DETECTING IT AND LIGHTING LOADS USING COMMON-MODE CONDUCTED EMI SIGNALS

MANOJ GULATI
SHOBHA SUNDAR RAM
ANGSHUL MAJUMDAR
AMARJEET SINGH

IIIT-DELHI (INDIA)

WHY IT AND LIGHTING LOADS ARE IMPORTANT?

A BRIEF SURVEY OF APPLIANCES IN AN OFFICE BUILDING IN DELHI(INDIA)

TABLE I
IT LOADS WITHIN THE INSTITUTE. HIGHLIGHTED APPLIANCES WERE USED FOR THE EXPERIMENT.

List of SMPS Appliances (connected to UPS)	Quantity	Power (Watts)	Total Power
Router	23	10	230
Projector	15	250	3750
Projector Screen Controller	5	10	50
CCTV Cameras	20	5	100
Fire Control Systems	2	250	500
Desktop (CPU + Monitors) *HP LE1902x Hewlett Packard (HP) Compaq 8200 Tower*	91	100	9100
RFID Access Control Systems	24	5	120
Laptop and Charger *(Lenovo X1 20A80056I)*	150	45	6750
A4 Sheet Scanner	10	25	250
Laser jet Printer *(HP LaserJet P1008)*	55	700	38500
CFL *(Crompton Greaves Roof*	380	18	6840

OVERVIEW

- IT and lighting loads consume ~20% of the total energy utilisation of a typical office building, second highest after HVAC systems (~41% of total).
- NILM can significantly help in reducing consumption in several ways like-
  - Reducing consumption in non-working hours.
  - Optimising consumption during non-occupancy & partial occupancy hours.
  - Circuit level shutdown over weekends and holidays.

WHY ELECTROMAGNETIC INTERFERENCE (OR EMI) IS IMPORTANT?

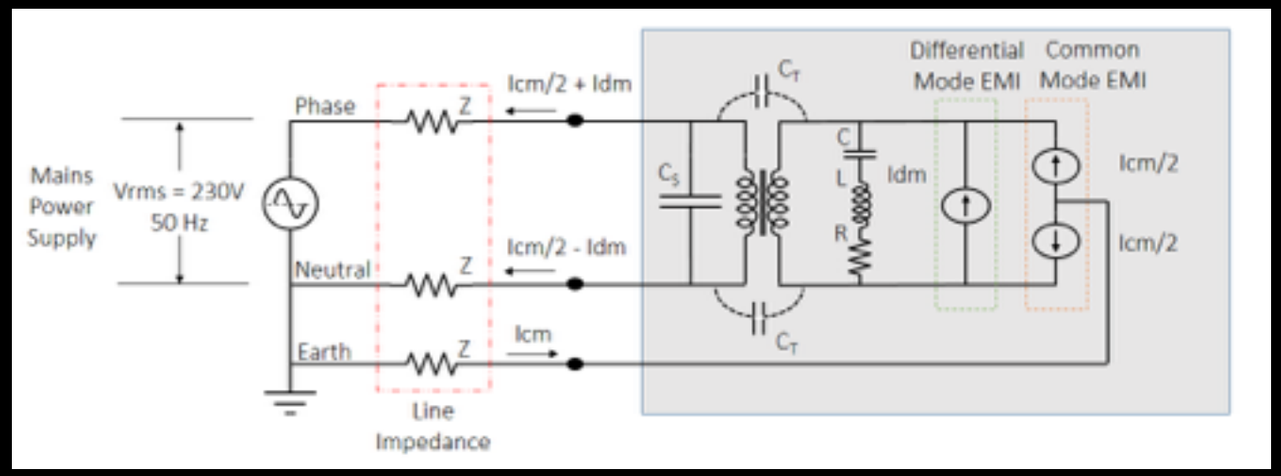
Electromagnetic interference (or EMI) is a high freq. noise conducted by SMPS* based appliances [Paul'07]

EMI can be used as a unique signature to detect SMPS powered appliances [Gupta'10]

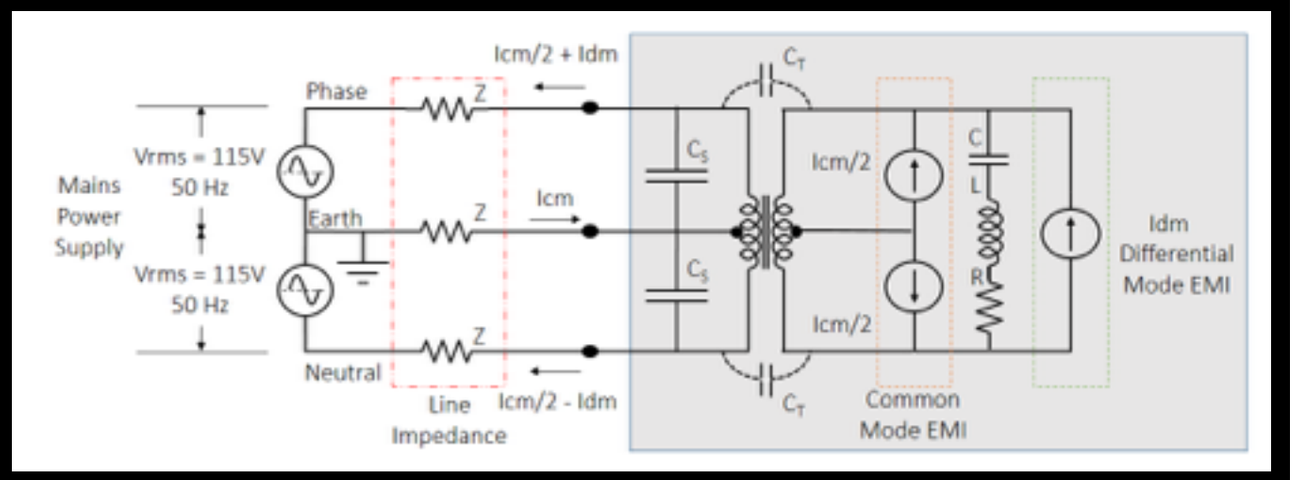
Since most of the IT and lighting loads (also known as complex loads) are powered using SMPS, EMI can be used as a feature to detect such appliances.

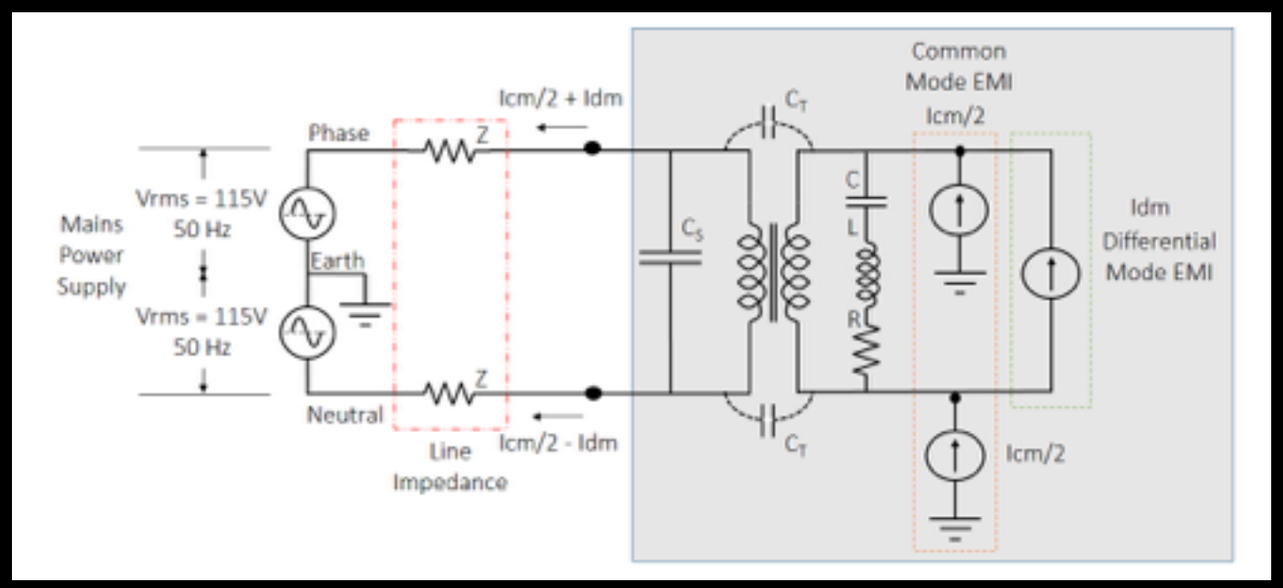
*Switched mode power supplies

CONDUCTED EMI: COUPLING MODES IN SINGLE PHASE AND SPLIT-PHASE POWER SUPPLIES



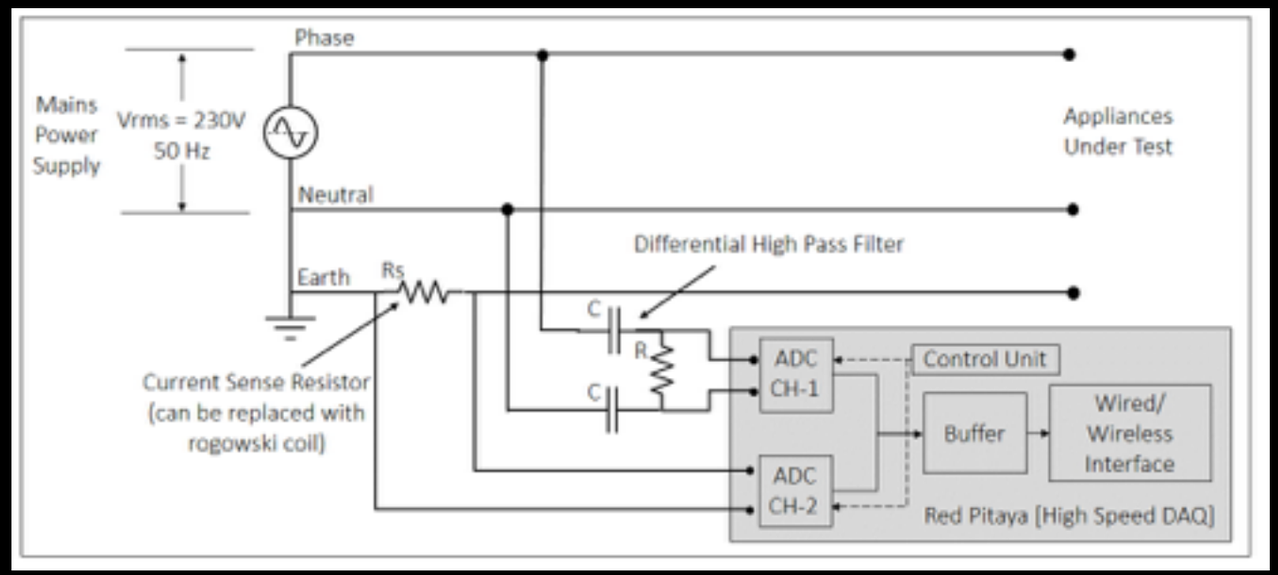
Single Phase Power Supplies



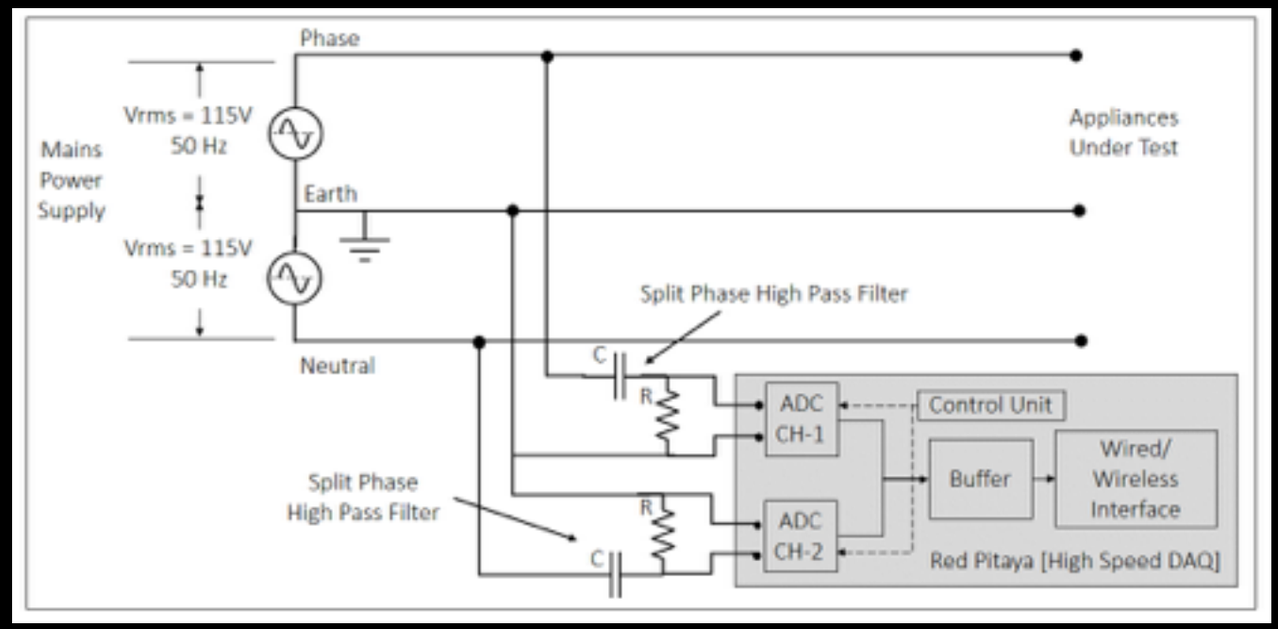


Split-phase Power Supplies

EQUIVALENT CIRCUIT: SENSING SYSTEM USED FOR MEASURING COMMON AND DIFFERENTIAL MODE CONDUCTED EMI

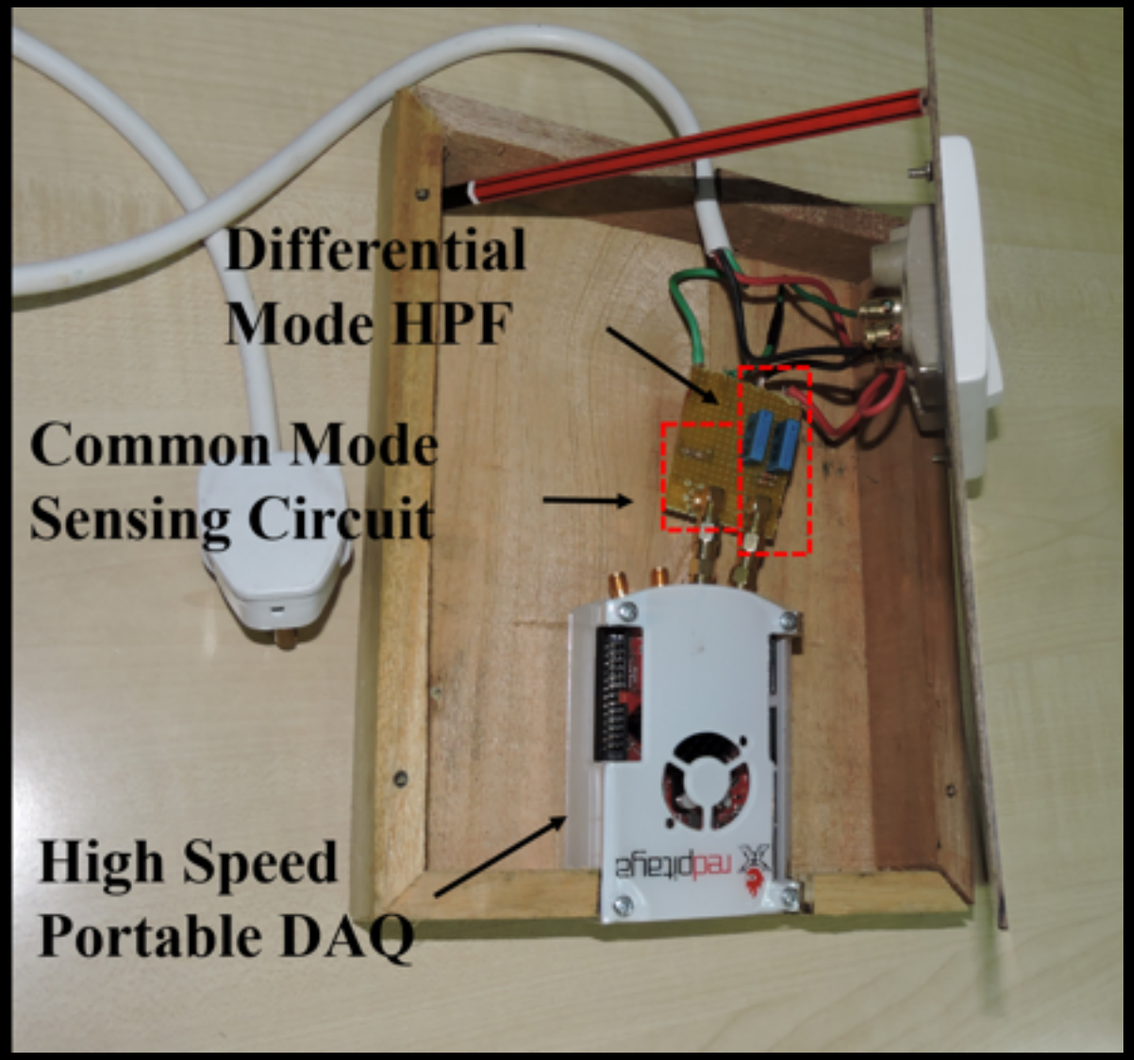


For single phase power supplies



For split-phase power supplies

ACTUAL SENSING SYSTEM USED FOR MEASURING COMMON AND DIFFERENTIAL MODE CONDUCTED EMI



Only for single phase power supplies

*Limitations are discussed in end

HYPOTHESIS

Common Mode Conducted EMI can serve as a better feature for detecting IT and Lighting loads, in comparison to previously used Differential Mode Conducted EMI.

MERITS OF COMMON MODE EMI OVER DIFFERENTIAL MODE EMI

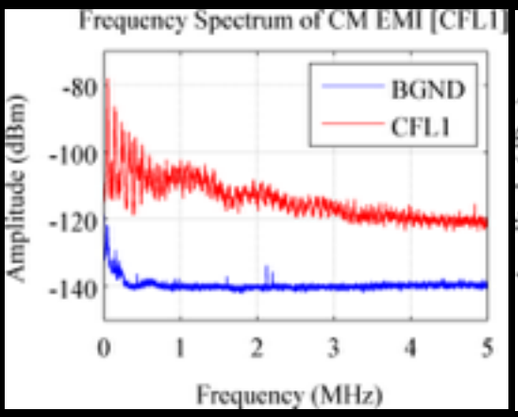
- CM currents are generated at low frequencies due to capacitive coupling. Hence, are likely to attenuate more gradually with the increase in line impedance.
- Earth wire (where the CM measurements can be made) is not meant for conduction of mains power supply and only meant for common mode leakage currents. As a result the noise floor on CM measurements is likely to be much lower than DM.
- In contrast to DM EMI, most appliances are not fitted with CM filters since CM noise is far less likely to impact the functioning of neighbouring appliances.

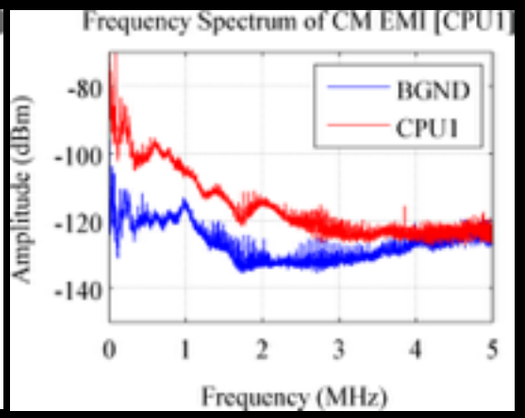
*More details can be found in NILM workshop paper and Buildsys'14 EMI paper.

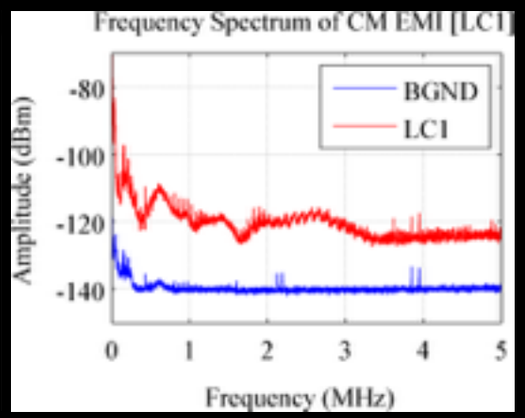
DETAILS OF EMI MEASUREMENTS (TAKEN FROM AN OFFICE SETTINGS IN INDIA)

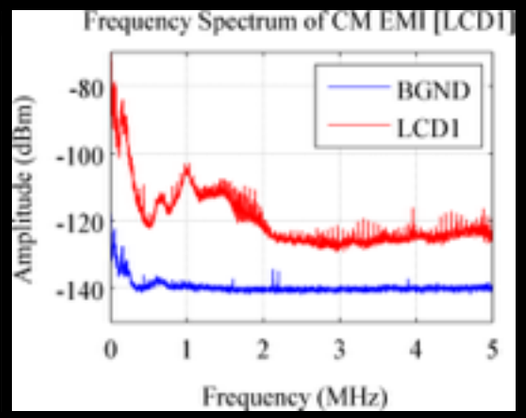
- Time domain measurements (Common mode and differential mode both)
- Five appliances (five instances of each)
  - Laptop charger (LC)
  - Liquid crystal display (LCD)
  - Printer (PRT)
  - CPU
  - CFL
- Sampling frequency (Fs) = 15.625MHz
- Total 10 traces are collected for each appliance instance (150ms each)
- Equal amount of background noise data for each appliance instance is also logged.
- Data collection spanned over a week (5-6 hours of data is actually used for this study) {This dataset is public and can be used for further research}

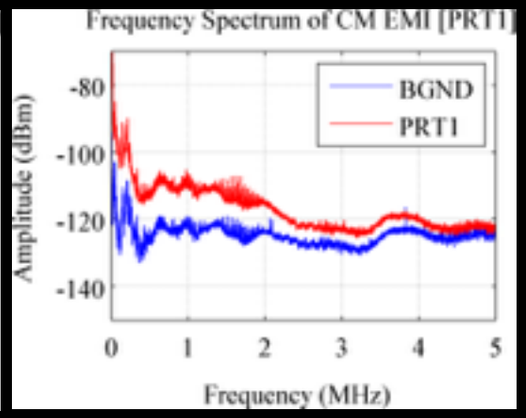
FREQUENCY SPECTRUM MEASURED FROM FIVE APPLIANCES



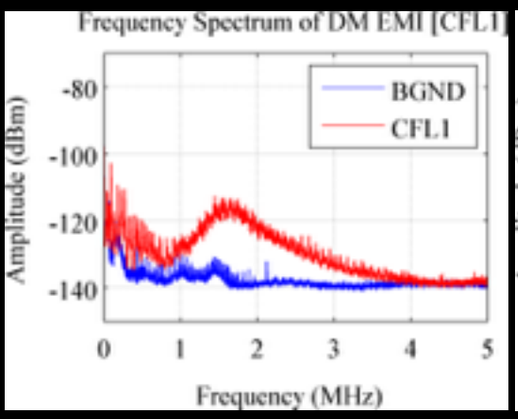


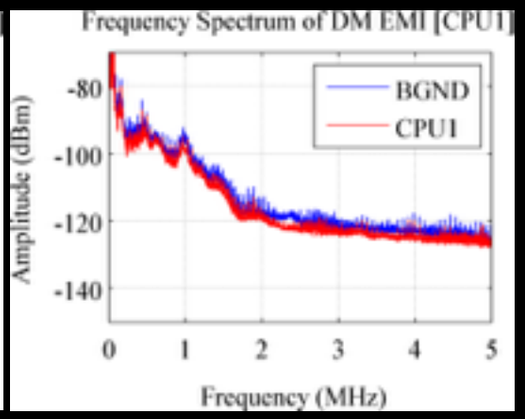


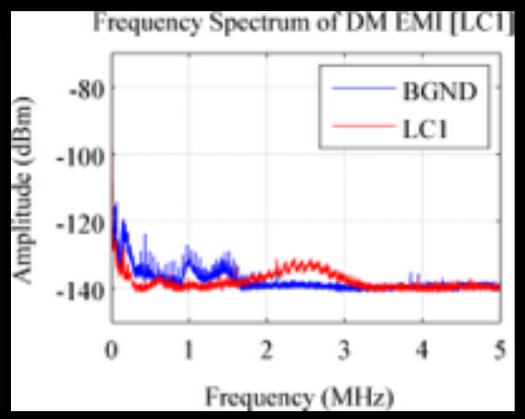


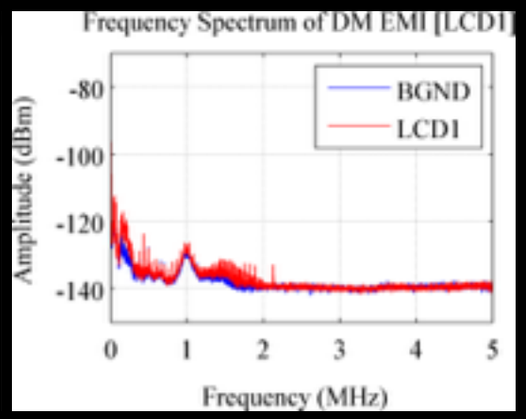


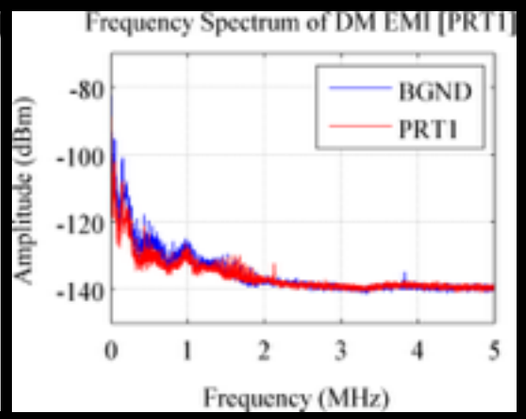
Common Mode EMI Spectrum









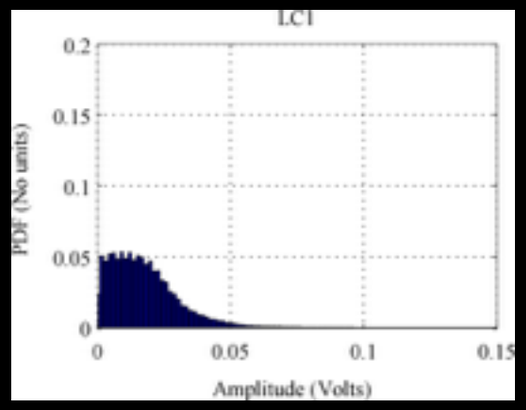


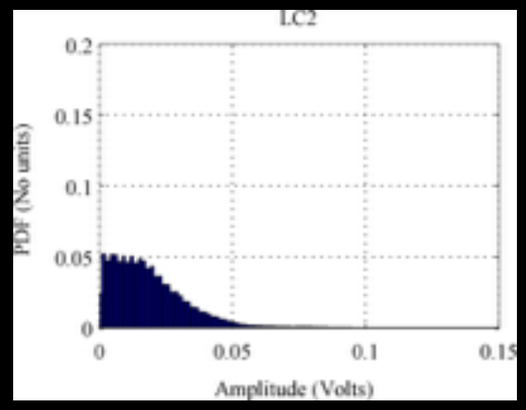
Differential Mode EMI Spectrum

CHALLENGES IN MODELLING AND FEATURE EXTRACTION FROM EMI DATA

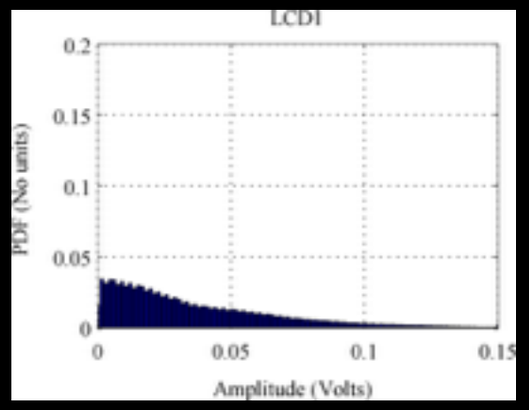
- Position and width of EMI peaks are not the best features for modelling EMI data as:
  - Number and shape of EMI peaks is dependant on powerline parameters and appliances operating in the vicinity.
  - Background noise (which is essentially baseline EMI present when the appliance under test is not operational) varies significantly with time.
  - Background noise subtraction for feature extraction is non-trivial and requires adaptive techniques for effective feature extraction.
  - Certain appliances don't show clear EMI peaks but do have wide-band noise spectrum (mostly because of complex coupling mechanisms with power line).
- Histograms derived from time domain EMI data show consistent pattern across multiple instances of the same appliance and discriminative features across different appliances.

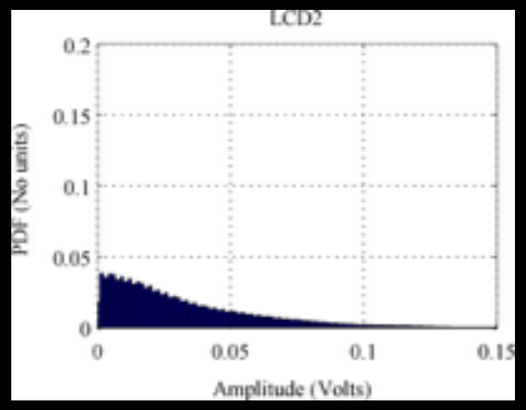
HISTOGRAMS DERIVED FROM TIME-DOMAIN EMI DATA



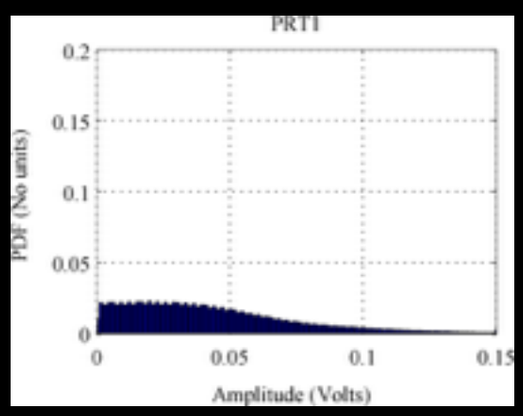


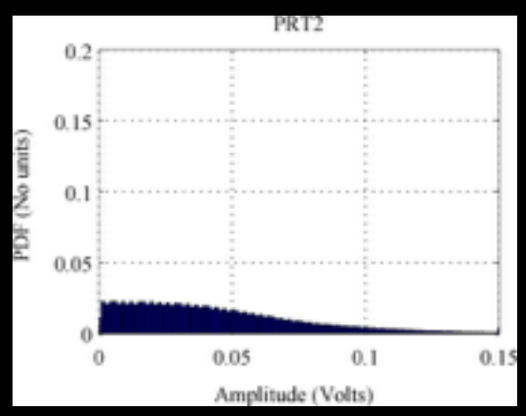
Laptop Charger



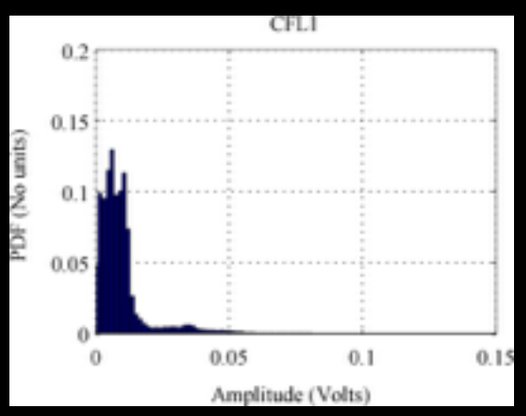


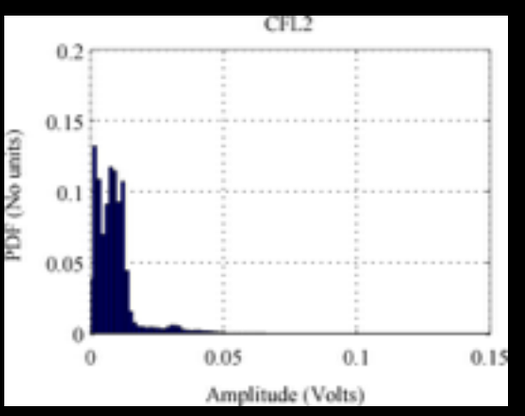
LCD



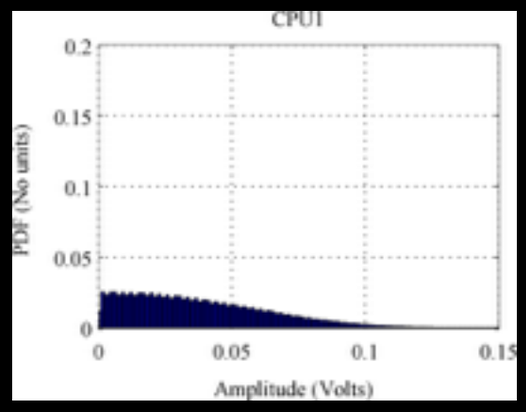


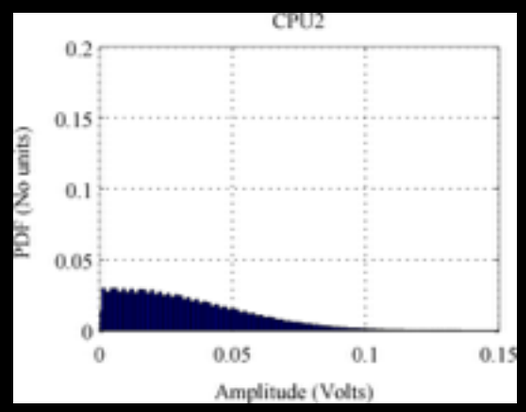
Printer



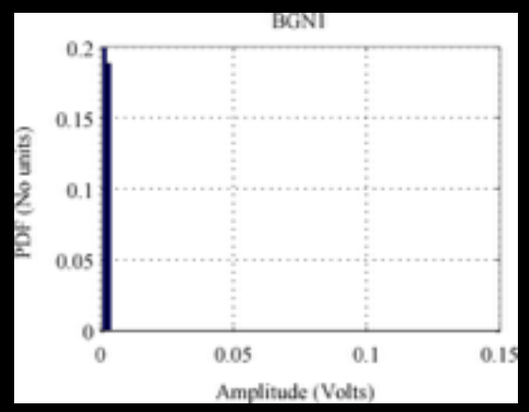


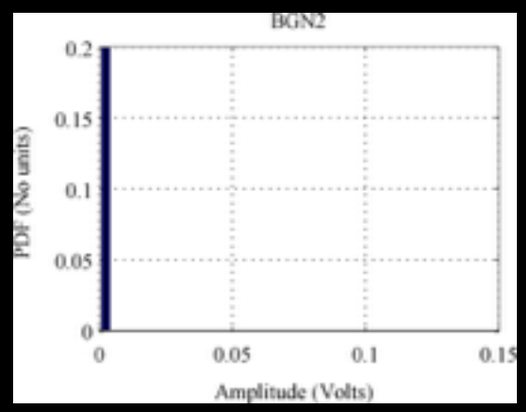
CFL





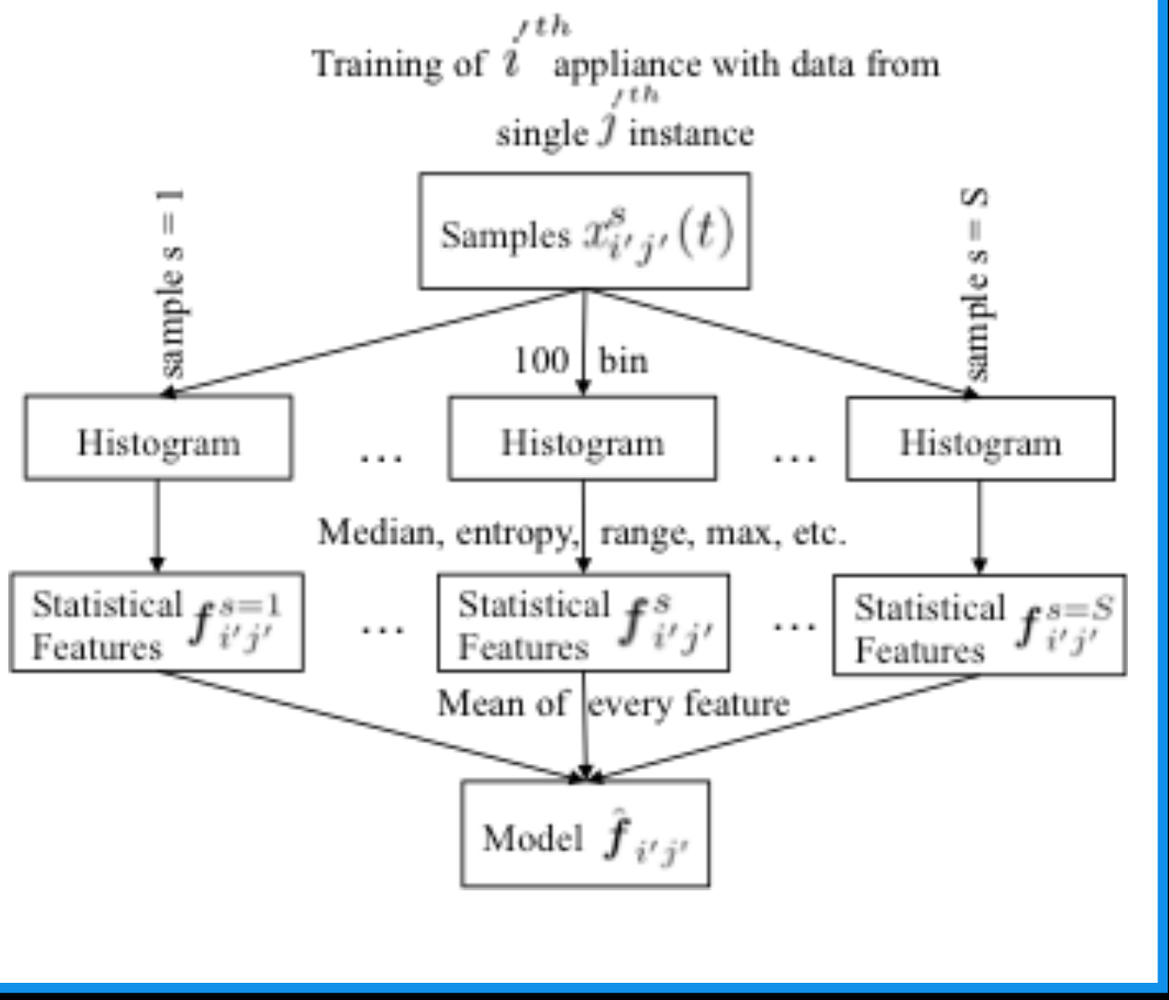
CPU



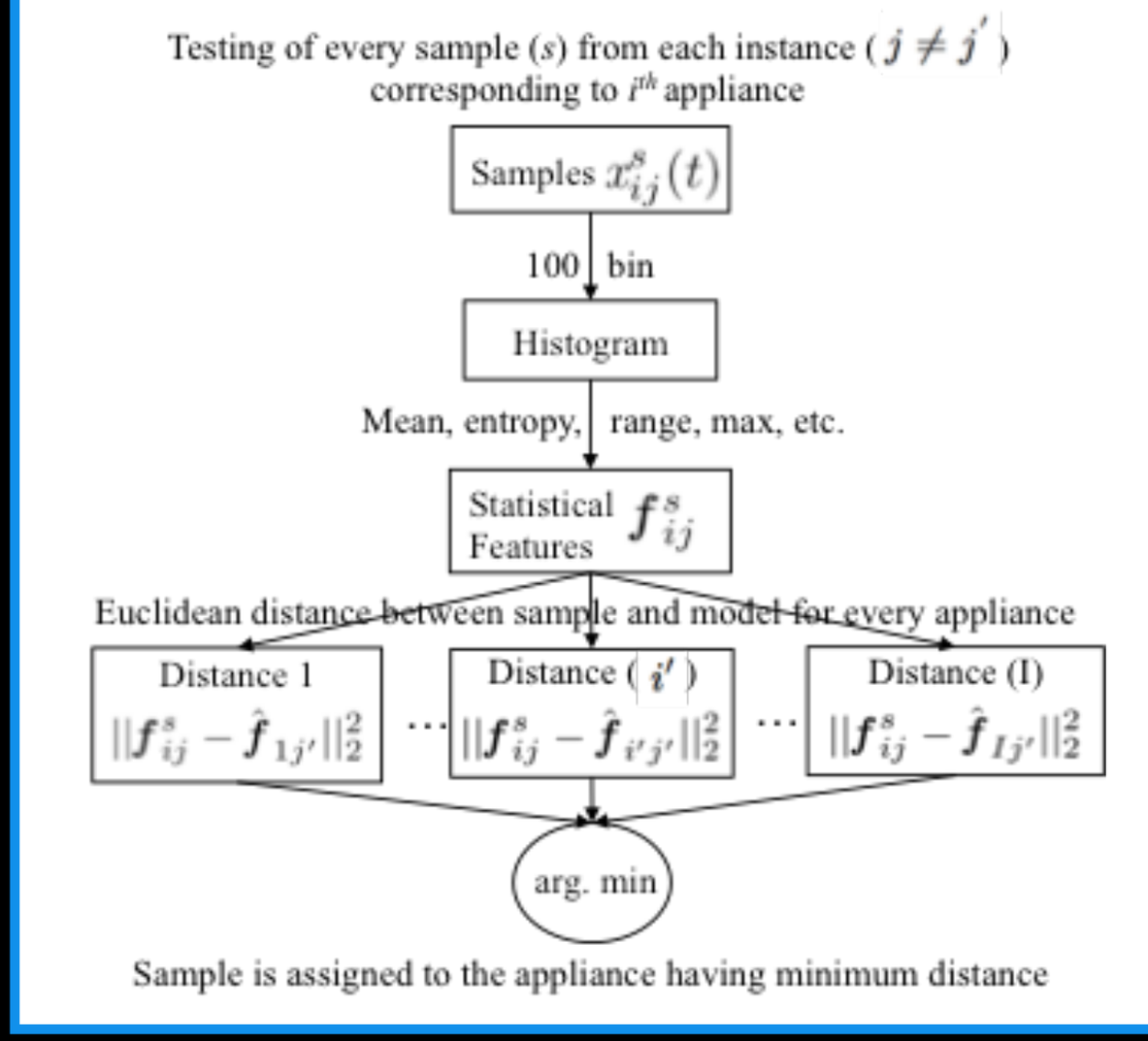


Background Noise

FEATURE EXTRACTION AND CLASSIFICATION



(a)



(b)

Steps followed during (a) training phase and (b) testing phase

NB: Training is performed on one appliance instance and testing is performed on remaining four instances of same appliance.

RESULTS FROM NEAREST NEIGHBOUR BASED CLASSIFICATION (A) CM EMI DATA (B) DM EMI DATA

	BGN	LC	LCD	CFL	CPU	PRT	Recall (%)
BGN	200	0	0	0	0	0	100
LC	0	197	3	0	0	0	98.5
LCD	0	15	144	0	33	8	72
CFL	0	0	0	200	0	0	100
CPU	0	0	12	0	119	69	59.5
PRT	0	0	1	0	17	182	91
Precision (%)	100	92.9	90	100	70.4	70.3	

(a)

	BGN	LC	LCD	CFL	CPU	PRT	Recall (%)
BGN	99	30	61	0	10	0	49.5
LC	106	33	43	0	18	0	16.5
LCD	87	29	67	0	17	0	33.5
CFL	3	4	0	193	0	0	96.5
CPU	51	22	38	0	69	20	34.5
PRT	7	5	12	0	97	79	39.5
Precision (%)	28.1	26.8	30.3	100	32.7	79.6	

(b)

Average precision and recall with CM EMI data is 87.3% and 86.8% while with DM EMI data it is 49.6% and 45.2% respectively.

LIMITATIONS

- Current sensor configuration is intrusive as existing wide-band current measurement systems are quite expensive.
- Current work explores the possibility of using CM EMI vs DM EMI. However these measurements are performed when only one appliance was operational.
  - This protocol is imp. in order to avoid any artefacts from powerline impedance and cross talk from adjacent appliances.

CONCLUSION

- New feature vector using CM EMI signals for appliance detection perform significantly better than previously used DM EMI based appliance detection.
- A new sensing system for measuring CM EMI is proposed which can be used for characterising SMPS powered appliances.

FUTURE WORK

- Define a robust feature extraction and learning technique to detect multiple IT and lighting loads operating together
- Combine smart meter data with features extracted from HF EMI data to close the loop for using EMI for disaggregation
- Compare disaggregation performance of algorithms after combining appliance operation details from EMI data
- Design a non-invasive sensor for sensing CM and DM EMI currents.

DETECTING IT AND LIGHTING LOADS USING COMMON-MODE CONDUCTED EMI SIGNALS

THANK YOU

CONTACT:
MANOJ GULATI
EMAIL: MANOJG@IIITD.AC.IN
IIIT-DELHI (INDIA)