# Tests & Measurement in Power Utilities




IEC 61850 is a Power Grid a standard was that defines a set of Ethernet-based protocols to be used by power devices to exchange data, send commands, measure values and get synchronized

ALBEDO Telecom

# ALBEDO a global manufacturer of Testers & Timing appliances


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# Abstract

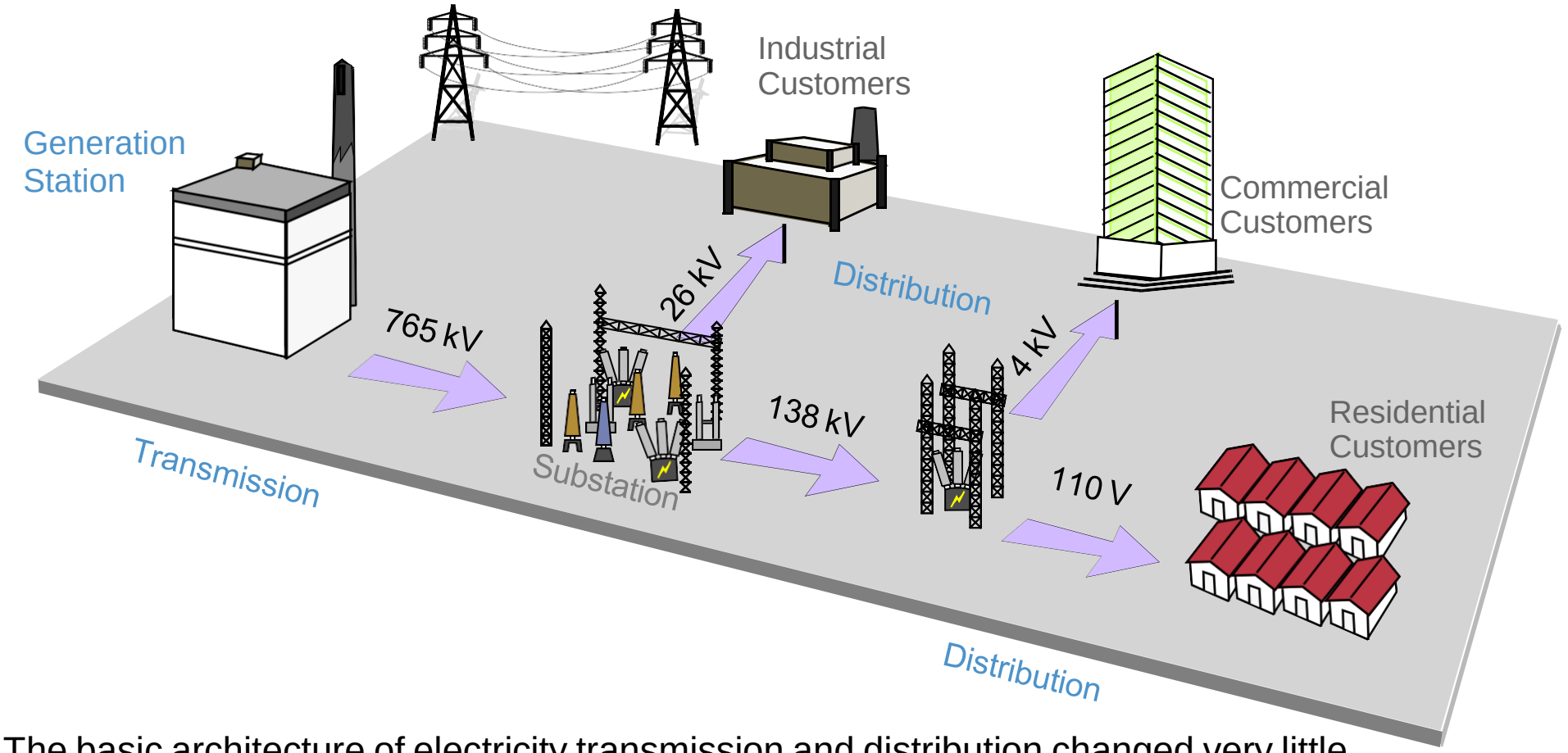


As result of the convergence process in the **Power Grid,** a new standard was released, the **IEC 61850**, that defines a set of Ethernet-based protocols.

The IEC 61850 objective is to facilitate the interoperability (between devices and systems), ease of configuration (allocation of functions to devices), long term stability (layered, object-model based design), and reliability (lossless network architectures) to replace wire communications.

# The **Power Grid**

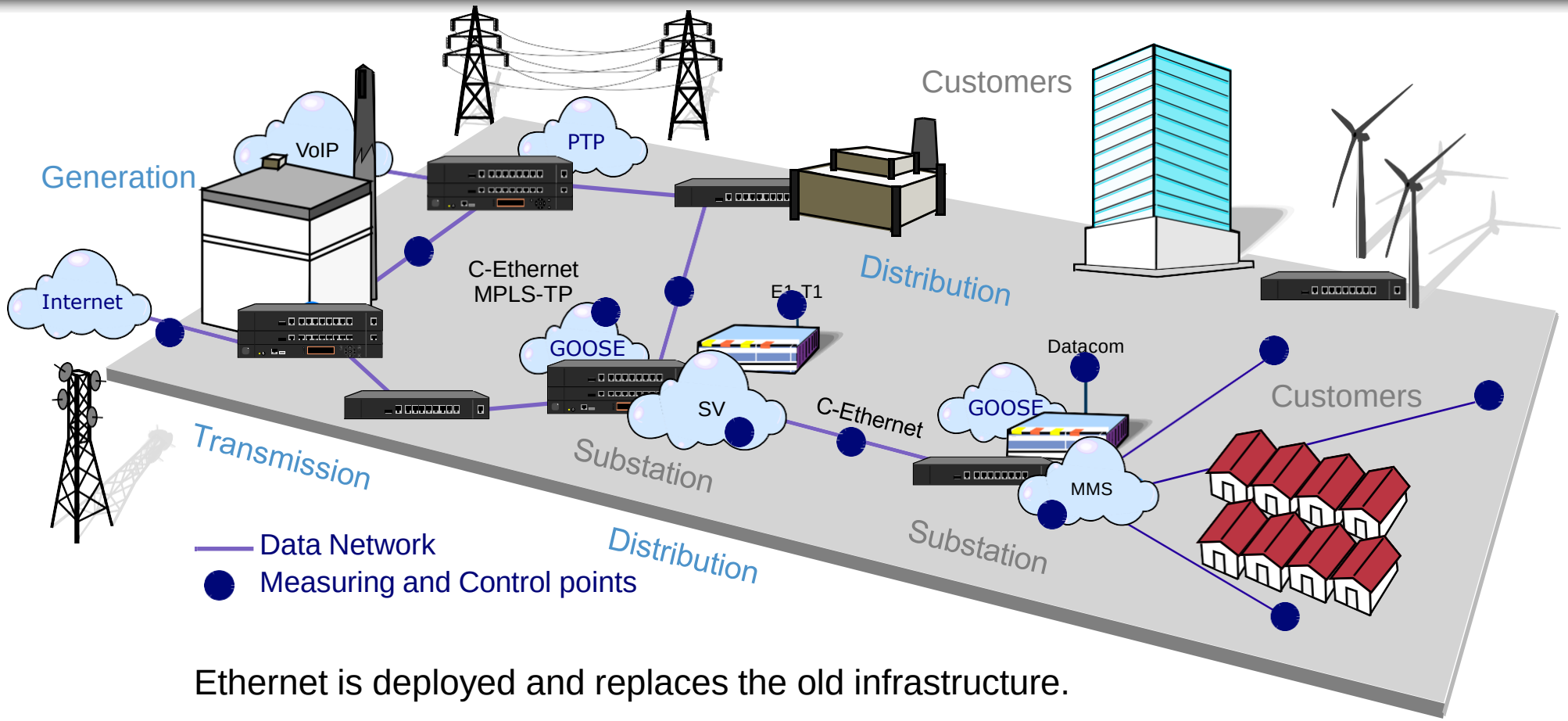





The basic architecture of electricity transmission and distribution changed very little during the first 100 years. However, in recent decades, the concept of **Smart Grid** emerged thanks to the massive use of digital technologies to increase efficiency, resilience and quality of the service.

# The new **Smart Power Grid**



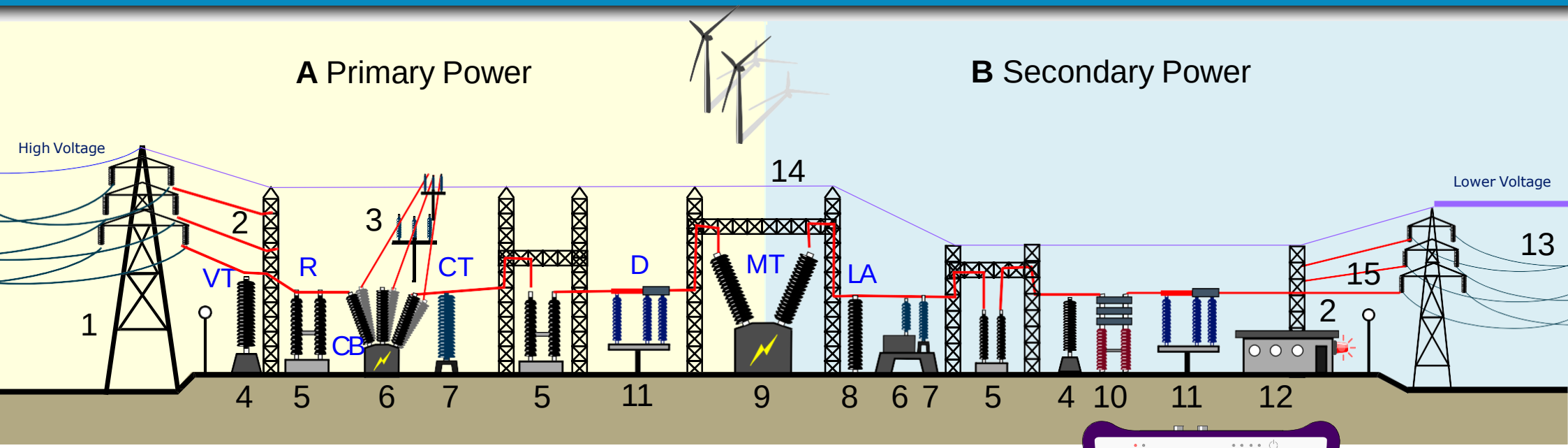



Ethernet is deployed and replaces the old infrastructure.

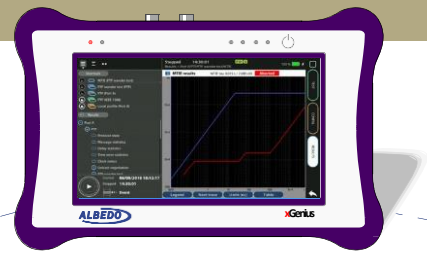
- IEC 61850 in substations: GOOSE, SV, MMS, PTP and SNTP
- Carrier-Ethernet, MPLS and MPLS-TP for WAN interconnections
- The C37.94 in teleprotection is maintained and also T1 / E1 although the trend is the substitution especially the serial communications.
- It expands on Internet access for the development of new applications..

# Components & **Systems** in a Substation






1.Primary Power (PP), 2.Feeder, 3. Busbar, 4.Voltage Transformer (VT), 5.Relay (R), 6.Circuit Breaker (CB), 7.Current Transformer (CT), 8.Lightning Arrester (LA), 9.Main Transformer (MT), 10. Capacitors (C), 11.Disconnector, 12.Control Shelter, 13.Secondary Lines, 14. Ground, 15. Overhead Lines




The **Primary Power** manages the high voltages lines coming from Generation while the secondary the lower voltages distributed to Industrial and residential consumers.

Zeus is a tester to install & maintain both legacy and new generation communication infrastructures.

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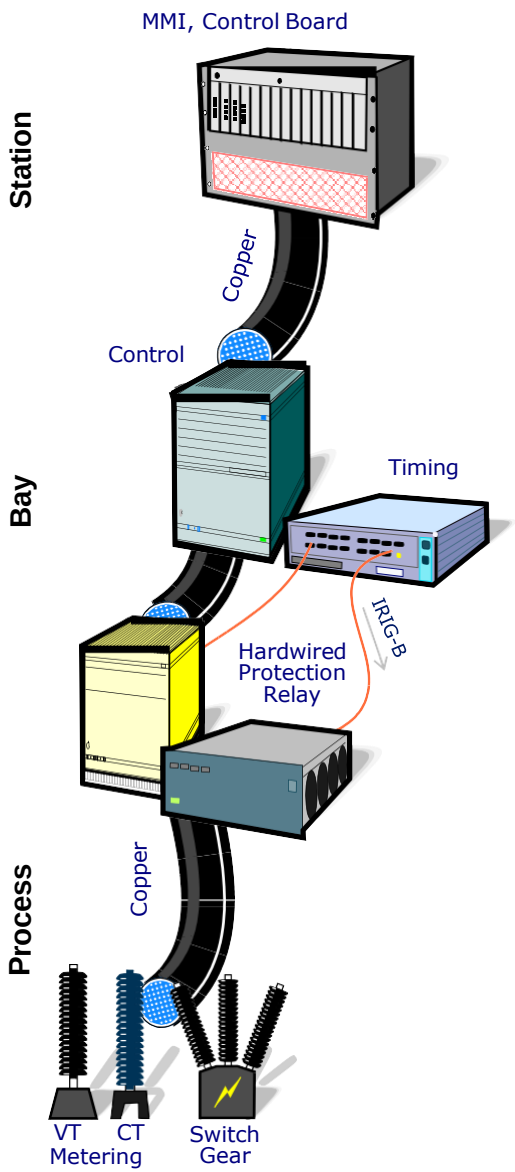
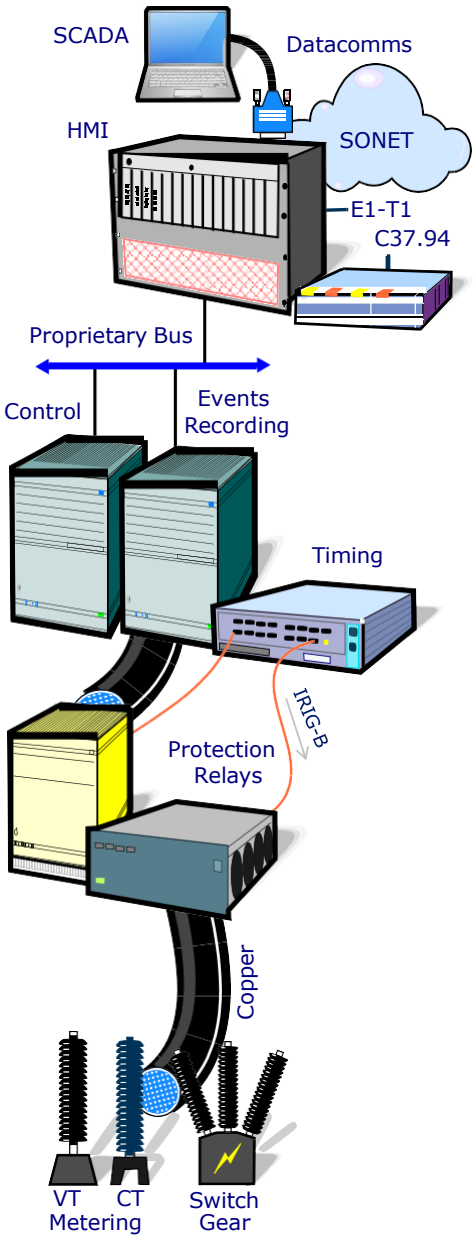
# Substation **Evolution**



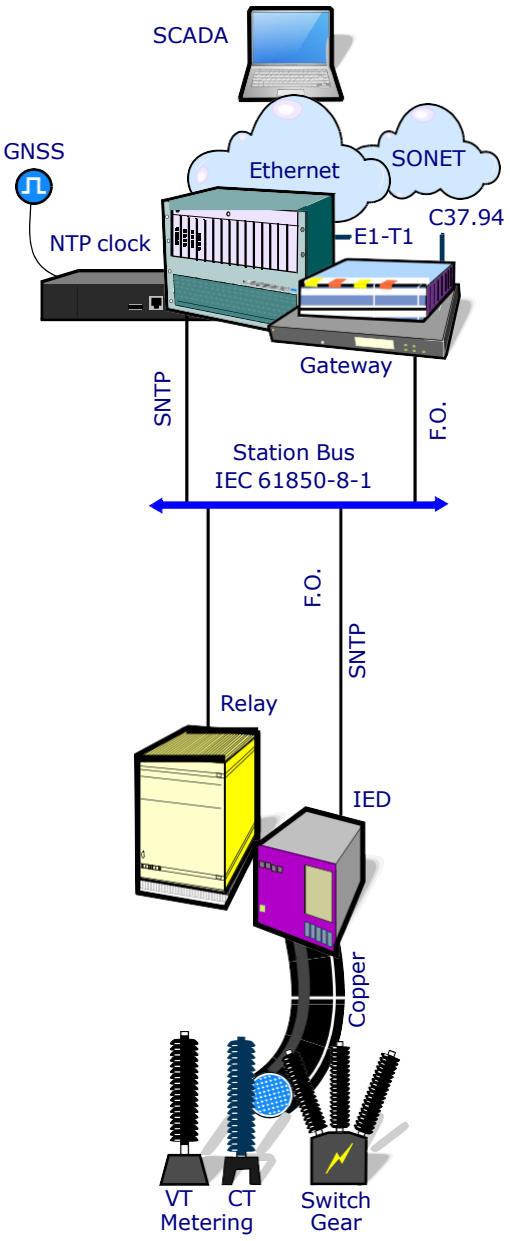
## SUBSTATION-1
**Legacy**



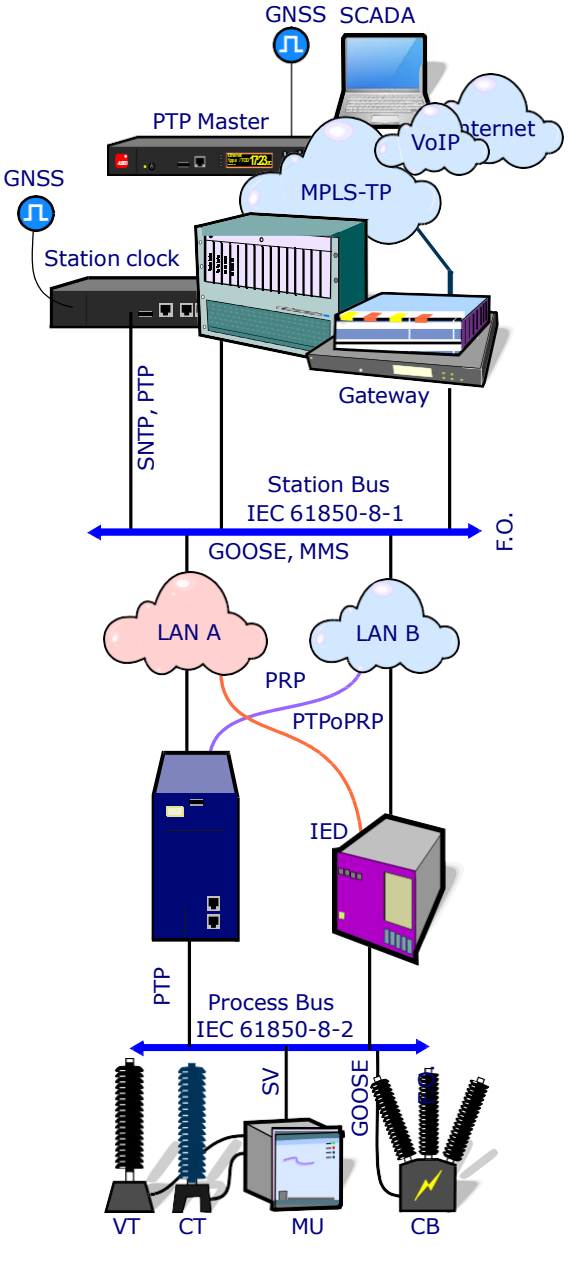

## SUBSTATION-2
**Conventional**

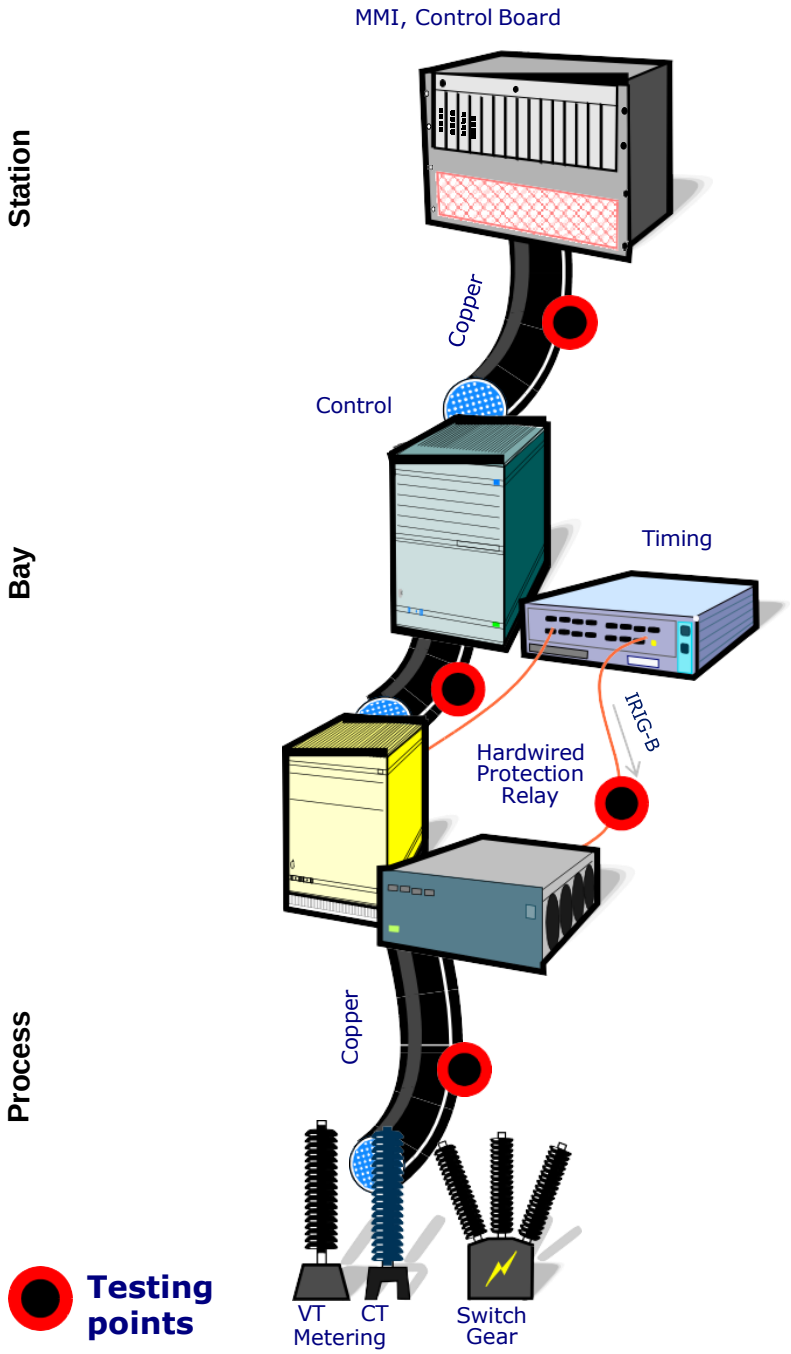



## SUBSTATION-3
**Digital**




## SUBSTATION-4
**Smart Grid**





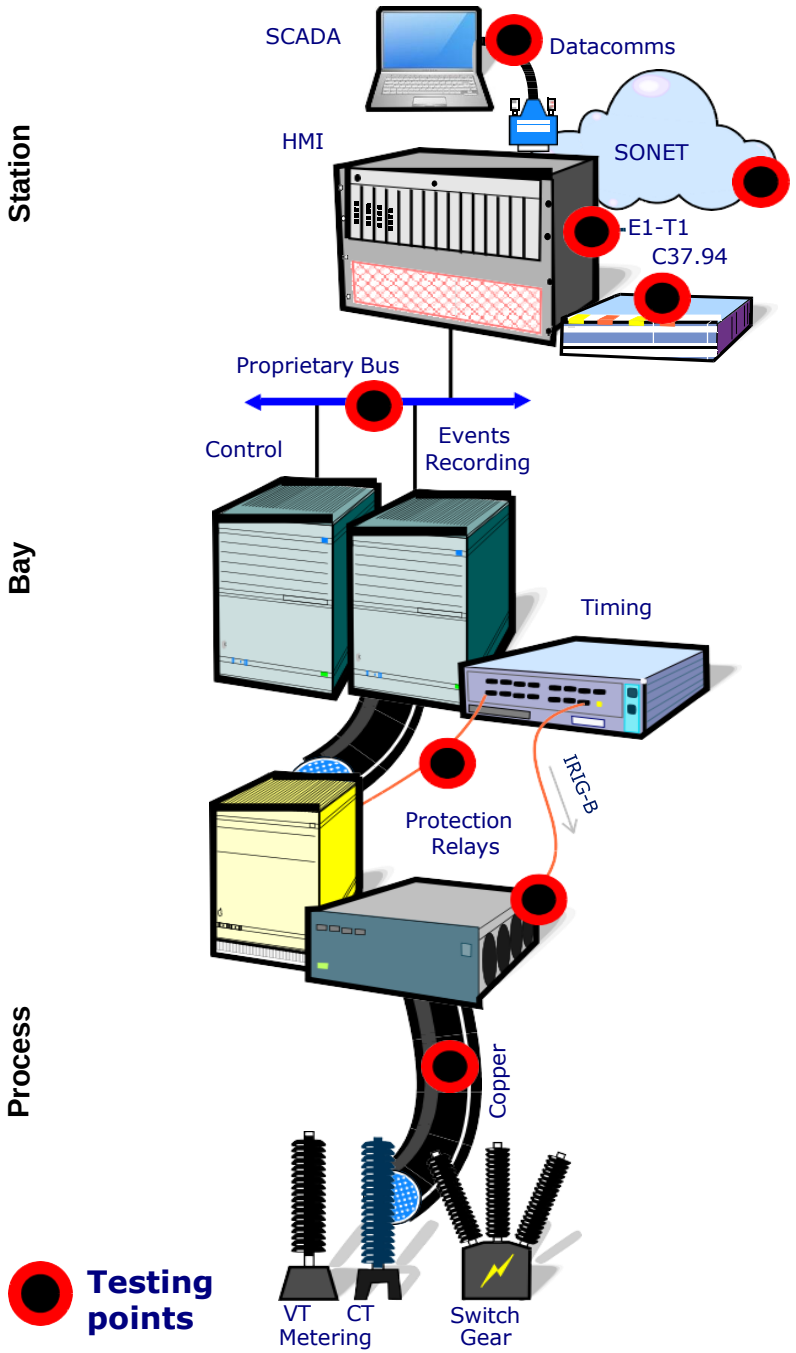

## Things to check

1. Serial communication: RS-232, RS-422, V.35, V.36
2. IRIG-B: time precision
3. E1 / T1: pulse, voice, data

## Objectives

1. Installation and maintenance of:
2. Serial data and communications
3. Synchronism quality
4. Voice circuits

*Serial communications*

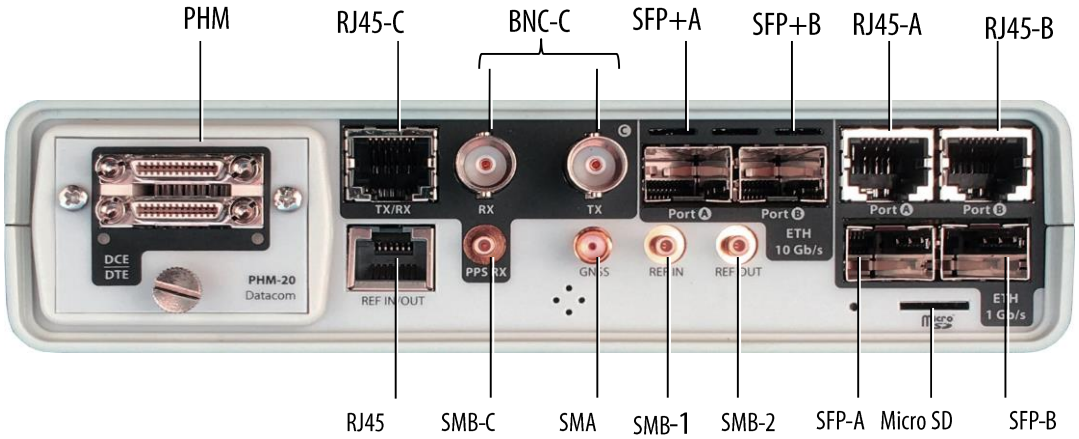



## Things to check

1. Serial communication: RS-232, RS-422, V.35, V.362.
2. IRIG-B: time precision
3. E1 / T1: pulse, voice, data
4. C37.94: delay, error rate, event emulation
5. Teleprotection: one-way delay (ref GPS)
6. Ethernet: RFC 2544, eSAM (Y1564), etc

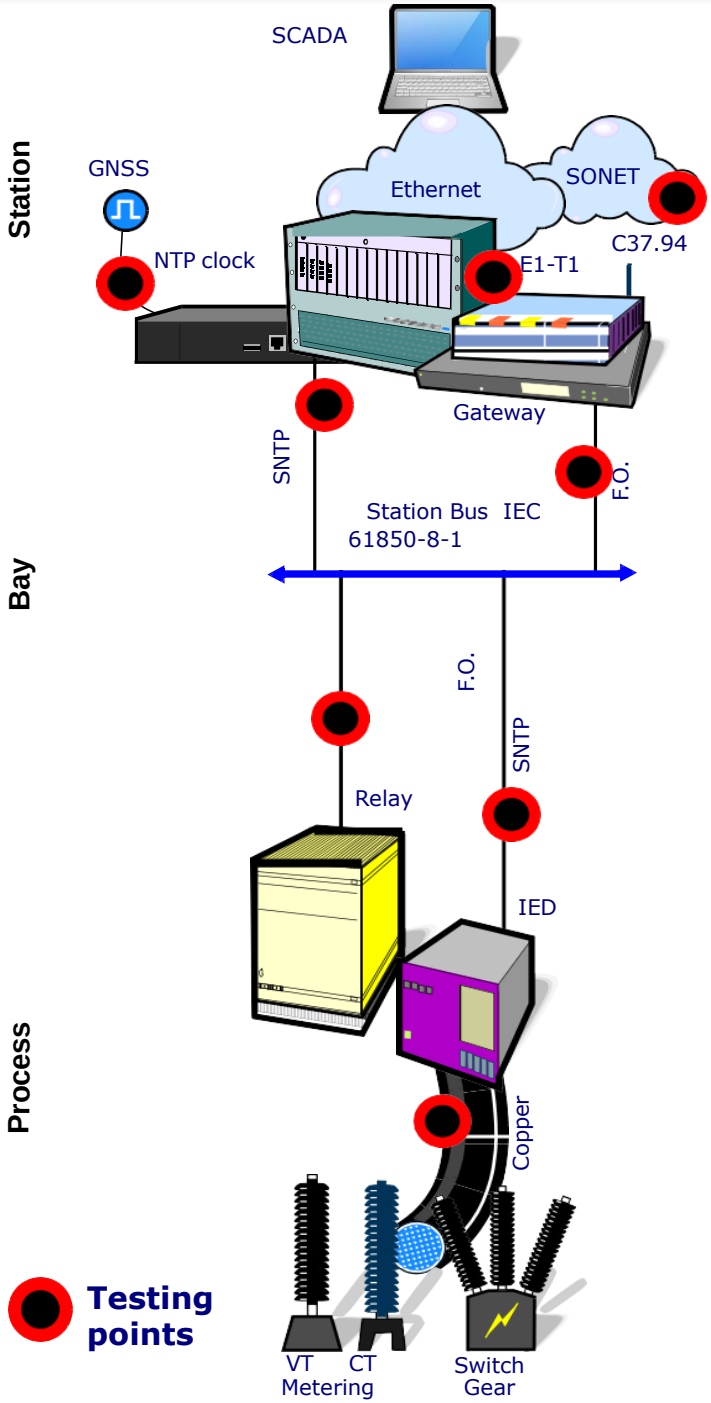
## Objectives

1. Check teleprotection according to C37.942
2. Check the quality of the synchronism
3. Verify the quality of the Ethernet network




*Multitechnology tester MADE IN ALBEDO*

# 3 –**Digital** Substation




## Things to check

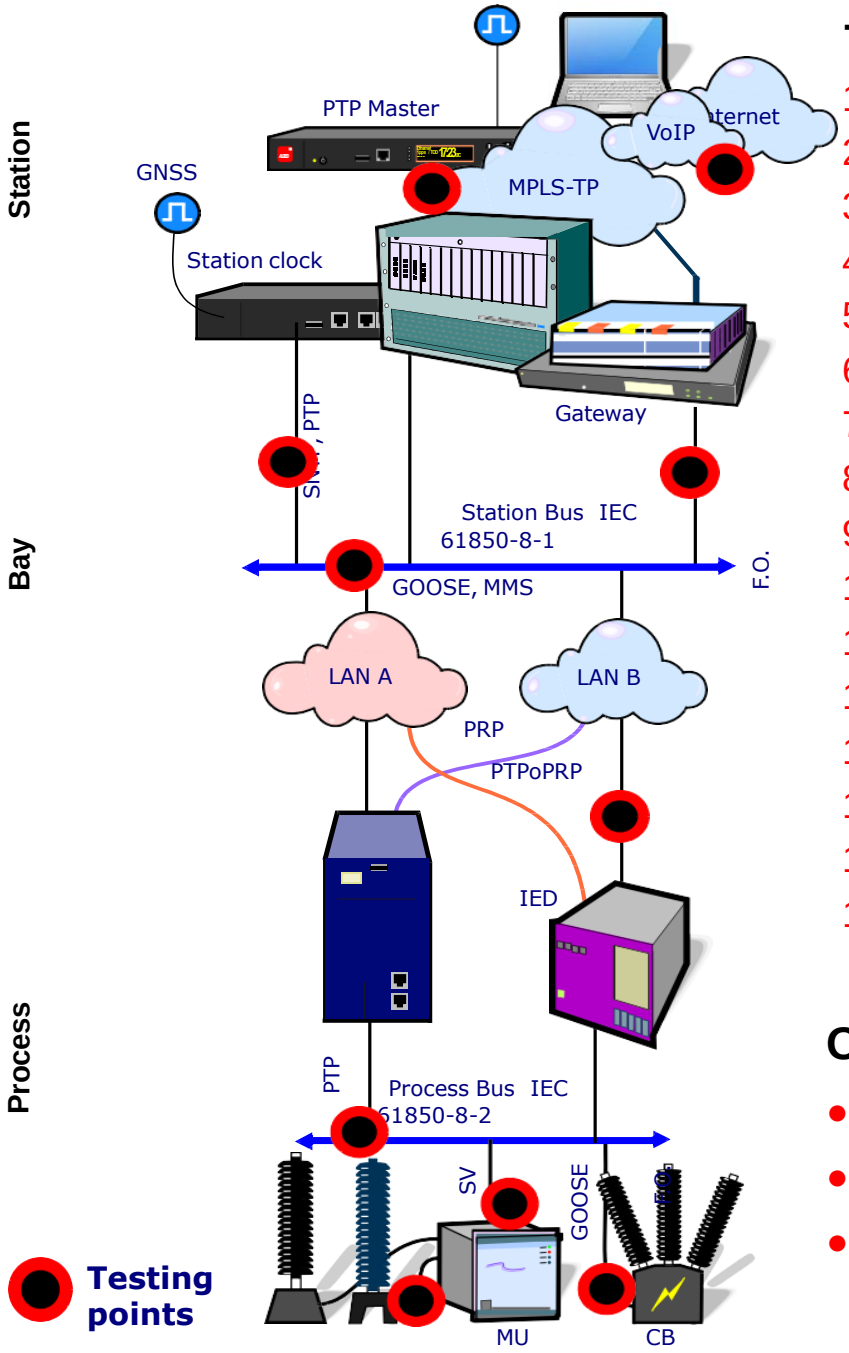
1. Serial communication: RS-232, RS-422, V.35, V.36
2. IRIG-B: Synchronization Accuracy
3. E1 / T1: pulse, voice, data
4. Ethernet: RFC 2544, eSAM, etc.
5. IP: ping, trace route
6. Fiber Optic: Power and Faults - OTDR
7. NTP: messages, delay, instability, TE
8. Teleprotection: C37.94, one-way delay, events

## Objectives

- Check teleprotection C37.94
- Verify IRIG-B and NTP synchronization
- Verify the quality of the Ethernet network
- Install and maintain fiber optics


*Net.Time PTP/NTP/IRIG-B clock*

# 4 – **IEC-61850** Substation




## Things to check

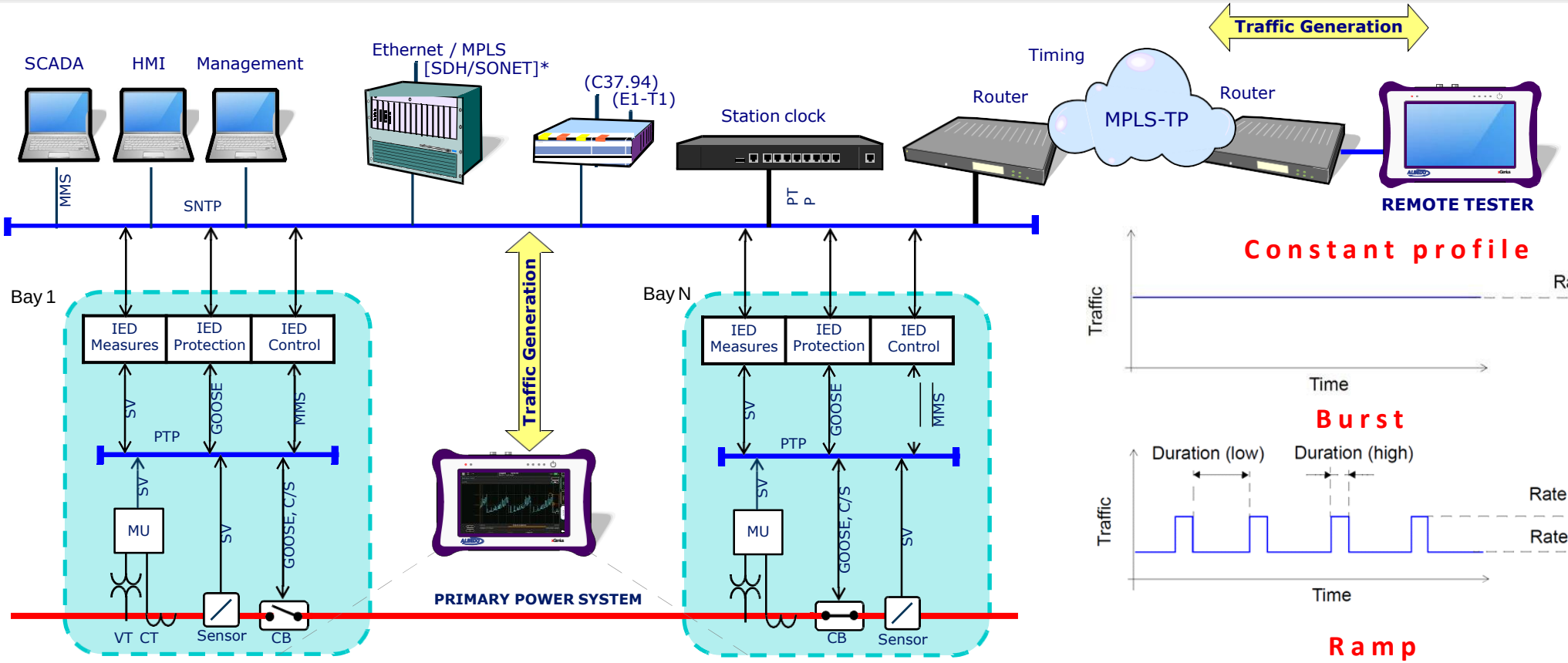
1. Serial communications RS-232, RS-422, V.35, V.362
2. IRIG-B: time precision
3. E1 / T1: pulse, voice, data
4. C37.94: delay, error rate, event emulation
5. Teleprotection: unilateral delay
6. Ethernet: RFC 2544, eSAM, etc.
7. IP: ping, trace route
8. MPLS-TP: test
9. Fiber Optic: Power, OTDR
10. NTP: messages, delays, jitter, TE
11. PTP: wander, PPS, TE
12. GOOSE: analysis / capture / decoding
13. SV: analysis / capture / decoding
14. MMS: analysis / capture / decoding
15. Master / slave clock emulation
16. IEC-61850: verification of delay on all interfaces

## Objectives

- Ensure interconnection between different manufacturers
- Ensure PTP-NTP-IRIG-B Synchronization Interconnect
- Install and maintain new protocols like GOOSE and SV

# Ethernet **Traffic Generation** Test







*Latency chronogram*

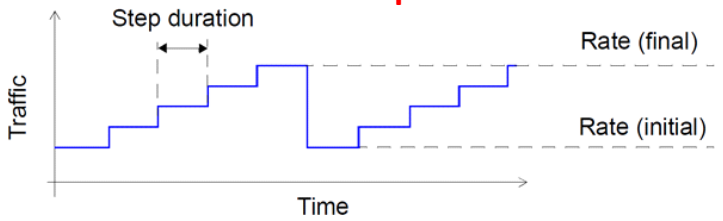
**Constant profile**




**Burst**




**Ramp**




## Objectives

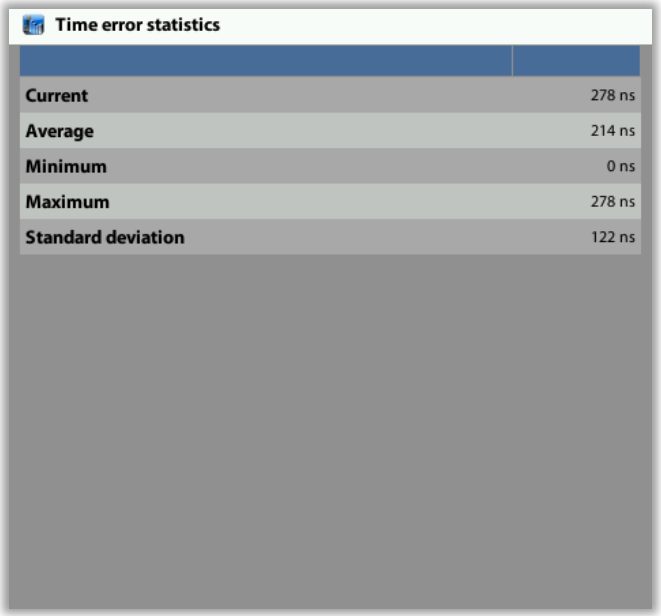
- Verify Ethernet / IP: RFC2544, RFC6349, Y1568
- Detect congestion points
- Identify causes of error

# IEC 61850 protocols & **Delay tests**



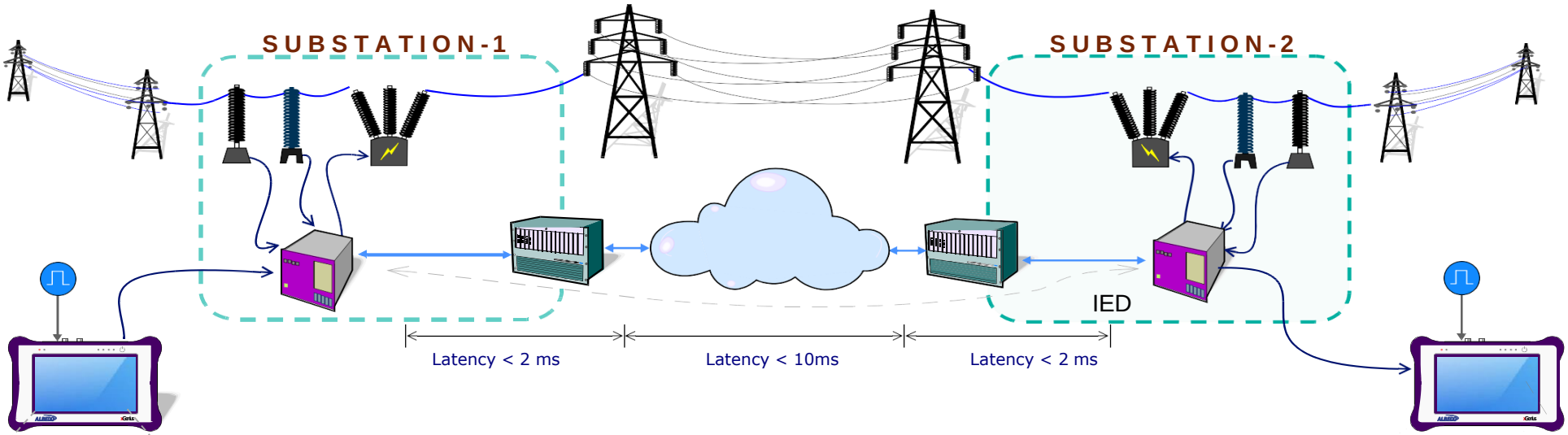
| Type | Message | Protocol | Layer | BWidth | Delay | Priority | Bus | Model | Application |
|---|---|---|---|---|---|---|---|---|---|
| 1A | Trip | GOOSE | L2 - Multicast | Low | < 3 to 10ms | High | Process | Publisher | Protection |
| 1B | Other | GOOSE | L2 - Multicast | Low | < 20 to 100ms | High | Process | Publisher | Control |
| 2 | Med Speed | MMS | L3 - IP/TCP | Low | < 100 ms | Medium Low | Process & Station | Client/Server | Data collection |
| 3 | Low Speed | MMS | L3 - IP/TCP | Low | < 500 ms | Medium Low | Process & Station | Client/Server | Data collection |
| 4 | Raw Data | SV | L2 - Multicast | High | < 3 to 10ms | High | Process | Publisher | Analysis, Protection |
| 5 | File Transfer | MMS | IP/TCP/FTP | Medium | < 1000 ms | Low | Process & Station | Client/Server | Management, Data |
| 6 | Timing | PTP | L2 - PTP | Low | Protection < 0,1 to 3ms<br>Transformers ±1 to ±25us | Medium High | Process & Station | Unidirectional | Timing, IED, Synchrophasors |
| 7 | Command | MMS | L3 - IP | Low | < 500 ms | Medium Low | Station | Client/Server | Cconfiguration |

*IEC-61850 protocols to synchronize, measure, exchange data, command and protect to be verified*

# **Latency** analysis in ALL interfaces







## Modes

- Two way delay
- One way assisted with GNSS or ToD and far-end identification

## Results

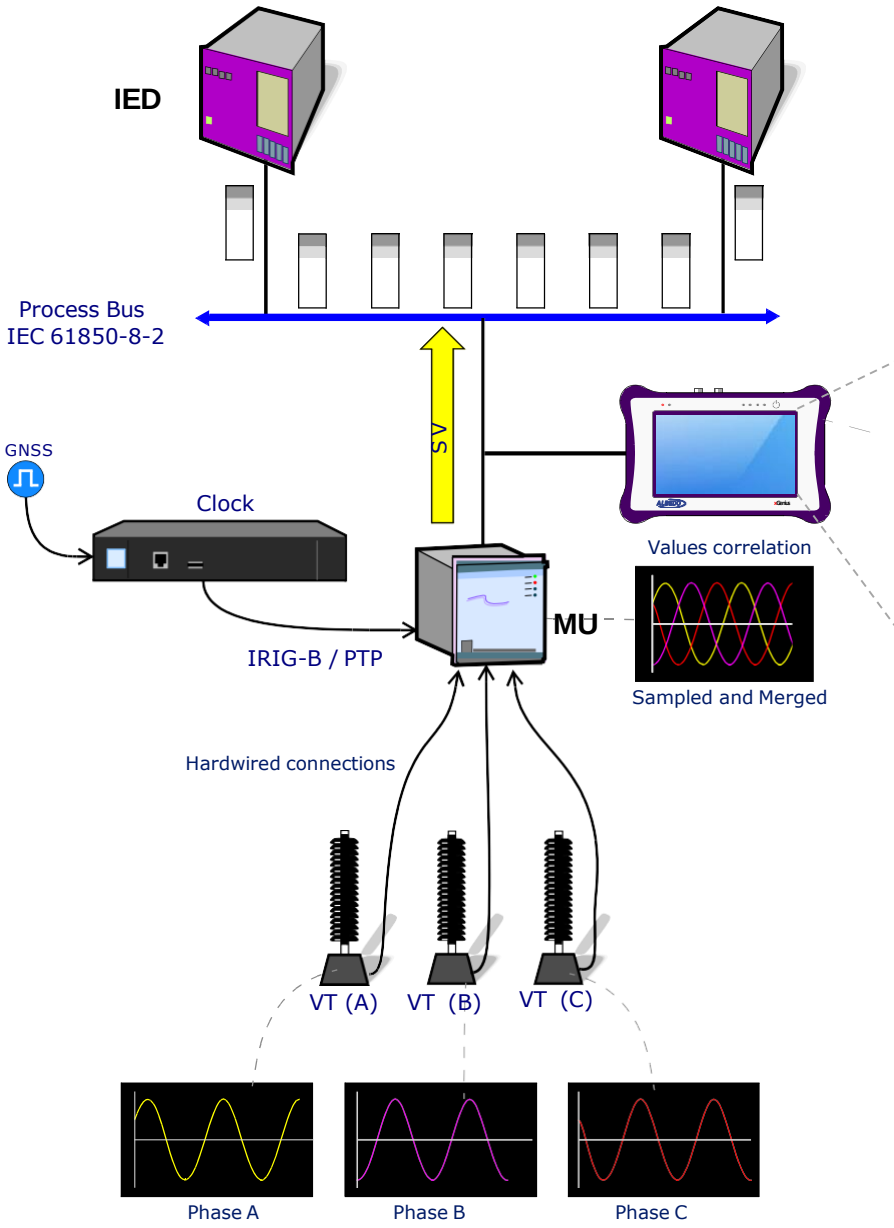
- Round Trip Delay (RTD)
- One way Forward / Reverse Path delay
- Asymmetry with min. / max. records
- Patch cord delay compensation
- Pass / Fail indication

## Objectives

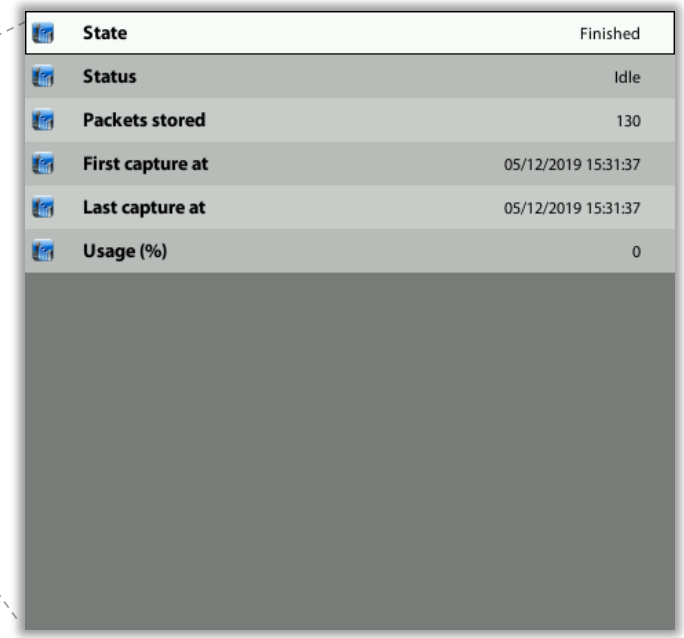
- Latency insights
- One way delay / Round-trip delay

# Traffic Capture **SV – Sampled Values**






A Merging Unit (MU) is an IED that digitizes data obtained from current (CT) or voltage (VT) transformers. MU publishes data as a stream at a constant and pre-established packet rate.

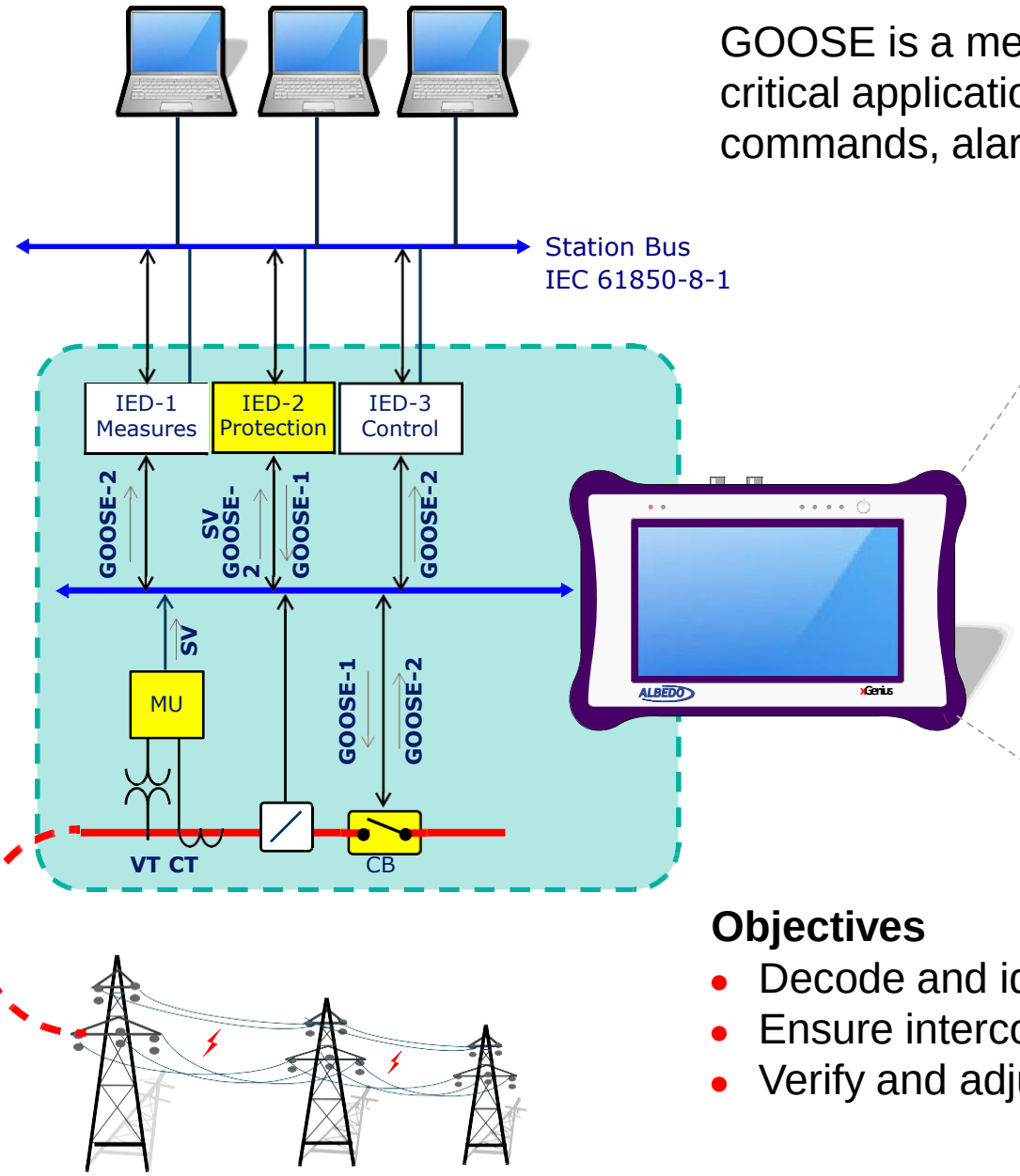



## Objectives

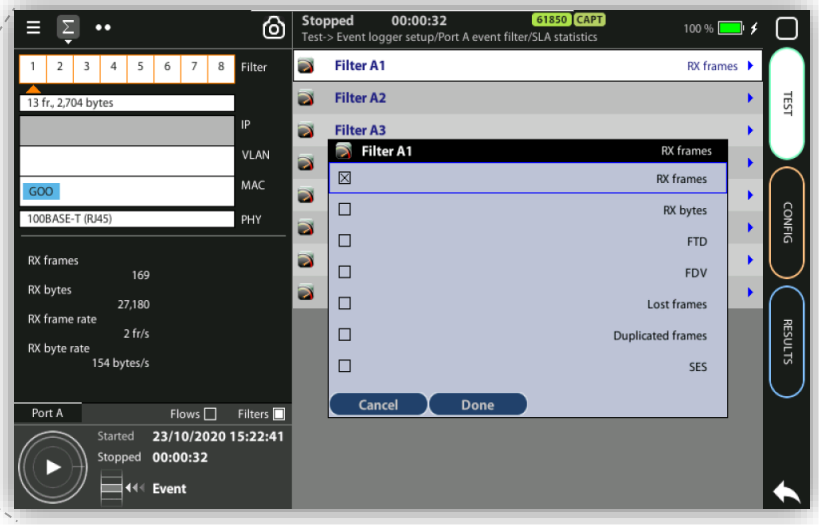
- Detect SV transmission faults
- Facilitates interconnection between manufacturers
- Verify and adjust the latency of SV samples

# GOOSE : **Traffic** Capture & Analysis






GOOSE is a messaging system used by IEDs and mission-critical applications to tell about substation events, such as commands, alarms, indications and measurements.

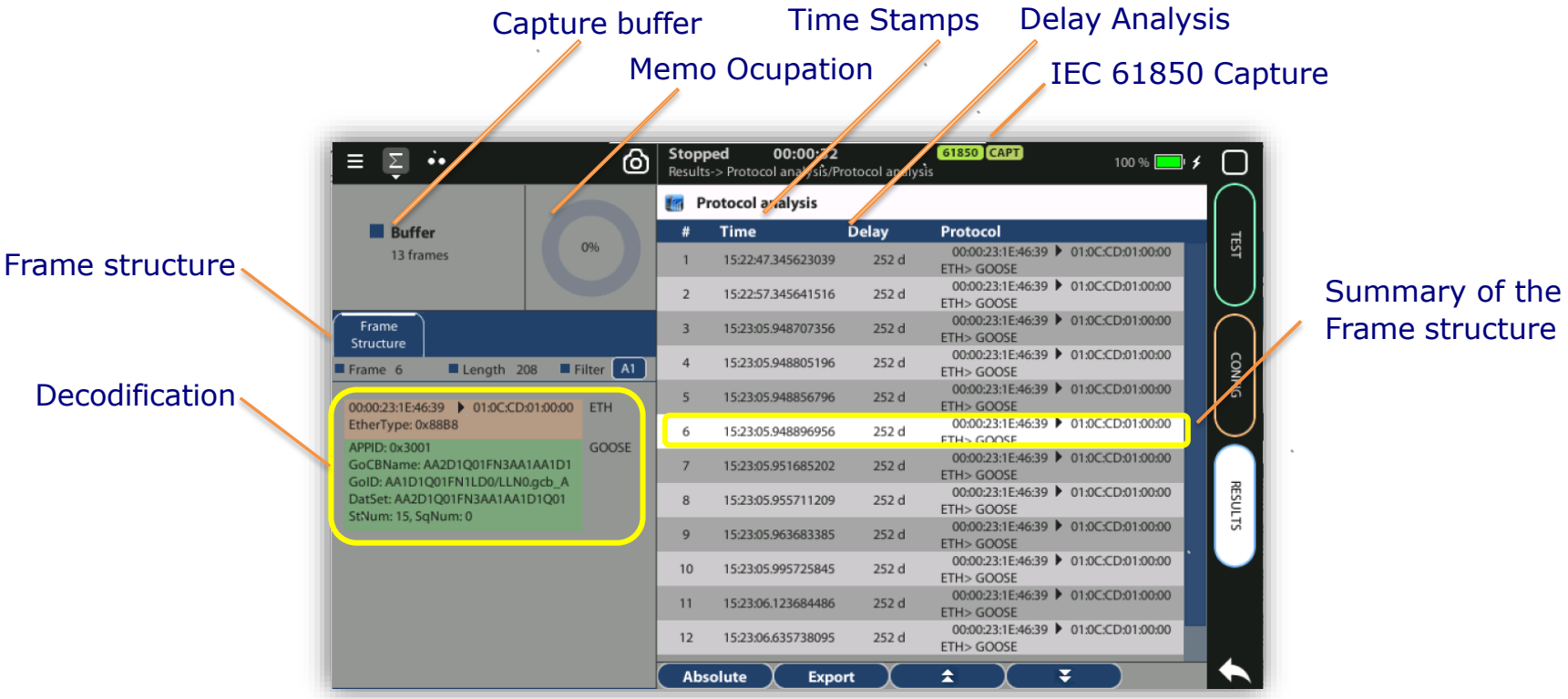



## Objectives

- Decode and identify flaws in the GOOSE protocol
- Ensure interconnection between different manufacturers
- Verify and adjust the latency of GOOSE packets

# **Ethernet**-based Traffic Capture






Analysis of the protocols DNS, DHCP, GOOSE, SV, NTP, PTP, etc.

- Captures in transfer and endpoint modes
- High resolution hardware timestamp
- Synchronized captures (GNSS, IRIG-B, 1PPS / ToD)
- Packet-to-packet delay analysis
- Export to PCAP and PCAPng

# **IRIG-B** decoding a time reference



**IRIG - Xabc**

**Rate**
- A: 1000 PPS
- IRIG-B: 100 PPS
- D: 1 PPM
- E: 10 PPS
- G: 10000 PPS
- H: 1 PPS

**Coding**
- 0: BCD, CF, SBS
- 1: BCD, CF
- 2: BCD
- 3: BCD, SBS
- 4, 5, 6, 7: others

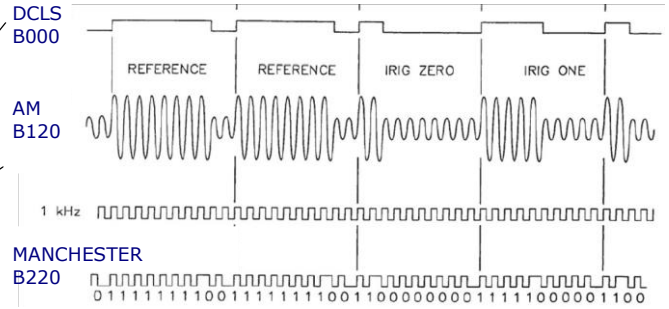
**Carrier**
- 0: No carrier (DCLS)
- 1: 100 Hz
- 2: 1 kHz
- 3: 10 kHz
- 4: 100 kHz
- 5: 1 MHz

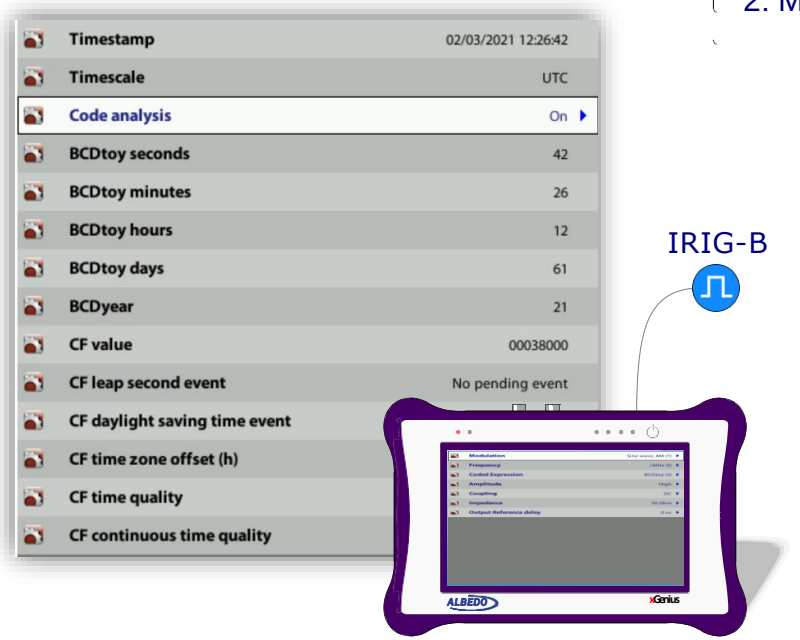
**Modulation**
- 0: Unmodulated DCLS
- 1: AM (Amplitude Modulated)
- 2: Manchester Modulated

BCD
0000 = 0
0001 = 1
0010 = 2
0011 = 3
0100 = 4
0101 = 5
0110 = 6
0111 = 7
1000 = 8
1001 = 9

IRIG SAMPLES: **B000, B120, B220**

BCD - Binary Coded Decimal, coding of time (HH,MM,SS,DDD)
SBS - Straight Binary Second of day (0....86400)
CF - Control Functions depending on the user application




IRIG-B sends a timing signal every second at 100 pulse/sec rate therefore the 100 is the number of bits of each frame. IRIG-B info includes Year, Day, Hour, Min, Sec.

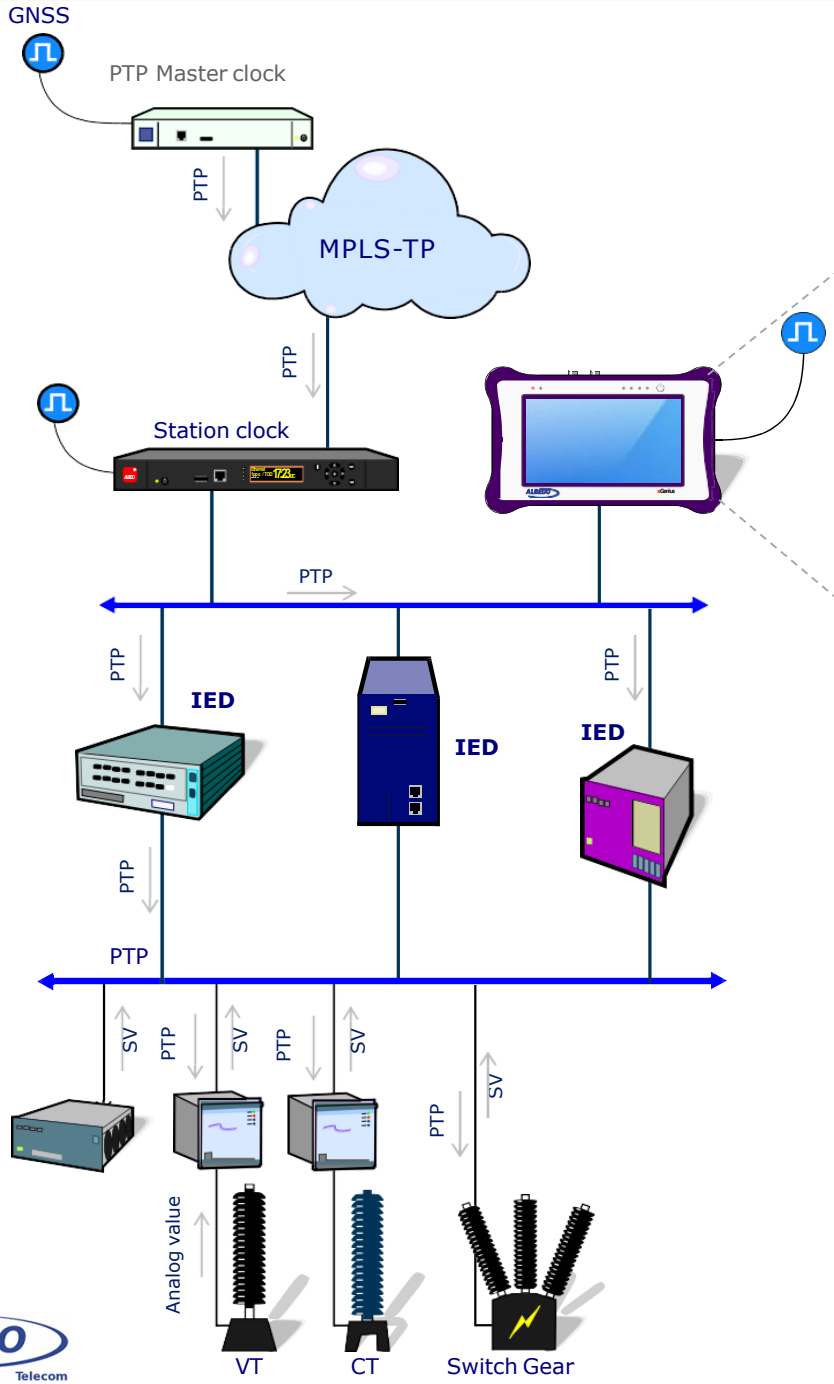
- AM modulated clock reference input and output
- Unmodulated (DCLS) i/o over RS-422 / RS-485 or TTL
- Manchester encoded IRIG-B input and output

## Test & Measurement

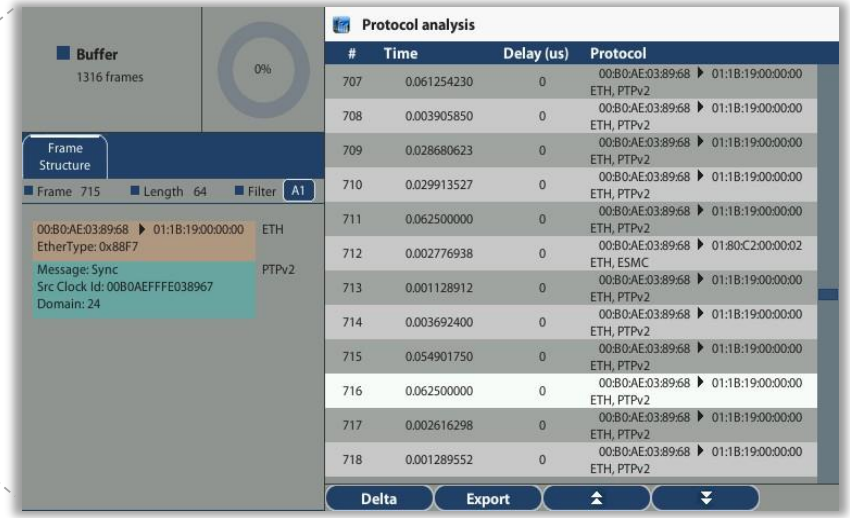
- Analysis of the received IRIG-B structure

# **PTP** (IEEE 1588) protocol testing






PTP satisfies the timing requirements of the power industry in terms of accuracy and flexibility.




## PTP test includes:

- Master / slave operation
- Performs frequency and phase accuracy tests.

## Objectives

- Synchronism network migration to PTP
- Calculate Clock Accuracy
- Identify installation errors
- Secure GPS interconnection
- Check operation in holdover

## Wander metrics

- TIE
- MTIE
- TDEV
- Tables and Graphs

## Time Error (TE) test

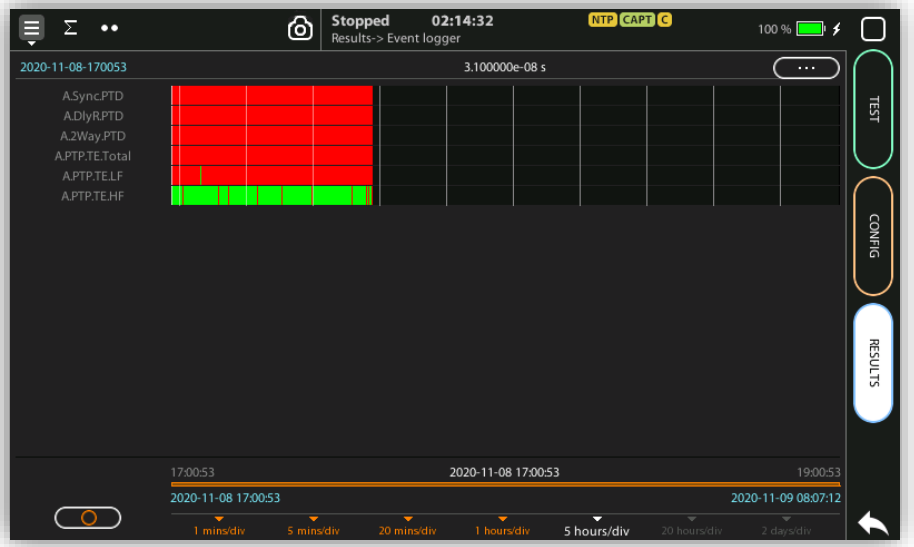
- Two-way TE and max |TE|
- Low frequency TE as the cTE + dLTE
- High frequency TE
- Path Delay Asymmetry
- Between PTP master to client clocks

## Objectives

- Monitor the PTP clock
- Determine if the timing error is acceptable
- Check waiting and recovery times

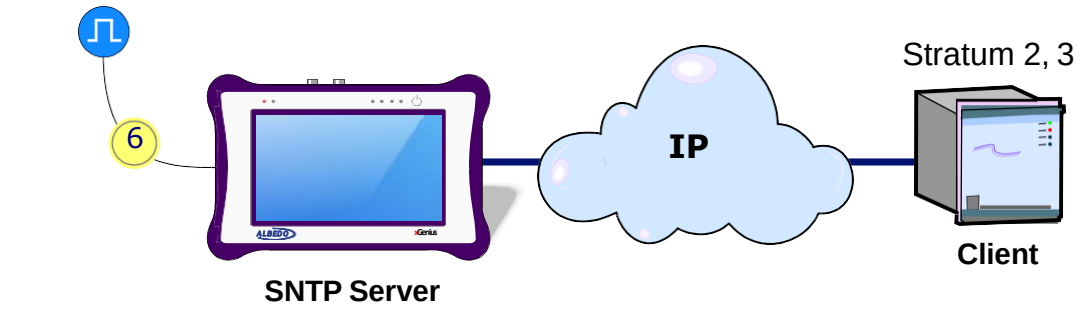
**Time Error (TE) results**

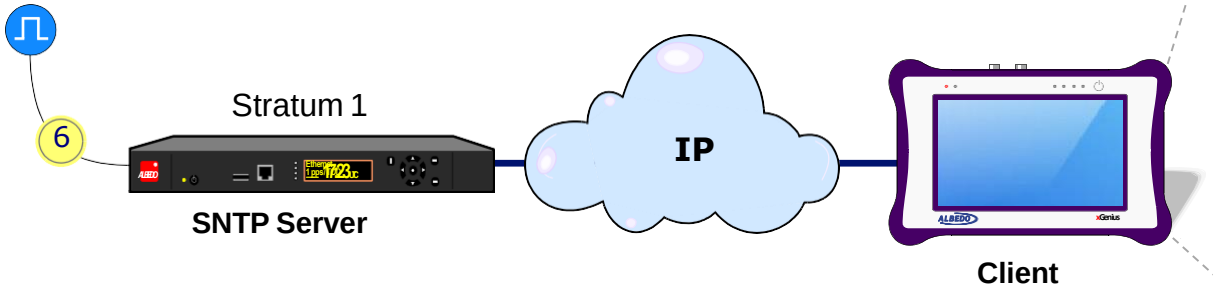

**TE analysis** (PASS/FAIL)

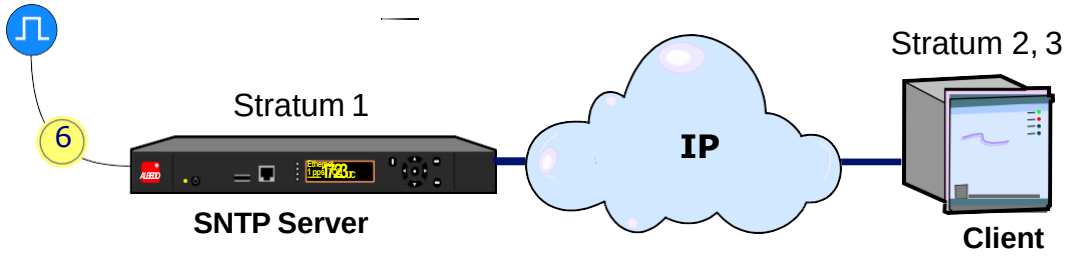


# **NTP** test & results

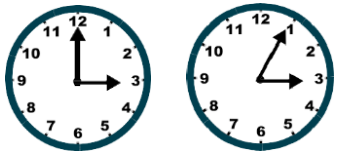





**Offset: difference between clocks**



**Offset = 5'**


## Zeus and xGenius can manage:

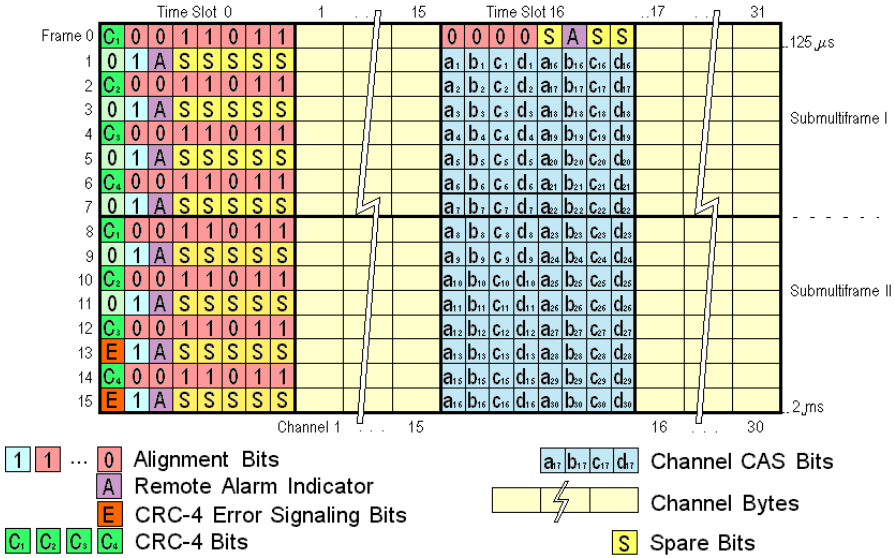
- NTPv3/v4 server and client emulation
- Traffic filtering, classification, analysis
- NTP delay, asymmetry
- Time Error (TE) statistics

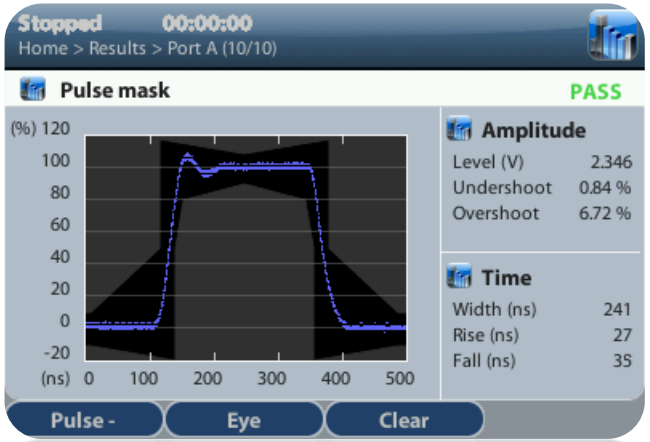
## Objectives

- Monitor the PTP clock
- Analyze time error tolerances
- Check waiting and recovery times

# Complete **E1 / T1 / G703 test**






## Analysis / Generation

- E1 / T1: frame / unframed with / without CRC
- Overheads: display and edition
- CAS analysis
- Pulse Mask
- Channel map: Busy / Free, Drop / Insert of 64 kb/s

## Measurements

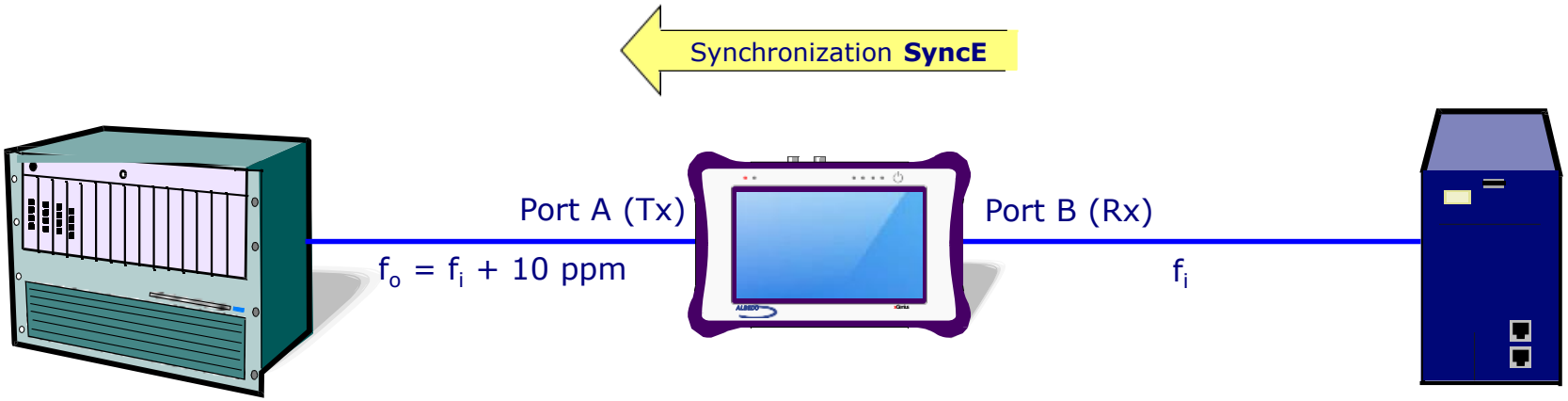
- BER
- Line / Freq
- Errors / Alarms
- G.821, G.826, M.2100
- VF: tone generation / analysis
- Attenuation, Freq, Freq. deviation, Level, Peak codes
- E1 / T1 in sync

## Analysis / Generation

- Jitter analysis: Peak to peak, RMS, hits, count (.1 at 100kHz)
- Wander: With mask (1µHz to 10Hz)
- Wander: 10 MHz, 2048 kHz, 1544 kHz, 1pps

# Verify **Synchronous Ethernet** (SyncE)






Testers have a set of tests to ensure SyncE

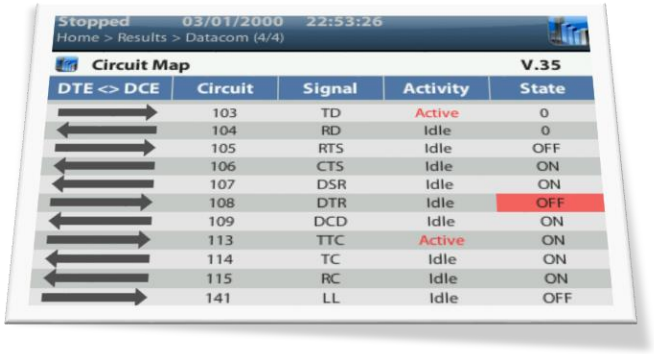
**Quality tests**

- Synchronism according to ITU-T G8261, G8262, G8264 standards
- Check Line Frequency (MHz), offset (ppm), drift (ppm / s)
- Analysis / Generation of ESMC and SSM messages
- SSM counter & speed

**Wander analysis**

- SyncE TIE, MTIE and TDEV measurement
- SyncE Wander generation

# **Serial** Communications tests


Based on hot pluggable modules

- V.24 / V.28, X.12 / V.11, X.21 / V.11, V.35, V.36 / RS-449, EIA-530 / A
- Data, Stop, Parity, inter word gap
- DTE / DCE emulation, Full duplex monitor

**Inserting events**

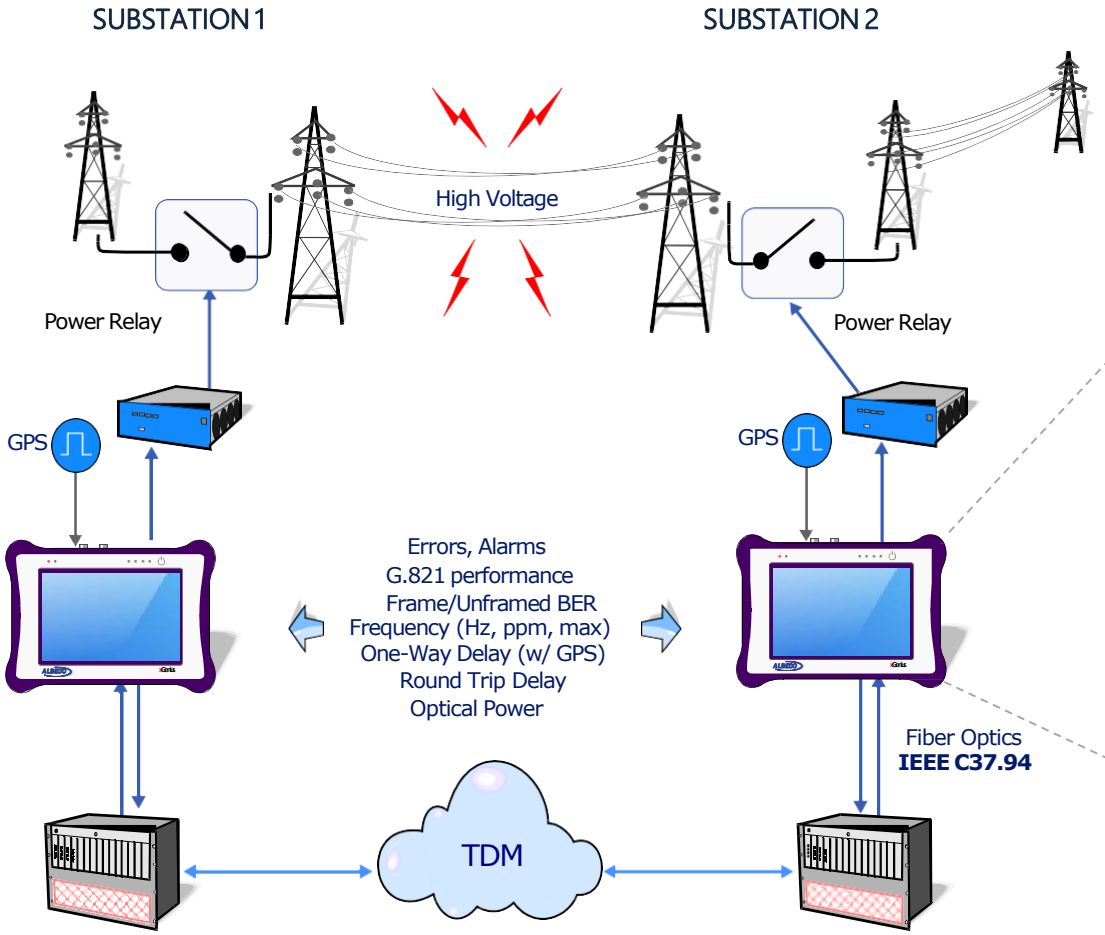
- Pattern: TSE, Slip, LSS, All 0, All 1
- Asynchronous interfaces: FRM, PRTY

**Modes**

- Anomalies: single, rate
- Defects: continuous
- V.24/V.28, X.12/V.11, X.21/V.11, V.35, V.36/RS-449,  EIA-530/A

# **C37.94** Interface: Teleprotection Test






## Operation Modes

- C37.94
- Through
- Monitoring
- Loop

**Delay statistics**

| | Current | Average | Range | Std. dev. |
|---|---|---|---|---|
| Offset (theta) | 0.278 µs | 0.278 µs | 0.003 µs | 0.000 µs |
| Delay (delta) | 0.954 µs | 0.954 µs | 0.000 µs | 0.000 µs |
| Delay (forward) | 0.697 µs | 0.697 µs | 0.002 µs | 0.000 µs |
| Delay (return) | 0.140 µs | 0.140 µs | 0.005 µs | 0.001 µs |
| Asymmetry | 0.557 µs | 0.557 µs | 0.000 µs | 0.001 µs |
| Jitter (psi) | 0.278 µs | | | |

## Measurements

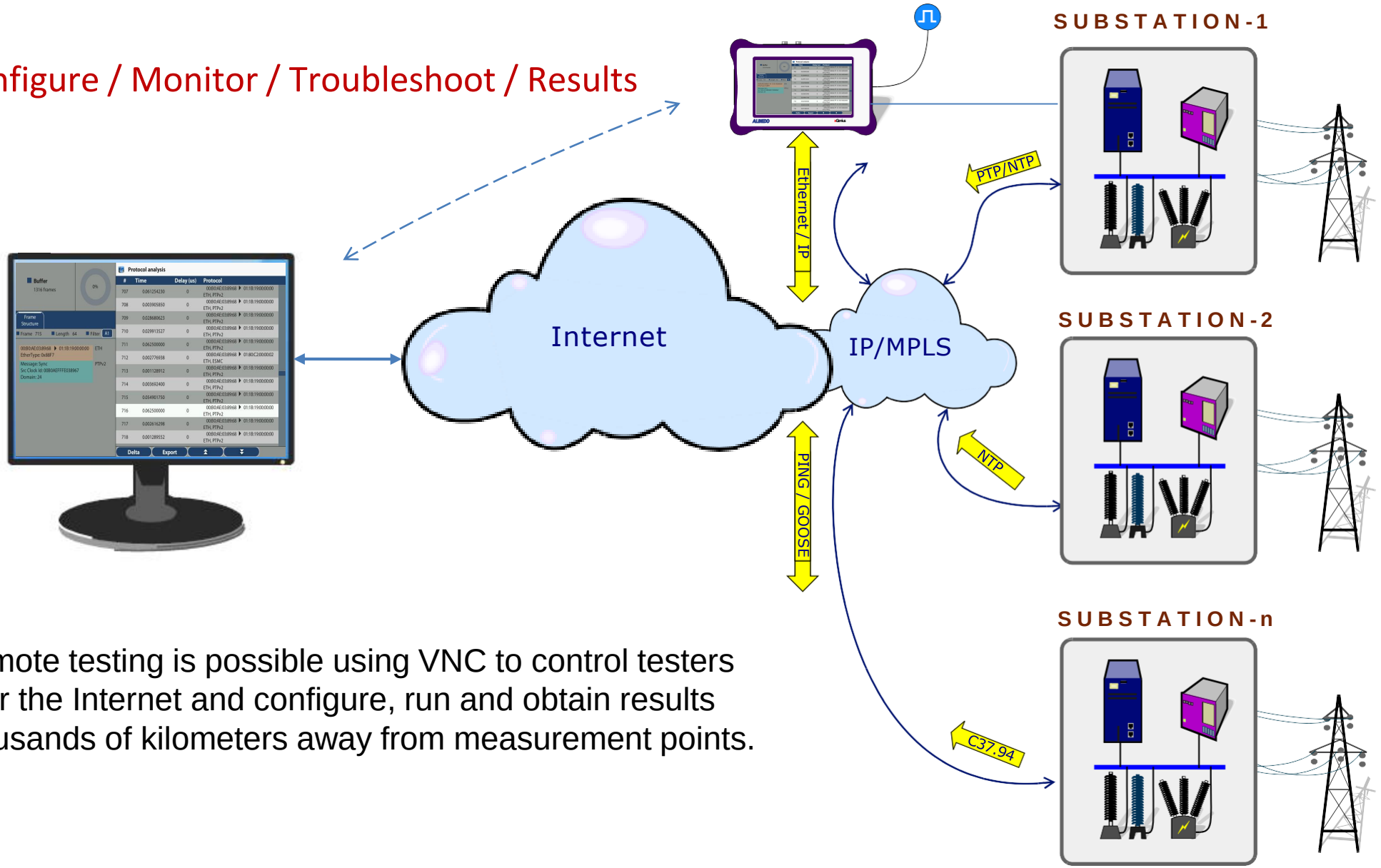
- Performance testing: BERT, G.821
- Analysis/generation of events
- Optical power and frequency metering
- One-way / round-trip delay, asymmetry
- Jitter / wander generation & analysis

## Objectives

C37.94 Activation, Verification, Troubleshooting

# **Remote** testing

Configure / Monitor / Troubleshoot / Results



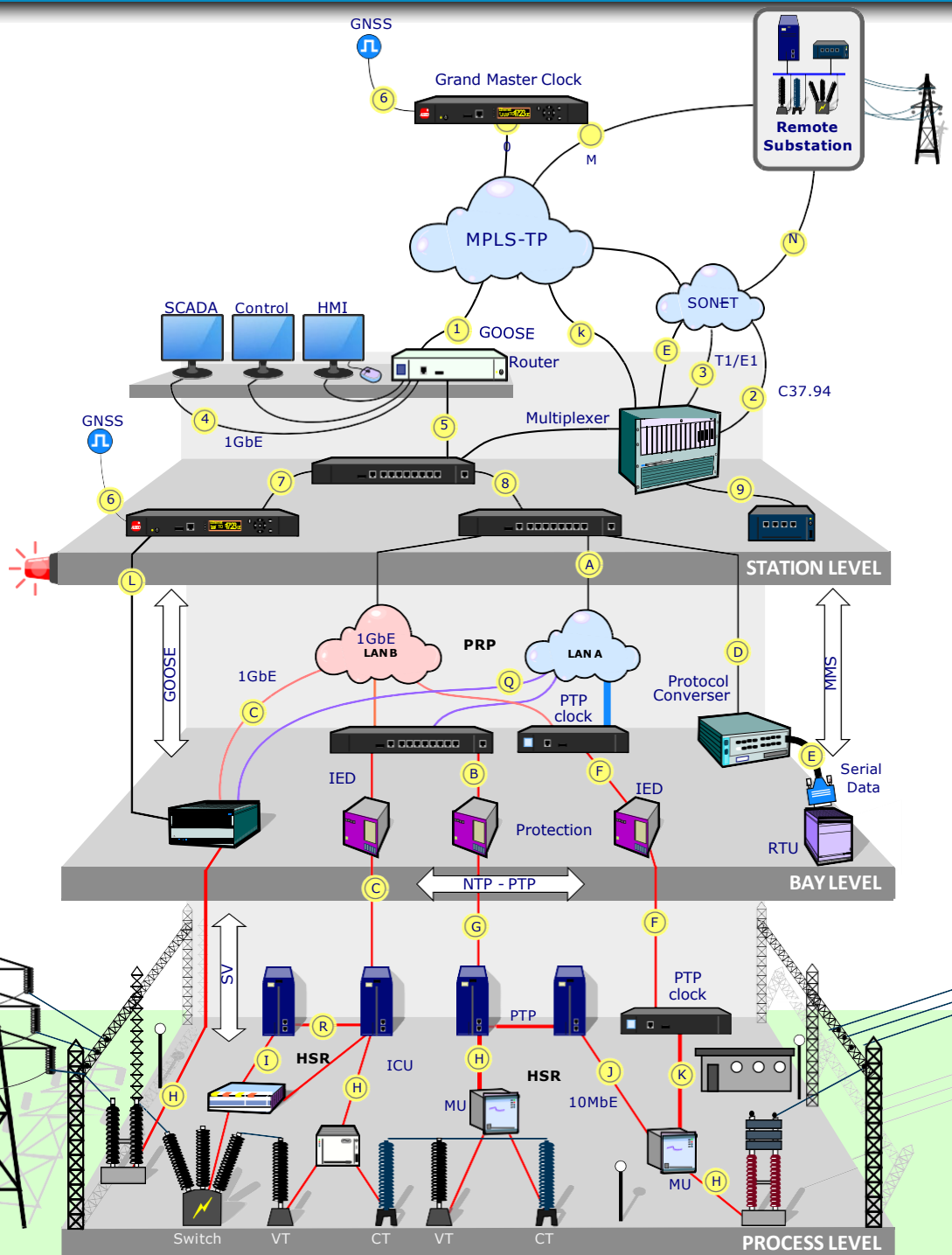

Remote testing is possible using VNC to control testers over the Internet and configure, run and obtain results thousands of kilometers away from measurement points.

# **Testing points** in the Power Grid



## Test & Measurement

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
9 - MPLS
A - PTP
B - NTP
C - GOOSE
D - PTP wander
E - RS-232
F - SyncE
G - Codir (G703)
H - SV capture
I - GOOSE capture
J - One Way Delay
k -100BASE-T
L - IRIG-B
M - GbE
N - Round Trip Delay
O - PTP Power / Telecom
Q - GOOSE offset
R - PTP wander



# Station level



**Test & Measurement**

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
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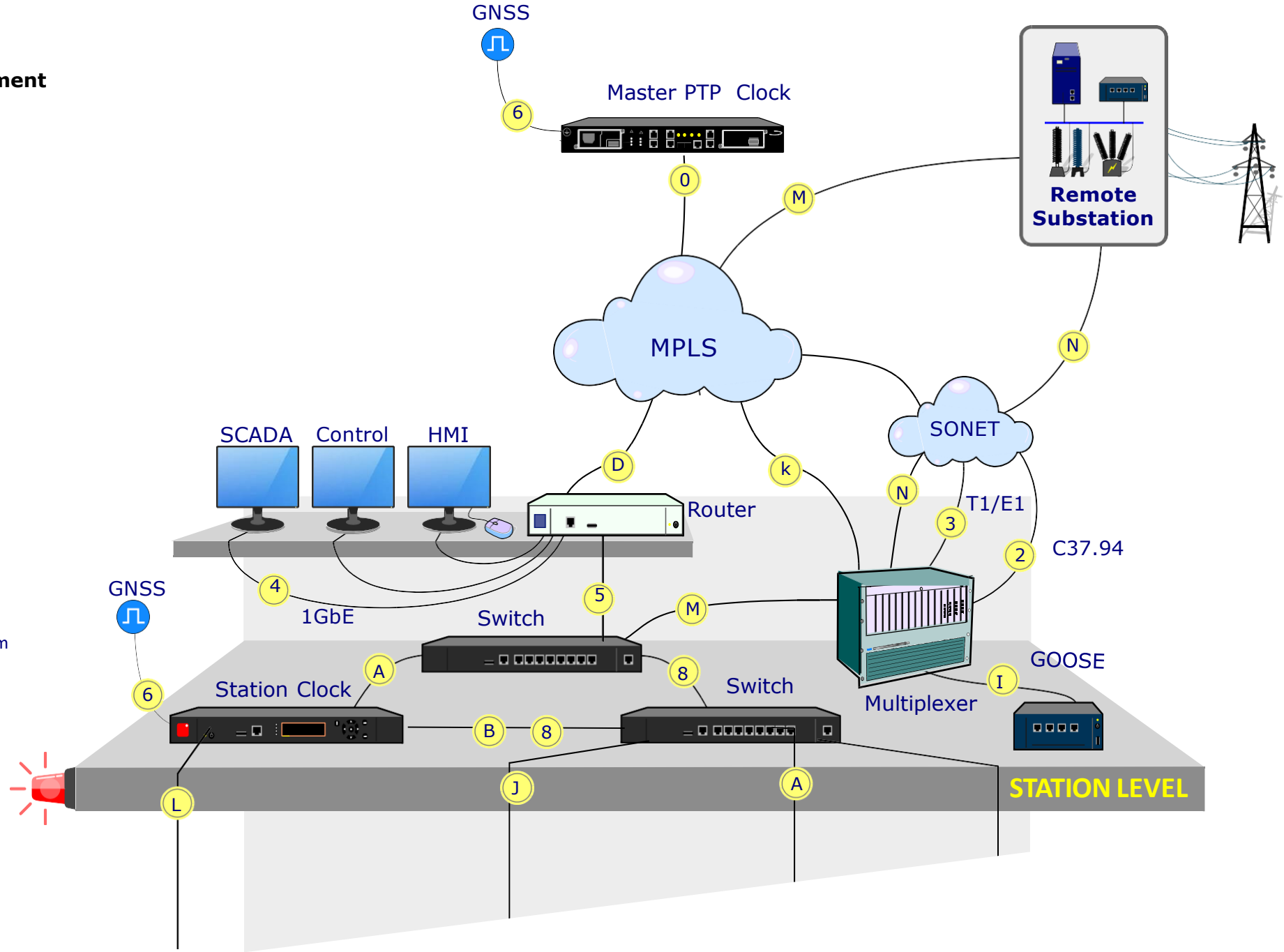

# Bay level

**Test & Measurement**

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
9 - MPLS
A - PTP
B - NTP
C - GOOSE
D - PTP wander
E - RS-232
F - SyncE
G - Codir (G703)
H - SV capture
I - GOOSE capture
J - One Way Delay
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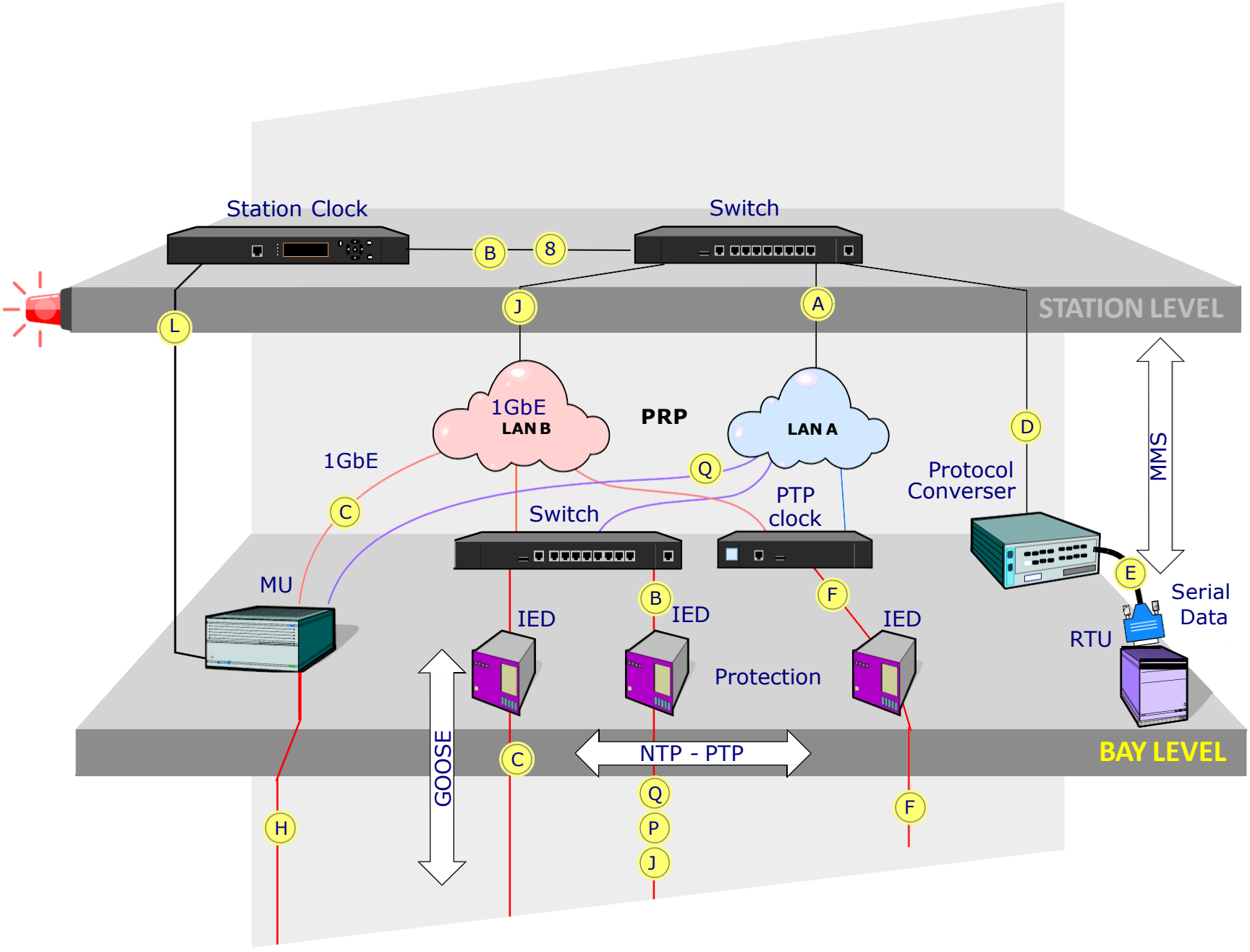
L - IRIG-B
M - GbE
N - Round Trip Delay
O - PTP Power / Telecom
Q - GOOSE offset
R - PTP wander



# Process level

**Test & Measurement**

1 - GOOSE delay
2 - C37.94
3 - E1/T1
4 - GbE
5 - MMS
6 - GNSS
7 - 1PPS
8 - Eth/IP
9 - MPLS
A - PTP
B - NTP
C - GOOSE
D - PTP wander
E - RS-232
F - SyncE
G - Codir (G703)
H - SV capture
I - GOOSE capture
J - One Way Delay
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O - PTP Power / Telecom
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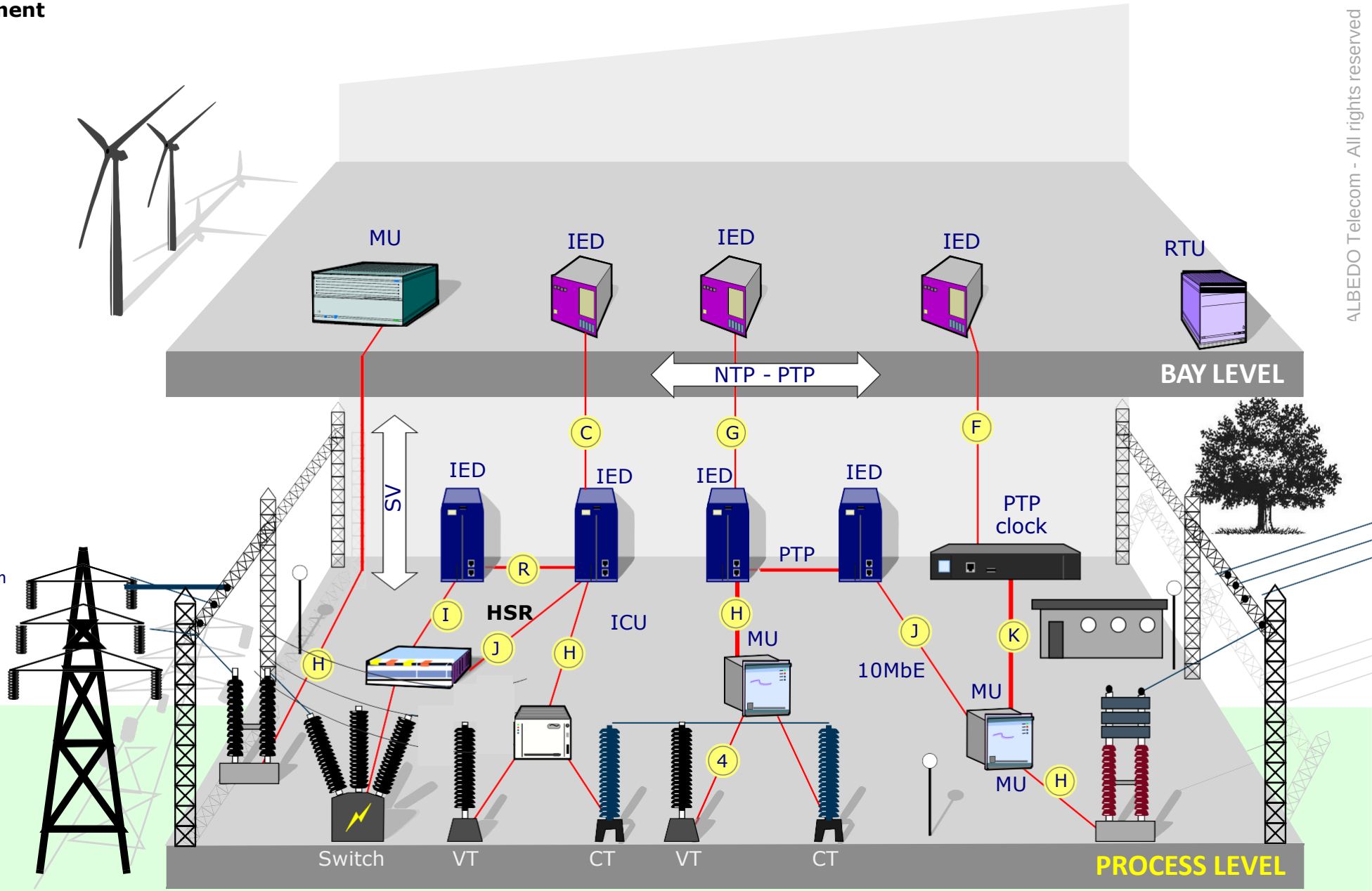
R - PTP wander



# **Net.Time** PTP/NTP/PRP clock




Net.Time Power is an IEC 61850 compliant clock that supports PTP over PRP and also supports NTP, SyncE, 1PPS, ToD, IRIG-B, etc. to satisfy all the needs in substations, both the most modern and the legacy ones. PTP includes Telecom and Energy profiles and may have a Rubidium oscillator.

# Zeus / xGenius testers



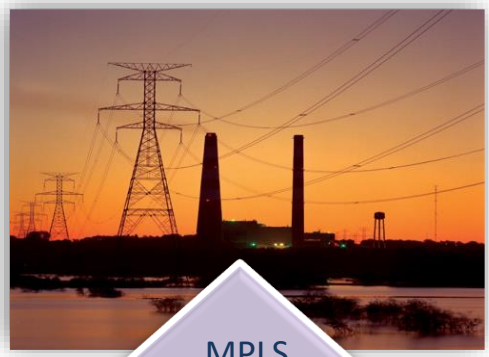
## Zeus


## xGenius

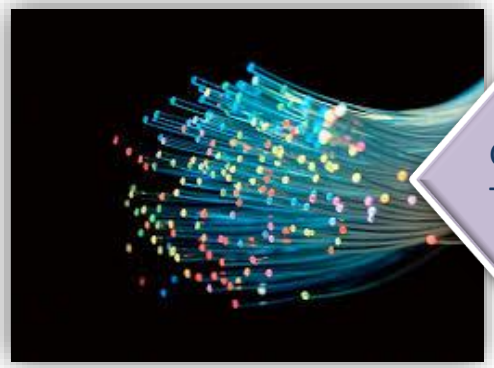

ALBEDO Testers have been designed to deploy infrastructures that manage and protect of new and legacy Power Utilities. From legacy to Smart Grid. **Zeus** and **xGenius** allow in-depth analysis to design, install and maintain communication infrastructures. Both test sets are multifunction devices, capable of verifying Ethernet / IP, PTP, GbE, IRIG-B, T1 / E1, G703, C37.94, GOOSE, SV and MMS protocols. They include one-way delay tests - assisted by GPS - on all interfaces. Special interest are the set of programmable filters to capture data traffic in real time and at high speed that allows protocol analysis, decoding and storage in PCAP.

# Test&Measurement applications

WAN



MPLS
SyncE
E1/T1



GOOSE / SV
TCP / IP

PTP / SNTP
IRIG-B / PPS

C37.94
OWD

IEC 61850

Substation

Teleprotection

# Glossary



**AAA**: Authentication, Authorization, and Accounting
**ACL**: Access Control List
**AP**: Access Point
**Busbar**: Metallic strip or bar, typically housed inside switchgear, panel boards, and busway enclosures for local high current power distribution **C37.94**: TDM interface devoted for teleprotection
**CB**: Circuit Breaker designed to close or open electrical circuit under normal or abnormal conditions. It operates on relays command.
**CBWFQ**: Class-Based Weighted Fair Queuing
**CG**: Connected Grid
**CID**: Individual configuration of each IED
**CIP**: Critical Infrastructure Protection
**CLI**: Command-Line Interface
**CorpSS**: Corporate Substation
**CT**: Current Transformer, used for measurement of current, if too high to apply directly to measuring instruments, a CT produces a proportional current which can be measured and recorded, CT are used in metering and protective relays
**DAN**: Doubly Attached Nodes implementing HSR or PRP
**DAU**: Data Acquisition Unit
**Disconnector**: isolates physically and visually the lines
**DMZ**: Demilitarized Zone
**DCB**: Directional Comparison Blocking
**DCS**: distributed control systems
**DSC**: Differentiated Services Code Point
**ESP**: Electronic Security Perimeter
**Feeder:** Transmits power to the distribution points
**GM**: Grandmaster
**GNSS**: Global Navigation Satellite System
**GOOSE**: Generic Object-Oriented Substation Events is a control model defined as per IEC 61850 which provides a fast and reliable mechanism of transferring event data over entire electrical substation networks. When implemented, this model ensures the same event message is received by multiple physical devices using multicast or broadcast services
**HMI**: Human Machine Interface
**PTP**: Precision Time Protocol
**RedBox**: Redundancy Box
**Relay:** is automatic device which senses an abnormal condition of electrical circuit and closes its contacts and complete the circuit breaker trip.
**REP**: Resilient Ethernet Protocol
**RCT**: Redundancy Control Trailer
**RTU**: Remote Terminal Unit
**SA**: Substation Automation
**SAN**: Singly-Attached Node
**Secondary Lines:** lower voltage side at the substation
**SCADA**: Supervisory Control And Data Acquisition, transmits and receives data from events of controls, measuring, safety and monitoring. Power system elements can be controlled remotely over. Remote switching, telemetering of grids showing voltage, current, power, direction, consumption in kWh, synchronization.
**SCD**: Substation Configuration Description **SCL**: Substation Configuration Language **SNTP:** Simple Network Time Protocol
**Station Bus**: Connects the entire substation and helps provide connectivity between central management and individual bays
**STP**: Spanning Tree Protocol
**SV**: Sampled Values, is a method to read instantaneous values such as currents, voltages, impedances, etc. from CTs, VTs or digital I/O and then transmitted to make them are available for those IED subscribed.
**Switchgear**: combination of switches, fuses or CB to control, protect and isolate electrical equipment
**SyncE:** Synchronous Ethernet
**TLV**: Type, Length, Value
**VT:** Voltage Transformer (see CT)Potential Transformer, gives the reference voltage to the Relay for Over-voltage or Under-voltage Protection
**UCA IuG**: Utility Communications Architecture International Users Group
**VDAN**: Virtual D
**HQoS**: Hierarchical Quality of Service
**HSR**: High-Availability Seamless Redundancy
**IA**: Industrial Automation
**ICS**: Industrial control systems
**ICU**: Intelligent Control Unit
**IEC**: International Electrotechnical Commission
**IEC 61850**: Standard defining communication protocols for intelligent y lectronic devices at electrical substations
**IED**: Intelligent End Device, microprocessor-based controllers of power system equipment, such as circuit breakers, transformers and capacitor banks to enable advanced power automation.
**IRIG**: Inter-Range Instrumentation Group
**ISE**: Identity Services Engine
**L3VPN**: Layer 3 Virtual Private Network
**LA**: Lightning Arrester protects the power grid from electric storms
**MQC**: Modular QoS Command-Line Interface
**MMS**: Manufacturing Message Specification, messaging system for exchanging real-time data and supervisory control information. Allows client such as SCADA, an OPC server or a gateway to access all IED objects **MPLS**: Multi-protocol Label Switching
**MU**: Merging Unit connected to the process bus converts analog data(ie. volts, currect...) into digital information
**NERC**: North American Electric Reliability Corporation
**NIST**: National Institute of Standards and Technology
**NMS**: Network Management System
**OAM**: Operations and Maintenance
**PCP**: Priority Code Point
**PIOC**: Instantaneous overcorrent Protection
**PLC**: Programmable Logic Controller
**PMU**: Phasor Measurement Unit
**POTT:** Permissive Overreaching Transfer Trip
**PP**: Primary Power
**Process Bus**: Connects primary units and control equipment to the IEDs
**PRP**: Parallel Redundancy Protocol
**PRTC:** Primary Reference Clock
**PT**: see VT
**T-GM:** Grand Master PTP
**T-BC:** Boundary Clock
**T-TSC**: Slave Clock

That' all

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ALBEDO

in Test we Trust