source that affects an electrical circuit by **electromagnetic induction**, **electrostatic coupling**, or **conduction**.
- *Although the terms **EMI and RFI are often used interchangeably**:*
  - ***EMI** is actually a disturbance at any frequency.*
  - ***RFI** refers to EMI that occurs in the radio frequency spectrum.*
- **Man-made** and **natural** sources generate **changing electrical currents and voltages** that can ***cause an EMI disturbances***.
- ***EMI may degrade the performance of the electrical circuit or even stop it from functioning***.
- In the case of a data path, these effects can range from an ***increase in error rate to a total loss of the data***.
- **EMI can be used intentionally for radio jamming, as in electronic warfare.**

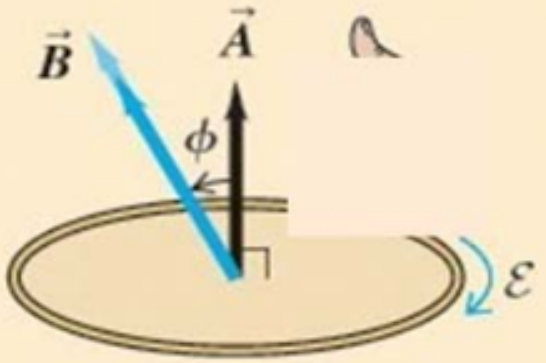
What is Radio Frequency Interference (RFI)

- RFI is a disturbance that affects an electrical circuit due to either:
  - RFI is a subset of EMI and it only applies to the radio frequency spectrum.
  - *Electromagnetic conduction* or *electromagnetic radiation* emitted from an external source.
  - ***Such disturbance may interrupt, obstruct, degrade or limit the effective performance of the circuit.***
  - *The source may be any object, artificial or natural, that carries rapidly changing electrical currents or voltages, from an electrical circuit or the Sun.*

Faraday's Law of Induction

Electromagnetic induction is the process by which a current can be induced to flow due to a changing magnetic field.

$$\mathcal{E} = -\frac{d\Phi_B}{dt} \qquad (29.3)$$



where: ε is the electromotive force (EMF) and Φ_B is the magnetic flux.

Articles about Faraday's Laws of Induction and Lenz's law can be found at: Kahn Academy and Wikipedia.

Lenz's Law (1 of 2)

- **Lenz's law** is a consequence of conservation of energy applied to electromagnetic induction. It was formulated by Heinrich Lenz in 1833. While Faraday's law tells us the magnitude of the EMF produced, **Lenz's law tells us the direction that current will flow**. It states that the direction is always such that it will **oppose the change in flux which produced it**. This means that any magnetic field produced by an induced current will be in the **opposite direction to the change in the original field**.
- Lenz's law is typically incorporated into Faraday's law with a ***minus sign***, the inclusion of which allows the same coordinate system to be used for both the flux and EMF. The result is sometimes called the ***Faraday-Lenz law***,

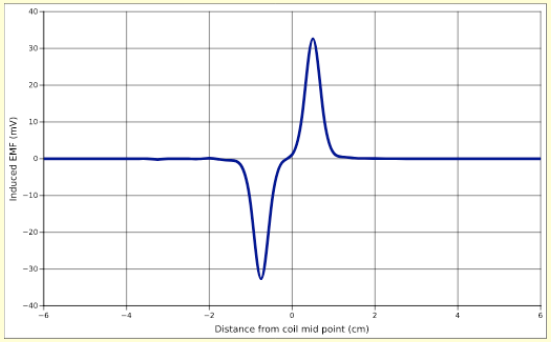
$$\mathcal{E} = -\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

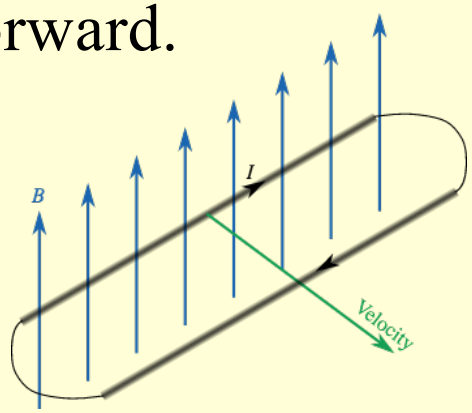
- In practice we often deal with magnetic induction in multiple coils of wire each of which contribute the same EMF. For this reason an additional term NNN representing the number of turns is often included, *i.e.*

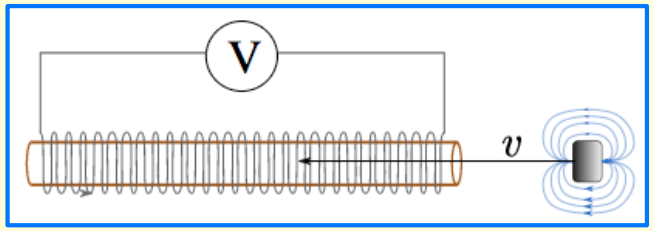
$$\mathcal{E} = -N\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

Lenz's Law (2 of 2)

- **What is the connection between Faraday's law of induction and the magnetic force?**
- While the full theoretical underpinning of Faraday's law is quite complex, a conceptual understanding of the direct connection to the magnetic force on a charged particle is relatively straightforward.







Sources of EMI disturbances

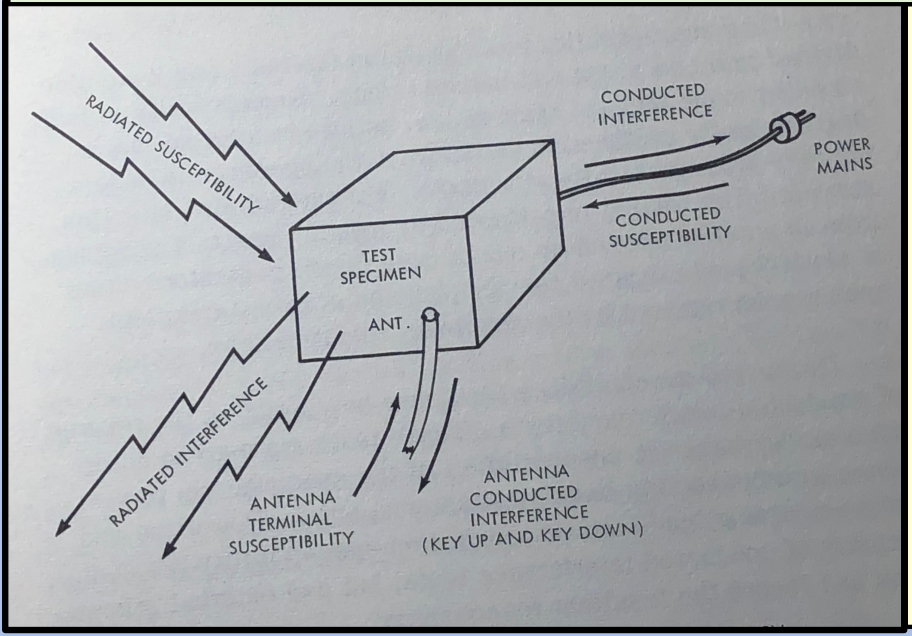
1. **Radiated EMI is caused by induction.**
   At higher frequencies EMI is caused by radiation.
2. **Conducted EMI is caused by the physical contact of conductors.**
   At lower frequencies, EMI is caused by conduction.
3. **Electrostatic EMI is caused by electrostatic coupling or discharge.**
4. **EMI through the ground wire is also very common.**
   Therefore, having a ground is an important step to mitigate many types of EMI.

Everything is an antenna

- The most fundamental cause of radio frequency interference to other systems is the fact that **the wiring for those systems, both inside and outside the box, are effectively antennas.**
- We may call them (patch, speaker, video, or Ethernet) cables, or printed circuit traces, **but Mother Nature knows that they are antennas!** ***And Mother Nature always wins the argument.***
- When we transmit, some of the RF from our transmitter is picked up by those ***unintentional antennas***, and ***RF current flows on them***.
- **What happens to that current determines whether there will be interference, and how severe it will be.**
- We know that antennas work in both directions – that is, they follow the principle of ***reciprocity*** – so when RF from inside the box flows on those antennas, it is radiated as noise and we hear it on the ham bands.

Types of EMI / RFI

There are many types of EMI and RFI and many ways it can take advantage of susceptibility



Radiated energy

- **Radiated susceptibility**
- **Radiated interference**

Antenna System

- **Antenna terminal susceptibility**
- **Antenna conducted interference**

AC Power Line

- **AC conducted susceptibility**
- **AC conducted Interference**

Differential Mode Signals and Noise

- *A differential mode signal is one that exists between the conductors of a cable.*
- *The **differential mode current interference** is related to the potential difference between signal lines (control, feeding, data, VCC) and between signal and ground lines.*
- At any given point along the cable, ***current flowing on one conductor is precisely balanced by current flowing in the other direction on the other conductor.***
- The ***intentional signals*** carried by cables are ***differential mode***.

Common Mode Signals and Noise (1 of 2)

- A ***common mode signal is one that places equal voltage on all conductors*** – that is, the ***voltage between the two ends of the cable are different***, but there is ***no voltage between the conductors***.
- The antenna produces a ***common mode voltage*** and ***current along a cable***.
- The antenna current induced on audio and video wiring is a ***common mode signal***. That is, with "ideal" cable, there is ***no differential voltage between the signal conductors*** as a result of this ***antenna action***.
- If the **cable is shielded**, ***nearly all of this current flows on the shield*** (***and skin effect causes it to flow on the outside of the shield***).

Common Mode Signals and Noise (2 of 2)

- If the ***shield is ideal*** (that is, if ***the current is distributed with perfect uniformity around it***), the ***field inside the shield will be zero***, and thus ***none of this antenna current will flow inside the cable***.
- When a cable shield is carrying differential mode current, as in the case with coax, **skin effect** will cause that ***differential mode current*** to flow on the ***inside of the shield***.
- The real world is not ideal, so most interfering signals will simultaneously exist in both common mode and differential mode, ***but in most real-world conditions, one or the other mode dominates.***

What is Electromagnetic Compatibility (EMC)

- Electromagnetic Compatibility (EMC) means nothing more than 'an electronic or electrical product shall work as intended in its environment and defined scope of use.
- *"The electronic or electrical product shall not generate electromagnetic disturbances, which may influence another product'. In other words, EMC deals with problems of noise emission as well as noise immunity of electronic and electrical products and systems."*
- *Electromagnetic disturbances occur as **conducted interference**, as well as **radiated emissions** and **immunity problems**.*

Who regulates, provides oversight of, enforces EMC?

- The Federal Communications Commission (FCC).
- The International Telecommunications Union (ITU) Region 2.
- The IEEE
- The American National Standards Institute (ANSI)
- UL / CSA
- Utility regulators

What regulations exist to protect consumers

The FCC CFR 47 Part 15 covers the FCC's rules and regulations for EMC and have been designed to align with the European CISPR regulations. There are some differences but in general the two sets of standards align on the major features.

Interference with Radio, TV and Telephone Signals

When designing an electronic circuit card it is necessary to take a number of precautions to ensure that its EMC performance requirements can be met. Trying to fix the EMC performance once the circuit has been designed and built will be far more difficult and costly.

✓Circuit design to minimum radiation	✓Grounding
✓EMC filters	✓Screened enclosure
✓Circuit partitioning	✓Screened lines and cables

Who is responsible for resolving EMI (RFI) issues?

- The manufacturers have primary responsibility for EMC compliance.
- The electronic product owner has secondary responsibility.
- The installer of electronic products
- The electric and other utilities
- The FCC Field Engineering office in Chicago, IL or Washington DC.

Real world EMI / RFI Problems and Solutions

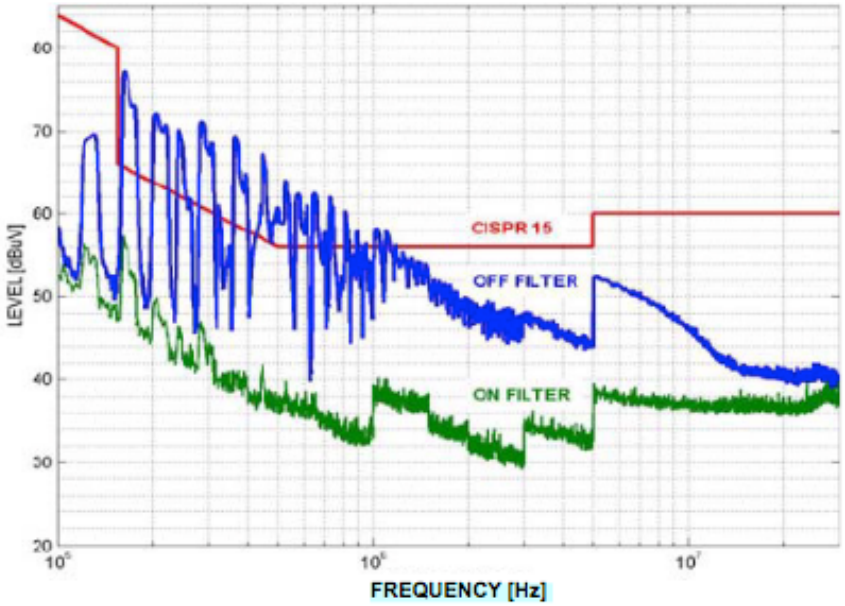
- The following slides show examples of many common EMI / RFI problems and how they were resolved.
  - **In your house, apartment, or condo**
  - **In your garage**
  - **Outside or overhead (power lines, street lights, or signs)**
  - **in the atmosphere, outer space, or the Sun**
  - **In your neighbors house or adjacent building**
- *Before looking at your shack your should resolve any EMI / RFI issues inside and outside your home.*
  - **In your shack**

Safe / Dangerous EMF, EF, and RF Radiation Exposure Levels

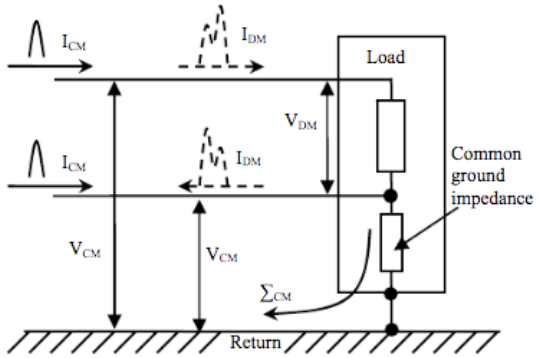
EMF	EF	RF	Recommendations
<2.5mG	<3V/m	<1μW/cm^2	**NORMAL**
>2.5mG	>3V/m	>1μW/cm^2	Check Regularly
>30mG	>50V/m	>1mW/cm^2	Not recommended for long term exposure
>100mG	>500V/m	>100mW/cm^2	Long term exposure is very dangerous
RF Density Unit:	1μW/cm^2 = 10mW/m^2		
	1mW/cm^2 = 10,000mW/m^2		
	100mW/cm^2 = 1,000,000mW/m^2		
Always take a confirmation measurement before taking any action.			
www.gqelectronicsllc.com			

The case of the badly designed CFL

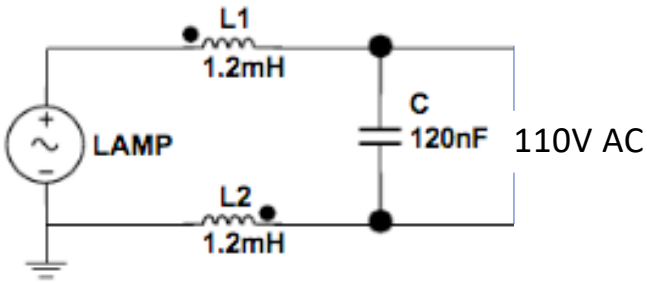
Conducted EMI emission spectrum of M3 CFL lamp (14W)



CFL Bulb with (on filter) and without filter (off filter).

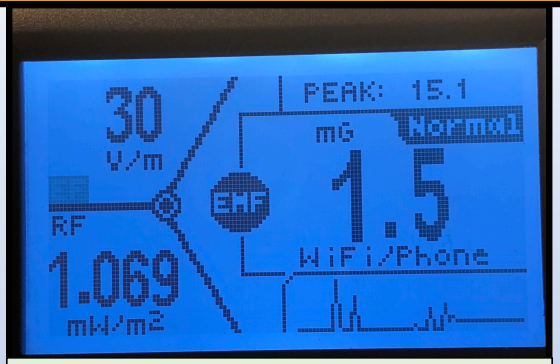


Common Mode (CM) vs Differential Mode (DM)



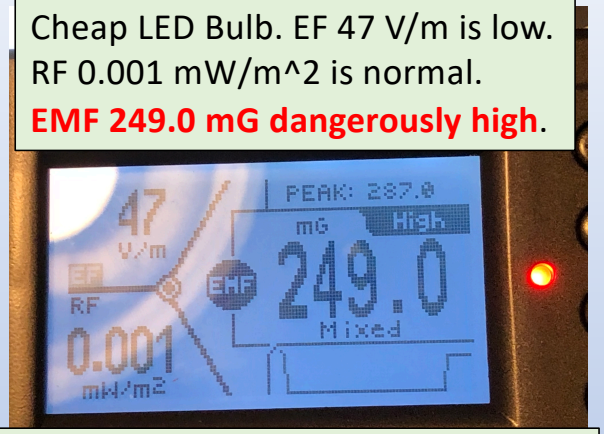
Inline filter with CFL Lamp

Quality Incandescent Bulb.
RF of 1.557 mW/cm^2 is quite high. EF of 49 V/m is moderately high. Background
noise is troughing this off a bit.

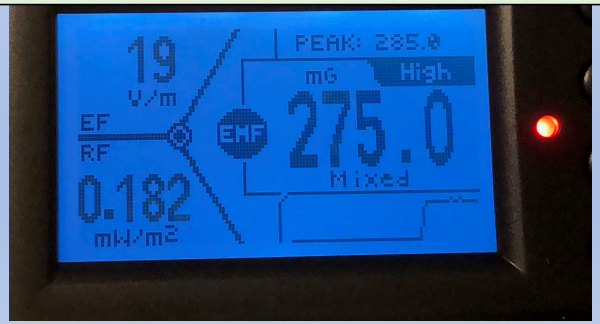


Quality LED Bulb shows normal. EF 30 V/m is low. RF 1.069 mW/M^2 is moderately high. Background noise is troughing this off a bit.

Cheap LED Bulb. EF 47 V/m is low.
RF 0.001 mW/m^2 is normal.
EMF 249.0 mG dangerously high.



Cheap CFL Bulb EF of 19 V/m is low.
RF of 0.182 mW/m^2 is low.
EMF of 275.0 mG is dangerously high.



This is not a scientifically isolated test environment; however, the cheap bulbs clearly are showing a red light and an alarm, so their numbers are more believable.

Demonstration

Compare the noise between a CFL, LED, and incandescent bulb using a GQ Electronics LLC GQ EMF-390

The case of the ugly wall-wart (1 of 6)

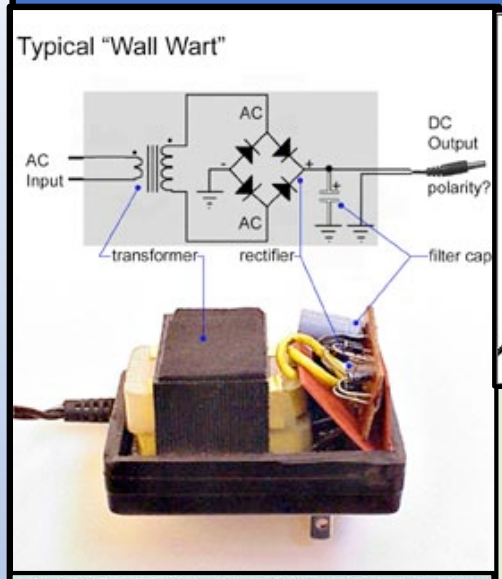
- **Problem:** Wall-warts & external power supplies fail over time and **CAN** cause EMI / RFI problems that can be difficult to identify as there often is no visible sign of damage.
- **Troubleshooting:** In most cases the only way you will find them is by **trial-and-error**:
  - Unplugging them one-at-a-time until you find the offending source.
  - A better way is to unplug all of devices in your home and plug them in one at a time until the problem reoccurs.

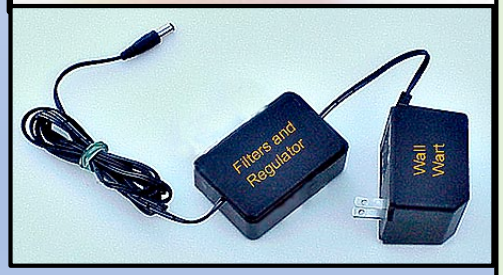
The case of the ugly wall-wart (2 of 6)

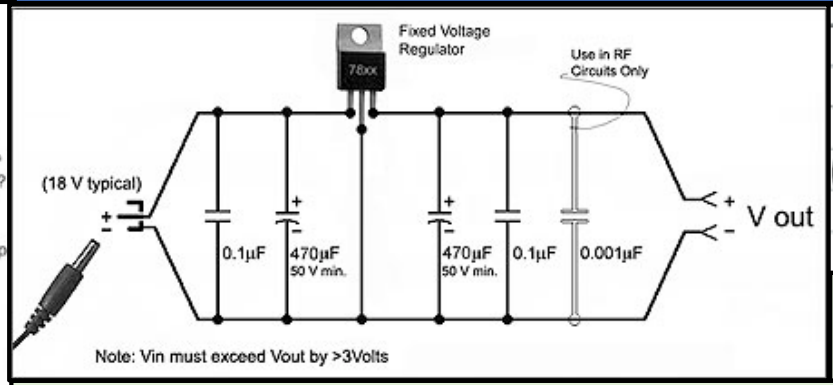
Solutions:

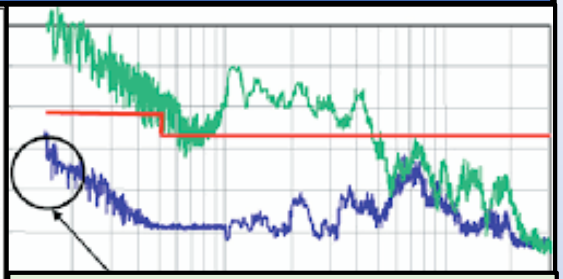
1. Replace the offending wall-wart or power supply.
2. Use an external EMI filter.
3. Installing a toroid core on the DC power cable side of the Wall Wart can help suppress the RFI interference to nearby electronic devices ***by suppressing the fundamental switching frequency (usually <1 MHz) and thereby suppressing harmonics at higher frequencies.***

The case of the ugly wall-wart (3 of 6)







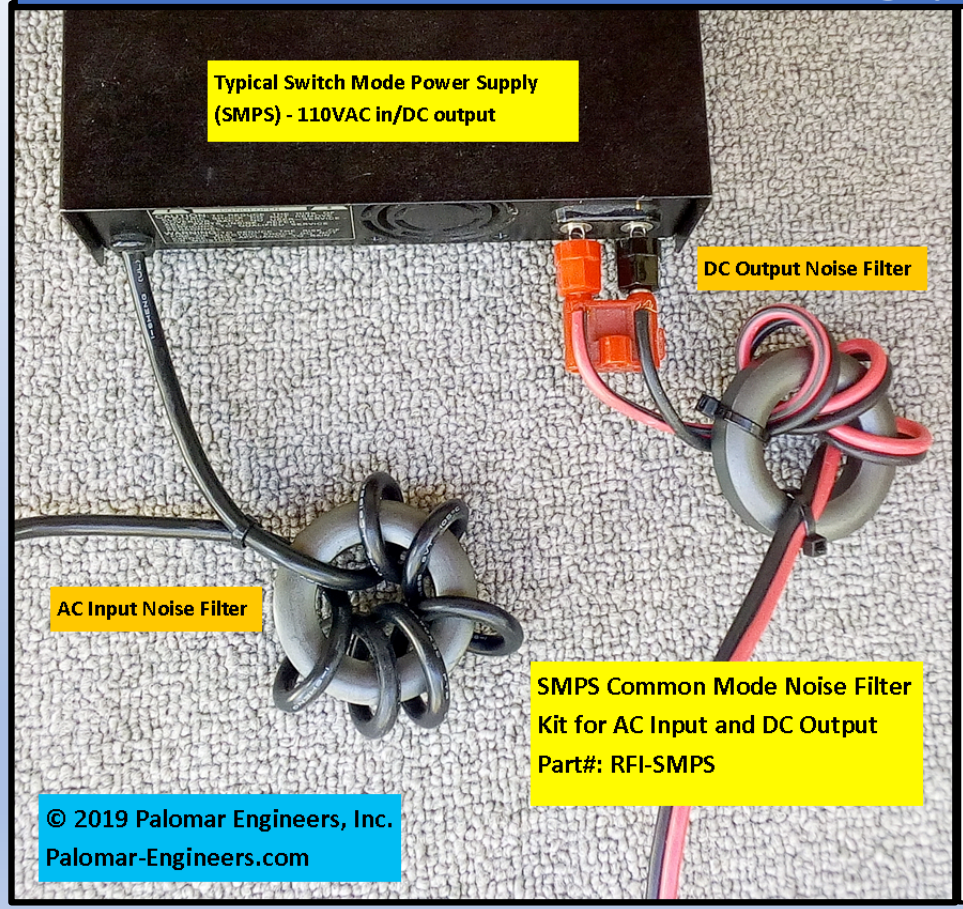


With a Power Line EMI filter (bottom) & Without Filter (top).

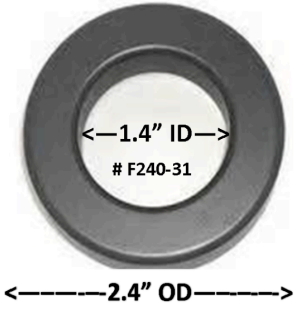
A Dummies Guide to Working with Wal-Warts.
http://www.dxing.info/equipment/wall_warts_bryant.dx

For mains transformer-based DC supply ripple frequency is 100/120 Hz after rectification. Switching supplies usually operate in 50KHz and up frequencies, with harmonics going into Megahertz range. This noise is able not only propagate through cables, leak through linear regulator unfiltered, but also radiate all around as radio waves.
https://en.wikipedia.org/wiki/Power_supply_rejection_ratio

The case of the ugly wall-wart (4 of 6)



The RFI-SMPS is a common mode noise filter set which filters both the AC input and DC output of common Switched Mode Power Supply. These filters effectively isolate the AC power cord and DC output cable from acting as antennas for the internal switching power supply. **The filters suppress RFI from 150 KHz to 10 MHz. Simple to install on cables without any device modification.**

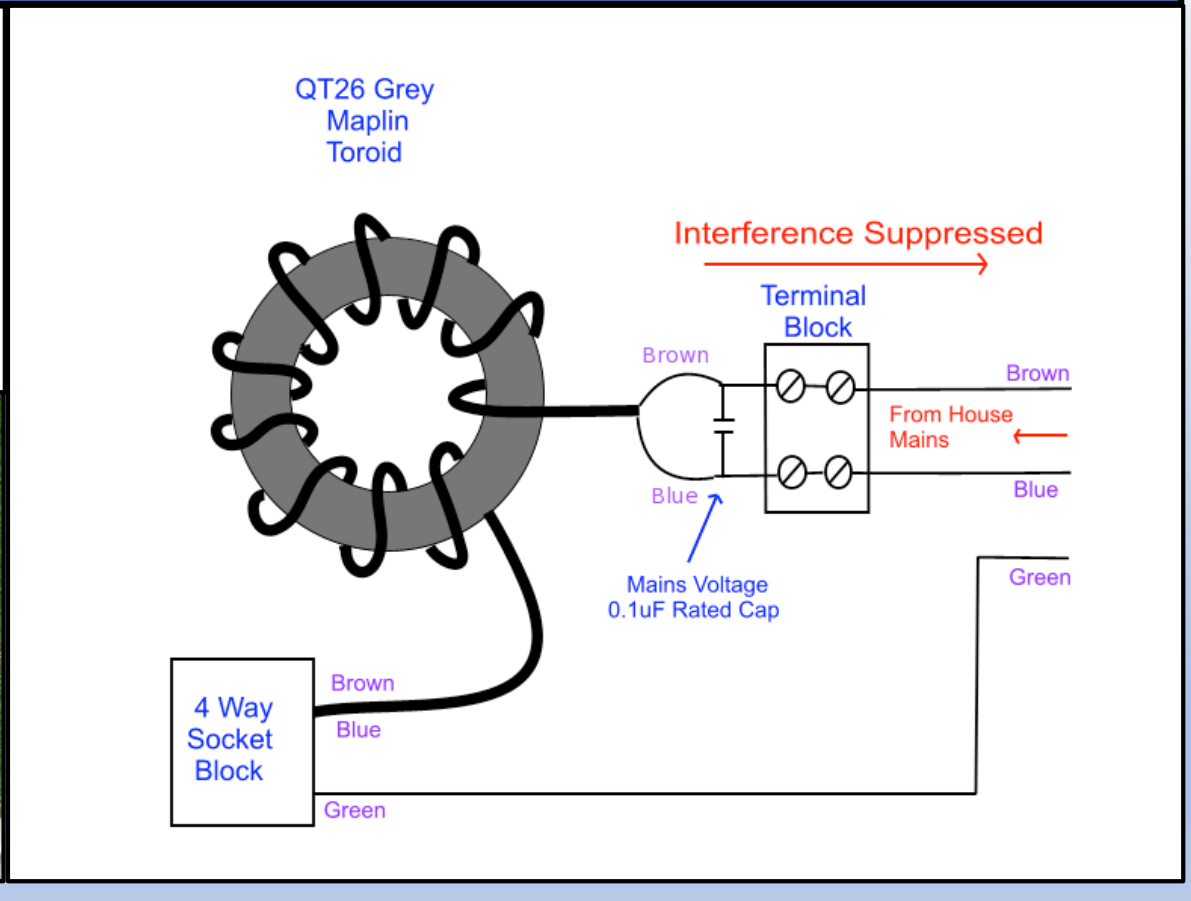


FT240-31

MPN: RFI-SMPS
Country of Manufacture: United States
Filter Power Rating (PEP watts): n/a
RFI Suppression Range: 50 KHz - 10 MHz
Typical Use: SMPS common mode noise suppression.

The case of the ugly wall-wart (5 of 6)

Using an ordinary 1900 electrical box you can make your own outlet strip. In addition to the four outlets you add QT26 Grey Maplin Toroid with nine turns of 12-gauge insulated wire. One side goes to the ground of the 1900 box and the other side has a 0.1 μF capacitor rated for at least 150V AC.



The case of the ugly wall-wart (6 of 6)

- **Known RFI Generators include:**
  - Amazon Fire, Roku, and Sling-TV power adapter.
  - Many Cable or DSL modem's / router's external power supplies.
  - Mobile device chargers and wireless chargers.
  - Laptop / tablet computer power adapters have the same issue: using the AC or DC side of the power supply cable as a radiating antenna.
- ***Radio Frequency Interference is heard on the AM broadcast band from 540Khz to1600KHz.***
- ***In general RFI interference occurs from 500Khz to 10MHz.***

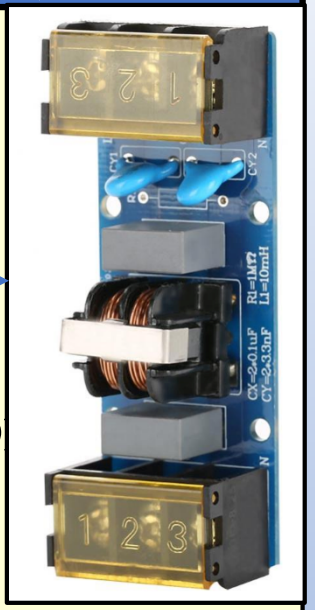
The case of the moving elevator (1 or 3)

- In 1986 I worked this case at Standard Oil's communication center. They were using IBM ATs at the time to log their radio communications with their domestic and international oil fleets.
- **Problem:** A spectrum analyzer showed that RFI was interfering with their radio communications and EMI was causing their computers to crash.
- **Observation:** This was observed every time an elevator passed the floor.
- **Solution:** The problem was solved by moving their communication console across the room to the parallel wall.

The case of the moving elevator (2 or 3)

Today we have many new options to fix EMI and RFI interference from the elevator's:

- ✓Add shielding and **EMI filters** to the power supplies.
- ✓Add shielding and ferrite beads to their Moto
- ✓Static electricity *(built up as it slides up and down its safety channels or cables) can be mitigated using contact brushes that are grounded.*



The case of the moving elevator (3 or 3)

- ✓**Incoming power wiring** (to the controller) **and outgoing power wiring** (to the motor) **must be routed in separate grounded conduits.**
- ✓Encoder wiring should be placed in a separate grounded conduit for flux vector applications.

The case of the talking keyboard (1 of 2)

In 1984 we installed IBM AT's at a law firm downtown. At the time they used capacitive keyboards. There was a wall mounted PBX on the floor just below the secretarial pool.

- **Problem:** Every time the phone rang the PBX generated EMI that the keyboard picked up and in response generated random characters all over their documents.
- **Solution:** I called the FCC field engineer (You could actually do that back then.) and they suggested using conductive paint with copper or nickel particles to add an EMI shield to the PBX and add ferrite beads on the cables that emerged from the PBX.

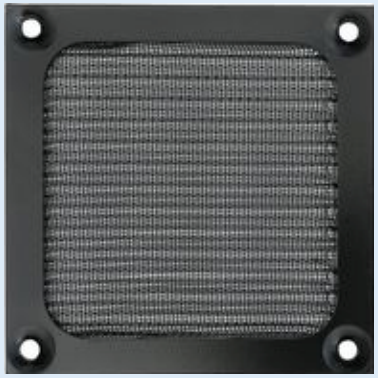
The case of the talking keyboard (2 of 2)

There are many brands of conductive paint on the market offering mixes of graphite, copper, nickel, aluminum, and steel.

You can also use metal tape or metalic gauze to add shielding

The case of the printer that printed too much

- **Problem:** At another law firm they had a standalone Wang word processing system that had a shared printer for every two secretaries. They told us the printer kept printing extra garbage characters when they printed their documents.
- **Observation:** Although the vendor had metal enclosures on their word processing stations, they had many unshielded fan openings.
- **Solution:** Installed copper cause shields over each fan openings.



The case of the well dressed woman (1 of 3)

- **Problem:** ***Electro-Static Discharge (ESD)*** in the Winter months from walking across tile or carpeted floors or from clothing. ESD can cause electronics to misbehave or be damaged.
- **Solutions:**

1. Make sure all equipment has a good ground.
2. Using Tenex or similar grounded chair mats.
3. Providing a grounded copper strip on the desk.
4. Using grounded carpeting or tile.
5. Controlling humidity is also very critical.

The case of repeated false alarms (2 of 3)

- **Problem:** My inverted-L antenna for 160 meters. It was grounded to a 000-copper wire that ran around my house with 12 guage lobe wires running out to the properties edge. **Sadly every time I keyed-up it set off my alarm system.**
- **Solution:** Make sure that all of the RF stays out of the shack by giving it a path outside using a 1” or wider copper strap tied to your station’s common ground bus, brought outside your house in PVC, and tied to your houses common ground.

The case of repeated false alarms (3 of 3)

When designing and implementing your grounding system, make sure to avoid ground loops and keep your grounds as short as possible and never make any sharp 90 degree bends.

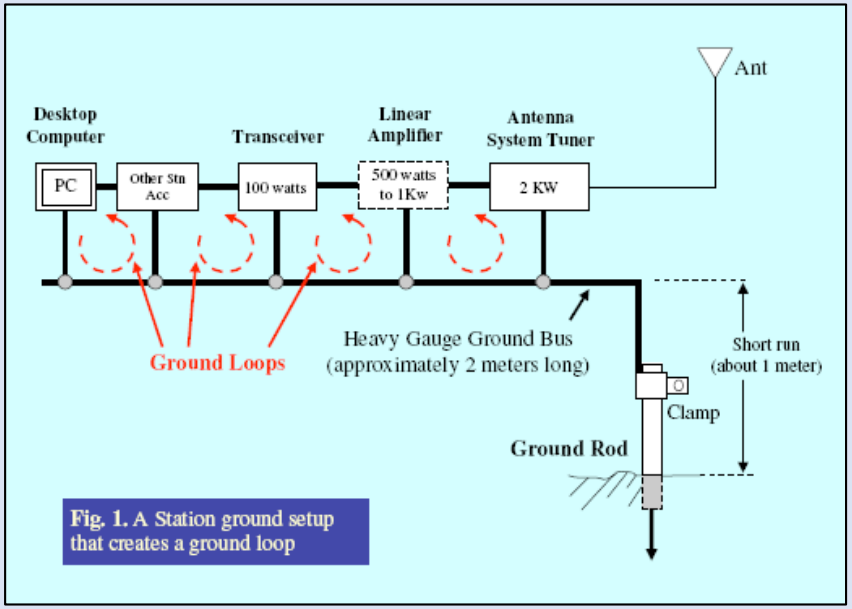


Fig. 1. A Station ground setup that creates a ground loop

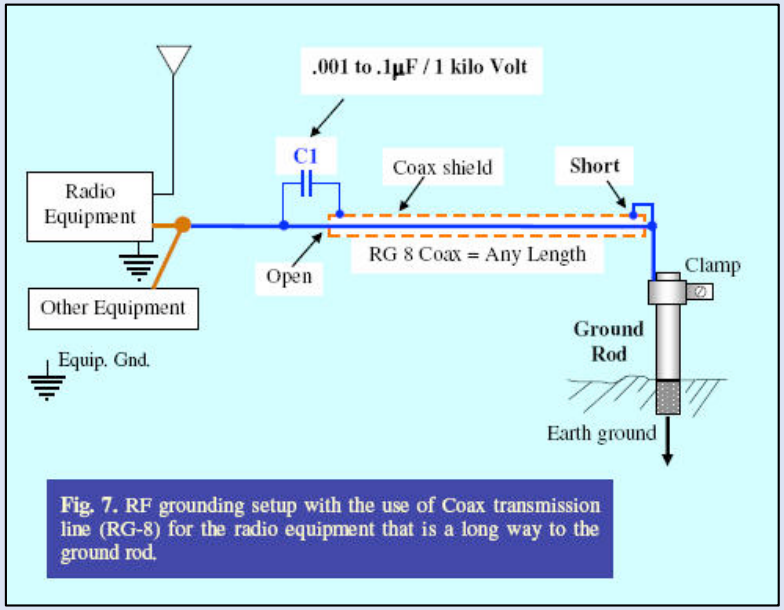


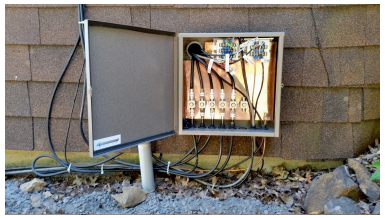
Fig. 7. RF grounding setup with the use of Coax transmission line (RG-8) for the radio equipment that is a long way to the ground rod.

The case the noisy TV

- **Problem:** When plasma TVs came out the TV sets were inadequately shielded and generated harmonic noise that interfered with radio communications and other electronics.
- **Observations:** Our TVs and entertainment system components are supposed to be EMC compliant. That is compliant with FCC rules in USC Title 47 Part 15.
- **Solution:** Fixing these issues comes down to opening an EMC compliance case with either the manufacturer or a regulatory body like the FCC. These issues often only get fixed with a class-action law suit.

The case the hungry little critter

- **Problem:** Mice & other critters love to chew on cables.
- **Solutions:**
  - ✓Regularly inspect / repair your coax and control wiring.
  - ✓Fix any chewed-up cables immediately to prevent damage to radios, amplifiers, and other electronic equipment.
  - ✓Protect your cabling by using burial rated cables or by placing them inside of outdoor rated conduit.
  - ✓Openings that cables leave from should be face down.
  - ✓Pack any openings with 0000 steel wool and weatherproof any with plumbers putty.



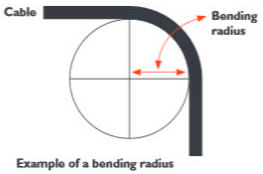
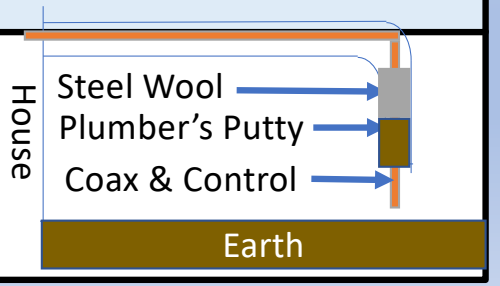


Figure 4 Example of a bending radius



The case of the mysterious powerline noise (1 of 2)

- **Problem:** Electrical power lines & transformers can be damaged by severe storms, high winds, fire, accidents, natural, or man-made disasters.
- **Troubleshooting:** You can use an AM radio tuned off frequency, an EMI meter, or a spectrum analyzer to find the source of the EMI.
- **Solution:** Ultimately you will have to open a case with your electrical utility company to ultimately resolve the issue.

The case of the mysterious powerline noise (2 of 2)

You can find a wide variety of EMI / RFI meters ranging in price from $30 to $30K. The ones below can all be found on Amazon.

Tacklife $34 Tacklife $33 Amtast $27 GQ $119

$1K+

$1K+

The case of the new fangled light (1 of 4)

- **Problem:** Elsäkerhetsverket (the Swedish national Electrical Safety Board), has had several cases with lighting causing radio interference. When new metal halide lamps are EMC compliant. *When the lamps have reached their service life the lamp starters begin oscillating as they are trying to re-ignite the lamp.*
- **NOTE:** It's a bit the same situation as for old fluorescent tubes, except that the oscillating rate is much faster for the metal halide lamp, making it hard to actually detect a bad lamp by the eye.

The case of the new-fangled light (2 of 4)

- Inside the luminaire there is a high voltage starter providing the igniting pulse. At each pulse there is a transient signal. As the igniting sequence normally is very quick the ignition shall pose no interference, but the oscillation of a bad lamp is a different matter.

The case of the new-fangled light (3 of 4)

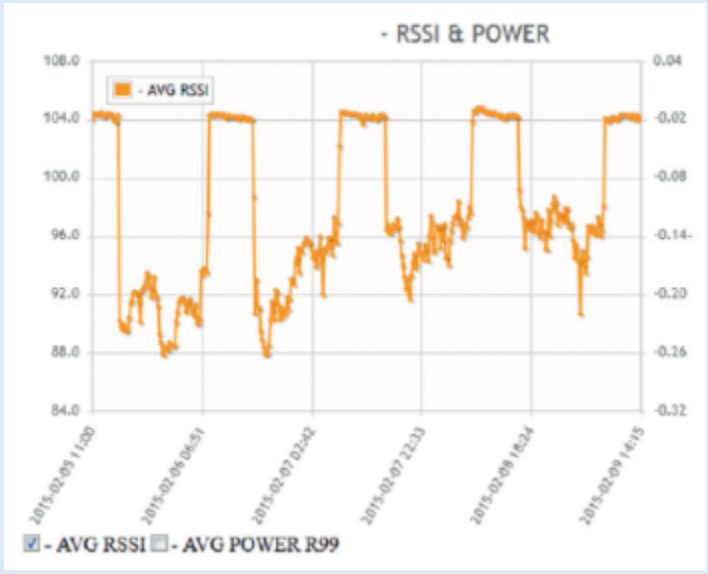
Light turned off

Light turned on

Here we can see the difference in interference level when the lightning illuminating a large shop sign is switched on. The network provider has also presented a graph showing how signal/noise ratio is affected. The sign is illuminated during the dark hours.

The case of the new-fangled light (4 of 4)

- The operator has reported loss of radio & network performance because of the interference.
- An order to remedy the RFI was given to the owner of the sign to resolve the interference, per Swedish law.
- This is a worrying situation as this is a very common type of lighting. The distance between lamps and antennas was ~250 meters.
- *Henrik Olsson - Elsäkerhetsverket*



The case of the knock-off XBOX (1 of 2)

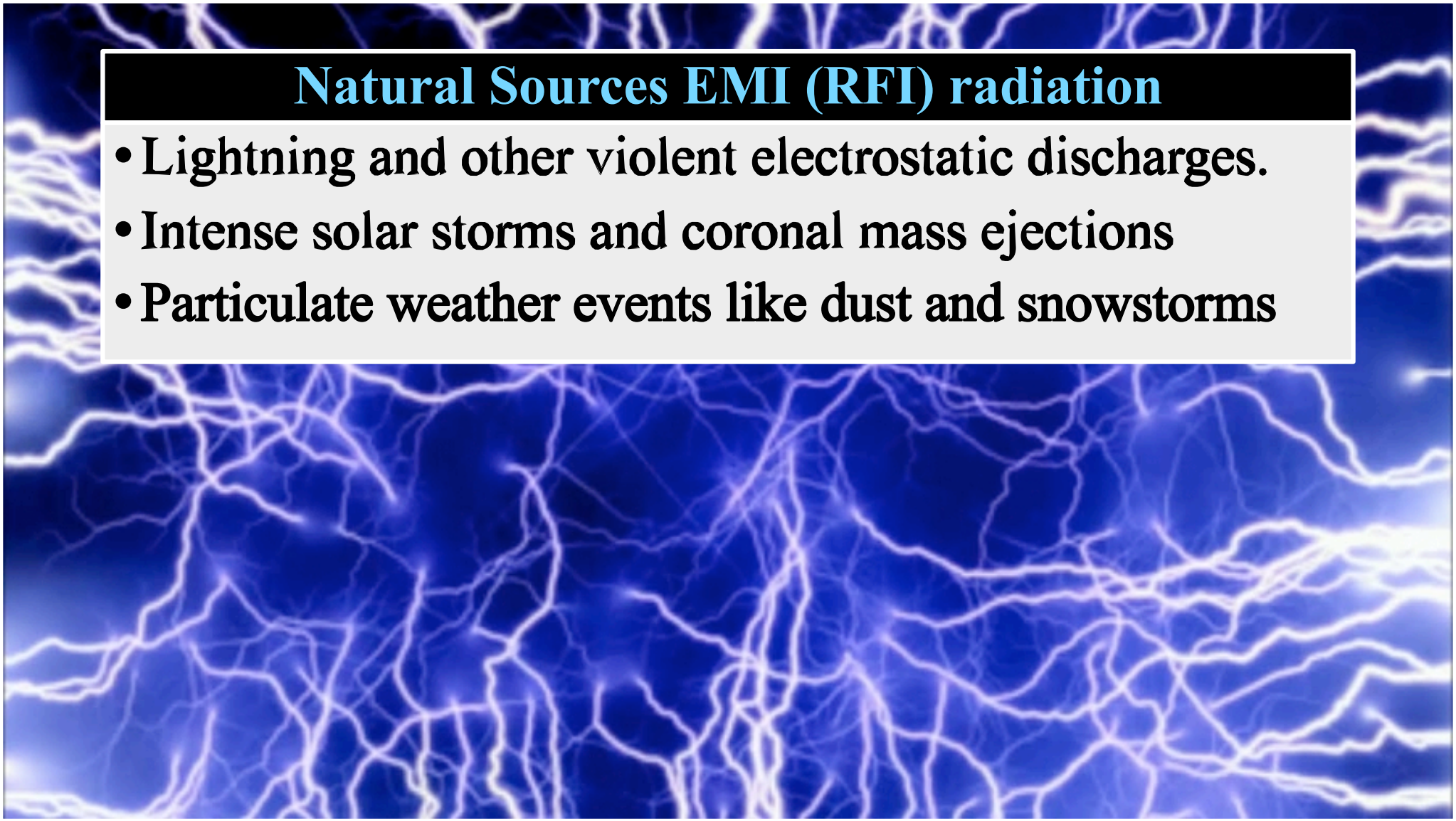
- **Problem:** A ham friend in Elmhurst had severe EMI & RFI on his VHF/UHF radio and also on his Wifi Network (802.11ac).
- **Troubleshooting:** We use an EMI / RFI meter and started walking around the neighborhood. We found a very strong noise signal at his new neighbor's house.
- **Solution:** We visited with the neighbor for a while and asked if we could use our EMI / RFI meter to try to identify the source. It turned out it was an knock-off XBOX from China. That the son had bought from an overseas importer. It had a fake FCC part 15 compliance sticker and pegged our meter.

The case of the knock-off XBOX (2 of 2)

- We asked the Son if he would mind shutting down his XBOX knock-off and went back to my friend's house. The interference problem went away as we expected it would.
- Now we had to address the thorny part of the problem. Getting the Son to leave his XBOX off and have him reach out to the vendor for a resolution. As expected, they offered no solution or explanation for the fake FCC compliance tag.
- The Son refused to leave his XBOX off. So we had to reach out to Microsoft and the FCC for their assistance. Both were aware of the issue and had been trying to shut down the vendor for many months now.

The case of the knock-off XBOX (3 of 3)

- The Son was not happy that he got ripped off.
- He refused to leave it off. His parents just shrugged.
- We offered to try to fix the XBOX by improving its shielding, but neither the boy or his parents were comfortable with that.
- We were forced to reach out to the FCC for help. They sent an enforcement officer to the boy's house and confiscated the fake XBOX. Which of course had painful consequences.
- After which the neighbor’s Son and his parents were fairly hostile. Which was a short-lived relationship problem, as my friend died and his wife moved to Minnesota.



Natural Sources EMI (RFI) radiation

- Lightning and other violent electrostatic discharges.
- Intense solar storms and coronal mass ejections
- Particulate weather events like dust and snowstorms

Unintentional Sources EMI radiation (1 of 2)

- **Power lines** and **transformers** on our electrical grid.
- **Electrical sparks** or **static electricity** of any kind
- **Microwave** and **induction burners**
- **Circuit Breakers** (can and often do create small arcs when thrown)
- **Consumer electronics** (Poorly engineered or manufactured)
- **DC Motors**, especially brush type, **Air compressors, elevators, …**
- **Arc Welders**
- **Subway / Railway switches** and **“third rail” contacts**

Unintentional Sources EMI radiation (2 of 2)

- **X-Rays** / **MRIs**
- Bunched **power cables**
- **Power strips** and **Wall-warts**
- **Uninterruptable power supplies (UPS) and Powerline conditioners**
- **Isolation transformers**
- **High Voltage Lighting** (theatrical, photographic, and streetlights.)
- **Florescent fixtures** (bad ballasts)
- **CFL** and **LED bulbs** (that are poorly engineered or manufactured)

Intentional Radiators Broadcast Band (54Mhz to 698Mhz) (1 of 2)

Primary users

- **Digital and analog TV** transmitters, boosters, relays, translators , and transcoders.
- **AM / FM radio** broadcasters, translators, and transcoders.
- **Aural TV** transmitters
- **Cellular** service transmitters
- **Fixed and mobile broadband** service transmitters
- **2-way radios** (land-mobile), used by fire, police, EMS, public works, park districts, railroads, utilities, …

Intentional Radiators Broadcast Band (54Mhz to 698Mhz) (2 of 2)

Secondary users

- **Amateur Radio**
- **Licensed wireless microphones** and **IEMS** (50mW to 250mW)
- **Remote or handheld broadcast TV camera** control signals

Tertiary users

- **Fixed and mobile TVBDs**
- **Unlicensed wireless microphones**, **intercoms**, and **IEMS** (<50mW)
- **Medical telemetry** devices

Intentional Radiators in the ISM bands (900Mhz, and 2.4, 5, 20, 60GHz, …) (1 of 2)

- **Wifi devices**
- **Bluetooth devices**
- **IoT devices (Zigbee, Z-Wave, …)**
- **Wireless USB devices**
- **Cordless (wireless) phones**
- **Key fobs for automobiles** (some operate at 315Mhz and 1.9GHz)
- **Baby monitors**
- **Medical telemetry devices**

Intentional Radiators in the ISM bands (900Mhz, 2.4Ghz, 5GHz, 20GHz, …) (2 of 2)

- **Hobbyist radio** (low power AM or FM transmitters)
- **Municipal SCADA systems**
- **RFID readers**
- **Door access**, **lighting, HVAC**, and **building management systems**
- **LAN point-to-point bridge links (Microwave, Infrared, …)**
- **Remote or handheld TV camera control signals**
- **Intercoms**
- **Remote controls**

Proactively mitigate EMI / RFI in your shack

- Make sure you have a good grounding system.
- Ensure all equipment is properly grounded.
- Keep signal and control cables away from AC power cables.
- If possible, shield your signal and control cables.
- Use conductive mesh over equipment fan openings.
- Use conductive paint and tape to add shielding to enclosures.
- Use ferrite beads or toroid cores on power, signal, and control cables to prevent them from being antennas.
- Use conductive lubricants on all cable connections. (i.e. PL259 and SO239) to mitigate

Toroid Mix, Frequency, and Usage

The table below gives our recommended applications for various mixes and effective frequency ranges.

Mix #	Material	Initial Permeability	RFI/EMI Common Mode Suppression Range	Tuned Circuits – Coil	Wide Band Transformer
31 (1)	MnZn	1500	1-300 MHz	–	1:1 only, <300 MHz
43 (2)	NiZn	800	25-300 MHz	< 10 MHz	3-60 MHz
52 (6)	NiZn	250	200-1000 MHz	< 20 MHz	1-60 MHz
61 (3)	NiZn	125	200-1000 MHz	<100 MHz	1-300 MHz
73 (7)	MnzN	2500	< 50 MHz	< 2 MHz	<10 MHz
75/J (4)	MnZn	5000	150 KHz – 10 MHz	< .75 MHz	.1-10 MHz

Source: https://palomar-engineers.com/ferrite-products/ferrite-cores/ferrite-mix-selection

Notes for Toroid Mix, Frequency, and Usage

- (1) Mix 31 excellent for 1-10 MHz common mode suppression
- Ok for ham radio 1:1 feed line choke applications.
- (2) Mix 43 excellent for common mode chokes from 25-300 MHz, Use Mix 31 below 10 MHz for higher choking impedance.
- (3) Mix 61 will withstand high power in multi ratio (2:1, 4:1, 9:1) impedance transformers (baluns/ununs).
- (4) Mix 75 (also known as Mix J) is a high permeability MnZn ferrite intended for a range of broadband and pulse transformer applications and common-mode inductor designs. Excellent for common mode suppression on AM broadcast frequencies from 500 KHz-1.8 MHz.

Methods, technologies and resources available to help you identify & resolve EMI (RFI) issues

- Use an analog AM radio tuned between stations.
- Use a spectrum analyzer (The NanoVNA is a good choice.)
- Use an EMF/EF/RF meter (GQ EMF-390).
- Attach an Oscilloscope to a AC line monitor to access line noise.
- Use a grid dip meter or accessory on your antenna analyzer.
- If using a UPS with a generator, reduce the sensitivity to tolerate noise the generator radiates or conducts.

What can you do to mitigate EMI (RFI)

- Make sure all transmitters have a solid ground.
- Place and properly ground lighting surge suppressors inline with your coaxial cable.
- Make sure all outside connections are made weatherproof.
- Use conductive paint o shield enclosures.
- Use metallic screens to cover fan or other enclosure openings.
- Use Shielded cables.
- Keep cables as short as possible.
- Replace swollen or defective electrolytic capacitors.

Use lighting surge suppressors inline w/ coax (1 of 2)

- PolyPhaser surge suppressor series uses blocking cap and gas tube protection technology.
- See: https://www.polyphaser.com.
- Signal and Surge Protection Solutions Guide
- See: https://www.polyphaser.com/pdf/e-literature/Signal-Surge-Solutions-Domestic/html5/index.html?&locale=ENG

PolyPhaser Surge Suppressor

Critter / weatherproof all outside connections

- Mice, cats, babies, and other critters love to chew on cables.
- Last year a mouse managed to push through the 0000-steel wool and chewed one of the control cables in my generator.
- To solve the problem, I infused plumber's putty with Peppermint and Citrus Oils and packed my pipe that coax entered the shack through along with the steel wool.

Use conductive paint to shield enclosures.

- Enclosures housing our electronics are often made of non-metallic materials allowing EMI / RFI to escape.
- You can use conductive paint on the inside of walls of enclosures to block EMI / RFI leakage.
- Conductive paint contains copper or nickel particles..

Strategies to work with neighbors, utilities & manufacturers to remedy EMI problems

- The league and the FCC both put out good reference material for interacting with your neighbors, utilities & manufacturers.
- Always have a positive attitude and be professional.
- Remember, it is better to walk through the problem, rather than jump to conclusions.
- Show you neighbor your shack. Recruit them into the hobby!
- Recruit all stake holders to help mitigate the issues.
- Create a station journal so you can document problems and solutions.

Useful Formulas and Reference Tables (1 of 2)

Assuming the antenna gain is numerically 1, or isotropic, and the measurement is in the far field and greater than 100 MHz

E-Field Levels versus Transmitter Pout			
Pout (W)	V/m at 1m	V/m at 3m	V/m at 10m
1	5.5	1.8	0.6
5	12.3	4.1	1.2
10	17.4	5.8	1.7
25	27.5	9.2	2.8
50	38.9	13.0	3.9
100	55.0	18.3	5.5
1000	173.9	58.0	17.4

- **Using Decibels (dB)**

  The decibel is always a ratio...

- **Gain = Pout/Pin**, where P = power
  Gain(dB) = 10log (Pout / Pin), where P = power
  Gain(dB) = 20log (Vout/Vin), where V = voltage
  Gain(dB) = 20log (Iout/Iin), where I = current

- **Power Ratios**
  3 dB = double (or half) the power
  10 dB = 10X (or /10) the power

- **Voltage/Current Ratios**
  6 dB = double (or half) the voltage/current
  20 dB - 10X (or /10) the voltage/current

- Multiplying power by a factor of 2 corresponds to a 3 dB increase in power. This also corresponds to a 6 dB increase in voltage or current.

Useful Formulas and Reference Tables (2 of 2)

Commonly Used Power Ratios (dB)		
Ratio	Power	Voltage or Current
0.1	-10 dB	-20 dB
0.2	-7.0 dB	-14.0 dB
0.3	-5.2 dB	-10.5 dB
0.5	-3.0 dB	-6.0 dB
1	0 dB	0 dB
2	3.0 dB	6.0 dB
3	4.8 dB	9.5 dB
5	7.0 dB	14.0 dB
7	8.5 dB	16.9 dB
8	9.0 dB	18.1 dB
9	9.5 dB	19.1 dB
10	10 dB	20 dB
20	13.0 dB	26.0 dB
30	14.8 dB	29.5 dB
50	17.0 dB	34.0 dB
100	20 dB	40 dB
1,000	30 dB	60 dB
1,000,000	60 dB	120 dB

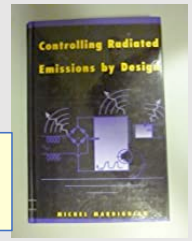
- Multiplying power by a factor of 10 corresponds to a 10 dB increase in power.
- Multiplying a voltage or current by a factor of 10 is a 20 dB increase.
- Dividing by a factor of 10 corresponds to a 10 dB reduction in power, or 20 dB for voltage and current.

EMI (RFI) Standards Bodies

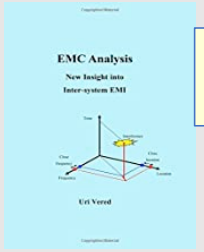
- The **ITU** and the **International Special Committee for Radio Interference** (**CISPR**) *(French acronym for "Comité International Spécial des Perturbations Radioélectriques"),* which is a committee of the **International Electrotechnical Commission** (**IEC**) sets international standards for radiated and conducted electromagnetic interference.
- Civilian standards for commercial, industrial, and automotive sectors. These standards form the basis of other international, national, or regional standards, most notably the **European Norms** (**EN**) written by **CENELEC** (**European committee for electrotechnical standardization**).
- US organizations include the **Institute of Electrical and Electronics Engineers** (**IEEE**), the **FCC**, the **American National Standards Institute** (**ANSI**), and the **US Military** (**MILSTD**).

Professional EMI / RFI Book Resources

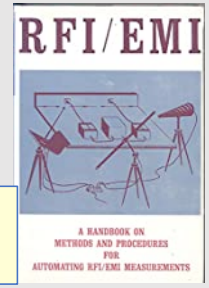
The 2020-2025 World Outlook for Electromagnetic (EMI) and Radio Frequency (RFI) Interference Shielding Materials and Technologies by Philip M. Parker Ph.D | Jan 21, 2019



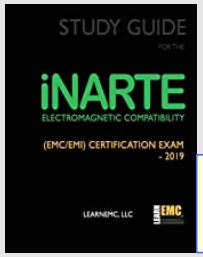
Controlling Radiated Emissions By Design: EMI/RFI reduction by Michel Mardiguian (1992-12-31)



EMC analysis: New insight into inter-system EMI by Uri Vered and Alan M. Egger | Dec 19, 2016



A handbook on methods and procedures for automating RFI/EMI measurements, by Donald R. J White | Jan 1, 1966



Study Guide for the iNARTE Electromagnetic Compatibility (EMC/EMI) Certification Exam - 2019 by LLC, LearnEMC,, Todd H. Hubing, et al. | Aug 1, 2019

ARRL EMI (RFI) Web Resources

- http://www.arrl.org/radio-frequency-interference-rfi *(Top level)*
  - Identifying & Locating Power Line Noise
  - Power Line RFI Investigation in Pleasant Hill, California
  - Hunting Down RF Noises *February 2015, 45 Pages*
  - Locating RF Interference at HF *February 2015, 33 Pages*
  - A Quick Look at Radio Frequency Interference *QST May 2009, 61 Pages*
  - Interference Primer *QST Lab Notes*

ARRL Suggested EMI (RFI) Web Resources

- A Ham's Guide To RFI, Ferrites, Baluns, And Audio Interfacing by Jim Brown, K9YC.
- In Compliance Magazine provides a tutorial on ferrites Using Ferrites to Suppress EMI.
- Audio Systems Group, Inc. Publications, Articles & application notes related to sound systems.
- The EMI (RFI) Page, Mark (ON4WW) provides some interesting background on some of his more memorable RFI experiences in Belgium.
- The EMI (RFI) Page, by Chris Gare, G3WOS.
- Variable Speed DC Motor Washing Machine RFI Fix, Gene Preston, K5GP.
- Grow Light Electronic Ballast RF Interference, by W0QE.
- eEngineer provides an EMI/EMC Glossary, as well as several other RFI pages pertaining to RFI.
- Lutron provides Applications Notes.
- V-Soft Communications® LLC, Provides AM/FM Zip Code Based Signal Strengths.

Information for Electric Utilities

- Center for Devices and Radiological Health, *Addressing EMI in medical devices.*
- Welcome to the RSGB EMC Web Pages, *"The RSGB Guide to EMC".*
- EMC Standards, *Details some of the major (EMC) standards in place worldwide.*
- Radioing eEngineer, has a page on Radio Frequency Interference (RFI).
- The United Kingdom's Radiocommunications Agency has a Radiocommunications Agency EMC Awareness, EMC/RFI info for the non-technical person & general public.

Naval Postgraduate School RFI Handbooks

- Special thanks to George F. Munsch, W5VPQ for providing these documents. They contain useful and comprehensive information for both RFI locating and noise mitigation.
- Power-Line Noise Mitigation Handbook for Naval and Other Receiving Sites
  This is a comprehensive manual that describes how to understand, locate and correct power line noise. A must for every utility or RFI troubleshooter.
- The Mitigation of Radio Noise And Interference From On-Site Sources at Radio Receiving Sites.

FCC EMI / RFI Resources

- The FCC and RFI: http://www.arrl.org/fcc-and-rfi-matters.
- FCC enforcement involving electric utilities
- Part 15 - Radio Frequency Devices
- No discussion of RFI would be complete without a discussion of FCC equipment authorization procedures which are based on Parts 2, 15, 18 and 68 of FCC Rules & Regulations: Learn More
- Federal RFI Preemption, In 1982 Congress passed 97-259, which gave exclusive jurisdiction to regulate RFI to the FCC.
- Regulatory RFI Information: http://www.arrl.org/regulatory-rfi-information.
- RFI Pocket Guide: http://www.arrl.org/shop/RFI-Pocket-Guide
- RFI: A customized Information Handout.
- **Additional Regulatory Information**
- This page details miscellaneous FCC regulatory information not found on other ARRL regulatory pages. ITU emissions designators can be found in this section
- **Sounds of RFI**

RFI Issues With:

- Automotive
- Broadband Over Powerline (BPL).
- Broadcast Station
- Cable Television Interference.
- Computer
- Electric Fence.
- GFCI and AFCI Devices.
- Grow Light RFI.
- Light Bulbs and RFI — A Closer Look.
- Motors
- Resolving Furnace and A/C RFI, Oct 2, 2017.
- Smart Meters
- Telephone
- Television
- Touch Lamp

Very useful EMI (RFI) web resources

- A Hams Guide to RFI, Ferrites, balunx, & audio interference
- Basics of EMI Troubleshooting
- Basics in EMC and Power Quality
- Fretting corrosion in electric contacts
- EMC Compliance Design Guide EDN Magazine
- Electromagnetic_interference Wikipedia
- EMI / RFI FAQ
- EMI Filter/RFI Filter: A Guide to the RF Interference Filter

FCC / ARRL RFI Desk contact information

- **Federal Communications Commission Call Center**
  1270 Fairfield Rd
  Gettysburg, PA 17325
  Email: fccinfo@fcc.gov
  1-888-CALL-FCC
- **American Radio Relay League RFI Desk**
  225 Main St
  Newington, CT 06111
  Email: rfi@arrl.org
  860-594-0214

- You can find a sample letter you can send to the FCC or the ARRL's RFI Desk at: http://www.arrl.org/fcc-power-utility-letter#letter.
- **Always send you letters "Certified return receipt requested".**
- *If you do contact the Call Center, be prepared to explain briefly the steps you have taken to try to resolve this with your power company.*
- *If you and the FCC staff agree that having the FCC send the "**RFI-Power-Utility Letter**" is appropriate, be prepared to supply them with the utility name, address and, if possible, an individual to receive the letter. This individual should be an upper manager or Vice President, if possible.*

Wireless Groups and Organizations (1 of 2)

APCO International *https://www.apcointl.org.*
APCO International is the world's oldest and largest organization of public safety communications professionals and supports the largest U.S. membership base of any public safety association. It serves the needs of public safety communications practitioners worldwide — and the welfare of the general public as a whole — by providing complete expertise, professional development, technical assistance, advocacy and outreach.

ATIS *http://www.atis.org*
In a rapidly changing industry, innovation needs a home. ATIS is a forum where the information and communications technology (ICT) companies convene to find solutions to their most pressing shared challenges.

Bluetooth Special Interest Group *https://www.bluetooth.com*
Join thousands of the world's most innovative companies already developing and influencing Bluetooth technology.

CTIA - The Wireless Association *http://www.ctia.org*
CTIA is an international nonprofit membership organization that has represented the wireless communications industry since 1984. The association's members include wireless carriers, device manufacturers, suppliers as well as apps and content companies.

ETSI - European Telecommunications Standards Institute *http://www.etsi.org*
We produce globally applicable standards for Information & Communications Technologies including fixed, mobile, radio, broadcast, internet, aeronautical, and other areas.

NAB - National Association of Broadcasters *http://nab.org*
The National Association of Broadcasters is the voice for the nation's radio and television broadcasters. As the premier trade association for broadcasters, NAB advances the interests of our members in federal government, industry and public affairs; improves the quality and profitability of broadcasting; encourages content and technology innovation; and spotlights the important and unique ways stations serve their communities.

Satellite Industry Association *http://www.sia.org*
The Satellite Industry Association (SIA) is a Washington D.C. based trade association representing the leading global satellite operators, service providers, manufacturers, launch services providers, and ground equipment suppliers.

Wireless Groups and Organizations (2 of 2)

Wireless Infrastructure Association (WIA) ***http://wia.org***
The Wireless Infrastructure Association represents the businesses that develop, build, own, and operate the nation's wireless infrastructure.

Wireless Innovation Forum ***http://www.wirelessinnovation.org***
WInnForum members are dedicated to advocating for the innovative use of spectrum and advancing radio technologies that support essential or critical communications worldwide. Through events, committee projects, and initiatives the Forum acts as the premier venue for its members to collaborate to achieve these objectives, providing opportunities to network with customers, partners and competitors, educate decision makers, develop and expand markets, and advance relevant technologies.

WiMax Forum ***http://wimaxforum.org***
The WiMAX Forum® is an industry-led, not-for-profit organization that certifies and promotes the compatibility and interoperability of broadband wireless products based upon IEEE Standard 802.16. The WiMAX Forum's primary goal is to accelerate the adoption, deployment, and expansion of WiMAX, AeroMACS, and WiGRID technologies across the globe while facilitating roaming agreements, sharing best practices within our membership and certifying products.

ZigBee Alliance ***http://www.zigbee.org***
Our innovative standards are custom-designed by industry experts to meet the specific market needs of businesses and consumers. These market leading standards give product manufacturers a straightfor-ward way to help their customers gain greater control of, and even improve, everyday activities.

Telecommunications Industry Association ***http://www.tiaonline.org***
The Telecommunications Industry Association (TIA) is the leading trade association representing the global information and communications technology (ICT) industry through standards development, policy initiatives, business opportunities, market intelligence and networking events. With support from hundreds of members, TIA enhances the business environment for companies involved in telecom, broadband, mobile wireless, information technology, networks, cable, satellite, unified communications, emergency communications, and the greening of technology.

Short Range Wireless Technologies (1 of 2)

NAME	PURPOSE	NETWORK TYPE	FREQUENCY BANDS	MODULATION METHOD	WEBSITE
6LoWPAN	IoT using IPv6 addressing	Mesh	<1 GHz and 2.4 GHz ISM	DSSS-PSK	www.datatracker.ietf.org/wg/6lowpan
Bluetooth	PAN data, multimedia streaming, two-way voice	Point-to-point ad-hoc	2.4 GHz ISM	FHSS-GFSK and FHSS-PSK	www.bluetooth.com
Insteon	Home automation	Mesh	131.65 kHz (over power line), 900 MHz ISM (RF)	PSK (over power line), FSK (RF)	www.insteon.com
IrDA	Short-range optcal data	Point-to-point (predominately)	Infrared optical	OOK (predominately)	www.irda.org
NFC	Very short range data	Point-to-point	13.56 MHz	Backscatter ASK	www.nearfield communication.org

Short Range Wireless Technologies (2 of 2)

NAME	PURPOSE	NETWORK TYPE	FREQUENCY BANDS	MODULATION METHOD	WEBSITE
RuBee	Product tagging and tracking	Point-to-multipoint	131 kHz inductively coupled	ASK and PSK	www.ru-bee.com
Wi-Fi	LAN data, multimedia streaming, two-way voice	Point-to-multipoint	2.4 GHz and 5 GHz ISM (predominately)	OFDM	www.wi-fi.org
ZigBee	Low power control and monitoring	Mesh	2.4 GHz ISM (predominately)	DSSS-PSK	www.zigbee.org
Z-Wave	Home automation	Mesh	900 MHz ISM	GFSK	www.z-wavealliance.org

Wireless Protocol Websites

WIRELESS WORKING GROUPS

- **802.11 Working Group** The 802.11 Working Group is responsible for developing wireless LAN standards that provide the basis for Wi-Fi. *http://grouper.ieee.org/groups/802/11/*
- **802.15 Working Group** The 802.15 Working Group is responsible for developing wireless PAN standards that provide the basis for Bluetooth and ZigBee. *http://www.ieee802.org/15/*
- **802.16 Working Group** The 802.16 Working Group is responsible for developing wireless MAN standards that provide the basis for WiMAX. *http://grouper.ieee.org/groups/802/16/*
- **Bluetooth SIG** The Bluetooth SIG is responsible for developing wireless PAN specifications. *https://www.bluetooth.com*
- **Cellular Telecommunications and Internet Association (CTIA)** The CTIA represents cellular, personal communication services, mobile radio, and mobile satellite services over wireless WANs for service providers and manufacturers. *http://www.ctia.org*
- **The GSM Association participates in the development of development of the GSM platform** - holds the annual 3GSM World Congress. *http://www.gsmworld.com*
- **Wi-Fi Alliance** The Wi-Fi Alliance develops wireless LAN ("Wi-Fi") specifications based on IEEE 802.11 standards and provides compliance testing of Wi-Fi products. *http://www.wi-fi.org*
- **WiMAX Forum** The WiMAX Forum develops wireless MAN standards based on IEEE 802.16 standards and provides compliance testing of WiMAX products. *http://wimaxforum.org*
- **ZigBee Alliance** The ZigBee Alliance develops standards for low-power wireless monitoring and control products. *http://www.zigbee.org*

Useful Websites (1 of 2)

- **ARRL RFI Information**
  http://www.arrl.org/radio-frequency-interference-rfi
- *Jim Brown* has several very good articles on RFI, including:
  "**A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing**".
  www.audiosystemsgroup.com
- **FCC, Interference with Radio, TV and Telephone Signals**
  http://www.fcc.gov/guides/interference-defining-source
- **IWCE Urgent Communications**
  http://urgentcomm.com has multiple articles on RFI
- *Jackman, Robin,* **Measure Interference in Crowded Spectrum, Microwaves & RF Magazine, Sept. 2014.**
  http://mwrf.com/test-measurement-analyzers/measure-interference-crowded-spectrum
- RFI Services, *Marv Loftness*
  has some good information on RFI hunting techniques
  http://www.rfiservices.com
- *TJ Nelson,* "**Identifying Source of Radio Interference Around the Home**", 10/2007
  http://randombio.com/interference.html

Useful Websites (2 of 2)

CTIA, Test Plan for Mobile Station Over the Air Performance
Method of Measurement for Radiated RF Power and Receiver Performance
http://files.ctia.org/pdf/CTIA_OTA_Test_Plan_Rev_3.1.pdf

Broadcom, Compliance with TIS and TRP Requirements,
https://www.broadcom.com/collateral/wp/21XX-WP100-R.pdf

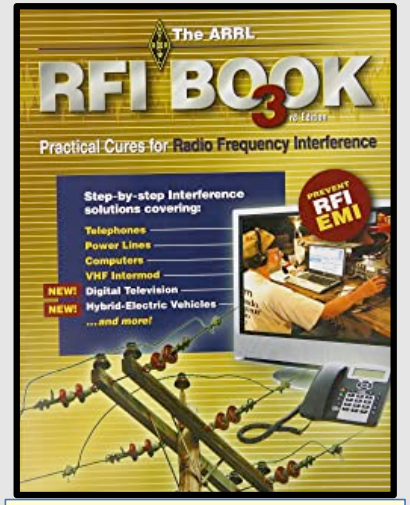
Beeker, Effective PCB Design: Techniques To Improve Performance,
https://www.nxp.com/files-static/training_pdf/WBNR_PCBDESIGN.pdf

Wyatt, Gaps in Return Planes (video),
https://www.youtube.com/watch?v=L44lTnQgv-o&t=9s

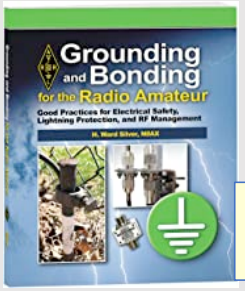
Hartley, Control of Noise, EMI and Signal Integrity in PC Boards (2-day seminar),
Rick Hartley Enterprises, managed by
https://www.pcb2day.com.

Bogatin, **Seven Habits of Successful 2-Layer Board Designers** (Signal Integrity Journal),
https://www.signalintegrityjournal.com/blogs/12-fundamentals/post/1207-seven-habits-of-successful-2-layer-board-designers

Suggested EMI / RFI Book Resources

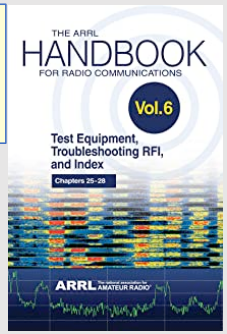


The ARRL RFI Book
by ARRL Inc. and Mike Gruber | May 1, 2010



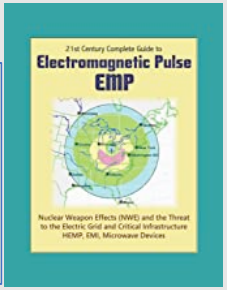
Grounding and Bonding for the Radio Amateur
by ARRL Inc. and Ward Silver (N0AX)

The ARRL Handbook for Radio Communications; Volume 6:
Test Equipment, Troubleshooting, RFI & Index



The Technician's EMI Handbook: Clues and Solutions
by Joseph Carr

21st Century Complete Guide to Electromagnetic Pulse (EMP): Nuclear Weapon Effects (NWE) and the Threat to the Electric Grid and Critical Infrastructure, HEMP, EMI, Microwave Devices
by U.S. Government, Department of Defense, May 9, 2017



Useful Books

- **"The RFI Book"** (3rd edition) *Gruber, Michael*, ARRL, 2010.
- "**AC Power Interference Handbook**" (3rd Edition) *Loftness, Marv,* ARRL January 1, 2007 or
  "AC Power Interference Handbook" (2nd edition) *Loftness, Marv,* Percival Publishing, 2001.
- **"Transmitter Hunting: Radio Direction Finding Simplified"** *Moell, Joseph and Curlee, Thomas*, TAB Books, 1987.
- **"Interference Handbook"** *Nelson, William*, Radio Publications, 1981.
- **"Electromagnetic Compatibility Engineering"** *Ott, Henry W.,* John Wiley & Sons, 2009.
- **"Platform Interference in Wireless Systems - Models, Measurement, and Mitigation"**
  Slattery, Kevin, and Skinner, Harry, Newnes, 2008.
- **"Spectrum and Network Measurements",** (2nd Edition) *Witte, Robert,* SciTech Publishing, 2014.
- **"Radio Frequency Interference (RFI) Pocket Guide",** *Wyatt and Gruber*, SciTech Publishing, 2015.
- *"***Testing for EMC Compliance**", *M. L. Montrose and E. M. Nakauchi.,* Wiley & Sons, NY, USA, 2004.
- "**Introduction to Electromagnetic Compatibility**", *D. Sanches, Interferência Eletromagnética, 1nd ed., Ed. Interciência, Rio de Janeiro, Brazil, 2003. C. R. Paul,* 3rd ed., Ed. Wiley & Sons, NY, USA, 1992.
- **"Electromagnetics Explained, A Handbook for Wireless/RF, EMC, and Highspeed Electronics"**, *Schmitt*, Newnes, 2002.
- **"Fast Circuit Boards Energy Management",** *Morrison*, Wiley, 2018.
- **"Electromagnetic Compatibility Engineering"**, *Ott***,** Wiley, 2009.
- **Signal Integrity - Simplified** (3rd edition), *Bogatin***,** Prentice Hall, 2018.

Useful Periodicals and Proceedings

- I*gor S. M. Torres, F. Paulo F. de Sousa, T. V. Ferreira e B. A. Luciano,* "**Lâmpadas Fluorescentes e Distorções Harmônicas: Eficiência Energética e Qualidade de Energia Elétrica,**" in **CBQEE** VIII'09, paper 033.
- *O. Monteiro, D. Báez, F. Alvarez, R. Alejos and G. E. Flores-Verdad,* "**Simulation and Experimental Results for a Compact Fluorescent Lamp with Electronic Adapter,**" in **Proc. MWSCAS'95**, 1995, p. 216-218, vol.1.
- *Z. Wei, N. R. Waston and L. P. Frater,* "**Modelling of Compact Fluorescent Lamp,**" in **Proc. ICHQP'08**, 2008, p. 1-6.
- *M. D. Teixeira, G. Paulillo, A. R. Aoki, R. A. Peniche and D. L. Archanjo,* "**Análise do Impacto de lâmpadas Fluorescente Compactas na Rede de Dstribuição da COPEL,**" in **VI SBQEE'05**, 2005, p. 309-315.
- *J. Rajamäki*, "**Lighting Interferences - An Ever-Increasing Threat! Will the Proposed Changes in CISPR 15 Correct the Situation?**" in **EMC'05**, 2005, p. 7-12. **FREQUENCY [Hz]**
- *W. A. Anderson, E. E. Hammer and A. Serres* "**The Interaction of Infra-Red Controls and Electronic Compact Fluorescent Lamps**" in **IAS'95**, 1995, p. 2066 – 2068, vol. 3.
- H. M. Nussenzveig, "**3 Eletromagnestismo – Curso de Física Básica**", 1nd ed., Ed. Edgard bücher, São Paulo, Brazil, 1997.
- "**Limits and methods of measurement radio disturbance characteristics of electrical lighting and similar equipment**", **CISPR** Std. 15, 2007.
- *P. Ixtânio L. Ferreira, G. Fontgalland, G. Falcão and A. Ricardo Z. Nascimento*, "**Investigation of the conducted EMI from compact fluorescents lamps put together in the same luminaries,**" in **ISEF'09**, 2009, paper 156

Useful White Papers

- **VIDEO / Handheld Interference Hunting for Network Operators** (Rohde & Schwarz)
  https://www.rohde-schwarz.com/us/solutions/wireless-communications/gsm_gprs_edge_evo_vamos/webinars-videos/video-handheld-interference-hunting_229255.html
- **Interference Hunting With The R&S FSH (Rohde & Schwarz)**
  https://www.rohde-schwarz.com/us/applications/interference-hunting-with-r-s-fsh-application-note_56280-77764.html
- **Interference Hunting / Part 1 (Tektronix)**
  http://www.tek.com/blog/interference-hunting-part-1-4-get-insight-you-need-see-interference-crowded-spectrum
- **Interference Hunting / Part 2 (Tektronix)**
  https://in.tek.com/blog/interference-hunting-part-2-4-how-often-interference-happening
- **Interference Hunting / Part 3 (Tektronix)**
  http://www.tek.com/blog/interference-hunting-part-3-4-use-mask-search-automatically-discover-when-interference-happenin
- **Interference Hunting / Part 4 (Tektronix)**
  https://www.tek.com/blog/interference-hunting-part-4-4-storing-and-sharing-captures-interference-hunter%E2%80%99s-safety-net

??? Questions ???