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A NEW TWO-WAY TIME TRANSFER MODEM

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Abstract

The use of commercial communication satellites for precise time transfer has been performed with a variety of techniques for a number of years. Military communications systems can also provide this function in a few deployed systems. This paper will demonstrate a new design of a time transfer modem that can be produced at a reasonable cost and enable users to make direct comparisons with the Naval Observatory with nanosecond precision. A flexible all–digital design is being implemented that will enable a variety of different codes to be employed. The design and operating modes of this equipment are demonstrated.

Introduction

Papers have been presented at the 1989 and 1990 PTTI meetings describing the hardware and the digital signal processing design of the NRL-USNO Two-Way Time Transfer Modem. This paper is intended to show the present status and preliminary results.

TWO-WAY TIME TRANSFER MODEM SOFTWARE OPERATION

The software for the Two-Way Time Transfer Modem allows for autonomous operation of the system. It handles the scheduling of time transfers, storage of the data, and post processing of the data. What will be described in this section is the operation of the software and how data is moved around.

The modem is controlled with a PC/AT type computer. The computer handles the user interface, scheduling of time transfers, and post processing of the data. The PC/AT is equipped with a VGA type display, a floppy disk drive, a hard drive, and keyboard. The modem consists of a digital signal processing card, a digital modem card, and an analog interface as shown in figure one. The PC/AT computer and digital signal processing card communicate to each other through dual port memory.

Operation of the modem is controlled by the PC/AT through the dual port memory. Various locations of the dual port memory are allocated to specific functions. Some memory locations store the parameters of the modem such as carrier frequency, code rates, and code sizes. This allows easy reconfiguration of the modem without changing the software. About three-fourths of the dual port memory is allocated to data being transmitted and received.

There are two memory locations that control the operating modes of the modem. One location is called 'modem control.' The other location is called 'modem mode.' 'Modem control' is controlled by the PC/AT. The PC/AT puts a number in this location to control the operating mode of the modem. 'Modem mode' is a memory location that is set by the digital signal processor showing what mode it is presently in. The operating modes are setup in a way that the PC/AT can set the 'mode control' to the desired operating mode and the digital signal processor will increment through all of the modes until it reaches the desired operating mode. There are eleven operating modes defined to this point and more will come as the software matures. The operating modes are defined in table one.

Table 1. Operating Modes

0 Power up mode, DSP waits for PC/AT program to boot.
1 Initialize transmitter and synchronize the internal lock system timing with an external clock source.
2 Idle mode, stay off air and keep system time.
3 Initialize receiver section of modem, adjust the receiver attenuator so the A/D is not saturated.
4 Search for signal in frequency and time.
5 Verify search by trying to find the signal peak again.
6 Adjust the carrier NCO to the signal frequency.
7 Track carrier and code.
8 Search for data sync block and track carrier and code.
9 Search for station ID, do one-way time transfer.
10 Perform two-way time transfer.

The first operating mode is '0.' The digital signal processor sets the 'modem control' and 'modem mode' to zero so that it can wait for the PC/AT to initialize itself. When the system powers up, the PC/AT first loads the digital signal processor software and starts up the digital signal processor. It then loads the modem control software. In the mean time, the digital signal processor is executing its software and has accomplished preliminary initialization. Before the PC/AT has loaded its software, the digital signal processor is waiting for the PC/AT to set the operating mode. If the PC/AT hasn't set the operating mode, the 'modem control' memory location has an undefined number in it and can cause the digital signal processor to step through the operating modes prematurely. That is why the digital signal processor sets the memory locations to zero. After that, the 'modem control' memory location is set only by the PC/AT.

Mode one is used to initialize the transmitter section of the modem. The transmitter section is synchronized to the 1 PPS source once and then generates its own 1 PPS. It is assumed that the clock providing the 1 PPS is also providing a coherent 5 MHz signal. The 5 MHz signal is multiplied to 25 MHz in the analog hardware. The phase of the 5 MHz signal is adjusted so that the positive edge of the 25 MHz matches the edge of the input 1 PPS. The 25 MHz provides the system timing. Once the transmitter is synchronized to the 1 PPS, the external 1 PPS signal is not required. After the transmitter circuit has been started, even though it is not transmitting to the satellite yet, the time of day can be kept.

The next mode, mode two, is the idle mode. The modem only keeps track of time and waits for a new mode. This mode is used only when a time transfer is not scheduled.

Mode three initializes the receiver section of the modem. The receiver NCO is set to about 2.5 MHz, and the code generator is loaded. The input to the receiver circuit is turned on so any signal received by the VSAT is sent to the analog to digital converter (ADC). The ADC has a bit to signal when it is saturated. The digital signal processor adjusts the receiver attenuator while monitoring the saturation bit. The modem is then ready to move on to the next mode.

Searching for a signal is done in mode four. The search is performed in a two-dimensional space through frequency and time. It performs a frequency search by way of an FFT operation. The search through time is by shifting its reference code against the incoming signal. An FFT is performed on each shift of the code. The code is shifted about one and a half code lengths. The maximum peak found is recorded for verification.

Mode five performs another search for the signal. This mode is the verification mode. Instead of searching for one and a half code lengths, the search stops when a peak in the signal is found that is equivalent to the peak found in mode four. The carrier offset found in the search is passed to the next mode. When the reference code matches the incoming signal code, the modem goes to the next mode.

In mode six, the carrier NCO is set to the incoming signal's carrier frequency to within 304 Hz. The digital signal processor acquires samples of the signal and makes a finer adjustment of the carrier NCO to a small offset.

Mode seven is another type of idle mode except that it runs the carrier tracking loop and the code tracking loop. Remember that while all of these operations have been going on, the modem is still keeping track of time.

In mode eight, the modem searches for a sync word in the data message. The word is a unique combination of ones and zeros. The hexadecimal representation of the sync word is FFFF0000h. This places a restriction on the rest of the data in that the data cannot in any way or combination appear as the sync pulse. This is overcome by aligning the data in thirty-two bit blocks. ASCII formatted data is aligned in eight bit characters and grouped in multiples of four characters. Data such as a time tag or time of arrival measurement are sent as binary integers. The integers or combination of integers can appear as a sync pulse. This is taken care of by determining the maximum number of bits required by the data and limiting the data to that size and adding an offset that only uses the unused bits of the thirty-two bit data integer. If the digital signal processor cannot find the sync pulse in five seconds, it starts over at mode four to reacquire the signal.

After the sync pulse is found, the modem can move up to mode nine. In this mode, the digital signal processor extracts the station identification information from the data and determines if it is the correct ID. If the incorrect ID is being received, the modem will keep extracting the ID from the data until the correct station ID is received. Then the next mode will be executed. While the modem is waiting for the proper station ID, it will be performing time of arrival measurements.

Finally in mode ten, a complete two way time transfer can proceed. The modem will continue making time of arrival measurements and transmit its result to the other site. At the same time it will record the other sites data transmissions along with its own transmission for post processing. The modem remains in mode ten for three hundred seconds and then returns to mode two until the next time transfer is scheduled.

A two- way time transfer requires that one modem have control over the communications of the other modems. Assuming USNO is a master site for the two-way time transfer, USNO will be performing the time transfer with more than one other site. This requires control over which sites may transmit. Only one site may transmit with the master station at one time. This is the reason for station IDs. What will be described is the operation of a time transfer between the master site and two target sites. The operating modes of both modems will be modified slightly from what was described earlier.

TIME TRANSFER OPERATION

Assuming that all of the modems have been powered up and initialized, they will be idle in mode two. The transmitter output is turned off so the target sites will not transmit a signal to the satellite. At some time, the target site PC/ATs will determine that it is time for a time transfer. The target site PC/ATs will set the 'modem control' memory location to mode ten, a full two-way time transfer. The digital signal processor cards will detect the change in memory and proceeds to mode three and then mode four. It will stay at mode four until a signal from the master site has been detected. The transmitter signal is still off.

In the mean time, the master station is sitting idle at mode two. It's transmitter output is turned off. When the master station PC/AT determines it is time for a time transfer, it will turn on the transmitter and select the target site to do the time transfer with by transmitting the target's ID. The master station moves to mode three and then four. It will keep searching until the selected target starts transmitting.

Now that the master station is transmitting, the target stations will eventually find the master station signal and start tracking it. The target stations will find the sync word and start looking for the ID in the master data being transmitted. When the one target station recognizes its station ID, it will move to mode ten. At mode ten, the target will start transmitting back to the station. The other target stations do not transmit and stay in mode nine.

Now that the target station has started transmitting, the master station tries to acquire the target's signal. Eventually the master station will reach mode nine. In mode nine, instead of looking for its own ID, the master station looks for the targets ID. The transmitting target station must transmit its own ID. If the master station determines that the wrong target is transmitting, it will shut off its transmitter. This will cause the target station to lose signal lock and drop down to mode four. This mode change makes the target station to shut off its transmitter. The whole process will then start over.

When both sites are at mode ten, they will perform a two-way time transfer. This will last for 300 seconds. The two sites will only transmit data when both are at mode ten. There is a 32 bit word in the data message that indicates when the site is ready to receive data. When handshaking indicates that one of the sites is not at mode ten, the only information that is updated in the data message is the seconds of the day time tag and the status word. All of the other information is not updated.

When the time transfer is completed, the master station will simply change the station ID to select another target. The previously selected target will notice the ID change and immediately drop to mode nine and shut off its transmitter output. The newly selected site will then begin transmitting and perform the time transfer.

Eventually the site's PC/AT will determine that time has elapsed and set the modem to mode two. At this point each site can proceed to process its data.

TRANSMITTING AND RECEIVING DATA

The data to be transmitted and received are placed in dual port memory. There is enough dual port memory allocated for fifty seconds of data transmission. Twenty-five seconds of data is available for receiving. This is obviously not enough for a 300 second time transfer. A technique called a circular buffer has been implemented with the memory.

The memory for transmitting data is preloaded with auxiliary data. The digital signal processor, when in mode ten, transmits the data over and over. The preloaded data is repeatedly transmitted every fifty seconds. Various preallocated locations in the data message are updated with measurements and a time tag every second.

On the receiving side, the data being stored is written over every twenty-five seconds. Since each second brings a new measurement, the data has to be saved before it is overwritten, The PC/AT monitors the receive data buffer and saves the data every twenty-five seconds. During the time transfer, the PC/AT saves the data in its memory. After the time transfer, the data is saved to disk.

Testing

Preliminary tests on the modem have been conducted but have not been completely analyzed. These tests were both bench and satellite tests. Additional tests are planned to investigate known problems and to study temperature, signal level and cross correlation problems.

The bench test used four different configurations of clocks and cabling. Stability and range rate sensitivity were investigated by using common or separate clocks. The 70 MHz cabling between the modem on the bench used both common and independent connections to investigate the cross correlation effects of the two signals. All bench test were done with very strong signal levels to look at systematic effects. Refer to Tables two and three.

Preliminary satellite tests were conducted with two modems and one VSAT to ease coordinate problems. The test used a common clock.

The data from each modem and the combined modem data was examined for residual noise by performing a least squares linear fit. The residual noise was calculated and plotted.

Results

In the single oscillator bench test, the residual plots showed a clean straight line without a slope. The rms modem noise was less than 100 picoseconds. (Figures 1, 2, and 3).

In the dual clock test, the modems have their own oscillator. The resulting plot showed the noise was not white. The use of two cables for modem communication did not change the data. The level of this problem was about 1 nanosecond peak to peak and about the same on both modems. It is not known if this is a hardware or software problem. (Figures 4, 5, and 6).

Data from the satellite test showed a parabola on both modems, this showed the presence of an acceleration term in the range and did not appear in the combined data. The satellite test showed an anomaly only in the data from the right modem. This anomaly is not a cross correlation problem because the code was generated by the same clock and the path is delayed by the same varying amount. Without this anomaly the quality of the time transfers was about 300 picoseconds rms. (Figures 7, 8, and 9).

Table 2.

TEST #	CLOCKS	PATH	FILE NAME
1	ONE	ONE WIRE	11111511
2	ONE	TWO WIRES	12131411
3	TWO	ONE WIRE	21081511
4	TWO	ONE WIRE	21091511
5	TWO	TWO WIRES	22141411
6	ONE	SATELLITE	11112511
7	ONE	SATELLITE	11122511

Table 3.
MODEM NOISE IN SECONDS

TEST #	LEFT MODEM LINEAR FIT	LEFT MODEM PARABOLA FIT	RIGHT MODEM LINEAR FIT	RIGHT MODEM PARABOLA FIT	COMBINATION LINEAR FIT	COMBINATION PARABOLA FIT	OSCILLATOR OFFSET
1	9.8E-11	9.8E-11	1.5E-10	1.5E-10	9.0E-11	8.9E-11	0.
2	9.3E-11	9.2E-11	9.9E-12	8.9E-12	4.7E-11	4.6E-11	0.
3	2.6E-10	2.6E-10	2.4E-10	2.4E-10	2.6E-10	2.4E-10	1.1E-10
4	2.8E-10	2.4E-10	2.8E-10	2.7E-10	1.9E-10	1.9E-10	2.2E-10
5	2.9E-10	2.1E-10	2.0E-10	2.0E-10	2.7E-10	1.4E-10	2.8E-10
6	5.3E-10	2.2E-10	6.9E-10	4.5E-10	2.6E-10	2.6E-10	2.7E-9*
7	5.5E-10	2.2E-10	7.9E-10	5.5E-10	3.1E-10	3.1E-10	2.6E-9*

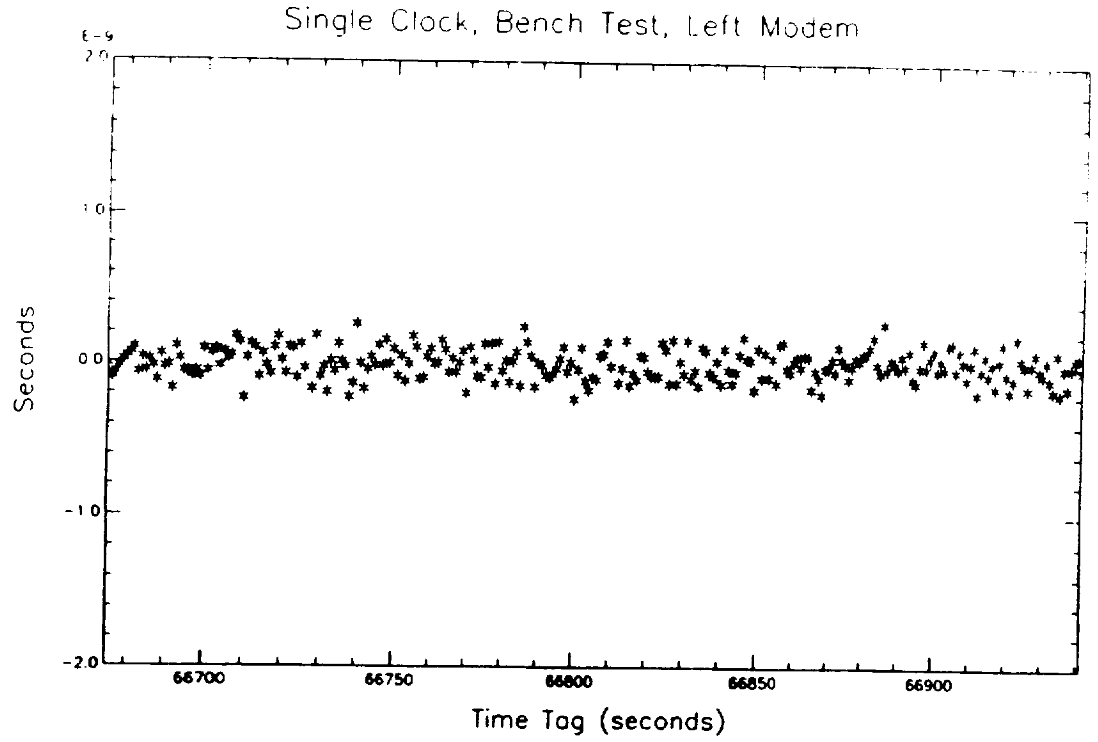


Figure 1

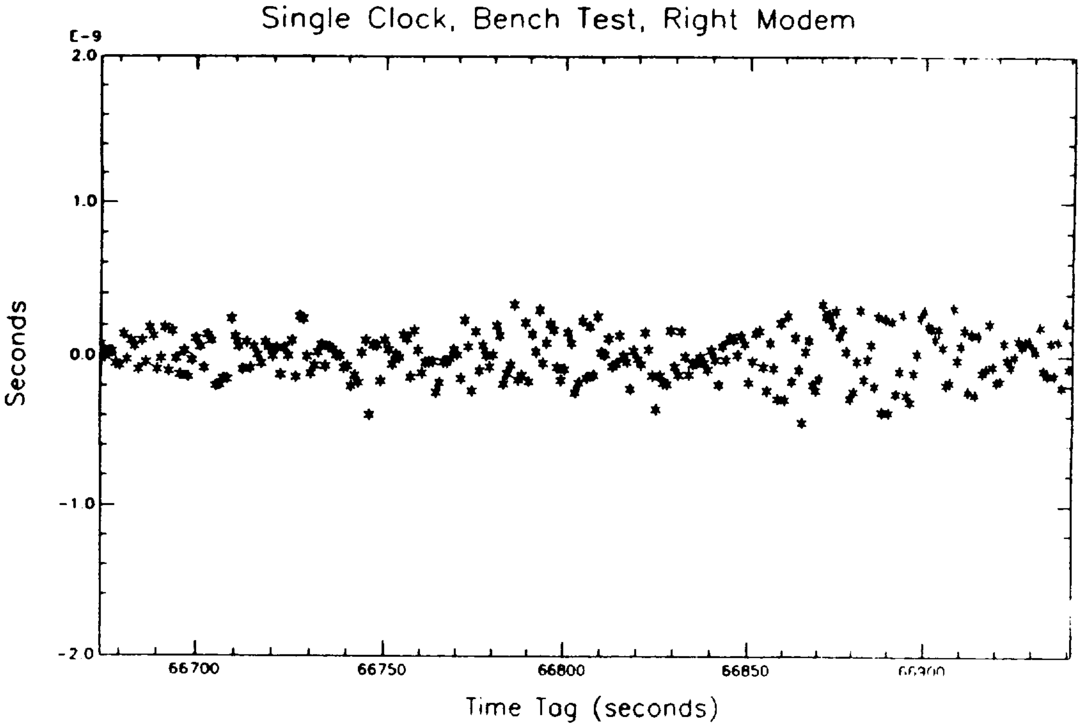


Figure 2

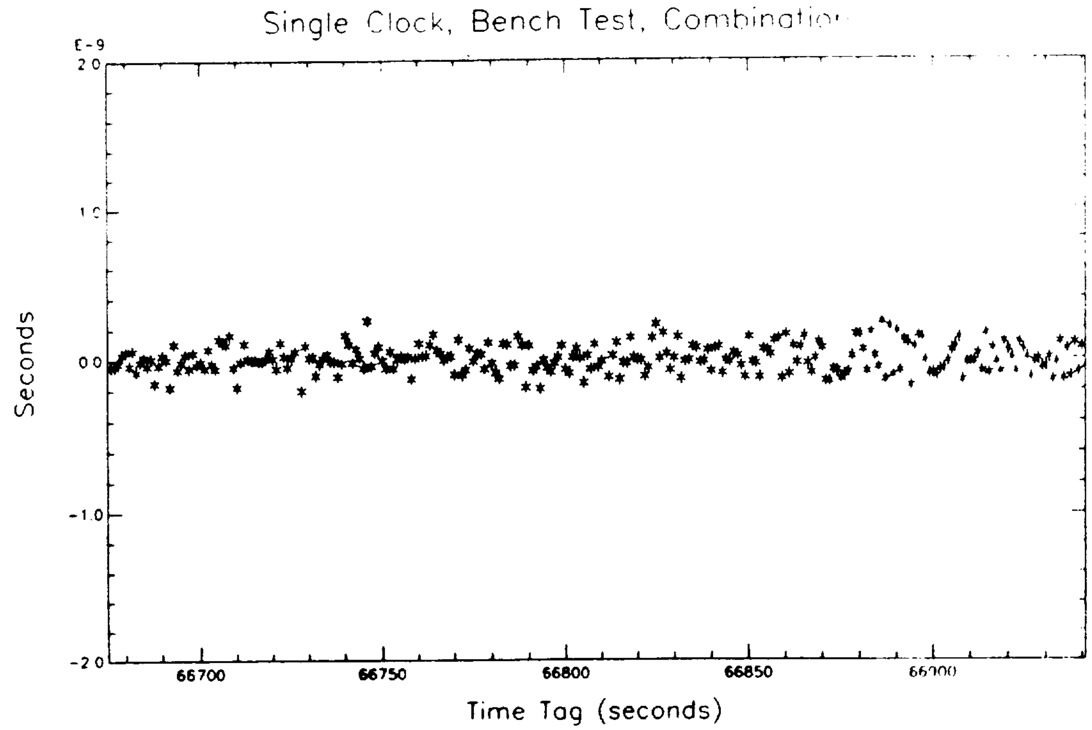


Figure 3

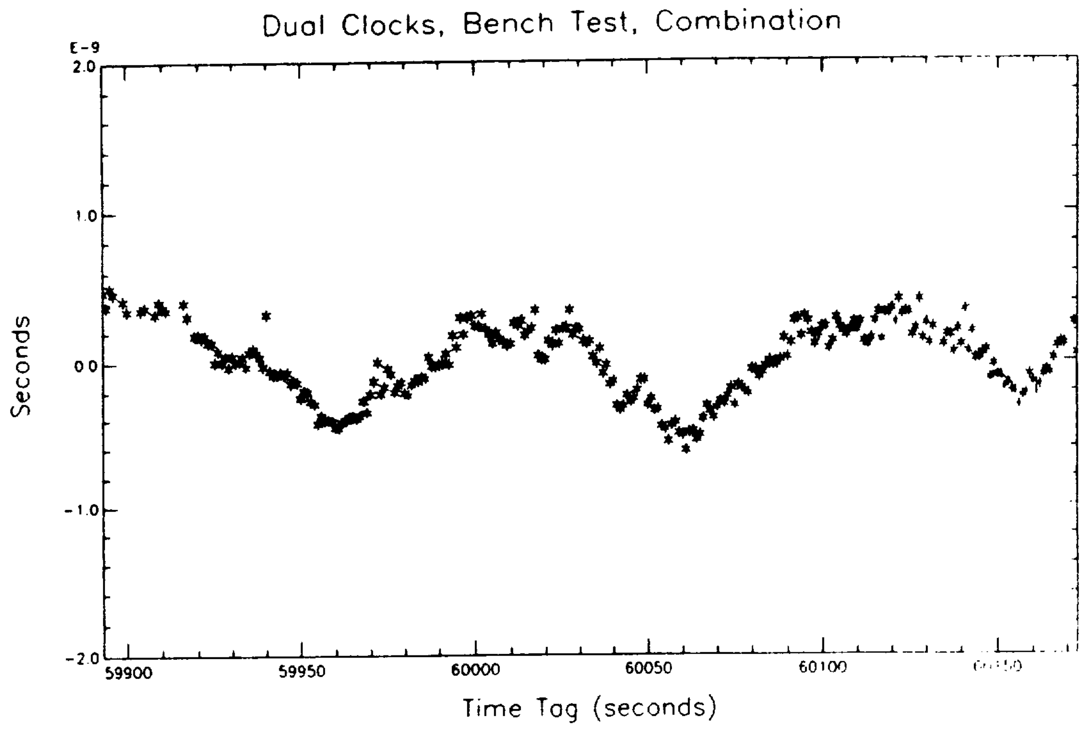


Figure 4

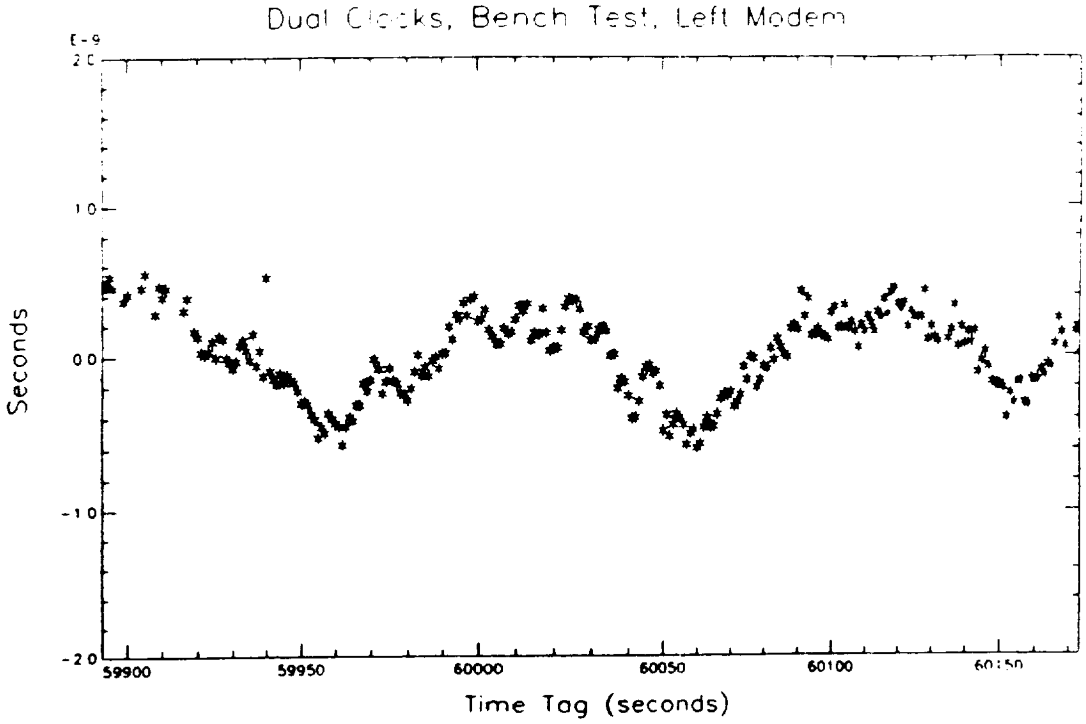


Figure 5

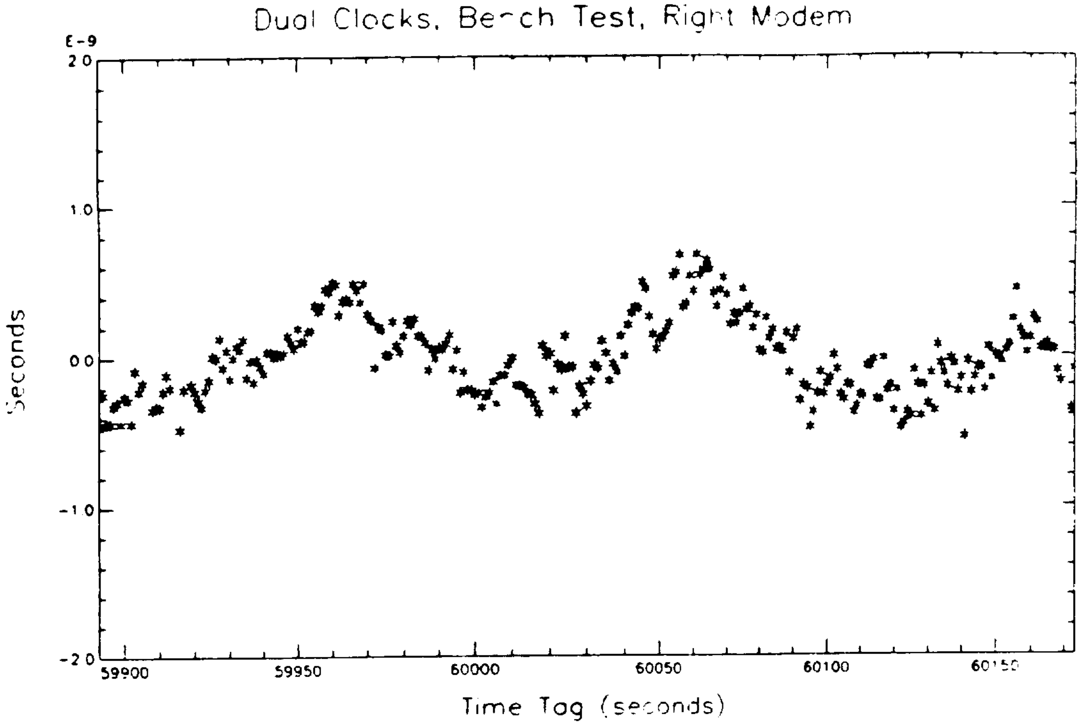
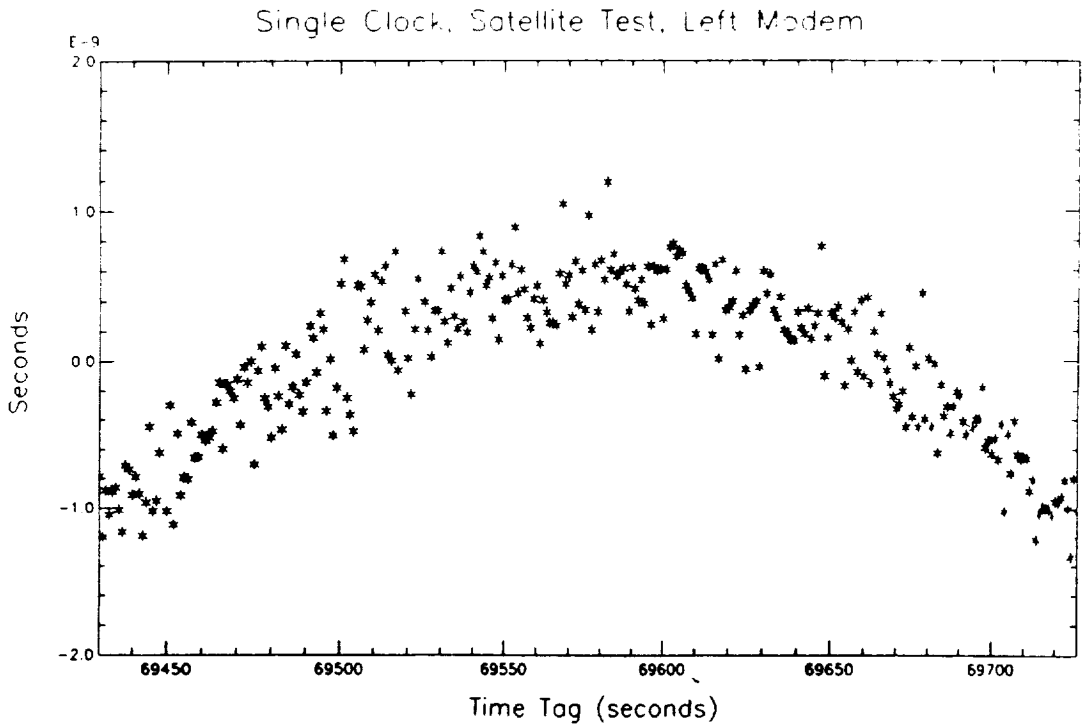
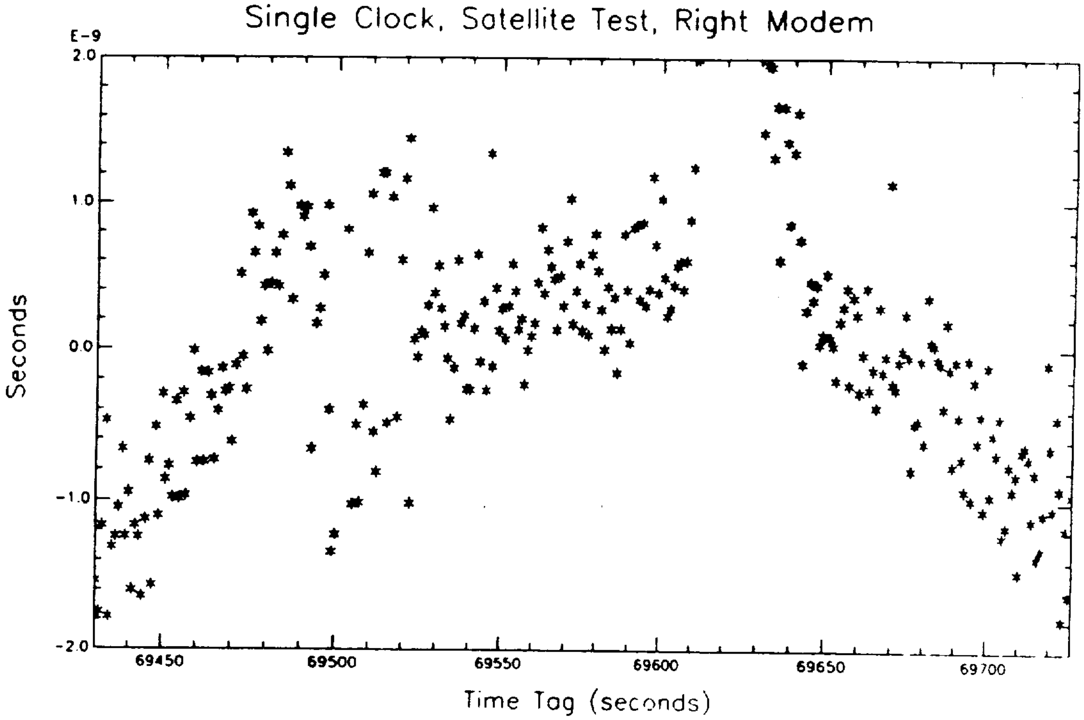


Figure 6



Single Clock, Satellite Test, Left Modem

Figure 7



Single Clock, Satellite Test, Right Modem

Figure 8

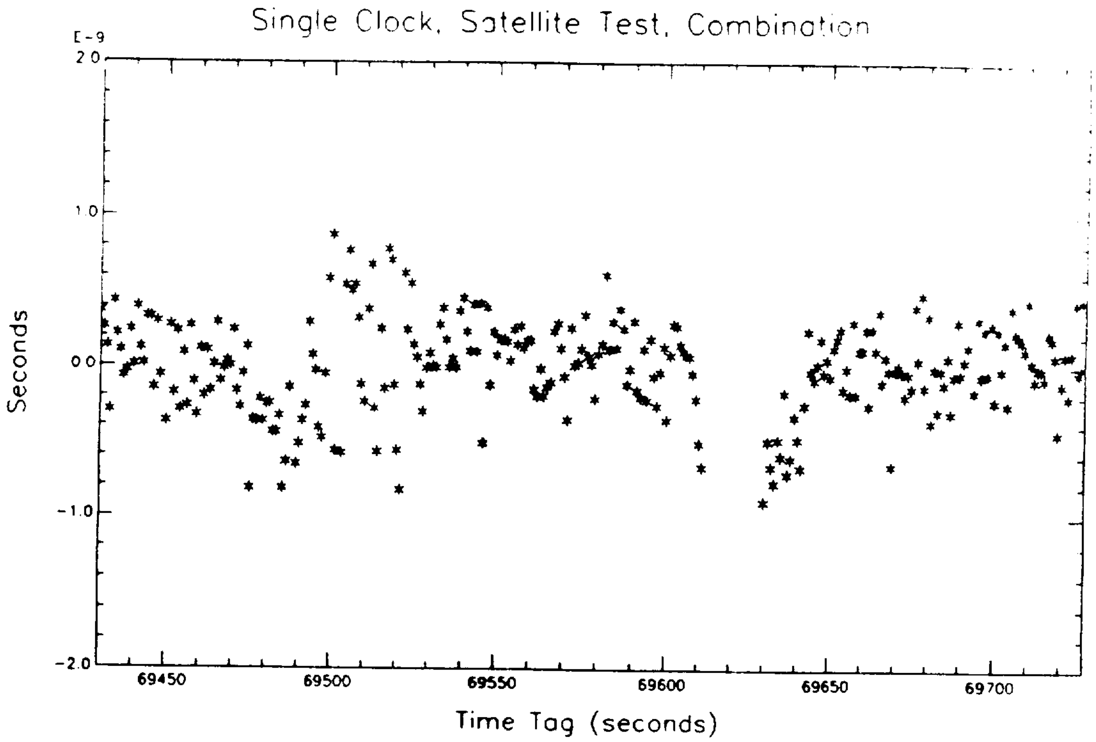

Single Clock, Satellite Test, Combination
E-9
2.0
1.0
0.0
-1.0
-2.0
Seconds
69450
69500
69550
69600
69650
69700
Time Tag (seconds)

Figure 9