# DELIVERY AND APPLICATION OF PRECISE TIMING FOR A TRAVELING WAVE POWERLINE FAULT LOCATOR SYSTEM

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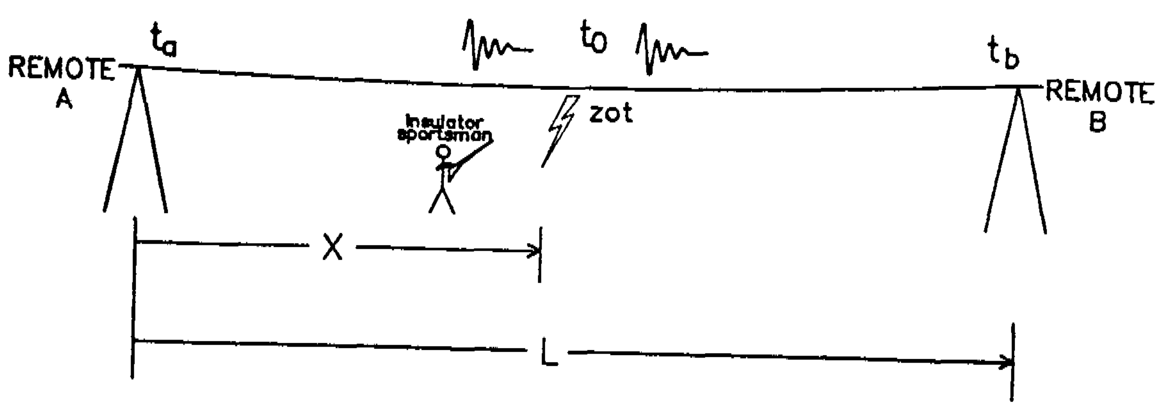
*Abstract*

***The Bonneville Power Administration has successfully operated an in–house developed powerline fault locator system since 1986. The BPA fault locator system consists of remotes installed at cardinal power transmission line system nodes and a central master which polls the remotes for traveling wave time–of–arrival data. A power line fault produces a fast rise–time traveling wave which emanates from the fault point and propagates throughout the power grid. The remotes time–tag the traveling wave leading edge as it passes through the power system cardinal substation nodes. A synchronizing pulse transmitted via the BPA analog microwave system on a wideband channel synchronizes the time–tagging counters in the remote units to a differential accuracy of better than one microsecond. The remote units correct the raw time tags for synchronizing pulse propagation delay and return these corrected values to the fault locator master. The master then calculates the power system disturbance source using the collected time tags. The system design objective is a fault location accuracy of 300 meters. This paper describes BPA's fault locator system operation, error producing phenomena and method of distributing precise timing.***

Figure 1 illustrates the basic principle of operation of the BPA fault locator system, which is known as the Fault Location Acquisition Reporter or FLAR system.




BASIC FAULT LOCATOR PRINCIPLE
FIGURE 1

Figure 1 illustrates a line of length L. A FLAR remote is coupled to each end of this line. A FLAR remote is actually a fancy electronic stopwatch. However, each remote timer is synchronized to a common timing standard. When a fault occurs at time to at a distance of X miles from an end of the line, the resulting arc (*ZOT!*) to ground or adjacent conductor causes transients with 2 to 10 microsecond leading edge rise–times to emanate from the fault point to the ends of the line at the finite velocity of 0.18628 miles per microsecond. The FLAR remotes time tag the transient arrival times to an accuracy of one microsecond. A microsecond time tagging accuracy will allow a fault location accuracy to as good as 1000 feet which is the typical distance between transmission line towers. By knowing the line length L and the time–of–arrival difference $(t_b - t_a)$, one can calculate the distance X, from the closest end by using the famous fault location equation:

$$X = \frac{[L - c \times (t_b - t_a)]}{2}$$

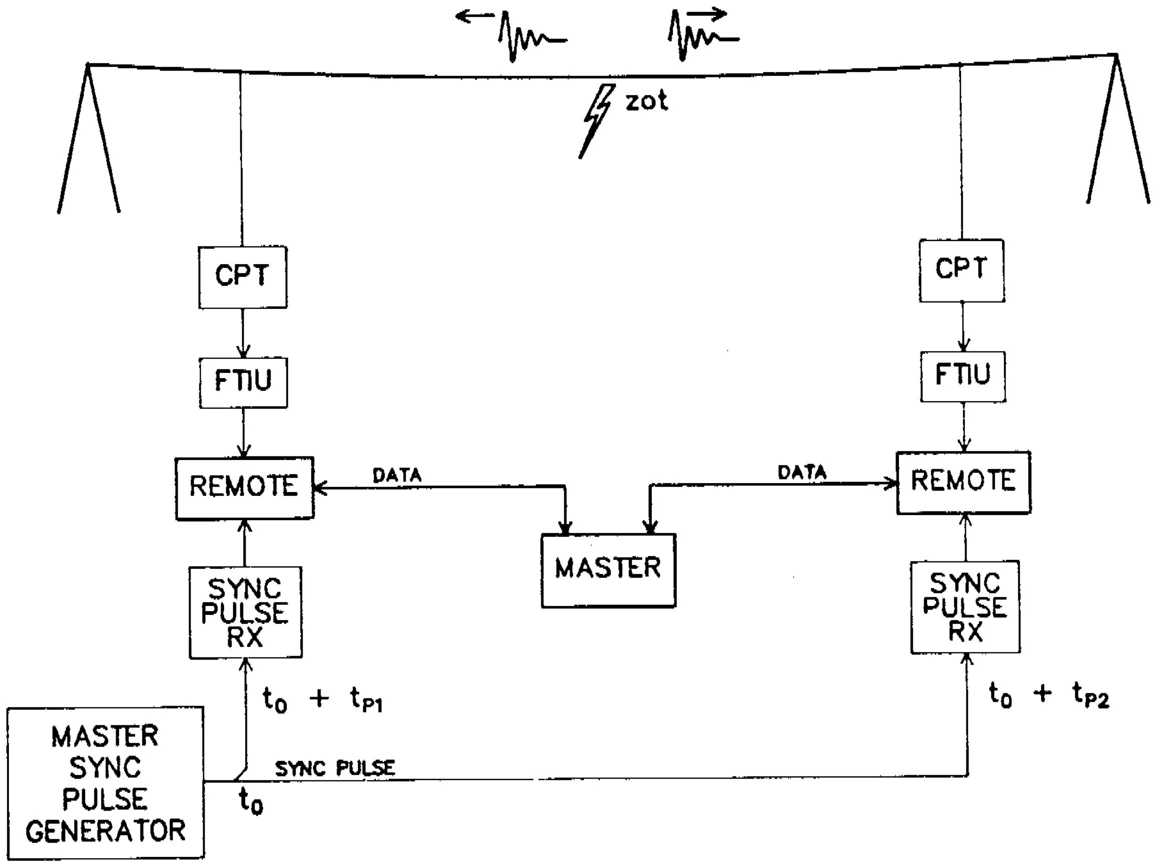
Where: $L$ = Line length
$c$ = Velocity of Propagation
= .18628 mi/usec
$t_a$ = End A arrival time
$t_b$ = End B arrival time

**FAMOUS FAULT LOCATION EQUATION**
**FIGURE 2**

Figure 3 shows a functional block diagram of the BPA fault locator system. The system master is located at the BPA Dittmer Control Center near Vancouver, Washington. Remotes are located at major nodes in a grid of 500 kV power transmission lines which cover the BPA service area of Oregon, Washington, Idaho and Western Montana. These nodes are called substations in the power utility business.

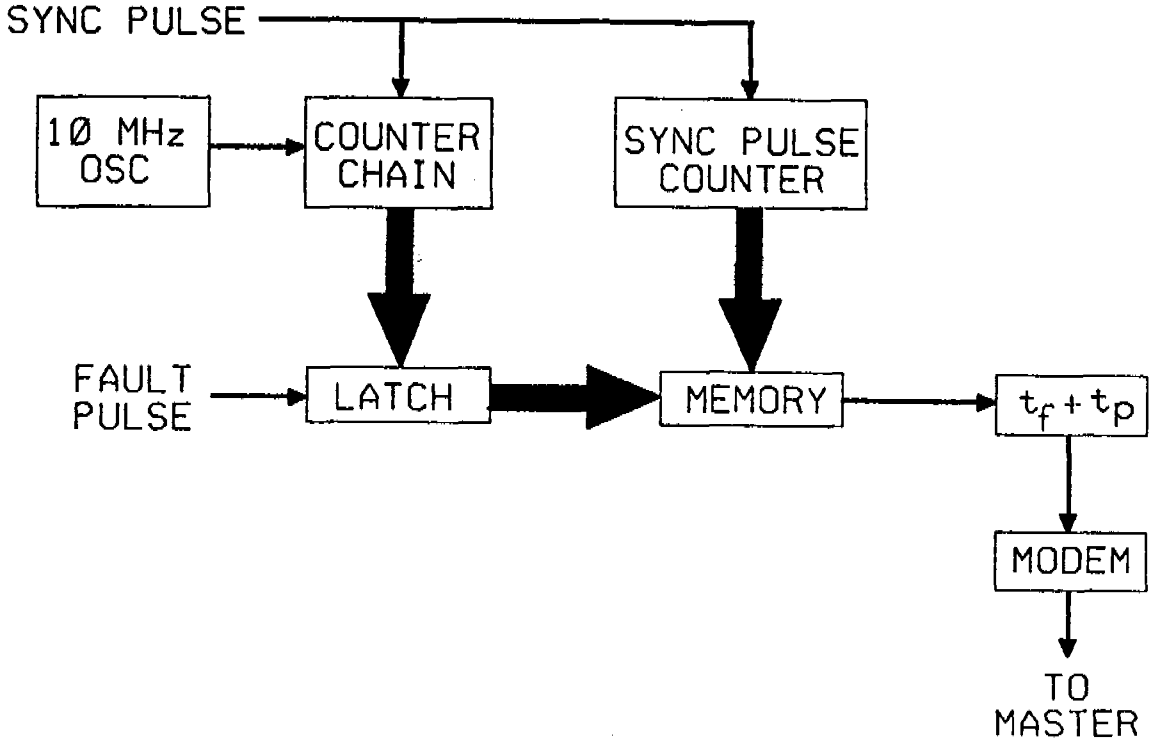
From the BPA Dittmer Control Center in Vancouver, Washington, 100 second period sync pulses, which synchronize each remote counter, are transmitted to the remotes via a wide bandwidth microwave channel on the BPA analog microwave network which covers the BPA service area.

At a substation equipped with a fault locator remote unit, fault pulses are coupled from the power lines to the fault locator remote via powerline coupling devices, known as Capacitive Potential Transformers (CPT). The CPT functions as an LC high pass filter which blocks 60 Hz energy, but passes the high frequency components of fault transients. The Fault Transient Interface Unit (FTIU) will accept transient pulses from up to three CPT's. When the FTIU detects a valid fault transient, it outputs a TTL pulse to the remote which time tags and stores the transient's arrival time. The Fault locator master retrieves the fault data by polling all remotes sequentially at the end of each 100 second period. The FLAR master then uses the transient arrival time data to calculate the fault location in response to operator commands.




**BPA FAULT LOCATOR SYSTEM BLOCK DIAGRAM**
**FIGURE 3**

Figure 4 illustrates a basic fault locator remote block diagram. The fault locator remote includes an accurate 10 MHz crystal oscillator. A divide–by–5 divider then produces a 2 MHz counter clock which drives a synchronous decade counter chain. This counter chain counts from 0 to 100 seconds in .5 microsecond increments. The counter is synchronized by the 100 second period sync pulses from the sync pulse receiver. This 0.01 Hz sync pulse train also acts as the reference frequency for an Electronic Frequency Control (EFC) loop which keeps the remote local oscillator locked to the master frequency reference from which the master sync pulse is derived. In normal operation, the counter will rollover from 99.999 999 5 seconds to zero at the same time a sync pulse is received. Re–starting the counter chain every 100 seconds minimizes accumulated time error while the local oscillator is acquiring lock. The master and all remotes also have a sync pulse counter which counts the sync periods since an absolute reference time. The master updates this reference time every three hours. A valid fault pulse received from the FTIU causes latches connected to the counter chain outputs to latch the instantaneous counter outputs. This stored count is the raw fault arrival time. The remote CPU then stores the raw fault time and corresponding sync pulse count in memory.




**BASIC FAULT LOCATOR REMOTE BLOCK DIAGRAM**
**FIGURE 4**

However, the remote counter time is delayed in respect to the master sync pulse time by the microwave free space propagation delay time ($t_p$) from the BPA control center to the remote site. Thus, the latched counter time must be corrected to master time by adding $t_p$ to the raw value before it is used to calculate a fault location. This is done in the FLAR system at each remote during the process of transmitting the raw fault times to the master at each polling time. The propagation time correction is done at the remotes rather than the master to facilitate the future design of a time code interface unit which will provide accurate time code output from the FLAR remote unit. The remote then calculates the actual transient arrival time by adding the latched counter value plus 100 times the sync pulse counter to the base absolute time.

## Sync Pulse Derivation

During the early years of the FLAR system, the master sync pulse was derived simply by dividing the output of a 10 MHz crystal oscillator by 109 to obtain the 100 second sync pulse period. Since the EFC loops in all the remotes caused all the remote local oscillators to track the master oscillator, the master oscillator drift requirements were not extremely tight. However, in 1987, BPA extended fault location coverage to a major power line which is jointly owned by BPA and The Montana Power Company. The far end of this line is not served by the BPA analog microwave system. Synchronizing the far end remote via the MPC digital microwave system did not prove successful.

Thus, BPA chose to use the Global Positioning System (GPS) as a timing source so that the BPA remotes and the remote at the MPC site were synchronized to a common timing source. Currently, the master sync pulse is supplied by a GPS timing receiver which is configured to output a sync pulse on the hour and every 100 seconds there after. This then allows an identical GPS receiver to synchronize the fault locator remote located at the isolated MPC substation.

### Sources of Fault Location Error

Fault location error results from three basic error sources:

| | |
|---|---|
| - Fault Detection Error | .5 to 5 microseconds |
| - Time Tagging Resolution | 0 to .5 microseconds |
| - Sync Pulse transmission Jitter | .15 to .35 microseconds |

**Fault Detection Error** – Fault detection error is, by far, the most significant error producing phenomenon. As a fault transient propagates along a transmission line, its amplitude decreases and rise–time increases. The FTIU employs a level comparator to detect that a significant disturbance has occurred. A transient with a longer rise–time will experience a longer delay through the FTIU than a faster rise–time transient. A transient which occurs near the center of the line sections between two remotes will have similar rise–times after propagating to those remote sites. Thus, the additional error will cancel when the arrival time difference is calculated. However, when the fault location occurs closer to one remote relative to the other, the residual error difference will increase and produce a location calculation error.

**Counter Resolution** — Detected faults are time–tagged by the synchronous counter which counts in steps of .5 microseconds. Obviously, fault transients are asynchronous to the remote clock, thus the remote adds from 0 to .5 microseconds of waiting time error to the time tagged value.

**Sync Pulse Jitter** — A remote counter chain is reset to zero by a sync pulse received via the BPA analog (FDM) microwave system. Because the sync pulse is transmitted in the presence of additive white gaussian noise (AWGN), a certain amount of timing error jitter will occur. The measured value of this jitter varies from .15 to .35 microseconds RMS and increases with increasing microwave circuit distance from the BPA control center.

## SUMMARY

The Bonneville Power Administration has successfully operated an in–house developed powerline fault locator system since 1986. This system has reduced the time required to find and repair power line outages. This translates into savings of both line maintenance personnel costs and lost power sales revenue. The BPA fault locator system consists of 23 remotes installed at cardinal power transmission line system nodes and a central master which polls the remotes for traveling wave time–of–arrival data. The remotes are fancy stopwatches which accurately time–tag disturbance arrival times to a microsecond level accuracy. An accurate sync pulse transmitted via the BPA analog microwave system synchronizes all remotes to a common timing reference. Future system plans include installing 15 additional remotes and developing a remote unit time code output interface to produce microsecond accurate time code for other substation time tagging requirements. The primary error sources are: Fault detection error, counter time tagging resolution and sync pulse transmission time jitter due to broadband noise.

# QUESTIONS AND ANSWERS

**Dr. Gernot Winkler, U. S. Naval Observatory:** Where do you get the number of 250 nanoseconds for the GPS receivers?

**Mr. Street:** That is the specified number that we got from the manufacturers. We are actually getting numbers larger than that in practise, measuring two receivers side by side in our laboratory.

**Dr. Winkler:** What receivers were they?

**Mr. Street:** I prefer not to give specific manufacturer names in a public forum. If you see me later, I can discuss it with you.