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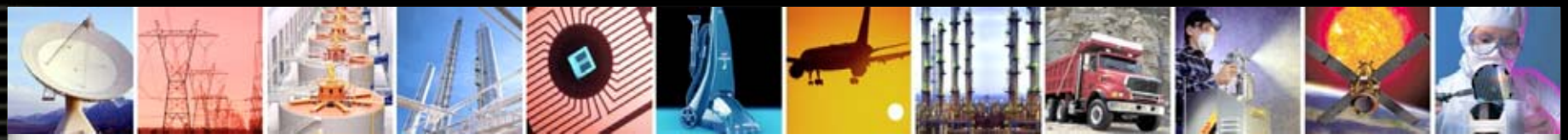

i-PCGRID Workshop 2018

Power Line Carrier Holes and Field Trial Tests

Presented by: Tony Bell
PLC Product Manager
AMETEK Power Instruments
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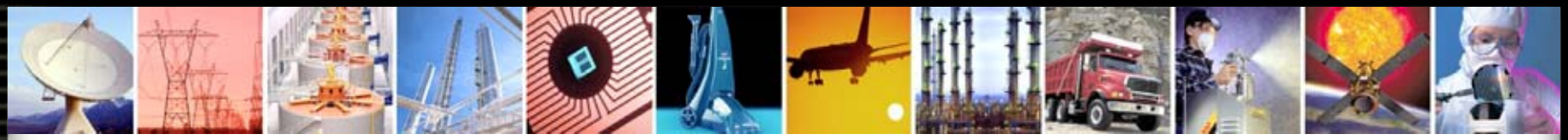

DEFINITION of Carrier Holes

1. Carrier holes is the name given to the loss of carrier signal when it should be present.
2. They can only occur in a DCB blocking On-Off system when there is an external fault and the carrier is keyed on.
3. For an FSK system they can occur any time as the system is always transmitting.

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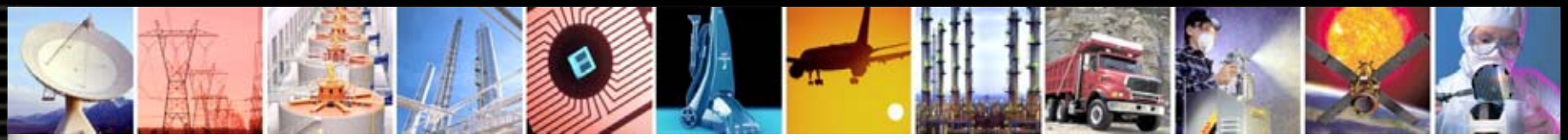

The PAIN of Carrier Holes

1. Carrier holes do not occur very often, but when they do they can cause the Protective Relay system to misoperate depending on how long they last.
2. Unexplained miss-operations due to carrier holes require much time/resources to be spent in investigation and troubleshooting.
3. Method of using extension timers in the protective relay to “ride through” carrier holes requires very judicious choices of timers. Balancing rope act.

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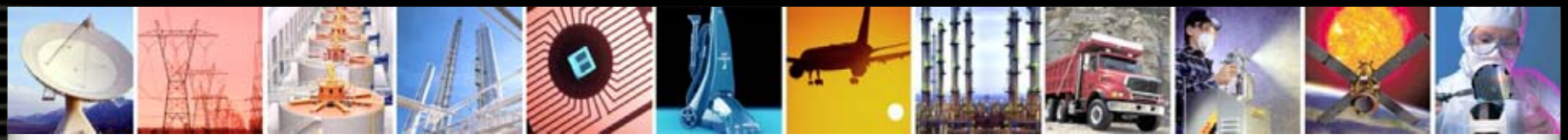

EFFECTS of Carrier Holes

1. In DCB ON-OFF systems during an external fault when blocking carrier needs to be sent, loss of carrier signal will cause an over-trip.
2. In DTT & POTT FSK systems during an internal fault, a Trip will be delayed or will not get through.
3. In an unblock DCUB FSK system a loss of carrier signal can cause a false Trip permission output window. (Delaying this trip permission window using an unblock delay timer can help ride through short time carrier holes in this situation as demonstrated by FPL & Ametek in a past Ga Tech protective relaying conference presentation.)

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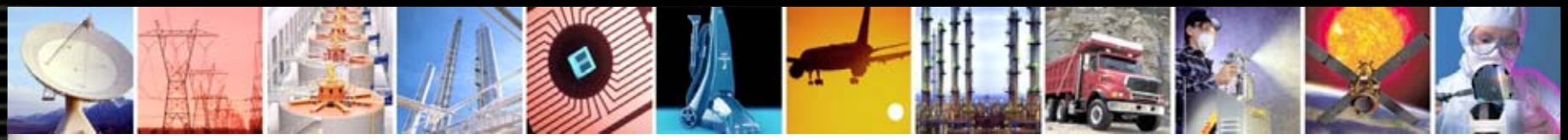

CAUSES of Carrier Holes

1. Spark gaps firing
2. Coax cable flashover from center to outer conductor due to deteriorated coax
3. Contact bounce when using EM protective relays
4. Incorrect settings or calibration of Power Line Carrier receivers.

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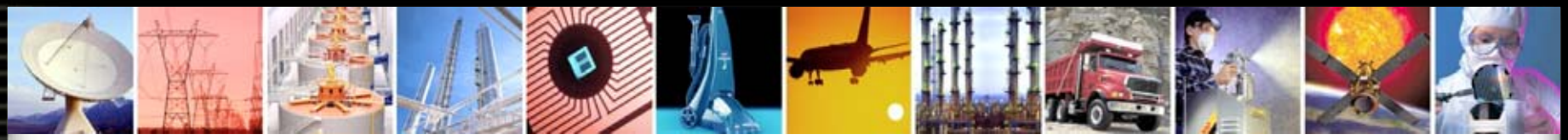

DOMINANT CAUSE of Carrier Holes

1. For a typical line to ground fault there is a transient produced at the beginning of the fault that usually will cause a protective spark gap to fire.
2. Primarily this is the line-to-ground gaps across the drain coil in the CCVT and Line Tuner.
3. The dominant source of carrier holes appears to be these spark gaps firing and shorting out the carrier signal for several msec of time during a fault, based on our extensive research of existing documentation and talking to experts. Our lab testing has confirmed this.

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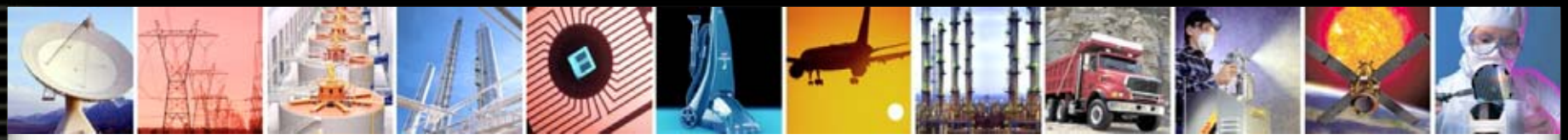
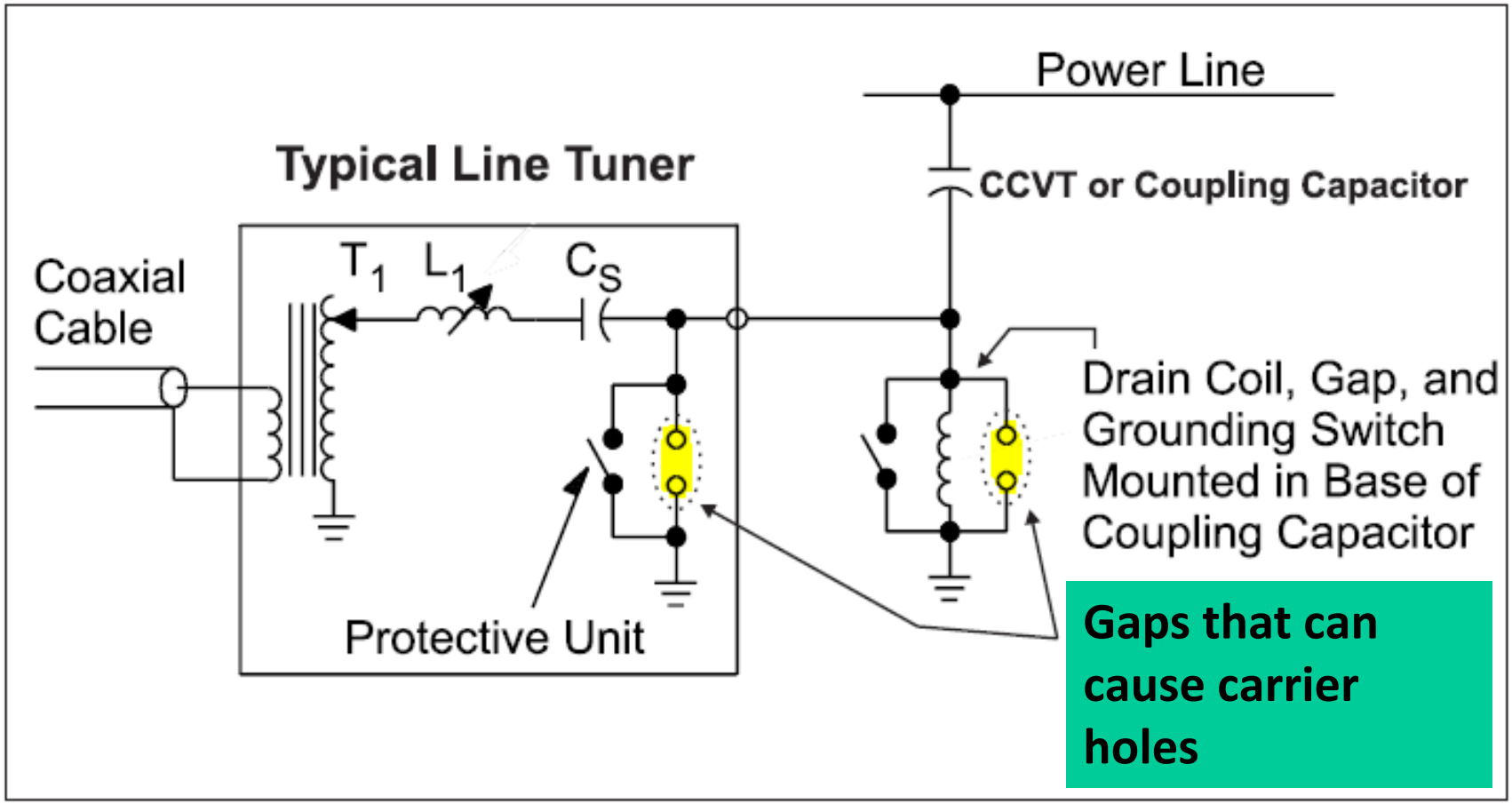


Location of Spark Gaps



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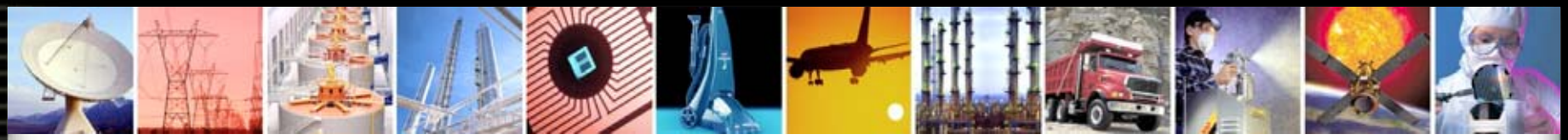
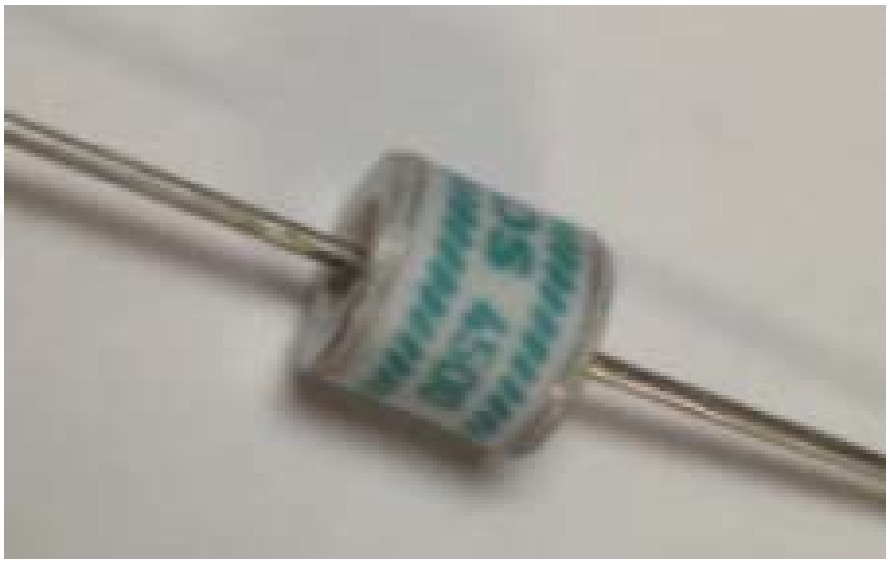


Present Spark Gaps in Tuners & CCVTs

Gas Tubes - Advantages

- Being used on many line tuners & CCVTs as they are more precise and sealed therefore not being exposed to contamination and do not require setting.



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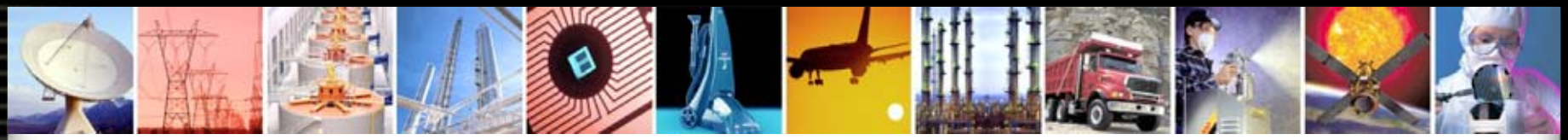
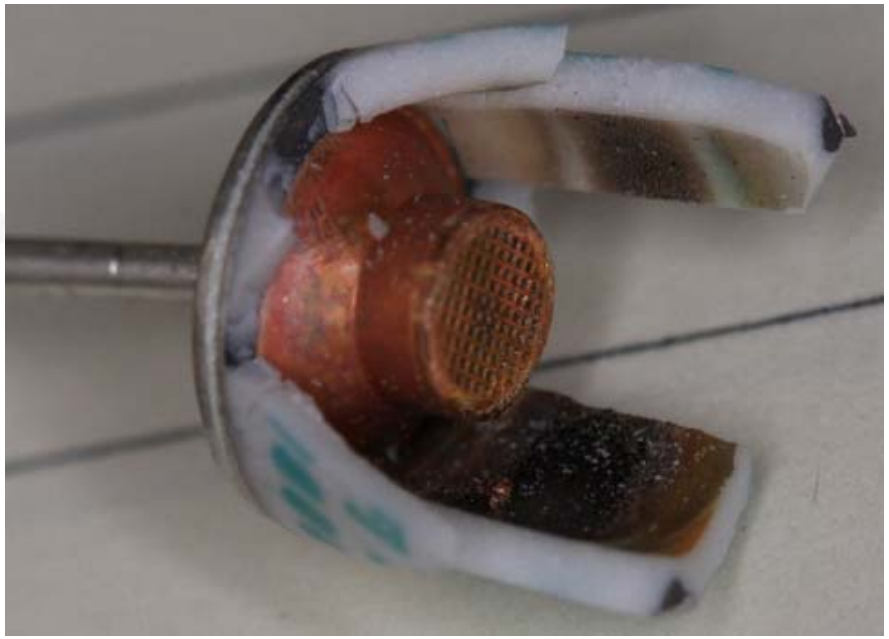


Present Spark Gaps in Tuners & CCVTs

Gas Tubes – Disadvantages

- Tend to have slower clearing times.
- More difficult to tell if damaged due to ceramic enclosure. May need to shine flashlight in them to clearly see if darkened.
- When they start to fail the inside of the gas tube will first have dark spots and then completely blackens with time.
- Failed 8mm gas tube that has been broken to reveal inside discoloration. →



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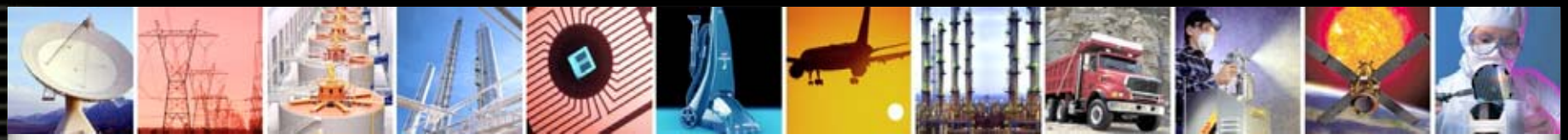

Present Spark Gaps in Tuners & CCVTs

Air Gaps - Advantages

- Still popular due to being able to physically see and clean the gap.

- They tend to extinguish arcs faster than gas tubes when in good condition.
- There are various types ranging from simple metal washers spaced apart to more sophisticated types.
- White arrow shows the thin gap. →

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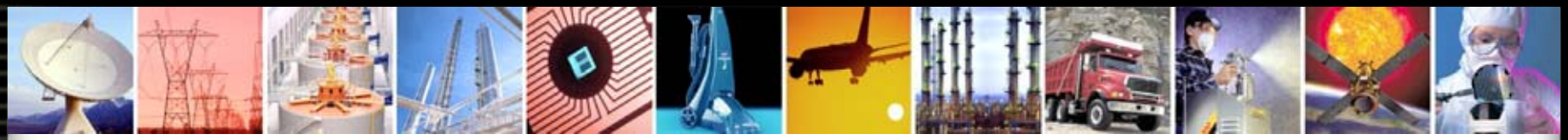

Present Spark Gaps in Tuners & CCVTs

Air Gaps - Disadvantages

- Get worse with time from carbon build up and pitting that occur during arcing, humidity/moisture/dust, oxidation, & insects. They can also be misadjusted.
- Photo shows corrosion and non-parallel surfaces of a poorly maintained air gap.

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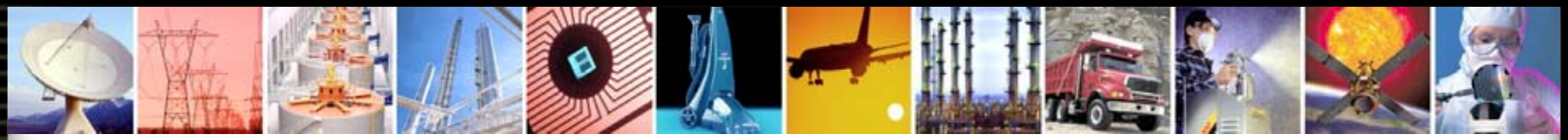

Eliminating the Source of Carrier Holes

1. Eliminating the source is always the preferable solution. So Ametek attempted to make a spark gap that would not short out the carrier signal and/or be quick to extinguish instead of making the power line carrier mask over the problem.
2. The idea was that this gap must normally fire before any other gaps in the system and take the bulk of the surge energy.
3. To lab test this gap a UPLC-II was connected via RG213 coax to a single frequency line tuner which was connected via standard HV lead-in wire to a simulated CCVT and power line.
4. The RF power level of the UPLC-II was adjusted at various levels as well as the 60 Hz voltage across the drain coil to see the effect of this upon the gap's ability to extinguish the arc.

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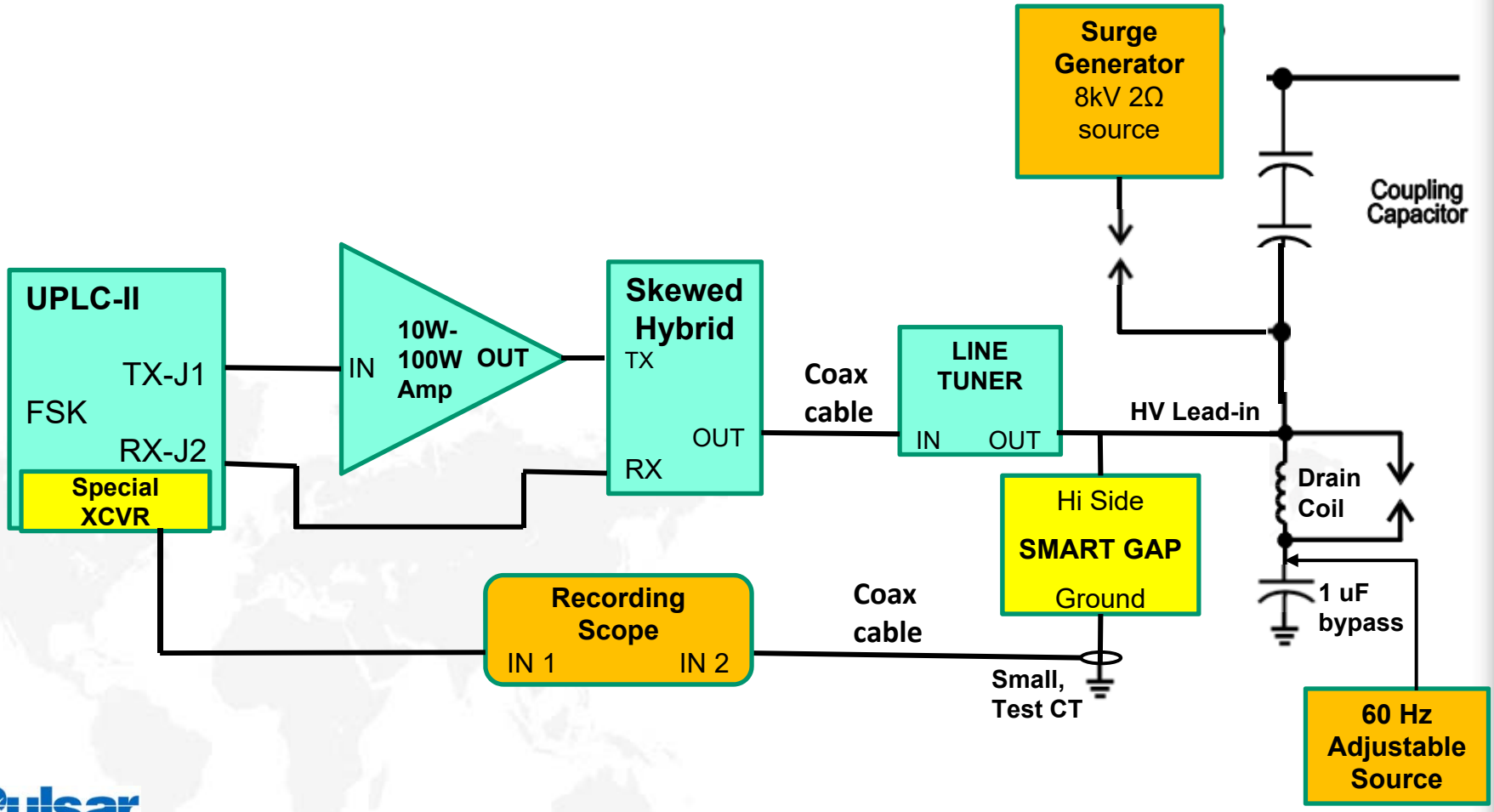
Lab Test Set Up for Testing Carrier Holes



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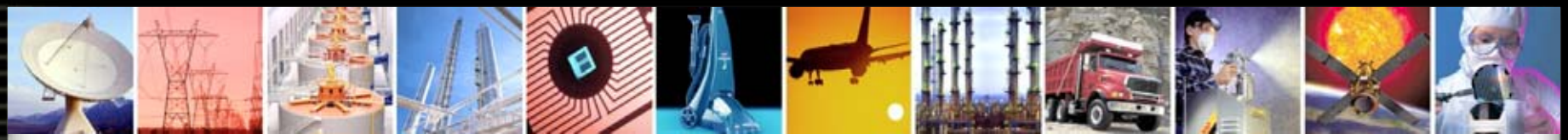

Carrier Holes Lab Test Conclusions

Note: All tests were run with single 8KV (1.2 X 50 usec) surges applied a few seconds apart at a max of 4000A peak.

1. Extensive lab testing was done that included many tens of thousands surges. We called a carrier hole any loss of carrier for > 2 msec.
2. Carrier holes were produced with an air gap in the line tuner, but only with the gap being “compromised” (set wrongly, damaged, or dirty).
3. Able to produce carrier holes much easier with the standard gas tube gap in the tuner & the carrier hole occurrence frequency increases with an increase in the amount of constant RF & 60 Hz power that is across the gap.
4. Protectors (especially gas tubes) fire at a much higher voltage than is required to keep them conducting. RF from the PLC TX + 60 Hz voltage across the drain coil can keep a protector conducting long after the surge has dissipated. This can cause elongated carrier holes & noise during the arcing time of the gap with about 50% lasting over 8 msec.

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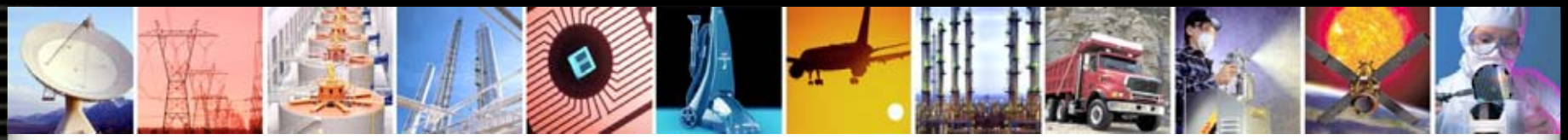

Ametek "Smart Gap" Lab Test Conclusions

1. **Multiple high hold-on voltage gas tubes in series are required to get above the holding voltage that prevents conduction.** Three high holding voltage tubes did the trick. Stopped 100% of carrier holes under the worst case conditions we could simulate for single surges. (Carrier holes without the smart gap in the same exact setup were occurring over 50% of the time.)
2. We **noticed several failures of the standard 8 mm gas tubes used in the line tuners during our tests**, so we chose to use a more robust 12 mm gas tube in the Smart Gap. After thousands of surges there was no sign of any degradation (unlike the 8mm gas tubes where several failed).

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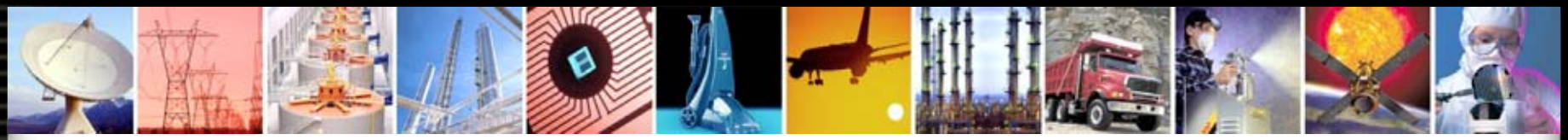
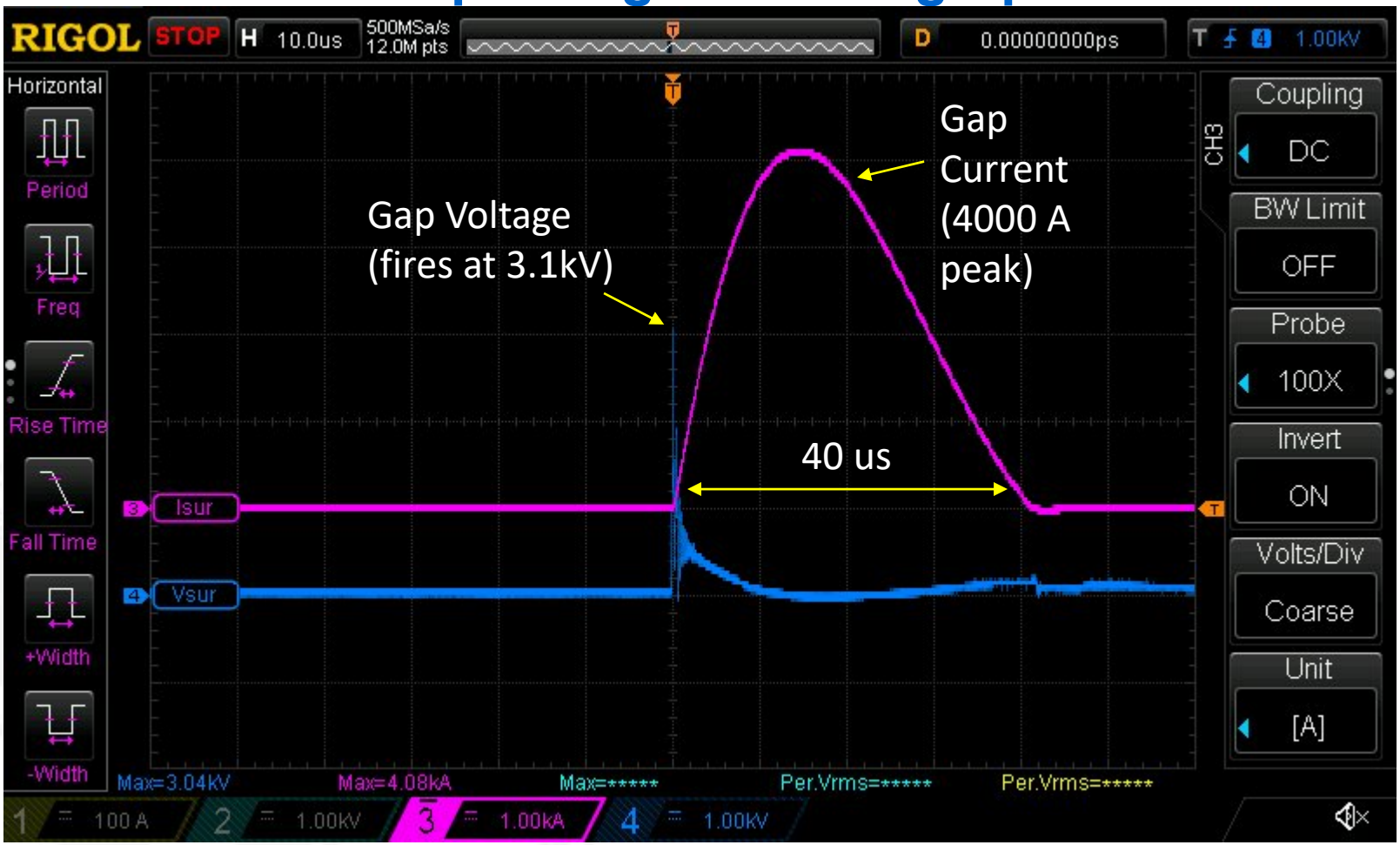


Ametek Smart Gap Firing & Clearing Speed <0.5 msec



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1.2 x 50 uS 4000A surge applied

Blue Trace = Voltage across gap,
Pink Trace = Current thru gap

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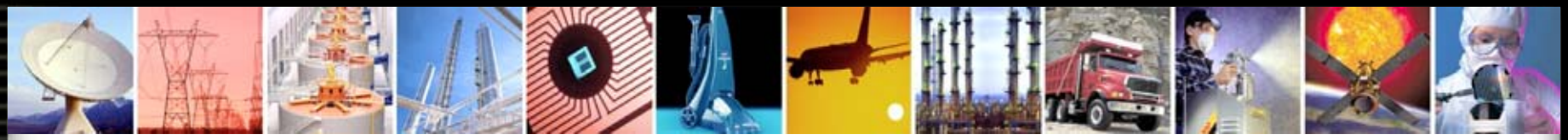
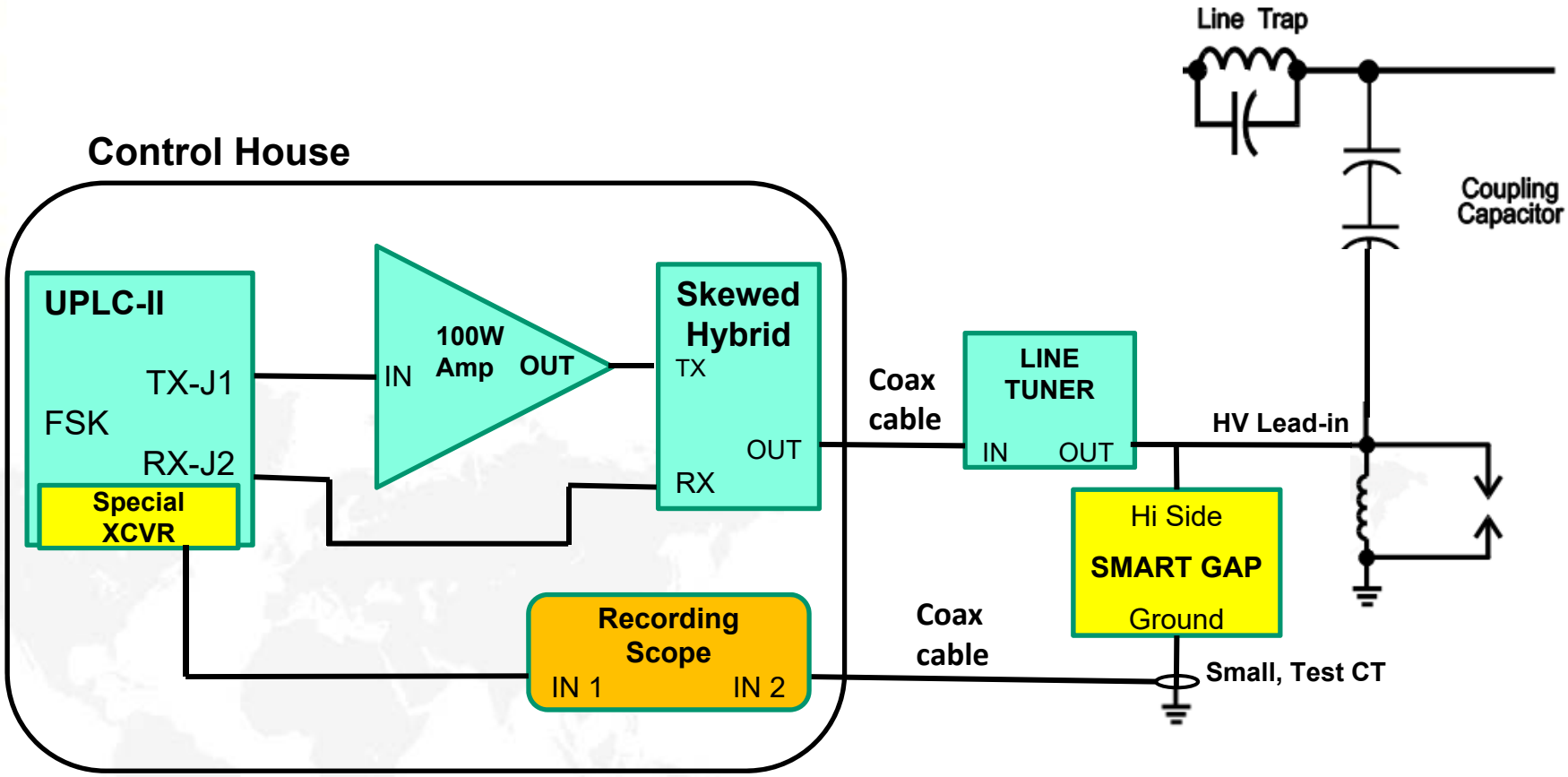


Field Test Set Up for Testing Carrier Holes



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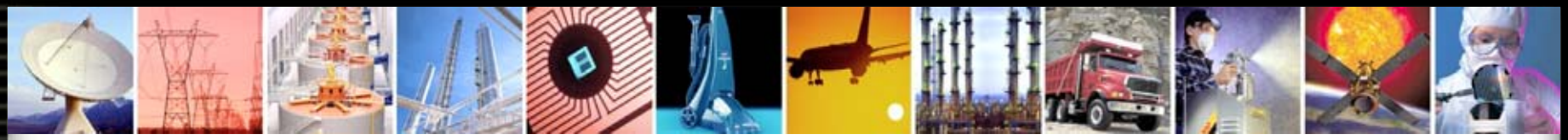
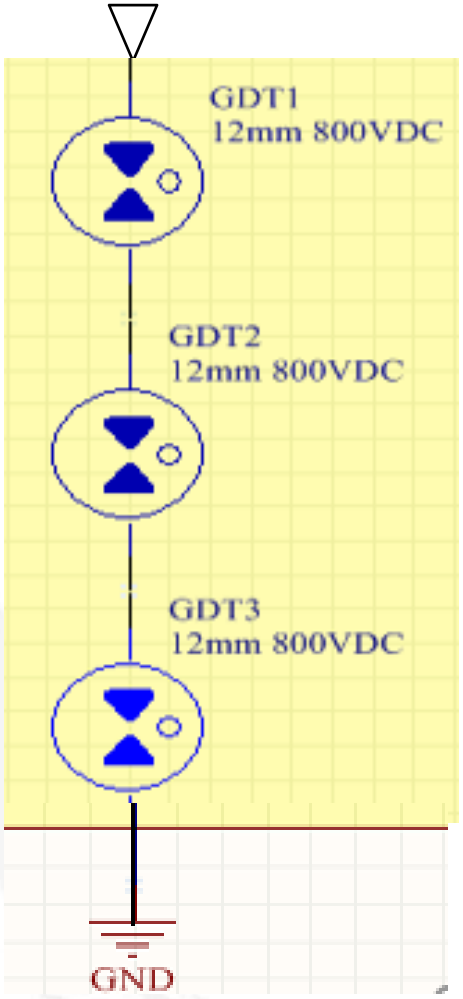


Carrier Holes Field Test Results

1. A field test was performed with surges created from opening a disconnect switch which revealed that a volley of surges will cause **all** gaps, in line tuner & CCVT, to fire even with a lower voltage smart gap.
2. To prevent carrier holes, the field test revealed the need for all gaps in the system to be properly spaced air gaps in good condition or they need be replaced with a Smart Gap.
3. The field test showed that a lower firing voltage gap could not prevent other higher voltage gaps that were electrically in parallel with it from firing.
4. UPLC-II SOEs showed many **loss of channel** events ranging from 3 – 13 msec with the standard gas tube gap in the CCVT or Line Tuner.

Ametek “Smart Gap”- Schematic

HV Lead-In from Line Tuner



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"Smart Gap"
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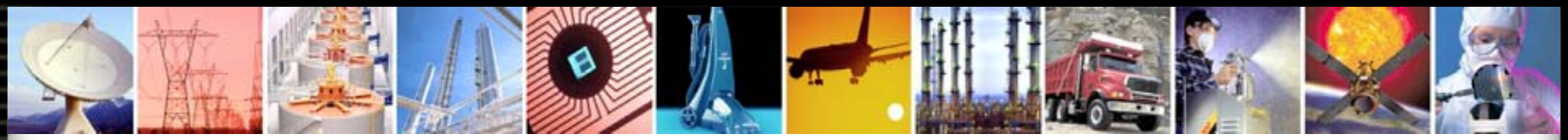

Carrier Holes Field Test Conclusions

1. In the field, our **smart gap prevented all carrier holes** for a 2 second volley of surges created by opening/closing a disconnect switch, as long other gas tubes gaps were not in the tuner or CCVT. This was supported by looking at a high speed RX output of the UPLC-II plus the lack of any SOEs occurring during the 2 second blast of surges.
2. Similarly properly set/maintained air gaps prevented carrier holes and only showed a single 1 msec single fade alarm SOE.
3. The **voltage transient from a real world fault** is probably not a 2 sec blast of transients from a disconnect switch opening/closing and neither is it a single 1.2 x 50 microsecond transient but probably is somewhere in between.
4. Final proof will come as utilities change their spark gaps and monitor the SOEs in their systems to verify no loss of carrier signal during faults.

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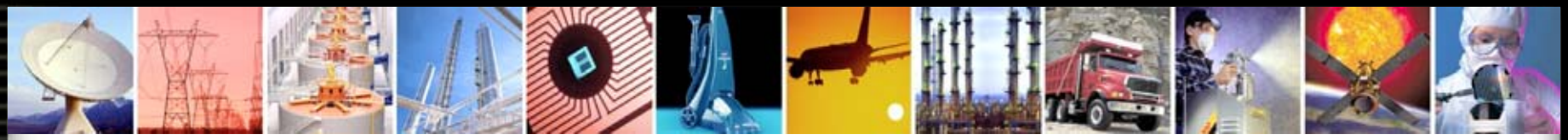
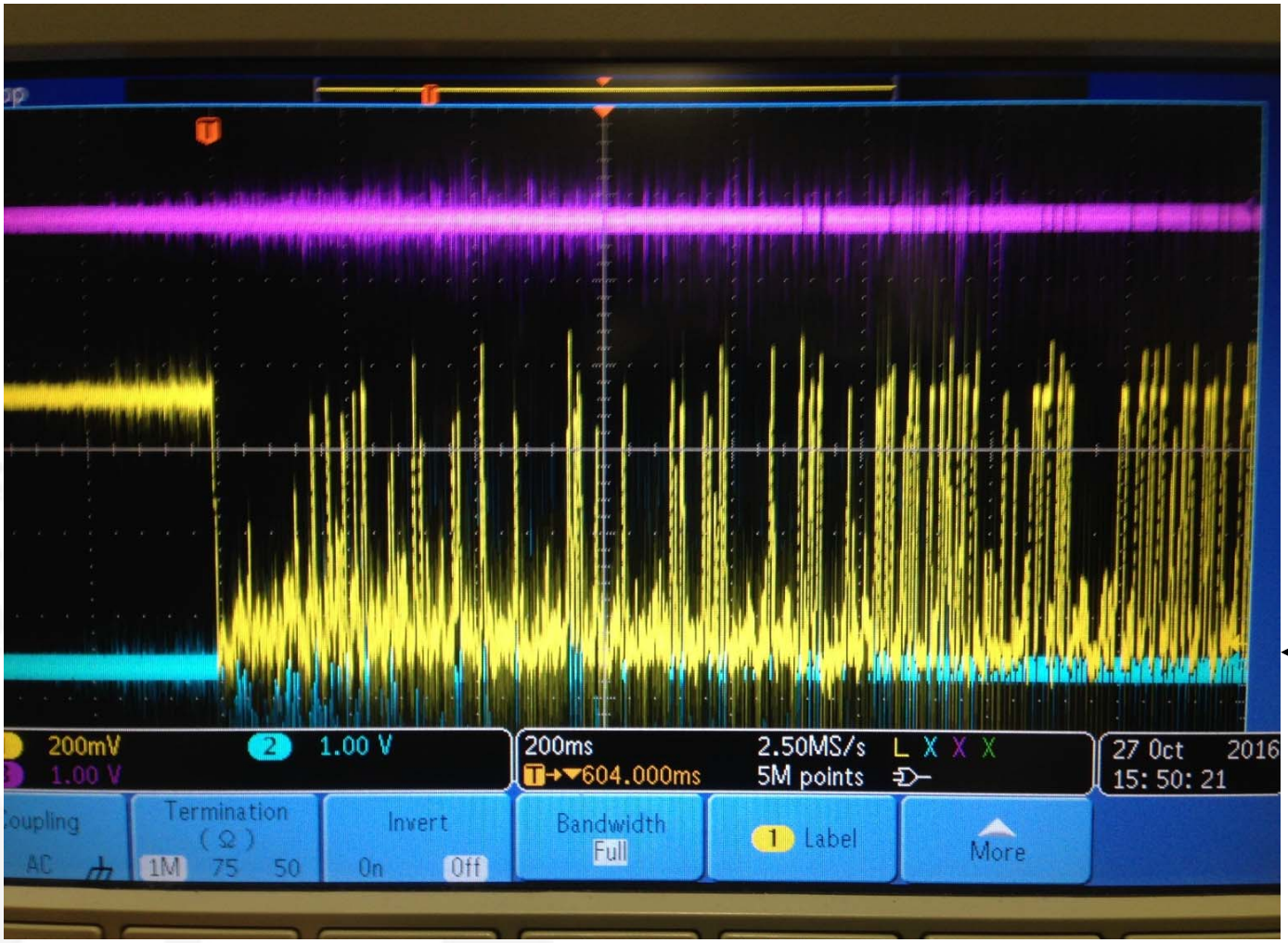


Field Test Results with Std CCVT Gas Tube Gap

Tuner air-gap current

RX level

CCVT Gas Tube gap current (blue)



RX level

15 dB signal fade margin

RX Drop-Out level

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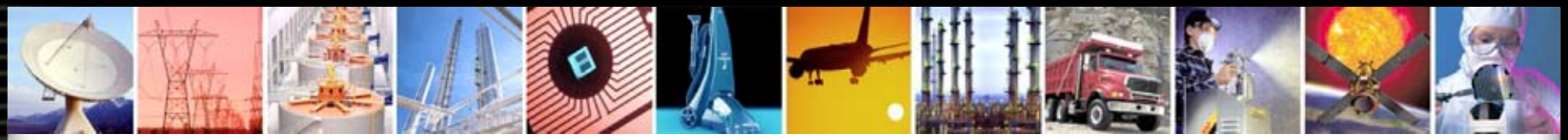
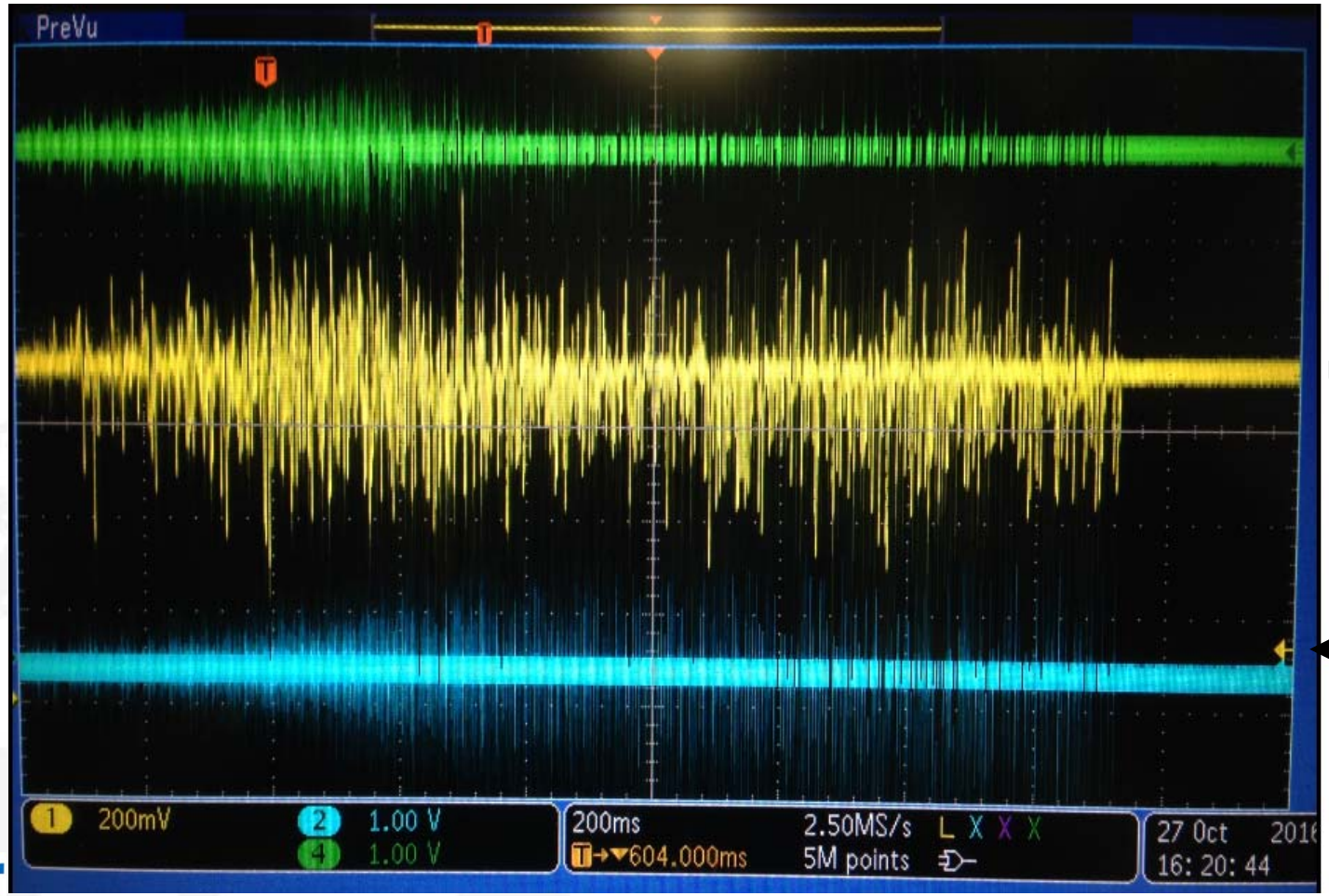


Field Test Results with Ametek Gap in CCVT

Ametek smart gap current

RX level

Tuner air-gap current



RX level

15 dB signal fade margin

RX Drop-Out level

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