Synchronization Implementation in Small Central Offices

1. Introduction:

Small central offices are characterized by a limited set of network elements centered on an end office circuit switching system. In addition to the switch, network elements typically include a 1/0 digital cross-connect system (DCS), transmission interfaces, DSL access multiplexer (DSLAM), modem server and associated packet network (internet) access elements including a router and Ethernet hub. The DCS and DSLAM may be integrated into one network element or different sets of equipment. An interexchange carrier may be collocated in some central offices in which case transmission equipment (usually satellite or microwave radio relay) will be involved. Most central offices also include operational support systems with serial port management and alarm management equipment.

All digital network elements require synchronization. In a synchronous network, all clocks have the same long-term accuracy under normal operating conditions. Historically, digital network elements in a local exchange carrier's central office were loop timed; that is, each network element, such as the end office switching system and primary multiplexers, received timing information from an upstream clock through their respective interface with the transmission equipment. Loop timing was adequate when only one interexchange carrier (for example, AT&T Alascom) was involved in transport.

As additional carriers place facilities and interconnect with local exchange carriers in a given exchange area, the synchronization requirements become more complicated and more demanding. The timing used by each carrier's own network elements almost always is traceable to a primary reference source (PRS) operated by that carrier. With some notable exceptions, the interexchange carriers do not install a PRS in a local exchange area. The process of distributing clocking frequencies by master-slave chains ensures that the accuracy of the first clock in the chain is replicated at the last clock and each in clock in between. In such a configuration, synchronization of all the clocks in the chains are *traceable* to the first clock (Fig. 1).

Different interexchange carriers operate pseudo-synchronously, in which all clocks have long-term frequency accuracy compliant with a PRS under normal conditions but the clocks are not traceable to the same PRS (Fig. 2). This means there are no explicit synchronization paths and no master-slave timing relationship between the different carriers. This often is referred to as plesiochronous operation, in which the carrier's clocks operate at the same nominal rate with any variation in rate being constrained within specified limits. It is clear that such operation is not possible unless all synchronization paths are traceable to a PRS. A PRS provides a synchronization signal that has long-term accuracy of $1x10^{-11}$ or better with verification to UTC (Universal Coordinated Time). All PRSs have Stratum 1 accuracy.[1]

[1] A Stratum 1 clock and PRS are not the same but both have the same accuracy. A Stratum 1 clock, by definition, is autonomous, whereas a PRS can be either autonomous or not. In any case, the PRS must be traceable to a Stratum 1. PRSs based on GPS or LORAN-C are not autonomous but they do meet the traceability requirement. A Cesium beam clock is the only autonomous clock used in telecommunication applications, so it is the only PRS that meets the Stratum 1 definition.

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Fig. 1
Traceable Clocks

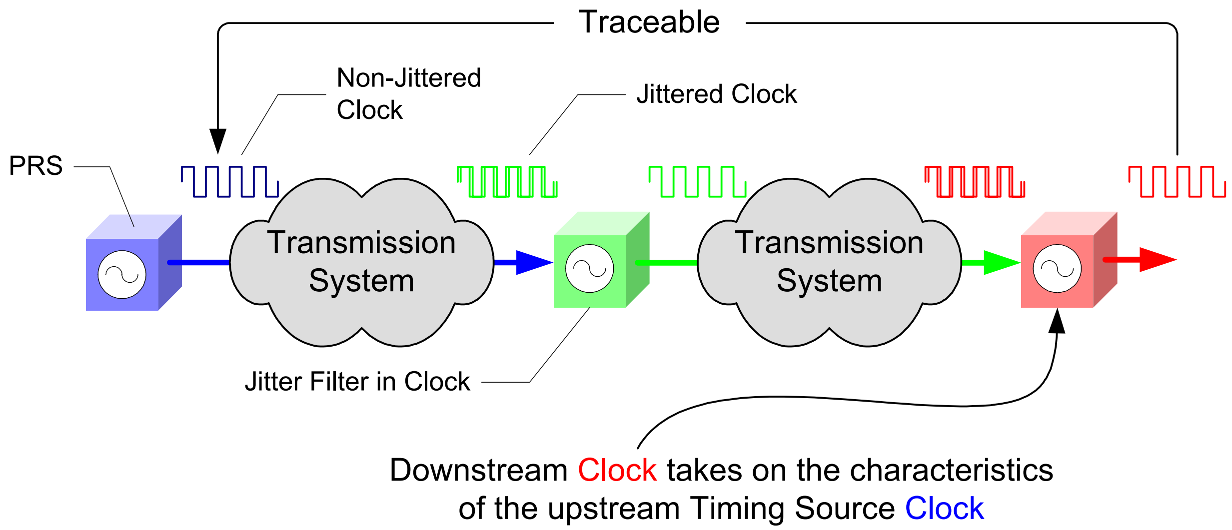
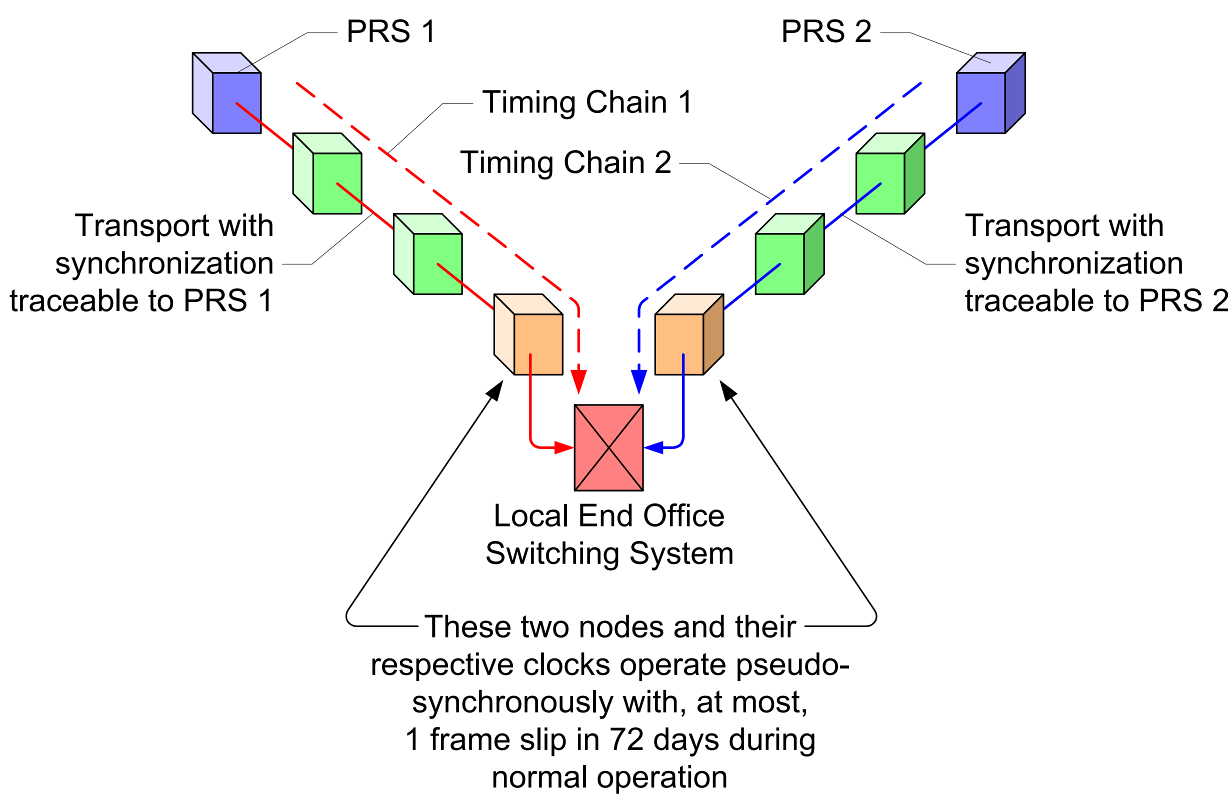


Fig. 2
Pseudo-Synchronous Operation



All carriers claim their synchronization is traceable to their own PRS (except for GCI's small DAMA earth stations). However, the carrier's transport systems may introduce timing impairments. For example, synchronization of various network elements is seriously degraded by the inherent motion of geostationary satellites and the usual clock recovery and regeneration mechanisms in satellite earth stations, all of which introduce jitter and wander. Large buffers normally are used on digital satellite circuits to mitigate the wander effects of satellite motion. Radio relay systems, including repeaters and drop-insert terminals, also introduce wander and jitter but not to the extent of satellite facilities. For additional information on timing issues related to satellite circuits, see [1].

Regardless of the cause of synchronization degradation, it is well known that the only way to resolve the inevitable timing problems that arise when multiple carriers interconnect is by installing a local synchronization system with its own PRS, which allows the local system to operate plesiochronously with the interexchange carriers.

2. Timing Source Characteristics:

In small CO applications, two types of timing signals are required:

- DS-1 – Framed 1.544 Mb/s DSX-1 compatible, for switching system applications; framing may be SF or ESF.
- Composite Clock (CC) – 8/64 kb/s, for primary multiplexer (channel bank, CB) and DCS (also applies to DSLAM if integrated with the CB and DCS).[2]

The framed DS-1 signals are used to synchronize switching systems of all types, SONET terminals (and similar fiber optic terminals) and higher-level multiplexers (except primary multiplexers).[3]

The Composite Clock must be used to synchronize any device that provides digital interfaces for dedicated digital services (DDS) that operate at 64 kb/s and subrate speeds (such as 56 kb/s and lower). This includes virtually all primary multiplexers and 1/0 digital cross-connect systems. The CC provides both a 64 kb/s and 8 kb/s timing component (the latter is provided through intentional bipolar violations in the 64 kb/s pulse pattern). The 64 kb/s component is required for bit synchronization and the 8 kHz component is required for byte synchronization of DS-0A and DS-0B signals.

For proper plesiochronous and pseudo-synchronous operation, the above synchronization signals must be traceable to a PRS. In small central office applications, synchronization signals normally are derived from an oscillator disciplined by a Global Positioning System (GPS) receiver. Such a clock is a radio controlled PRS since the timing information from Cesium beam clocks in the GPS satellites (which, in turn, are disciplined by an ensemble of Cesium beam clocks on the earth) is transmitted to and processed by the receiver. With GPS, all PRSs ultimately are traceable to a common set of clocks.

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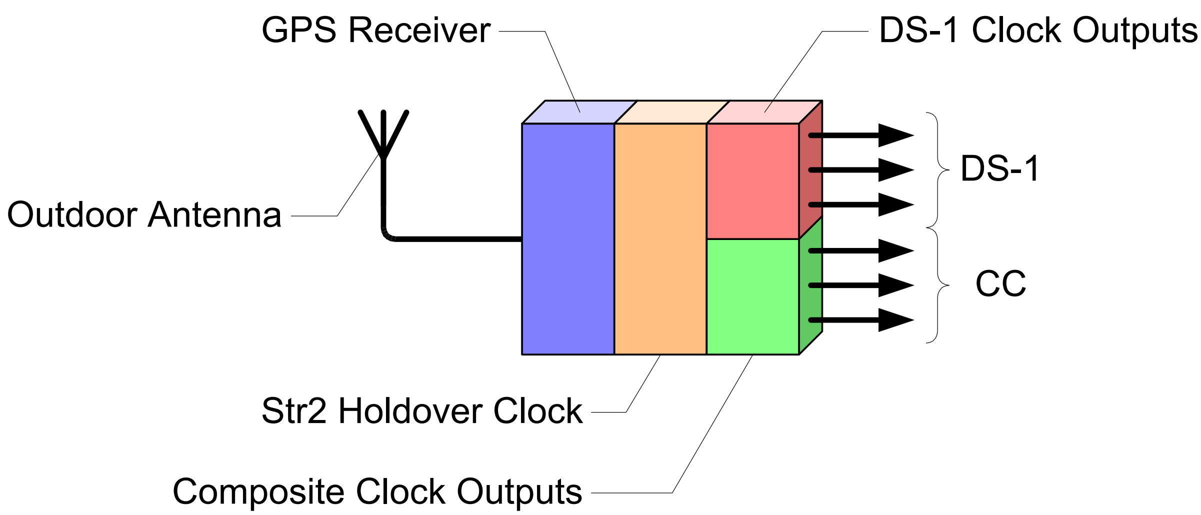
[2] Note that standalone DSLAMs normally do not have any type of external timing input and are almost always loop timed through their optical or electrical interfaces.

[3] Some small end office switching systems, notably the DMS-10 and the Taqua OCX, require a 10 MHz sinewave external synchronization interface.

Prior to late 2000, the oscillator typically was an oven-controlled quartz crystal oscillator, which provided Stratum 3E holdover during GPS outages or GPS receiver failure.[4] The cost of small synchronization systems with rubidium oscillators dropped in late 2000, and it now is possible to obtain Stratum 2 holdover at about the same cost as the original Stratum 3E. In this type of synchronization system, the GPS disciplines a rubidium oscillator, which also includes a quartz crystal oscillator for short-term accuracy purposes. Because of the cost decrease, Stratum 2 now is the recommended holdover clock stratum level for central office applications. It has a holdover stability of $1x10^{-10}$, which will limit DS-1 slips to no more than 1 slip in 13 days during holdover operation.

The PRS and holdover clock drives output cards, which generate the required output frequency and signal format (DS-1 and CC). A synchronization system with multiple outputs and multiple output types is called a Synchronization Supply Unit (SSU).[5] An SSU coupled to a GPS receiver is called a GPS/PRS/SSU in this paper (Fig. 3). As its name implies, the SSU provides synchronization signals to all network elements in a given building, or CO.

Fig. 3
GPS/PRS/SSU

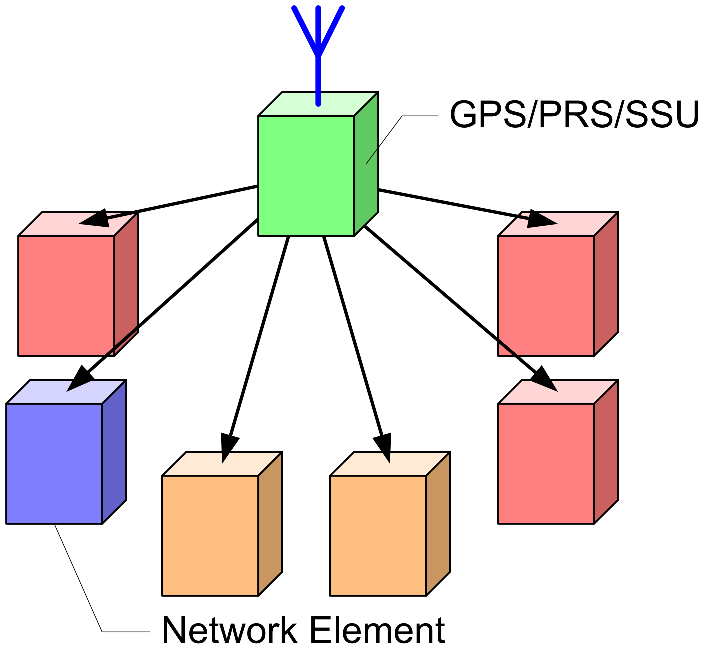


Synchronization signals are transported from an SSU in one building to an SSU in another building. The SSU concept establishes a single control synchronization source in each network node. The direction of synchronization flow always is from a lower numbered stratum level to an equal or higher numbered stratum level. For example, a Stratum 2 may be synchronized by a Stratum 1 or another Stratum 2 but never by a Stratum 3 or Stratum 3E. The SSU is used for all network elements requiring synchronization and always is synchronized to the lowest numbered stratum level clock in the building. For example, if both Stratum 2 and Stratum 3E clocks are available in a central office, the Stratum 2 always is used as the clock source for the SSU, and the Stratum 2 would be synchronized to an upstream Stratum 1 clock. The SSU outputs always

[4] See Sect. 8 for stratum level performance data.
[5] The SSU previously was called Building Integrated Timing Supply, or BITS.

are connected in a star configuration as shown in Fig. 4 (under certain conditions, the Composite Clock may be daisy chained as discussed later).

Fig. 4
Star Configuration for SSU Connection to Network Elements



Fully redundant synchronization systems are expensive and the proposed model does not use them in central offices smaller than approximately 500 access lines. However, the choice of implementing or not implementing redundancy in any particular CO must take into account not only the cost but also the consequences of SSU failure. It very well may be a good choice to implement redundancy is central offices not meeting the proposed 500 line threshold. Redundancy can be achieved by two methods:

- Installing two inexpensive (single-thread) GPS/PRS units with a third shelf for the timing distribution and automatic switchover functions
- Installing one fully redundant synchronization shelf that includes the GPS/PRS/SSU and has integrated automatic switchover functions

There are several variations of these two methods. Redundancy and switchover increases the cost of a timing system by a factor of three. The installed cost of a non-redundant GPS/PRS/SSU is about $10,000, while the installed cost of a fully redundant system with automatic switchover functions is about $30,000.

A desirable alternative to fully redundant synchronization equipment is to rely on one or both interexchange carriers as a secondary clock source. This requires that the GPS/PRS/SSU provide pass-through timing on traffic-bearing DS-1 interfaces. GCI deploys GPS/PRS clocks in its larger earth stations. Therefore, the traffic-bearing DS-1 circuits from GCI's larger earth stations could be used as a secondary timing source.

On the other hand, GCI's small DAMA earth stations *never* should be used as a secondary timing source. The traffic-bearing DS-1 interface in GCI's small DAMA earth stations is a primary multiplexer with Stratum 4 clock (the lowest level of clock performance). If the local exchange CO is not equipped with an SSU, the DS-1 circuits from GCI's small DAMA earth stations never should be used as a primary timing source for the same reason. AT&T Alascom does not deploy PRS clocks in any of its earth stations but synchronization is traceable to its PRS in Anchorage, even in its small DAMA earth stations. As previously mentioned, this source is somewhat degraded and, thus, should be used as a secondary source *only* if the local GCI earth station is not equipped with a GPS/PRS.

3. Timing Sink Characteristics:

Not all network elements have external timing inputs. These implicitly rely on loop-timing (receive- or line-timing). All network elements that have external timing inputs should be connected to the SSU.

Some small switching systems (specifically, Mitel GX5000) do not have external synchronization interfaces (ESI). The Redcom MDX can be equipped with an ESI. The only way to synchronize all Mitel GX5000s and Redcom MDXs without ESI to an external GPS/PRS/SSU is through a digital trunk interface (DTI). The DTI can be either a non-traffic-bearing circuit dedicated to synchronization or a traffic-bearing circuit. The former leads to a somewhat simpler timing scheme but inefficiently uses DTIs and is not recommended for that reason (this is particularly important on the Redcom MDX in which DTIs are very costly).

DS-1 signals require proper termination and normally are wired to DSX-1 jacksets via 1x22 shielded twisted-pair (STP) cables. The DSX-1 is then used to cross-connect the timing outputs to network elements for testing convenience.[6] The Composite Clock outputs from the SSU are wired directly to network elements via 1x22 STP cables.

4. Timing System Configurations:

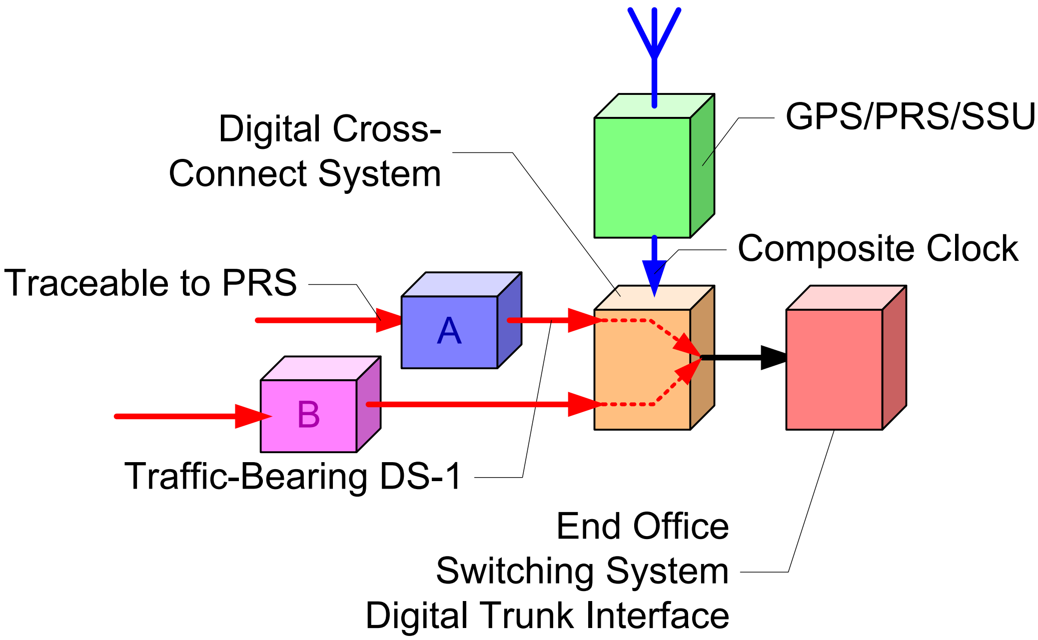
There are two ways to use a traffic-bearing DS-1 for synchronization. These methods only apply to interexchange carrier DS-1 circuits that have timing traceable to a PRS. Neither method applies to DS-1 interfaces connected to GCI's small DAMA earth stations (because the timing is not traceable).

One method connects the traffic-bearing DS-1 from the interexchange carrier via a Digital Cross-Connect System (DCS) to the end office switch DTI (Fig. 5). The DCS, in turn, is synchronized to the SSU and, thus, retimes the DS-1 accordingly. All DCS have buffering equivalent to at least two DS-1 frames, which is adequate for retiming purposes. Many central offices already

[6] In large central offices, where a large number of DS-1 signals are used for synchronization, the SSU timing outputs usually bypass the DSX-1 panels and are connected directly to network elements via dedicated 1-pair cables.

have a DCS as a matter of operational necessity in which a fractional DS-1 from each carrier is groomed into a single DS-1 to the switch DTI. The only disadvantage to this arrangement is DCS failure leads directly to switch timing source failure.

Fig. 5
Digital Cross-Connect System Used to Retime a Traffic-Bearing DS-1



The other method uses a timing insertion unit (TIU). In this case, the traffic-bearing DS-1 from the interexchange carrier is connected through the TIU to the end office switching system DTI. The TIU uses the SSU as its timing reference and, with buffers, retimes the DS-1 interface connected to the DTI (called "pass-through timing"). Depending on the GPS/PRS/SSU, the TIU function may be integrated or external. Fig. 6a shows an external TIU and Fig. 6b shows an integrated TIU. Proper operation of a TIU requires that the synchronization of the traffic source be traceable to a PRS, which normally is the case.

If a non-traffic-bearing DS-1 from a carrier or other source is to be used as a secondary source, it is connected as shown in Fig. 7. Normally, the SSU uses the GPS as the primary source. If the GPS fails, the SSU automatically selects the secondary source.

Fig. 6a
External Timing Insertion Unit Application

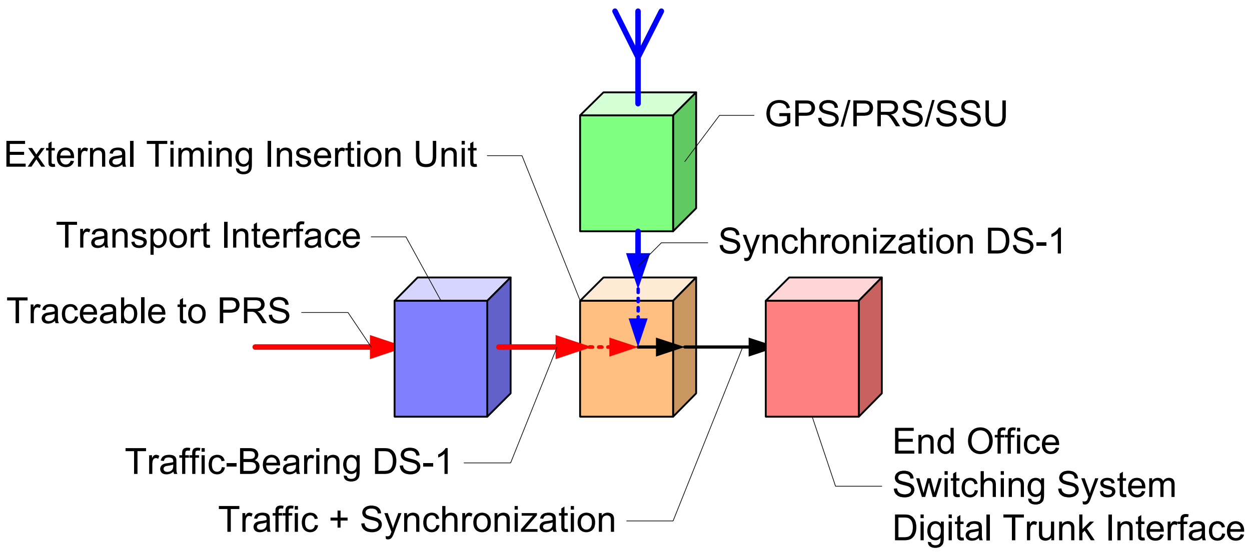


Fig. 6b
Integrated Timing Insertion Unit Application

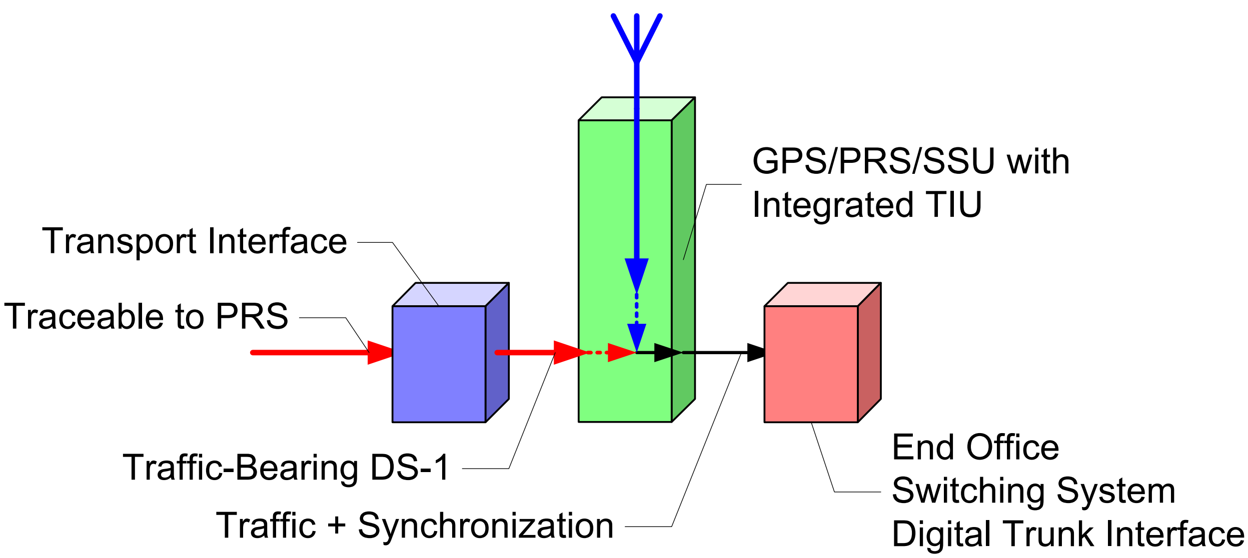
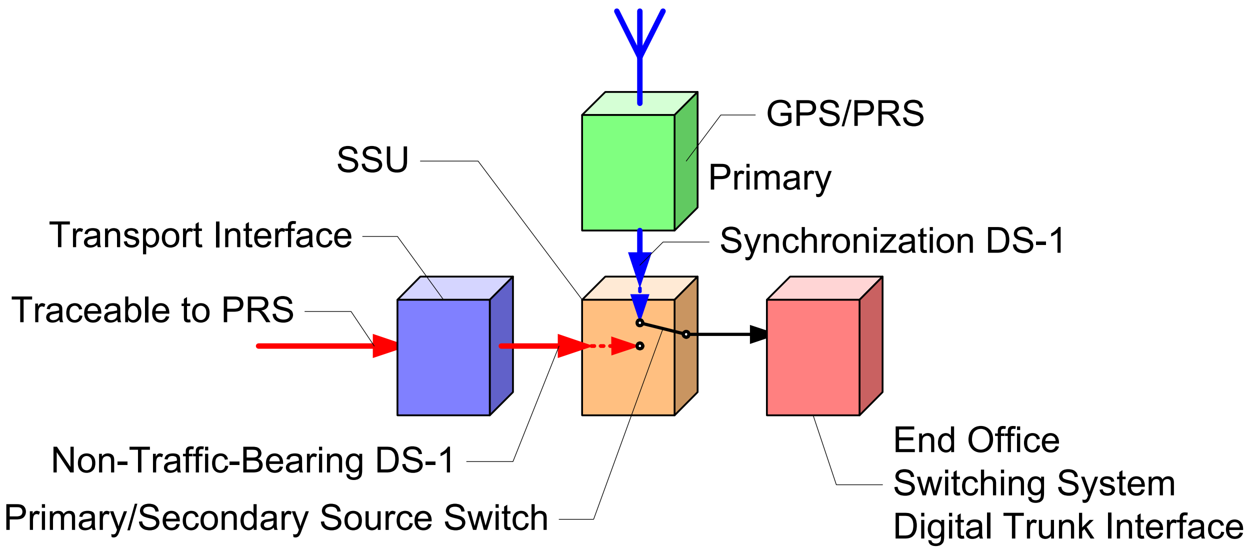


Fig. 7
Application of Non-Traffic-Bearing DS-1 Interface as a Secondary Source



5. Other Considerations:

Proper planning is a fundamental requirement for any synchronization scheme. In particular, it is necessary to avoid timing loops in which the input to a synchronization source is traceable to its output.

In most situations, the PRS will be based on a GPS receiver as mentioned above. In some situations, central offices may be interconnected via optical fiber transport systems such as SONET. By definition, a SONET has a synchronization source traceable to a PRS and, thus, is a preferred synchronization source for an SSU. However, it is important that a DS-1 byte-mapped SONET virtual tributary (VT1.5), or any virtual tributary for that matter, not be used as an SSU synchronization source because a VT1.5 does not meet the jitter requirements of synchronization sources. Instead, a framed DS-1 derived from the optical line signal must be used (referred to as a “derived DS-1”). All SONET terminals provide a derived DS-1 signal for synchronization purposes. The derived DS-1 does not carry traffic of any type.

As previously mentioned, equipment is connected to the SSU in a star configuration. However, if the number of Composite Clock outputs from an SSU is limited, the timing inputs to primary multiplexers can be daisy-chained. If this is done, the differential delay (due to cable length differences) between the clock inputs of all equipment requiring Composite Clocks should be limited to 6.5 µs.[7] For normal 22 ga. shielded cable, this is approximately 400 ft. The maximum cable distance from the SSU to the equipment timing input is limited to 1,500 ft. (22 ga.), and the end of the timing cable must be properly terminated in a 130 ohm termination impedance (this may require an external resistor wired across the timing input or adjustment of a jumper block).

[7] Conversation in April 2001 with Dennis Coleman of QWEST, who experimented with differential delay on SS7 links operating at 56 kb/s.

For DS-1 timing signals, the maximum cable distance from the SSU to the DSX-1 or equipment is 655 ft. (22 ga.) and the termination impedance is 100 ohms.

6. Proposed Synchronization Model:

The proposed synchronization model takes into account the relative costs of timing equipment and the network equipment it supports by trading cost for redundancy. Smaller central offices use a non-redundant configuration while larger central offices use a redundant configuration (Table 1). Table 1 should be used as a general guide since there is no clear central office size threshold between redundant and non-redundant configurations.

Table 1
Characteristics of Proposed Synchronization Model

Central Office Size	Configuration
< ~ 500 access lines	Non-redundant
~ 500 – 2,000 access lines	Either redundant or non-redundant
> ~ 2,000 access lines	Redundant

The basic requirements for GPS/PRS/SSU in small central office applications are:

- Redundancy per Table 1
- PRS based on GPS receiver
- Stratum 2 holdover accuracy
- DS-1 and Composite Clock outputs (minimum 2 each)

7. Equipment:

Four companies that make non-redundant synchronization systems suitable for small central office applications are listed in Table 2. All systems listed are based on GPS and can be configured for Stratum 2 holdover and DS-1 and CC outputs. None of the clocks shown are redundant and do not easily lend themselves to redundancy without external timing switching shelves.

Table 2
Non-Redundant Synchronization Systems for Small Central Offices

Manufacturer	Model	Rack Space	Remarks
Datum	OT-21 series	3.5”	Integral TIU
Larus	STS5800-5	3.5”	Requires external TIU (see note)
Symmetricom	3500 series	3.5”	Requires external TIU (see note)
TrueTime	XL-DC series	1.75”	Requires external TIU (see note)

Note: TIU shelf requires 5.25” rack space

Of the equipment listed in Table 2, only the Datum OT-21 series can be configured with integral timing insertion unit functionality for DS-1 pass-through synchronization. This functionality has to be specified at the time of order.[8] All others require an external TIU, such as the Larus 5620-0, when used with switching systems that do not have an external synchronization interface. Unfortunately, the Larus TIU requires a 12-slot shelf in which only one or two slots are used, leading to an inefficient use of relay rack space.

All manufacturers' GPS antennas are functionally identical and similar in size and include a low noise amplifier. The antenna LNA is powered via the coaxial cable that also carries the GPS signal to the receiver. GPS antennas always are installed outside. The antenna should be mounted where it has a clear view of the sky and away from other interfering antennas.

For operation in Alaska, GPS antennas should have a low temperature rating to at least –40°C (–40°F) with –55°C (–67°F) rating preferable in northern areas. However, most GPS antenna manufacturers indicate their –40°C rated antennas will function normally and are suitable for use at colder temperatures.

The coaxial cable between the antenna output and the receiver input must be protected from transient overvoltages caused by lightning or electrostatic discharge. The protector normally is mounted where the coaxial cable enters the building. The grounding conductor from the protector assembly must follow the most direct path to the earth grounding electrode system. The grounding conductor must be no smaller than #6 copper and must be connected directly to the earth electrode system outside of the building; this grounding conductor should not be connected to the Building Principal Ground Bar (Master Ground Bar).

With some systems, particularly the Larus STS5800, the protector assembly is specially equipped with isolation components because the coaxial cable shield must be ungrounded. This leads to a more complicated installation that must be considered during the system engineering and installation process.

[8] Part Number OT21-0006 (Item Number 25413151-431-0) includes NEBS chassis, SSU (retiming) functions with GPS receiver, 2E rubidium holdover clock, 6x DS1 outputs (2 retimed + 4 output only), and 4x CC outputs via wirewrap terminals.

8. Stratum Levels

Stratum Level	Free-Run Accuracy	Holdover per day in 1st 24 Hours	Slip Rate @ DS-1 rate
1	$1x10^{-11}$	N/A	≤ 1 Slip/72 days
2	$1.6x10^{-8}$	$1x10^{-10}$	≤ 1 Slip/13 days
3E	$4.6x10^{-6}$	$1x10^{-8}$	≤ 7 Slips/1 day
3	$4.6x10^{-6}$	$3.7x10^{-7}$	≤ 255 Slips/1 day
4	$32x10^{-6}$	N/A	N/A

Note: Some manufacturers advertise a Stratum 2E holdover clock. ANSI T1.101 does not specify the performance of Stratum 2E clocks but they presumably are better than the standard Stratum 2 clock.

Definitions:
Free-Run – An operating condition of a clock that has never had, or has lost, external reference input and has no access to stored data that was acquired from a previously connected external reference.
Holdover – An operating condition of a clock that has lost controlling input and is using stored data, acquired while in normal operation, to control its output.
Slip – The repetition or deletion of a block of bits caused by a sufficiently large discrepancy in the read and write rates at the receiver buffer. At the DS1 rate, the block of bits is equal to 192 user data bits plus a framing bit.
Slip Rate – The rate at which blocks of bits (for example, a data frame) are repeated or deleted; the number of slips that occur during a predetermined time period (for example, a day).

9. Calculating Slip Rate

Example 1: Plesiochronous operation with both networks synchronized to Stratum 1 clocks:

Assume Clock 1 is operating at $+1x10^{-11}$ accuracy and Clock 2 is operating at $-1x10^{-11}$ accuracy. The difference between the two is $2x10^{-11}$. This is worst-case plesiochronous operation. At the DS-1 rate, there are 193 bit/frame. Therefore,

$$Time = \frac{193b/fr.}{2 \cdot 10^{-11} \cdot 1.544 \cdot 10^{6} b/s} \text{seconds/fr. slip} = 6.25 \cdot 10^{6} \text{ seconds/fr. slip} = 72.3 \text{ days/fr. slip}$$

Example 2: Operation with one network synchronized to a Stratum 1 clock (Clock 1) and the other network synchronized to a Stratum 2 holdover clock (Clock 2). This would be a typical situation when the GPS receiver in an SSU has failed and the SSU Stratum 2 clock has gone into holdover mode:

Assume Clock 1 is operating at $+1x10^{-11}$ accuracy and Clock 2 is operating at $-1x10^{-10}$ accuracy. The difference between the two is $1.1x10^{-10}$. Using 193 bits/frame,

$$Time = \frac{193b/fr.}{1.1 \cdot 10^{-10} \cdot 1.544 \cdot 10^{6} b/s} \text{seconds/fr. slip} = 1.14 \cdot 10^{6} \text{ seconds/fr. slip} = 13.1 \text{ days/fr. slip}$$

Example 3: Operation with one network synchronized to a Stratum 1 clock (Clock 1) and the other network synchronized to a Stratum 3 holdover clock (Clock 2). This would be a typical situation when an end office switching system is in free-run (not synchronized) and carrying traffic from an interexchange carrier whose DS1 interfaces are synchronized to a PRS:

Assume Clock 1 is operating at $+1x10^{-11}$ accuracy and Clock 2 is operating at $-3.7x10^{-7}$ accuracy. The difference between the two is $3.7001x10^{-7}$. Using 193 bits/frame,

$$Time = \frac{193b/fr.}{3.7 \cdot 10^{-7} \cdot 1.544 \cdot 10^{6} b/s} \text{seconds/fr. slip} = 338 \text{ seconds/fr. slip} = 5.6 \text{minutes/fr. slip}$$

This is equivalent to 255 frames slips/day, which is the maintenance limit for DS1 interfaces in switching systems.

10. References

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T1X1.3/2000-002R1, Technical Report on Synchronization Network Architecture, T1 Committee T1X1.3 (www.t1.org)

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