Televisions, Video Privacy, and Powerline Electromagnetic Interference

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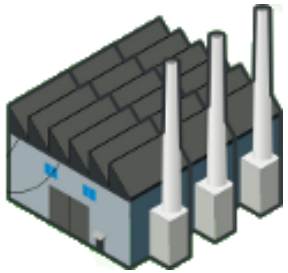
Security & UbiComp Labs @ **UW**

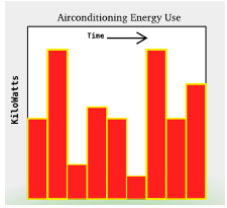
Smart Home = Smart Devices + Smart Sensors

The Picture Today

power sensor

Utility





3rd Parties

The Picture Today

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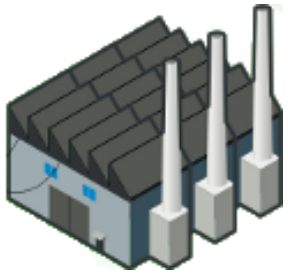
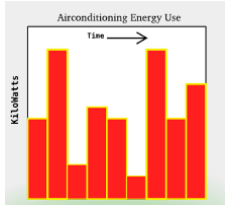
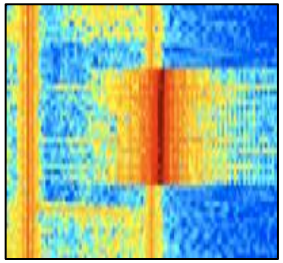




3rd Parties

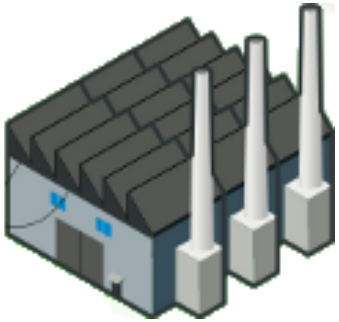
UbiComp



Emerging Trends:

Sophisticated electrical sensors are already deployed in homes to help achieve new efficiency and utility goals.

Benefactors:



Research Q:

What **private information** is available from the powerline?

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Answer:

Modern TVs leak **substantial information** on the power line that is indicative of the **screen content**

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Information can be collected using a **single sensor** installed anywhere on power line

What's the **BIG** deal?

U.S. Video Protection & Privacy Act of 1998 states that video viewing records **be kept private**

TITLE 18 > PART I > CHAPTER 121 > § 2710

§ 2710. WRONGFUL DISCLOSURE OF VIDEO TAPE RENTAL OR SALE RECORDS

(a) Definitions.— For purposes of this section—

(1) the term "consumer" means any renter, purchaser, or subscriber of goods or services from a video tape service provider;

(2) the term "ordinary course of business" means only debt collection activities, order fulfillment, request processing, and the transfer of ownership;

(3) the term "personally identifiable information" includes information which identifies a person as having requested or obtained specific video materials or services from a video tape service provider; and

(4) the term "video tape service provider" means any person, engaged in the business, in or affecting interstate or foreign commerce, of rental, sale, or delivery of prerecorded video cassette tapes or similar audio visual materials, or any person or other entity to whom a disclosure is made unde subparagraph (D) or (E) of subsection (b)(2), but only with respect to the information contained in the disclosure.

What's the **BIG** deal?

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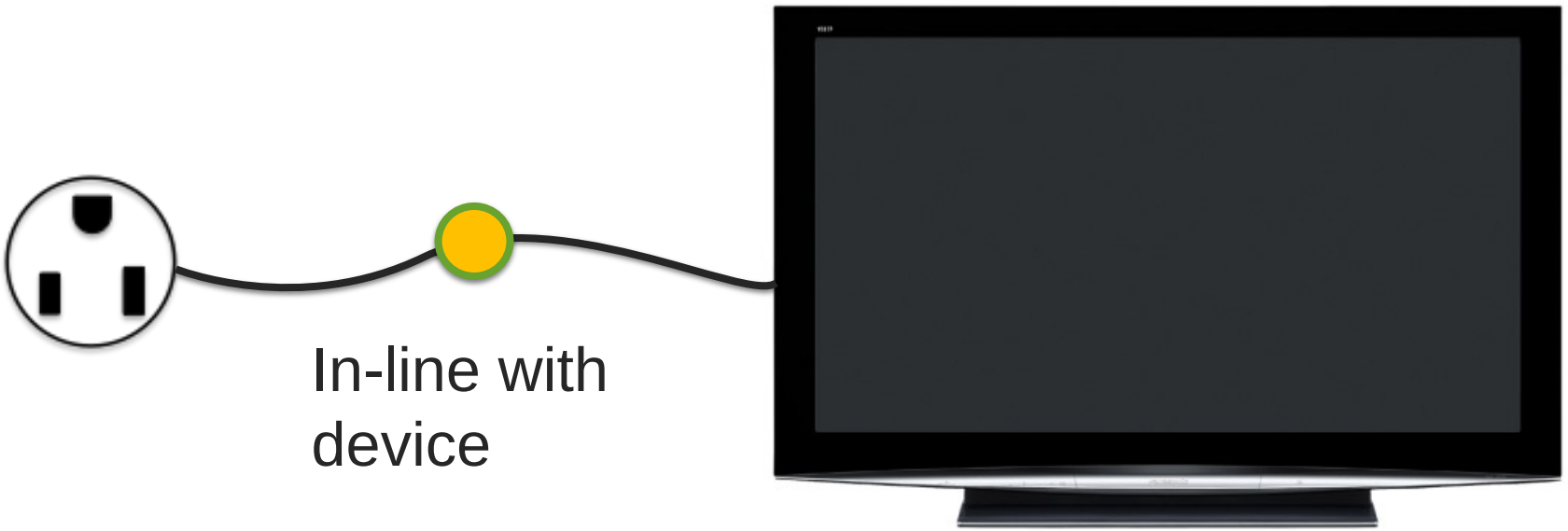
We hope our work can **inform future discourse** about the directions of Powerline sensing technologies

Related Work

Smart Sensor Power measurements reveal private information about homeowner's activity [Markham 2010]; concurrent work also looks at TVs [Greveler 2011]

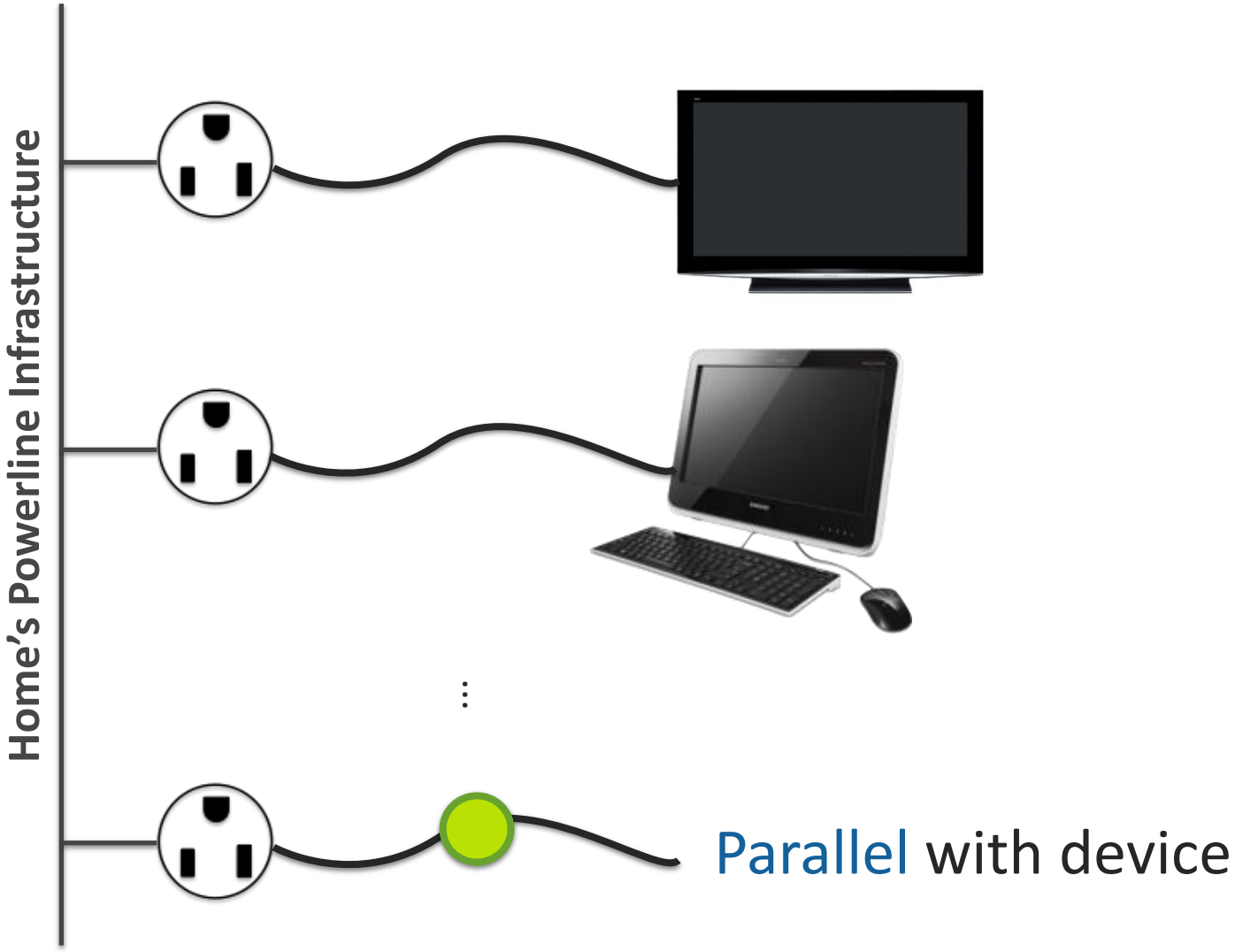
In-line power measurement of a PC can reveal web browsing habits [Clark 2011]

Power Based Measurement



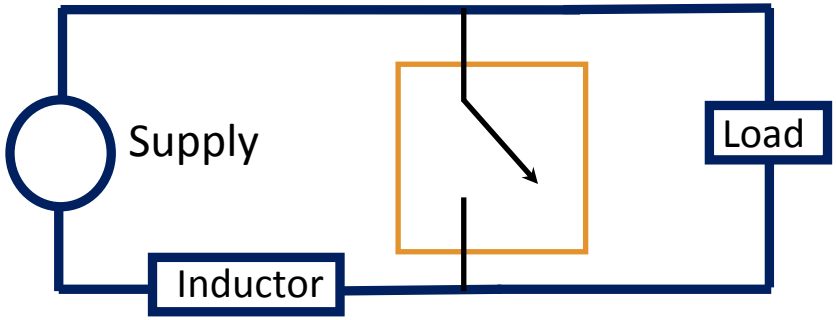
In-line with device

Voltage Based Measurement



Switched Mode Power Supply

Switching Circuits generate high frequency Electro Magnetic Interference (EMI)



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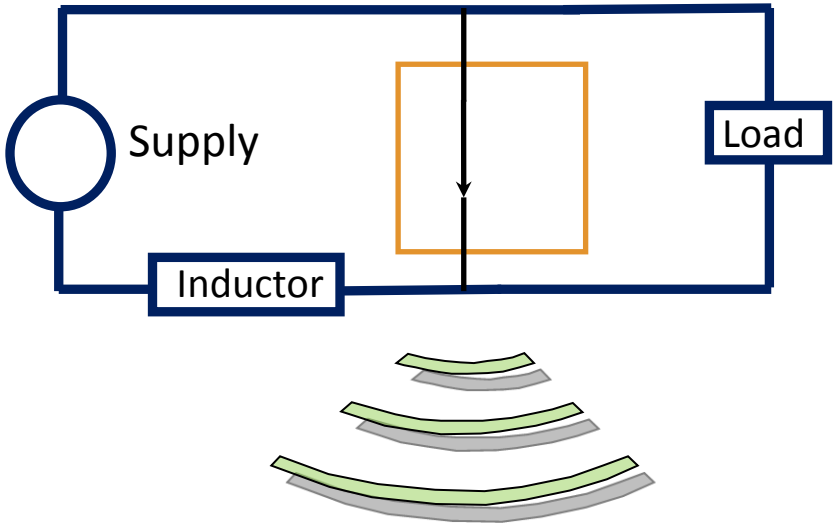
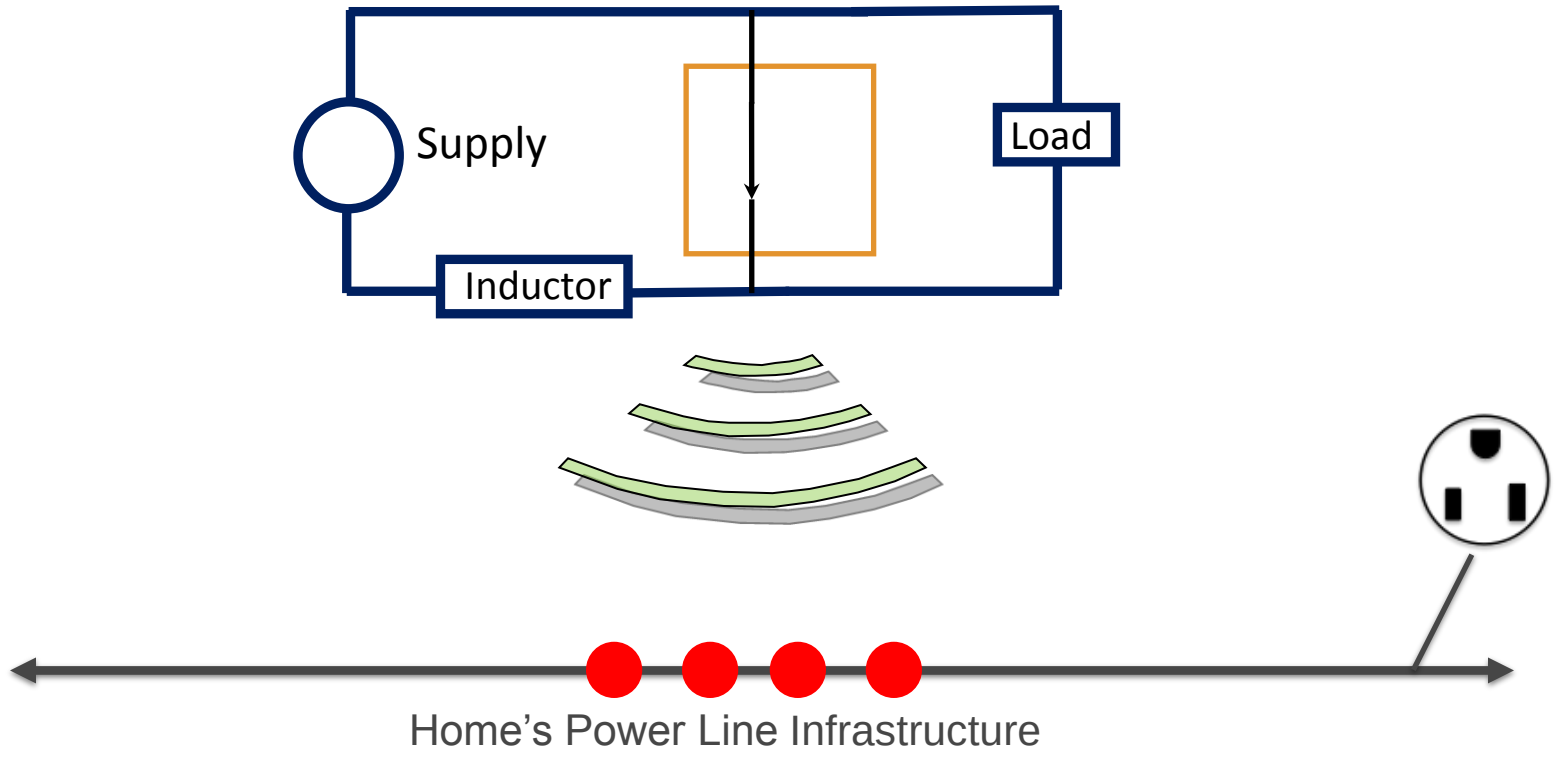


Switching Circuits generate high frequency EMI which **couples** onto the powerline



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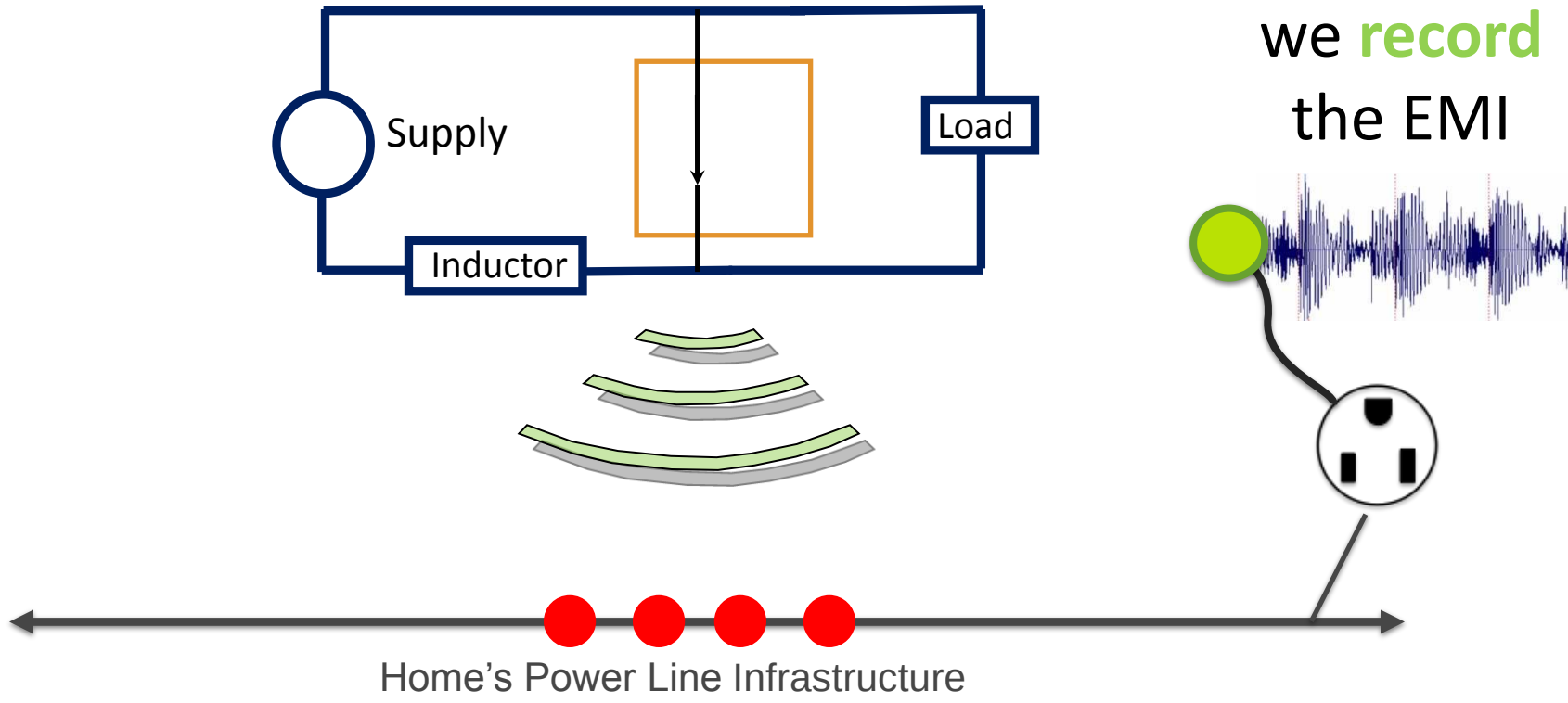
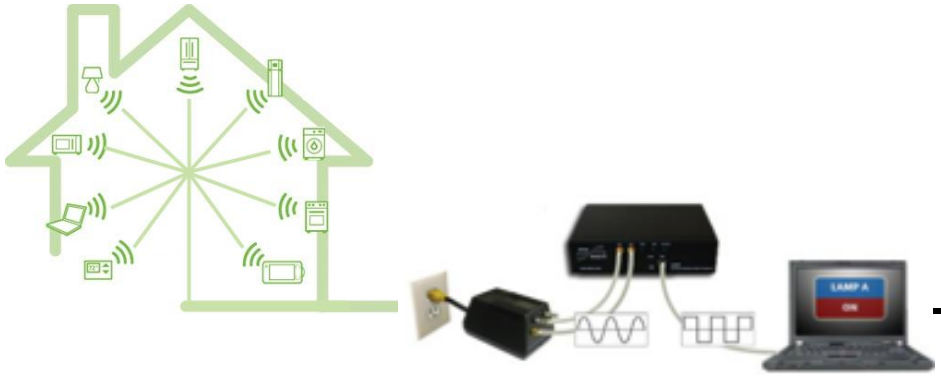
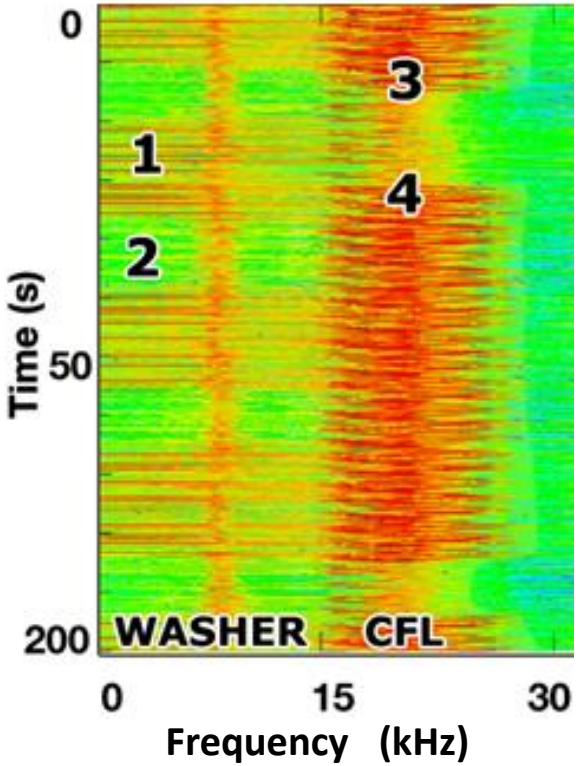


EMI: Summary



ElectriSense (2010 Gupta et al.)



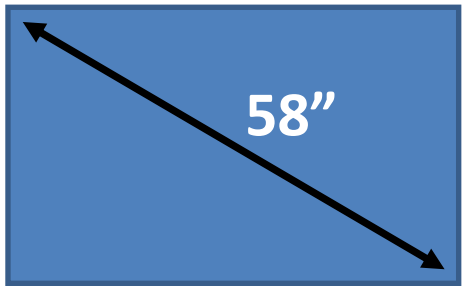
Many modern devices produce **EMI!**

EMI can be collected with a **single sensor!**

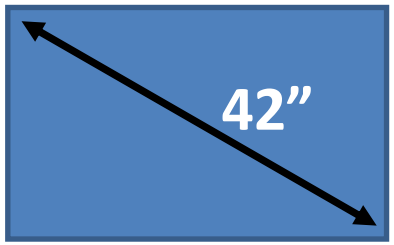
Signals live in the **frequency domain!**

EMI @ Home

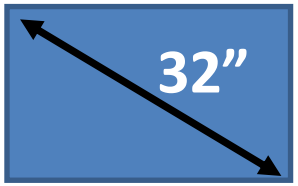
Our 8 TVs



Samsung 58-A
Samsung 58-B



Panasonic 42-A
Panasonic 42-B
Sharp 42



Sharp 32-A
Sharp 32-B
Samsung 32

Plasma, 2010

LCD, 2007 - 2009

Research Questions?

Q1: Do TVs produce **repeatable EMI** given **repeated screen content**?

Q2: For a given TV, does **different screen content** produce **different EMI**?

Q3: Is EMI **consistent** across **TVs from the same model family**?

Q4: Can we use EMI to **determine what is being watched** on TV?

Q5: Can we **match lab EMI** to EMI recorded in **various home settings**?

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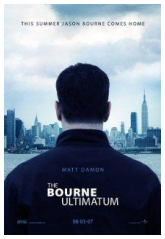
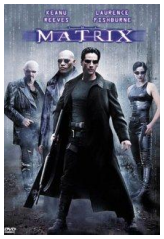
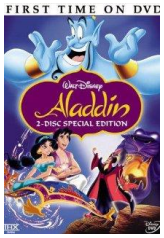
Screen Content = 20 IMDB Top Grossing Movies

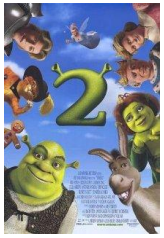
Action



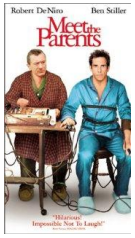


Animation

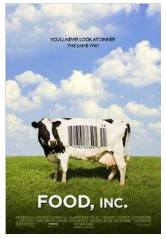


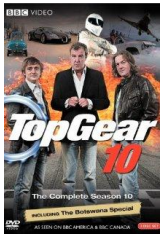


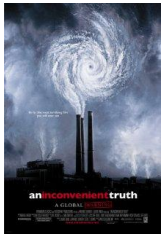
Comedy

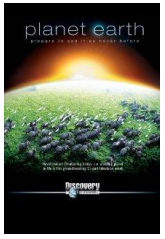



Documentary

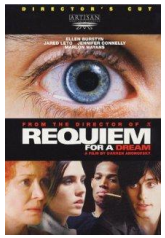


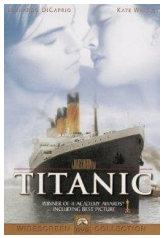


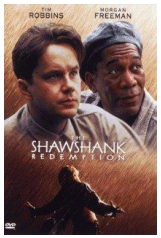


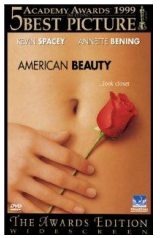


Drama

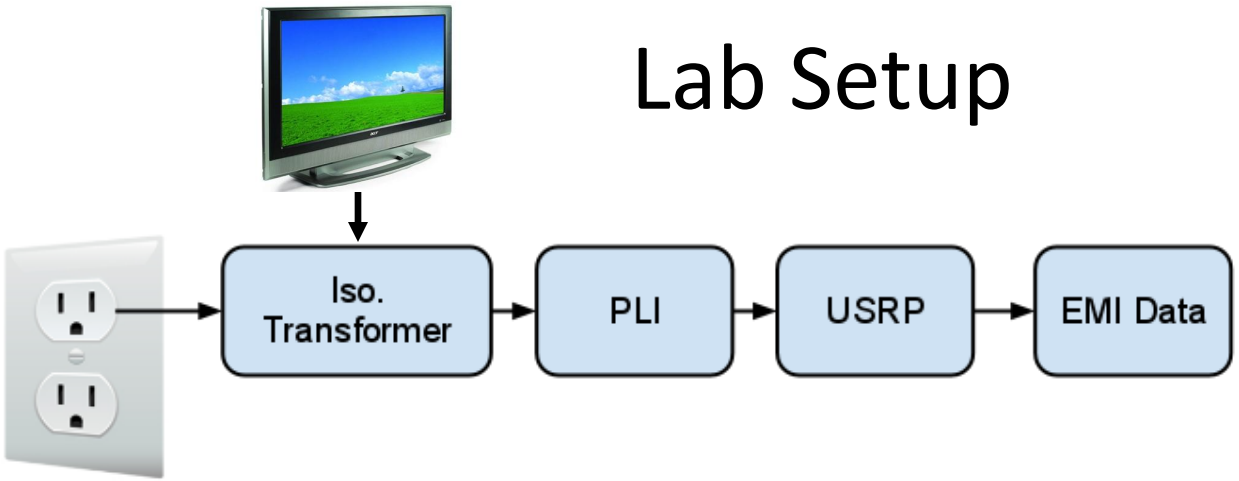


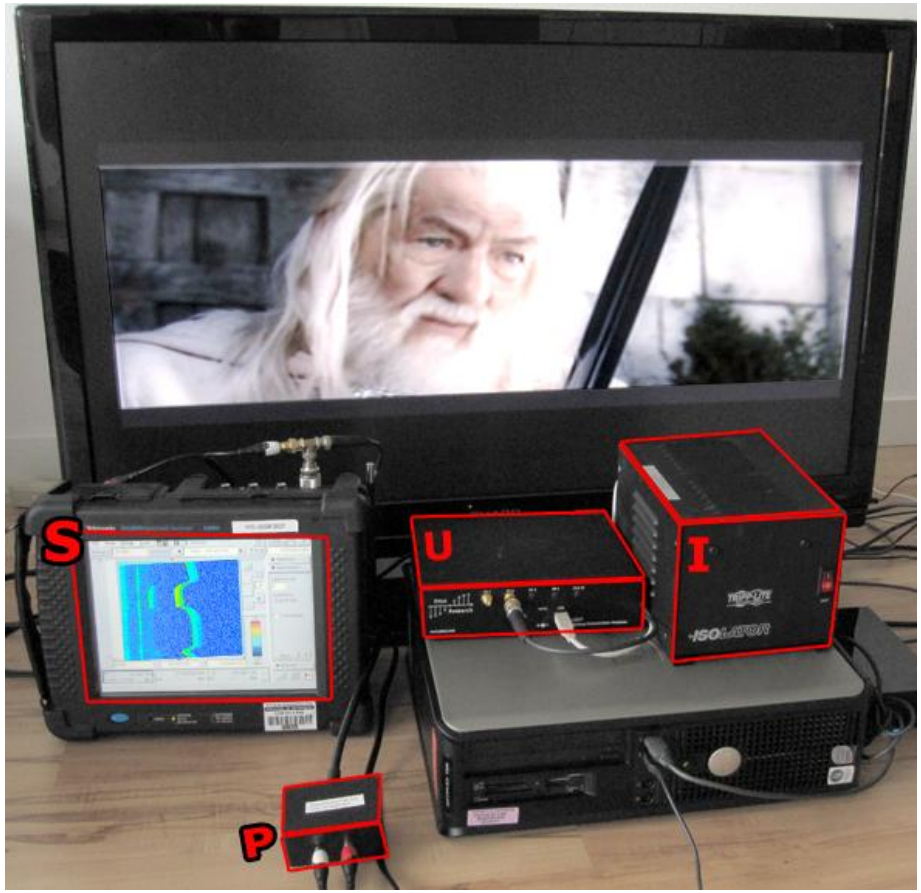






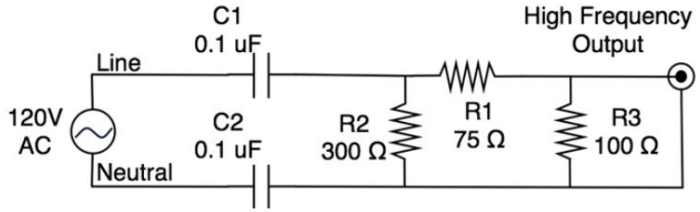
Lab Setup





(I)Isolation transformer
- external EMI filter

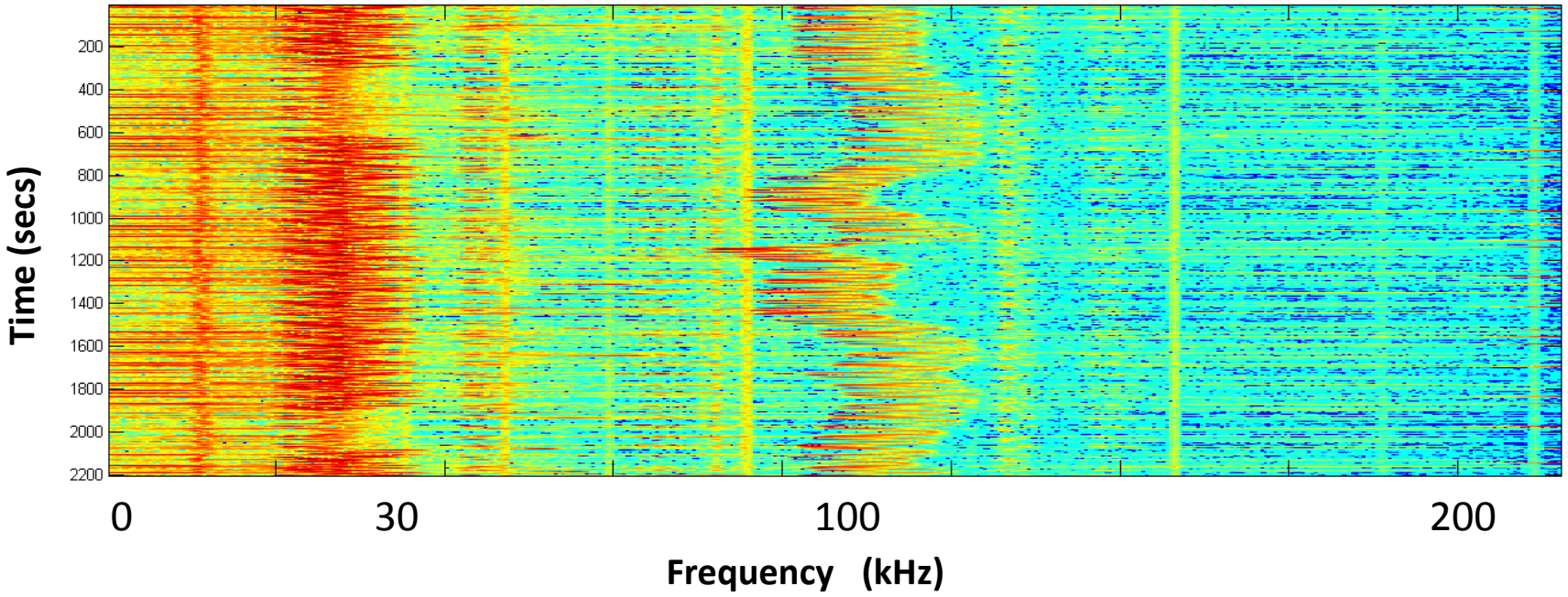
(A)Power Line Interface
- custom voltage sensor



(U) Universal Software Radio Peripheral
- analog to digital convertor

(A)Spectrum analyzer
- visualization & logging

Signal Extraction



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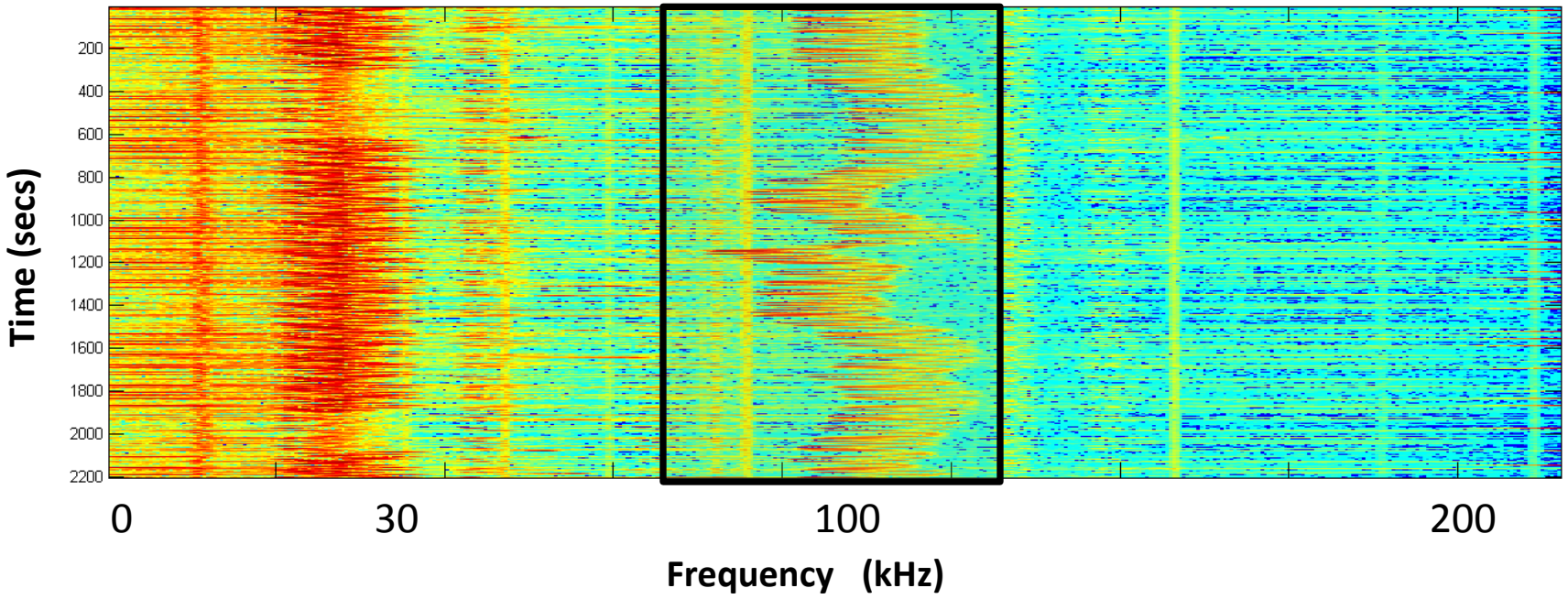
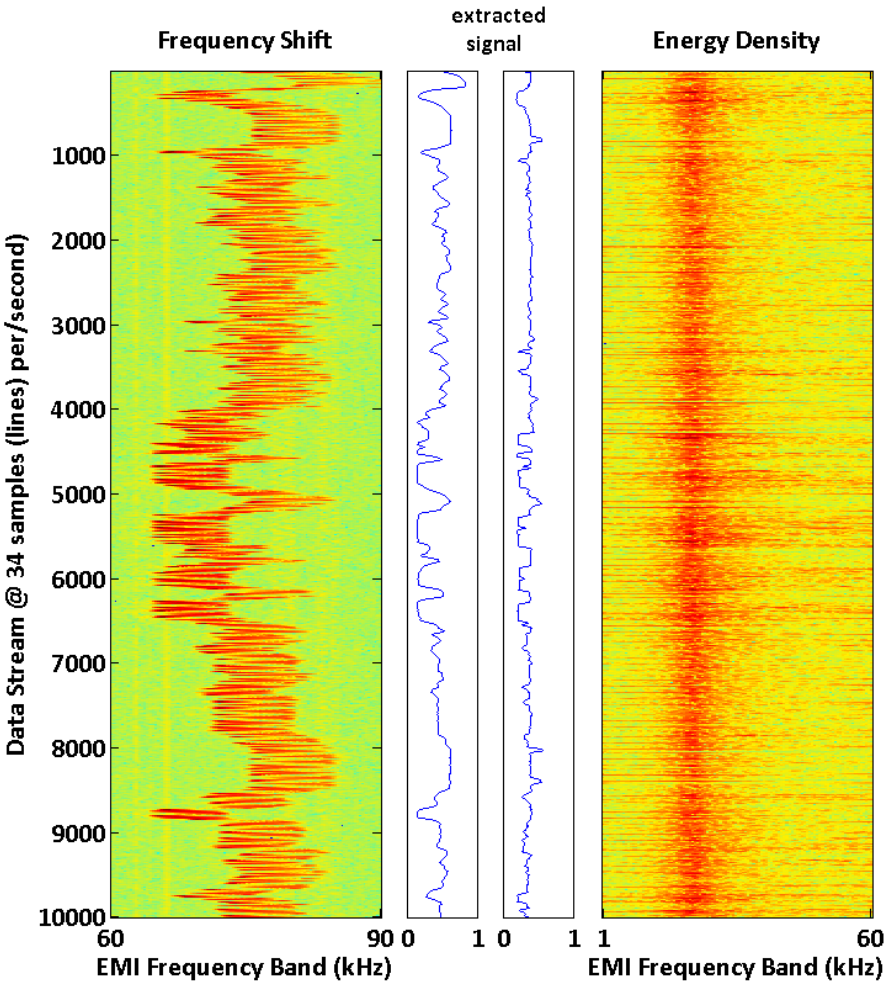


Extracting TV EMI



Television Name	Freq. Range	Signal Type
Panasonic-42-A/B	1 to 60 kHz	Energy Density
Samsung-58-A/B	45 to 55 kHz	Frequency Shift
Samsung-32	10 to 50 kHz	Energy Density
Sharp-42	60 to 90 kHz	Frequency Shift
Sharp-32-A/B	35 to 40 kHz	Energy Density

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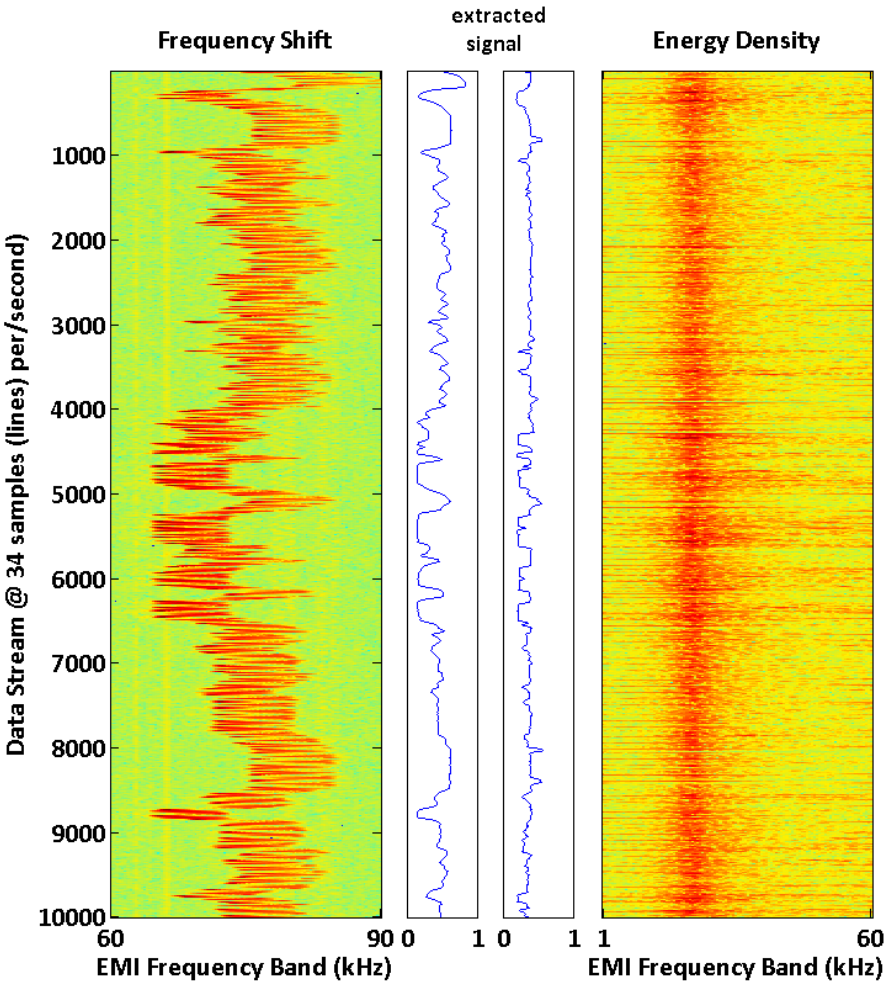

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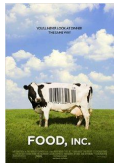
Approach: Match EMI to a DB

Building an EMI Database

Iso. Transformer → PLI → USRP → EMI Data

0 — Time (mins.) — 60

EMI



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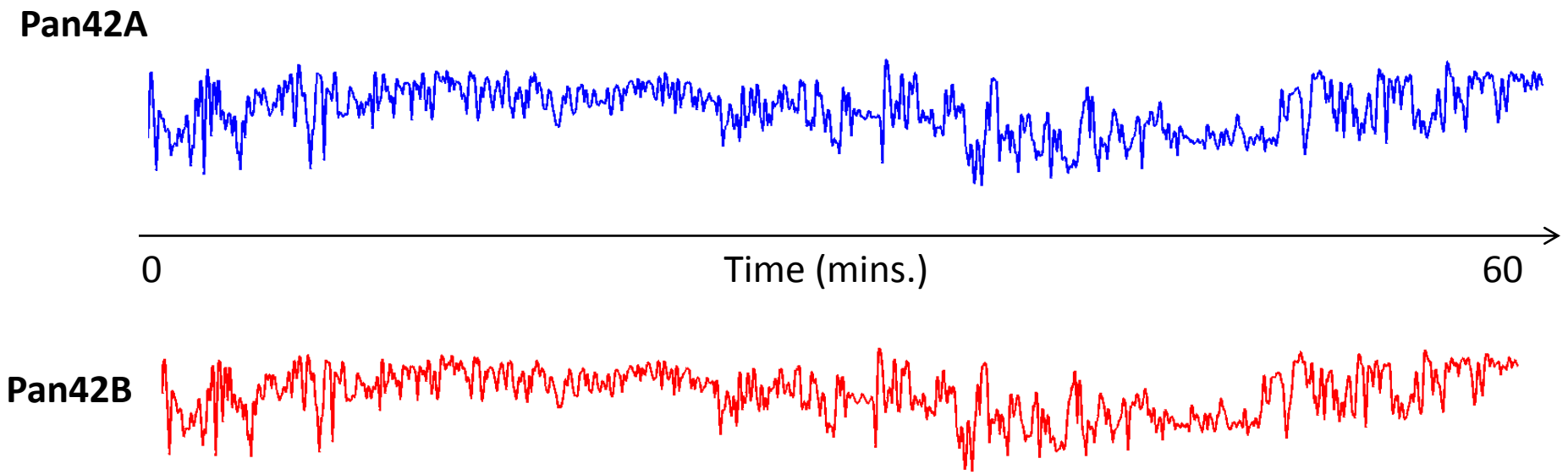
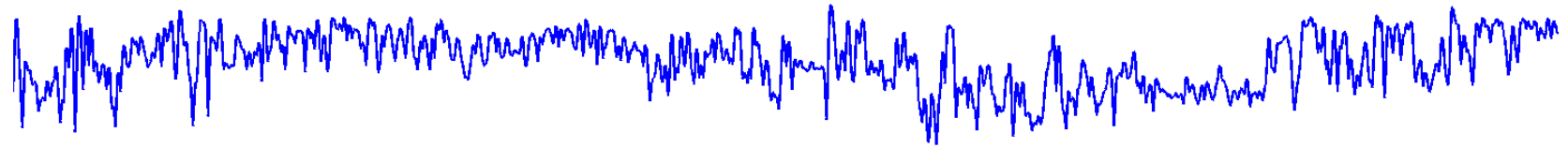
Multiple Runs

Multiple TVs
Same Content



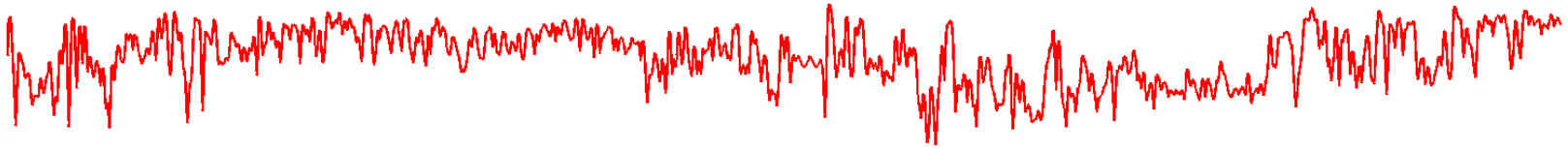
Multiple Runs { Multiple TVs Same Content

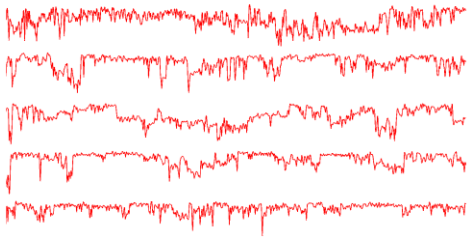
Pan42A



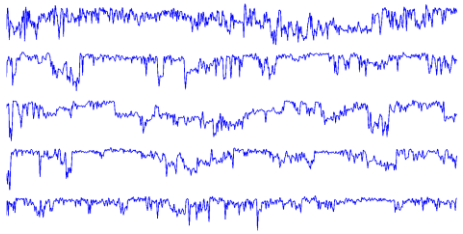
0 Time (mins.) 60

Pan42B





Query vs **DB**



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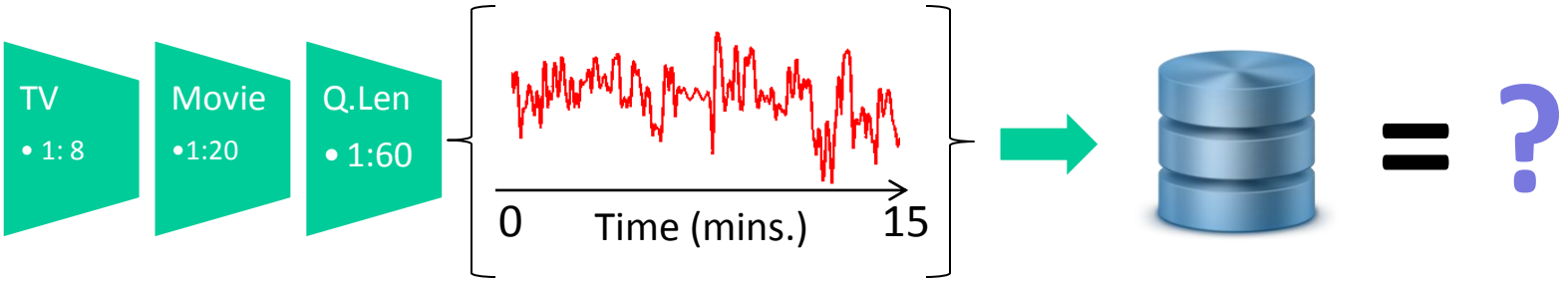

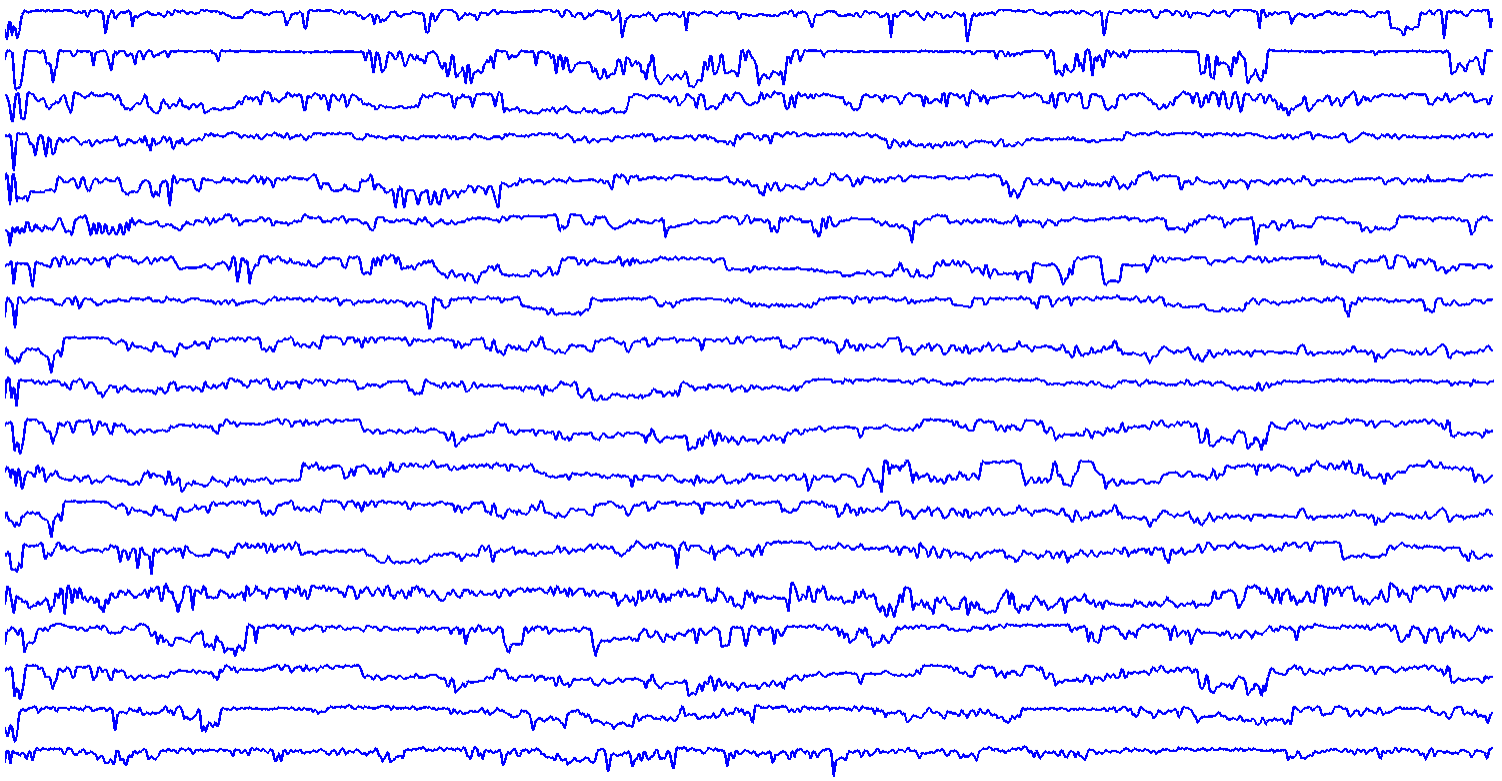

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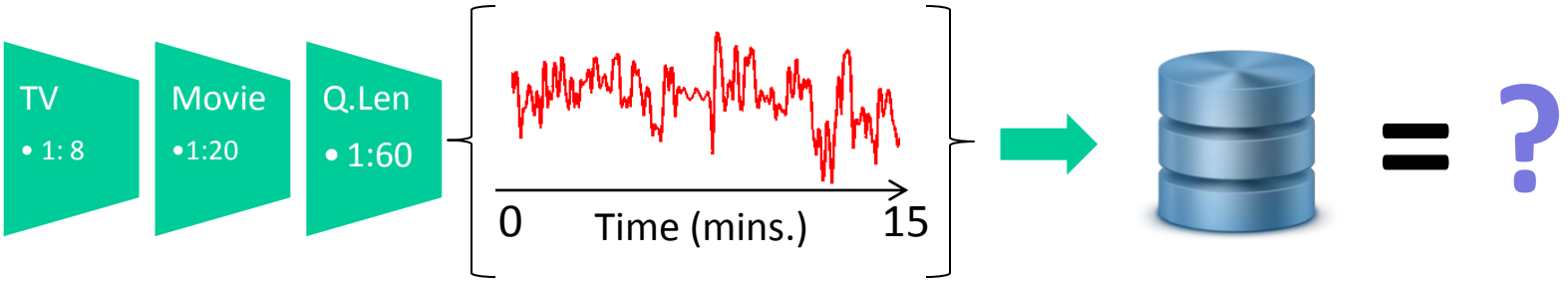

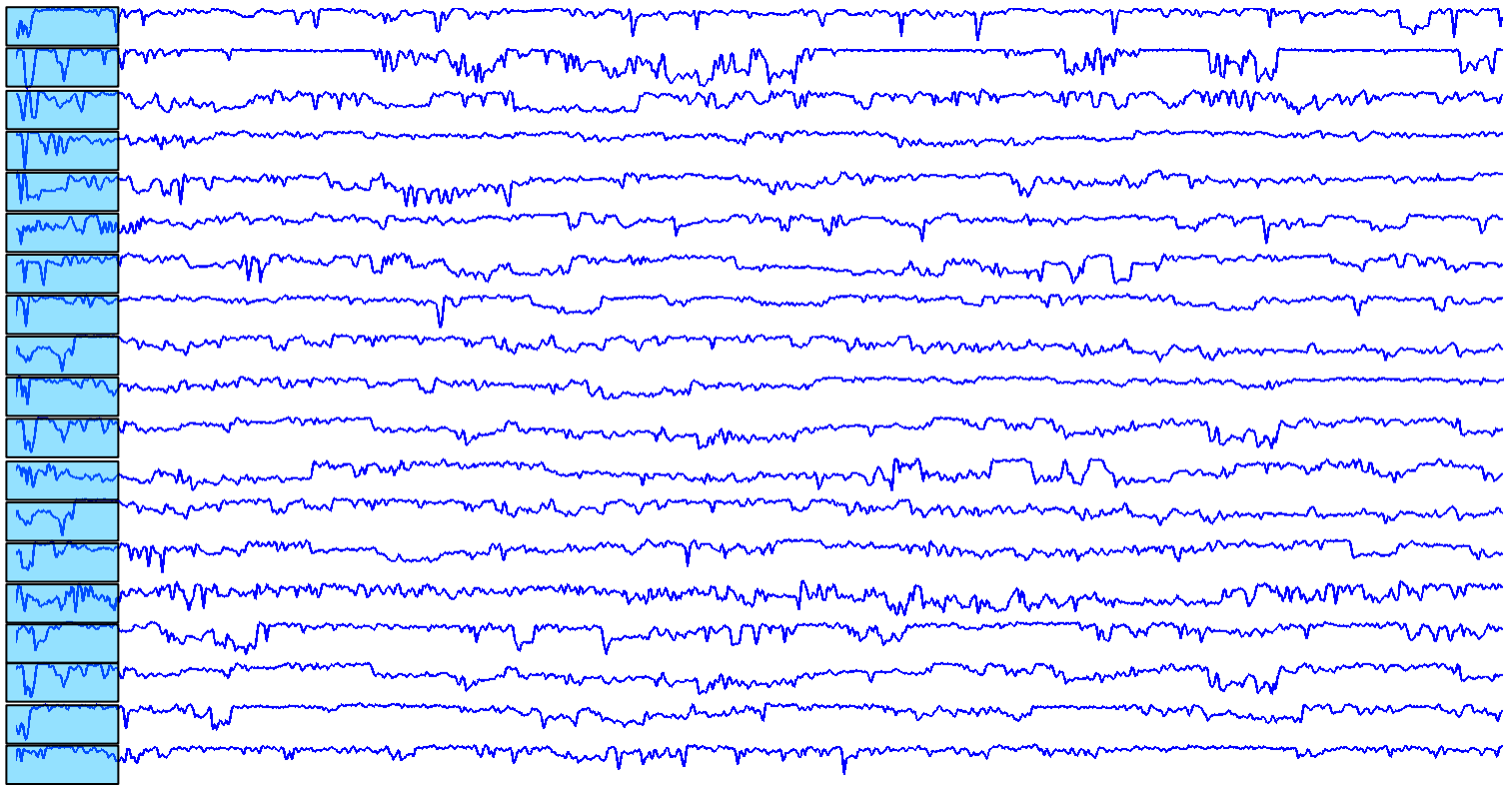

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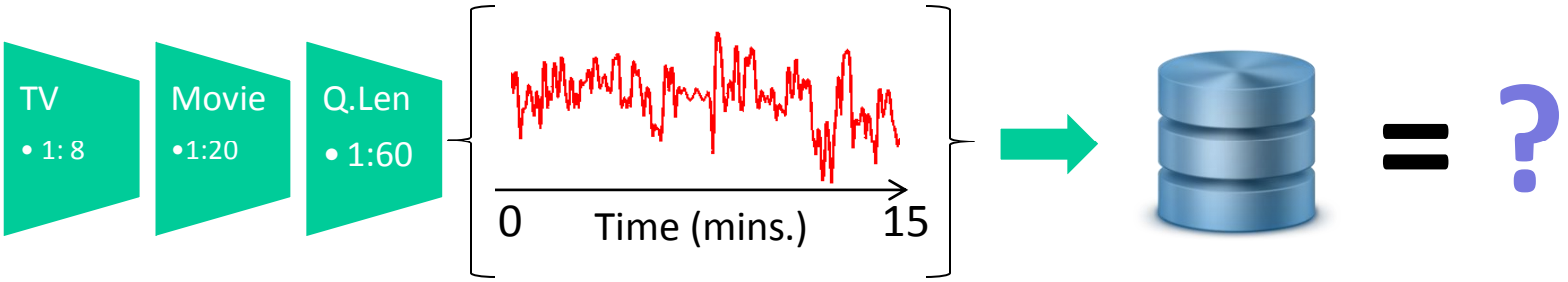
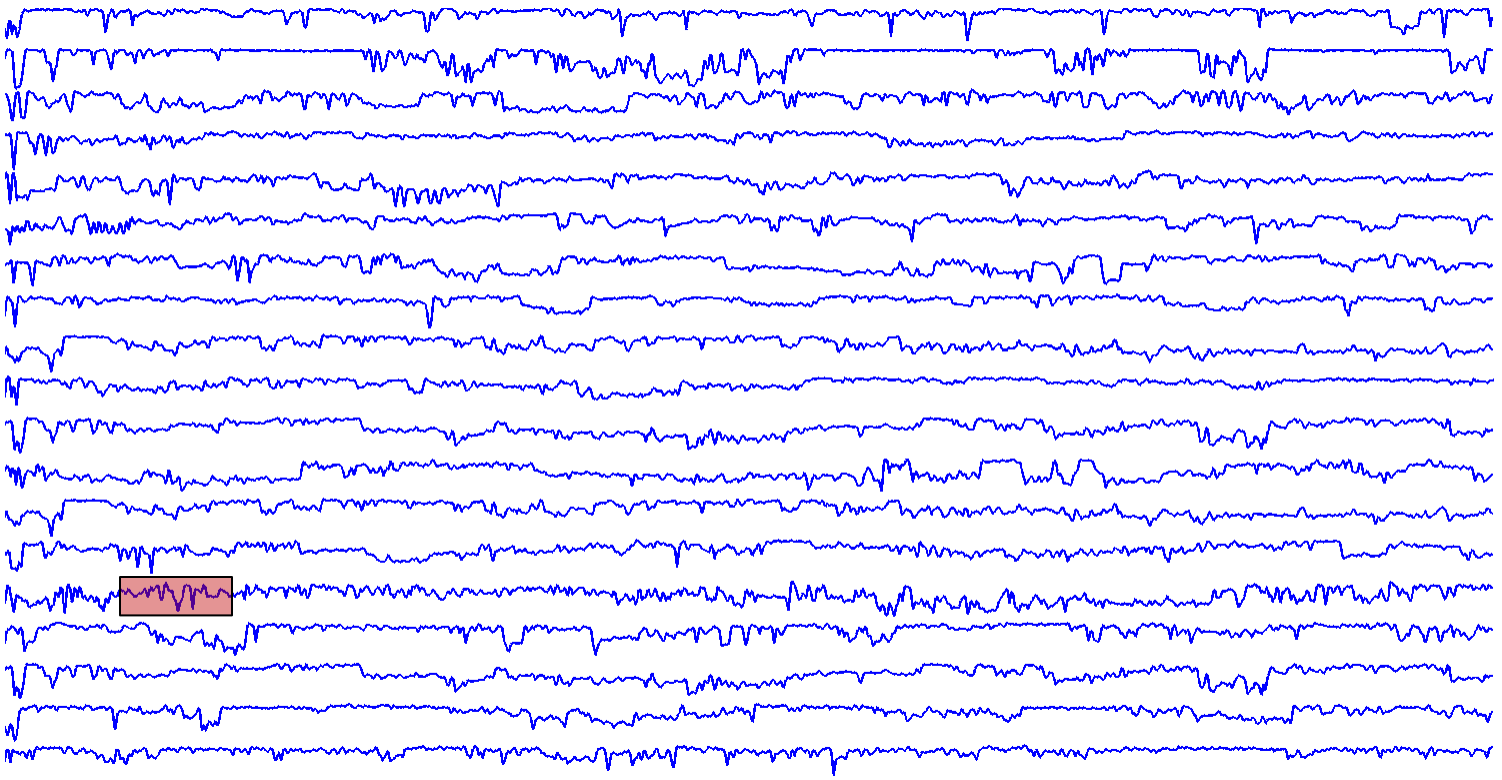




Best match

Possible Query Results

- **Hit:** the search engine is confident* in the match (accept) and the match was the movie from which the query itself was extracted. (Success.)

- **Miss:** the search engine is confident* in the match (accept) but there is a mismatch between the search engine's best guess and the query origin. (Failure.)

- **Reject:** the best match was a not a clear winner*, and the matching algorithm chooses not to respond. (Neither success nor failure.)

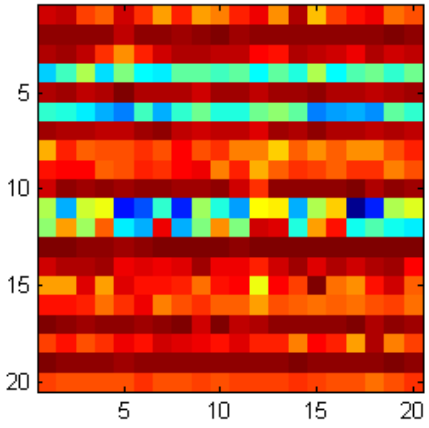
* Confidence is the gap size between the top match and the runner up

Query Length & Confidence

Confidence is the gap size between the top match and the runner up

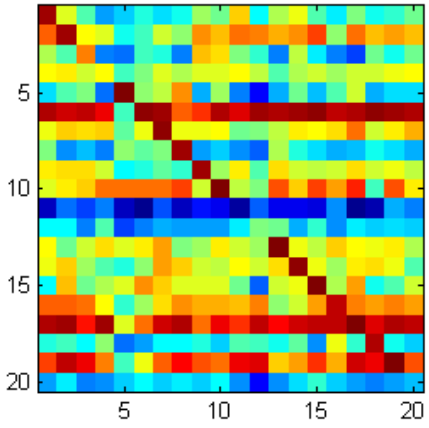
Query Length

1 min



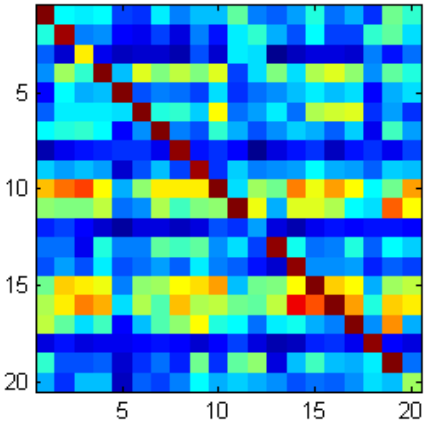
Reject

6 min



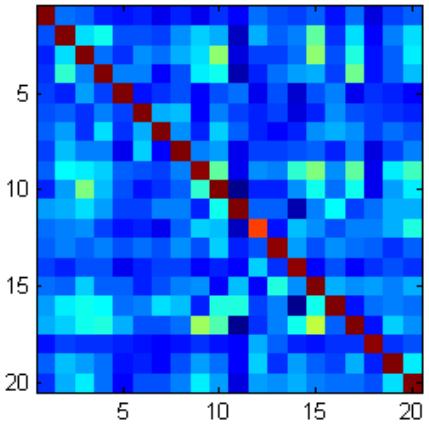
Reject

12 min



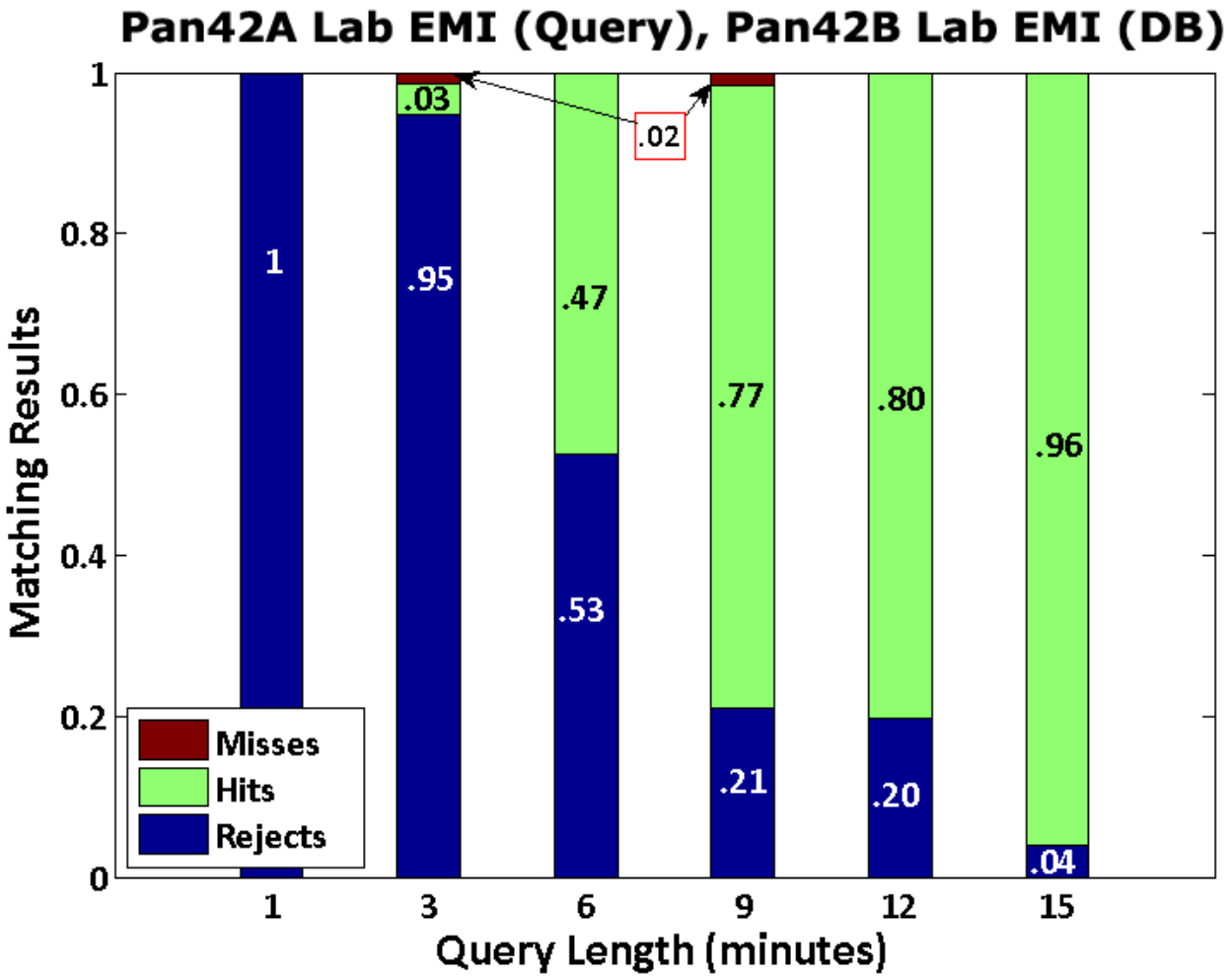
Reject

15 min

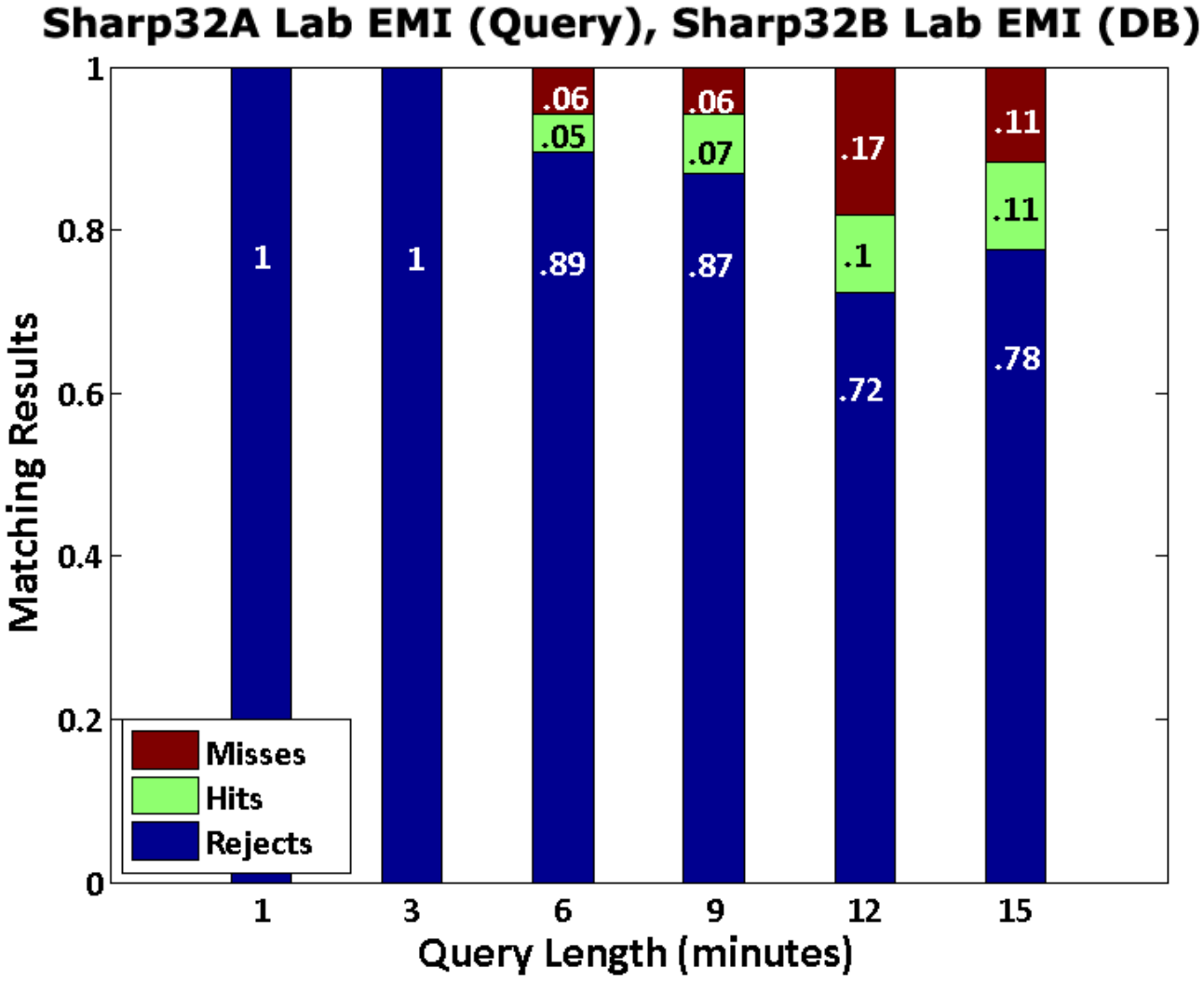


Reject

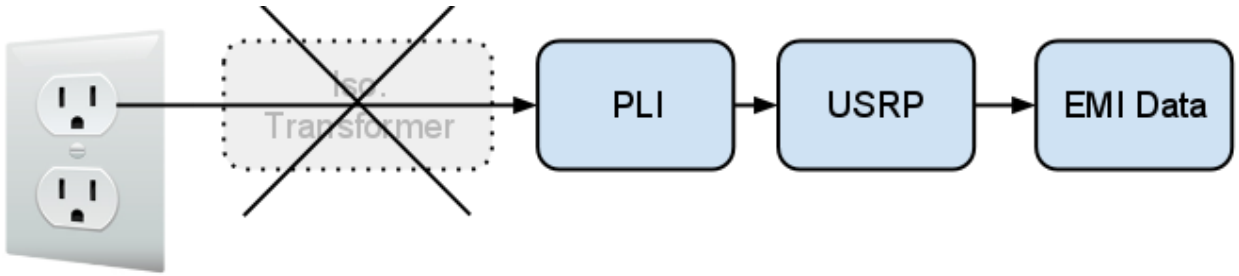
Q4: Can we **determine what is being watched** from EMI?



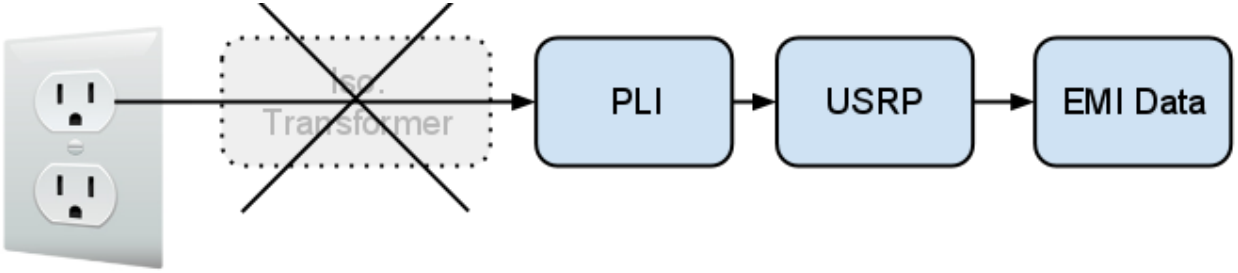
Q4: Can we **determine what is being watched** from EMI?



Q5: Can we **match lab EMI** to **home EMI?**

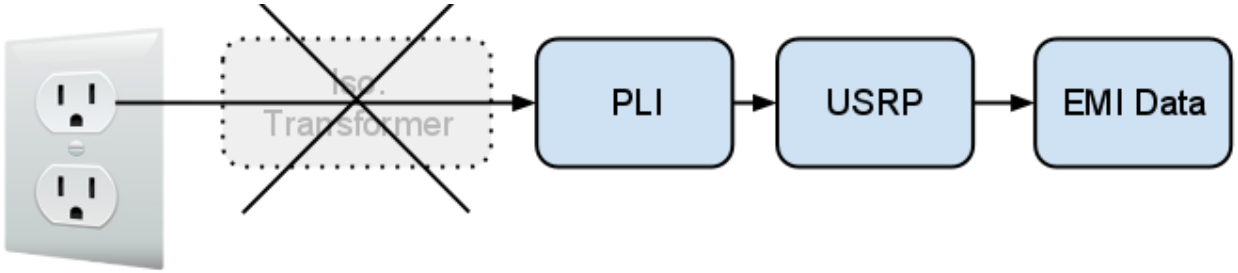


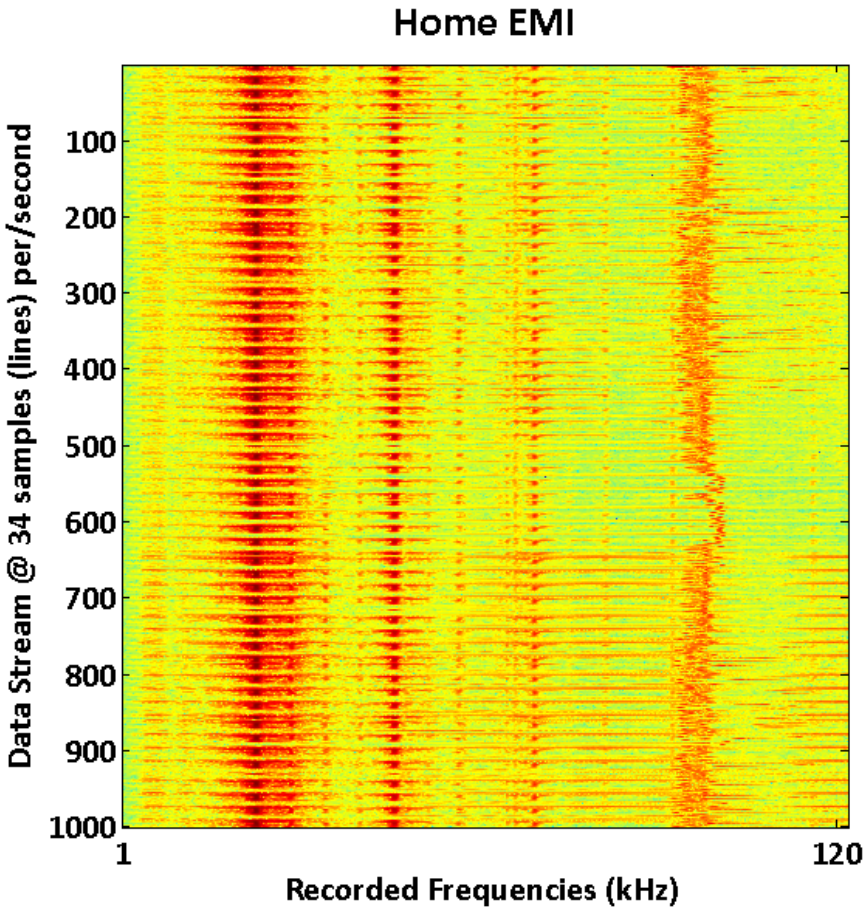
Home Details



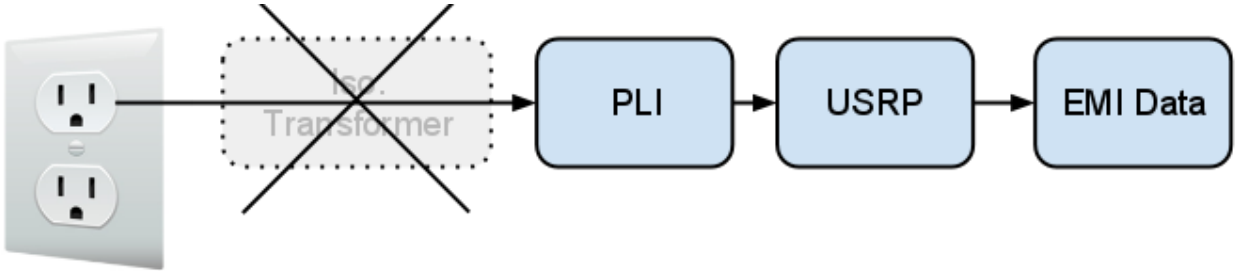
Style	Year Built	Size
Single family Home	2003	3000 sq. ft
Apartment	2009	657 sq. ft.
Multi-family Home	1906	800 sq. ft.

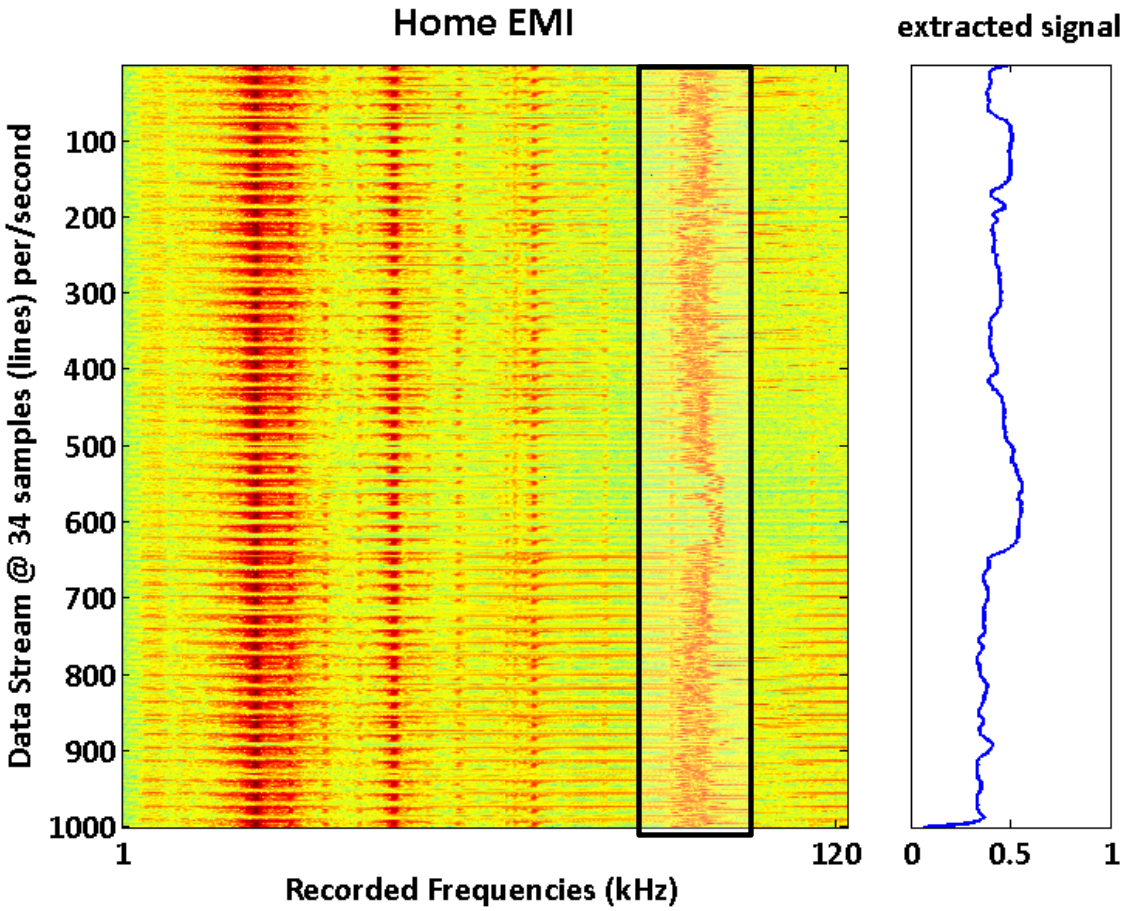
Home Setup


Isolation Transformer
PLI
USRP
EMI Data

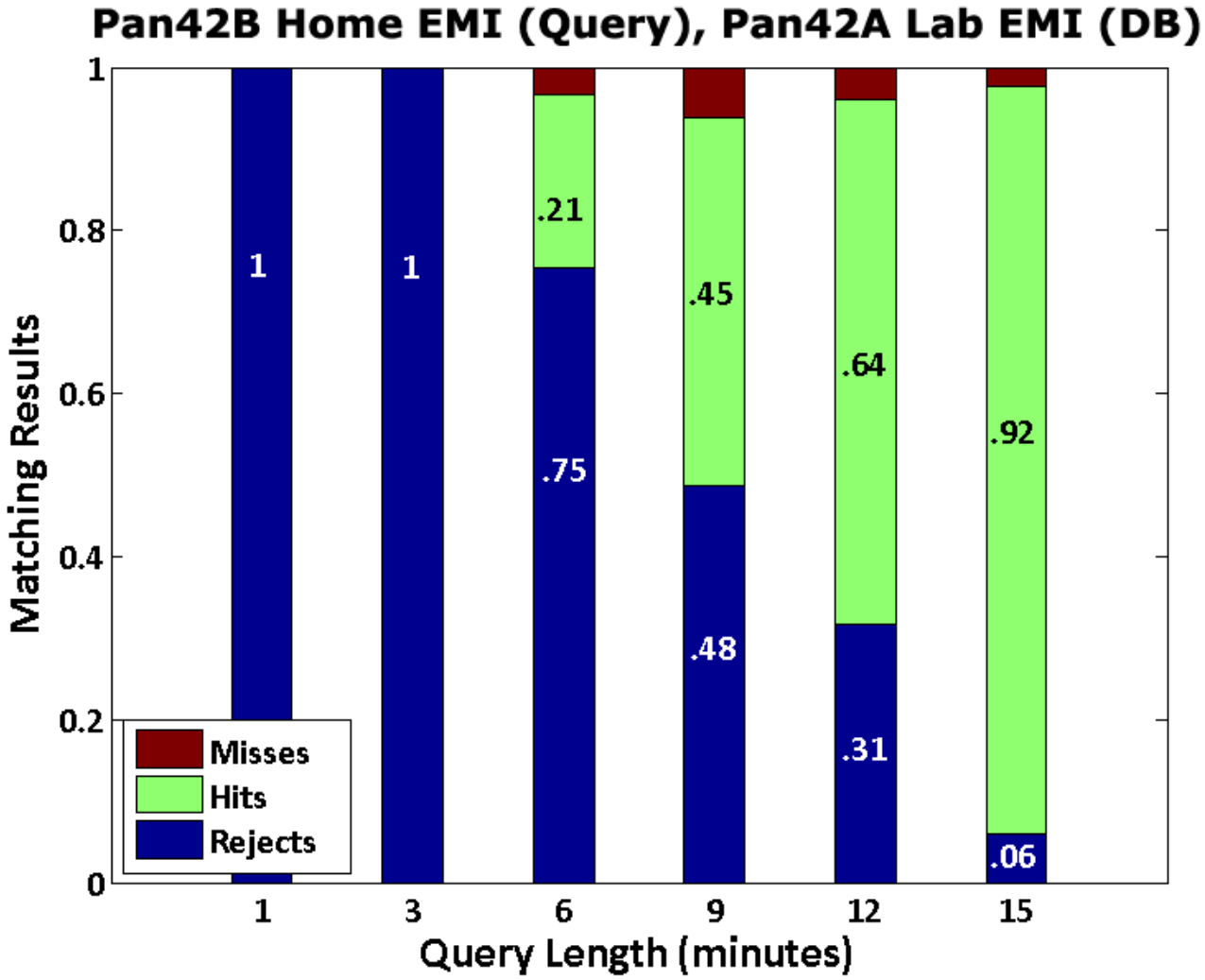

Home EMI
Data Stream @ 34 samples (lines) per/second
100
200
300
400
500
600
700
800
900
1000
1
120
Recorded Frequencies (kHz)

Home Setup


Isolation Transformer
PLI
USRP
EMI Data


Home EMI
extracted signal
Data Stream @ 34 samples (lines) per/second
100
200
300
400
500
600
700
800
900
1000
1
120
Recorded Frequencies (kHz)
0
0.5
1

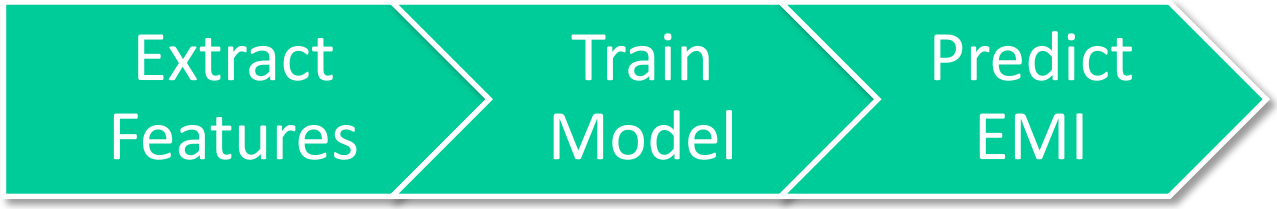
Q5: Can we **match lab EMI** to EMI recorded in **home settings**



Extensions:

Can we predict EMI from screen content without a TV?

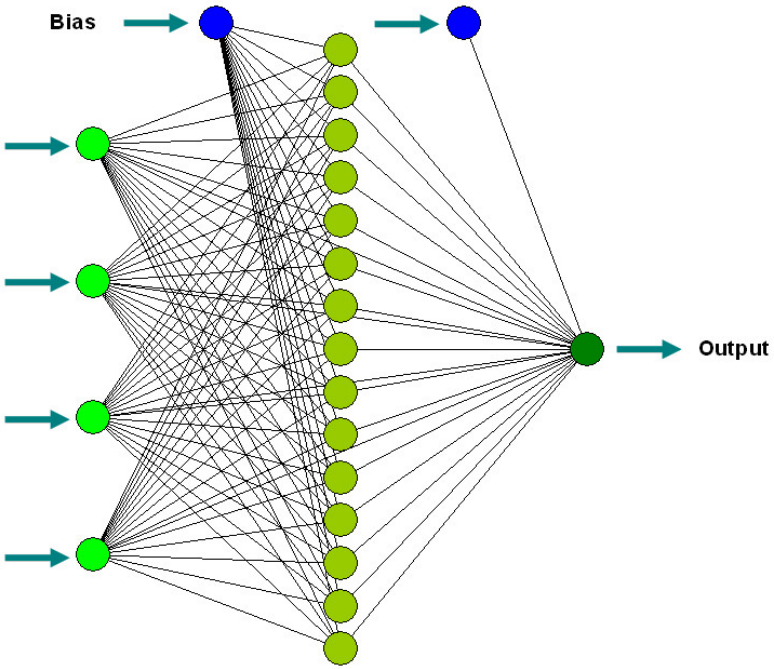
Predicting EMI



Input Features:

- **Brightness**: cumulative sum of averaged RGB intensities
- **Flux**: change in brightness between consecutive frames
- **Edge Intensity**: pixelsum of a Canny Edge filter
- **FFT:** slope of the best fit line to an FFT
- **Color:** mean and standard deviation for Gaussians fitted to R, G, and B color histograms
- **Bitrate:** kbits/second computed using FFMPEG

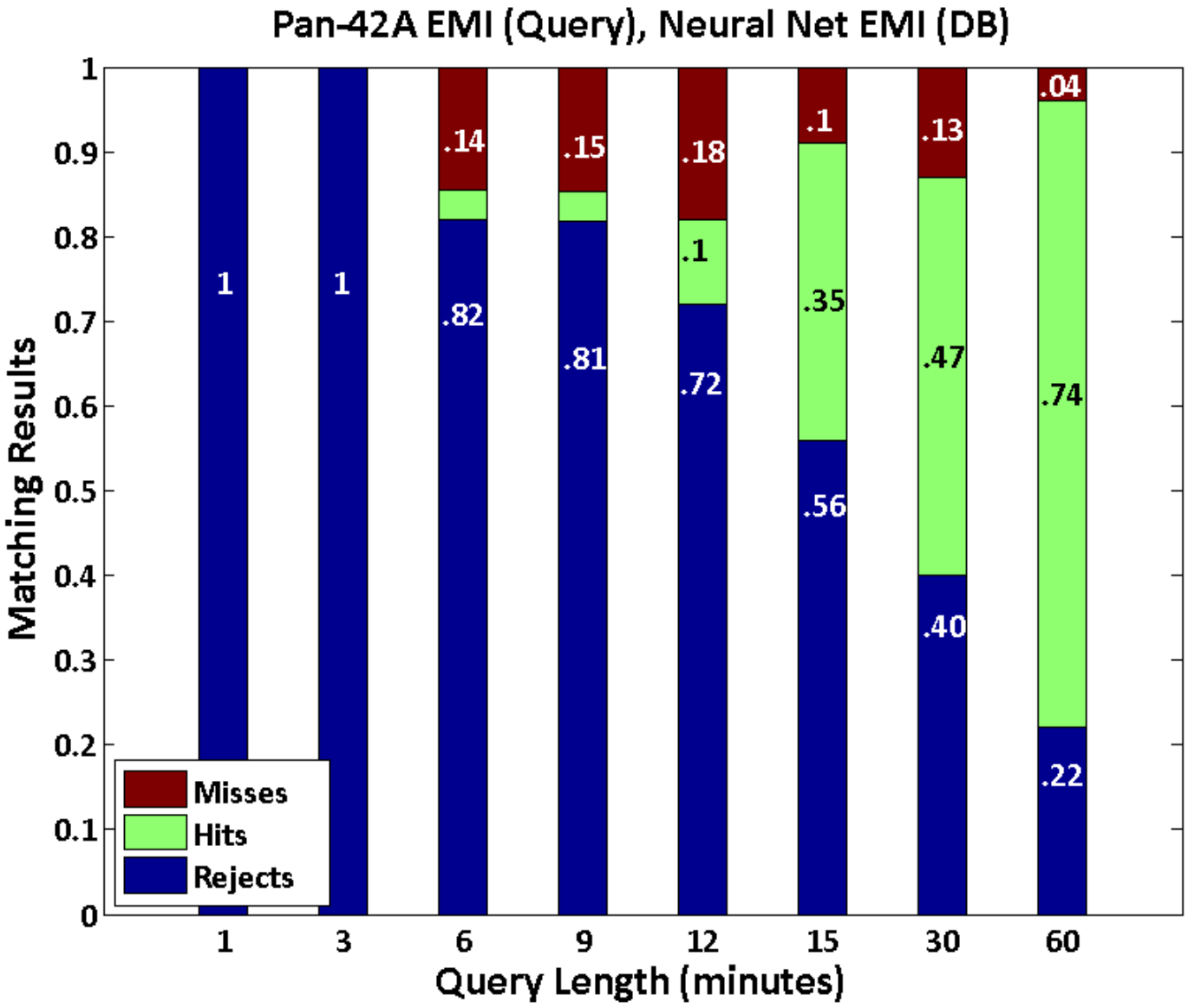
Model: Neural Net



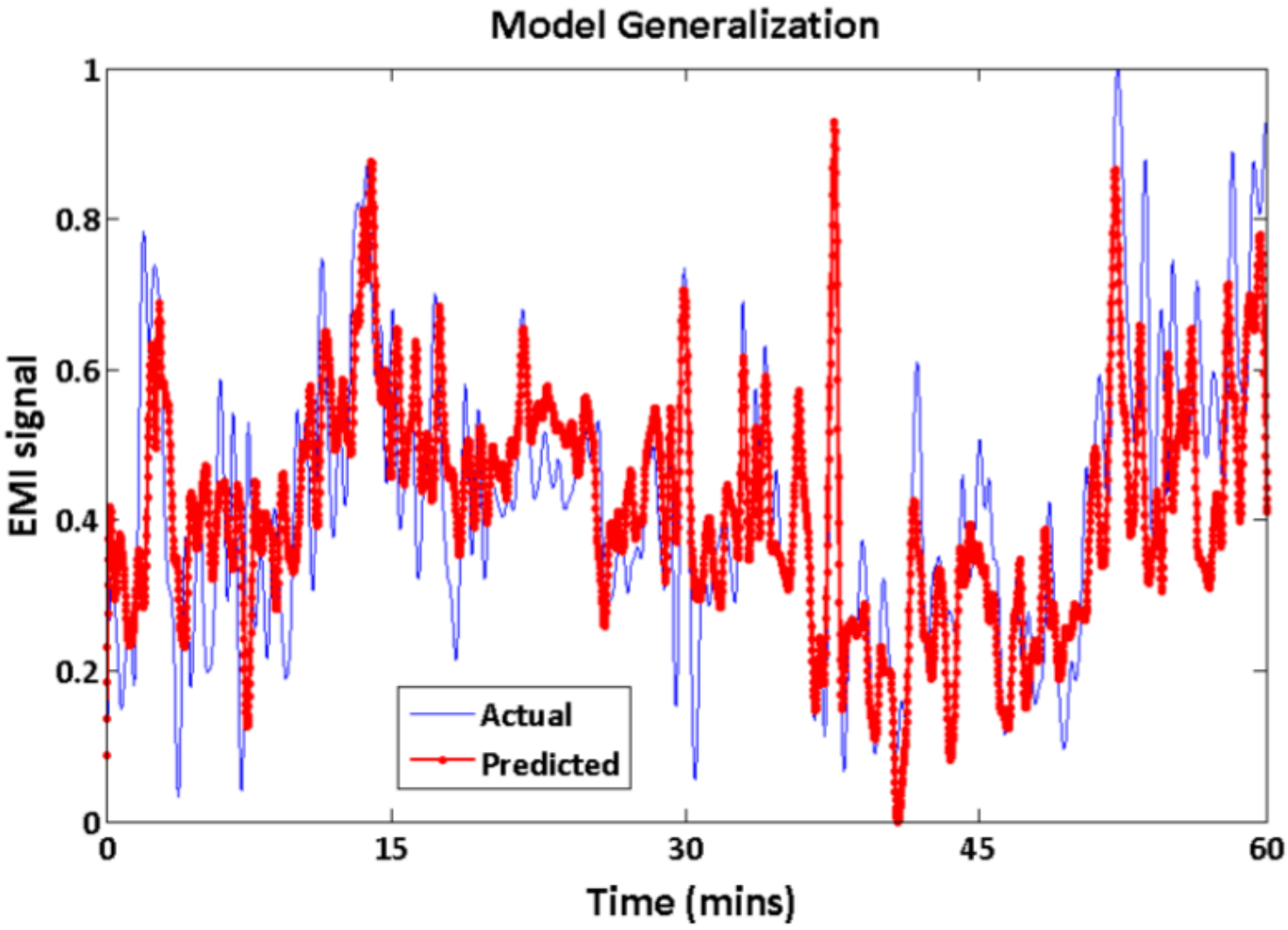
Cross Validation:

10 Train, 5 Test

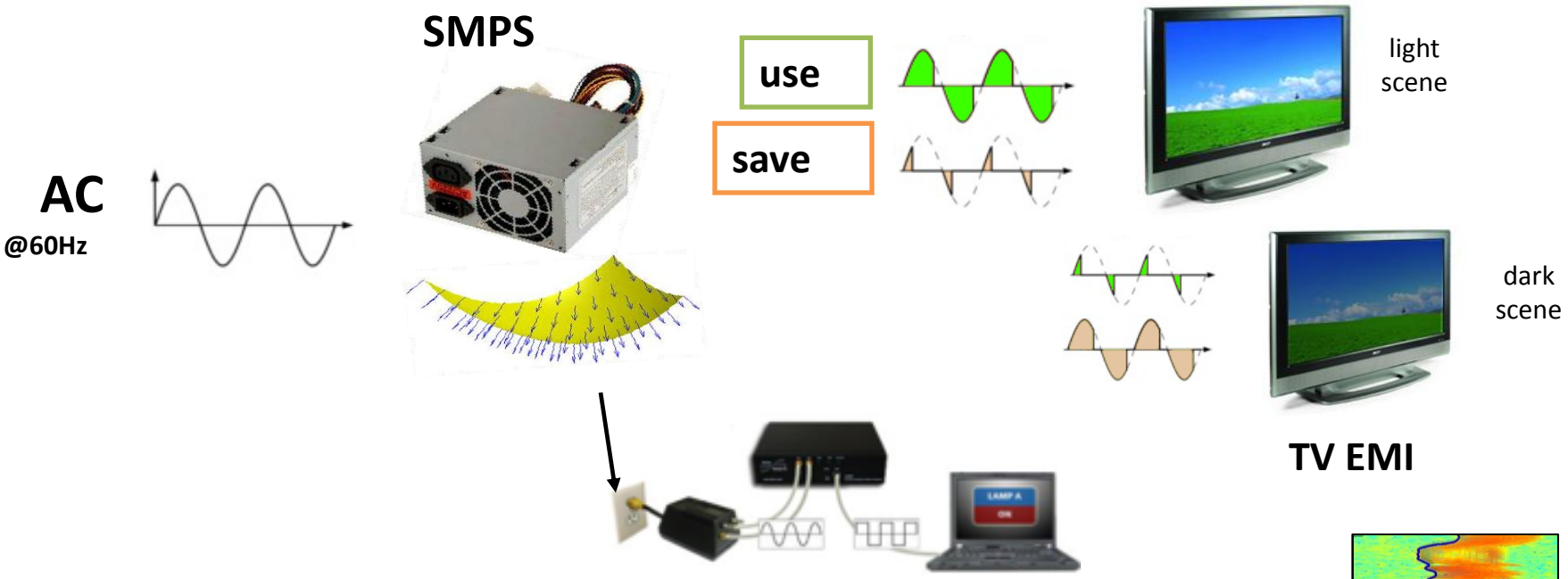
Predicting EMI



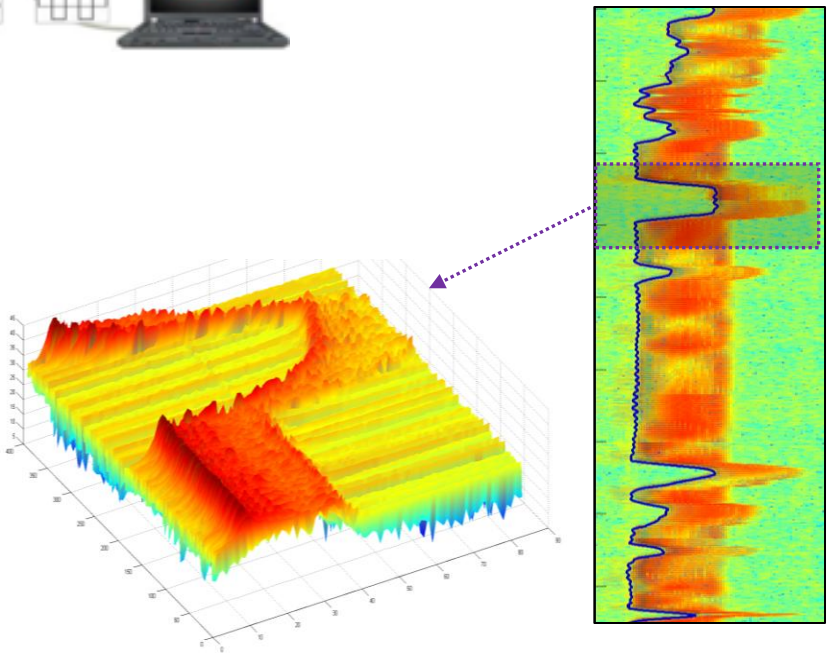
Predicting EMI



TV EMI: Theory of Operation



Backlight (brightness)
is key source of TV EMI



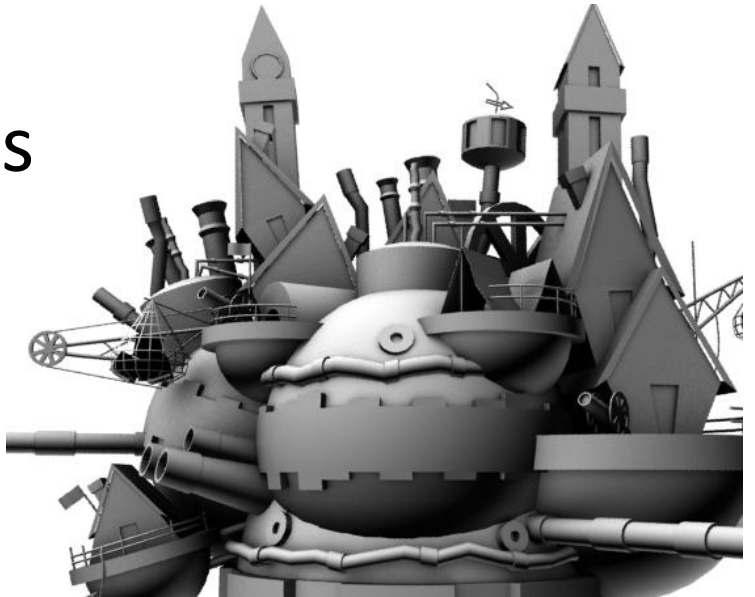
Defenses and Tensions

> Better filtering by power supplies

> Signal Injection & Jamming (Energy Star)

> Battery Masking [Mclaughlin 2011]

> Infrequent sensor readings



Takeaways

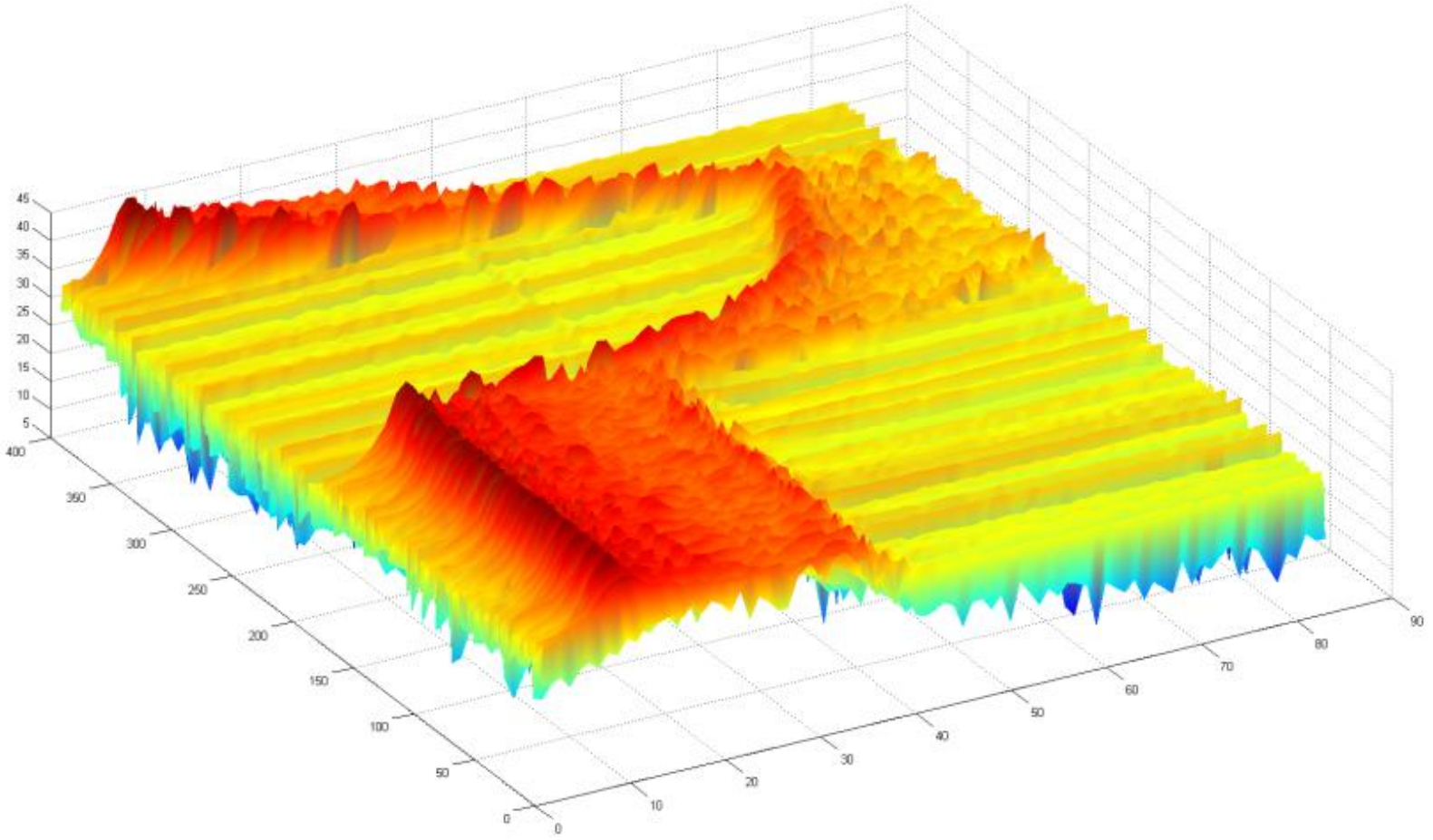
> Devices **produce EMI** on the powerline

> **Single sensor** tracks many devices

> EMI can be **modeled**

> Growing attack surface

Questions?



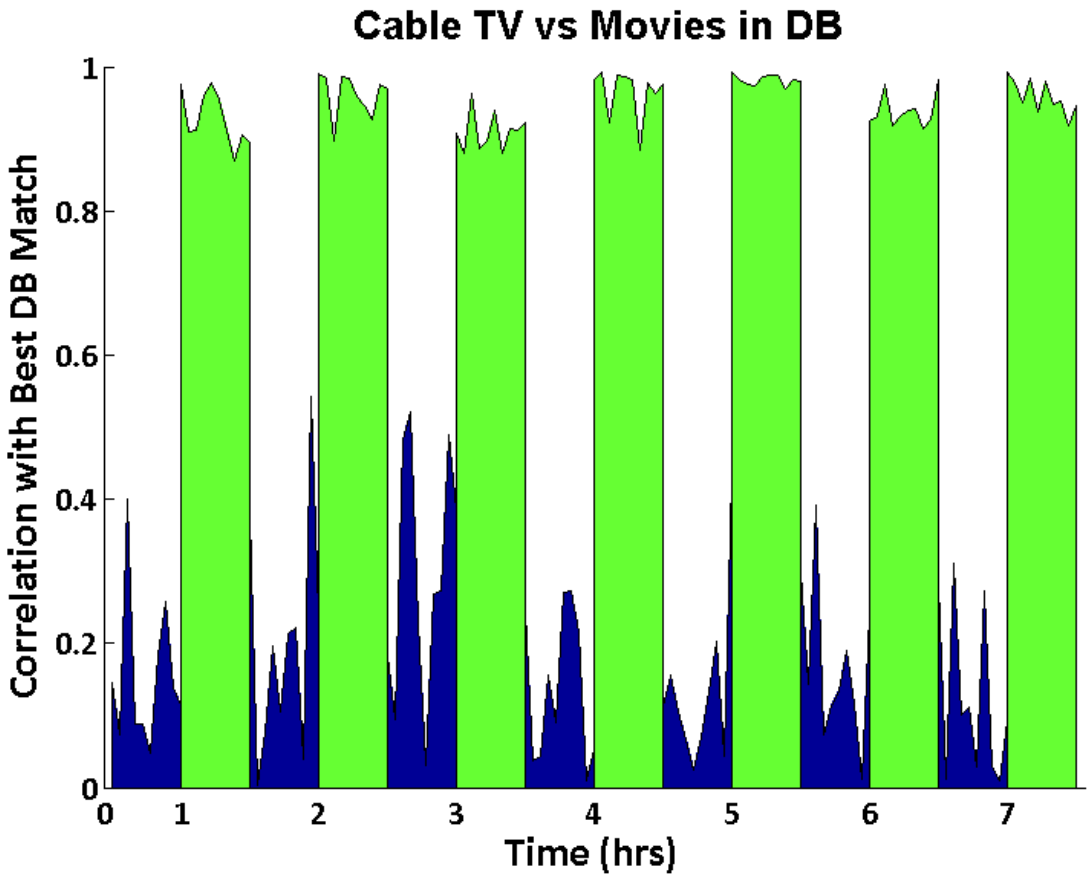
miro@cs.washington.edu

Does EMI matching scale?

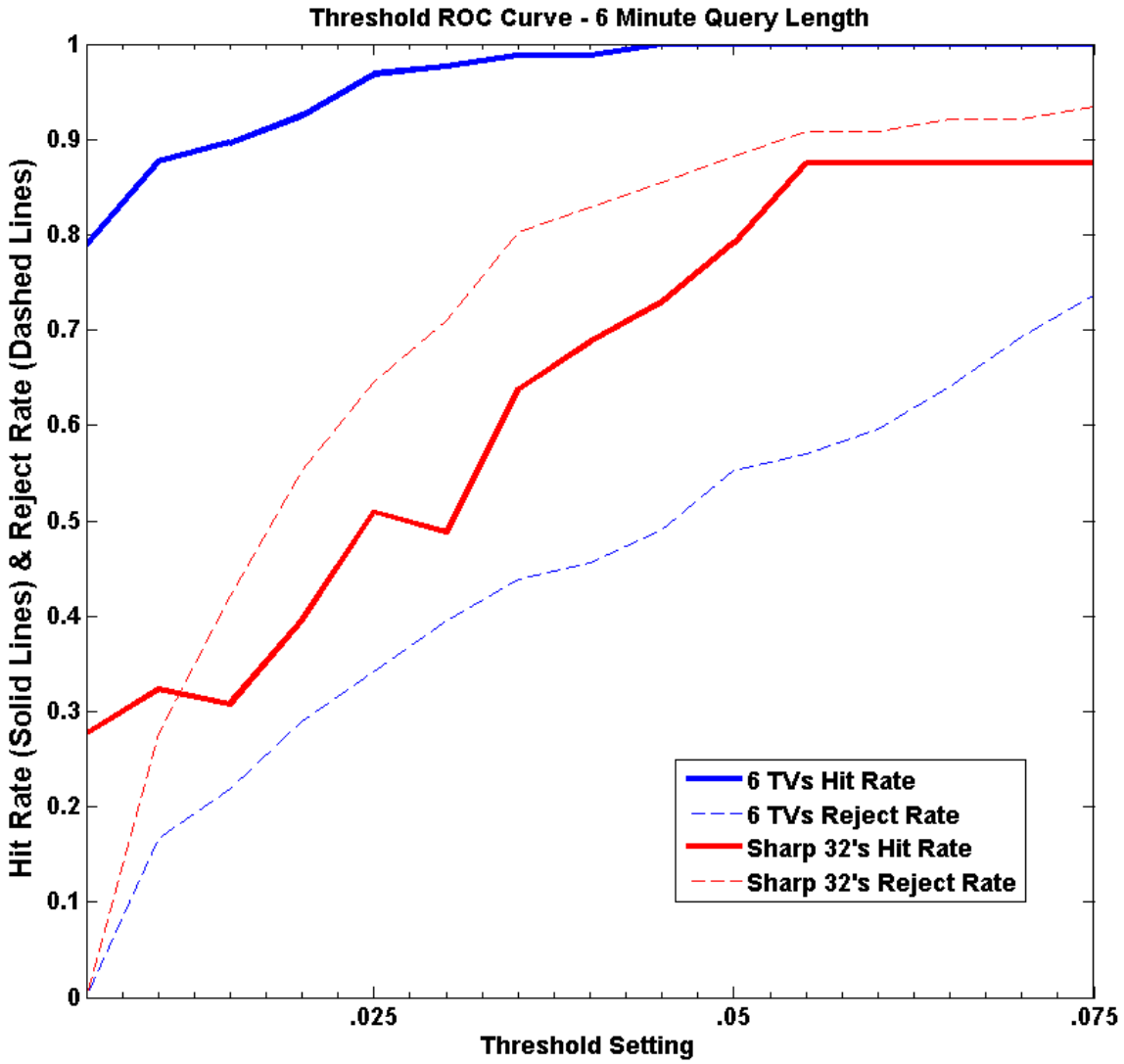
abc FOX

HBO ESPN

Does EMI matching scale?



Sharp 32 and SNR

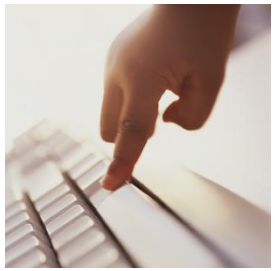


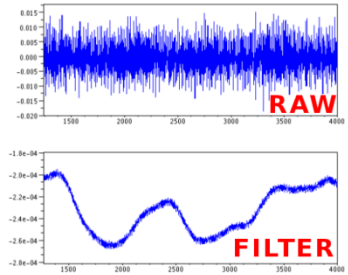
Related Work

Stream Content

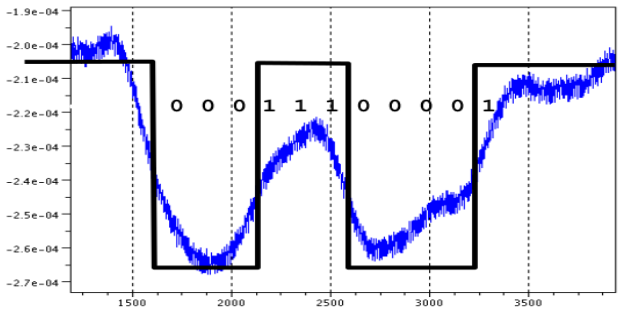
```
POST /api/w.html HTTP/1.1
Content-Type: application/x-www-form-urlencoded
Host:85.214.93.99
Content-Length:851

version=0.9&identity=[redacted]&msg=228320&values=
[{"meterdata":"00000285.8265446*kwh","tickdelta":"00000285.8263451*kwh","seconds":"399508724.94"},
{"meterdata":"00000285.8267477*kwh","tickdelta":"00000285.8265446*kwh","seconds":"399508726.94"},
{"meterdata":"00000285.8269547*kwh","tickdelta":"00000285.8267477*kwh","seconds":"399508728.94"},
{"meterdata":"00000285.8271654*kwh","tickdelta":"00000285.8269547*kwh","seconds":"399508730.94"},
{"meterdata":"00000285.8273806*kwh","tickdelta":"00000285.8271654*kwh","seconds":"399508732.95"},
{"meterdata":"00000285.8276015*kwh","tickdelta":"00000285.8273806*kwh","seconds":"399508734.95"},
{"meterdata":"00000285.8278268*kwh","tickdelta":"00000285.8276015*kwh","seconds":"399508736.95"},
{"meterdata":"00000285.8280557*kwh","tickdelta":"00000285.8278268*kwh","seconds":"399508738.95"}]
&now=399508746.98HTTP/1.1 200 OK
```

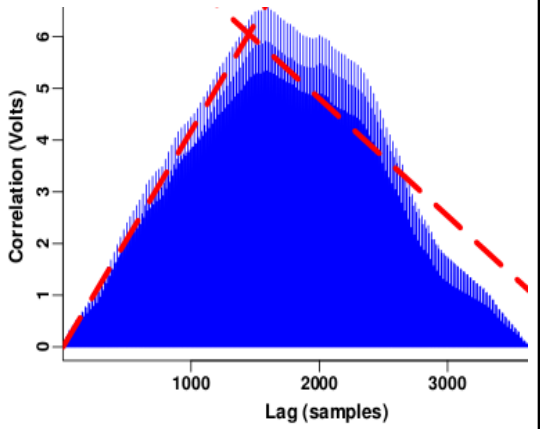
"Our research shows that the analysis of the household's electricity usage profile does reveal what channel the TV set in the household was displaying. "





• | 0 | 00111000 | 0 | 1 | = letter 'a'



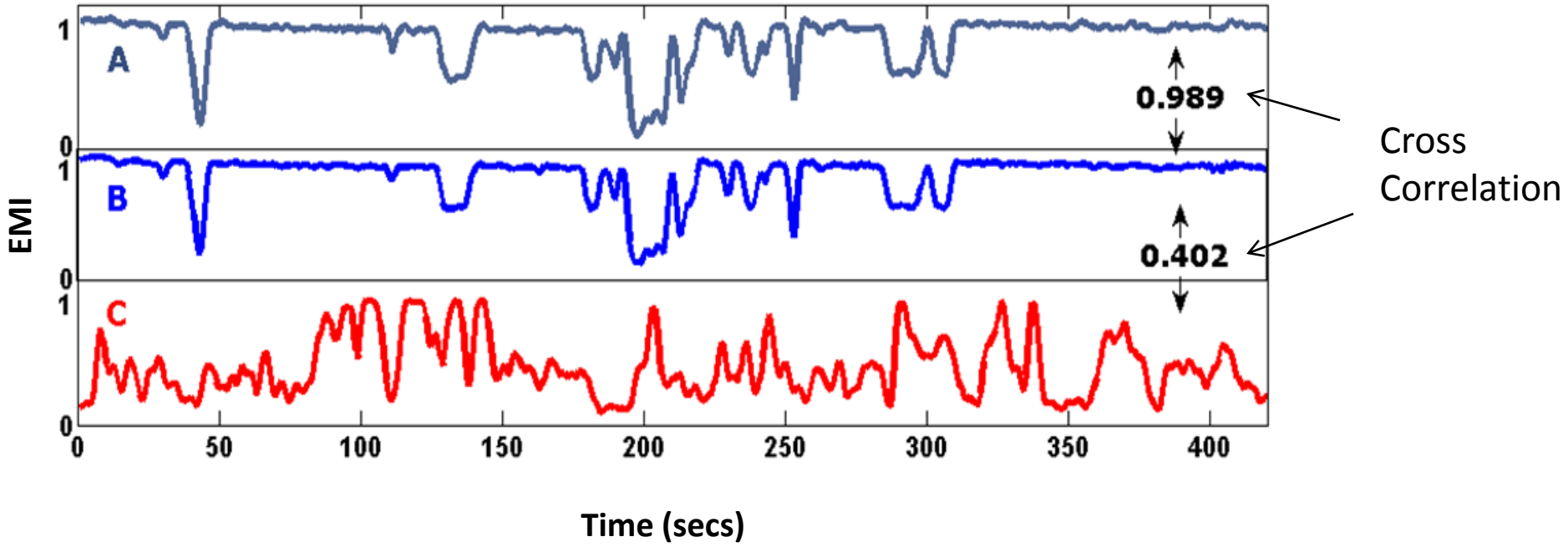


Target trace	Classifier		
	Length	Motif	Xcorr
centerpill2	X	✓	✓
centerpill5	X	✓	X
cnn3	✓	✓	✓
cnn9	✓	✓	✓
csumassedu4	✓	✓	X
csumassedu5	✓	✓	X
facebook4	✓	X	✓
facebook6	✓	X	✓
facebook8	✓	X	✓
gmail1	✓	✓	✓
gmail3	X	X	✓
gmail4	✓	X	✓
gmail7	X	✓	✓
google1	X	✓	✓
google2	✓	X	✓
google3	✓	X	✓
google6	✓	✓	✓
msnbc6	✓	X	✓
msnbc7	X	X	✓
msnbc8	✓	X	✓
youtube4	✓	X	X
youtube9	✓	✓	✓

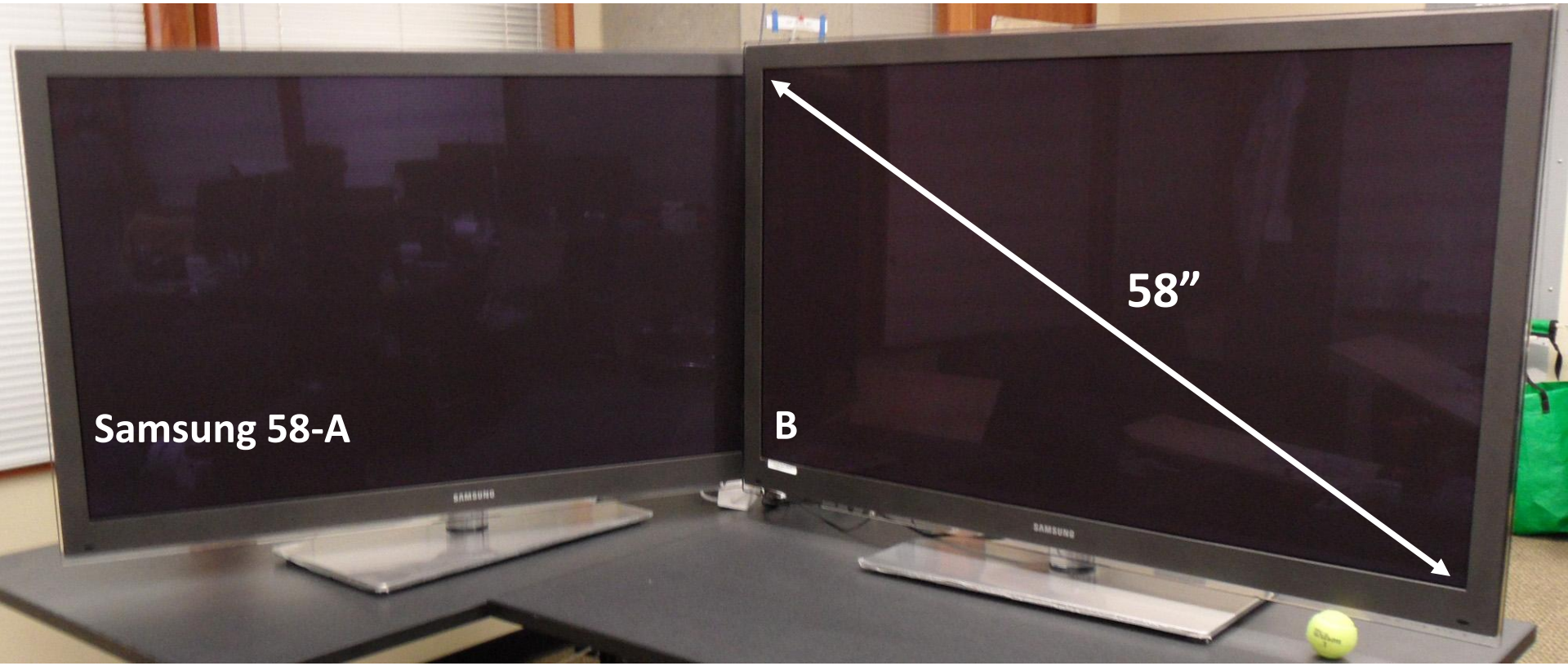
Q1: repeatable EMI from repeated screen content?

A & B : Lion King

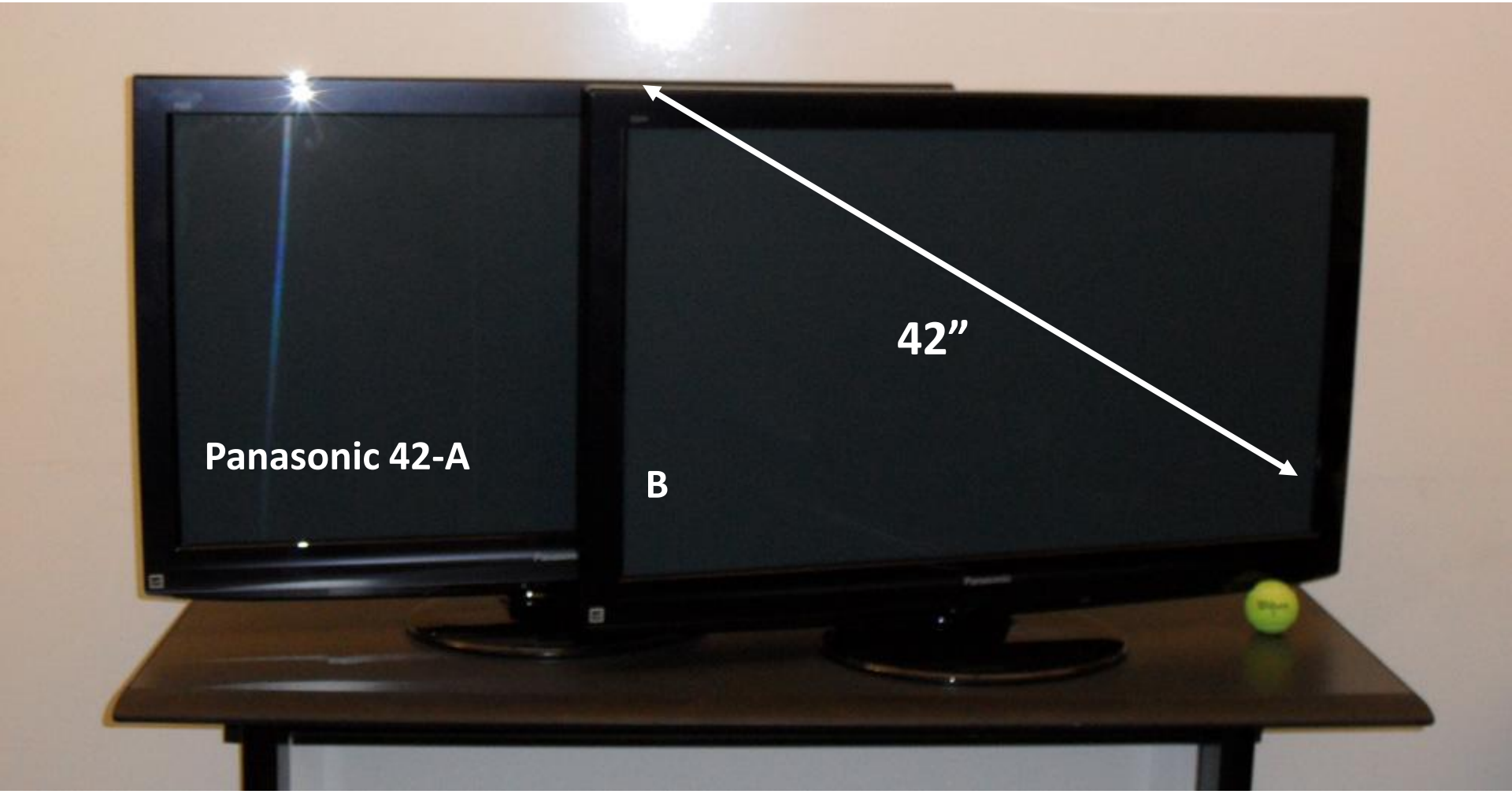
C: Bourne Ultimatum



TVs (1)



TVs (2)



TVs (3)