Resolving Furnace and A/C RFI (*Radio Frequency Interference*) Problems: Lessons Learned

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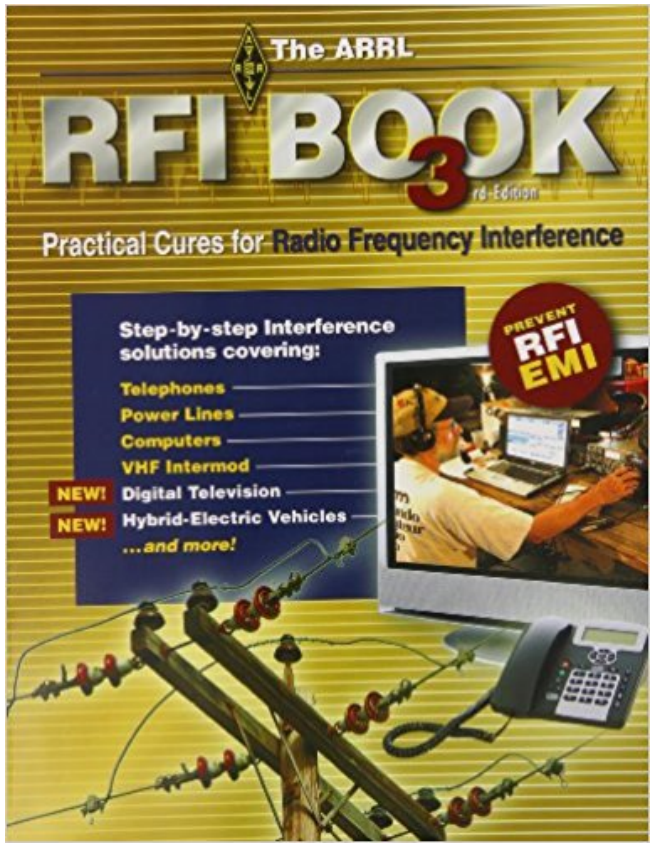
A presentation for the Virginia Wireless Society

https://viennawireless.net/wp/

2 OCT 2017– (version 9 – with post-presentation corrections & extensions)

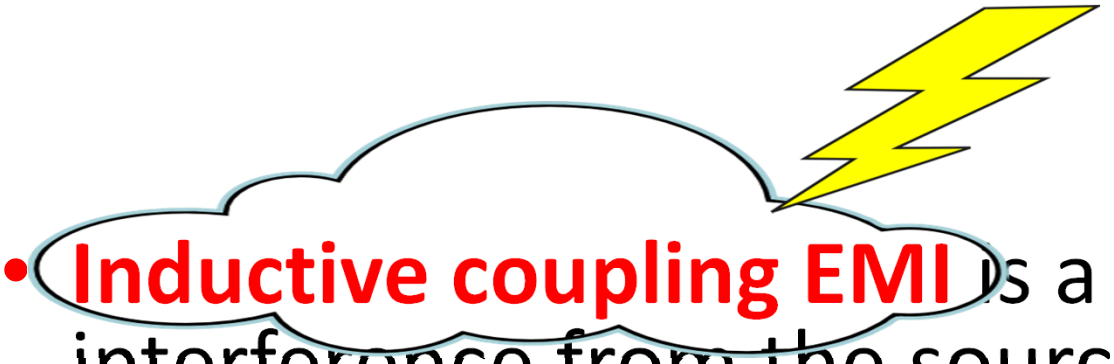
The ***ARRL RFI Book*** 3rd edition



- Excellent resource
- Edited by Mike Gruber W1MG
- No chapters on HVAC (*Heating, Ventilation, and Air Conditioning*) RFI
- Referenced here as **ARB**

- ***EMI*** and ***RFI*** are used interchangeably here.
  - ***EMI*** is any frequency of electrical noise
  - ***RFI*** is a specific subset of electrical noise on the *radio frequency* spectrum.
  -
- **Conducted *EMI*** is electromagnetic energy that is propagated along a conductor(s). In a typical RFI scenario, the conductor(s) act as an antenna to radiate the RF energy. House wiring is a common radiator of conducted emissions. This tends to be more of an RFI issue at frequencies below 30 MHz.

- **Radiated EMI** is electromagnetic energy that is directly radiated by the source device. This tends to be an RFI issue at frequencies above 30 MHz.



- **Inductive coupling EMI** is a path in which interference from the source device is coupled into the victim device by a magnetic field. Inductive coupling is typically a low frequency phenomenon with a very short propagation path.

The Most Common RFI Mode

- Interference from conducted emissions is usually caused by radiation from wires and cables connected to the RFI source.
- The radiated noise from the power and house wiring is then picked up by the antenna, and enters the radio via the RF connection.
- *Conducted RFI* via the power connection is a less common source of interference.
  - Re: Mike Gruber / W1MG / personal communication

FINDING LOCAL RFI SOURCES BY ELIMINATION

Because sometimes it's *good* to be out of the loop ...

AC = alternating current

A/C = air conditioning unit

Common Mode Noise: noise that is in phase in 2 or more conductors of an antenna lead or other differential signal source. There is typically a ground return path for the in-phase noise in both conductors.

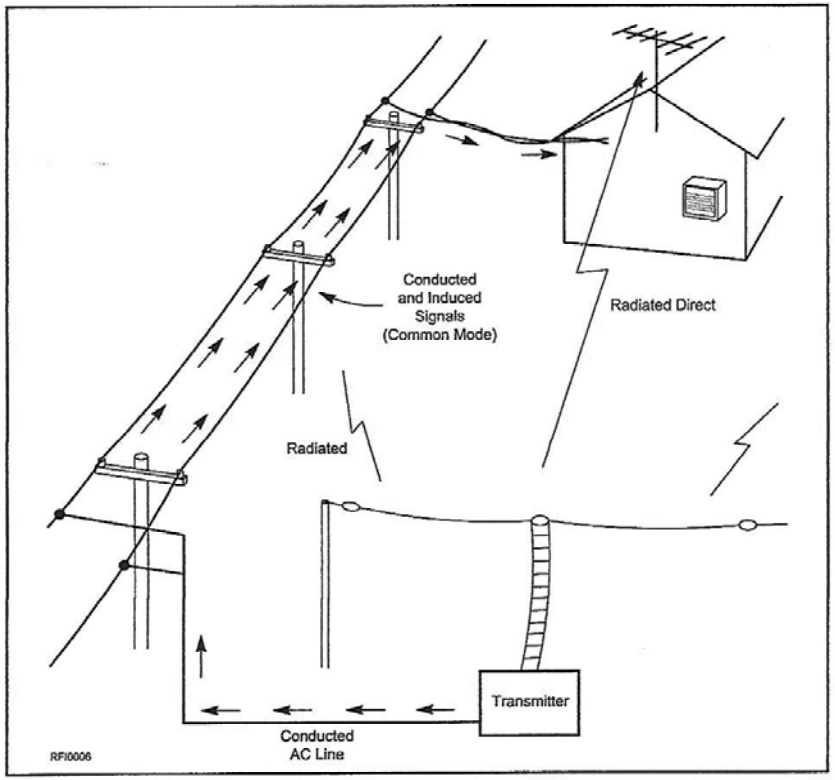


Figure 2.4—Conducted and radiated interference.

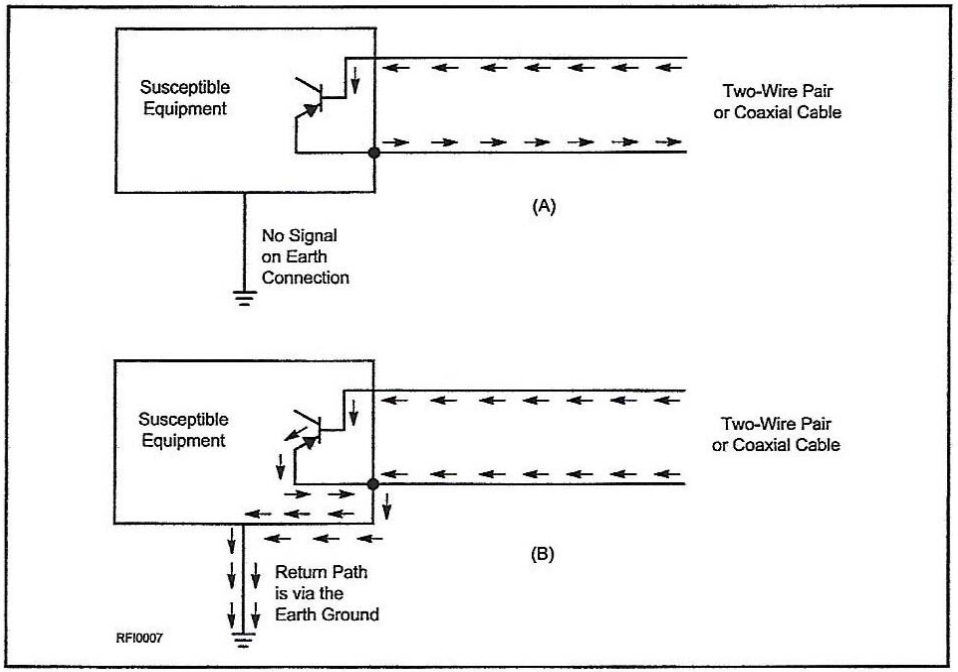


Figure 2.5—(A) Differential-mode signals are conducted between two wires of a pair. This signal is independent of earth ground. (B) A common-mode signal is in phase on all wires that form the conductor (this includes a coaxial cable). All wires act as if they are one wire. The ground forms the return path, as with a long-wire antenna.

Conducted & **radiated** interference:
Conducted: FROM a transmitter TO the AC powerline
Radiated: FROM the transmitter antenna to a TV antenna
from ARB p. 2.5

Common-mode signal with ground return, as with a long wire antenna.
from ARB p. 2.6

1. **Turn off EVERYTHING electrical** (fluorescent lights, computers, cell phone chargers, television monitor and box, routers, furnace, A/C...)
2. **Turn elec. devices back on individually.**

   With furnace on, try 'fan only' mode, 'heating' mode, and 'cooling [AC]' mode.
3. **Document the RFI with monitor screen shots if possible .**

Radiated vs **Conducted** RFI 1/2

- If possible, operate the radio on battery power.
  - **Conducted RFI** through the AC power line and/or outboard transceiver power supply may be temporarily eliminated.
  - **Radiated RFI** will still cause RFI.
  - Of course, *both* conducted and radiated RFI may be present.

Radiated vs **Conducted** RFI 2/2

- As an alternative to using battery power, disconnect the antenna.
  - **Conducted RFI** through the AC power line and/or outboard transceiver power supply will – if present - still cause RFI.
  - It may be necessary to reset the threshold for the spectrum waterfall display, if the transceiver has one.
  - **RFI sniffers** ... (next slide).

RFI Sniffers

MFJ-856 directional
RFI noise finder
135 MHz ~$150

Model 243 RFI locator:
0.5 – 1000 MHz
www.radarengineers.com

The "Sniffer"

It is fortunate that the FCC doesn't require us to measure chassis radiation levels accurately, as this requires sophisticated equipment. The home-built "sniffer" illustrated in Figure B can give a qualitative measure of chassis leakage.

The sniffer does not respond strongly to electric fields, but favors magnetic fields, which are prevalent in radiation from poor RF shields. Connect the sniffer to a device capable of receiving the interfering signal (such as a TV set) and move the loop around the suspect chassis. Maximum pickup should occur with the loop wire at right angles to any slots or seams and parallel to any wires exiting the shield enclosure.

The "sniffer" is used to measure unwanted chassis leakage of harmonics and other spurious emissions. Construct as follows:

1) Remove 12 inches of outer insulation from the end of the coaxial cable.
2) Remove 11 inches of shield from the end of the cable, leaving 1 inch of exposed shield.
3) Remove ½ inch of inner insulation from the end of the cable.
4) Wrap the end of cable into a coil with three or so loops as shown in Figure B.
5) Wrap and solder the center conductor to the exposed shield.

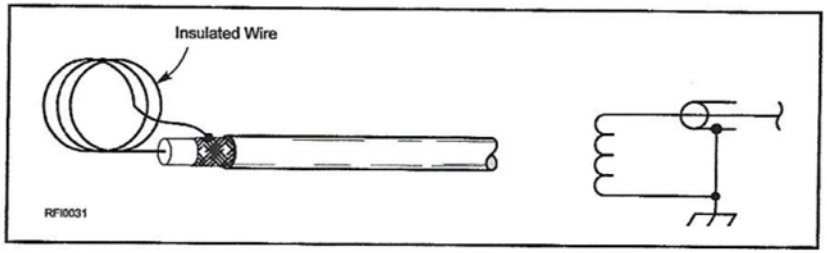


Figure B—A pickup loop for detecting cabinet radiation and IMD from external rectification. Use the loop with an appropriate radio or television receiver.

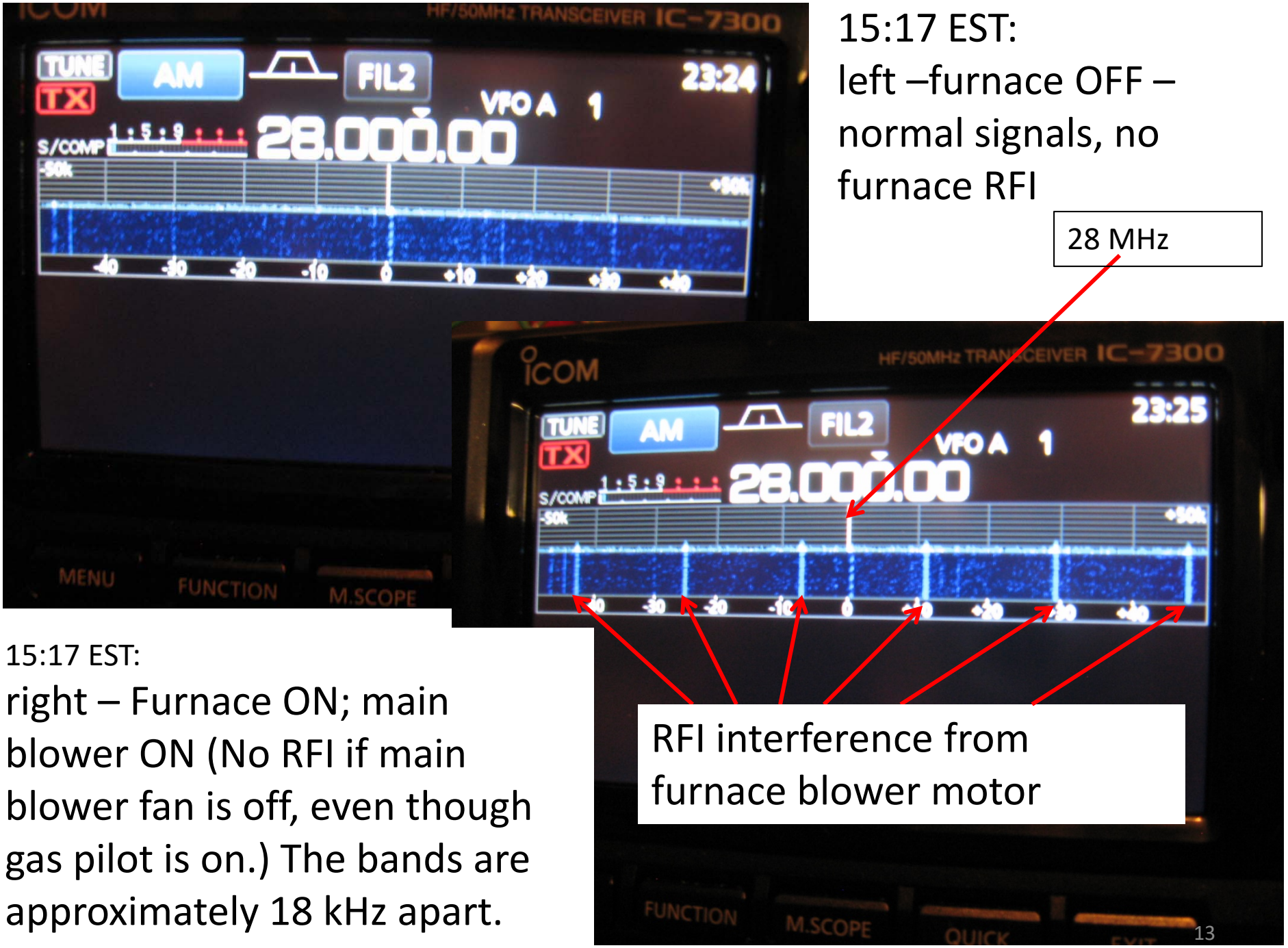
ARB p. 3.7: home-made chassis RFI leakage sniffer

Documenting my RFI problems

- ‘Myantennas’ 65 ft endfed EFHX-4010-1K wire antenna
- ‘Myantennas’ CMS-130-3K common mode choke (between the downfeed and the lightening arrestor)
- IC-7300 with built-in monitor

(Screenshots taken with Canon A590 Powershot camera)

15:17 EST:
left –furnace OFF – normal signals, no furnace RFI



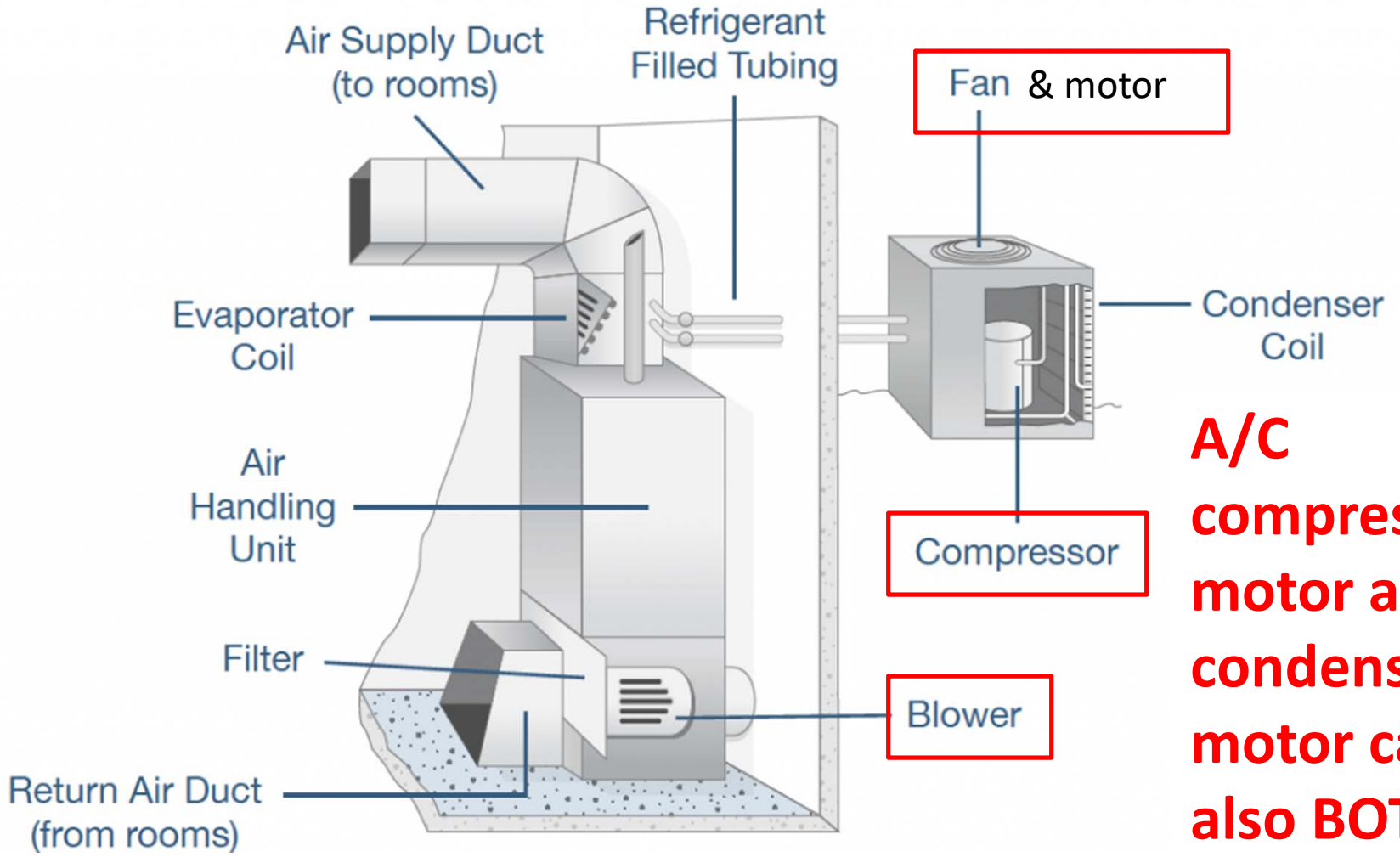
15:17 EST:
right – Furnace ON; main blower ON (No RFI if main blower fan is off, even though gas pilot is on.) The bands are approximately 18 kHz apart.

When the A/C (outside unit; 240 v) is turned on, additional interference bands present on top of the ‘picket fence’ bands from the blower, approximately 35 kHz apart. The blower interference is still present.

Overview of furnace and air conditioning systems

Furnace and A/C components:

- Furnace:
  - ***induction fan***, which draws air from the outside- until recently, rarely the source of RFI, but newer systems may use an ECM or induction motor with a variable frequency drive. In either case, there is the possibility of RFI.
  - ***blower* fan** which circulates heated/cooled air.
- A/C units:
  - a ***condenser fan motor***
  - **a *compressor motor***.

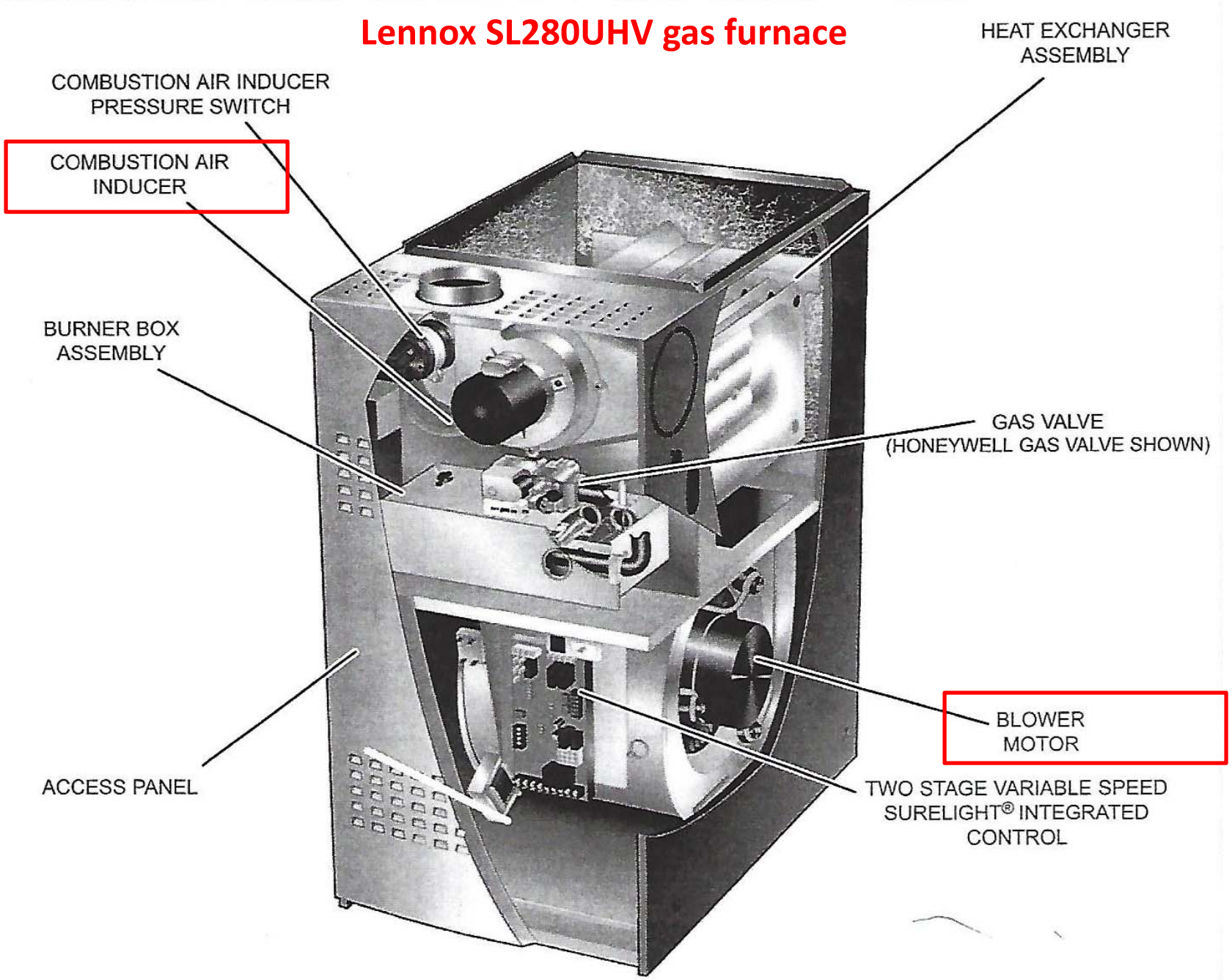


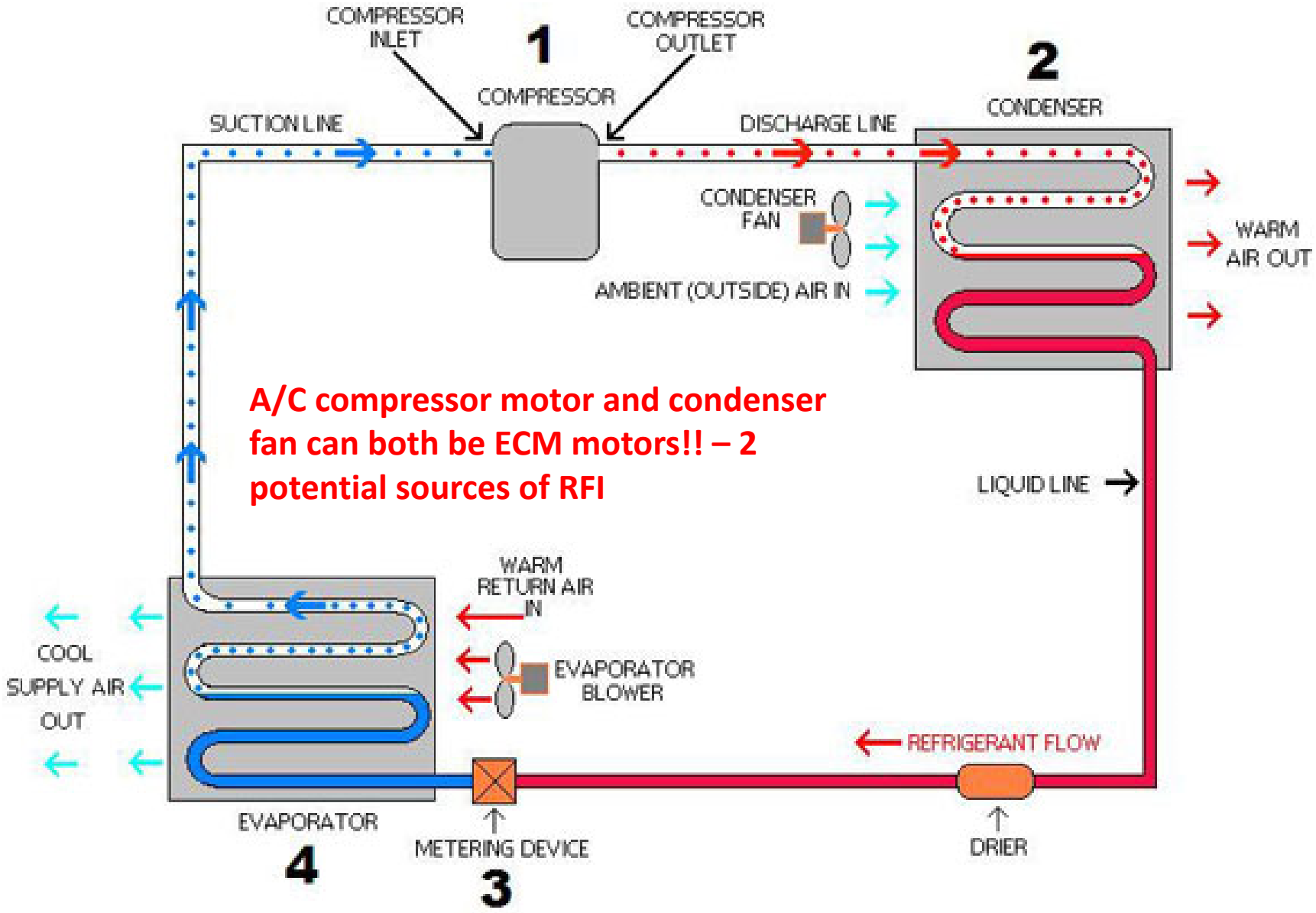
A/C compressor motor and condenser fan motor can also BOTH be ECM motors!! – 2 potential sources of RFI

In a furnace, both the blower motor and induction motor can be ECM motors. Both are potential sources of RFI.

http://www.standardheating.com/hvac-maintenance/hvac-diagram/

Lennox SL280UHV gas furnace




COMPRESSOR INLET
1
COMPRESSOR OUTLET
2
COMPRESSOR
CONDENSER
SUCTION LINE
DISCHARGE LINE
CONDENSER FAN
WARM AIR OUT
AMBIENT (OUTSIDE) AIR IN
A/C compressor motor and condenser fan can both be ECM motors!! – 2 potential sources of RFI
LIQUID LINE
WARM RETURN AIR IN
COOL SUPPLY AIR OUT
EVAPORATOR BLOWER
REFRIGERANT FLOW
EVAPORATOR
4
METERING DEVICE
3
DRIER

SOURCES OF *RFI* FROM "HIGH-END" [I.E. HIGH-EFFICIENCY] FURNACES AND AIR CONDITIONING UNITS USING ECM (ELECTRONIC COMMUTATORLESS MOTORS)

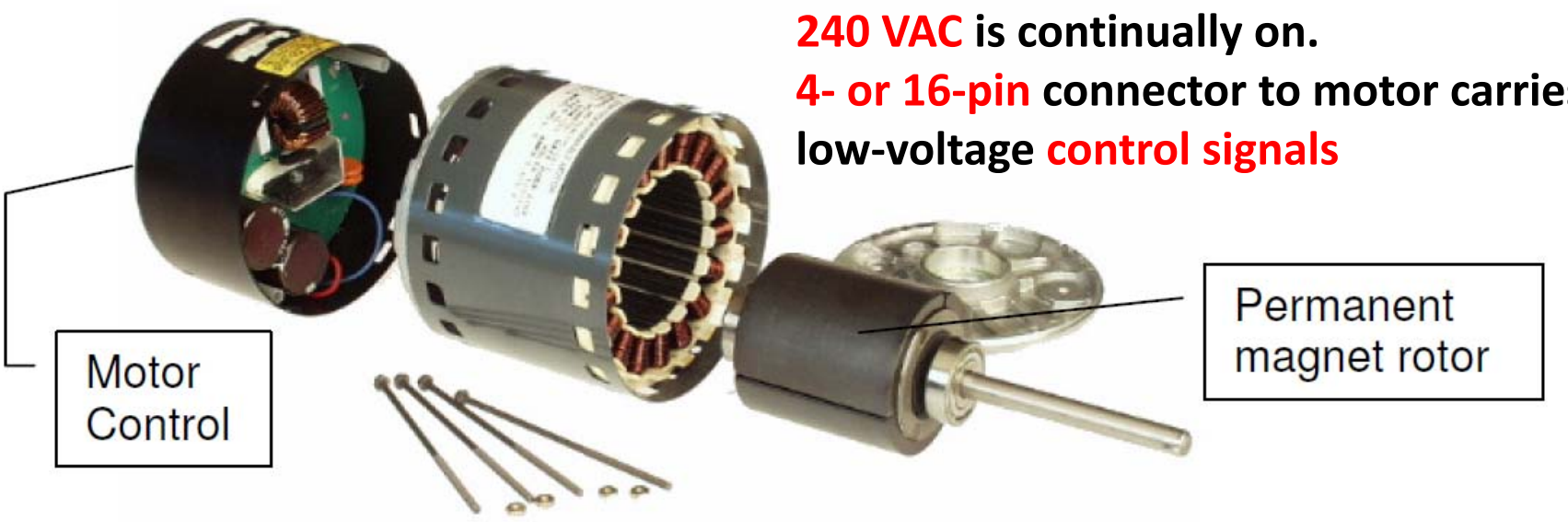
Why "going green" with HVAC may contribute to RFI:

Because ECMs (*Electronically Commutated Motor*) may be used for the furnace blower, A/C compressor, and/or A/C Condenser fan

ECM (Electronically Commutated Motor) 3.0

5-pin connector to motor: 120 VAC or 240 VAC is continually on.

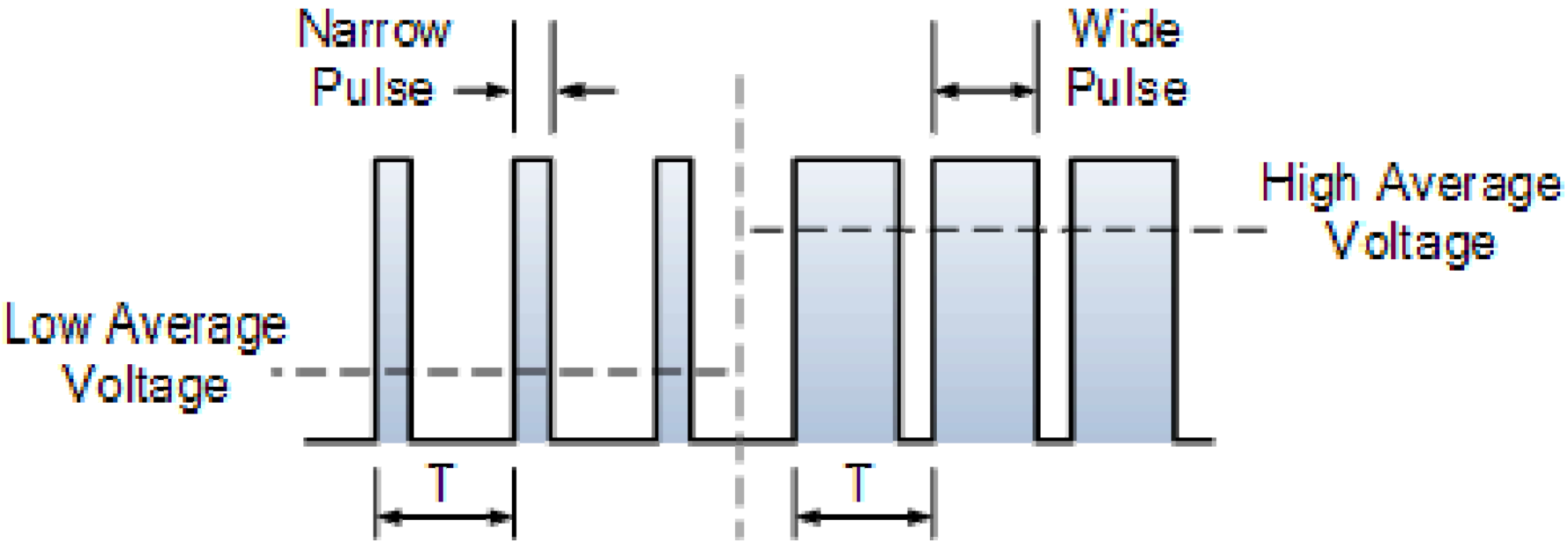
4- or 16-pin connector to motor carries low-voltage control signals



from 'The ECM Textbook'

ECM 3.0 ECM 2.3/2.5

from:
http://www.electronics-tutorials.ws/blog/pulse-width-modulation.html



Pulse Width Modulation

There are many different ways to control the speed of motors but **Pulse Width Modulation (PWM)** is common/simple.

(1) http://www.samlexamerica.com/support/faqs/faq18.aspx

(2) https://www.engineersgarage.com/articles/smps-switched-mode-power-supply

Sources of switching power supply noise (ref 1):

(1) Switching frequency harmonics [15-50 kHz (2)]

(2) Broadband noise created by under-damped oscillations in the switching circuit.

(3) The AC input rectifier / capacitor "are notorious" for generating power supply harmonics because of the non-linear input waveform.

Radiated RFI

1. RFI can be both *conducted* and *radiated*.
2. If there was a short line cord to the furnace blower motor, rather than a 'long' wiring harness, the *radiated* RFI would probably be very low.
3. **The unintentional antennas created by the wiring permit the [legal] *conducted* RFI to be *radiated* from the ECM motors. IF there is also a current return path via shield or ground loop, a ¼ wavelength resonator could even result (!): e.g. 7 ft ~ ¼ wavelength at 10 m.**

FCC Regulations

Not as stringent as you think?

FCC Regulations Regulating RFI

CFR (Code of Federal Regulations) (2009)

Title 47:

- Telecommunications

Volume (Chapter) 1

- Federal Communications Commission regulations

Part 15:

- RADIO FREQUENCY DEVICES

Parts 15.105 – 15.109 [Unintentional Radiators]

- RFI standards, etc.

The entire 120 page document is available at :

http://www.curtisind.com/files/pdf/CFR-2009-title47-vol1-part15.pdf

Permissible Levels of ***Conducted Radio Frequency Voltage*** (15.107)

Frequency of emission (MHz)	Conducted limit (dBµV)	
	Quasi-peak	Average
0.15–0.5	66 to 56*	56 to 46*
0.5–5	56	46
5–30	60	50 316 µV

*Decreases with the logarithm of the frequency.

µV	mV	dBµV
1	0.001	0
10	0.01	20
100	0.1	40
1000	1	60
10 000	10	80
100 000	100	100

(Above) Permissible RF voltage conducted back into the AC power line, as measured using a 50 µH/50 ohms ***Line Impedance Stabilization Network*** (**LISN**), which should drive the line impedance to 50 ohms. (µH=microHenries)

dBµV = 20log$_{10}$(V_{OUT}/1µV) [not dimensionless]

Emission Testing: **Incidental** vs **Unintentional radiators**

- ***"Incidental radiators"*** **have no oscillators, or oscillators below 9kHz.**
- **"*Unintentional radiators*" have at least one oscillator with a frequency > 9 kHz. [Part 15 Subpart A - 15.3 (k)]**
  - ECM motors can have switching frequencies of 18 kHz, and the harmonics can be higher.
  - ECM motors with high-speed switching power supplies are typically classified as **Unintentional Radiators**, rather than as **Incidental Radiators**.
  - The emission measurement procedures for **Unintentional Radiators** are covered in IEEE/ANSI C63.4-2014

Emission Test Requirements for **Unintentional** Radiators

- ECM motors can have switching frequencies of 18 kHz, and the harmonics can be higher.
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  - The emission measurement procedures for **Unintentional Radiators** are covered in IEEE/ANSI C63.4-2014

Emission Testing: **Unintentional radiators**

For **Class B** (residential) digital devices

Frequency of emission (MHz)	Field strength (microvolts/ meter)
30–88	100
88–216	150
216–960	200
Above 960	500

[Above] The emitted field strength from **unintentional radiators** shall not exceed the above at a distance of 3 meters. [Continued on next slide.]

There is no requirement to test field strength below 30 MHz.

Eliminating the RFI

Safety first ...

- For the air conditioning unit, the A/C disconnect switch or breaker should be set to ‘off’ (right) prior to attempting any repairs Turning off the furnace does not disconnect the power to the A/C unit.

Lockout ‘ON.’ Remove, invert, and reinsert the disconnect switch (breaker) to lockout ‘OFF’.

Lockout ‘OFF’

Steps in troubleshooting HVAC I

1. Check your HVAC warranty – (3 years into 10 year Lennox warranty)
2. If system under warranty, work through your dealer.
3. If possible, differentiate between *conducted EMI* into power line and *radiated EMI*
4. Test system in different modes (may require dealer support):
   - furnace blower on; no heating or cooling
   - A/C: compressor only; condenser fan OFF. (May be necessary to have furnace blower fan on.)
   - A/C: condenser fan only; compressor OFF

Steps in troubleshooting II

5. Identify specific components causing RFI – in my case:
   - furnace blower ECM motor, induction motor in my system is not ECM.
   - A/C compressor ECM motor
7. Try to identify *manufacturer*, *model*, and *S/N* for above components. *Vendor [e.g. Lennox] part number may be insufficient.*
8. Document with screen shots, if possible.

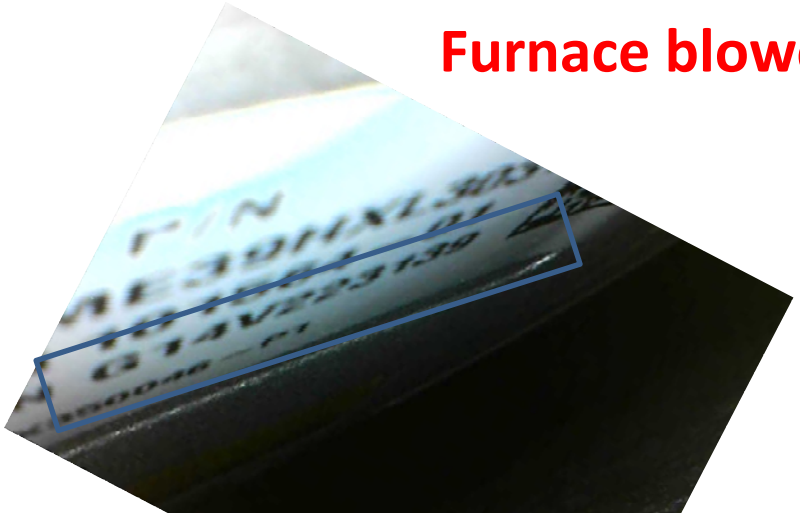
Steps in troubleshooting III

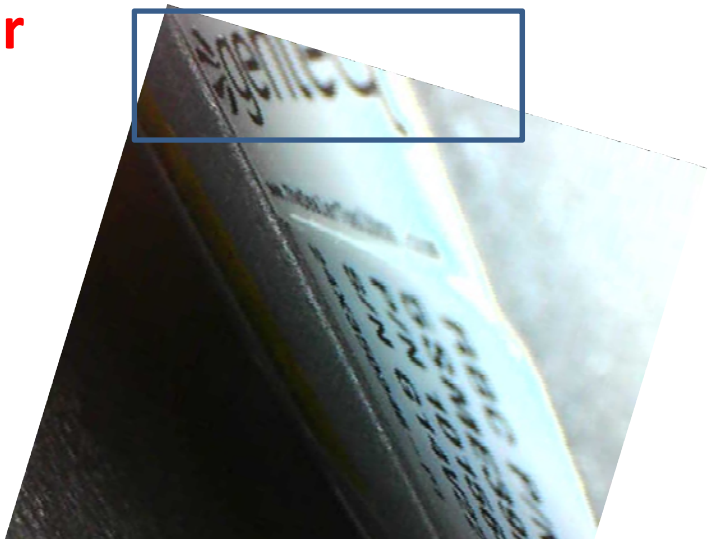
8. Fix & test – hopefully with assistance from HVAC dealer and manufacturer. In my case, ACE HVAC covered all costs of repair.
   - ***Furnace lower fan ECM motor.***
   - ***Regal Beloit*** *[pronounced BEL'-oit - rhymes with DE'-troit]* provided custom RFI filter for furnace blower motor – Genteq ECM 3.0 model
   - **Compressor ECM motor. LG** has large inductive reactance filter.
   - There is also 3-phase drive to the motor windings, and the return current must be properly handled to avoid radiated EMI.
   - **Lennox field service** diagnosed and fixed **LG** compressor motor issue due to radiated EMI.

AC unit with panel removed. Condenser fan is concealed by circuit board

Lennox A/C unit has ***LG*** ECM compressor motor (not shown) and ***emb pabst*** ECM condenser fan motor (above) – both potential sources of RFI!

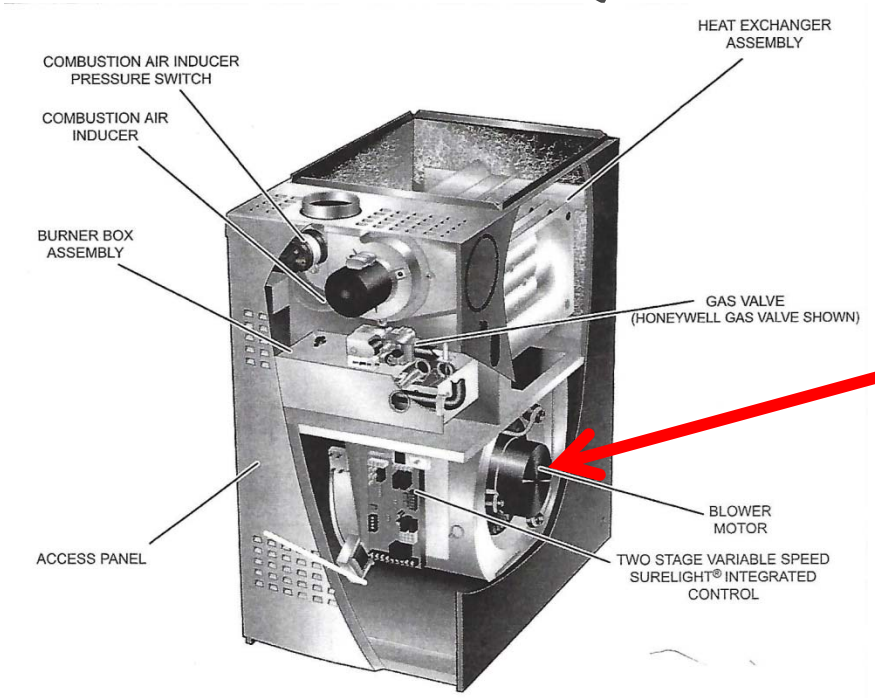
Furnace blower motor





S/N G 14V223139 …

Genteq (Regal Beloit) blower motor



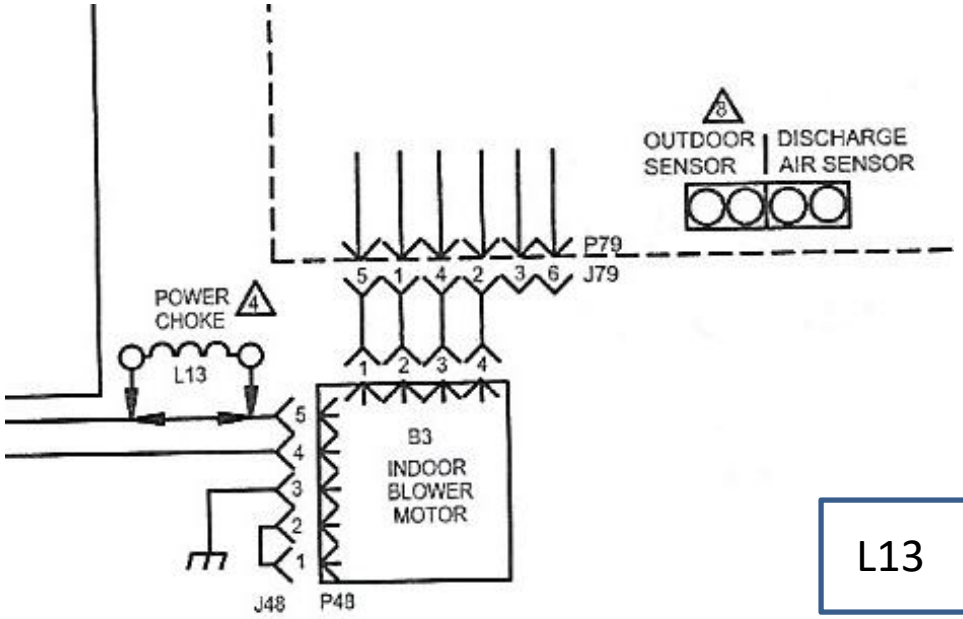
An endoscope with a reversing mirror attachment was used to read S/N and manufacturer of furnace blower motor.

Furnace blower motor filter

Provided by Regal Beloit to eliminate radiated RFI via potential ground loop

The Regal Beloit blower motor RFI filter

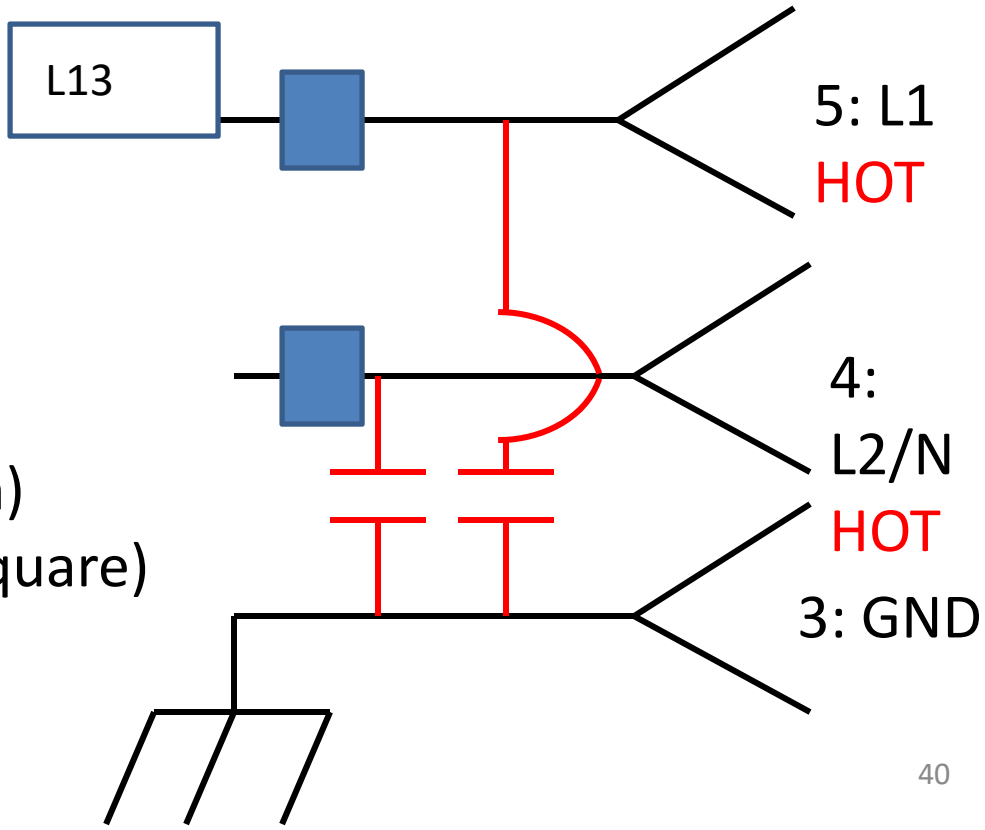
- After I confirmed the manufacturer (*Genteq,* manufactured by *Regal Beloit*) and model S/N, Regal Beloit provided a custom RFI filter for the ECM 3.0 blower motor.
- The filter plugs directly into the control port of the ECM motor, and the wire harness plugs into the filter.
- Installed by ACE Heating and Cooling.



Regal RFI filter:

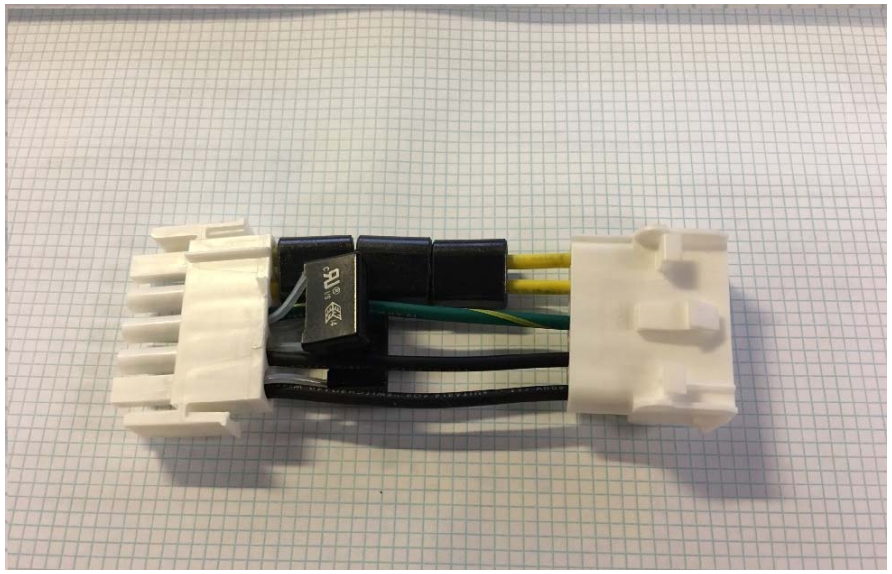
At the J45 connector of the wire harness to the B3 indoor blower motor.

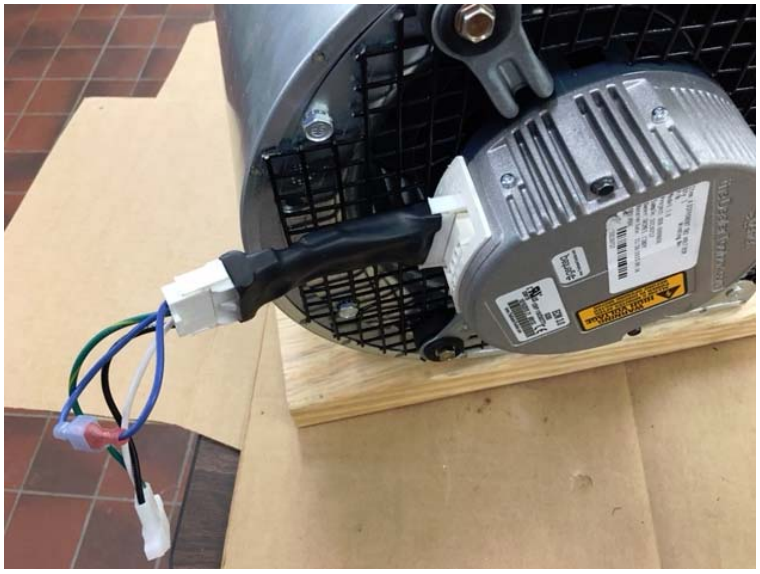
1. capacitor from 5 to 3
2. capacitor from 4 to 3
3. ferrite chokes on control wires 5 and 4 – between L13 and the blower motor. (L13 may not be present in my system.)



3 binocular (clamp-on) ferrite chokes (blue square)

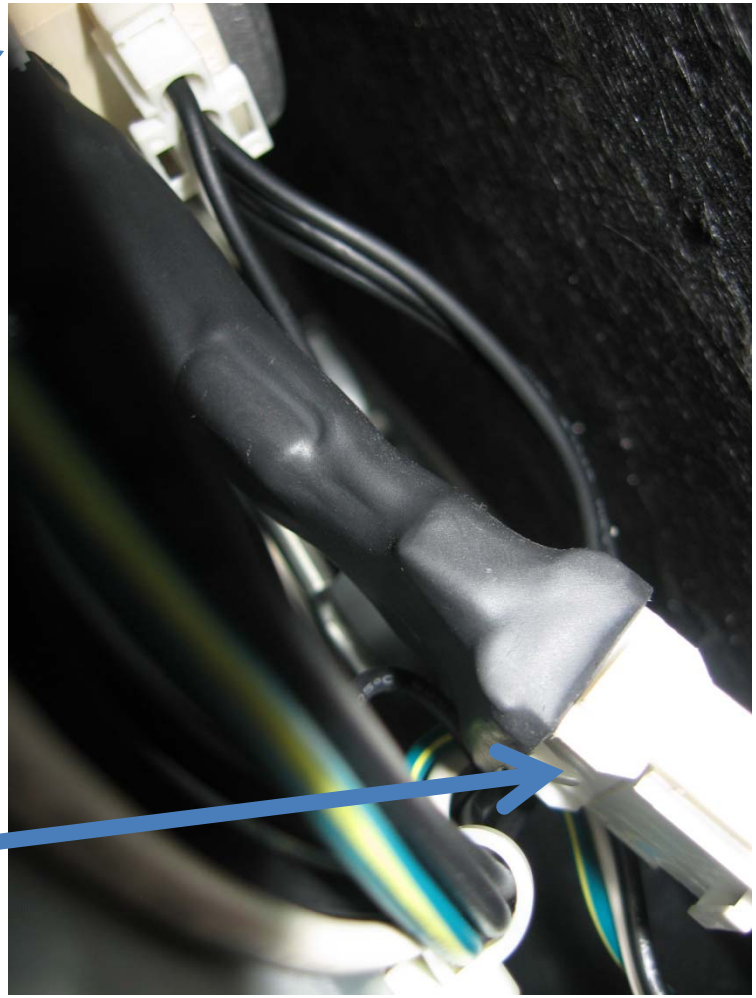
capacitor (.01 ufd, 250 v)





The ECM 3.0 filter – images provided courtesy of Regal Beloit.

Regal Beloit RFI filter plugs into ECM 3.0 motor



Plug for control wire harness to blower motor

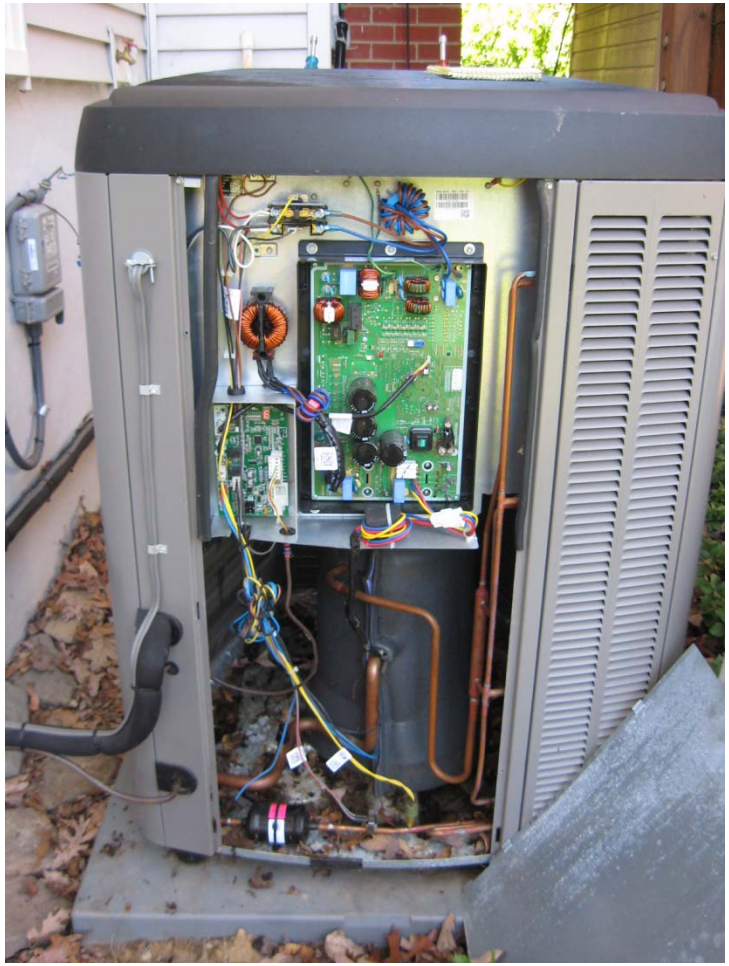
The shrink-wrapped Regal Beloit RFI filter plugged into the ECM 3.0 Genteq blower motor.

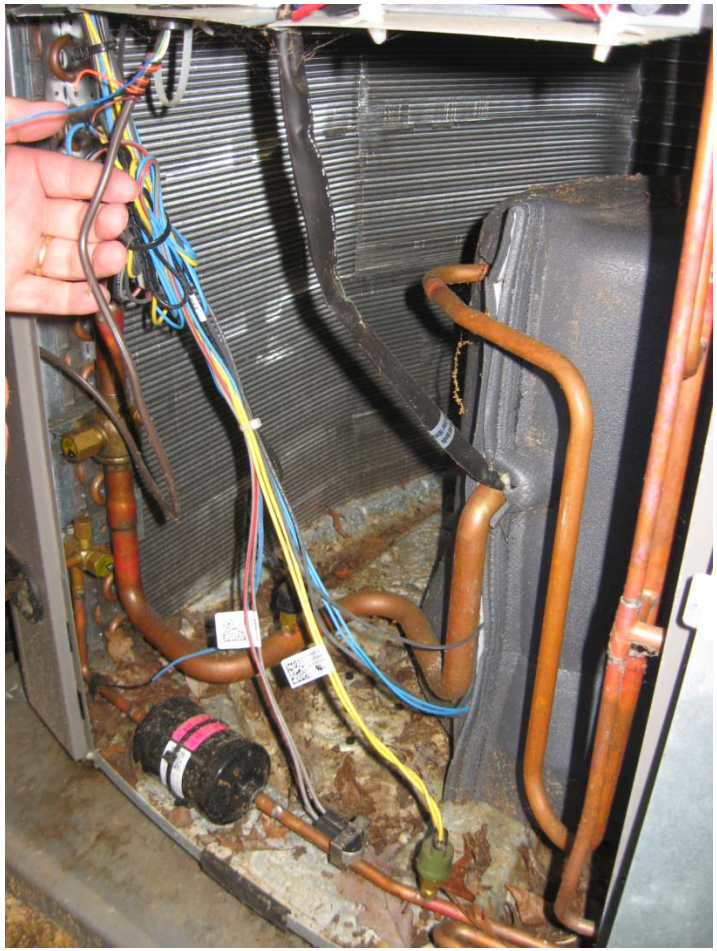
A/C unit

Fix ungrounded wires in thermostat harness

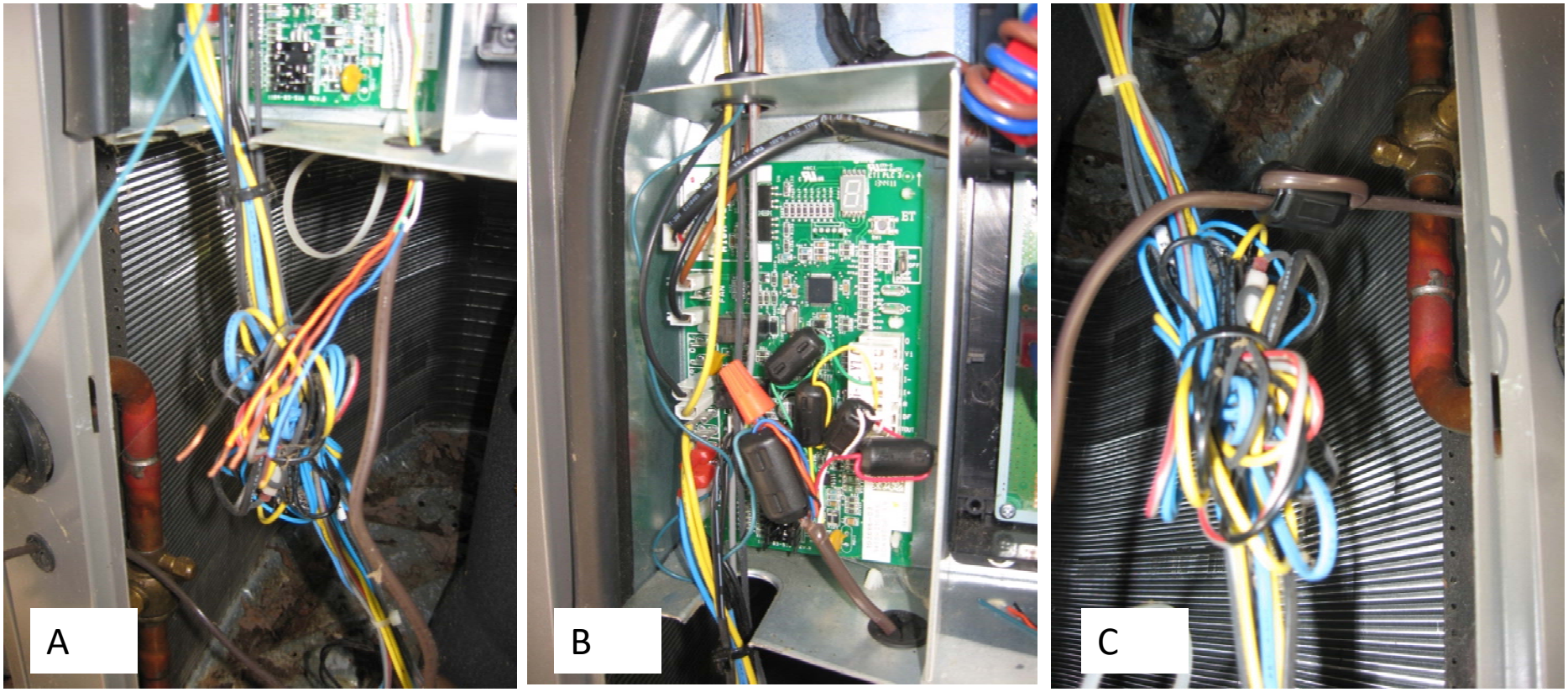
LG compressor motor

- Company asserts no significant conducted EMI because of significant **inductive reactance EMI filter** on control board.
- Radiated RFI could not be ruled out as a function of the installation





The A/C problem: there was an **8**-wire harness connecting the control unit to the internal thermostat, but **4** wires were both unused and ungrounded! (It is standard to have extra wires in a thermostat cable for possible future use.)



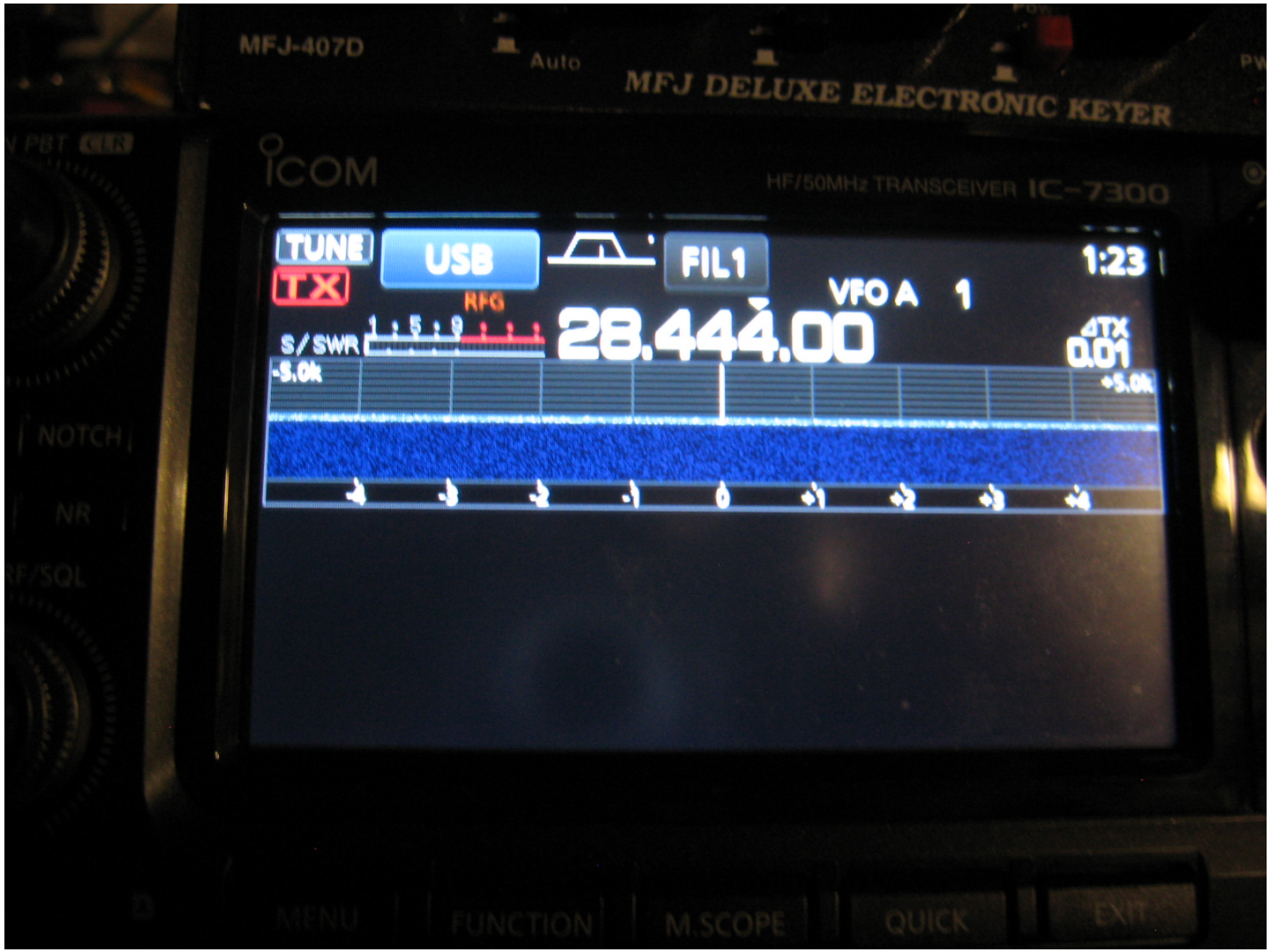
Lennox's solution: bare (A) and **ground** the 4 unused wires, and add **external ferrite core chokes** as an added precaution (C and D). The 4 unused wires no longer serve as inductive radiators propagating RFI back into the house.

Manufacturer-specific motor and wiring harness identification

- Identifying the motor and wiring harness can facilitate RFI diagnosis and resolution.
- For example, each ***Genteq/Regal Beloit*** motor, typically have a *(1) family designation* and a *(2) manufacturer model number*:
  - The motor family designators e.g. **ECM 3.0**, **Endura**, **EON** ... identify the class of indoor blower motor.
- The model *number* on the Regal nameplate will always begin with ***5SME93xxx***.
- This number identifies the distinctive wiring harnesses used in external units. e.g.
  - In a 'remote' motor, the switching control unit is physically separated from the motor body proper.
  - If so, a torroidal ferrite choke may be required to suppress unintentional radiation from the cable connecting the control unit to the motor.

Problem solved …

With furnace blower and A/C on full,
no more interference on any bands



SUCCESS! With the furnace blower and A/C running at full power, 10m had no RFI, and 20m had normal activity and also no RFI.

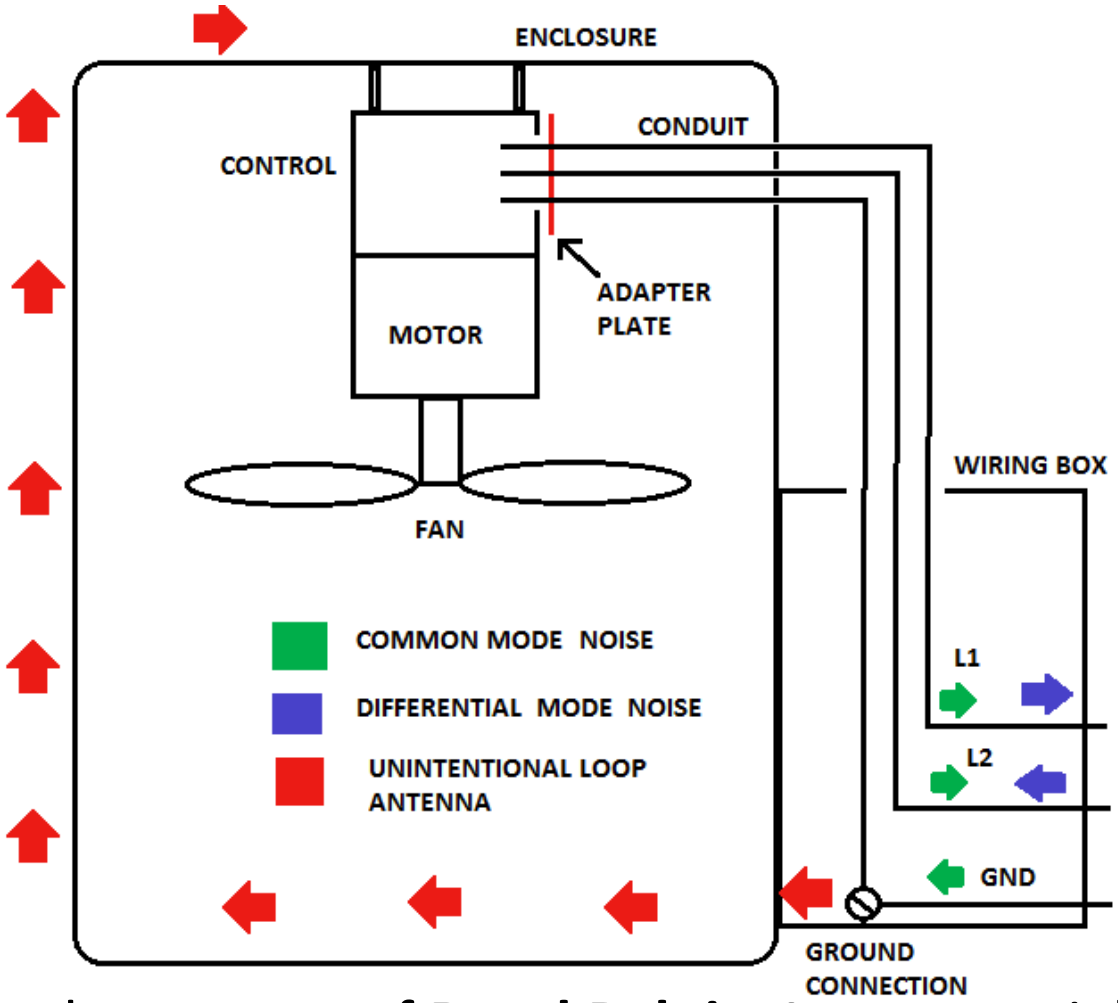
A few internet memes ….

"(1) Since I'm getting interference, the furnace or A/C is not FCC-compliant"

- *Usually not true ...*

- A small level of **conducted** AC EMI is permitted by regulation – see preceding slides.
- Manufacturers are not required to test for ***radiated*** EMI below 30 mHz.

- Radiated EMI can occur because of improper grounding, inadvertent ground loops, or improper wiring installation.



Example courtesy of **Regal Beloit**. A commercial EMI filter will **not** eliminate RFI here, because it will shunt RF from L1 and L2 to ground, but the *return conduction* (in **red**) through metal case is being radiated. Instead, we must shunt RF to ground right at the adapter plate.

"(2) Installing an EMI line filter will eliminate your problems"

- *Depends on the cause ...*

- An EMI line filter may not have any effect on *radiated* RFI, but *can* help with conducted common mode RFI from power lines, etc.
- I have a CMC (common mode choke) inline with my antenna, and a Tripp-Lite surge protector with a cascaded RFI filter bank.

- No FCC requirement to test for radiated EMI below 30 mHz.
- Radiated EMI can occur because of improper grounding, inadvertent ground loops, or improper wiring installation (as in my case).

"(3) Shielding the ECM control cables in your furnace will eliminate RFI"

- *This DIY could help, but alternative solutions may exist*
- See: **RFI Mitigation in Rheem RGFG High Efficiency Furnace (AC2EV)** for a discussion of successful DIY cable shielding
- *http://www.eham.net/articles/32146*

- In my system, a custom Regal Beloit filter for the furnace blower motor was used to correct for radiated EMI.
- Ungrounded/unused wires in the A/C wiring harness should be identified and grounded.

"(4) If the RFI isn't fixed, I'll file an FCC complaint" 1/2

- *Always a legal option – but:*
- (1) RFI may be due to local installation issues, rather than component malfeasance.
- *(2) "Many complaints are simply acknowledged, however, and the complainant is told that it will be used for statistical analysis." re:*
  - http://www.arrl.org/news/redesigned-fcc-website-makes-it-easy-for-hams-to-file-interference-complaints
- (3) Informal complaint can be filed for free.
  - Fee for formal complaint is $225.
- (4) The FCC may simply refer you elsewhere (next slide).

"(4) If the RFI isn't fixed, I will file an FCC complaint" 2/2

- See: *"The Noise Frontier [NY2RF]"* ***QST*** November 2016:
- After a post FCC-consultation by the local authorities, ham radio operators were asked for assistance, and helped the Evanston Illinois police in locating "*an errant neon-light power supply*" causing wide-spread RFI.
  - The FCC original referred the Evanston police to the automobile manufacturers (!), since wireless key fobs in the area had stopped working.

Acknowledgements

ACE Air Conditioning and Heating Services (northern VA)

- **14088-H Sullyfield Circle, Chantilly, VA 20151**
- Honored 10-year warranty on Lennox system 3 years after installation
- Multiple no cost service calls in response to RFI issues
- 'Fine business'

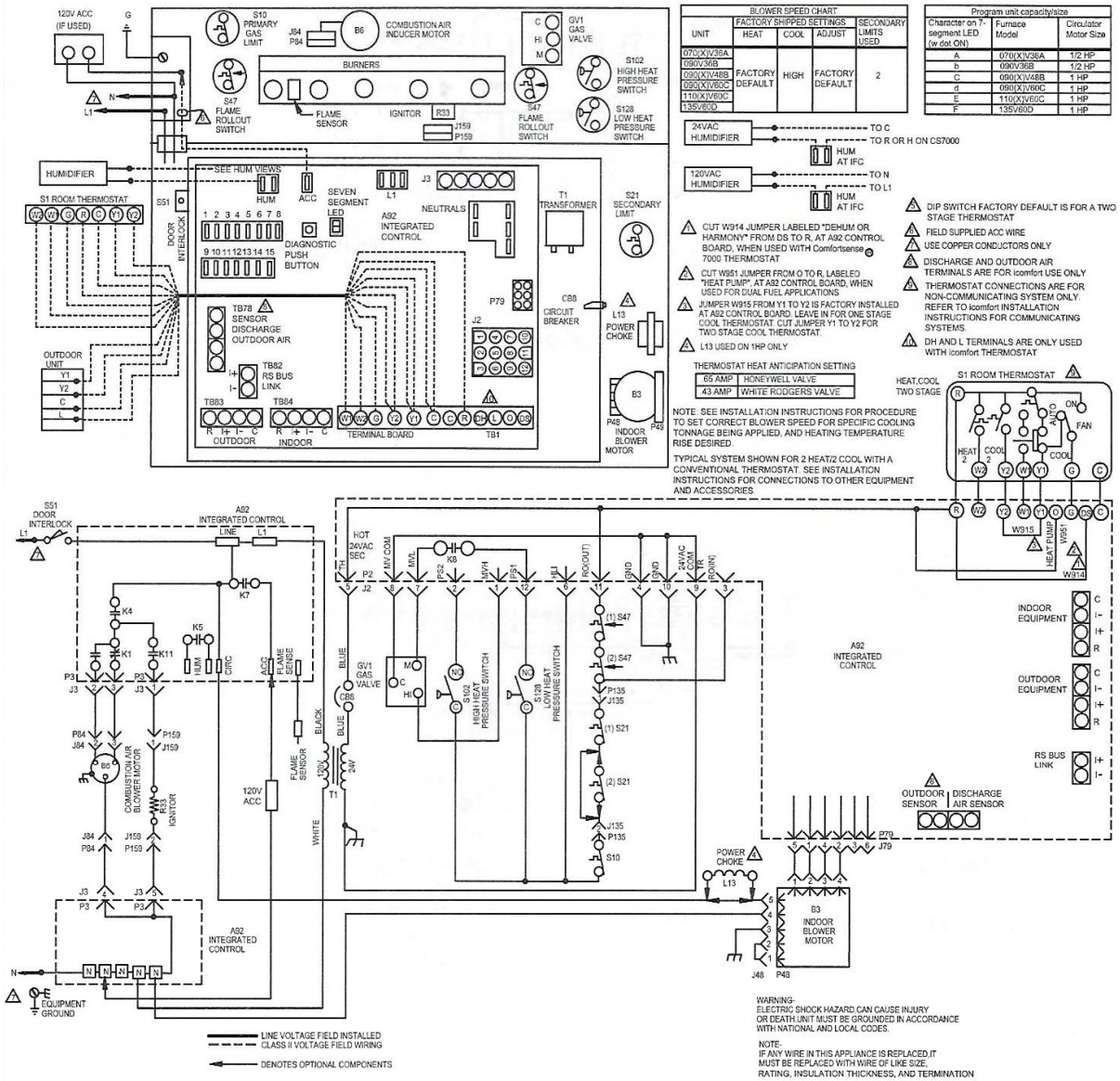
Services provided through ACE

- Lennox field engineering services
  - 2 site visits to my home (no cost)
- Regal Beloit, Fort Wayne, Indiana
  - email analysis and support
  - ECM 3.0 filter provided at no cost by mail
  - *Note - 'Beloit' is pronounced BEL'-oit] – rhymes with 'Detroit' - and not as Bel-WAH' - as in my audio presentation. – r.h.*

APPENDIX

dBµV or dBuV (decibel microvolt, amplitude ratio) — absolute voltage in decibels relative to one microvolt, used to measure the signal strength in RF and audio cables. That is $dB\mu V = 20\log_{10}(V_{OUT}/1\mu V)$ where V_{OUT} in µV. This shows that dBµV is independent of impedance. Since it is the ratio of two voltages, they can be measured as peak-to-peak or RMS and with the same units. Reference voltage 1 µV.

SL280UHV Schematic Wiring Diagram



§ 15.105 Information to the user.

(b) For a Class B digital device or peripheral, the instructions furnished the user shall include the following or similar statement, placed in a prominent location in the text of the manual:

NOTE : This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

—Reorient or relocate the receiving antenna.

—Increase the separation between the equipment and receiver.

—Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.

—Consult the dealer or an experienced radio/ TV technician for help§.

Switching Power Supplies

- Switching power supplies are light and efficient, but the switching frequencies may be as high as 1 MHz.
- Manufacturer's acknowledge this can create RFI problems ... (next slide)

- From the Samlex website:

http://www.samlexamerica.com/support/faqs/faq18.aspx

- **1. Why are Switched Mode Power Supplies (SMPS) associated with radio interference?**
- **Switched mode power supplies (SMPS) employ high frequency (HF) switching and thus, are a source of radio interference, a recipient of radio interference and a conduit of radio interference.** (Older linear type transformer based power supplies do not employ HF switching voltages).

2. What are the typical sources of radio interference in a SMPS?

The primary emission sources originate in the switching devices due to their fast switching current transitions: **(1) harmonics of the switching frequency** and **(2) broadband noise created by under-damped oscillations in the switching circuit**. The secondary source is from the bridge rectifier, both rectifier noise and diode recovery. **(3) The AC input rectifier / capacitor** in the front end of the switching power supplies (excepting those with power factor correction) **are notorious for generating power supply harmonics due to the non linear input current waveform. (4) The noise is both conducted and radiated through the input power cord and the DC output wiring to the radio.**