# Mitigating Carrier Holes in Power Line Carrier

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***Abstract*— Carrier holes is loss of a power line carrier signal when it should be present during a fault resulting in a miss-operation. A study was performed to determine the dominant cause of unexplained carrier holes which has pointed to the extended firing time of spark gaps located in line tuners and CCVTs (Coupling Capacitor Voltage Transformers). Then lab tests and field tests were performed to simulate carrier holes caused by transients in typical pilot protection systems. Finally, the same tests were run with improved spark gaps and compared with significant improvements noted. Results are presented, and recommendations made to mitigate carrier holes.**

**Keywords— Carrier holes, PLC (power line carrier), spark gap, gas discharge tube**

## I. Introduction

For years, power line carrier has been plagued by the occasional unexplained loss of carrier signal which led to a miss-operation during a fault. These carrier signal losses have been labelled as "carrier holes". Carrier holes have caused miss-operations in protective relay systems resulting in over trips on DCB (directional comparison blocking) systems, delayed trips in POTT (permissive overreaching transfer trip) or DTT (direct transfer trip) systems, or false permission to trip in DCUB (directional comparison unblock) systems. Although the frequency of occurrence of carrier holes is low, the effort and time required to identify the source of them can be considerable. And often the result of the system testing yields the undesirable result of "no problem found" after completely testing the entire system.

## II. Possible causes of Carrier holes [1] [2]

Although there can be many causes of carrier holes, listed below is some of the more dominant ones.

### A. Spark Gaps Firing

Spark gaps located in line tuners and CCVTs protect these devices from being damaged when transients occur. However, while these gaps are firing they short the power line carrier signal to ground which disables the protection system's high-speed communications. (See figure 1.)

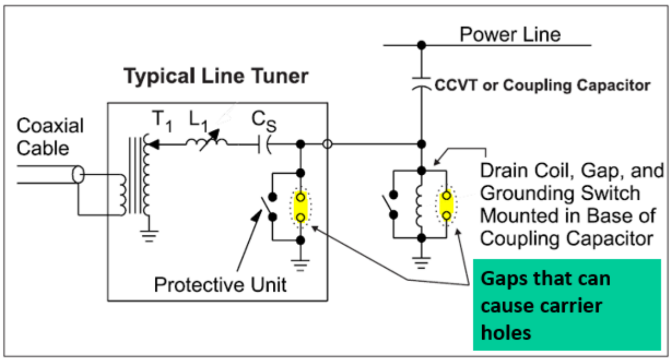


Fig. 1. Location of Spark Gaps in a Typical PLC Installation

### B. Coax Cable Flashover

Over time weather and rodents can deteriorate the heavy-duty coax cables that are run into the switch yard for connection to the line tuner. If the deterioration is such that there is a high voltage flashover from inner to outer conductor, the signal will be lost similar to a spark gap firing.

### C. Contact Bounce when Using Electromechanical Relays

Contacts can bounce when initiating a protective relaying keying operation to the PLC (power line carrier) terminal causing interruptions of the PLC signal. This especially true for normally open contacts that are closing to key the PLC in a DCB system.

### D. Improper Setting/Calibraton of PLC Receivers

User error in making wrong settings or improper calibration of the PLC receiver can have a significant impact on whether the PLC receiver will respond correctly.

## III. Existing methods to mitigate Carrier holes

### A. Spark Gaps Firing

Spark gaps located in line tuners and CCVTs come in two basic types: open air gaps or enclosed gas discharge tubes (GDT). Open air gaps should be maintained to prevent carrier holes by blowing away debris with forced air, cleaning/burnishing the gaps surface for any rough spots created by previous arcing, rotating the gap to a clean surface for some types, and then checking the gap for correct spacing with a feeler gauge. Gas discharge tubes must be replaced if they show signs of discoloration or they are suspected as being bad.

### *B. Coax Cable Flashover*

Coax cables can be “meggered” with a high voltage to check for any insulation issues. Various types of coax cables are available, some of which are more weather resistant than others. Jell-filled coax cables are available to help reduce the effects of water intrusion. Triax cables is another option.

### *C. Contact Bounce when Using Electromechanical Relays*

To reduce the effect of contact bounce, normally closed contacts that open can be used to key the PLC inputs as they tend to bounce less. Contact bounce is also much less with newer digital relays which often have solid state outputs.

### *D. Improper Setting/Calibraton of PLC Receivers*

Proper training of personnel can never be over emphasized. Also, many receivers used in DCB systems require calibration to the remote and local transmitter, which is a fact that can easily be overlooked causing miss-operation due to improper calibration.

### *E. Use of Delay/Hold Timers to Ride Through Carrier Holes*

The use of delay/hold timers obviously brings delay to the needed action by the protective relay system and this must be considered when considering this option for mitigating carrier holes. It has been shown to be an effective method but requires a judicious choice of the delay/hold time.

- DCB systems have had block extension timers added to the protective relay to ride through brief losses (1-10 msec) of a received blocking output from a PLC unit. Of course, the choice of how much time delay must be based on experience and will not cure the issue if the carrier hole is longer than the time delay. [3]
- DCUB systems have had delay timers added to delay the trip permission window on loss of channel that can occur during a spark gap firing, for example. Again, the choice of the time delay is based on experience. [4]

## IV. Spark Gaps – a Major Source of Carrier Holes

When a line-to-ground fault occurs on a transmission line, at the beginning of the fault it creates a transient which usually causes the spark gaps in line tuners and CCVTs to fire. It has been assumed that this firing time was insignificant and would only cause negligible delay to the power line carrier signal.

There are 2 main types of spark gaps used in line tuners and CCVTs: GDTs (gas discharge tubes) and air gaps. After, researching the common types of spark gaps, the conclusion was reached that typical GDTs had an important weakness in their application for power line carrier. This weakness was that, although they fired at a voltage above 4.5 kV (typical rating of a GDT in a line tuner or CCVT), they would continue to fire or hold-on for voltages less than 180 V. So even though these gaps could be in good condition, if there was enough voltage present from other sources besides the transient, then the gaps could continue to fire until the current finally dropped below a minimum level. Lab testing proved this could extend the clearing time of the gap by up to 20 msec all the while killing the PLC signal.

Air spark gaps inherently did not have this issue as long as they were properly maintained and their air gap spacing did not change with time. If the air gap became too narrow due to previous arcing distorting the surfaces, then testing showed extended clearing times of 2 msec and longer.

The two main sources of power that could keep a spark gap continuing to fire after the transient voltage had decayed include:

1. The PLC transmitter which can put out anywhere from 10 W to 100 W of carrier frequency power.
2. The residual 60 Hz voltage that comes through the CCVT and is kept at 30V maximum by the drain coil at the bottom of the CCVT capacitor stack. [5]

### *A. Lab Testing*

While varying these two power sources (mentioned above) in our lab testing, the results showed that as the voltage level of these two sources increased, then so did the probability of the occurrence of carrier holes. Carrier holes were defined in our testing as any loss of signal for > 2 msec. Figure 2 is a block diagram of the lab set up that was used.

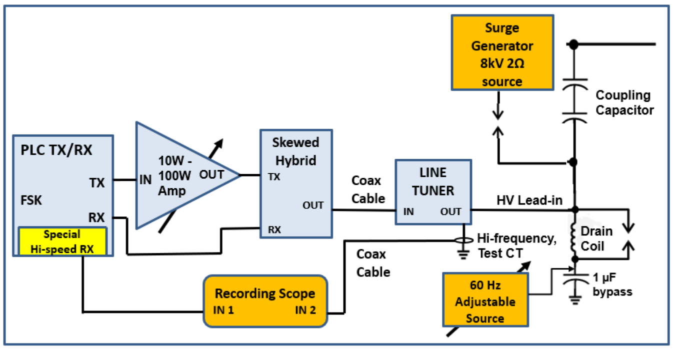


Fig. 2. Lab Setup for Spark Gap Testing for Carrier Holes

- Actual equipment used in the field was used for all devices except for the capacitor of the CCVT being simulated with a high voltage small capacitor and the power line simulated by a 300 Ω resistor.
- The hi-speed output of the PLC receiver was monitored for any loss of received output on one channel of an oscilloscope, with the other channel of the scope being triggered by surge current flowing through the spark gap in the line tuner which was monitored by a high frequency current transformer on the ground lead of the tuner spark gap. This setup was used to verify if the receive output of the PLC ever dropped out and if so, for how long.
- A single 1.2 x 50 microsec impulse of 4000 A of current (8 kV, 2 Ω surge generator) was applied about every 30 seconds through a series isolating air gap to prevent the surge generator from affecting the test setup. Tens of thousands of surges were applied.
- Test results showed that for worst-case conditions the standard GDT in the line tuner would stay firing from 2 – 20 msec after the surge for about 50% of all the surges that were applied.

- Lowering the voltage levels of the PLC transmit and the 60 Hz source reduced the percentage, but it still occurred.
- Carrier holes were also produced with an air gap in the line tuner, but only with the gap being "compromised" (set wrongly, damaged, or dirty).
- When the line tuner typical GDT was replaced by a properly spaced clean air gap or by a high-holding voltage GDT device the total arcing time of the gap decreased to less than 1 msec for 100% of the time for the same worst-case conditions and there was no loss of receiver output shown on the oscilloscope.

### B. *Field Testing*

The same test setup was replicated in the field on an actual PLC installation in a substation with similar results.

- The surge generator was removed, and a manual disconnect switch was opened and closed to produce transients while observing the oscilloscope and high-speed receiver output.
- With the standard GDTs in the line tuner and/or CCVT, there were many consistent losses of receiver output lasting from 3 – 13 msec for the approximate 2 second duration of the disconnect switch arc while being opened or closed.
- Both the line tuner and the CCVT had to have their spark gaps replaced with either properly spaced air gaps or high-holding voltage type of GDTs in order to stop all loss of receiver output.

## V. Conclusions

Although there are several causes of carrier holes in power line carrier, a dominant source that has not been properly mitigated has shown to be spark gaps. Present mitigation methods for carrier holes relating to spark gaps in line tuners and CCVTs is often inadequate. This is primarily due to the use of GDTs with low-holding voltage and secondarily due to GDTs and air gaps not being maintained on a regular basis. Better and significantly more robust spark gaps are now available in the market that solve these issues and should be considered. Transmission lines with particular issues due to unexplained carrier holes should have existing GDTs replaced with high-holding voltage GDTs or properly set/maintained air gaps. High-holding voltage GDTs do have the advantage of being sealed and not being affected by the environment and accidental miss-adjustment unlike air spark gaps.

## Acknowledgment

The author gratefully acknowledges the contributions of Jeff Brown of Georgia Transmission Company and Danny Worrell of Georgia Power Corporation for their participation in the field testing and the use of their substations. In addition, the efforts of the author's Ametek colleagues in testing and discussion had a significant impact on this paper.

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## Biography

Tony Bell is the Power Line Carrier Product Manager for Ametek Power Instruments/Pulsar Products. He is responsible for giving marketing/technical direction to all related activities for the product line and has worked in this position since 2011. He has worked with power line carrier in some capacity for his 37-year career, working previously for Pulsar Technologies, ABB, and Westinghouse Relay Instrument Division. He is a 1980 graduate of Georgia Tech and is active in the IEEE PSRCC and PSCCC groups.