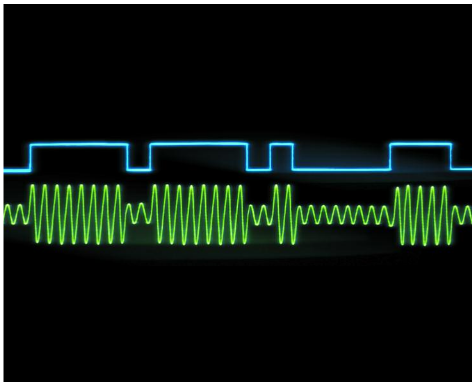
Continuous Satellite Two-Way Time Transfer using Commercial Modems



WHITE PAPER

Continuous Satellite Two-Way Time Transfer using Commercial Modems

T. P. Celano, *Symmetricom*
S. P. Francis, *Zeta Associates*
G. A. Gifford, *NIST*

Abstract
Satellite two-way time transfer has traditionally been used as a periodic measurement of the offset between two-clocks. It is often used as a secondary measurement to GPS or a sole means of time recovery with performance that is superior to GPS time transfer. In this paper, we propose a continuous two-way system based on commercial modems where the two-way time transfer is performed in the background of normal data transfer. The intent of such a system is to provide a cost effective means to achieve high accuracy two-way time transfer in the background of an active data channel. The timing functionality is buried in the administrative portion of the communications channel and thus is provided as a byproduct of data transfer. This provides lower cost, lower bandwidth options for users who require sub-nanosecond time transfer between sites. It also provides a continuous record of clock differences with no impact to data transmission for users who have access to a data communications link.

This paper begins with a review of the concept of two-way time transfer and time based communications and presents the requirements for implementing two-way over a communications channel. The requirements are then satisfied with commercial modems using two examples: an internal implementation and an external implementation. Data is presented for each case and tradeoffs are discussed.

1.0 Two-Day Time Transfer

Two-way time transfer is a simple process by which the time of a clock at one location is transmitted to a clock at a second location where a time difference measurement is made (MEAS1 in Figure 1). In order to eliminate the Propagation delay, the reverse process is performed simultaneously (MEAS2 in Figure 1). Measurement data is exchanged in order to compute the instantaneous clock difference (T_2-T_1 in Figure 1).

There are four requirements for performing two-way time transfer:

- An event to measure, representing the time of a clock
- A low noise measurement of the event
- A means to exchange measurement data
- Slowly changing propagation delay over the measurement interval

The next section describes how these requirements are met using a synchronous data channel.

2.0 Scenarios for Using Tactical LORAN

Time based communications is a concept where the synchronous layer of a data communications channel is used to provide continuous two-way time and/or phase transfer [1]. Most data communications channels employ a synchronous physical layer where the low level functions, like frame synchronization and forward error correction, are performed. The communications data payload (where the users' data is transmitted) can be synchronous or asynchronous but is

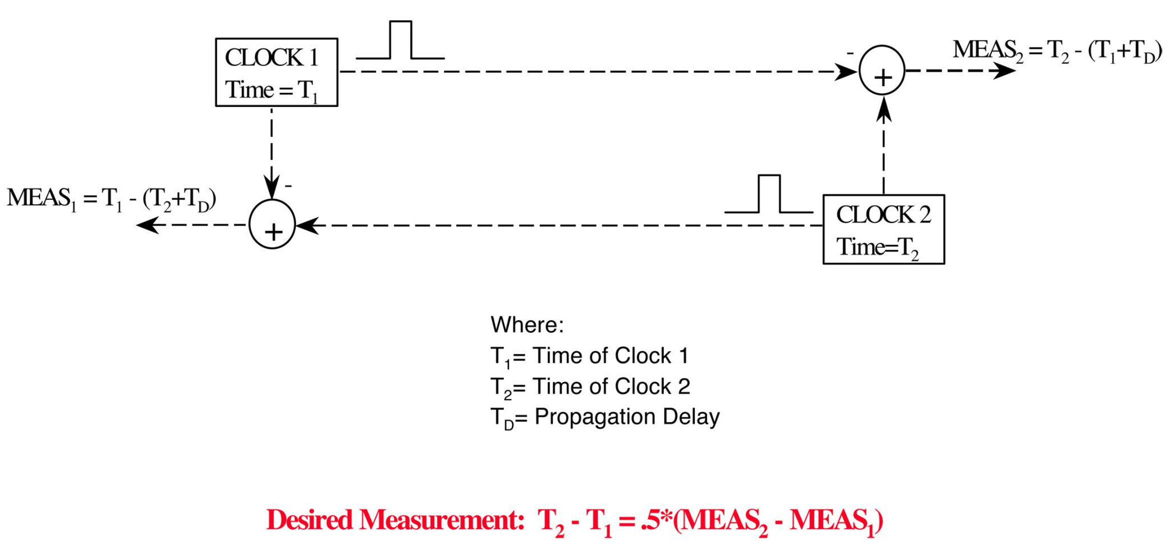


FIG.1 Two-Way Time Transfer

typically built on top of the synchronous physical layer. For point-to-point links, the synchronous physical layer provides a constant delay over short measurement intervals. This constant delay channel is used for two-way measurements.

To satisfy the requirements listed in section 1, some timing functionality must be added to the synchronous layer. The first requirement, an event to measure, is typically satisfied by inserting a known bit pattern in the data stream or by picking a known pattern such as frame sync bytes that is already present in the data stream. The second requirement, a low noise measurement of the event, is achieved by detecting the known pattern in the data stream and generating a TTL pulse upon detection. The TTL pulse can be measured against a user clock using a time interval counter. The third requirement, transmitting measurement data, is easily achieved using the payload or an engineering service channel in the communications channel. The final requirement, slowly varying delay, is satisfied by the synchronous nature of the channel.

The time based communications concepts are generic and can be applied in almost any synchronous channel with slowly varying delay. This includes many different transmission mediums such as satellite channels, fiber, or microwave links. The method is also framing independent and has been achieved with SONET [2, 3], LANET, and on comms links with no framing at all. The remainder of this paper concentrates on the satellite communications application.

3.0 Satcom Implementation

Time based communications implementation over satellite channels is depicted in Figure 2. The data communications functions of the modem are unchanged. That is, the modem is required to establish and maintain the connection in order to transmit and receive data. This includes error correction coding and other signal processing associated with low error rate data transfer. The timing function, depicted in the bottom portion of each modem in Figure 2, requires tasks that are separate from the data communication function. In order to perform two-way time transfer, on-time markers (OTMs) are inserted in the data stream. The OTMs are detected in the send path of one modem as the data is transmitted and in the receive path of the second modem as the data is received. Pulses that are created upon OTM detection are measured at each end of the link and measurement data is transmitted to the other side so the two-way offset can be computed on each side of the link. The same series of events takes place on each end of the link. In fact, near simultaneous transmission (within milliseconds for geosynchronous satellites) is required for the path delay to the spacecraft to cancel at the nanosecond level.

Depending on the level of access to the modem, the insertion and detection of the OTMs can be accomplished externally or internally. The technology for each case has been demonstrated with different modems. Examples of each method are presented in this paper.

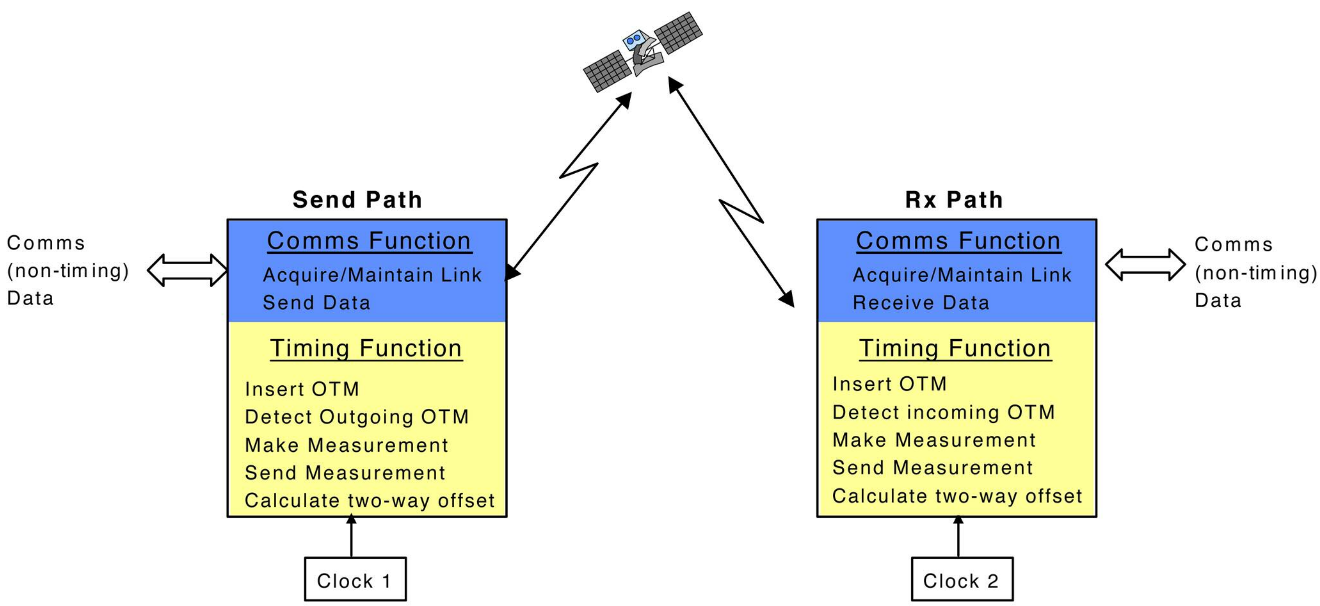


FIG.2 Satcom Two-Way Implementation

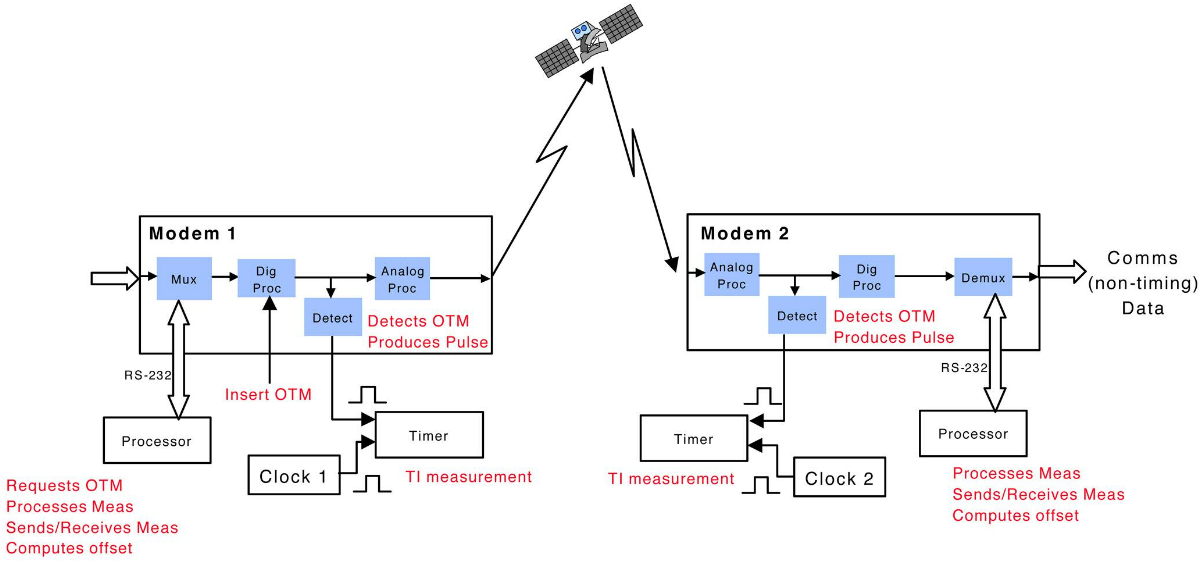


FIG.3 Internal OTM Insertion

3.1 Internal OTM Injection Method

Internal implementation requires modifying a modem that is normally only used for data communication. Figure 3 shows the functions required both inside and outside the modem in order to facilitate the two-way process. The additional requirements levied on the modem are to insert an OTM pattern when requested and to detect the OTM pattern as it leaves the transmitter or arrives at the receiver. How the insertion/detection is accomplished within the modem architecture is immaterial as long as the modem demonstrates constant and repeatable delay through link drops/acquires and power off/on.

In the system depicted in Figure 3, OTMs are requested by an external processor and inserted by the modem. Since the OTM is detected upon transmission and reception, latency between the request and the insertion of the OTM is not an issue. The OTMs are detected in the modem and a pulse is generated by the modem upon detection.

This pulse is measured against the local clock using a low noise timer. The measurement is computed using the external processor and measurement data is passed across the link using an engineering service channel in the modem. An engineering service channel is a low speed auxiliary channel that is multiplexed in with the user data. The engineering service channel is typically used for administrative functions required to administer the communications link. In this case, 100 bytes each second are passed over the engineering service channel to communicate measurement data.

Data was collected using the internal method in a Radyne/Comstream modem with both ends of an X Band link at the same location (representing a calibration of system biases). The link was a 512 Kbps QPSK channel with concatenated coding (Viterbi 7/8 and Reed/Solomon). The system was run over a 12 hour period with OTMs requested each second and averaged to produce a continuous two-way offset plot. The result of the measurement is illustrated in Figure 4. With the exception of outlier rejection and removal of the mean, no postprocessing of the data has been conducted. Figure 4 shows an RMS of .8 ns using a sliding average of 150s.

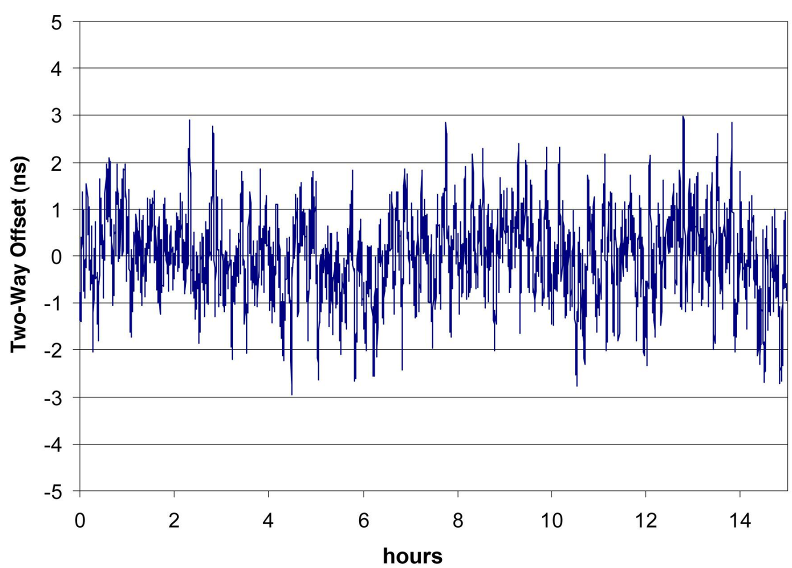


FIG.4 Satellite Two-Way Time Transfer Performance using Internal Method

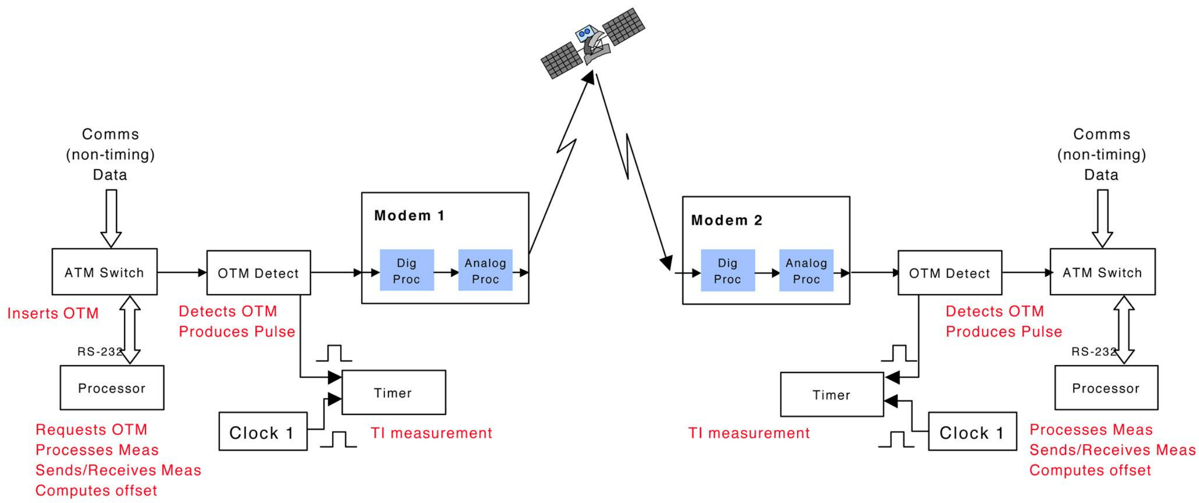


FIG.5 External Implementation

3.2 External OTM Injection Method

External implementation requires that the OTMs be inserted and detected outside the modem by auxiliary hardware. The hardware configuration used to do this is illustrated in Figure 5. In order to detect OTMs external to the modem, a framer was designed that acts as a buffer amp in the baseband bit stream. The framer creates a copy of the bits and correlates the copy against the OTM pattern. When the OTM pattern is detected, a TTL pulse is generated and measured against the local clock using a precision timer. Data collected from the timer is transmitted across the link to the other side in the user data channel. The data source in Figure 5 is an ATM switch that utilizes the LANET [4] protocol for data framing. The LANET frame, depicted in Figure 6, includes frame sync bits that are used for the OTM. The OTM can be chosen as any known pattern in the bit stream. No pattern is going to be unique, but bit patterns can be chosen to minimize false detection.

Frame synchronization bits, which are typically present in every framing protocol, can be used as OTMs. The frame synchronization bits are convenient because they are inserted by the data source and need only to be detected in the bit stream.

An overnight run using the external method was conducted using a Ku Band link. QPSK modulation at a bit rate of 768000 (symbol rate of 384000) was used which corresponds to the bit rate of the payload of 1/2 of a T1. One end of the link was in Washington DC and the other was in California. Data was collected every second and averaged to produce a continuous record of the two-way time offset. The mean and the slope of the data has been removed to allow observation on a smaller scale. Since the measurement was made between two un-steered HP 5071s, it is appropriate to remove a constant drift between the clocks to examine the quality of the measurement. The drift is removed by fitting a linear curve to the data set and then computing the residual to this curve. The resulting data is seen in Figure 7. The RMS of the raw 1s data is 6.5 ns. Processing the raw data with a block average produces the curve in Figure 7 that has a 150 second RMS of 1ns.

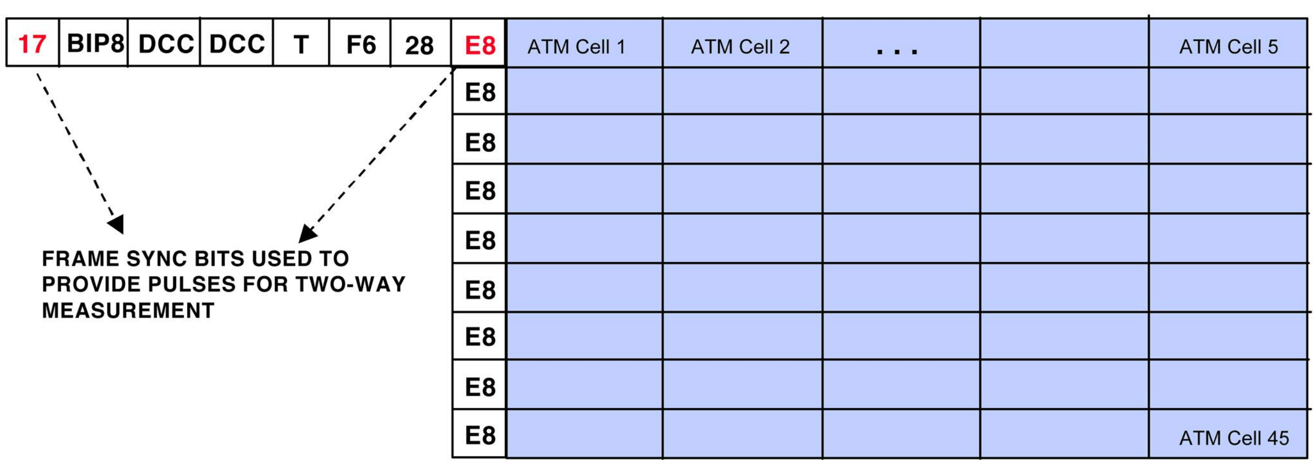


FIG.6 LANET Frame Structure

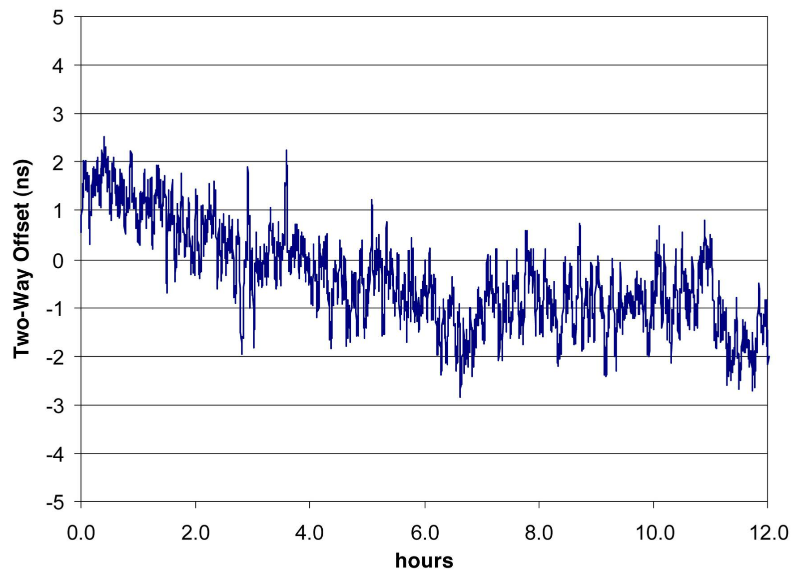


FIG.7 Satellite Two-Way Time Transfer Performance using External Implementation

Absolute calibration of the system is an issue for the external case. There are variable delay sources in both the send and receive paths of the modem. A FIFO buffer in the send path of the modem results in a variable delay. The resolution of the delay variation is one bit at the data rate (for T1 it amounts to 1/1536000 or 651ns). In order to account for the unknown delay in the modulator path, an additional measurement for delay calibration is required. The additional measurement is the propagation delay of the know bit pattern from the modem input to the input of the D/A converter in the send path of the modem. This creates the following restrictions:

1) No signal processing that changes bits (like scrambling or error correction coding) can be used
2) An external device (such as an oscilloscope) must be added to the hardware in order to determine the delay in the modulator.

The first restriction is severe for data communications users. Virtually every communications link uses scrambling as well as some form of error correction coding. The restriction that this coding cannot be used makes the external method very difficult to field on real comms links.

4.0 Summary

Continuous satellite two-way time transfer has been demonstrated using commercial modems. The methods used allow the timing function to be performed in the background of the data transfer function without impact to the data user. Sub-nanosecond level performance was demonstrated with two different modems and two different methods. The internal OTM injection method provided the best balance of time transfer and data communication with the modem being used to its full communications capacity while providing sub-nanosecond time transfer. An external OTM injection method was also presented with nanosecond level time transfer. The external method has the disadvantage that error correction coding and scrambling cannot be used when absolute calibration is required. The use of commercial modems for two-way time transfer provides a low-cost option to timing users who can leverage off existing or planned comms links to achieve time synchronization between sites. It can also be considered as a lower cost solution for current two-way users as the bandwidth requirements are smaller and the equipment costs less than current modems that are designed for dedicated two-way time transfer.

5.0 References

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Symmetricom
SYMMETRICOM, INC.
2300 Orchard Parkway
San Jose, California
95131-1017
tel: 408.433.0910
fax: 408.428.7896
info@symmetricom.com
www.symmetricom.com