Wyatt Technical Services, LLC
EMC Seminars & Design

Urban RFI and Ham Radio

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60 min

Kenneth Wyatt – WA6TTY (1973)
Aerospace – 10 years
HP/Agilent – 21 years
EMC Consulting – 12 years

Author:
EMI Troubleshooting Cookbook
EMC Pocket Guide
RFI Pocket Guide (ARRL)
EMC Troubleshooting Kit – Vol 1 (Oct 2020)
Troubleshooting Emissions – Vol 2 (June 2021)
Troubleshooting Immunity – Vol 3 (Sep 2021)

Introduction

Urban RFI sources have increased to the point where it's an issue for HF and (even) VHF operators

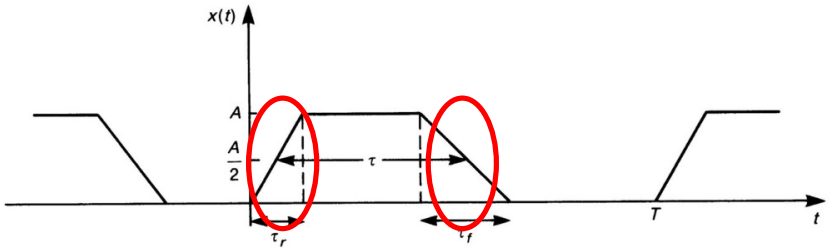
- Large increase in noise floor over 25 years
- I see S7 to S9 (urban) and S0 (rural)
- Switch-mode power supplies
- Lighting, appliances, power supplies/modules
- Easy to see on waterfall displays
- Some mitigations

Types of Noise

Generally, three dominant sources:

1. **Impulse** – defective equipment in the mains (arcing or corona) or lightning (typically affects up through 7 MHz)
2. **Electronically-generated (dominant now)** – digital bus, VF motor drives, SMPS, solar controllers, wall warts, LED/CFL lighting, kitchen appliances (major issue today!)
3. **Signal Leakage** – VDSL modem, CATV cable, etc.

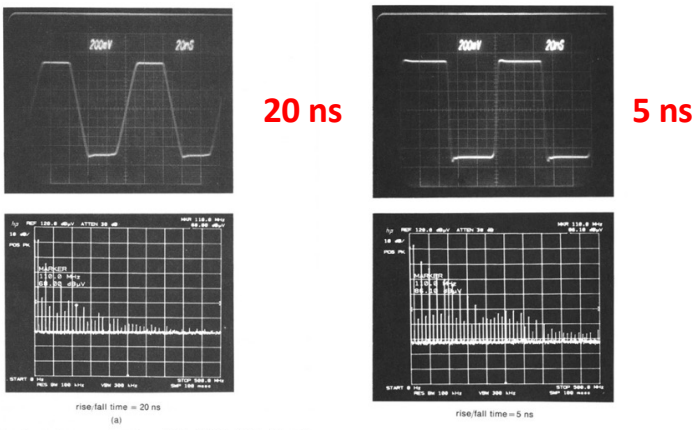
Generalized digital trapezoidal waveform



The key contributor to high-frequency harmonic emissions is primarily due to the rise/fall-times of the waveform.

Faster rise/fall times generate higher harmonics

- The risetime and fall times contain all the harmonic energy.
- The faster the switched waveform, the higher the harmonic content.
- Most SMPS switch in ms or ns.
- Effective bandwidth of the energy is equal to BW (GHz) = 0.35 / Risetime (ns).
- Example: a 1 ns risetime has an effective bandwidth of 350 MHz of harmonic content.



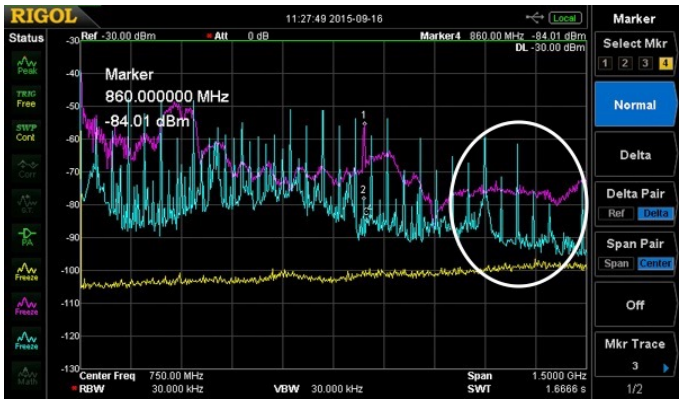
Experimentally measured spectra of 1 V, 10 MHz, 50% duty cycle

Bus/clock noise for a typical digital product

EMI measured from a typical digital product using a near-field probe. The on-board noise spectrum from 1 to 1500 MHz shows:

- Yellow = Ambient noise floor
- Aqua = Ethernet clock
- Violet = On-board DC-DC converter

This self-generated EMI can affect cellular phone and GPS bands (circled).



(10 MHz to 1.5 GHz)

https://www.edn.com/platform-interference/

60 Hz power line noise signature

- Power line time domain signature of 120 Hz (or pulse intervals of 8.3 ms).
- 60 Hz sine wave crosses zero twice per cycle.
- Example (QST, Sept 2021):
- Set the receiver to AM at 6 kHz BW and set the oscilloscope to sync at line frequency at 2 ms/div.
- Connect to the audio output.
- RFI can occur from HF into the VHF bands

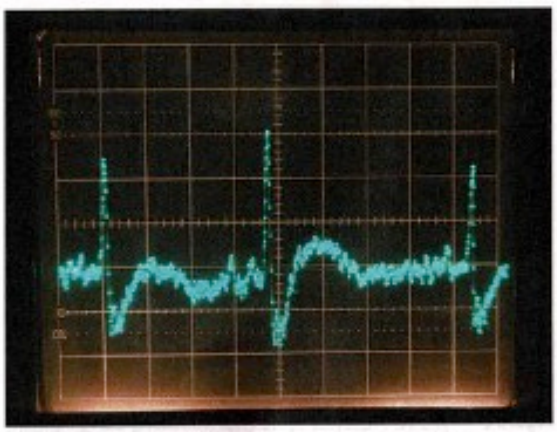


Figure 1 — The oscilloscope display of the power line noise signature at the audio output of IC-7700 receiver, 2 ms/div.

Source QST, Sept 2021, Page 35.

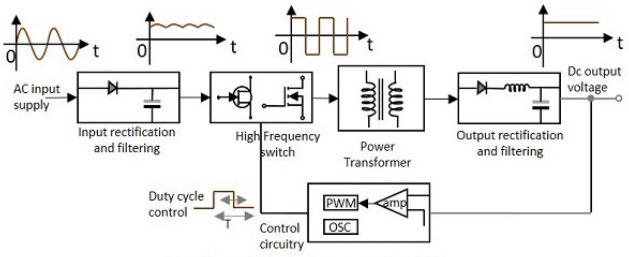
DC-DC (switch mode) converters are everywhere

Lighting, electronic products, appliances, etc.

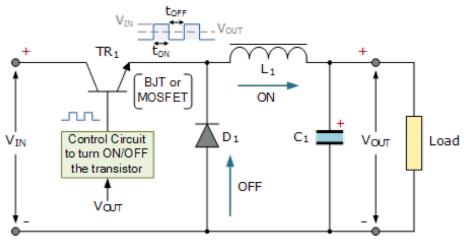
Most products today use switch-mode power supplies for energy efficiency.

AC-DC Supplies: The mains voltage is rectified and filtered to about 300 VDC and then switched on and off at 50 to 500 kHz, then transformed down and filtered to the desired secondary voltages.

DC-DC Supplies: The DC input is directly switched and either boosted or reduced and filtered to the desired voltages. Switch frequency 100 kHz to 3 MHz.



Functional block diagram of SMPS



Typical SMPS time domain pulses

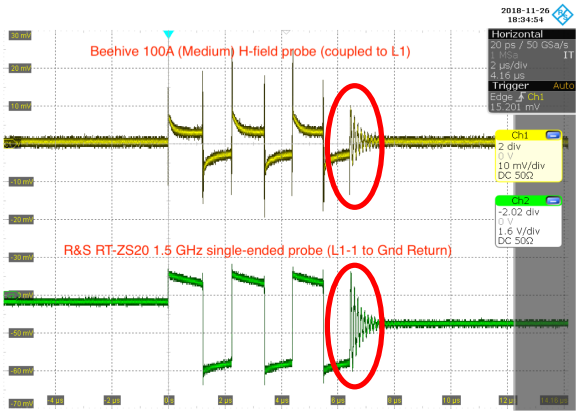
Switch mode power supplies (SMPS) typically switch at:

Mains powered: 10 to 500 kHz

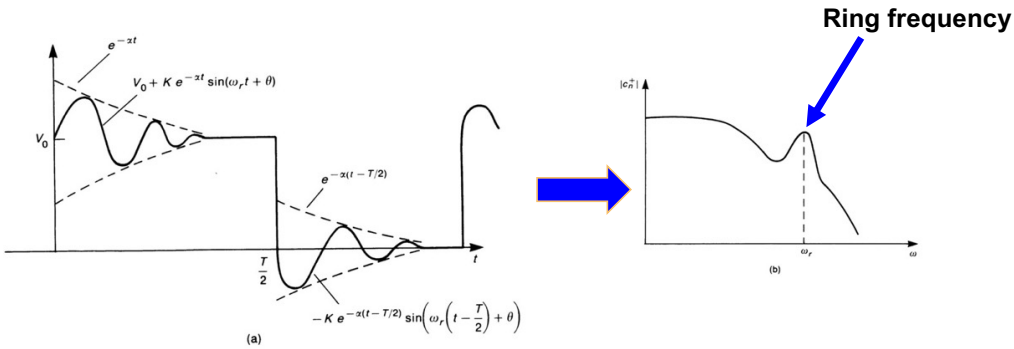
On-board DC-DC: 100 kHz to 3 MHz

The example is an on-board DC-DC converter switching at 1 MHz. We're comparing inductive coupling using an H-field probe versus a conventional scope probe.

RFI can occur through 1 GHz. Harmonic spikes will occur every 2X the switch frequency. Note the ringing.



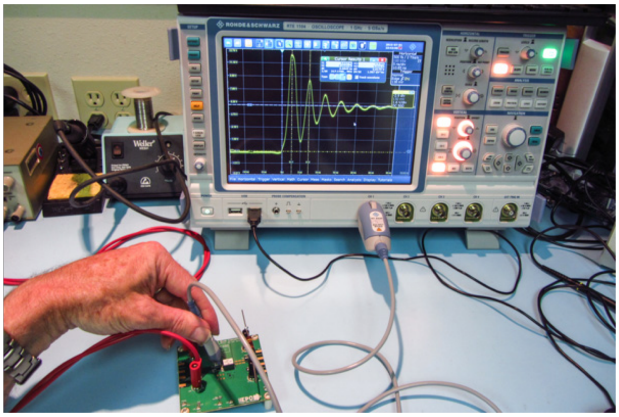
Effect of ringing



- Switch-mode power supplies, DC-DC converters and AC/DC inverters typically have ringing associated with the switched waveforms
- Ringing on a switched waveform will cause a resonance in the spectral emissions

Measuring switched-mode power supply ringing

- A Rohde & Schwarz RTE 1104 oscilloscope and RT-ZS20 (1.5 GHz) HF probe was used
- An H-field probe held close to the switching inductor may also be used
- Line up cursors on adjacent peaks to read off the ring frequency
- Ring frequency of 217 MHz

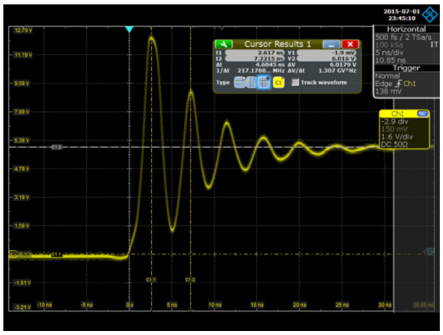


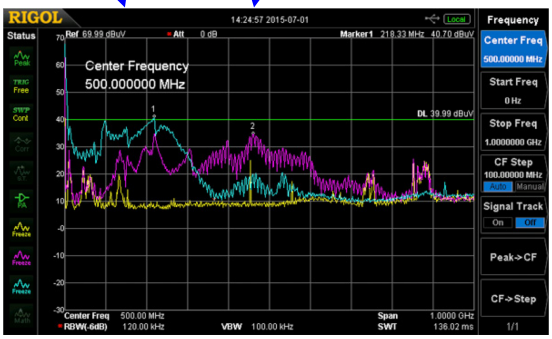
https://www.edn.com/gan-technology-and-the-potential-for-emi/

Ringing causes peaks in the emissions

Ring frequency

Second harmonic



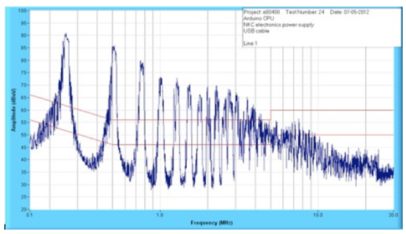


- 1 MHz GaN switcher with 300-500 ps rise time and a 217 MHz ring frequency creates broadband EMI as high as 800 MHz with peaks at 217 and 434 MHz as measured with Fischer F-33-1 current probe
- Yellow = ambient measurement, Aqua=input current, Violet=load current

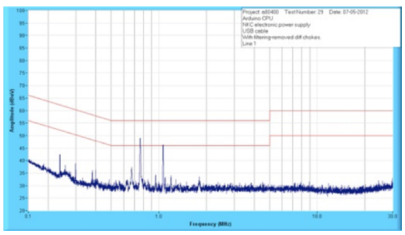
Example: Wall wart RFI

Many non-branded switch-mode "wall wart" power supplies lack a line filter. The one pictured has none!

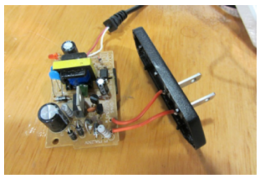
Conducted emissions is measured from 150 kHz to 30 MHz and the unfiltered wall wart measured as high as 70 dB over the FCC Class B (residential use) limit.



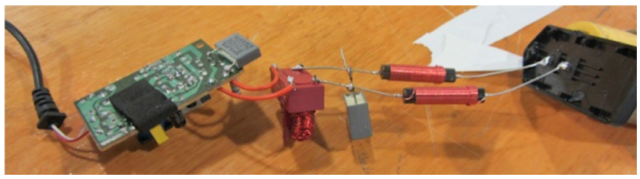
No Line Filter!



Line Filter Added

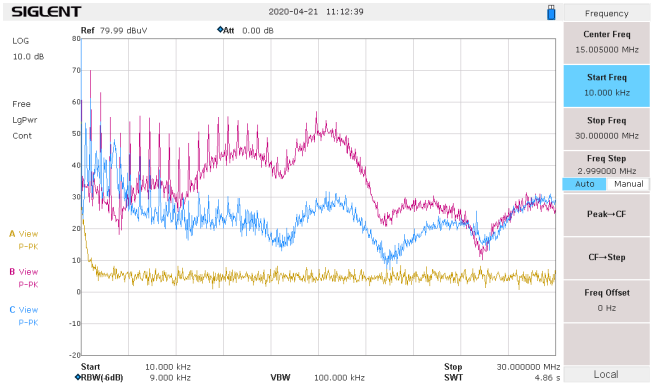


No Line Filter!



Line Filter Added

RFI from a typical DC-DC converter IC

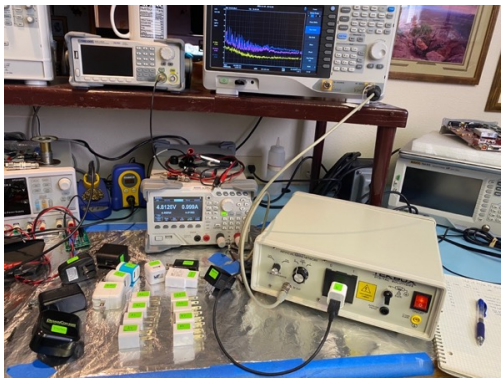


Measured with DC (5uH) LISN

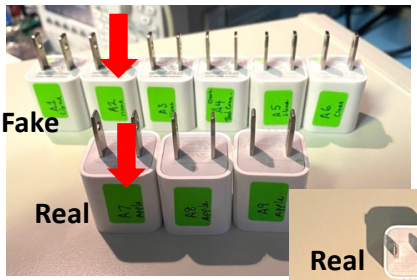
(10 kHz to 30 MHz)

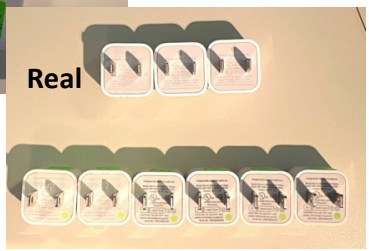
Yellow = ambient, Violet = differential mode, Aqua = common mode

Apple versus counterfeit power modules



Test setup for conducted emissions.

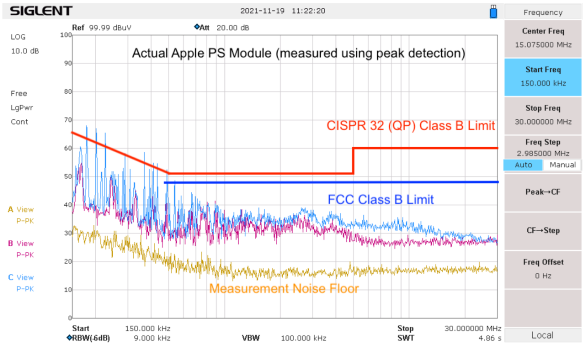




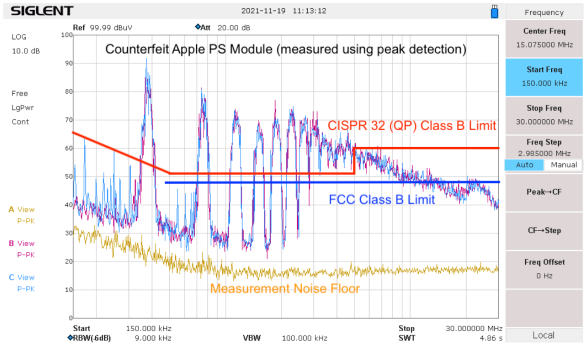
The markings all look legit.

Comparison of Apple versus counterfeit modules

Apple Model A1385



FAKE "Apple Model A1265"

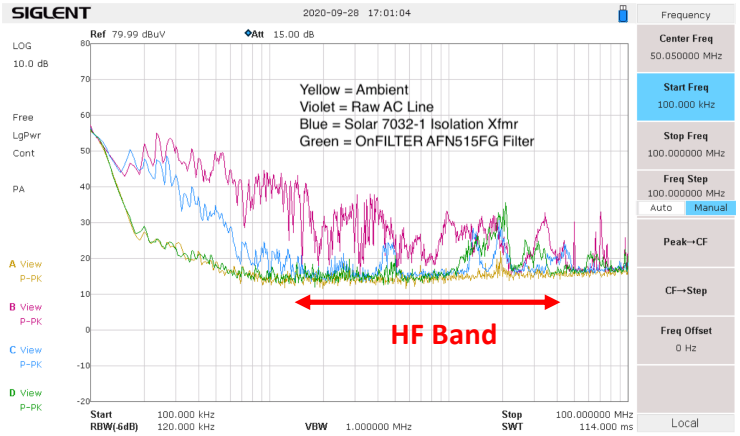


Yellow = ambient noise floor, Violet = Line, Blue = Neutral (Measured from 150 kHz to 30 MHz)

Power Line RFI

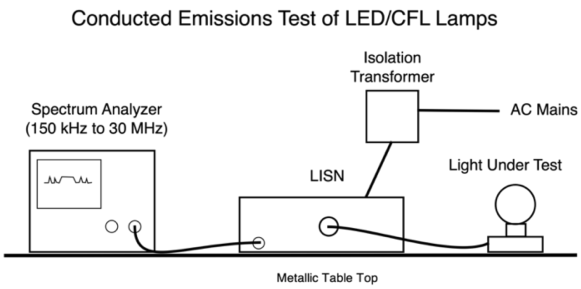
This is a measurement of my own power line EMI, as measured from 100 kHz to 100 MHz. I was testing some power line filters for an article.

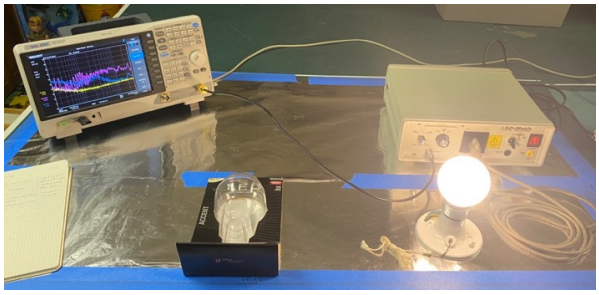
- Yellow = Ambient noise floor
- Violet = Raw line EMI
- Blue = Solar 7032-1 isolation transformer
- Green = OnFILTER AFN515FG filter



https://www.edn.com/review-tool-measures-power-line-emi/

LED/CFL lighting RFI tests

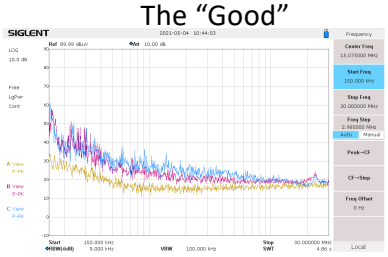




Several LED and CFL bulbs were tested for conducted emissions in the range 150 kHz to 30 MHz at 9 kHz RBW

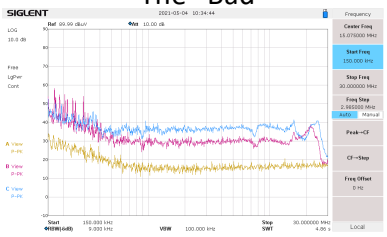
LED lighting conducted RFI tests (2010 vintage)

The "Good"



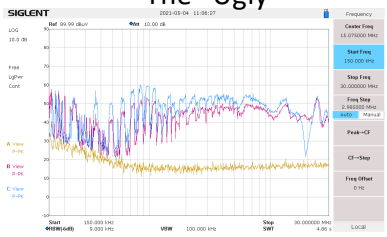
CREE Model 12DE26

The "Bad"



Philips Model 12E26A60

The "Ugly"

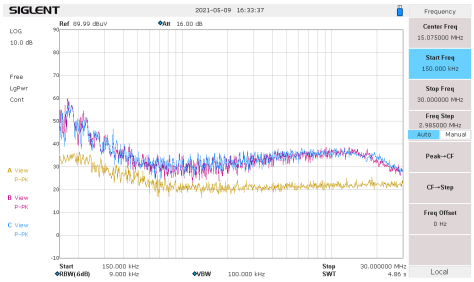


Utilitech Model G2560F

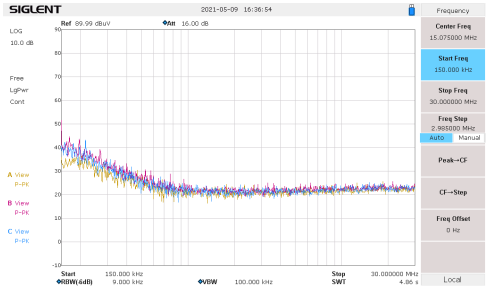
Yellow = ambient noise floor, Violet = Line, Blue = Neutral (Measured from 150 kHz to 30 MHz)

A sampling of several LED and CFL bulbs tested. The CFL looked similar to the "Good" example and the switching noise tapered off above 1 MHz. Bulbs were tested using "peak" detection, as that's similar to what you'll hear in the receiver.

LED lighting conducted RFI tests (2021 vintage)



Philips Model 9290020363



Every Day Living (Kroger) Model E343253

WOW!

Yellow = ambient noise floor, Violet = Line, Blue = Neutral (Measured from 150 kHz to 30 MHz)

A sampling of several more recent LED bulbs tested. Bulbs were tested using "peak" detection, as that's similar to what you'll hear in the receiver.

Filtering techniques

- Good ferrite types for HF: (Fair-Rite 31, 43, 75 material)
- Clamp-on ferrites don't work well at HF, best to use toroid cores
- Powdered iron (hi-Q) is only good for RF power transfer – don't use
- Commercial line filters
- Filtering the transmission line and antenna

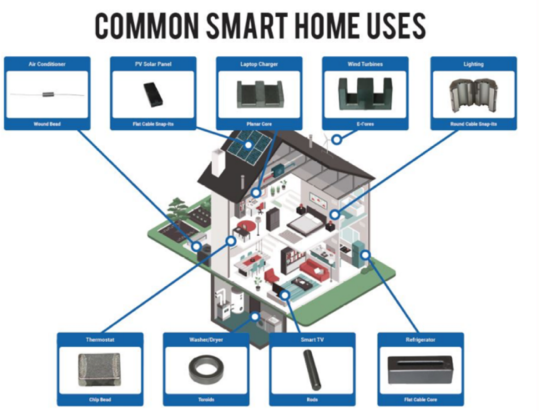
Fair-Rite "Smart Home"

Inside

- **Laptop Charger: *Planar Cores***
- **Lighting and Light Fixtures: *Round Cable Snap-its***
- **Thermostat: *Chip Beads***
- **Washer/Dryer: *Toroids***
- **Smart TV: *Rods***
- **Refrigerator: *Flat Cable Cores***

Outside

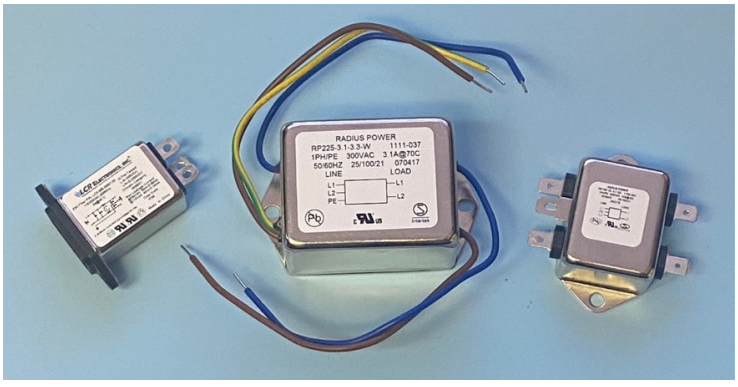
- **Air Conditioner Units: *Wound Beads***
- **PV Solar Panels: *Flat Cable Snap-its***
- **Wind Turbines: *E-Cores***



At least one ferrite company has attempted to address RFI in the residential home environment.

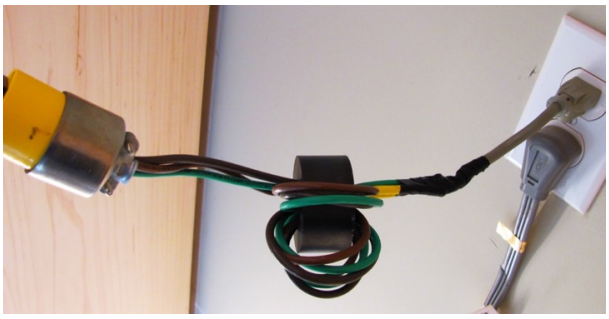
https://www.fair-rite.com/animate/#smart_home

Commercial line filters

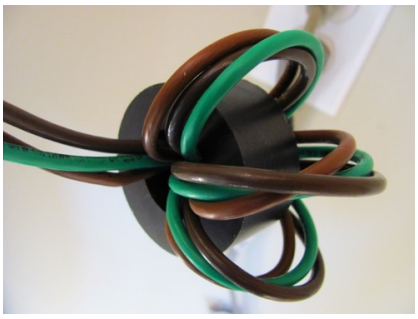


Filter body MUST be bonded to chassis and located near the mains input for common mode filtering.

Example: An alternative to line filters



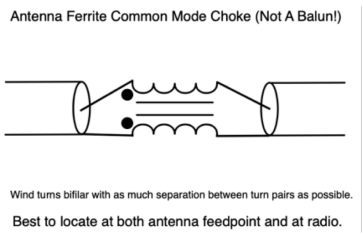
Appliance filter adapter - Bifilar-wound on 2.8 OD #75 core



Close-up (3 turns)

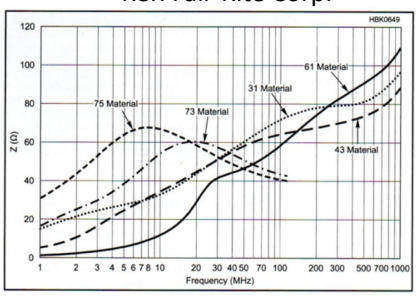
Courtesy, Dave Eckhardt (W0LEV)

Filtering antenna EMI with common mode chokes



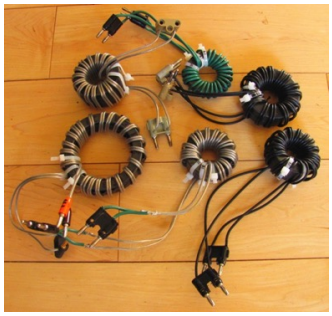
Schematic

Ref: Fair-Rite Corp.



Good materials to use, depending on frequency bands desired. #31 best for lower bands / #43 best for upper bands.

Examples of bifilar-wound common mode chokes – these ARE NOT baluns



Ideally, these should be located at both the antenna and radio

Courtesy, Dave Eckhardt (W0LEV)

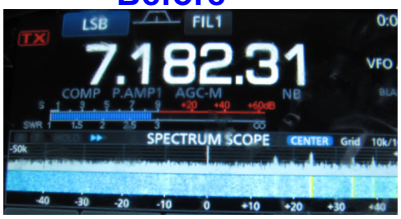
Using a single common mode choke at transmitter

Test Conditions:

Data taken using an ICOM 7300, with 450-long doublet fed with parallel wire transmission line and antenna tuner set to 1:1 match.

A single common-mode choke (CMC) was used between the tuner and feed line. A second CMC at the antenna feed should also show some improvement.

Before



- S8.5 noise floor / many signals hidden

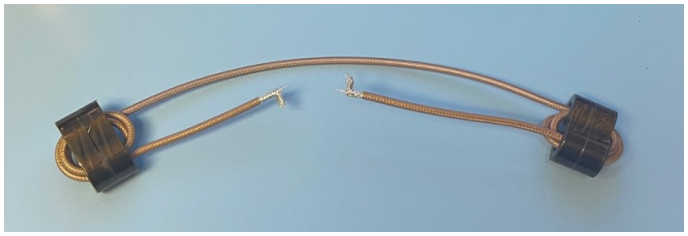
After

- S5.5 noise floor / many weaker signals readable
- 9 dB reduction in noise floor
- (based on the uncommon, but verified 3 dB/S-unit for ICOM 7300)

Courtesy, Dave Eckhardt (W0LEV)

An different example of a CM filter for antennas

Frequency (MHz)	Measured CM Z (Ohms)
3.75	3.8k
7.15	3.8k
10.1	3.2k
14.2	2.5k
18.1	2.0k
21.25	1.7k
24.1	1.5k
28.4	1.2k
50	680



- Uses doubled #31 cores with 3T RG142 coax, each
- W1HIS design
- Kit available from www.kf7p.com

Locating/reducing your own RFI sources

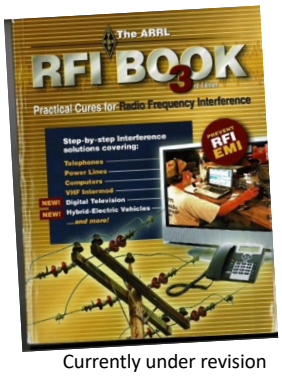
Always try to minimize the RFI sources at your own home

- Best way is to turn off circuit breakers in turn (watch for battery-backed devices)
- Avoid buying noisy switching power supplies (refer to QST reviews)
- Avoid (or remove) noisy LED or CFL lamps
- Replace switching type wall warts with linear power supplies (James Electronics)

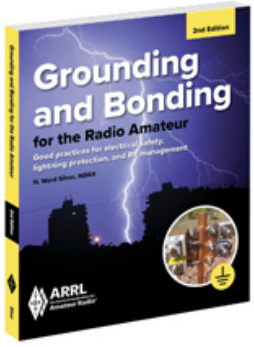
Locating Sources

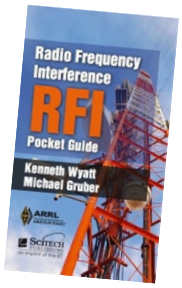
- Spectrum analyzer
- AM/SW radio (or portable QRP rig)
- Flag or loop antenna

Locating/reducing your own RFI sources



Currently under revision





ARRL RFI Page: http://www.arrl.org/radio-frequency-interference-rfi

Example sounds of RFI, http://www.arrl.org/sounds-of-rfi (includes spectra)

Pre-purchase tests

Before purchasing new products:

- Examine FCC or “CE” product label (not always legit)
- Use an AM/SW radio to detect potential RFI
- Use a spectrum analyzer

- Story of my TV purchase at Best Buy

Pre-purchase tests

You can always bring in a portable spectrum analyzer!

https://www.edn.com/review-tti-psa2702t-handheld-spectrum-analyzer/

https://www.edn.com/6-ghz-spectrum-analysis-in-your-hand/

RFI detector

Tecsun PL-360 (with RSSI in dBuV)

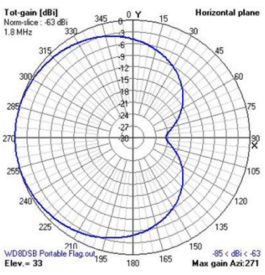
Grundig “Mini 400”

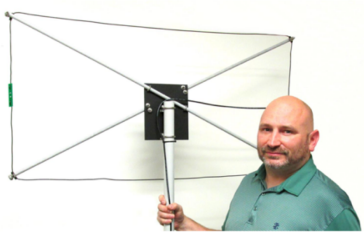
- AM/FM/SW receivers
- Good for locating line-operated or portable RFI sources
- Can also use portable HF/VHF radios, such as Yaesu FT-817/818

https://www.edn.com/review-tecsun-pl-360-emi-receiver/

A “flag” antenna for locating 1.8 to 30 MHz RFI

- Resistive-terminated untuned loop
- Sharp null helps locate direction
- 2 x 4 feet in size





Flag Antenna Construction and Test Results, https://www.qsl.net/wa1ion/flag/flag_antenna.htm
Also, available from DX Engineering as a kit and custom preamplifier,
https://www.dxengineering.com/parts/dxe-noiseloop

Other mitigations

- Reserve operation for “quiet” areas
- SOTA / POTA (may have ”noisy” neighbors, though)
- My vacation experience (S5 to S7 at home versus “S0” in Utah)
- Mobile (may deal with automobile RFI)

The future – not so rosy

- Appliance manufacturers not regulated by FCC (they ARE elsewhere in the world
- Overwhelming number of cheap (unfiltered) SMPS, lighting and power supplies
- Ultimately, it may be the FAA or military that will force change, not the FCC
- Hams will need to depend on filtering and new technologies to battle RFI pollution

Suggested references

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