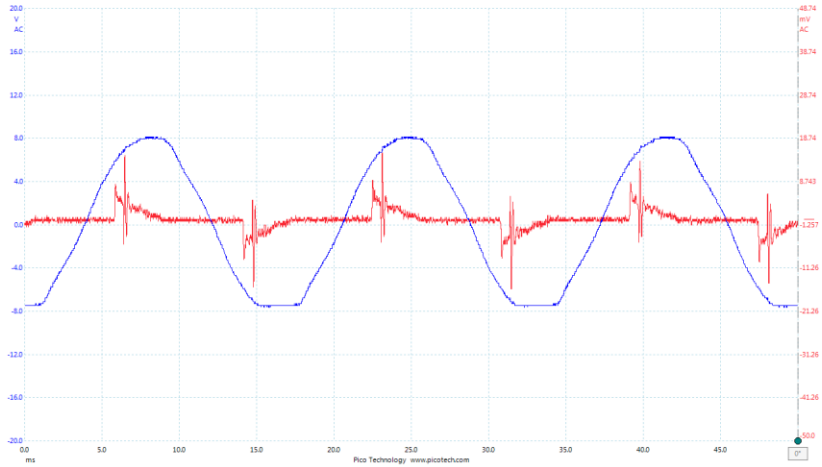
DIRTY ELECTRICITY



What is it

Where does it come from

How is it measured

How is it mitigated

Speaker:

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IBE Conference 2015

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DIRTY ELECTRICITY

Michael Schwaebe

A presentation for IBE Conference 2015, Islandwood Retreat Center, Bainbridge Island, Seattle WA

July 10 -12, 2015

DE Perception Questionnaire (true/false)

- Dirty Electricity (DE) is the bi-product of 60 cycle AC use in electrical devices (e.g., > 60 Hz to infinity)
- DE has properties of current (amps), potential (volts) and frequency (hertz)
- CFL bulbs have more DE than LED bulbs
- Stetzer/Greenwave filters remove DE
- Stetzer/Greenwave meters measure DE

Dirty Electricity

- Harmonic bi-product of the AC power from non-linear devices (examples shown here)
- Synonymous with electromagnetic interference (EMI), electrical transient noise and VLF fields.
- Measureable properties
  - current (amps)
  - potential (volts)
  - frequency (hertz).
  - and therefore EMR
- May also be found as EMR from stray current (earth return to the Grid)

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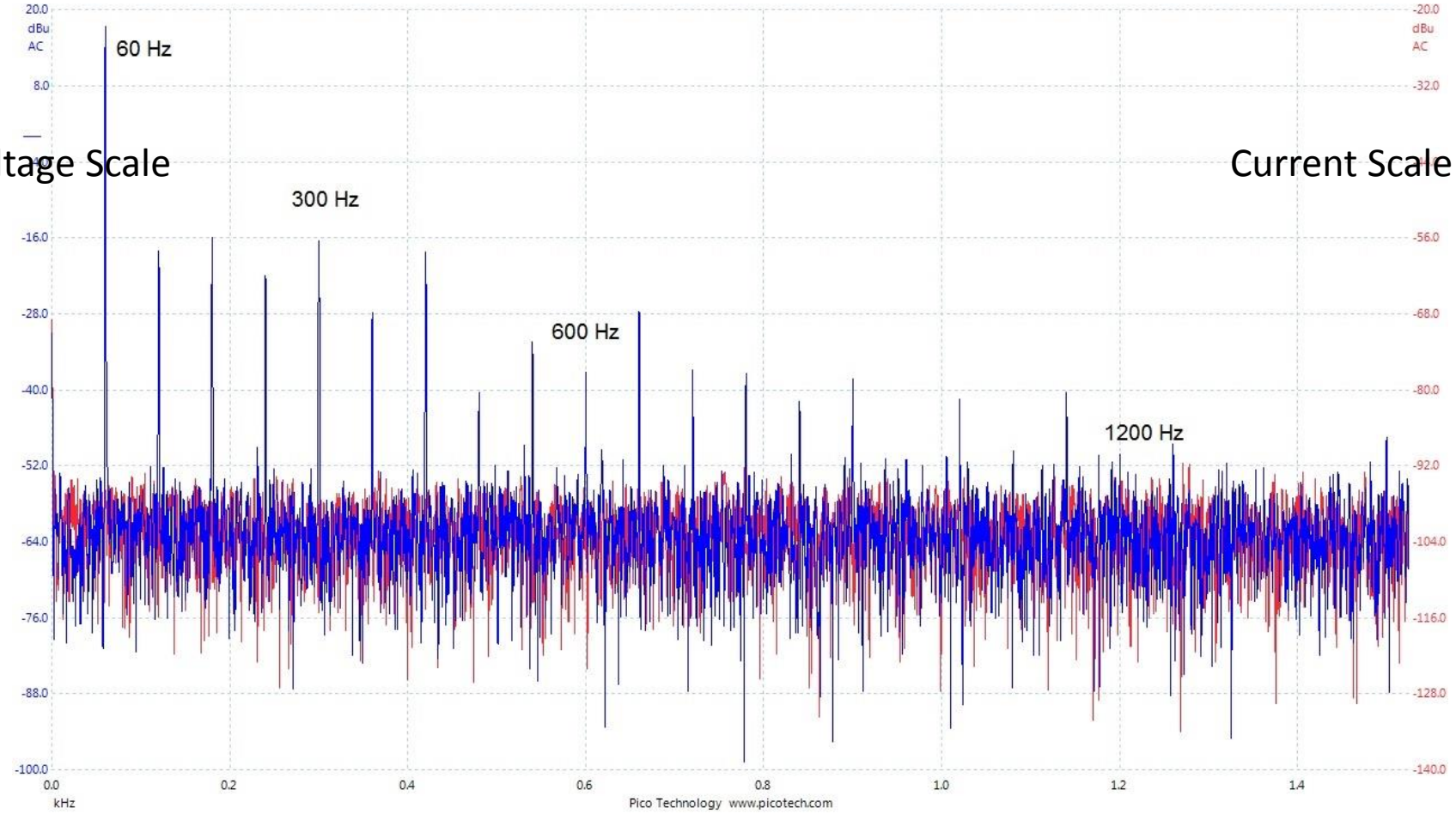
Power System Harmonics

Multiples of 60 Hz



Voltage Scale

Current Scale

Frequency

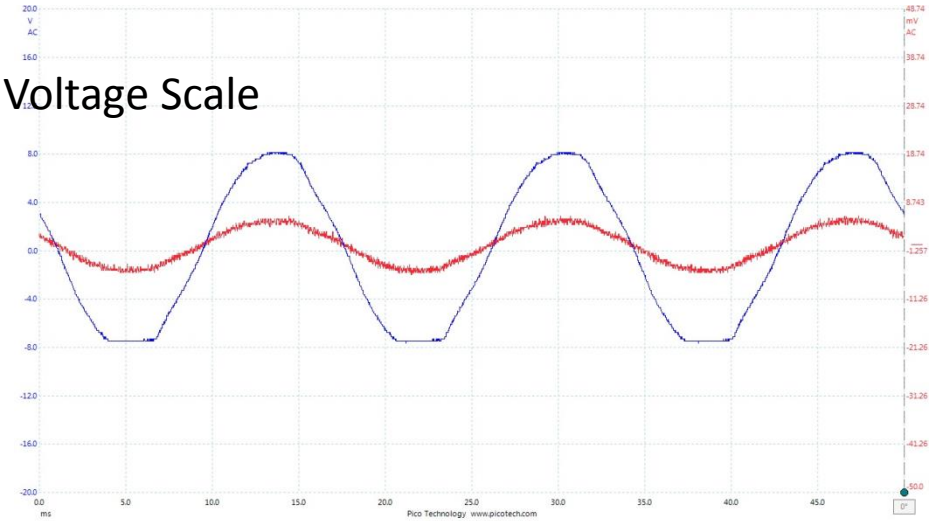
Harmonic Voltages and Currents

- Linear electrical load, e.g., incandescent light
  - draws a sinusoidal current at same frequency as source
  - with a small phase shift from the voltage waveform
- A non-linear load, e.g., CFL and LED bulbs
  - Distorts current wave and distorts voltage wave
  - May lead or lag voltage waveform
- Waveform distortion is source of DE
  - superimposes additional frequencies onto the 60 Hz AC sine wave
  - harmonics are at integer multiples of the fundamental frequency

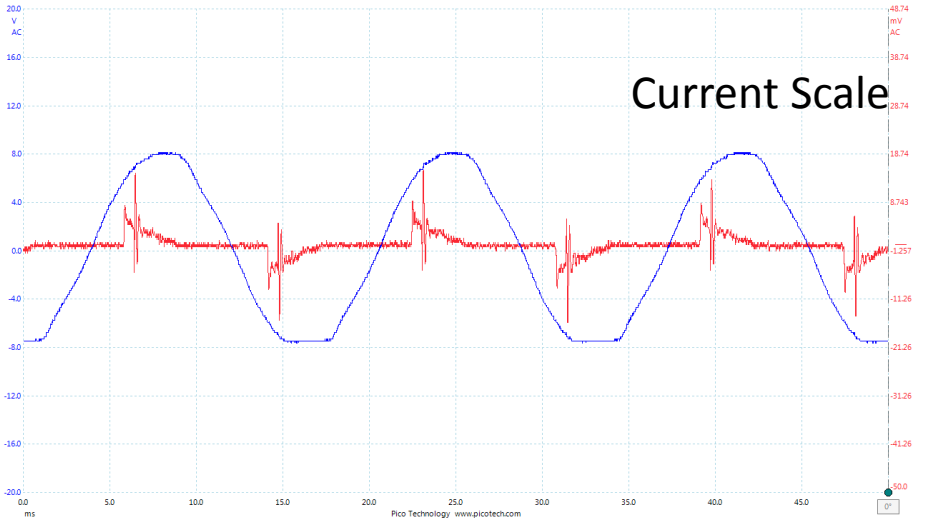
Voltage (blue) and Current Waveforms (red)

Linear Vs. Non-Linear Devices

Incandescent/Halogen



Ecosmart CFL



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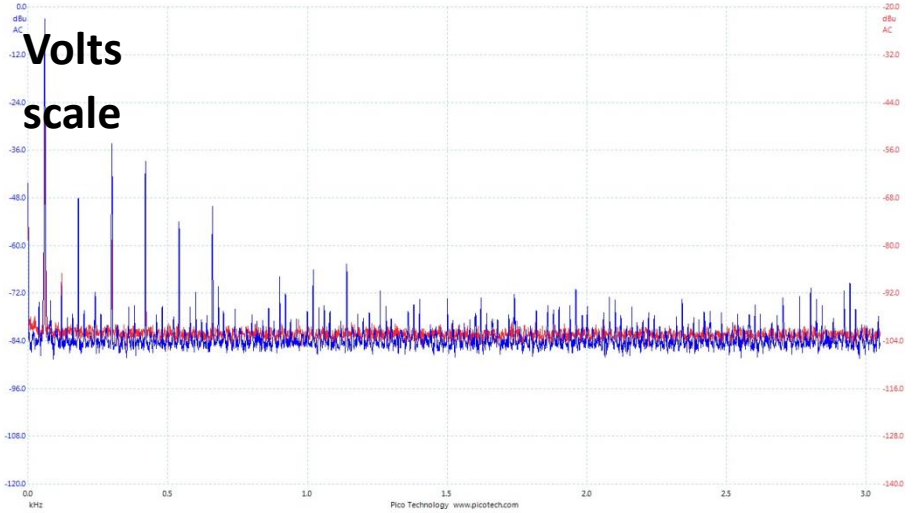
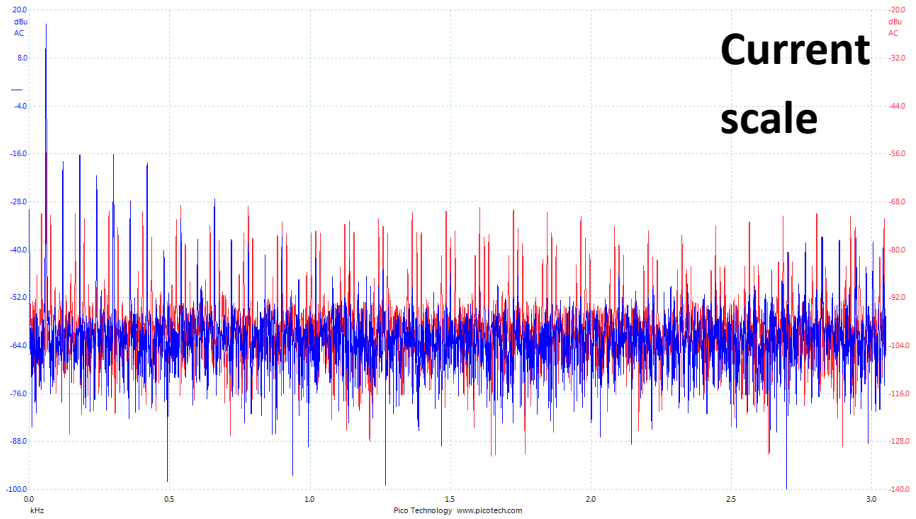
Harmonics 3 KHz range spectrum (frequency domain)

- Halogen Incandescent light spectrum (shows harmonics from “grid”)
  - Seen as voltage (blue) spikes
- CFL bulb harmonics of 60 Hz sinusoidal wave
  - Seen as voltage (blue) and current spikes (red)

Incandescent/Halogen



Ecosmart CFL



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Origins of “Dirty Electricity”

- Concept first developed by Dave Stetzer, an EHS electrician
  - USSR research showed VLF heath affects accentuated > 5KHz (reference not available)
- Assisted by Martin Graham PhD at UC Berkeley Electronics Research Center, also EHS.
  - http://www.electricalpollution.com/

- Early research by Magda Havas indicated significant health benefit when DE was reduced
  - http://www.magdahavas.com/
  - No follow on research
- No scientific data base for ELF frequencies, intensities and biological consequences
  - Anecdotal stories show mixed benefits

Measuring Dirty Electricity

- Broadband DE Meters
  - Stetzerizer
  - (10 KHz to 100 KHz, dimensionless 1 to 1999. The GS units are a measure of "harmful energy" which is a function of frequency, or more generally, rate of change of voltage or dV/dt. 1 unit = 24 V/S)
  - Greenwave
  - (2 KHz to 100 KHz, 1 to 1999 MV))
  - Alpha Lab Line EMI Meter
  - (1 KHz to 100 KHz, 1 to 1999 MV)

  - NOTE: these meters measure only DE potential, not current.

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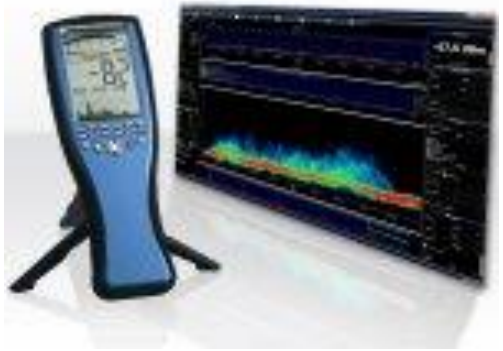
Measuring Dirty Electricity (cont'd)

- Spectrum Analyzers
  - Oscilloscopes
  - Spectran Analyzer
- Multiband
  - Gigahertz NFA 1000 (B and E Field, frequency ranges 16.6 Hz, 50/60 Hz, 100/120 Hz, 150/180 Hz, other frequencies < 2 kHz, and > 2K to 400KHz)
  - Gigahertz ME 3951A B and E Field, frequency ranges 50 to 400K Hz and 2K to 400K Hz)
  - Alpha Lab AC Milligauss Meter UHS2 (ranges 13 Hz to 75 kHz and 1kHz to 75 kHz)



Examples of DE Measurements

- Which energy efficient bulb is best?
  - Depends on how it is measured
  - 120 VAC Halogen has the lowest DE

- DE and Parallel Filters
  - Multi instrument comparison of 4 filters
  - DE mitigation effects of multi filters

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EMR from Energy Efficient Lights

Halogen bulb has the lowest EMR

- Setup for measuring EMR from a light (>60 Hz)
  - NFA1000 in middle by tape
  - Spectran NF5035 tilted behind
- NFA1000 data Logs
  - Philips CFL has most EMR
  - Ecosmart CFL and LED are close
- NF 5035 spectrum color history
  - Philips CFL has most EMR

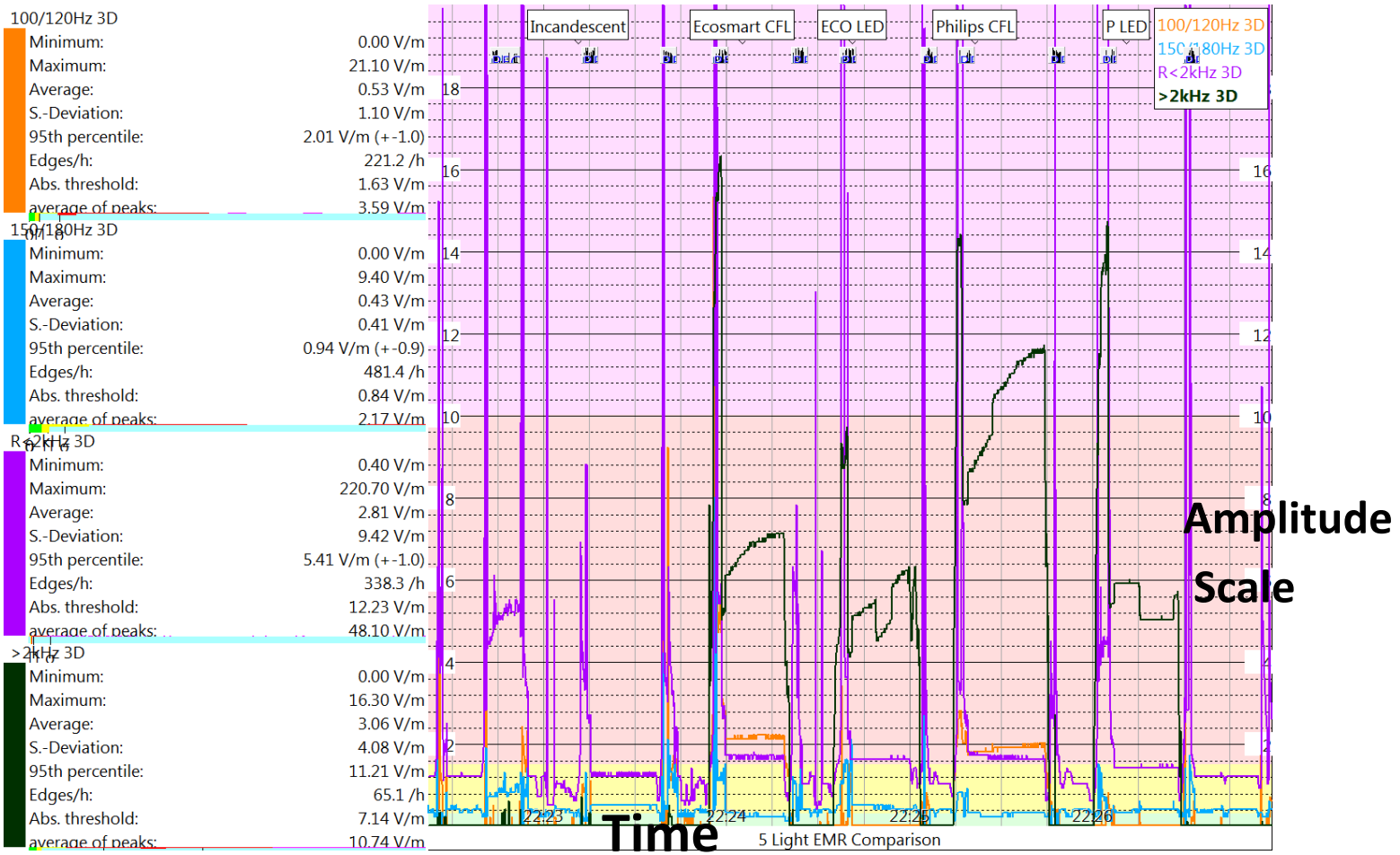
EMR CFL/LED E-Field Step Changes, NFA Log

The R < 2 KHZ spikes are switching transients

Lights “on” indicated by step changes

Color Code

Channel info in the left column



Amplitude Scale

Time

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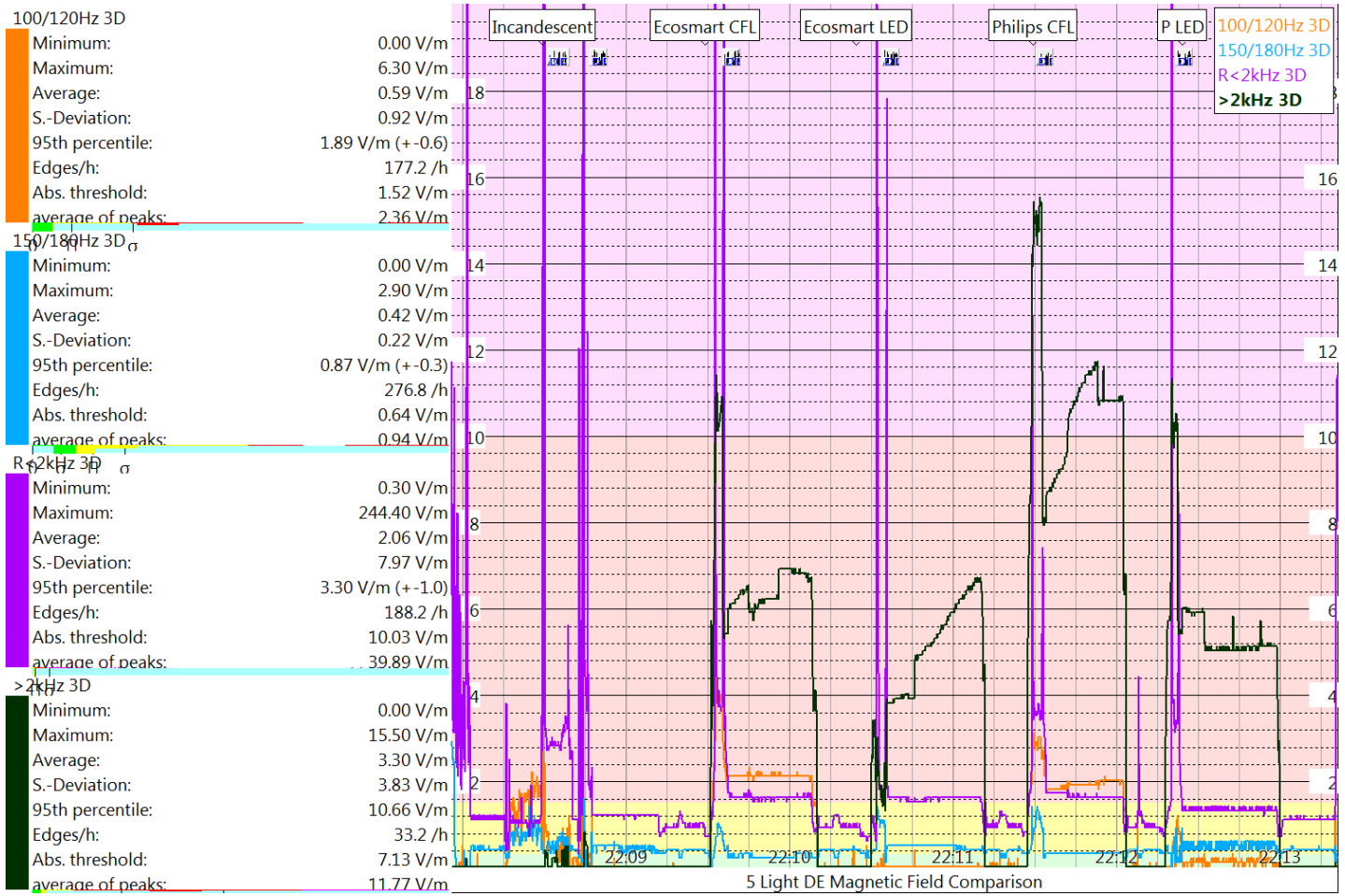
EMR CFL/LED B-Field Step Changes, NFA Log

The Philip's CFL has the highest B-Field

Lights "on" indicated by step changes



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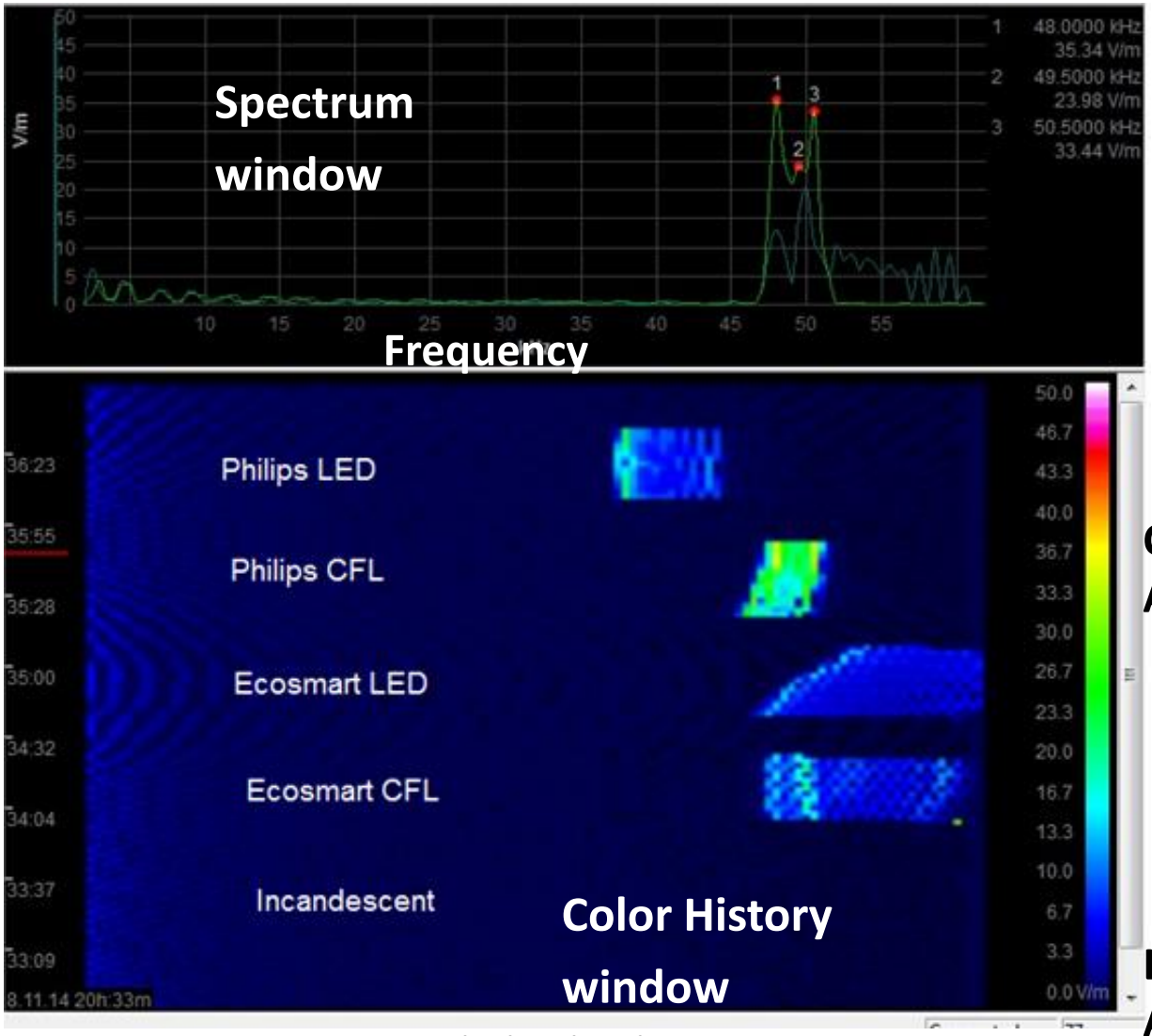
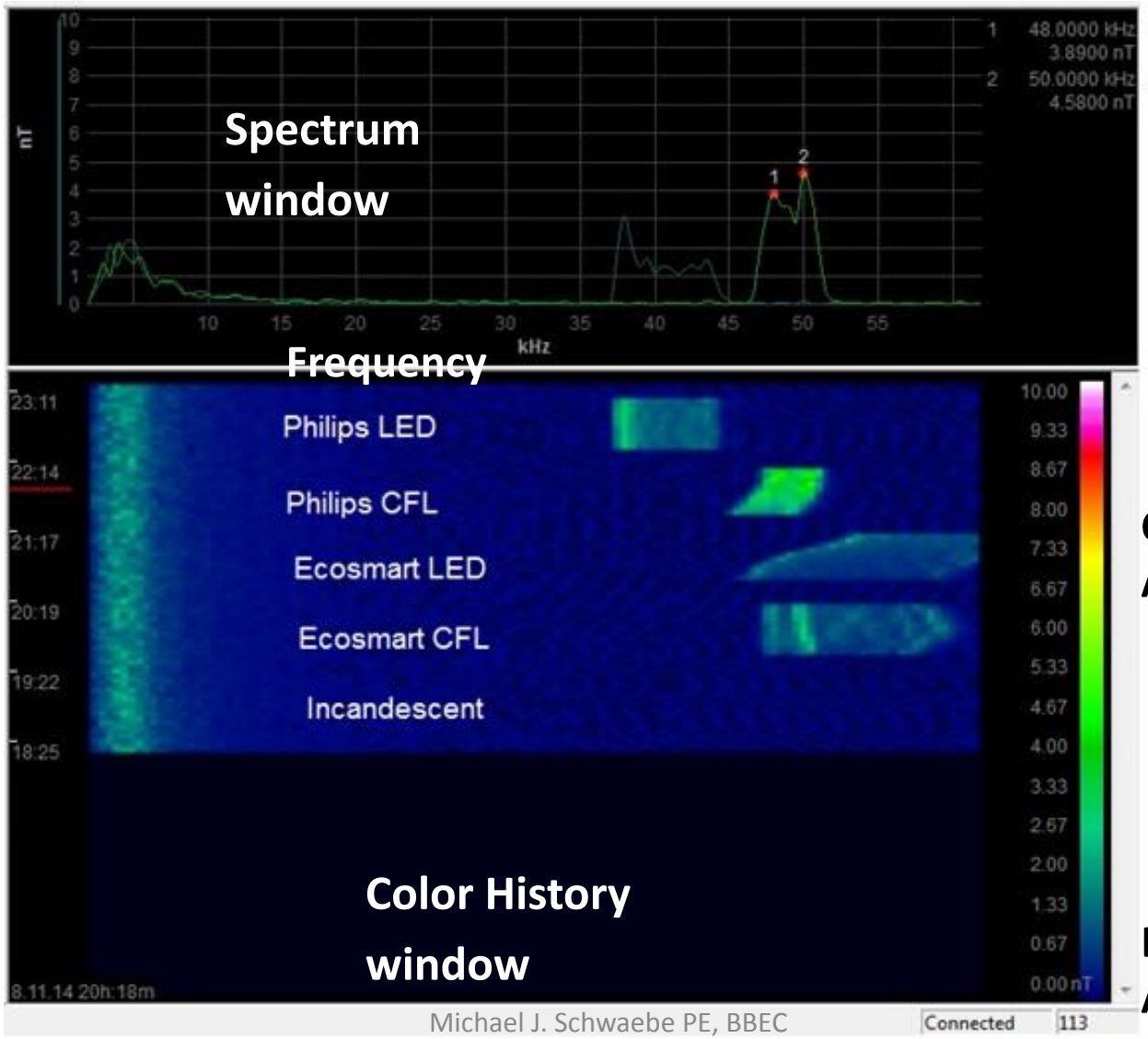
EMR CFL/LED E-Field Spectrum Color History, 2-62 KHz

The spectrum window green line is Philips CFL E-Field



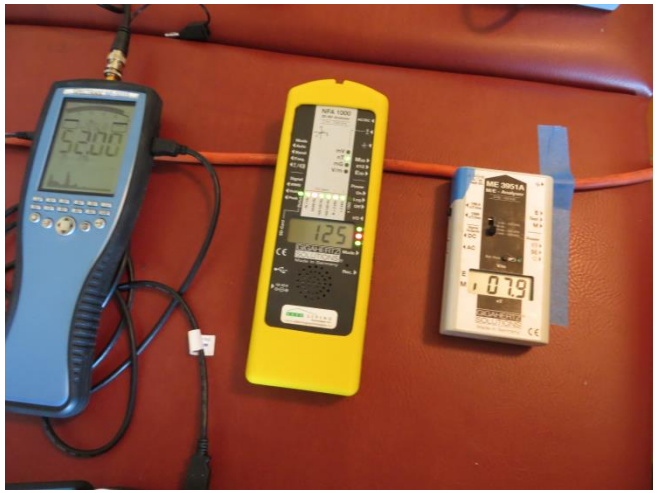
EMR CFL/LED B-Field Spectrum Color History, 2-62 KHz

The spectrum window shows Philips CFL B-Field



DE from Energy Efficient Light Bulbs

- Setup for measuring DE in a circuit
- Oscilloscope waveforms/spectrums
  - show harmonics of non-linear devices
- Light bulb DE meter comparison
  - Phillips Halogen and CFL have least DE
  - Philips LED or Ecosmart CFL has most DE depending on DE meter
- NFA 1000 data logs
  - CFLs appear equal
  - Philips Halogen and LED have least DE
- NF5035 spectrum color history charts
  - Philips CFL has least DE (Halogen not shown here)



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Setup for measurement of EMR and DE phenomenon

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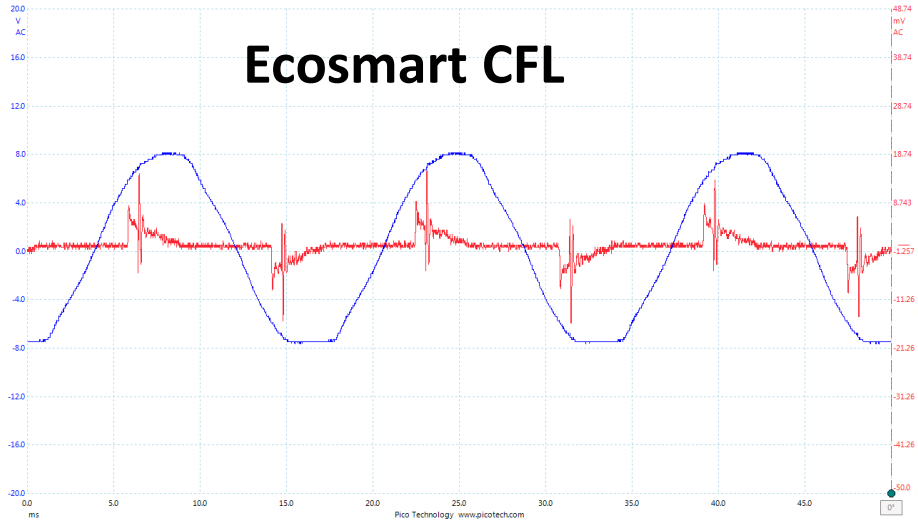
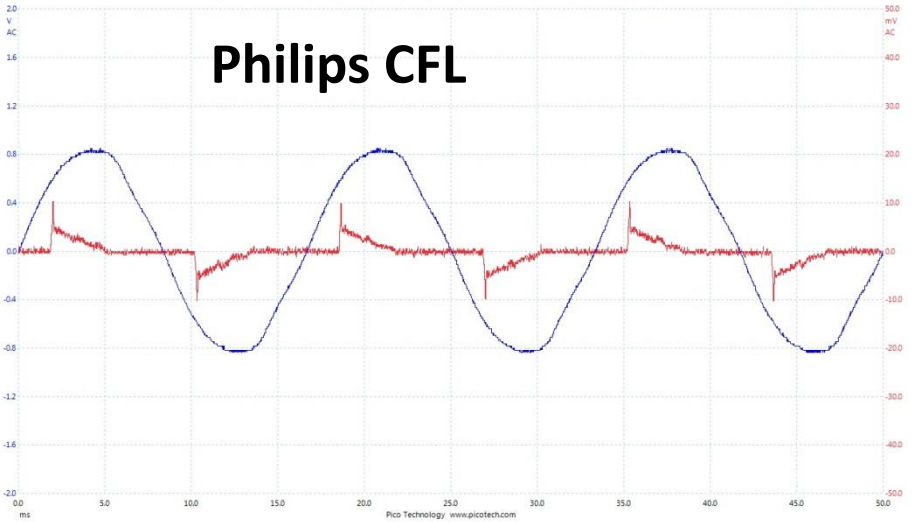
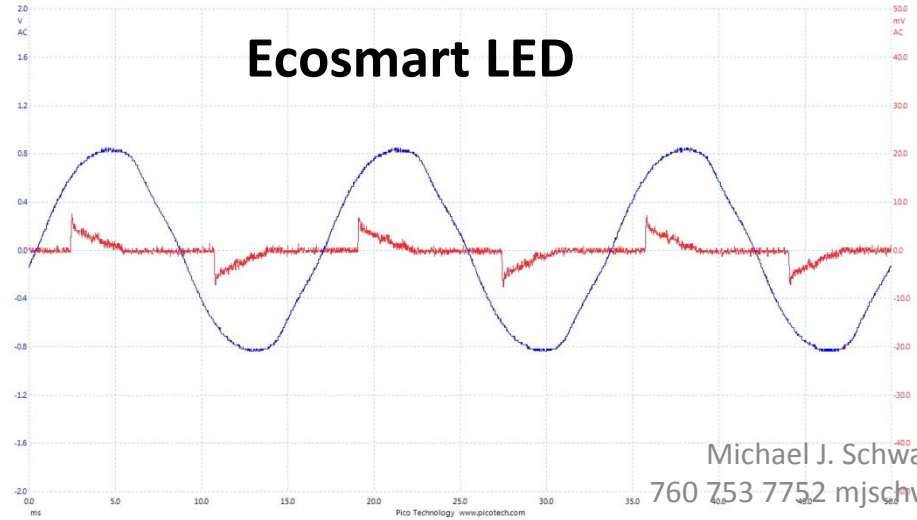
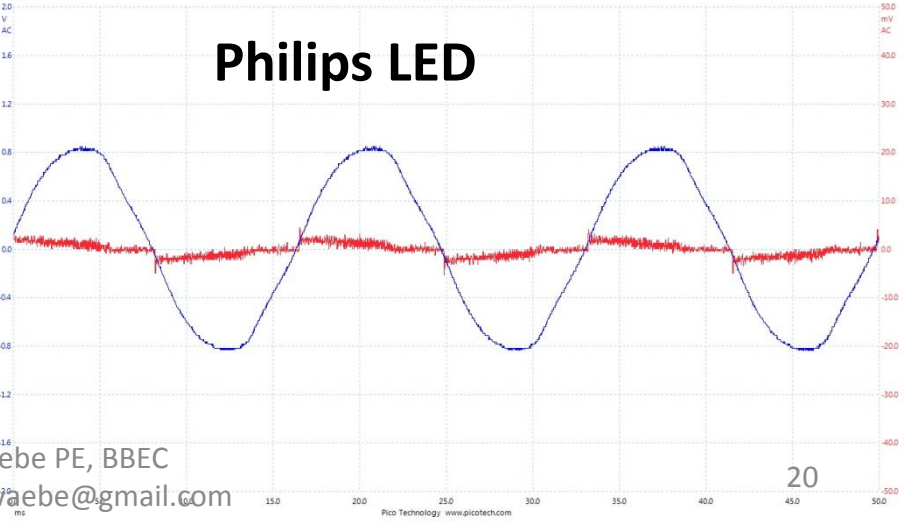
DE Voltage and Current Waveforms of CFL/LEDs

Ecosmart CFL has highest current peak









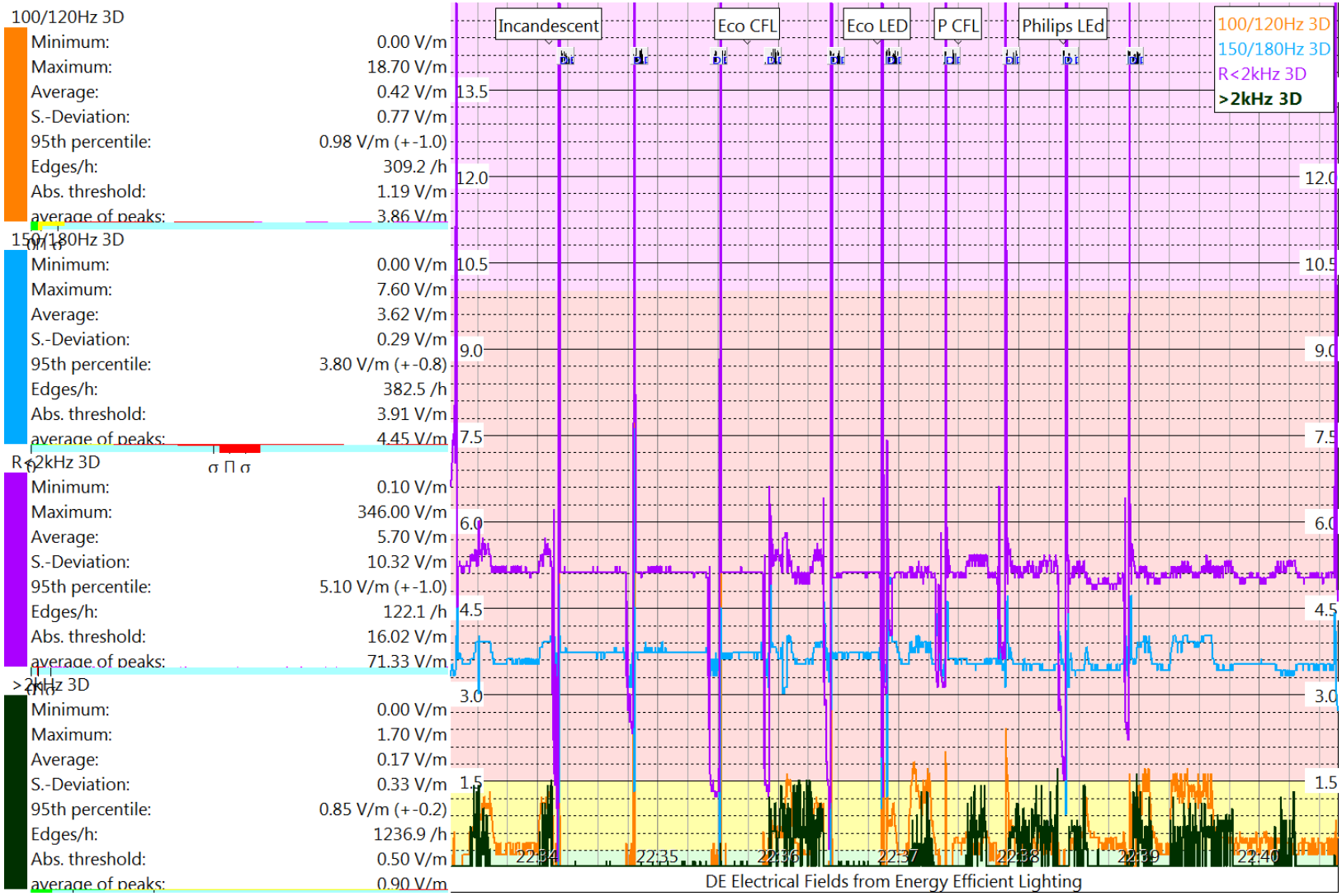
Light Bulb DE Effects

Device	Amps	DE Effect Stetzer/Line EM Meters
Philips Halogen (43 W 750 L)	0.30	30/28
Ecosmart CFL (14 W 900 L)	0.15	700/350
Ecosmart LED (14 W 800 L)	0.10	520/220
Philips CFL (13 W 900 L)	0.12	80/57
Philips LED (13 W 800 L)	0.08	440/630
No Light DE Baseline	n/a	30/28
DE effect of lights is with DE meters on downstream power strip connected to light stand with DNA Line Filter upstream of sensor location to block grid harmonics.		

DE CFL/LED E-Field Step Changes, NFA Log

The R < 2 KHZ spikes are switching transients lights on and off

NO clear picture of E-Field trends



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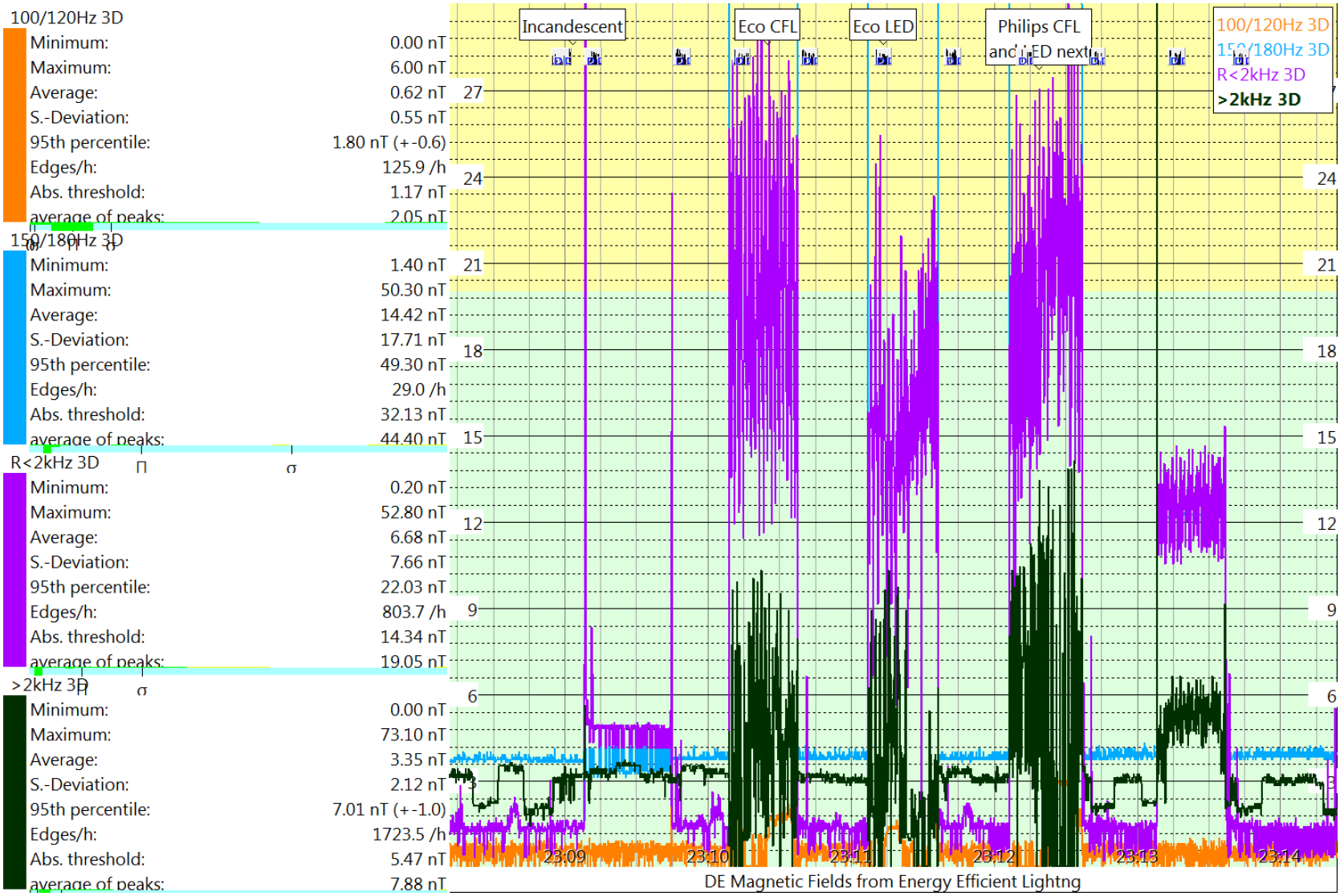
DE CFL/LED B-Field Step Changes, NFA Log

Each light is on and then off consecutively for roughly equal increments



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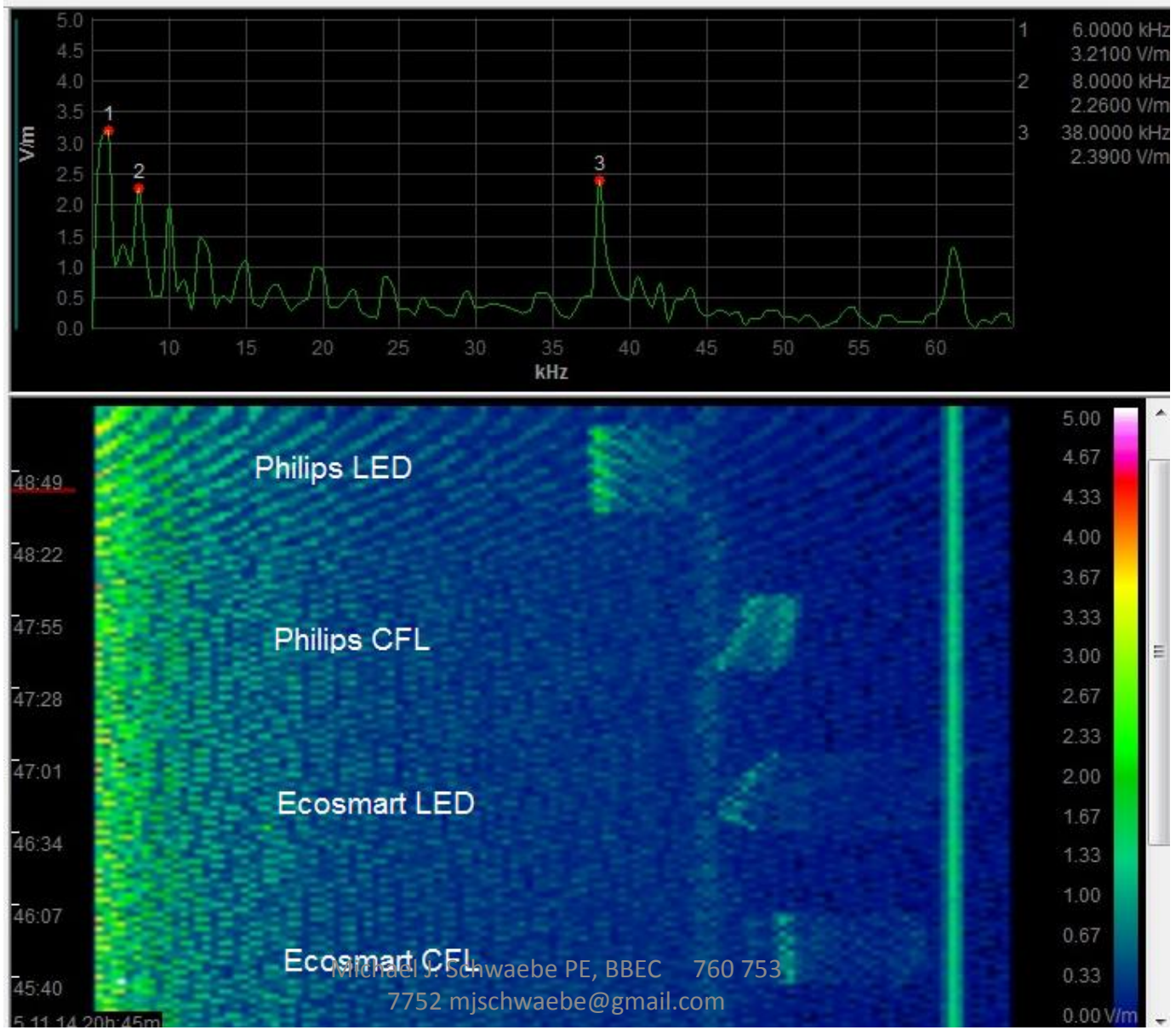
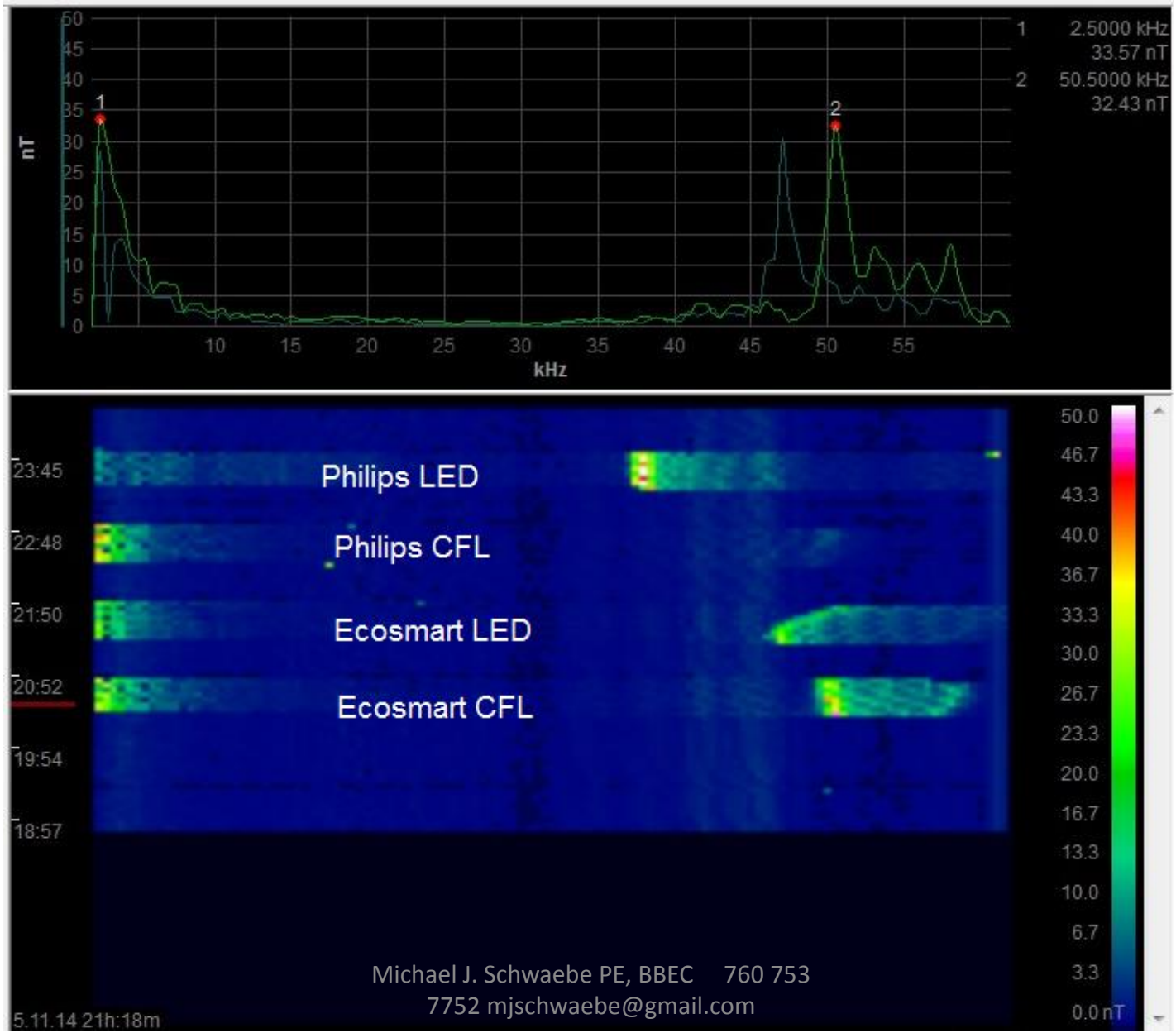
DE CFL/LED E-Field Color History 5-65 KHz

The spectrum window shows the Philips LED
Philips LED appears to have largest E-Field



DE CFL/LED B-Field Color History, 5-65 KHz

The spectrum window shows the Ecosmart CFL



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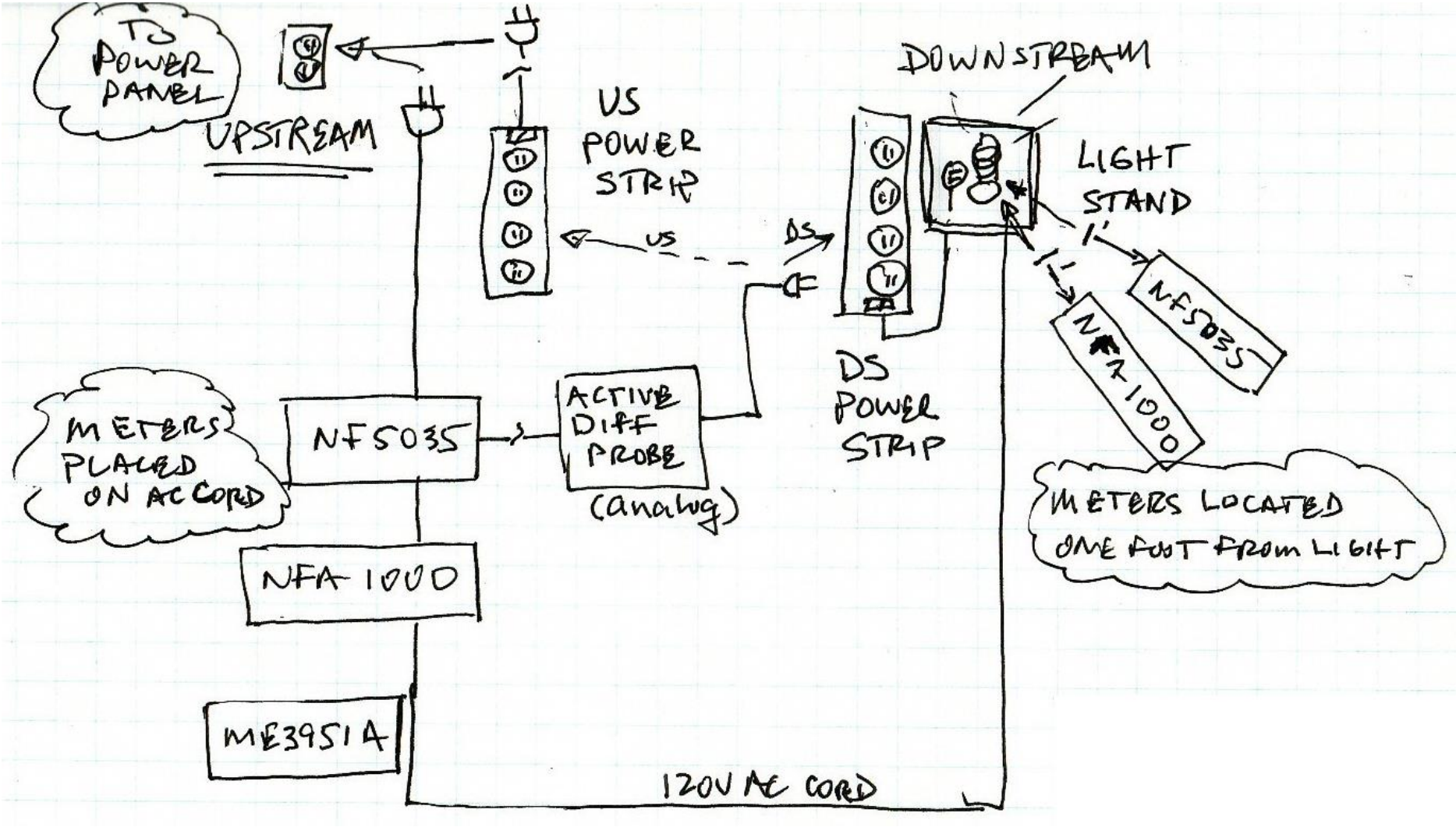
DE (Parallel) Filter Examples

- Capacitive and inductive DE filters create DE as well as ~~re~~move it
  - Open circuit to 60 Hz
  - Closed circuit to > 5 KHz
  - Create DE by shunting reactive current at the DE frequencies to the neutral (and ground in some designs)
- Multi instrument comparison of 4 filters
  - E-Field decreased for downstream and upstream filter locations > 10KHz (moved to lower frequencies)
  - B-Field DE is increased for downstream filter locations for filters F1, F2 and F3
- Effects of multi filters
  - Diminishing benefit after 2 filters
  - No published basis for Greenwave and Stetzer DE criteria

DE Filter Measurements

- Setup for measuring filter phenomenon and filter data
- Oscilloscope waveforms and spectrums
  - Indicate non-linear device
- DE Filter comparison using ME3951A >2KHz
  - E-Field decreased for downstream and upstream filter locations
  - **B-field increased for downstream filter location**
  - B-field decreased for upstream filter location
- NFA 1000 data logs (filters bands > 60 Hz)
  - E-Field log shows no discernable benefit
  - **B-Field log shows step increase in B-Field with filter in downstream location**
- NF5035 spectrum color history charts (5-65 KHz)
  - E-Field decreased for downstream and upstream filter locations > 10KHz
  - **B-field increased for downstream filter location**
  - B-field decreased for upstream filter location > 15 KHz

Setup for measurement of EMR and DE phenomenon from energy efficient lights and DE filters



DE Filter information

Device (all plug-ins)	Amps	DE Effect Stetzer/Line EM Meters
Greenwave #1500G	0.50	170/425
PX-DNA	0.41	405/870
Satic ES120	0.84	115/262
Stetzer GS-F110-A	0.83	100/235
in-line DNA Filter	n/a	28/25
No Filter DE Baseline	n/a	1080/1380
Note: **Filter list here does not correspond to test order to avoid prejudice in data presentation** DE effect is for a branch circuit with the measurement downstream of filter		

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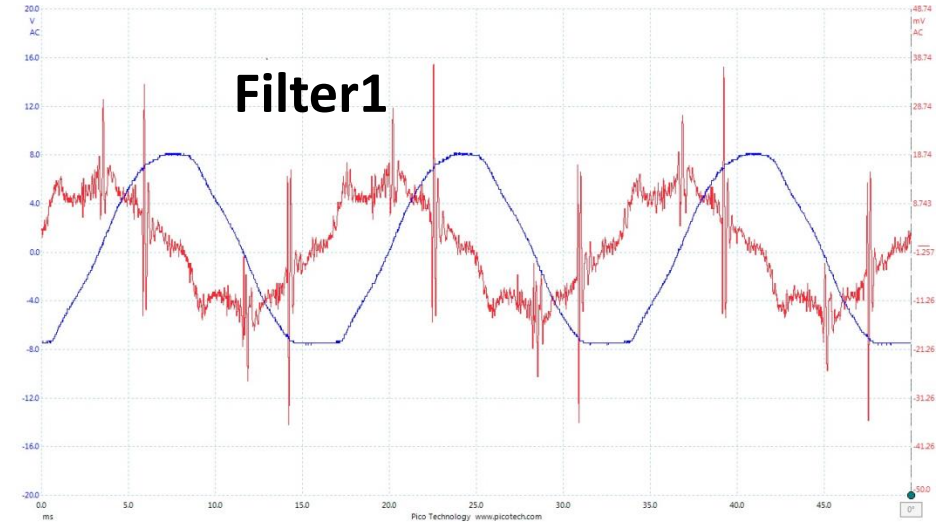
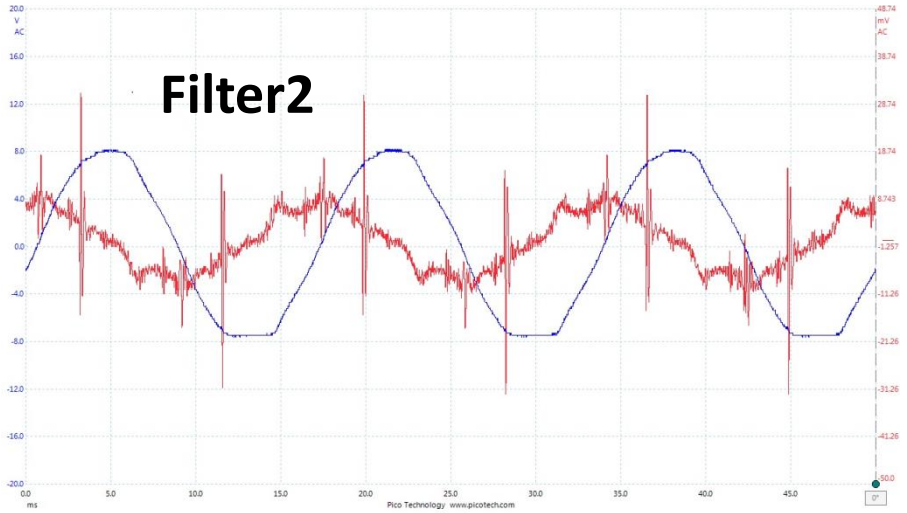
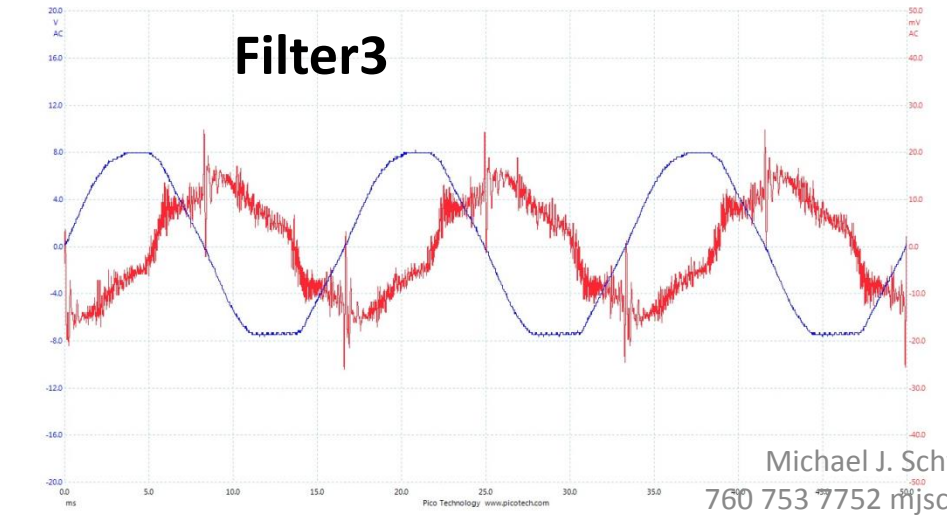
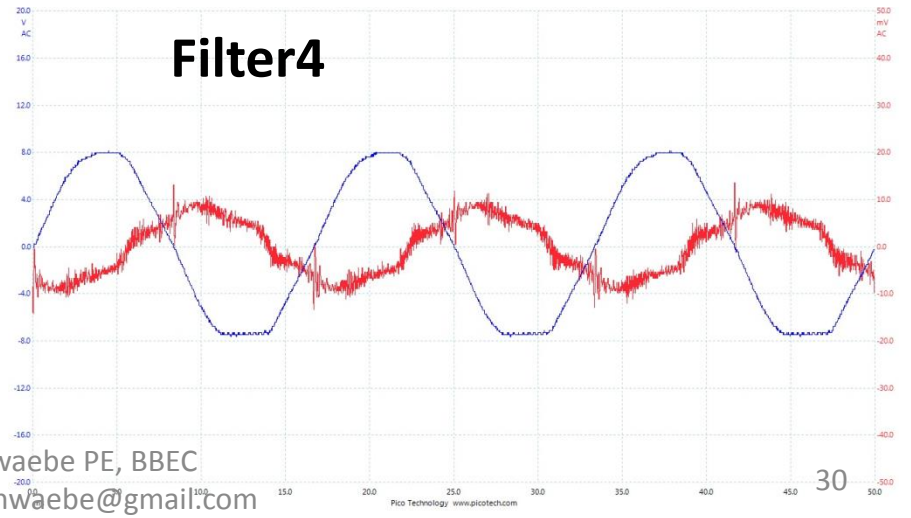
DE Voltage and Current Waveforms for DE Filters

Current (red) waveform indicates a non linear device







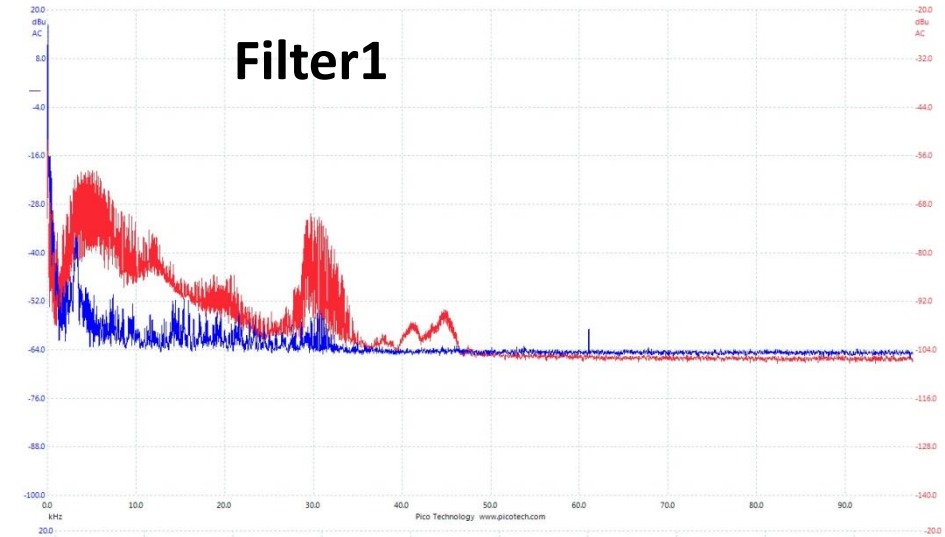


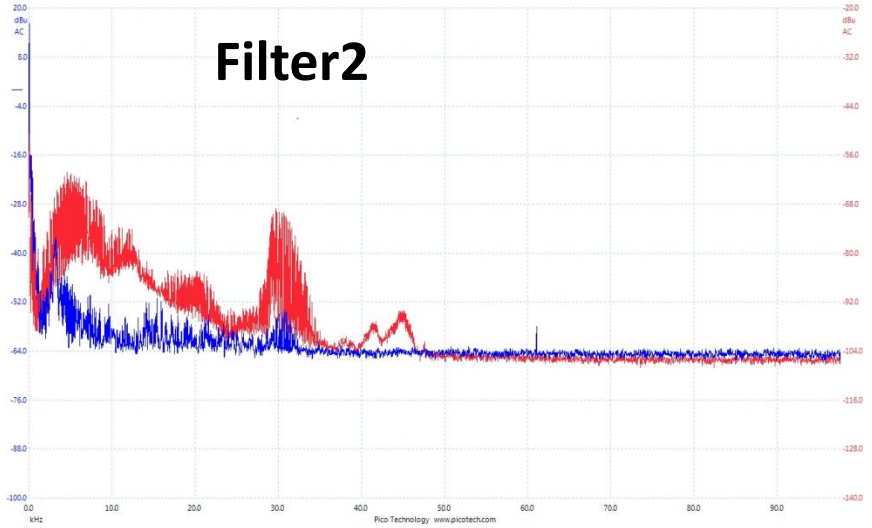
DE Voltage and Current Spectrums for DE Filters DS

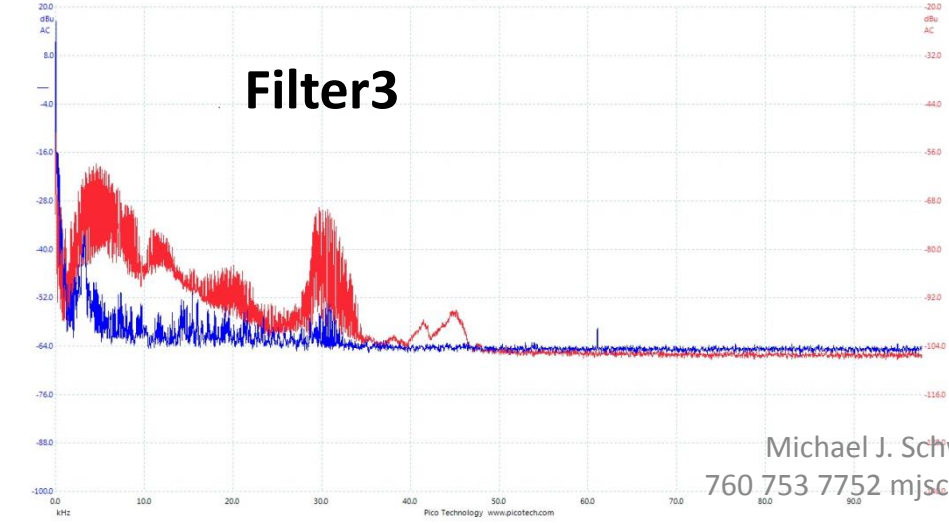
Voltage spectrum (blue) is dominated by DE from the grid

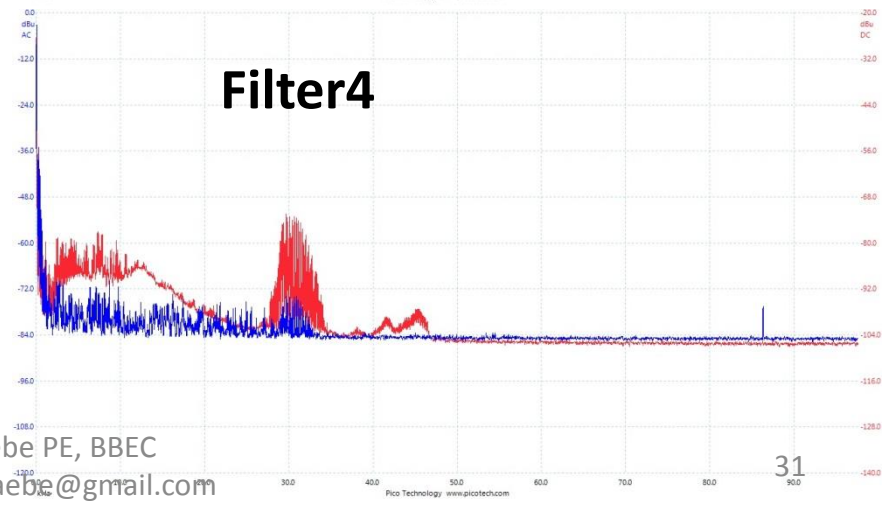
Current spectrum follows voltage spectrum

Current spectrum (EMI) is amplified at the low end for filters 1, 2 and 3









DE Filter Comparison, ME3951A selected to 2-400KHz Range

No load conditions, filter effects only

ME3951A 2-400KHz	Filter Downstream			
E-Field (V/M)	F1	F2	F3	F4
Baseline	2.4	2.4	2.4	2.4
with filter	2.2	2.2	2.2	2.2
ME3951A 2-400KHz	Filter Upstream			
E-Field (V/M)	F1	F2	F3	F4
Baseline	2.4	2.4	2.4	2.4
with filter	2.2	2.2	2.2	2.2
ME3951A 2-400KHz	Filter Downstream			
B-Field (nT)	F1	F2	F3	F4
Baseline	1.7	1.7	1.7	1.7
with filter	14	11.8	13.8	8.1
ME3951A 2-400KHz	Filter upstream			
B-Field (nT)	F1	F2	F3	F4
Baseline	1.7	1.9	1.9	1.7
with filter	1.7	1.9	1.9	1.7
All readings in no load condition, filter effect only. ME5931 position relative to AC cord can change the reading significantly.				

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DE Filter under load with ME3951A selected to 2-400KHz

Ecosmart CFL installed at downstream location.

ME3951A 2-400KHz	Filter Downstream			
E-Field (V/M)	F1	F2	F3	F4
Baseline	2.4	2.4	2.4	2.4
with filter	2.2	2.2	2.2	2.2
ME3951A 2-400KHz	Filter Upstream			
E-Field (V/M)	F1	F2	F3	F4
Baseline	2.4	2.5	2.5	2.5
with filter	2.2	2.3	2.3	2.3
ME3951A 2-400KHz	Filter Downstream			
B-Field (nT)	F1	F2	F3	F4
Baseline	4	4	4	3.7
with filter	14.7	12.5	14.5	9.2
ME3951A 2-400KHz	Filter Upstream			
B-Field (nT)	F1	F2	F3	F4
Baseline	3.9	3.9	3.9	3.9
with filter	3.6	3.6	3.6	3.6

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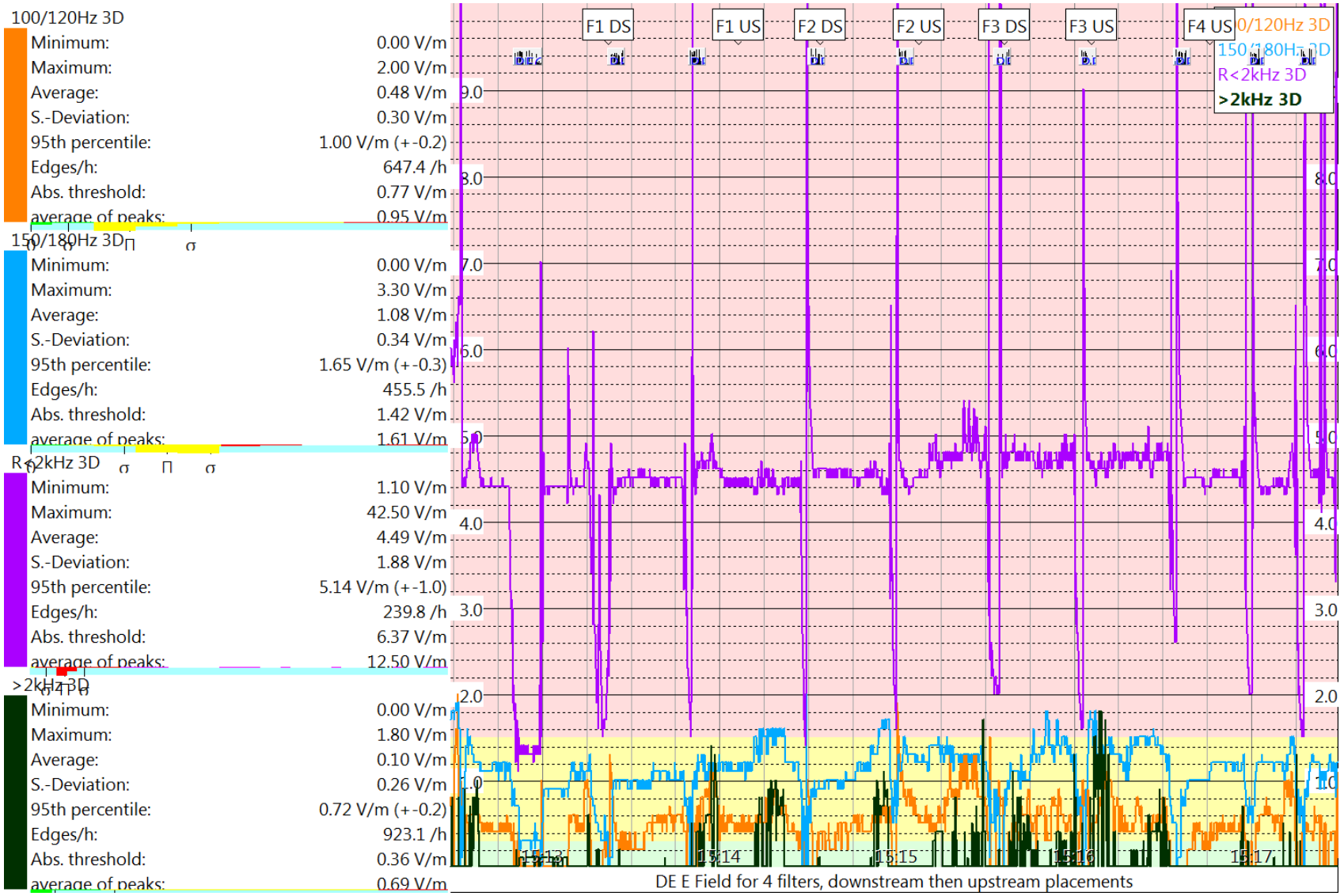
DE E-Field of DE Filters, NFA Log

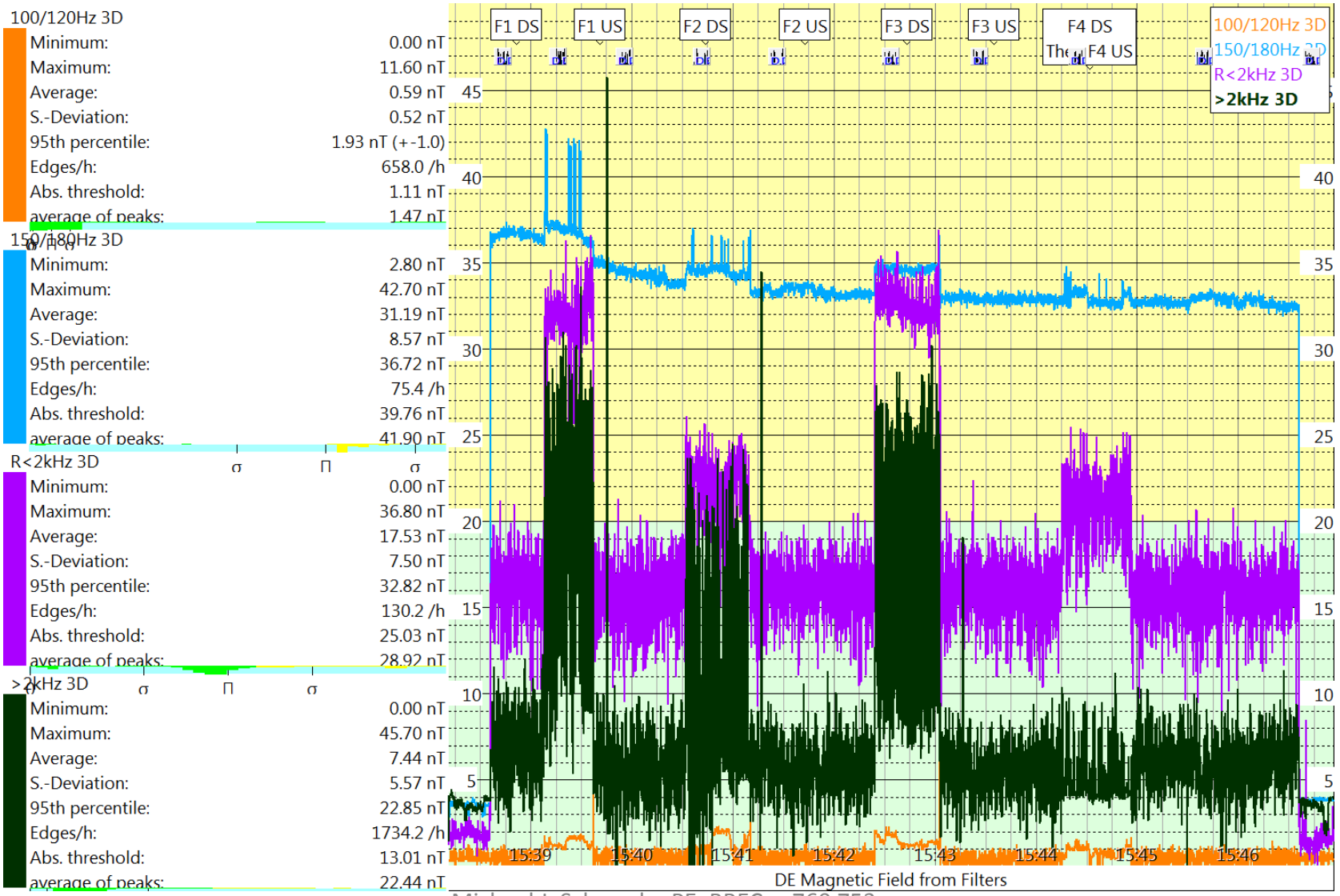
R < 2 KHZ band spikes are switching transients

No E-Field benefit discernable with filters



DE B-Field of DE Filters, No Load Condition, NFA Log

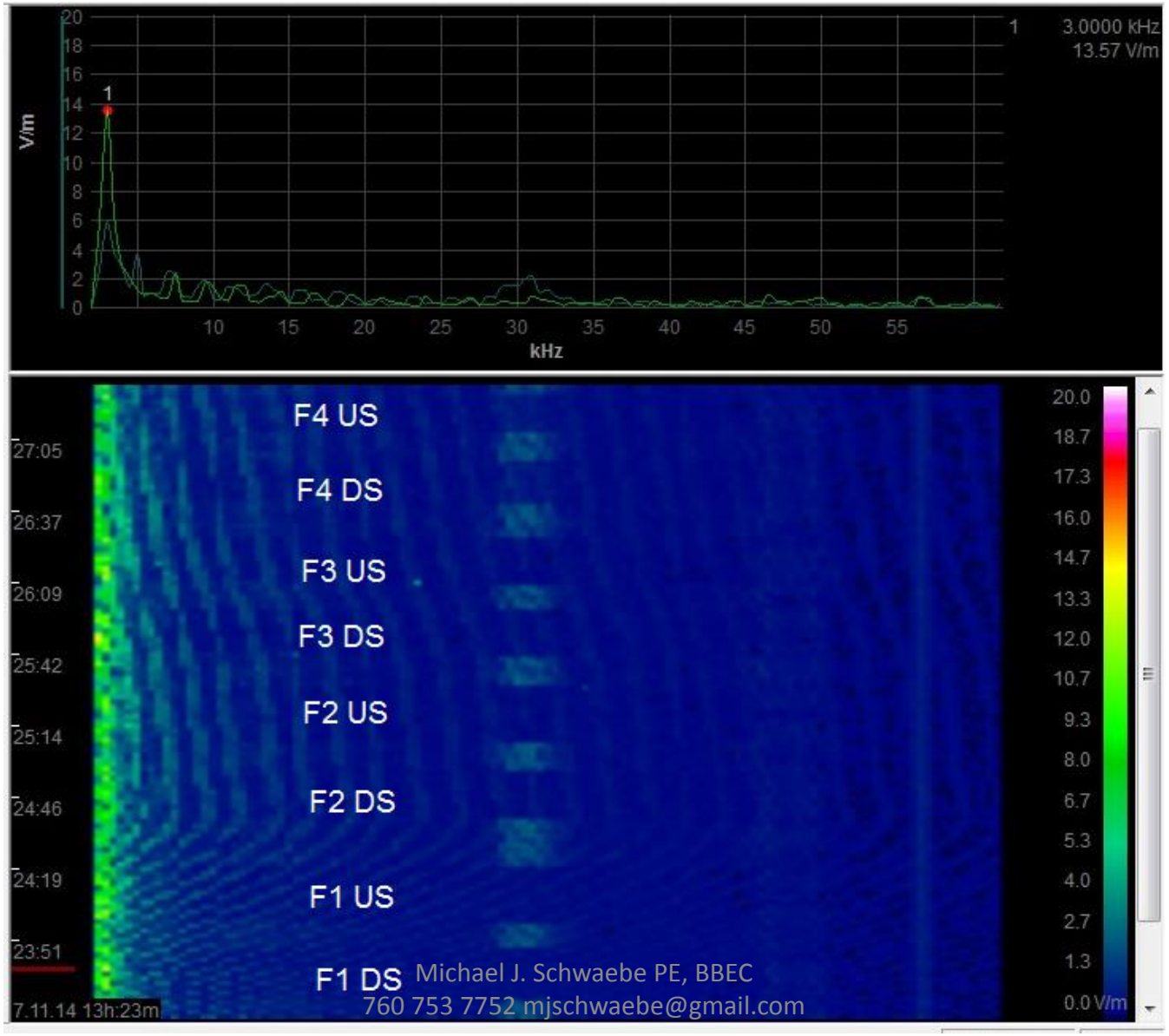
DE step changes = filters moved from downstream to upstream location



DE Filter E-Field Spectrum Color History, 5-65 KHz

downstream vs. upstream effects show similar E-field reduction

The spectrum window shows frequencies for Filter 1 in DS location.



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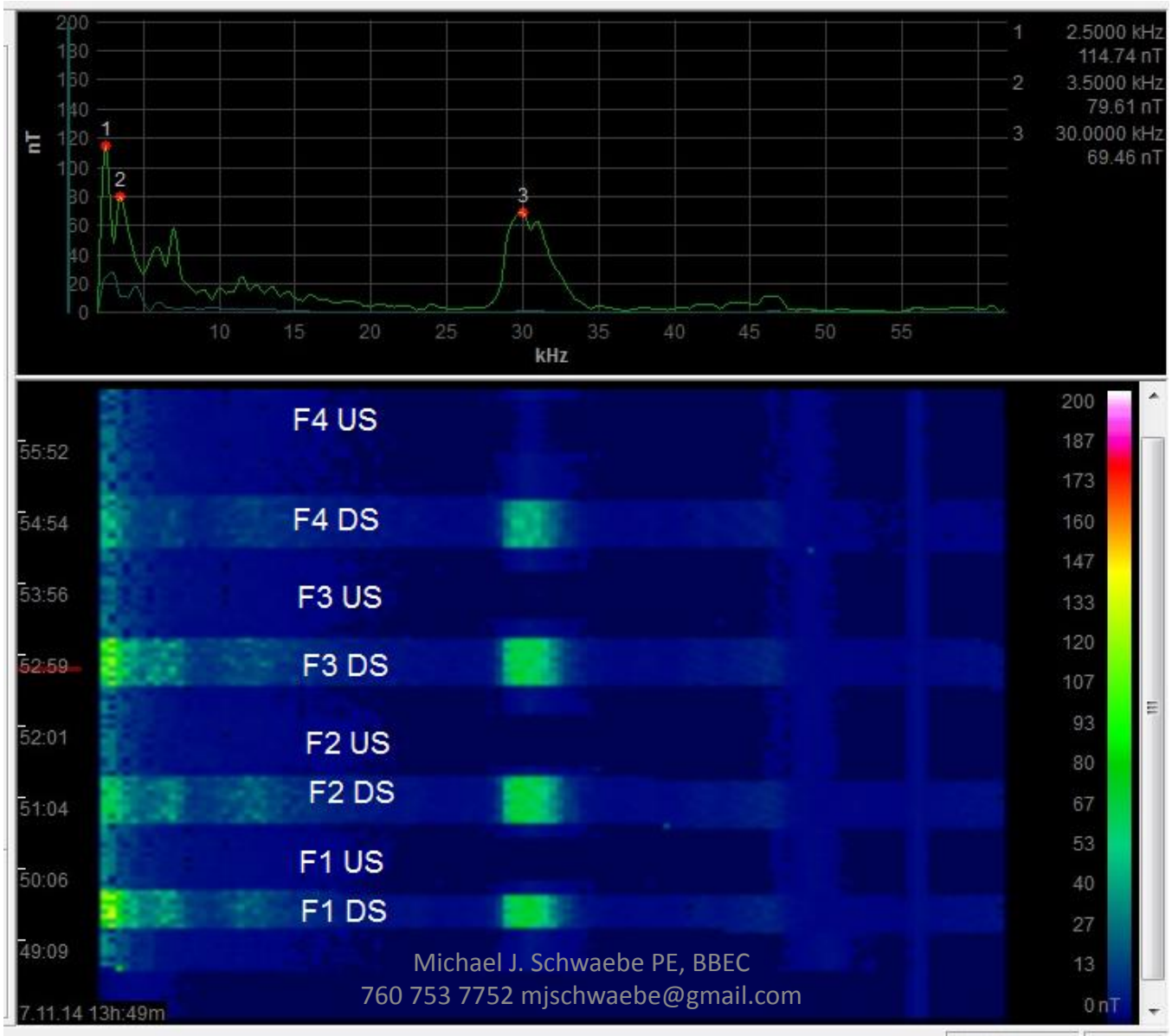
DE Filter B-Field Spectrum Color History, 5-65 KHz

downstream causes increase in B-Field throughout range

spectrum window shows frequencies for Filter 3 in DS location



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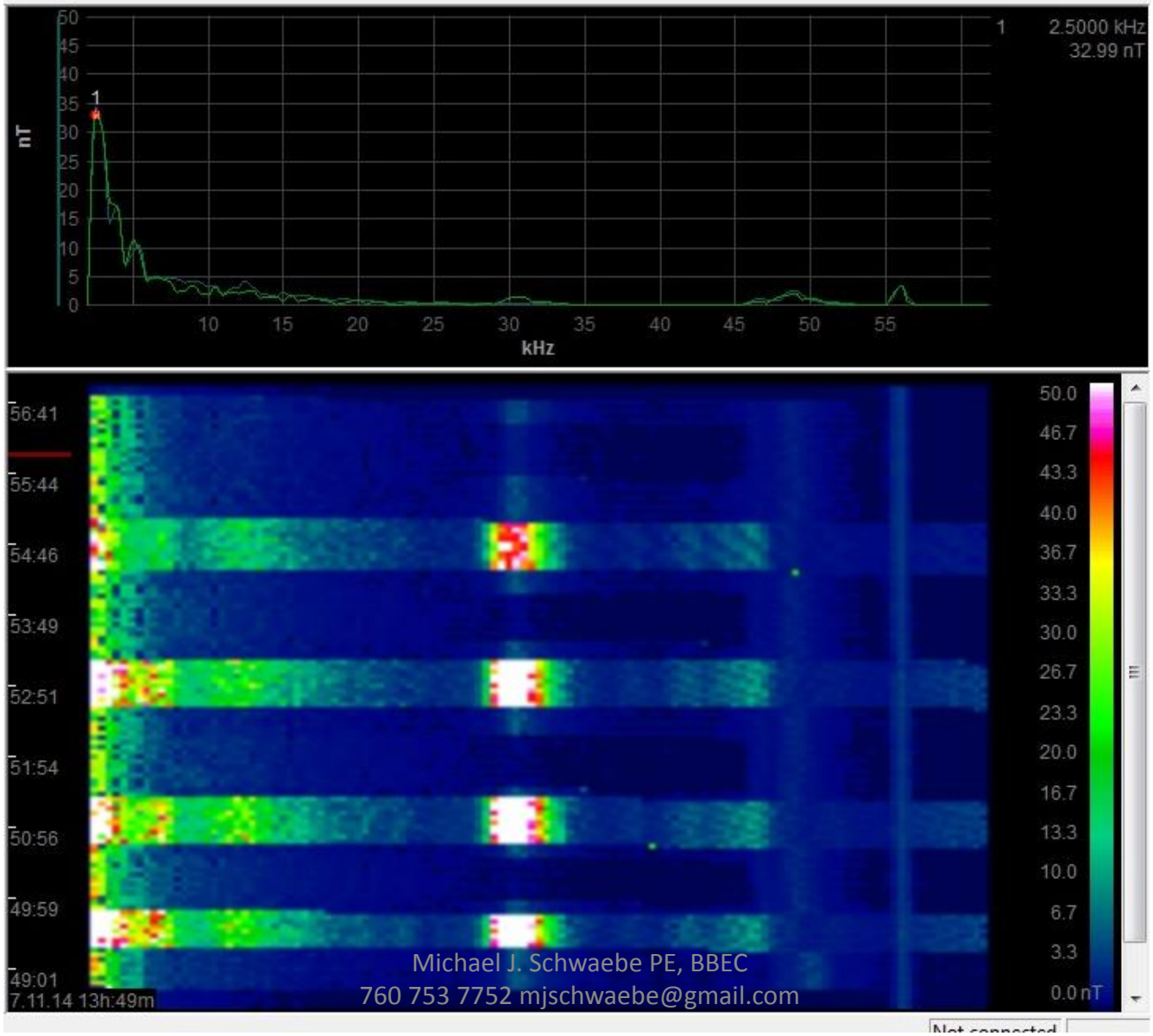
DE Filter B-Field Spectrum Color History, 5-65 KHz

different scale illustrates B-Field phenomenon for downstream location

spectrum window shows frequencies for filter4 upstream location



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How Many Filters?
DE phenomenon with multiple filters upstream

- ME3951A at > 2KHz and DE meter
  - The DE meters are not linear in their indications when compared with ME3951A
  - no decreases in E-Field > 2KHz after 2 DE filters
  - In-line EMF filter very effective compared to 3 F1 DE filters
- NFA1000 data logs
  - E-Field logs ambiguous for E-Field effects
  - no change for > 2KHz B-Field
- NF5035 spectrum color history
  - significant change with 1 filter located upstream
  - marginal improvement with more than 2 filters
  - Analog spectrum color history shows decrease in DE > 10KHz and increase < 5 KHz with filters
- "Capacitive filters installed with in the house" consequences
  - 10 to 20 amps reactive current at DE frequencies in the house wiring

How Many DE Filters Upstream?

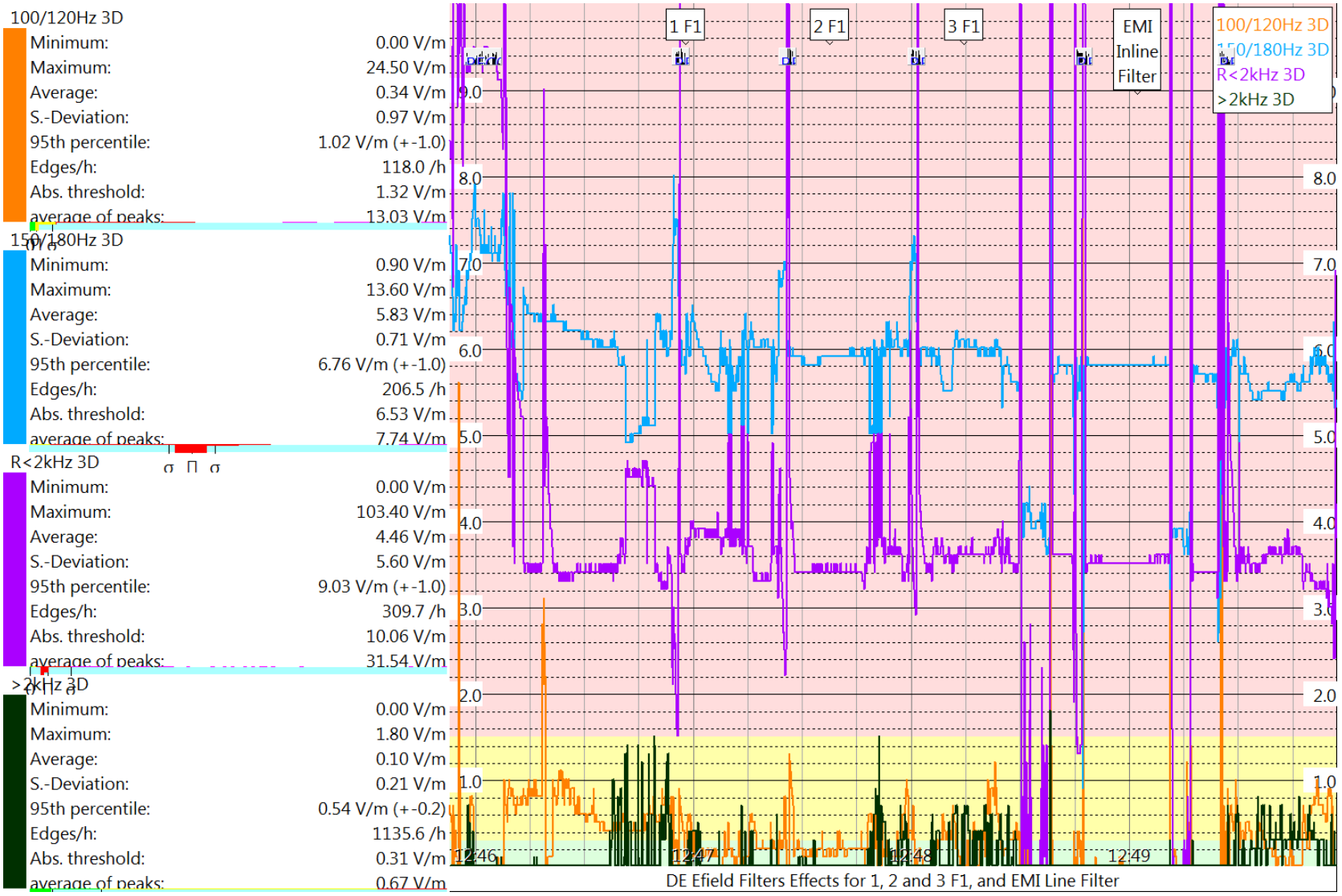
Filter	DE Meter Reading Stetzer	Line EM, V	ME3951A > 2KHz, V/M
Multi filter comparison			
w/out F	1170-1200	1475-1509	1.6
1 F1	110-114	243-280	1.1
2 F1	100-107	130-160	0.9
3 F1	99-105	130-140	0.9
F1 comparison to In-line F			
w/out F	1150	1400	1.6
3 F1	88	140	0.9
in-line	28	25	1.1
All readings downstream of filters. No load conditions.			

The DE meters show changes (benefits) that are not clearly reflected in the E-Field spectrums, NFA logs and ME3951A readings, which start at lower frequencies

E-Field Effects with Multiple DE Filters Upstream

E-field appears to be about the same with one or several F1s

In-line filter very effective for DE > 2 KHz relative to the F1 filters



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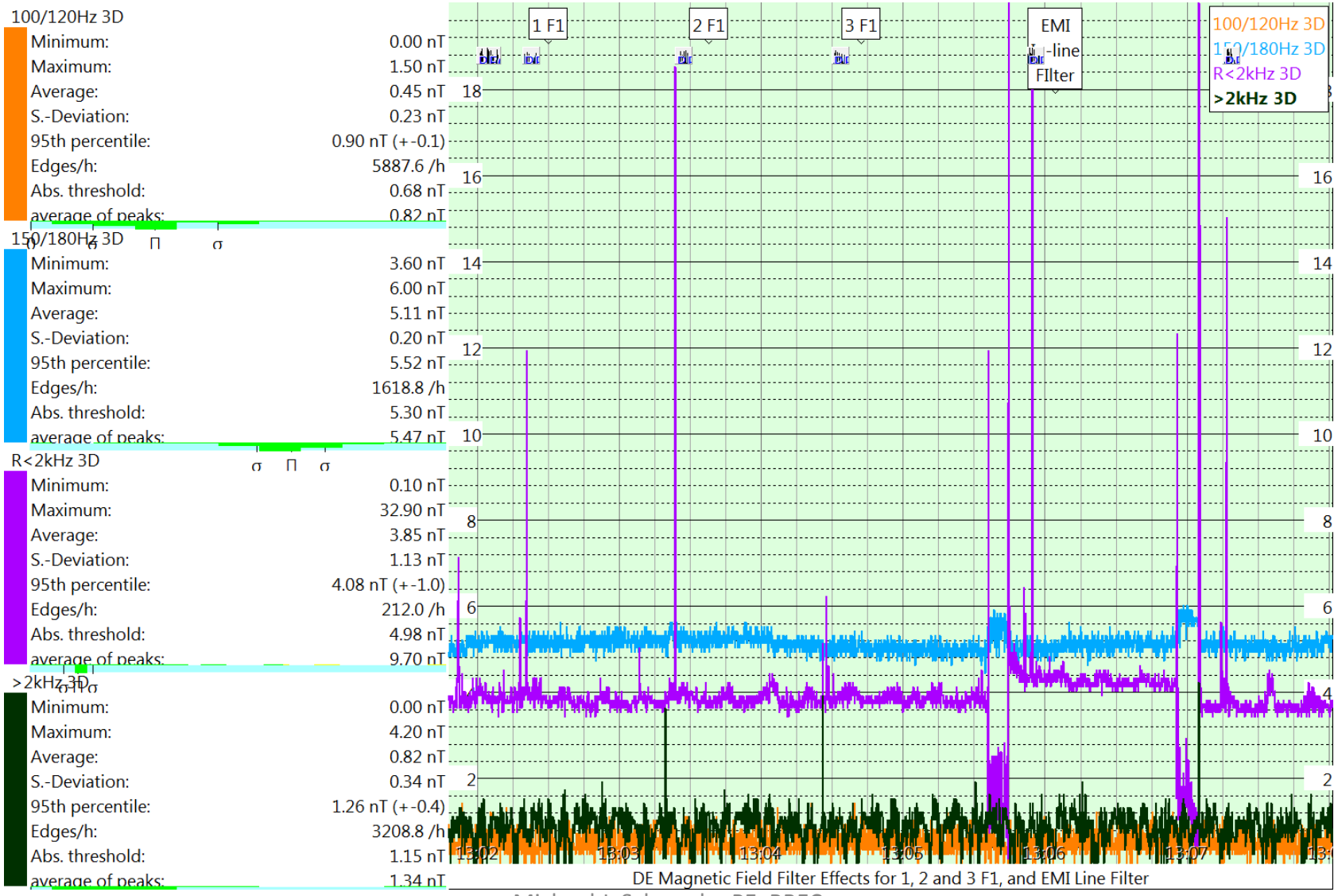
B-Fields Effects with Multiple DE Filters Upstream

Benefit of multiple filters is not apparent here



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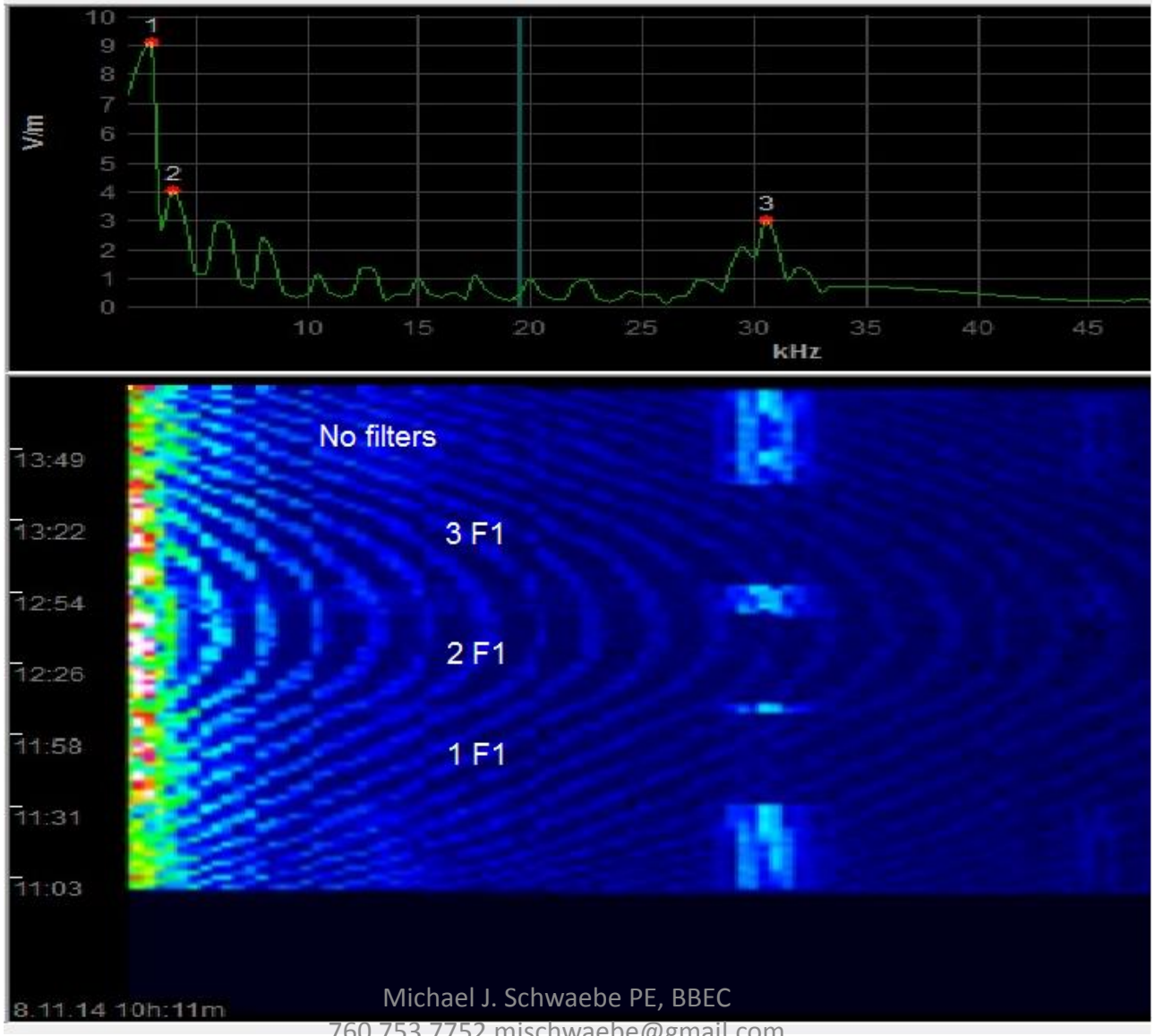
DE E-Field Effects with F1 Filters Upstream, 2-62 KHZ

Spectrum window shows DE frequencies without filters

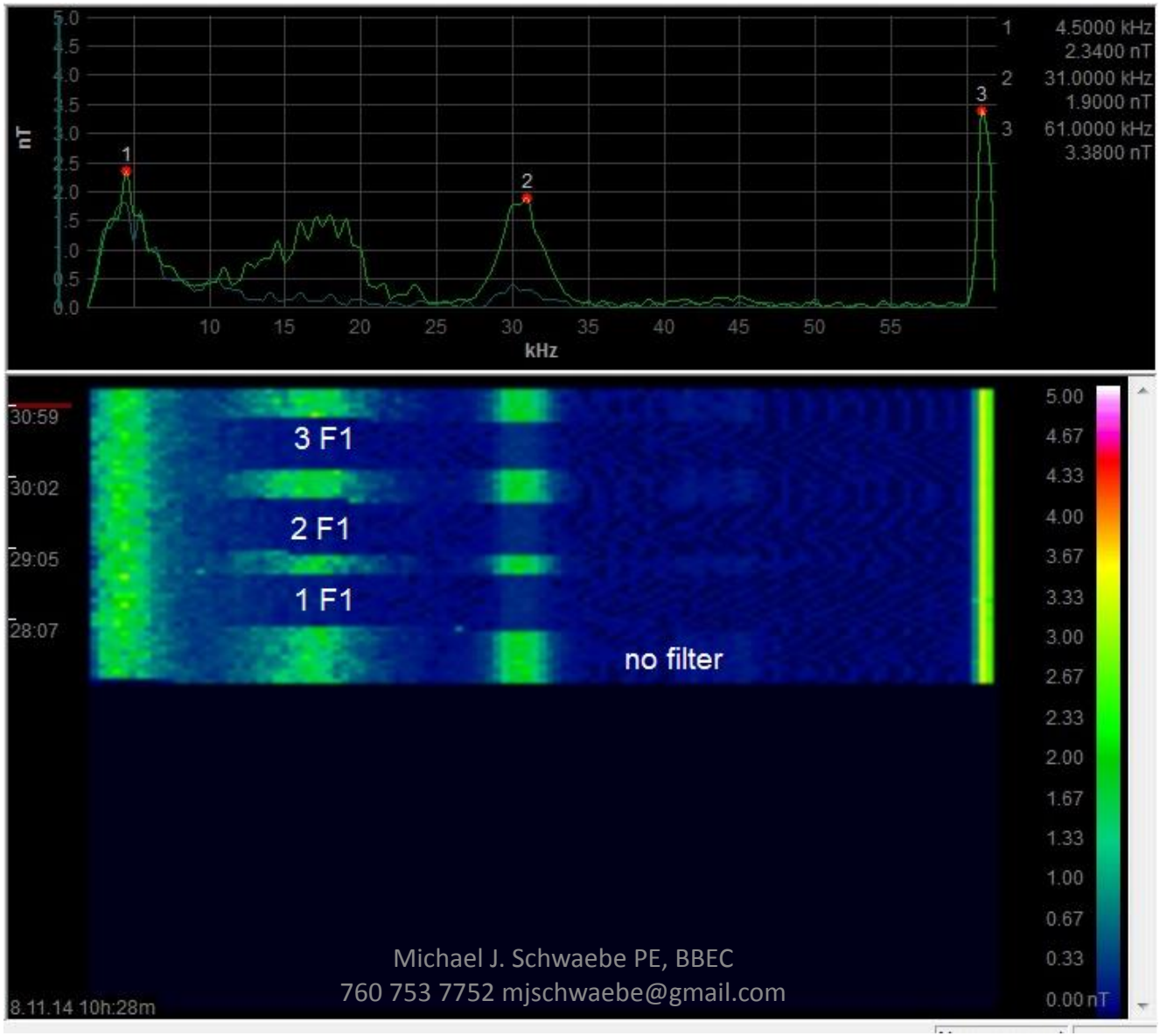
Spectrum color history shows decrease in DE > 5 KHz and increase < 5 KHz with filters



B-Field Effects with 1, 2 and 3 F1 Filters Upstream, 2-62 KHZ

Spectrum window shows DE frequencies without treatment

Spectrum color history shows decrease in DE > 15 KHz and slight increase < 5 KHz with filters



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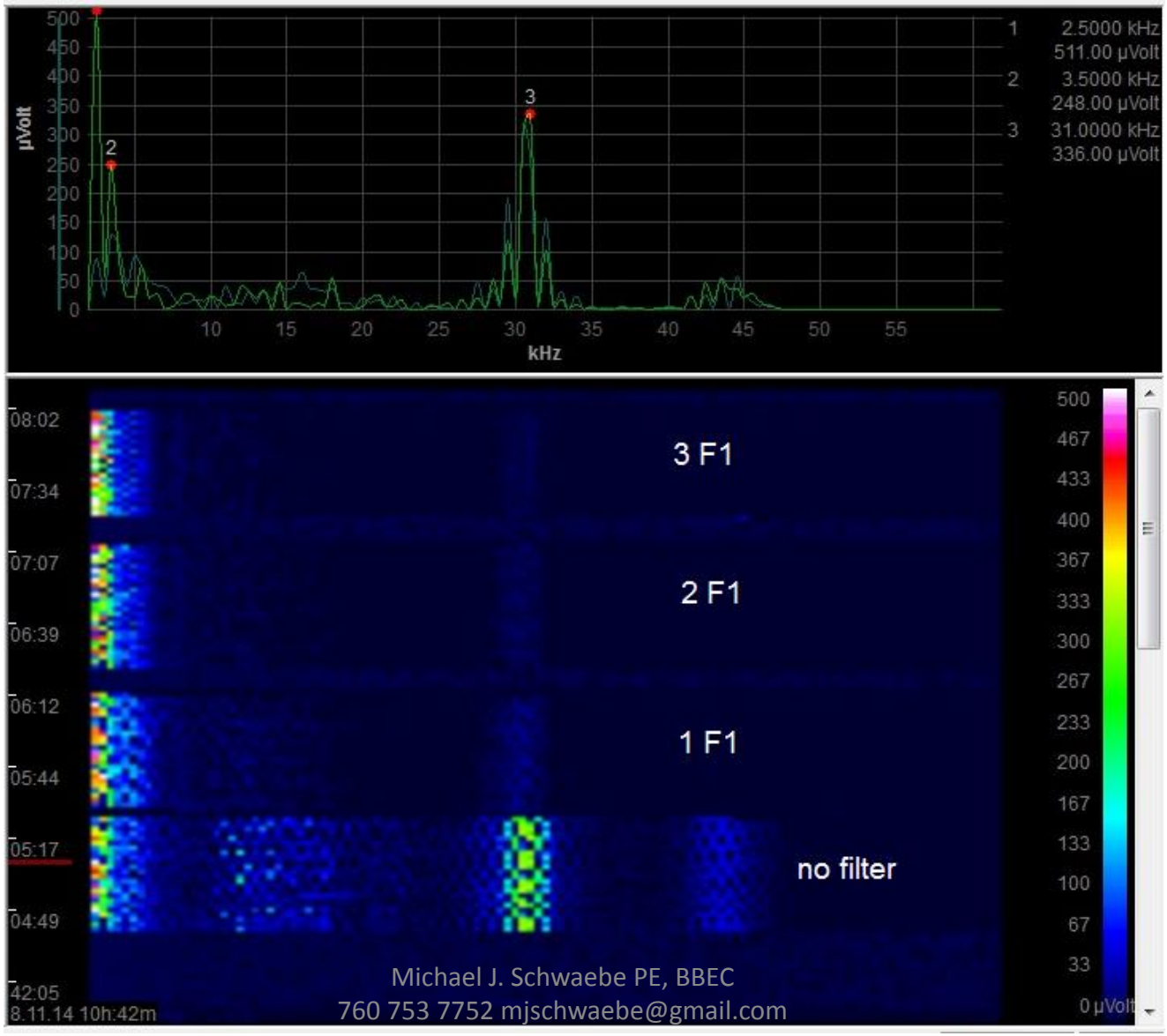
Analog (volts) with F1 Filters Upstream, 2-62 KHZ

Spectrum window shows DE frequencies without treatment

Spectrum color history shows decrease in DE > 10 KHz and increase < 5 KHz with filters



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Capacitive Filter Consequences

Increase in Dirty Electricity B-Field throughout the house

- Stetzer recommendation
  - The average home needs about 20 **STETZERiZER®** Filters to effectively clean up the electrical environment
- Greenwave recommendation
  - Ideally, EMI levels should be below 20 millivolts (mV) in all rooms. Levels between 20 mV and 50 mV are marginal and should be reduced if possible. Levels above 50 mV are undesirable and should definitely be reduced.
- Reactive current from filters in the house wires
  - Stetzer 20 x 0.85 amps = 17 amps DE current
  - Greenwave 20 x 0.5 amps = 10 amps DE current

DE Mitigation

- DE mitigation protocol
- Examples of DE mitigation
- Personal Observations
- Future work

DE Mitigation Protocol

- Use combination of EM meters and DE meter to assess the DE condition
- Mitigate internal sources
  - Remove non linear devices from home, e.g., replace CFLs with halogen bulbs.
  - Computers and entertainment systems on power strip that gets turned off when devices are not in use and at night
  - Replace variable speed controllers and motors with single speed or multiple speed selectable controls, or
  - PV and wind inverters and variable speed devices can be treated with In-line EMI filters
- External sources
  - Have the utility address power quality if THD > 5% (per IEEE-519 Std)
  - Place appropriate DE filter(s) at the service entrance in both phases
- Use DE filters inside home only if there is clear benefit to occupants

Examples of DE Mitigation

- DE filters at power panel
  - Filter comparison
- Assessing DE Mitigation
  - Variable speed spa pump from neighbor
  - ME3951A measurements within the house
- Solar voltaic inverter filters

Filter Comparison at Power Panel

- Filters are wired into the mains power panel
  - PXDNA is installed at receptacles next to panel
- DE meter effects are not representative
- Oscilloscope spectrums for 2 filters
  - show shift in DE to lower frequencies
  - show new resonance frequencies
- Conclude that not every filter is right for DE mitigation

Whole House Filter Comparison

Filter Effects for Dirty Electricity Reduction		
Filter Model	Stetzerizer Meter	EM Line Meter
Satic	288	300
EP2700	280	308
EP2000	290	755
PXDNA	300	500
Baseline	529	919

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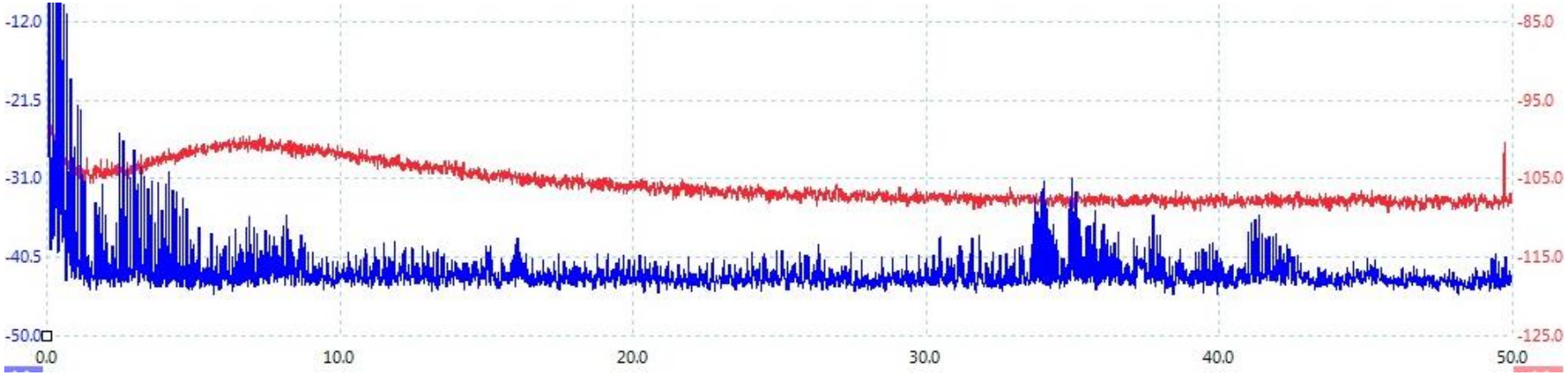
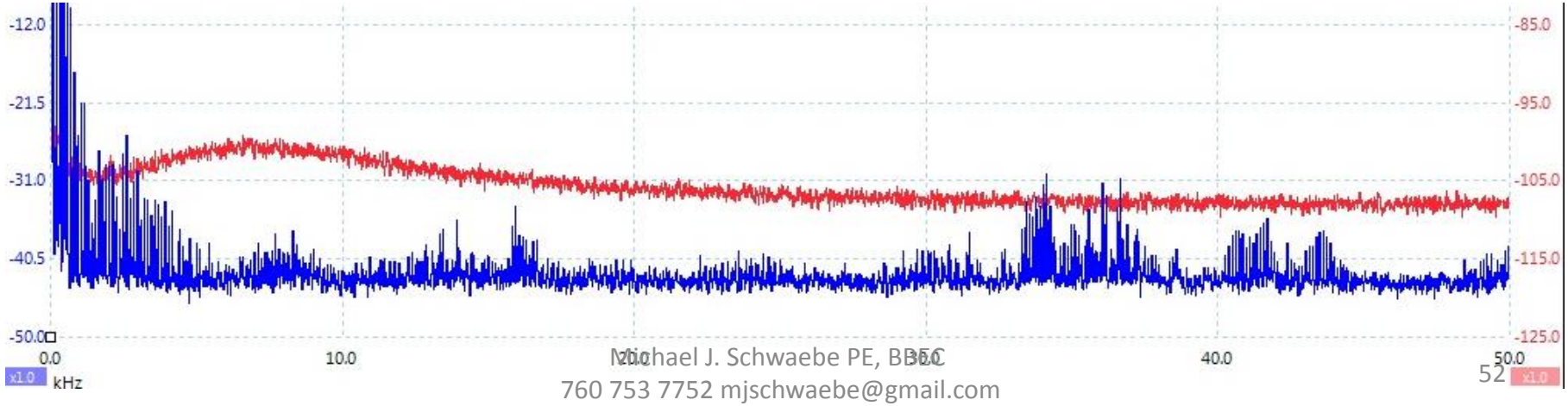
Satic DE Filter at Power Panel

pushes DE to low end and creates new frequencies

Baseline



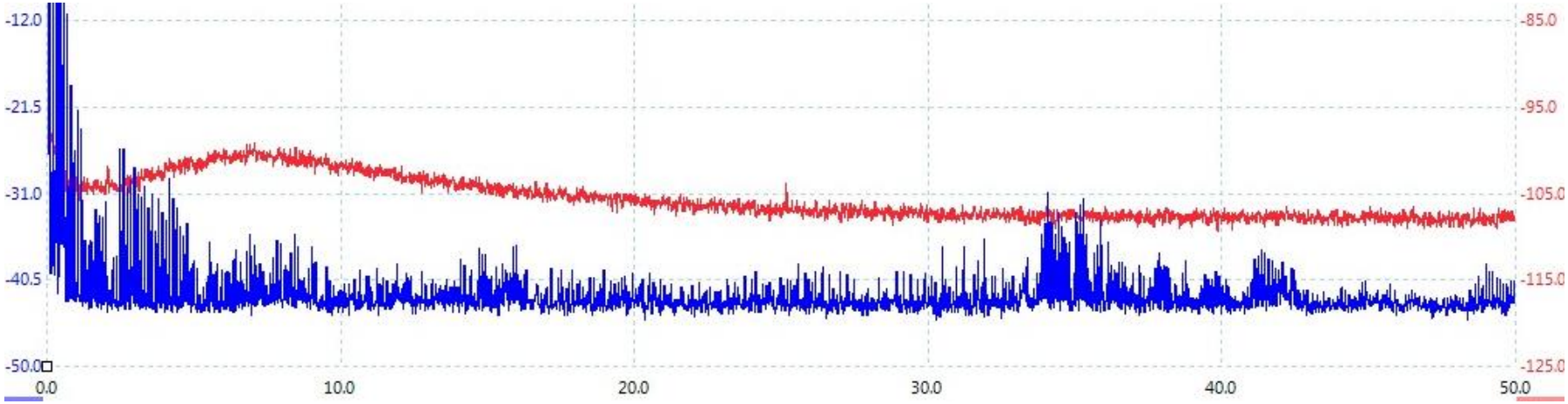
Satic



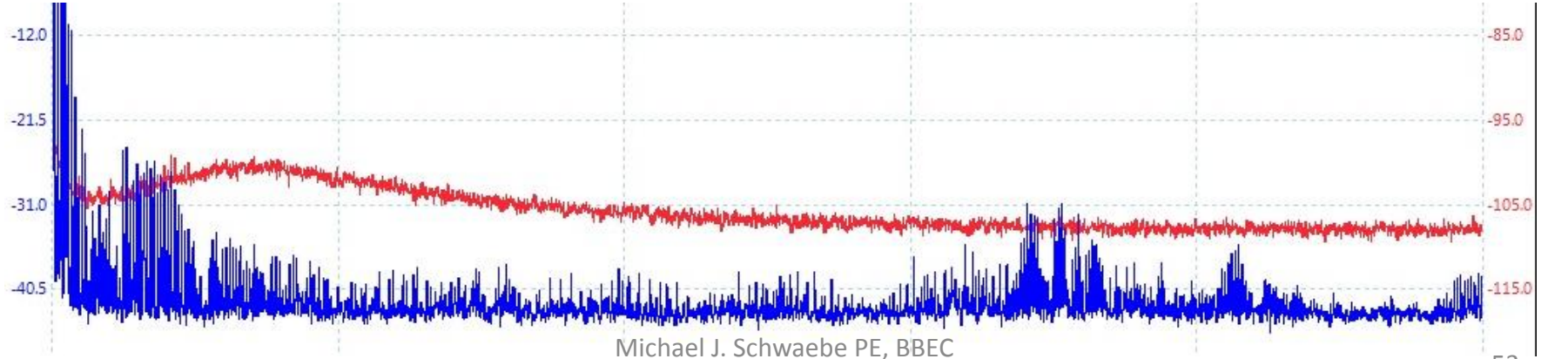
EP2700 DE Filter at Power Panel

pushes DE to low end and creates new

Baseline



EP2700



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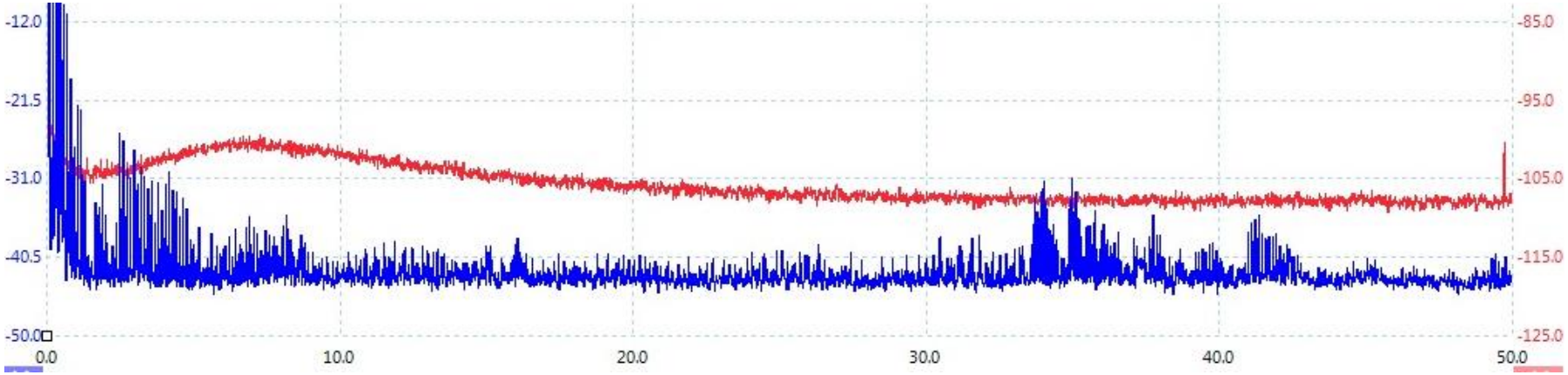
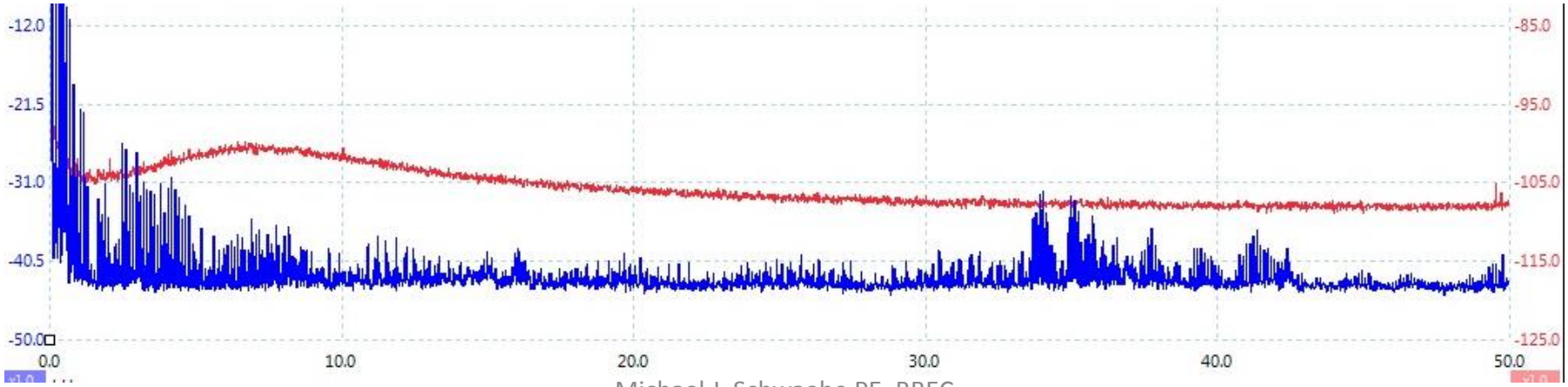
EP2000 DE Filter at Power Panel

smoothes both the potential and current spectrums

Baseline



EP2000



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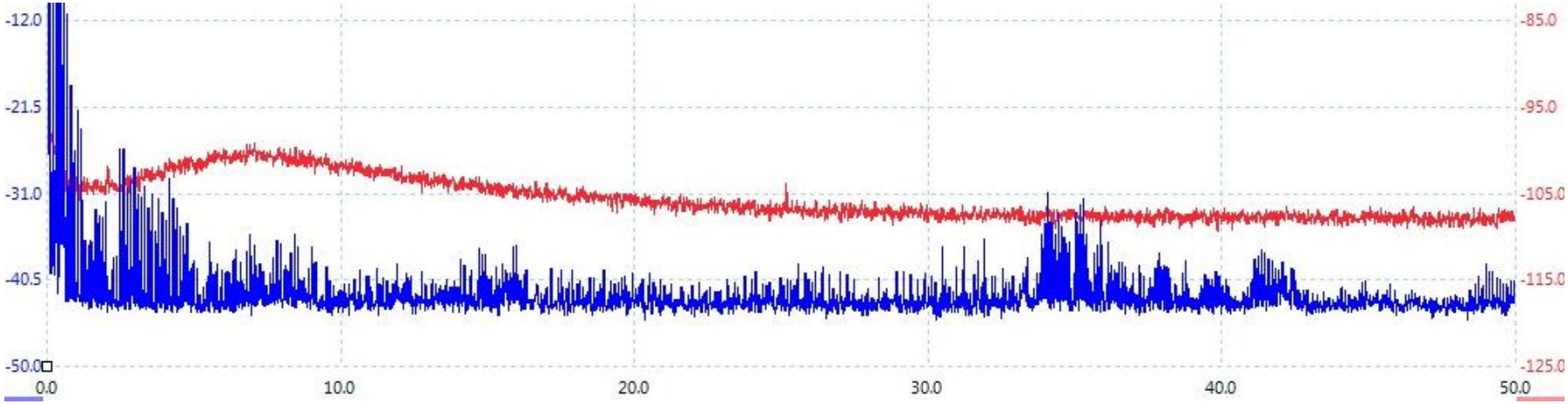
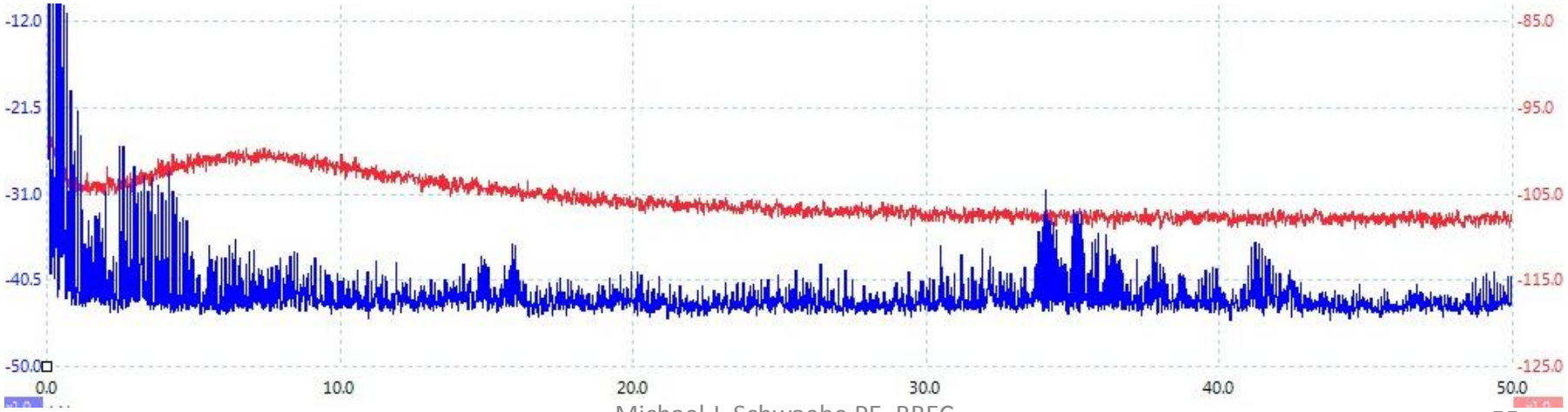
PXDNA DE Filters at Power Panel

smoothes both the potential and current spectrums

Baseline



PXDNA



Assessing DE in a House, Example Using ME3951A >2KHz

Power off readings provide the goal

Power on is “as found condition”

1 filter for each phase located in receptacle near power panel

Only B-Field shows an improvement in 3 areas

Description	Power Off		Power On		w/ 1 F1 Filter		w/ 1 F4 filter	
	V/M	nT	V/M	nT	V/M	nT	V/M	nT
DR Table	0.15	0.3	0.15	0.4	0.15	0.3	0.15	0.3
Hall	0.2	0.6	0.2	0.7	0.2	0.6	0.2	0.6
Kitchen	0.2	0.3	0.2	0.45	0.2	0.35	0.2	0.35
Office	0.15	0.3	0.15	0.4	0.15	0.4	0.15	0.4
Porch	0.15	0.3	0.15	0.3	0.15	0.3	0.15	0.3
DE Readings			Stetzer	Line Em	Stetzer	Line EM	Stetzer	Line Em
DE at location # 1 in kitchen			580	1100	305	560	375	800
DE at location # 2 in kitchen			1000	1462	225	410	430	960
DE is from an external source. Improvement in DE B-Field shown in red.								

Solar Voltaic DE Mitigation

DNA line filters installed on 1 of 3 inverters

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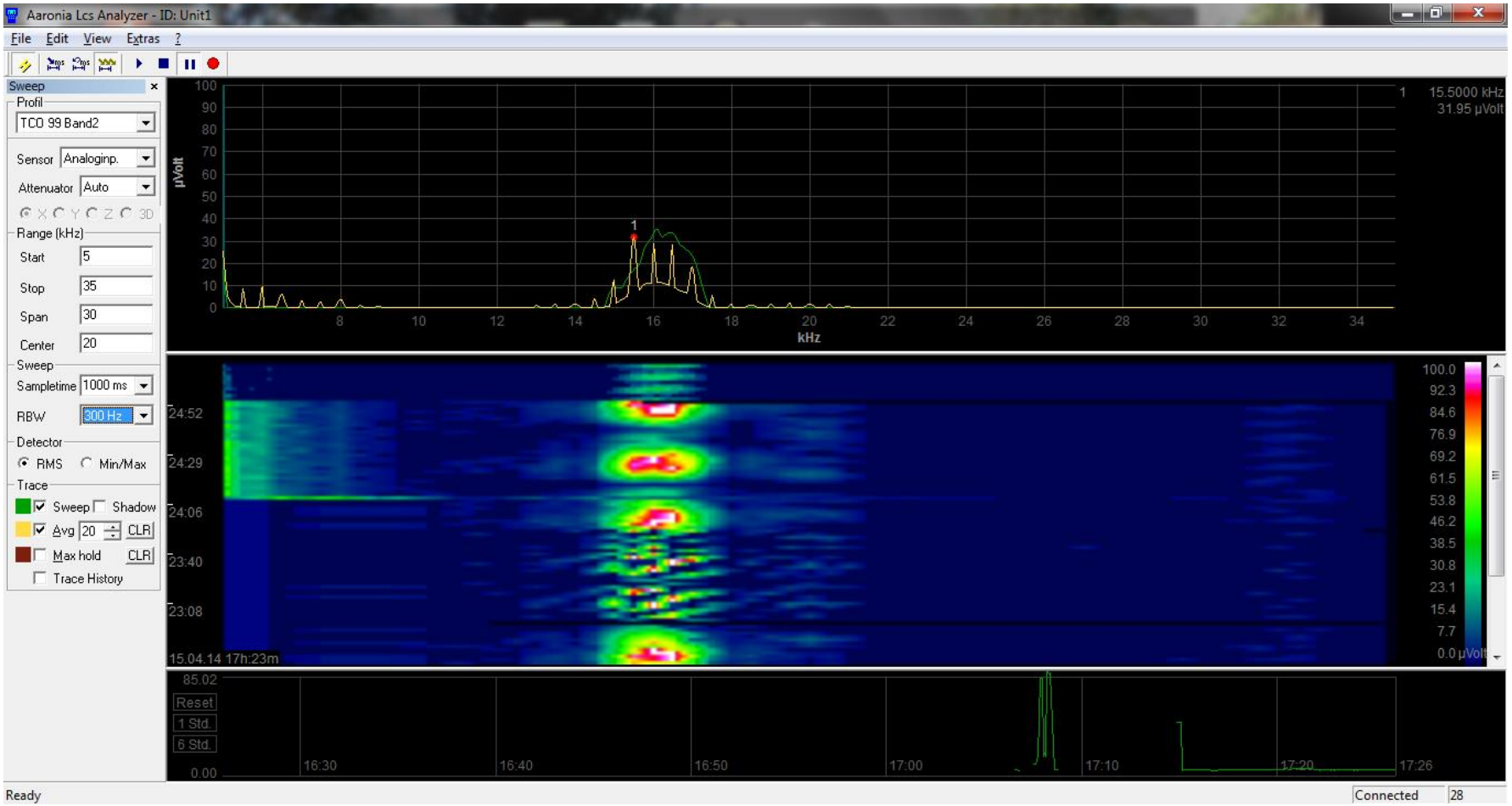
Solar Voltaic Inverter DE at 16 KHz unmitigated

Spectran Analog (volts), 2-62 KHZ frequency range

Spectrum waterfall display shows history, frequency, and amplitude

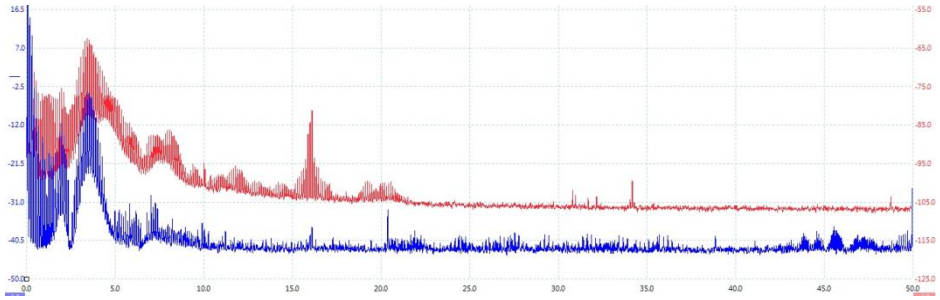


DE Oscilloscope Images for SV Inverters

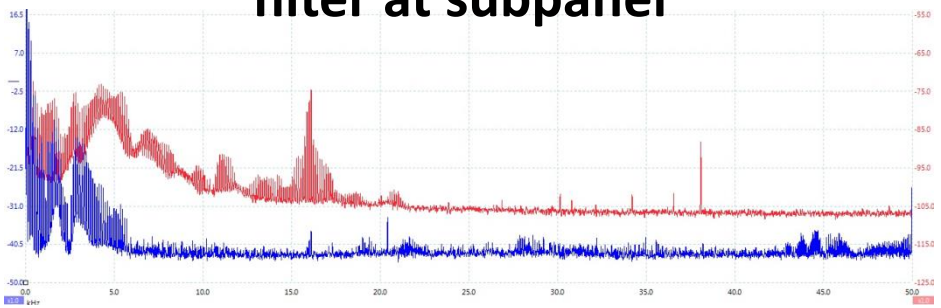
Voltage spectrum (blue) and current spectrum (red)

Test points at SV breaker and cable feed

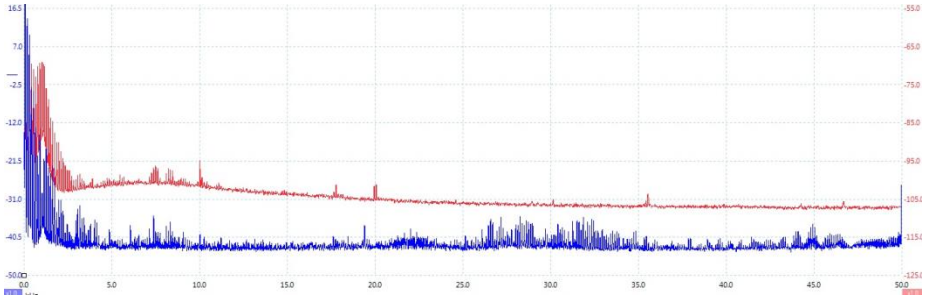
SV Inverter w/out filter



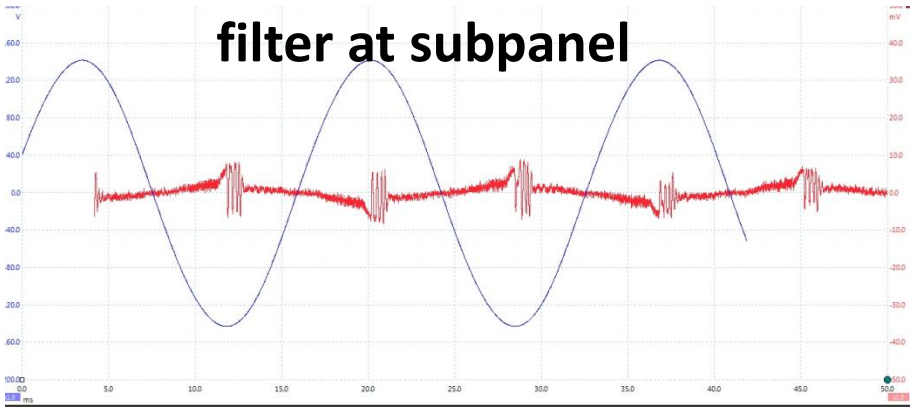
SV Inverter with Satic filter at subpanel



SV Inverter with DNA line filter



SV Inverter with Satic filter at subpanel



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Personal Observations

- DE filters F1, F2 and F3 within a living space or connected near the power panel are discomforting
  - subtle energy harmonics cause disturbance in the mid-brain and CNS
- Cleanest PV systems are Sunny Boy SMA, dirtiest are Outback
  - SMA produces a 16 kHz EMI that elicits tension and severe headaches
  - dirtiest PV system is the Outback, DE can be detected at > 10 feet from the house
- I feel discomfort in homes
  - with wireless devices, PV, fluorescent lights
  - when the Stetzer meter > 400
  - When ME3951A (selected to 2KHz – 400KHz band) > 0.4 nT
- DE fields can be detected easily
  - near circuits and devices anytime
  - in the middle of small rooms (kitchens and bathrooms)
  - even when the Stetzer meter <100
  - Local hotspots of DE EMR can be unrelated to devices and circuits
- Installing one DE filter within the home can increase DE in other circuits

Future work

- Assess DE filter devices like the F4 filter for suitability in a whole house application (without side effects)
- Assess in-line EMI filters for suitability in a whole house application
  - The issue is selecting a filter that would be effective at low frequencies and the variable impedance of a house scenario
- Develop an IBE protocol for DE measurement
  - Easiest and most efficacious assessment methods
  - Effective mitigation strategy
- Develop DE exposure guidelines that fit into the Building Biology methodologies.
- Identify appropriate research references for health effects from DE.

Take Away from This Presentation

- Dirty Electricity (DE) has potential (volts-electric field), current (amps-magnetic field), frequency and EMR
- DE EMR phenomenon is readily detectable
  - Greenwave and Stetzer DE meters look only at potential > 2 and 10 KHz respectively. There is more to the DE picture
  - Use sensitive (0.1 V/M and 0.1 nT) EM meters with selectable ranges on wiring and within home
- Best location for DE filters is at the power panel
  - DE filters shunt DE volts to current, which increases the B-Field component of DE in all upstream circuits
  - Use DE filters inside home only if there is clear benefit to occupants
- Halogen light bulbs (not the low voltage kind) have the lowest DE