New Methods in Power Line Carrier Monitoring and Analysis – Real World Examples and Implications for Protection System Reliability

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Introduction

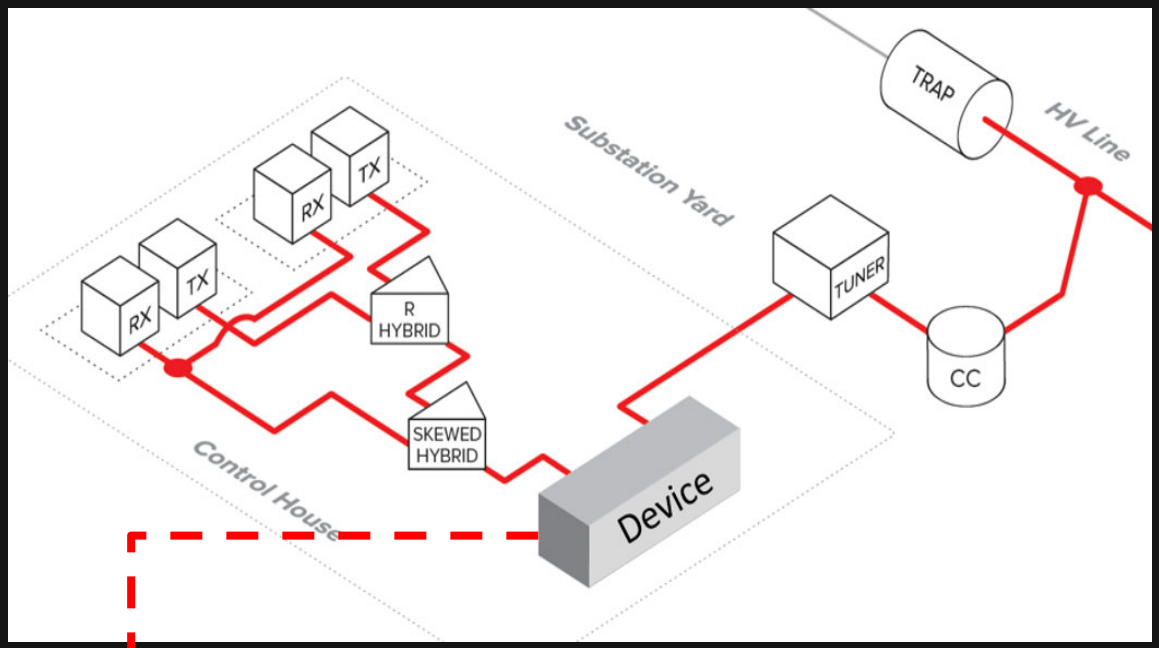
- Power Line Carrier has been protecting transmission lines in the US for at least 94 Years
  - *1927, Ohio Power Company, Newmark-Crooksville, 66 kV, 35 miles*

- Utilities find that many records of carrier channel events, even in this era, are not adequate for misoperation event analysis
  - *NERC Misoperations Report, 2013, etc.*

- Continuous monitoring devices, specific to PLC protection channels, provide enhanced carrier channel data

- "Improvements in data…help entities determine areas to improve by identifying misoperation causes and proper mitigation steps"
  - *NERC 2013*

How is the data obtained?



Wideband (to 5 MHz) Sampling = 20 MHz	**Mid-band (10 kHz BW)** Sampling = 20 kHz	**Narrow-band** 300, 600, 1200 Hz typ.
-RF transient detection -Wideband level	*-Time-domain capture* *-Spectral analysis*	-Impedance -Levels, Freq, Trend

“New Methods” - Summary

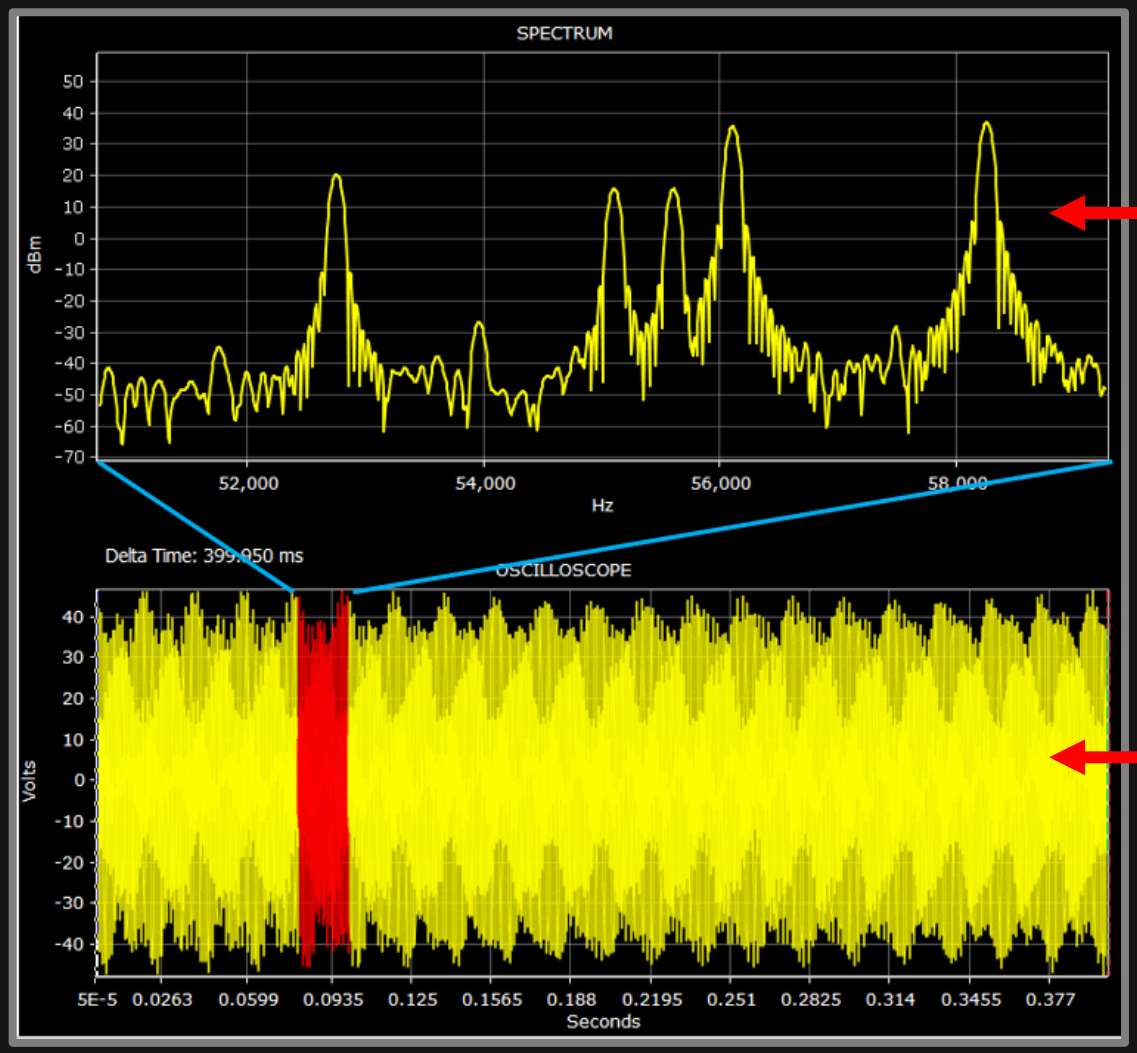
- Trending: long-term storage of instantaneous data points, sampled at regular intervals (once an hour is typical)
  - *Levels (dBm), impedance / reflected power*

- Time-domain voltage capture / fast Fourier transform (FFT)
  - *400 ms of frequency-selective voltage “on the coax”*
  - *10 kHz BW at channel center frequency*

- Transient Detection
  - *Wideband voltage and current detected independently*
  - *Thresholds at ~300 V peak, ~2 A peak, min. 250 ns*

- Impedance – “where reflected power comes from”
  - *The impedance looking into the line tuner (typical installation)*
  - *Magnitude and phase (50 ohms 0 degrees ideal)*

Time-domain / FFT



Frequency analysis of RED portion of data shows 2 Tx and 3 Rx signals

Composite voltage signal in 10 kHz BW (steady state)

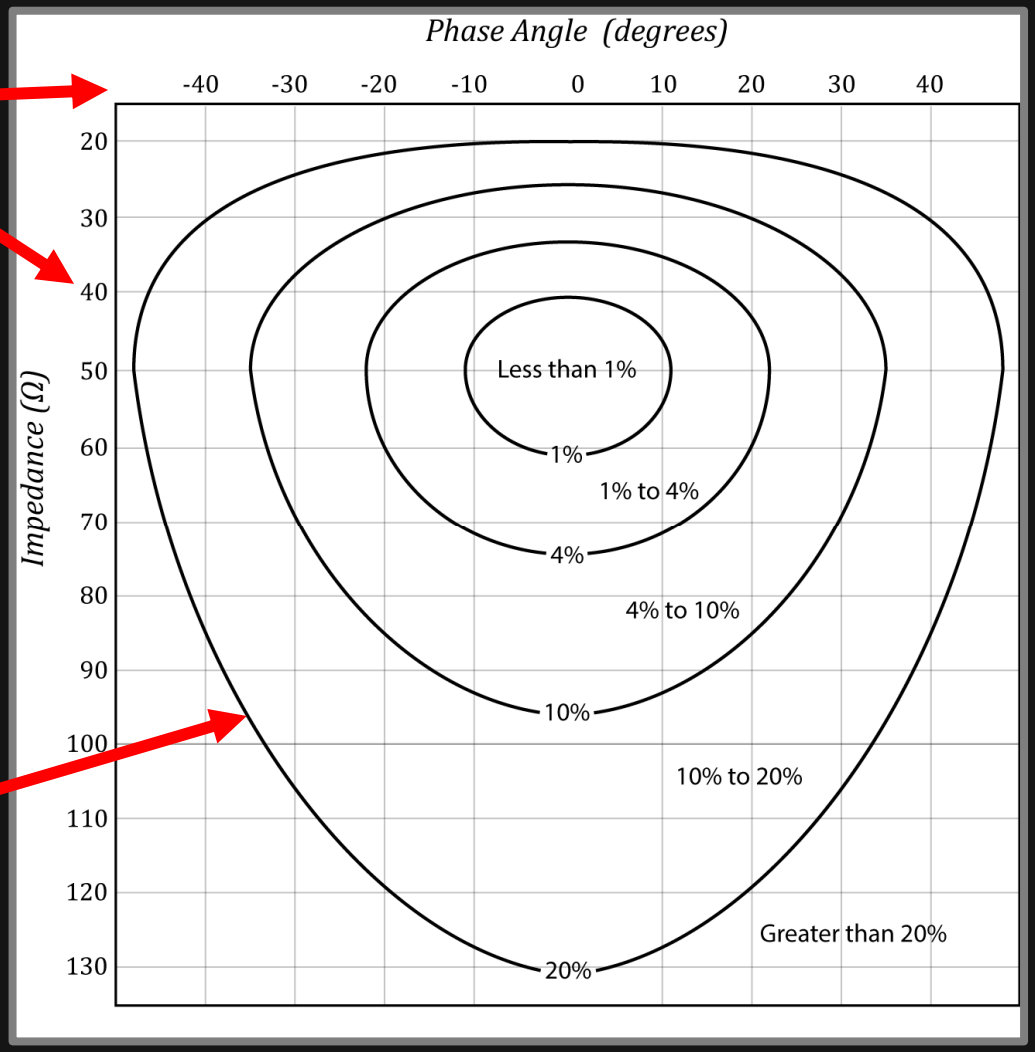
Impedance vs Reflected Power

Z_{TERM}

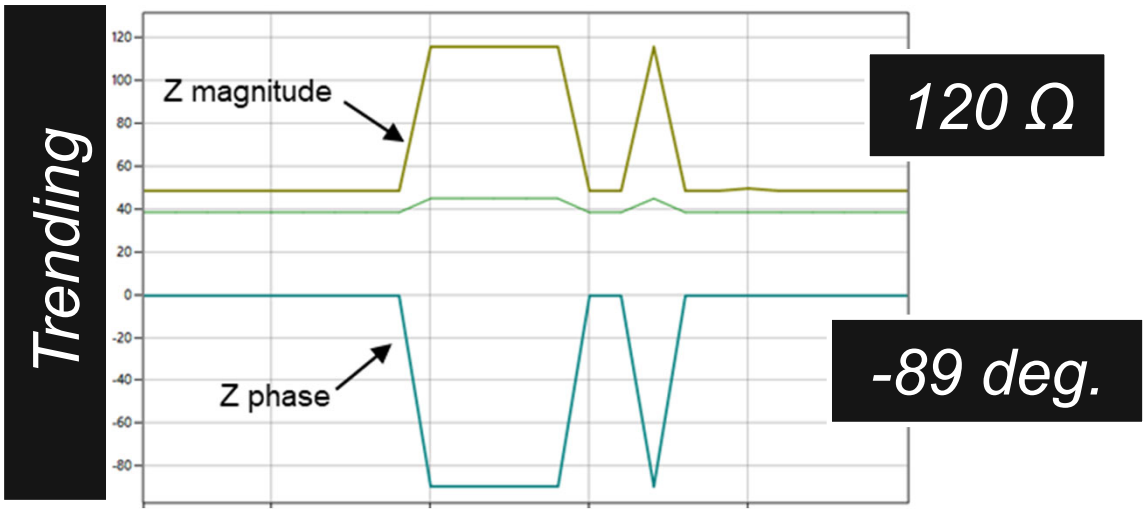
$$\rho = \frac{Z_{TERM} - Z_{SOURCE}}{Z_{TERM} + Z_{SOURCE}}$$

$$RP_{(\%)} = 100 * \rho^2$$

Reflected Power



Real-World Examples – Impedance and Phase



	Mag (Ω)	Phase (deg)	RP (%)
Baseline	49.8	0.0	0.0
Tuner input *shorted*	24.6	+84.3	85.2
Tuner ground sw. *shorted*	173.8	+86.5	93.4
CCVT ground sw. *shorted*	179	+85.9	92.9
Tuner input *open*	*117.9*	*-88.8*	96.9
Tuner prot. unit *open*	*120.3*	*-88.6*	96.5
Line disconnect *open*	88	-86.1	89.2

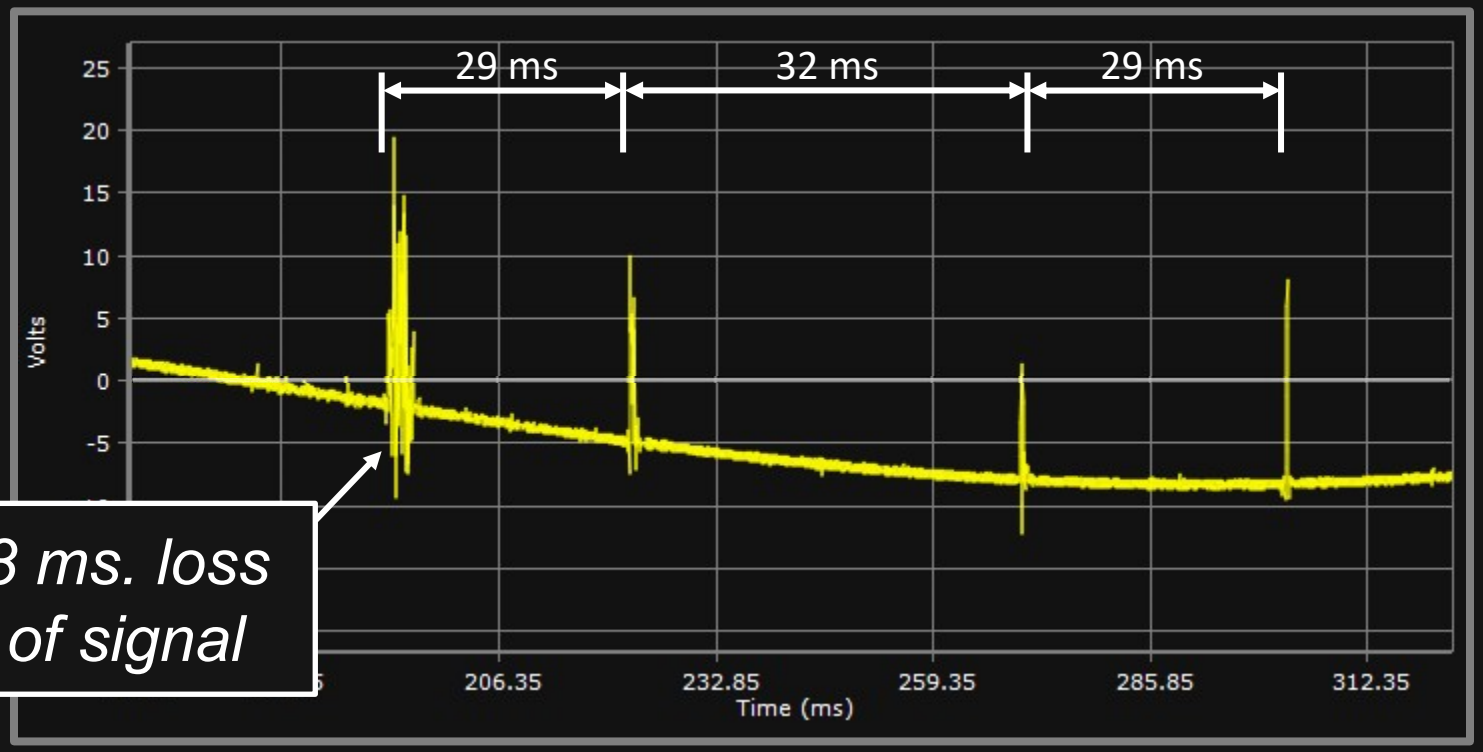
Power System Sources of PLC Noise

- Switching events generate transient carrier-band energy
  - *"Noise"*

- Transmitters/receivers are particularly helpless here
  - *No time-domain picture of the carrier – what did it look like??*

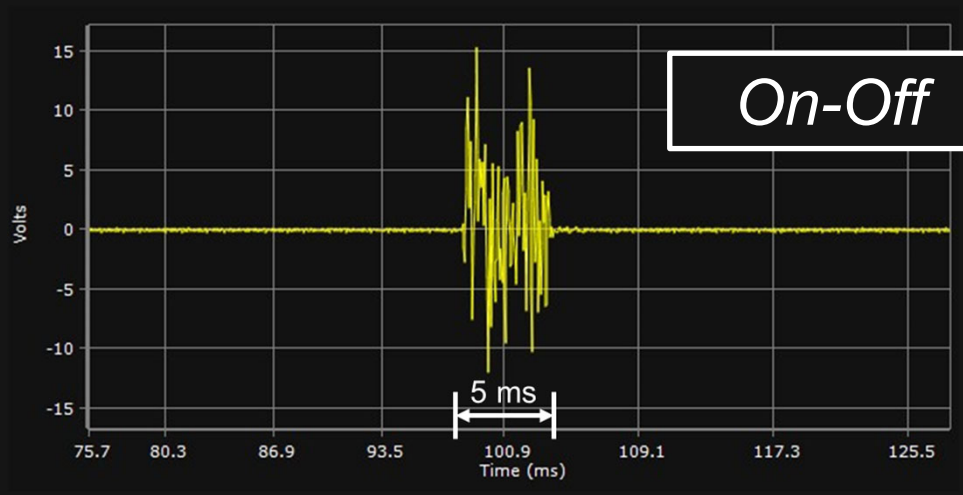
- New data help to observe the day-to-day interaction between PLC systems and the power system
  - *Signatures and characteristics*

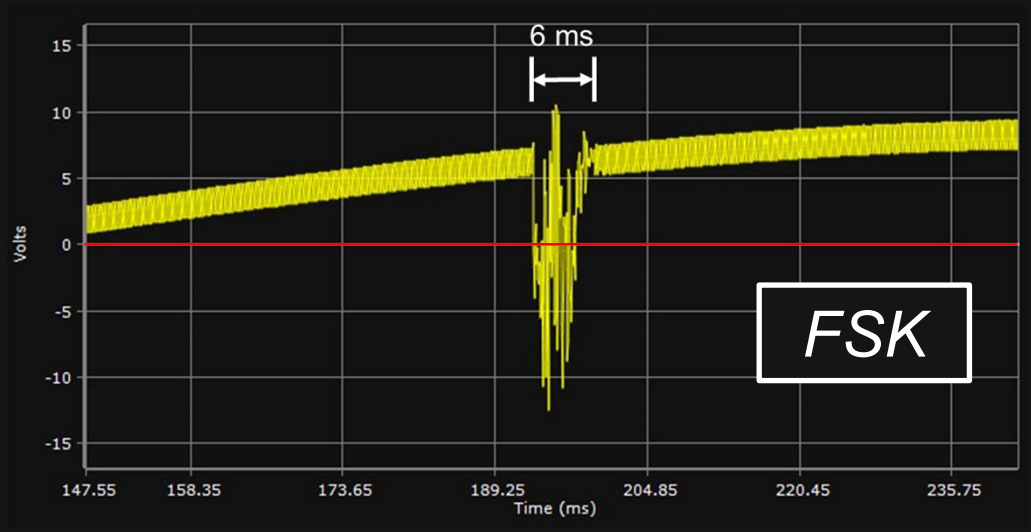
Power System Related – Lightning



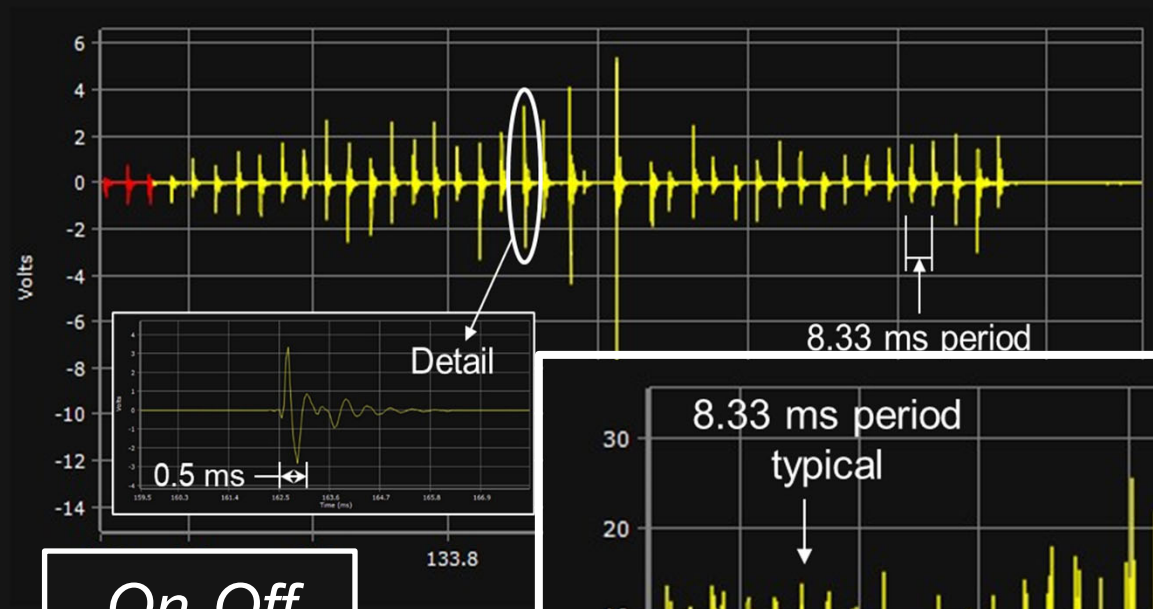
3 ms. loss of signal

Power System Related – Breaker Operations

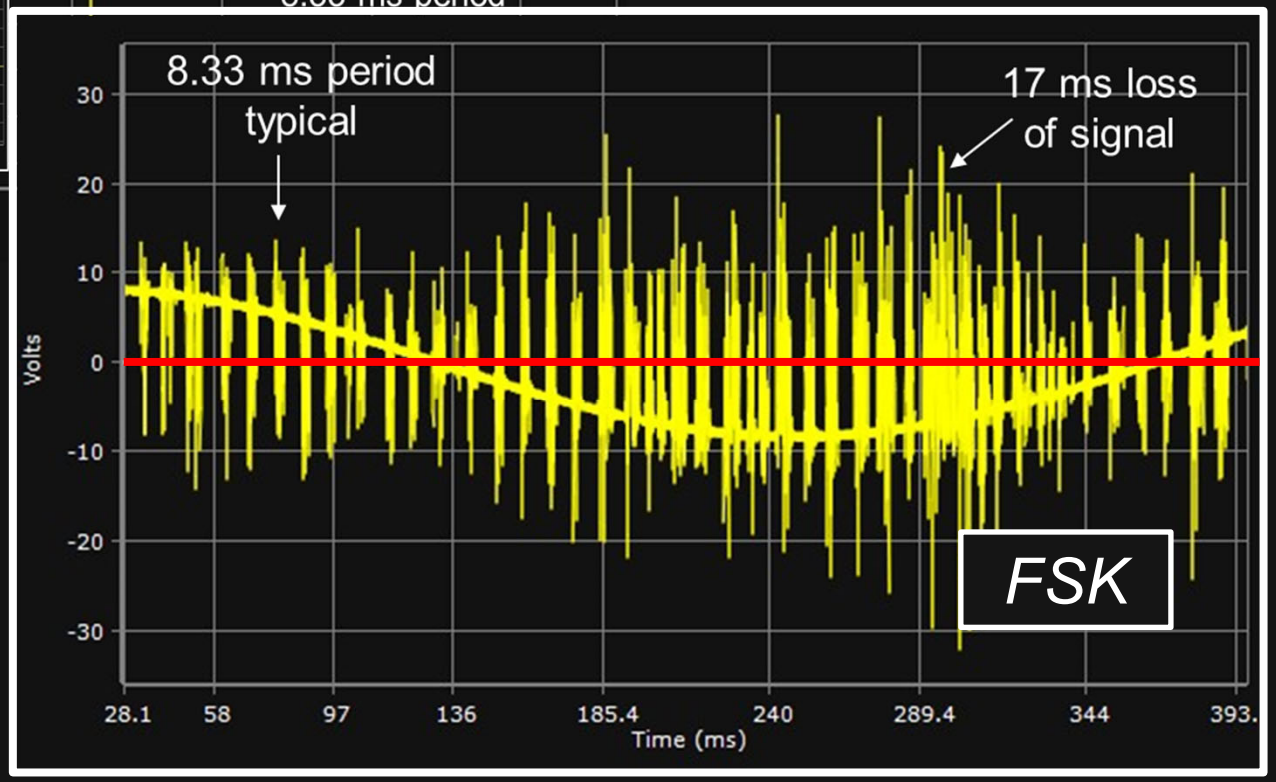




Power System Related – Line Disconnect



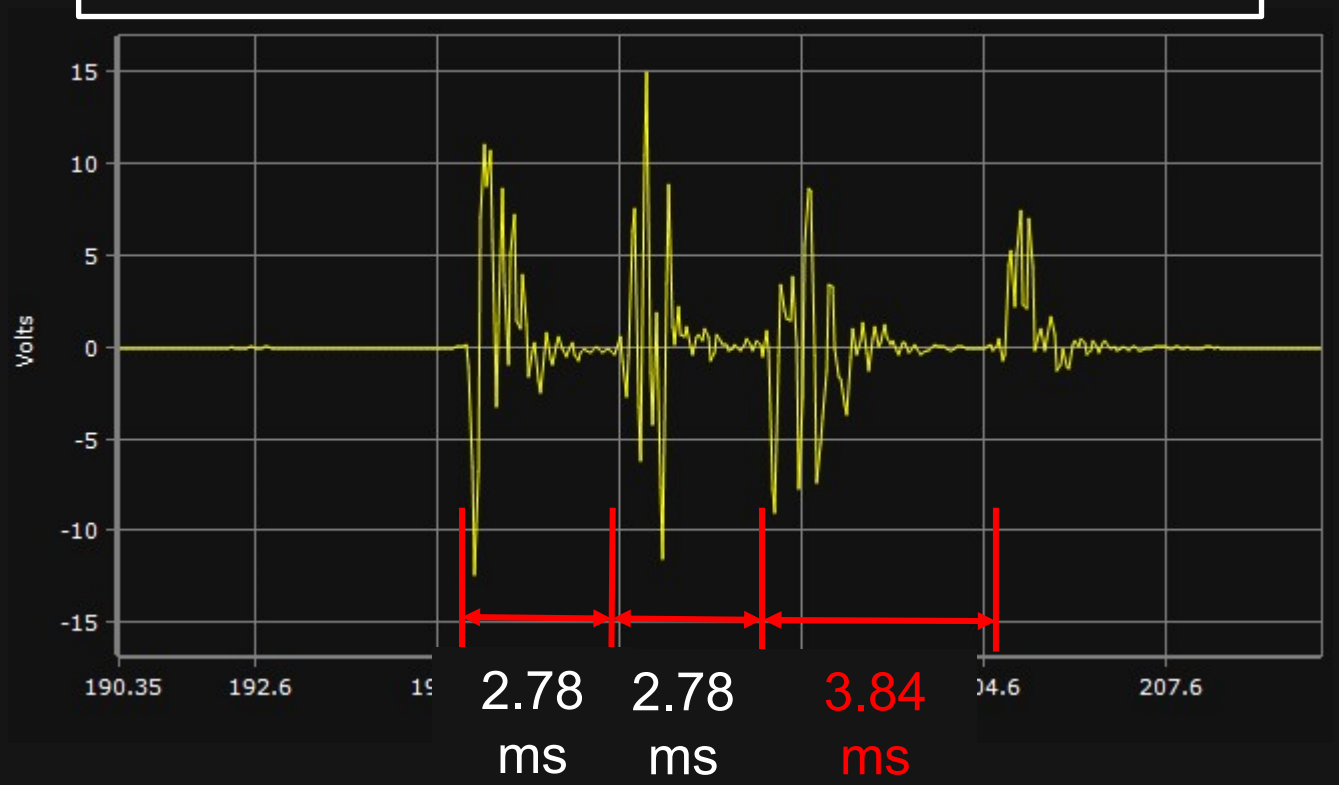
On-Off



FSK

Power System Related – Shunt Capacitor Banks

Controlled switching and re-ignition show up on carrier coax cable



Carrier Holes

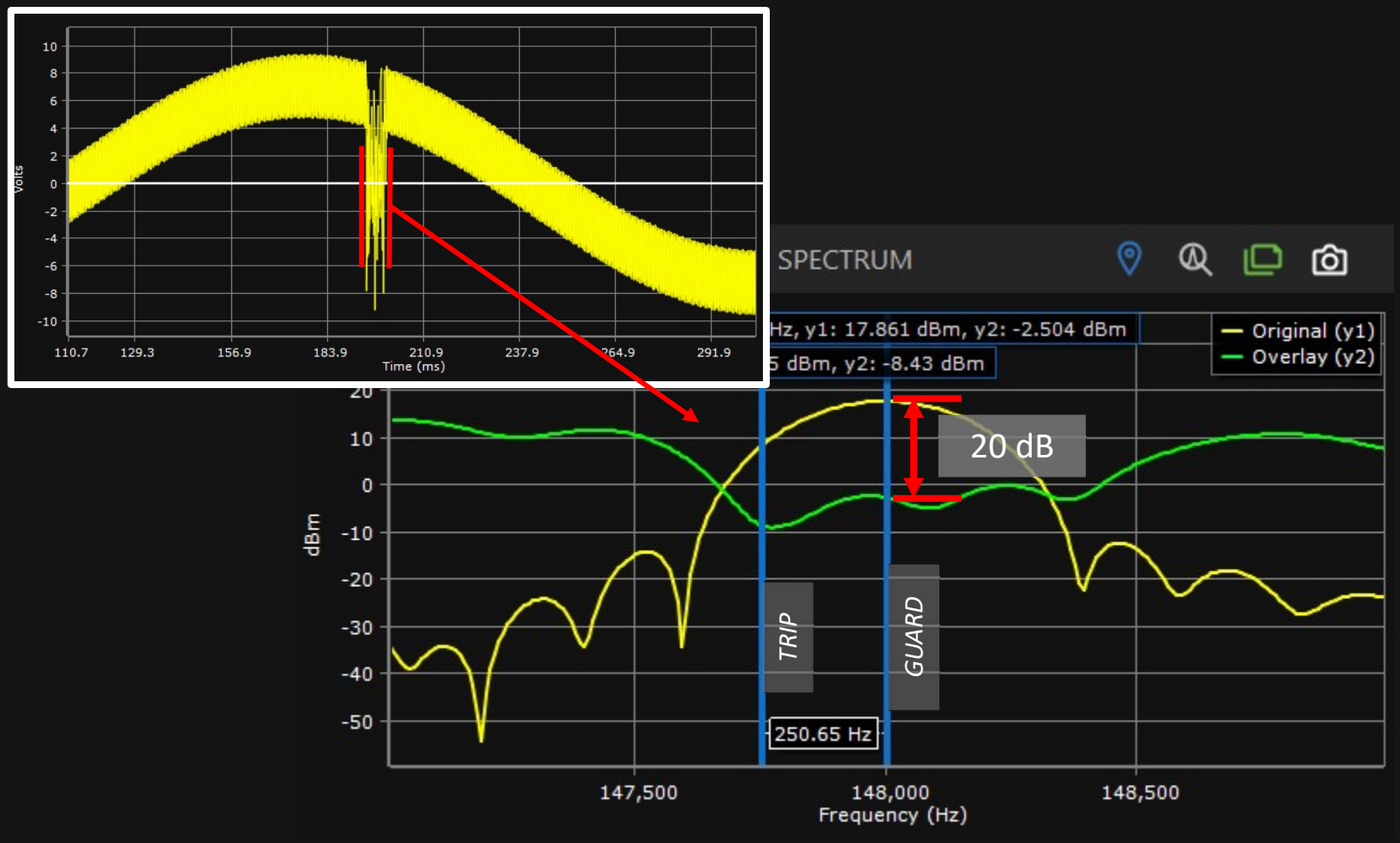
- "The lack of a signal where one should appear"
  - *Typically, due to some kind of flashover*

- "Tend to be a mystery"
  - *Available records show only the state of a relay contact, not the nature of the analog energy ultimately driving the relay contact*

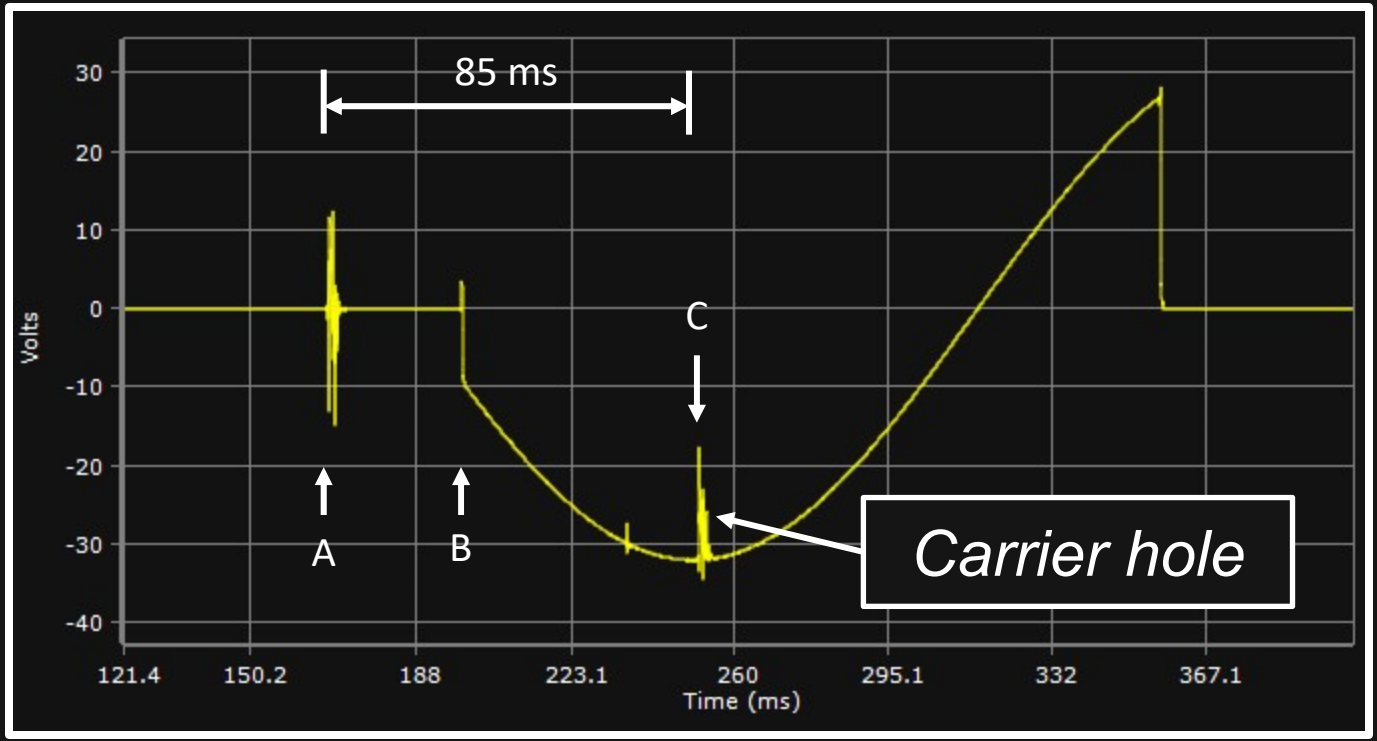
- Block-hold timers - beware
  - *May mask carrier hole issues as they get progressively worse*

- Transient detection, time-domain, and FFT used for carrier holes

Carrier Holes



DCB – Observing Operations



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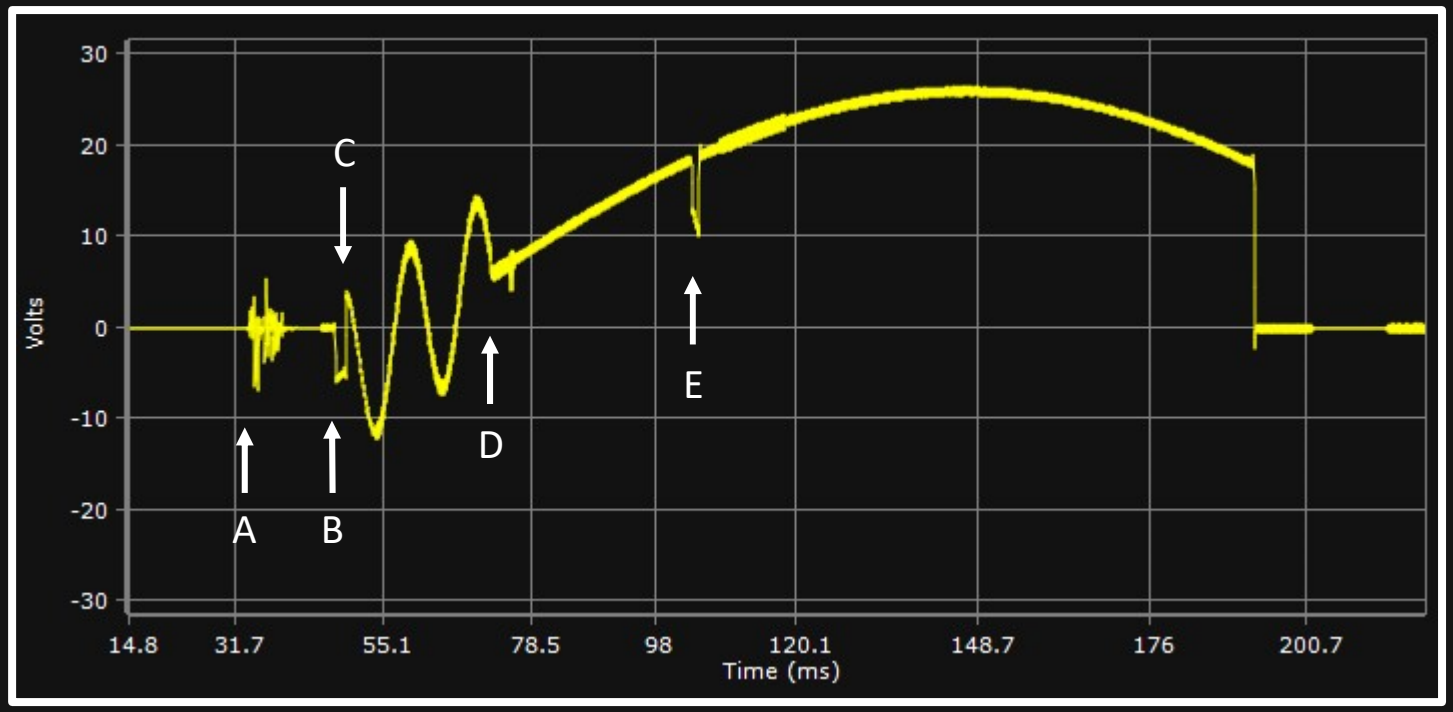
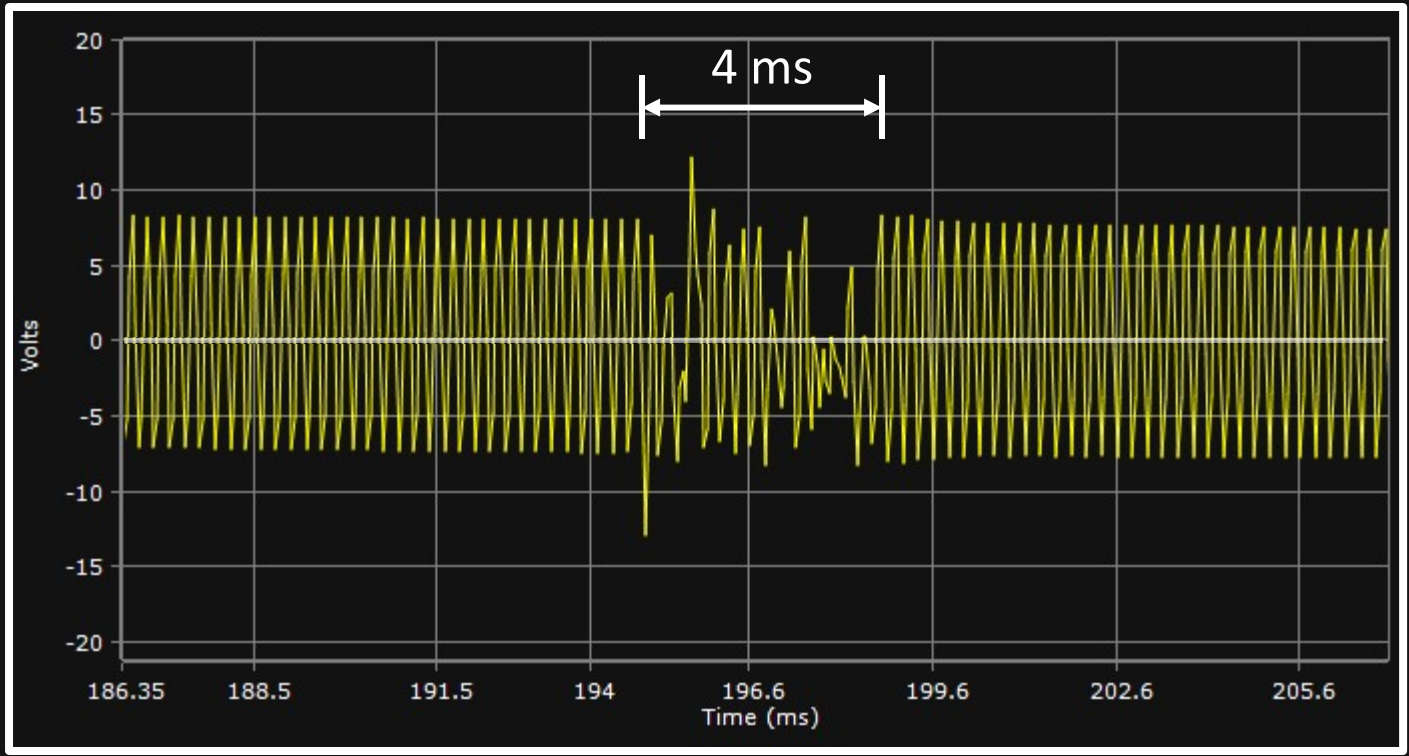


DTT Misoperation



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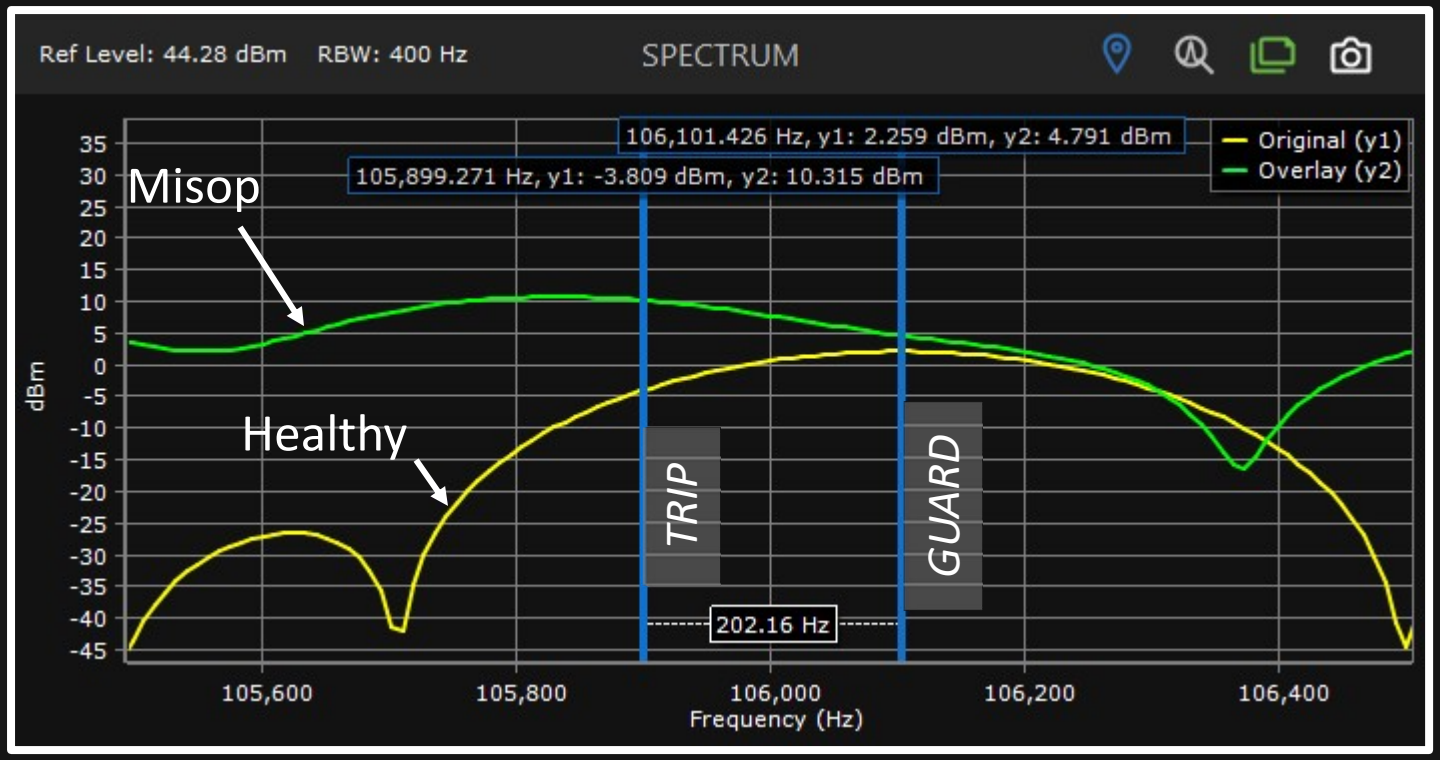


DTT Misoperation

Transient Monitoring

- Line traps isolate PLC systems from impedance changes on the bus
  - *And, from switching transients on the bus !!!*

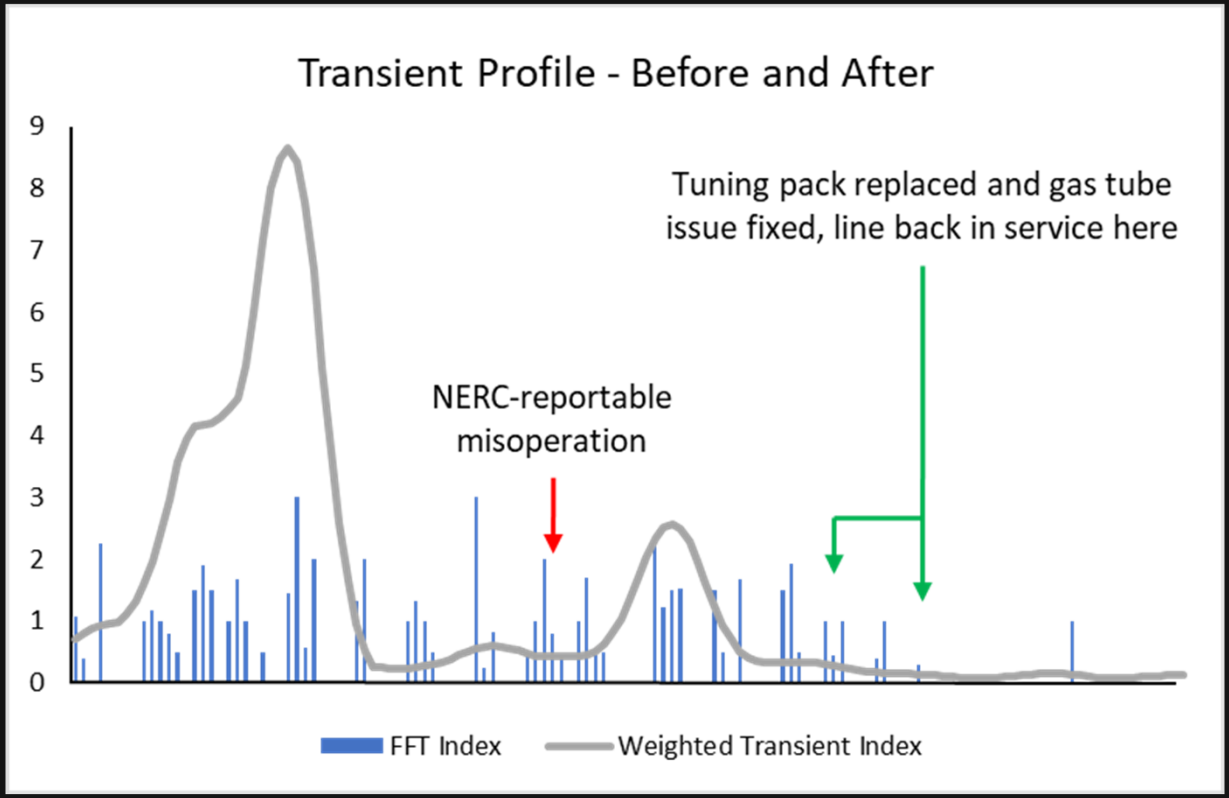
- A failed trap tuning pack allows more carrier-band transient energy onto the line
  - *Once on the line, the energy has a tuned path to PLC receivers*

- Failing or de-rated gas tubes and spark gaps make transients worse
  - *Lower flashover means more flashovers*
  - *Carrier holes / loss of signal last longer*

- When these two factors combine – failed traps and de-rated gaps/tubes – misoperation risk is dramatically increased

Transient Monitoring

- Continuous monitoring devices can track baseline transient activity
  - *And indicate when it has increased beyond normal limits*



Implications for PLC Reliability

- NERC 2013 Misoperation Report (and subsequent reports)
  - *17% of misops caused by communications channel (396 of 2279)*
  - *12% of misops have "unexplainable" cause*

- Estimates made for the remaining groups' share of PLC
  - *30% of all communications-related misoperations involve PLC*
  - *5% of total protection misoperations*

- Trends continue to this day

- *Consistent use of continuous monitoring data for PLC can put a dent in this number*

Conclusions

"To only review data after obvious misoperations is analogous to a doctor ignoring your reports of anxiety, tightness in chest, nausea, and shortness of breath and only treating you for a heart attack if you experience cardiac arrest"

- R. W. Patterson, "The Importance of Power System Event Analysis"

- By using continuous monitoring data to inform PLC operations, maintenance, and analysis, utilities accomplish the following:
    - *Reduce effort, uncertainty, and costs associated with operating PLC channels for pilot protection of transmission lines*

Questions ?