Hands On Relay School
2017
PLC
Teleprotection
The PLC uses the Power lines to transmit and receive signals from station to station. These signal handed off from protective relays (21, 50BF) and can be either from hard-wire connections (inputs to outputs) or Ethernet LAN per the IEC 61850 standard. It is well suited for standard and non-standard pilot protection schemes such as:

- Permissive Transfer Trip
- Direct Transfer Trip
- Blocking and Unblocking
Where does PLC fit???
PLC Channel

PLC Channel consist of three distinct parts:

1. The Terminal Assemblies
   • Transmitter, Receivers, Protective Relays

2. The Coupling Equipment
   • Line Tuner, Coupling Capacitor, Line Traps

3. The Transmission Line
   • Provides a Path

Figure 1—Diagram of a PLC channel
PLC System Puzzle

**Outside Station**
- Bus Section
- BUS ISOLATION (dB)
- Line Trap
- Breaker
- Underground Coax
- CCVT
- Coupling Cap
- Power line
- Line Tuner Unit

**Inside Station**
- Hybrids
- May or may not be used depending on application
- TX/RX PLC
- Flavors:
  - Transmitter and Receiver
  - Transmitter only
  - Receiver Only
- Hard wired or 61850
- Relay
- Flavors:
  - RFL
  - SEL
  - ABB
  - GE

To remote Terminal
Focus on the equipment and not the Power Line

Think of the Power Line just like the internet, a means of getting information from one place to another and back.
TERMS & DEFINITIONS

TWO BASIC TYPES OF PLC CARRIER EQUIPMENT

* SINGLE FUNCTION
One specific action performed:
EX:  Protective Relaying
     OR Voice
     OR Telemetering

* MULTI FUNCTION
Capable of handling several functions simultaneously:
EX:  Protective Relaying
     AND Voice, AND Telemetering, AND Tones, AND Data
Frequency of the Generated Power = **60 Hz**
Voltage Levels = 138KV, 345KV

PLC Freq. range 30 to 300 KHz
Millivolts to Volts, typically expressed in Watts i.e. 1Watt/10Watts/50Watts/100Watts
Using Frequencies to Communicate
On/Off vs. FSK

ON/OFF
Carrier
50Ω termination
1 W = 7.07 V
10 W = 22.3 V

FSK
99.9Khz/100Khz/100.100Khz
CF =100Khz
Shift= +/- 100Hz
Bandwidth = 200Hz

1 to 10 Watts
Power Line Carrier Technology

PLC Signal Types

• “AM” Keyed Carrier (On-Off)
  • Blocking/Unblocking

• “AM” Single Sideband Modulation
  • Data/Voice

• “FSK” Frequency Shift Keying
  • DTT/POTT
  • Blocking/Unblocking

125 Vdc
To Relay Contacts

125 Vdc
To Relay inputs or Lock-Out/Breaker coils
TERMS AND DEFINITIONS

PLC KEYED CARRIER
‘AM’ SPECIAL CASE

- CARRIER NORMALLY OFF
- TRANSMIT INTELLIGENCE BY TURNING CARRIER ON

Turning it On or Off is:
Commonly called “Keying”

FUNCTIONAL USE FOR
BLOCKING TYPE RELAYING SYSTEM
ON/OFF SIGNALLING AND CHECKBACK

EQUIPMENT EXAMPLES
RFL 6785P and 9785 Guard, Ametek UPLC

SPECTRUM USE: DEPENDS ON RECEIVER BANDWIDTH (SPEED)
TERMS AND DEFINITIONS

FREQUENCY SHIFT KEYING
- CARRIER ALWAYS ON
- CARRIER SHIFTS UP (HIGHER) AND DOWN (LOWER)

Energizing an input to shift the Frequency is:
Commonly called “Keying”

Trip
Guard

determined by
Shift direction

100Khz
+/- 100Hz

Guard
Trip

Single Functions
Multi-Functions

FUNCTIONAL USE
- 2 FREQ TRANSFER TRIP
  TELEMETERING & SCADA
- 3 FREQ TRANSMIT KWHR READINGS
  LOAD CONTROL — RAISE-LOWER-HOLD
  DUAL PHASE COMPARISON

AMPLITUDE

FREQUENCY

TIME
Table 2-1. Minimum permissible channel spacings and delays times, RFL 9785 Programmable ON/OFF Powerline Carrier System

<table>
<thead>
<tr>
<th>Nominal Bandwidth</th>
<th>Delay</th>
<th>Channel Spacing w/voice</th>
<th>Channel Spacing w/o Voice</th>
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</thead>
<tbody>
<tr>
<td>500 Hz</td>
<td>5 ms</td>
<td>4 KHz</td>
<td>1 KHz</td>
</tr>
<tr>
<td>1000 Hz</td>
<td>3 ms</td>
<td>4 kHz</td>
<td>2 kHz</td>
</tr>
<tr>
<td>1500 Hz</td>
<td>1.5 ms</td>
<td>4 kHz</td>
<td>3 kHz</td>
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Table 3. Minimum permissible channel spacings and delay times.

<table>
<thead>
<tr>
<th>Frequency Shift ±Hz</th>
<th>Nominal Bandwidth</th>
<th>Delay Time</th>
<th>Unidirectional Channel Spacing</th>
<th>Bi-Directional Channel Spacing</th>
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</thead>
<tbody>
<tr>
<td>100 Hz</td>
<td>200 Hz</td>
<td>12 ms</td>
<td>500 Hz</td>
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<td>250 Hz</td>
<td>500 Hz</td>
<td>7 ms</td>
<td>1250 Hz</td>
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<tr>
<td>500 Hz</td>
<td>1000 Hz</td>
<td>5 ms</td>
<td>2500 Hz</td>
<td>5000 Hz</td>
</tr>
</tbody>
</table>

a. Unidirectional system (500-Hz minimum spacing, 100 Hz shift)
b. Bidirectional system (1000-Hz minimum spacing, 100 Hz shift)
PLC Terms

**GUARD Freq**
The Frequency sent from terminal to terminal all the time during the quiescent state of the power system.

**TRIP Freq**
The Frequency sent from terminal to terminal during the faulted state of the power system.

**Keying**
A term use when wetting voltage is applied to the input designated as the ‘Trip Key’ this will cause the frequency to shift from Guard tone to Trip tone.

**FSVM**
The frequency selective level meter (SLM) is a meter designed to measure the signal level of individual frequencies from 5 Hz to 5 MHz.
Typical levels are measured or recorded in dBms.

**Nominal Level**
A signal level which sets the receive level so that it represents 0 dBm and defines the parameters of the dynamic range.

**2-Wire**
Single coax to LTU

**4-Wire**
Multiple path for TX and RX via Hybrid
PLC Signal Levels

Voltage/Watts

• Typical On/Off = 10W/40dBm/22.3V @50Ω
  – Reserve keying = 1W/30dBm/7.07V @50Ω
    • Check-Back = 1W/10W

• Typical FSK =
  – 1W/30dBm/7.07V @50Ω Guard
  – 10W/40dBm/22.3V @50Ω Trip
On/Off Signals Levels

1W/30dBm/7.07V @50Ω

1W/30dBm/7.07V @50Ω

10W/40dBm/22.3V @50Ω

10W/40dBm/22.3V @50Ω
Guard and Trip Frequencies

Frequencies 30 To 300KHz

Guard & Trip

Shift Down Channel

Voltage Amplitude
Or Level
Typically measured
In dBm

Un-Keyed to Keyed
Vice-versa

100Khz
+/- 100Hz
Guard and Trip levels

Channel is defined as:

- **F0=100Khz**
- **BW=200Hz**
- **SH = +/- 100Hz**
- **Power =1W/10W**

- **Un-Keyed**
  - Guard: 1W/30dBm/7.07V @50Ω
  - Trip: 10W/40dBm/22.3V @50Ω

- **Keyed**
  - Guard: 10W/30dBm/7.07V @50Ω
  - Trip: 99.9Khz
RX DET
Operating Range & Dynamic Range
Nominal Level

Maximum receiver sensitivity 25 Vrms

Rx AGC Setpoint setting – Sets headroom in analog portion of receiver. Set to 30 dB.

Nominal Trip Level (Boost) +10 dB

Nominal Guard Level 0 dB

Dynamic Range

Receiver Operating Range

Signal Dropout Alarm (FSK only) Sets alarm point

Min Rx Level Setting On/Off = -15dB / FSK = -11dB
For On/Off, determines the minimum level of signal detection
For FSK, determines max inst. drop from Nominal to Trip

FSK Trip Rx Threshold (FSK Only) Absolute minimum level required to trip. Recommended setting 25 dB (Range 0 dB to 100 dB)

Minimum receiver sensitivity 5 mVrms

Signal to Noise Alarm (FSK Only) Issues an alarm, and disables tripping for noise levels exceeding the ratio setting.
Recommend setting 10dB. (0dB to 100dB range).
Power Line Carrier Technology

Terms and Definitions

**dB**
*Logarithmic ratio of powers
*Express ‘gain’ or ‘loss’ without reference to absolute quantities.

**dBm**
...A unit of POWER

**ORIGIN:** Originally used as a standard for telephone circuits,
1 mw is the reference standard

**DEFINED AS:**
0 dBm = .001 WATT = 1mW

Have been used to mean the same thing

“Field Slang”
dBm . . . A unit of POWER

ORIGIN: Originally used as a standard for telephone circuits, 1 mw is the reference standard

DEFINED AS: \[ \text{dBm} = 10 \log_{10} \frac{\text{Power}}{1 \text{ mw}} \]

0 dBm = .001 WATT = 1mW

\[ \frac{10 \text{ Watts}}{1 \text{ mw}} = 10,000 \log \text{ of } 10,000 = 4 \times 10 = 40 \text{ dBm} \]

- 1 Watt = 30 dBm
- 10 Watts = 40 dBm
Test Equipment

FSVM

*Frequency Selective Volt Meter*

- Signal Crafters Model 110
- PowerCom Model PCA 4125
1.1 Instrument Functions

The following is a list of the different instrument functions that the PCA-4125 offers:

- Signal Generator
- Frequency Selective Voltmeter (RMS Voltmeter)
- Impedance Analyzer
- VSWR Meter
- Frequency Response Analyzer
- Oscilloscope
- LCR Meter Inductance, Capacitance, Resistance Measurements
- Bit Error Rate (BER)

1.4 Power Line Carrier Applications

- Power Line Carrier Alignment & Maintenance
- Line Trap Testing
- Line Tuner Testing
- PLC Transmitter & Receiver Test & Set-up
- Audio Tone Protection Relay Channel Test & Setting
The Model 630 line simulation test box is used to simulate coupling a Power Line Carrier (PLC) to a transmission line. This simulation allows the technician to preset new installations or test the line tuner to determine if it is working correctly. The line simulation test box may also be used to troubleshoot line tuner problems.

The Model 560 was designed to aid the technician in this very challenge by providing a simple hardware interface for validating test instrumentation settings and connections.
The Model 110 (M110) is a multi-function instrument for measuring voltage levels at frequencies in the range of 50 Hz to 5 MHz (FSVM) and incorporates a signal generator operational over the same frequencies.
RECAP

• PLC can be used as a Communication Path for Relay with no on board communications
  Channel/PLC has Intelligents

• Typically PLC equipment will function in Single function mode, but can be multiple function

• There are two modes normally used are:
  • 1.) FSK mode
  • 2.) On/Off

• The Frequencies range from 30 to 300 KHz

• The voltage levels Range from 1 Watt (30 dBm) to 10 Watts (40 dBm) but can be
  up to 50 (47dBm) or 100 Watts (50dBm)

• The Nominal Signal level is a reference level which indicates the actual receive level
  and sets the Dynamic range.

• A dB is a ratio of one signal level to another

• A dBm is a unit of measurement referenced to 1 mw or 0 dBm

• The Test equipment used to measure the signal level is a FSVM
PLC Equipment
RFL

3U GARD Pro PLC

6U GARD Pro PLC
3U GARD Pro PLC

6U GARD Pro PLC

FRONT VIEW OF CHASSIS
FRONT PANEL REMOVED
3U GARD Pro PLC

6U GARD Pro PLC
RFL 9780 FSK

RFL 9785 ON/OFF
RFL 9780 TX/RX

RFL 9785 On/Off
UPLC
Ametek
PLC System Puzzle

Outside Station
- Power line
- CCVT Coupling Cap
- Underground Coax
- Line Trap
- Breaker
- Line Tuner Unit

Inside Station
- Hybrids?
- TX/RX PLC
- Relay Connections
- Relay

Bus

To remote Terminal

May or may not be used depending on application
Relay Connections

• Hard Wired
  – Relay Output to PLC Input

  ![Diagram of Relay Connections]

Station Batt., (+)

Station Batt., (-)

SEL 321

9780 FSK PLC

SEL 321 Rear Panel Diagrams

SEE INSERT A
 Relay Connections

- **61850**
  - Ethernet to Ethernet
• So the Relay sends a signal to the PLC

• Then what happens?

• Let’s follow the Signal path of the TX and RX
**Signal Path**

**G8K TX/RX**

- **Develop Signal @ desired Frequency**
  - Transmitter

- **Amplify Signal**
  - Power Amp

- **Filter for Harmonics**
  - Output Filter

- **Combine TX with RX send to LTU**
  - Skewed Hybrid

- **RX** received and sent to the Transceiver module for processing
  - Levels etc. are viewed via software
G8K Block Diagram FSK

Figure 10-1. GARD 8000 PLC FSK Block Diagram

Relay Connections
Figure 10-3. GARD 8000 PLC On/Off Block Diagram
Signal path for 9780

**TX**
- Develop Signal @ desired Frequency
  - Transmitter
- Amplify Signal
  - Power Amp
- Filter for Harmonics
  - Output Filter

- Combine TX with RX send to LTU
  - Skewed Hybrid

**RX**
- Interface between the Input
  - RF Interface
- Incoming RF signals/shifted down to 4kHz
  - IF/BF
- Narrowband Filter/Signal monitoring circuit/Signal level indicator
  - CLI
- Carrier Envelope Detector/Filter, Frequency Discriminator
  - Limiter/Slicer
Output signal
Levels for 10 Watt system

• TX Levels
  
  * Most system are 1 Watt/10 Watt
    
    – On/Off
      
      • Blocking/Un-Blocking
        
        – Full Power = 10 Watts or ? dBm
        
        – Reduced Power = 1 Watt or ? dBm

    – FSK
      
      • Guard
        
        – 30 dBm or ? Watts
        
        – Could be higher

      • Trip
        
        – 40 dbm or ? Watts
Termination

• TX
  – Typically (almost always) 50Ω

• RX
  – Typically (almost always) 50Ω
  – Occasionally 75Ω

• SCE who measures all Audio at 600Ω
  – Not incorrect if you always use 600Ω
  – Just change the reading on the meter.
What Frequency/Frequencies or should we measure?

FSVW Bridged @ 50Ω
What Frequency/Frequencies or should we measure?

LTU

FSVW Bridged @ 50Ω
2-Wire vs. 4-Wire

To LTU or Hyb & From LTU from Hyb
2-Wire vs. 4-Wire
PLC System Puzzle

**Outside Station**
- Bus
- Line Trap
- Breaker
- Line Tuner Unit
- Power line
- CCVT Coupling Cap
- Underground Coax

**Inside Station**
- Hybrids ?
- Hybrids and what the Do for Us
- TX/RX PLC
- Relay

To remote Terminal
RF HYBRIDS
Auxiliary Coupling Devices
Why Use Them?

To Minimize
- Intermodulation
- Loading Influences

Function
- For Equipment Separation (TX/TX or TX/RX)
- For Channel Separation (F1, F2, F3)

Types
- Band Pass Filter: 0.5 dB Insertion Loss
- Series L/C Unit: 1.5 dB Insertion Loss
- Resistive Hybrid: 3.5 dB Insertion Loss
- Skewed Hybrid: 0.3/12.5 dB Insertion Loss
RF HYBRIDS

Balanced Resistive Hybrid

Balanced Reactive Hybrid

Skewed Hybrid
RF HYBRIDS

RULES:

1. INPUT TO ANY PORT IS SPLIT AND APPEARS AT THE ADJACENT TWO PORTS
2. DUMMY LOAD IMPEDANCE MUST BE ADJUSTED TO “BALANCE” PORT 2 IMPEDANCE
3. NO OUTPUT APPEARS AT THE OPPOSITE PORT.
Transformer Hybrid
Provides isolation between the two Transmitters

Adjustment Procedure

1. Measure and record the level of the transmitter No. 1
2. Measure and record the level of the transmitter No. 2

The 97 PLC Transformer Hybrid presents 3.5 dB of loss in either transmitting port, The hybrid provides greater than 25 dB of trans-hybrid loss when operating into the specified output impedance.
Skewed Hybrid
Provides isolation between transmitters and receivers

The Skewed Hybrid presents 0.5 dB of loss in the transmitting path, and 13.5 dB of loss in the receiver path. Hybrids can provide greater than 40 dB of Trans-hybrid loss when operating into the specified output impedance.

Adjustment Procedure

1. Measure and record the transmitter level at the transmitter port.
2. Measure and record the level of the transmitter frequency at the receiver port.

TX 1 = 10 Watts @ output
RX 1 = +3 dBm@ Input what would it Be before the SK Hyb

If measured here What would the TX level in dBm be?
MULTIPLEXING WITH HYBRIDS
2 Transmitters + 2 Receivers

What would be the value of the TX level @ the point between the LTU and the SK
TX 1 & 2 = 1 Watt @ output
What would be the best setting for termination of two RX on one line?

RX 1 & 2 = 7 dBm @ input
What is the value of the RX level @ the point between the LTU and the SK

z=?

50Ω

R

z=?

50Ω

50Ω

50Ω

50Ω
Line Tuners

Functions......Why?

- Couple Carrier with minimum loss
- Isolate Power Frequency
- Separate Carrier Signals (sometimes)
Single Frequency Line Tuner

- Trap
- Transmission Line
- Coupling Capacitor ($X_c$ @ $f_0$)
- Grounding Switch
- Surge Arrester
- Optional Drain Coil
- 60 Hz Blocking Capacitor
- Adjustable Inductance
- Impedance Matching Transformer

- Tuner Cabinet
- Line Side = $?\Omega$
- Equipment Side = $?\Omega$

To/From PLC Terminal
<table>
<thead>
<tr>
<th>C (nF)</th>
<th>Fc (kHz)</th>
<th>Equipment-side jumpers</th>
<th>Line-side jumpers</th>
<th>Fc (kHz)</th>
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</table>

Table 3 (Cont.)  Available cut-off frequencies for the high-pass tuning circuit
Impedance Matching Transformer

To Coupling Capacitor

Tune to pass F1

Tune to block F2

Impedance Matching Transformer

Frequency 1

Frequency 2

Tune to block F1

Tune to pass F2

Impedance Matching Transformer

Frequency Separation

30 – 200 kHz.
25% of higher freq. (25kHz. Min)

200 – 500 kHz.
40% of higher freq.
PLC System Puzzle

Outside Station
- Power line
- Line Trap
- Bus
- CCVT Coupling Cap
- Underground Coax? RG 8 or RG 213
- Bus Isolation (dB)
- Line Tuner Unit

Inside Station
- Hybrids?
- TX/RX PLC
- Relay

To remote Terminal

Bus

Inside Station

Outside Station
COUPLING CAPACITORS

COUPLING CAPACITOR

VOLTAGE TRANSFORMERS
COUPLING CAPACITORS

• The coupling capacitor operates with the line tuner to form a resonant, or bandpass filter at the carrier frequency.

• Higher values of coupling capacitance provide greater RF bandwidth.
COUPLING CAPACITORS

- The coupling capacitor, and drain coil form a frequency dependent voltage divider.
PLC System Puzzle

Outside Station
- Power line
- CCVT Coupling Cap
- Line Trap
- Breaker
- Underground Coax
- Line Tuner Unit

Inside Station
- TX/RX PLC
- Relay
- Flavors: Transmitter and Receiver, Transmitter only, Receiver Only
- Hybrids?
- May or may not be used depending on application

Hard wired or 61850

Bus

To remote Terminal
LINE TRAPS
“THE THREE BASICS”

1. A line trap must provide high impedance at carrier frequencies and negligible impedance at the power frequency.

2. A line trap must be designed to operate at rated continuous current and insure long life (operating temperature vs. materials capability).

3. A line trap must be designed to withstand forces resulting from power short circuit forces and transient overvoltages.
Basic Line Traps

• Single Frequency Traps

• Two Frequency Traps

• Fixed Wide Band Traps

• Adjustable Wide Band Traps
Single Frequency Line Trap

• Tuning range defined as the band of frequencies over which the impedance magnitude is greater than 400 Ω.

• Tuning range is greater with larger inductance.

• Typically less than 0.5mh inductance, 0.265mh very common.
Single Frequency Line Trap

Single Frequency Resonant Trap

Trap Bandwidth @ 400Ω

Impedance

Frequency

F1 F2 F0

Single Frequency Trap
Two Frequency Traps

• Has a blocking band around two distinct resonant peaks.

• Typically used with two frequency line tuner.

• Requires 25kHz. frequency separation, or 25% of the higher frequency, whichever is greater.
Two Frequency Line Trap

![Diagram of Two Frequency Line Trap]

Trap Bandwidth
@ 400Ω

Dual Frequency Trap
Adjustable Wideband Traps

• Consists of a inductance coil, and a field adjustable tuning pack.

• Typical coil inductance range 0.265 to 1.59mh.

• Uses same bandwidth formula as fixed wideband trap.

• Typical terminating resistance 400, 600, or 1,000 Ω
Adjustable Wideband Traps

Trap Bandwidth @ 100 W @ 400Ω

Field Adjustable Wideband Trap
ADJUSTABLE WIDEBAND

GREATER BANDWIDTH AT HIGHER FREQUENCIES

\[ f_1 = \text{LOWER FREQ.} \]
\[ f_2 = \text{HIGHER FREQ.} \]
\[ f_0 = \sqrt{f_1 \times f_2} = \text{GMF} \]

\[ \text{B.W.} \approx f_0^2 \]
\[ \text{B.W.} \approx \frac{L}{\text{(IND.)}} \]
PLC Losses

- Transmitter frequency
- Type of line construction
- Line geometry
- Phase conductor size,
- Material, surface, condition, etc.
- Ground wire size,
- material, location, etc.
- Method of coupling Type and location of transpositions
- Weather conditions
- Ground conductivity
- Insulator leakage
PLC Losses
IEEE Std 643-2004

• Losses on the line are due lengths and weather conditions
  – A single transposition in a very long line can result in 6 dB of added loss.
  – Typically for a 100 mile 10 to 20 dBm

• Coupling losses are minimal and mostly due to tuning

• Hybrids have fixed losses
  – R (X) Hybrid 3.5 dBm per port
  – Skewed Hybrid TX= .5 dBm/RX = 12 dBm
Let’s Review.

• What Applications can the PLC be used?
• What is the Communication link for the PLC?
• What is the Difference between On/OFF and FSK?
• What is a FSVM? Why do we use this?
• What is the difference between dB and dBm?
• 30 dBm =? W  40dBm=? W
• What is the Nominal RX level?
• What is the Guard Signal used for?
Let’s Review.

• What is the Trip Signal used for?
• How does the Trip Signal become active?
• What is the Typical Termination value?
• What is a X or Resistive Hybrid used for?
• What is a Skewed Hybrid used for?
• What is the Line Tuner purpose?
• What is the Coupling Capacitors purpose?
• Why do we need a Line Trap?
• What is 2 + 2?