TWO-WAY SATELLITE TIME TRANSFER USING LOW POWER CW TONES

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ABSTRACT

In the search for an economical means of precise time transfer, the NRC Time Laboratory decided to adapt, for time transfer, the techniques used by radio astronomers in an experiment to compare the phases of the local oscillators at widely separated VLBI stations. The objective is to design a system which would use commercial satellites, and which would be of reasonable cost for the ground sations and for operations.

Two satellite ground stations have been installed at NRC about 100 m from the Time Laboratory. The antennas are 3 m in diameter, and the transmitter power is 1W. For the preliminary experiment, a channel on the Anik A1 6/4 GHz satellite was made available by Telesat Canada.

Two tones were transmitted ± 16 MHz from the suppressed carrier. The difference frequency of 32 MHz was recovered using narrow band receivers. A low level 1 MHz phase modulation was added to identify the 32 MHz cycle, giving 1 μs ambiguity in the time transfer. With less than ¼ W in each tone, the EIRP is 43 dB below that of a normal TV earth station, and no frequency dispersion is required.

The measurements taken each second for the 32 MHz have an rms scatter of 1 ns. The transponder of the failing Anik A1 (now out of service) was 15 dB down on normal performance, so that much better results are expected on the Anik A3 later this year.

It is three years since I reported here, in 1979, on the two-way satellite time transfer between NRC/NBS, NRC/USNO and USNO/NBS using the Hermes CTS satellite, and the NRC/LPTF transfer using the Symphonie satellite. The Hermes experiment ended July 1, 1979 after one year, and the Symphonie experiment ended July 1, 1982 after four years.

The PTB in Braunschweig joined the Symphonie experiment in February 1980, and I would like to make a brief report on the results of the past two years, because the results are relevant.

The primary interest in the time transfer between NRC and PTB was to compare the frequencies of the NRC primary clock CsV with the PTB primary clock Cs1. The results are shown in Figure 1.

CsV was evaluated at MJD 44512, with a resulting increase in frequency of 4×10^{-14}. There was little change in the frequency of CsV at MJD 44865 for the next evaluation in September 1981. The regular variations, over the central period, we attributed to the reversal of the beam of Cs1, about every 35 days, because there appeared to be a correlation between the reversal dates and the change frequency of the order of 5×10^{-14}. However the PTB assures us that from their internal evaluation this could not occur, so it must be attributed to noise.

This curve, and the fact that the curve for the previous three years also lies in this 2 μs interval, gives a long term agreement between the PTB and NRC standards of 2×10^{-14}. Measurement of frequency differences to 1×10^{-14} on a monthly basis was achieved, except for the last year, where for two periods there were numerous equipment failures and changes in the CRC terminal used by the NRC.

Except for these periods, transfers between the three sations normally gave closures of ± 2ns - 10 ns. The 10 ns bias resulted from the change in frequency and the satellite transponder which was necessary for the LPTF/PTB transfer. Because the three transfers were run consecutively over a period of an hour, it was also necessary to determine the relative rates of the station clocks and extrapolate to a common time.

These results of 1 or 2 parts in 10^{14} are in marked contrast to the seasonal variations of 3×10^{-13} which are evident in comparing our frequency to that of the USNO via Loran C. While Loran C has been, and remains, very useful to us, it has been obvious for some time that we need a better system for precise time dissemination, and that need is reflected in many of the papers to be presented at this meeting.

It has also been obvious from the first that both the Hermes and Symphonie satellite time transfer experiments had a limited lifetime. In searching for a resonably economic means to achieve precise time transfer, we decided to experiment with methods used by the radio atronomers to establish phase coherent links between VLBI stations at the Naval Research Laboratories, Washington, Algonquin Park, Ontario and Penticton, British Columbia[1]. In this experiment two CW tones were exchanged over each path, and the beat notes recorded at each station were subsequently compared to determine the relative phases of the local oscillators at the three stations. They recently achieved an rms noise of 25 ps for 0.1 s averaging time.

For the NRC time transfer experiment, and we hope for ultimate operational use, we have set up two transmit-receive satellite ground stations about 100 meters from the Time Laboratory, with several triax cables connected directly to the Time Laboratory facilities. The antennas are 3 m in diameter, and the transmitter power 1 W. For the preliminary experiment, a channel on the Anik A1 6/4 GHz satellite was made available by Telesat Canada. The EIRP of our stations is about 40 dB below that of a normal TV ground station, and so frequency dispersion is not required. A 120 K low noise preamplifier preceded the narrow band receiver.

In our experiment the initial CW tones were ± 16 MHz from the carrier frequency, with the carrier suppressed 35 dB below the tones. In the receiver, with 70 MHz IF, the frequency of 54 MHz was recovered first, with a 1MHz bandwidth filter, and a 54 MHz VCO with a ramp search and 15 Hz bandwith in the acquisition loop. The ramp search was necessary to accommodate a possible 20 kHz offset arising from the satellite transponder, the Doppler shift and the receiver local oscillator. For the received 54 MHz, the signal to noise was -37 dB for 1 MHz bandwidth or 23 dB Hz. The 32 MHz was recovered from the 86-54 signal with a crystal oscillator in the loop, because only a Doppler shift of 1 to 2 Hz is to be expected.

For cycle identification of the 32 MHz, two methods were tried. In the first, the ± 16 MHz tones were switched to ± 16.5 MHz at a 10 kHz rate, and 33 MHz was recovered as well as the 32 MHz as above. This gave a 1 MHz signal with 1μs ambiguity in the time transfer. In the second method, a 1 MHz signal was used to phase modulate the 16 MHz at a low modulation index, and the 1 MHz was recovered directly. The results obtained are shown in Figure 2. The upper dots are the measurements taken each second of the 1 MHz locked signal. The middle section gives the measurements of the 32 MHz signal, and the lower set of measurements are from a Canada/France transfer using the Symphonie satellite. It can be seen that the quality of the CW tone transfer is not as good as the Symphonie results, but it should be mentioned that the performance of the Anik A1 satellite was 15 dB below normal.

In Figure 3, the results of another run are presented, with a line giving the 10 point moving average. The 1 MHz results are adequate to identify a cycle of the 32 MHz, and the 32 MHz results show that sub-nanosecond precision was obtained.

The feasibility of using 3 m terminals with 1 W power for sub-nanosecond time transfer has therefore been demonstrated. However, we are not now so certain of the practicality of the system. One difficulty arises from the fact that commercial up-converters and down-converters have too much FM noise for the narrow band system, and direct synthesis for frequency agile units becomes complex and expensive.

A more serious difficulty is the cycle ambiguity. While the present 1 μs ambiguity could be reduced to 10 μs or 100 μs, power is lost with each additional modulation frequency. The complexity also makes it more difficult to achieve a fully automated system.

We are now planning to make tests with a pseudo random noise code with our low power terminals. This method has been proved out by the RRL in Japan[2], and much earlier between RRL and NASA, but at a rather higher S/N than we will have available.

I would like to suggest that an effort should be made to agree on a standard PRN modulator and demodulator that could be used on any time transfer experiment, geostationary satellites, GPS, STIFT, etc. The goal should be sub-nanosecond precision and accuracy, and economy.

We would like to thank Telesat Canada for making the experiment possible in giving us access to the Anik A1 satellite, and for the very helpful assistance and advice of their staff in the course of the experiment.

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[1] S.H. Knowles et al "Time Transfer via Satellite-Link Radio Interferometry", Proc of the 11th Annual PTTI Meeting, p. 471, Nov. 27-29, 1979, NASA CP 2129.

[2] M. Imae et al "Time-Comparison Experiments with a Small K-Band Antenna SSRA System via a Domestic Geostationary Satellite", CPEM 1982, page M-5.

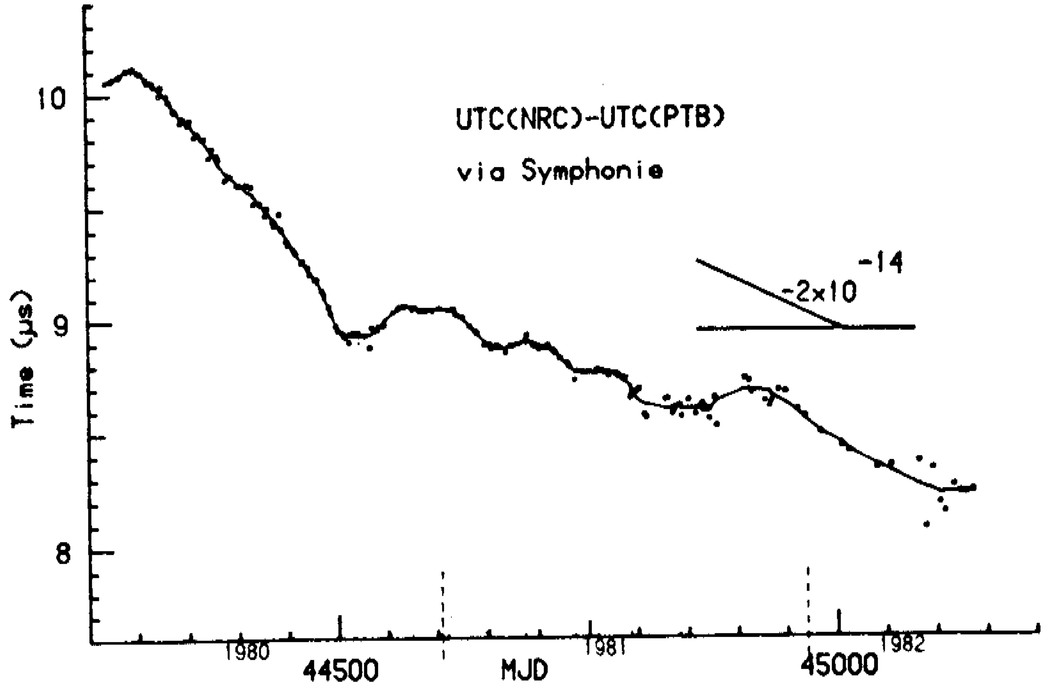

Fig. 1 - The absolute time difference UTC(NRC) - UTC(PTB) via the Symphonie satellite.

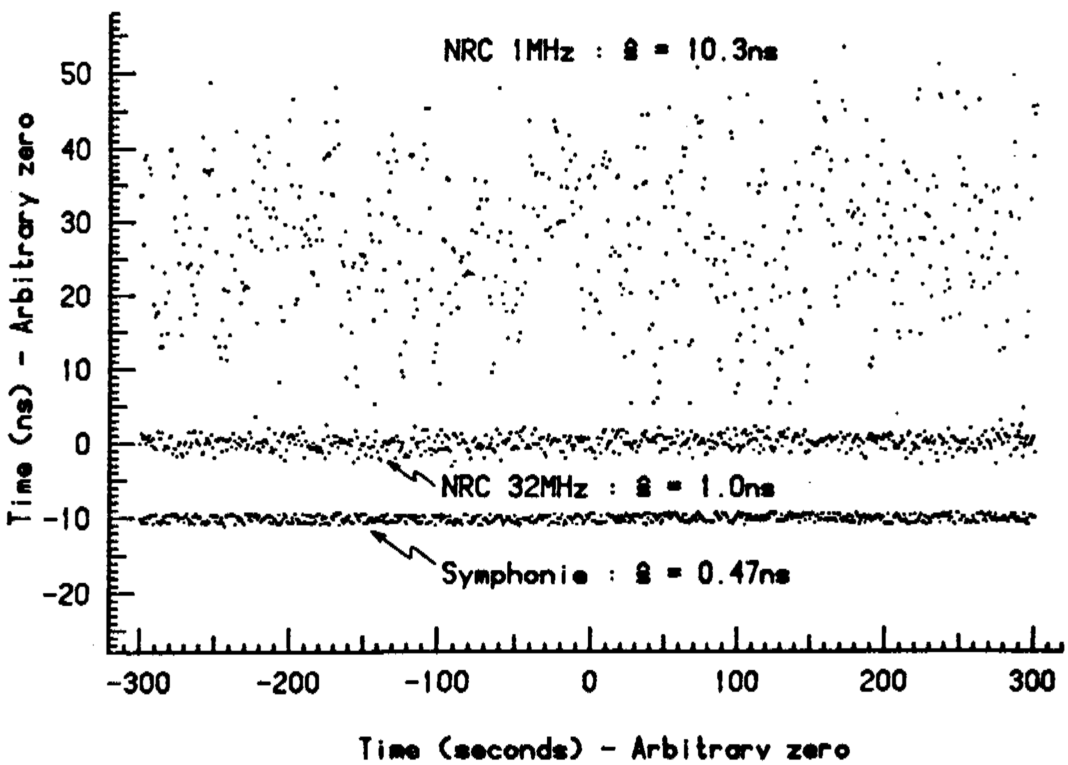

Fig. 2 - A comparison of the results using CW tones via Anik A1 with the results using a 6 MHz video band via Symphonie.

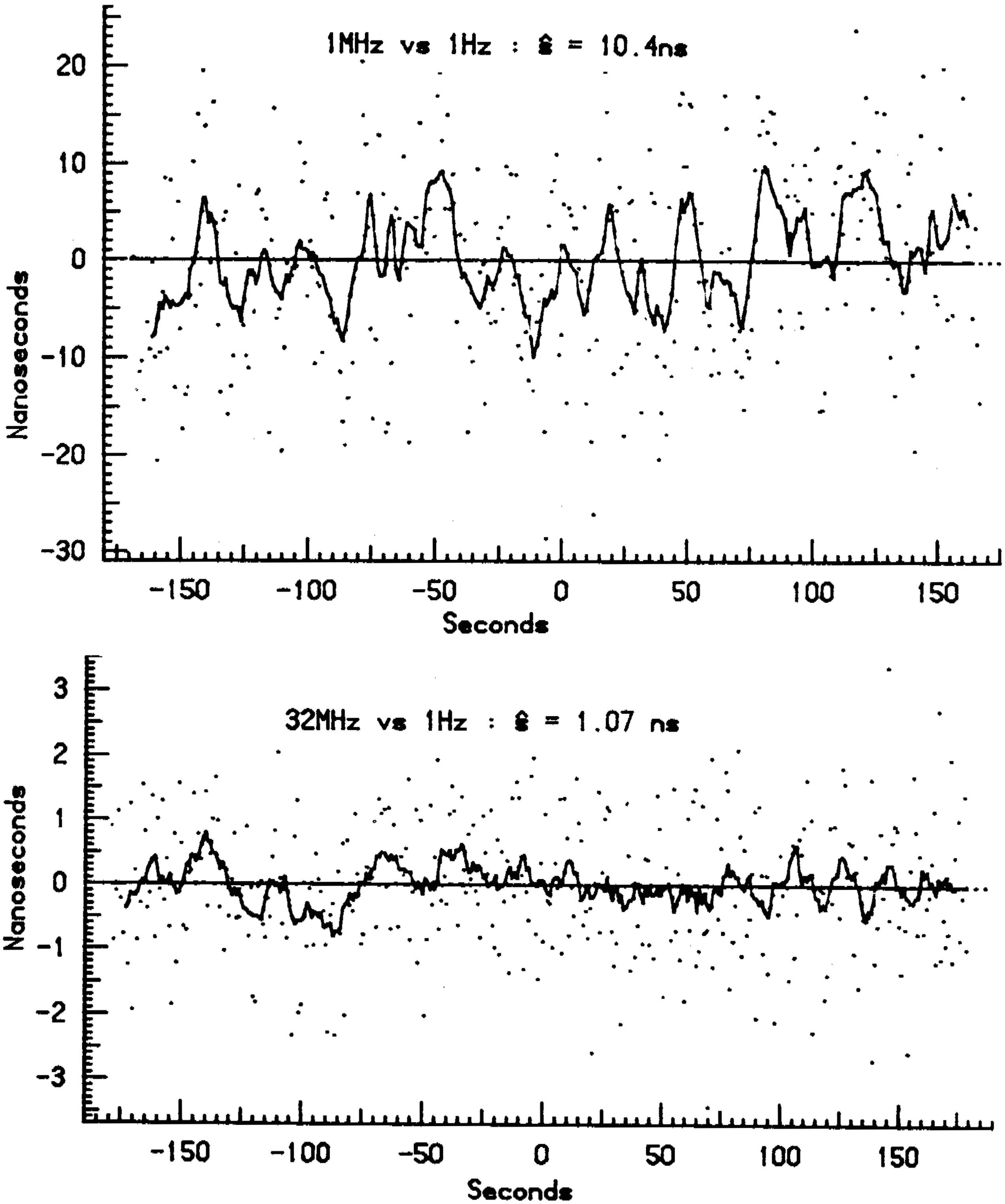

Fig. 3 - The 10 point running average and standard deviation of the recovered 1 MHz and 32 MHz signals via Anik A1.

QUESTIONS AND ANSWERS

MR. L. J. RUEGER, JHU/APL

Have you obtained permission to use active transmitter links to the satellites in other countries?

DR. COSTAIN:

Yes, I should qualify my statements by the fact that we now have an experimental license to use a commercial satellite. There is probably rather a bigger step to get a commercial license to operate a ground station when it is an active station transmit/receive. In Canada we might be able to do this by giving title of the station to TELESAT, who are the only ones allowed operate. And I think in some countries it is even more difficult.

I think that we could probably accommodate on this continent with the motherhood that we have for systems, it might be a little more difficult in Europe. But if we can keep the EIRP 40 dB down, in fact you really can't be detected except by the compatible system. And one of the virtues is that we cannot interfere with other systems, which makes it a little more practical to get licensed.

DR. WINKLER:

I may add the important thing seems to be as Dr. Costain said, low power but the second one, I believe, it is easier to obtain licenses if you can stick to a fixed schedule of 5 or 10 minutes a day; the same time, because then the primary user of such a frequency assignment can notify you if he needs to pre-empt. In this case, it seems to be easier to obtain licenses. And we have had no difficulty to obtain an experimental license for a peak power of ten watts, for the anticipated LASSO experiment, which unfortunately did not materialize.

DR. COSTAIN:

Yes, also, this is one reason why we have very simple programming really in this type of experiment and one reason I want fully automated outfits so that we could do it at 3 o'clock in the morning, and I don't have to be in the laboratory.