Study on Measurement Methods for GNSS Antenna Cable Delay

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***Summary*—This paper discussed the technique behind the TIC, the VNA and the GNSS simulator measurement, implemented the delay measurement for a coaxial GNSS antenna cable with different methods and obtained their discrepancy. Results can be used for the determination of more suitable measurement method in different scenarios for further study. In addition, the impact on the measurement results of some test settings in the instruments was studied. Suitable measurement parameters for the measurement methods were proposed.**

***Keywords*—Cable Delay, Coaxial Cable, Delay Measurement, GNSS**

I. INTRODUCTION

Time link calibration with time transfer equipment is the precondition to ensure accurate time transfer. Usually, a complete set of GNSS time transfer equipment is composed of a GNSS antenna, an antenna cable, and a receiver host. In the solution of absolute calibration in which each element is calibrated respectively using artificial GNSS signals, high-precision and low-uncertainty cable delay measurement methods are urgently needed. Besides, in other precise timing scenarios, such as the installation of GNSS antenna cable for NTP/PTP grandmasters, or PPS time distribution applications, accurate measuring the actual signal delay from antenna cable or general coaxial cables to compensate is also of particular significance. Overall, the coaxial cable delay measurement should be accurately and precisely employed for all timing compensation purposes to minimize time measurement uncertainty.

At present, the measurement of cable delay is mainly carried out through TIC-based time interval measurement among timing laboratories. Other antenna cable delay measurement techniques represented by VNA-based group delay measurement or pseudorange difference measurement using a GNSS simulator have also been adopted according to [1, 2], which are whereas not available in many laboratories. Besides, in [3], a $\lambda/2$ resonator technique is also introduced.

Prior experience has shown that the cable delay is not a well-defined measurement and its value will be dependent on the shape of signals passing over the cable and the measuring instruments. At the same time, whichever method comes first in the antenna cable delay measurement during a GNSS time transfer equipment calibration process is still inconclusive.

In this paper, we mainly studied the measurement methods via the TIC, the VNA and the GNSS simulator in principle. For support, a comparison and cross validation were carried out using different methods on a Linktrend 5D-FB antenna cable of 50 m long with a lightning arrester.

II. PRINCIPLES OF MEASUREMENTS

A. TIC-based Time Interval Measurement

Time interval measurement is defined as the time difference between a specific Start event and a Stop event. It is measured usually via the first and the second edges that the TIC triggers on, determined by selected slopes and levels. When the Start trigger is detected, the TIC will be cumulatively counting the clock pulses of its time base until the Stop event comes up, as shown in Fig. 1.

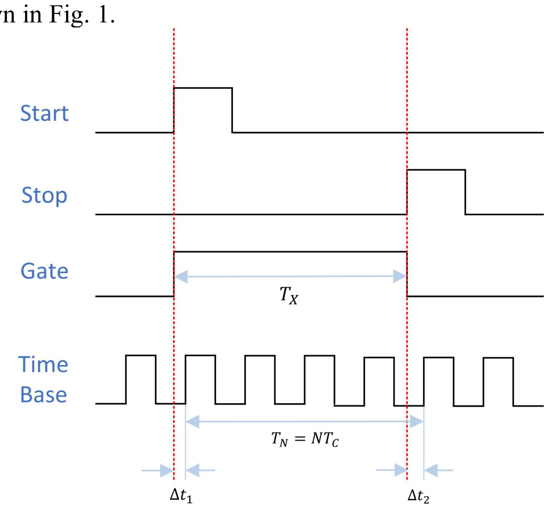

Fig. 1. Scheme of time interval measurement.

The time difference between the Start/Stop events can be obtained from equation (1).

$$T_X = NT_C + \Delta t_1 - \Delta t_2 = T_C\left(N + \frac{\Delta t_1 - \Delta t_2}{T_C}\right) \qquad (1)$$

T_X: Time interval measurement;
N: Number of clock pulses of the time base;
T_C: A pulse cycle of the time base;

Δt_1: Time difference between the edge of the first counting pulse after the start of count and the Start event;

Δt_2: Time difference between the edge of the first pulse after the end of count and the Stop event.

The error derived from this method can be expressed as equation (2).

$$\delta = \Delta t_1 - \Delta t_2 \quad (2)$$

For a counter with a time base of frequency f, a time resolution of $\frac{1}{f}$ can be easily provided, and can achieve more accuracy with interpolation. However, the improvement in time resolution is limited by the fact that the frequency of time base cannot be increased indefinitely, the major measurement error still comes from the TIC's time base itself.

B. VNA-based Group Delay Measurement

The S-parameters are the reference parameters used to describe the transmission characteristics of microwave networks and are commonly employed in VNAs. Among the S-parameters, S21 is used to measure the signal's transmission loss and phase variation through the microwave network under test. It quantifies the amplitude and phase changes of the input signal as it propagates through the microwave network and appears at the output port. The group delay obtained via a S21 measurement of VNA is considered as the signal delay through the cable, and defined by equation (3), i.e., the negative derivative of phase in radian to frequency, where *group* stands for *a group of frequency* (aperture).

$$\tau = -\frac{1}{2\pi}\frac{d\varphi(rad)}{df} \quad (3)$$

Because of velocity dispersion (VD), waves at different frequencies will be propagating at different speeds through a transmission cable, causing the delays of signals featured by different frequencies to be different as well. With the same frequency variation for an ideal coaxial cable under S21 measurement, the greater the phase change between the transmitted wave of port-2 and the incident wave of port-1, the greater the group delay will be, as shown in Fig. 2.

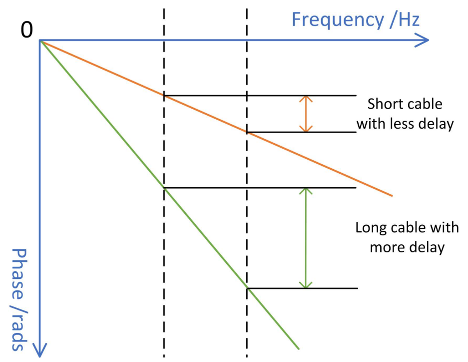

Fig. 2. Ideal coaxial cable frequency-phase curve.

However, for the actual measurement of a non-ideal coaxial cable characterized by a nonlinear phase response versus frequency, hat is, when the phase change between the transmitted wave of port-2 and incident wave of port-1 does not always show a strict linear relationship as the frequency of the transmitting signal varies, the measurement under different apertures will directly lead to different results of the cable group delay, as shown in Fig. 3. If a wide aperture is chosen, the resolution of group delay measurements relative to frequency will be affected, thus causing fine details of observation to be undetected.

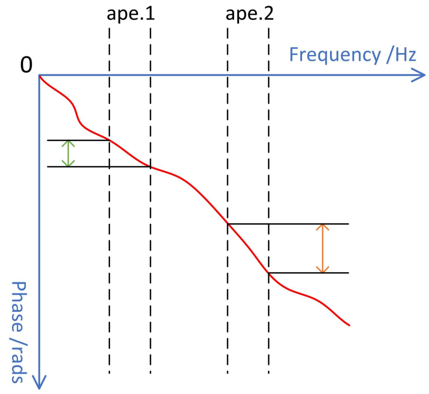

Fig. 3. Scheme of actual coaxial cable frequency-phase curve.

C. GNSS Simulator-based Pseudorange Difference Measurement

A GNSS constellation simulator is capable of generating artificial GNSS radio frequency (RF) signals without extra influence factors (e.g., ionosphere, troposphere and multipath, etc.). Ideally, the pseudorange observed by the receiver should be identical as the one broadcast by the simulator, but will inherently exhibit a difference due to various delays among the setup as expressed in equation (4) and (5).

$$\Delta pr_0 = \tau_{\mathrm{int}} + \tau_{\mathrm{ref}} - t_{\mathrm{RFcable}} - t_{\mathrm{SD}} \quad (4)$$

$$\Delta pr_1 = \tau_{\mathrm{int}} + \tau_{\mathrm{ref}} - (t_{\mathrm{RFcable}} + t_{\mathrm{CUT}}) - t_{\mathrm{SD}} \quad (5)$$

Δpr_{i}: The pseudorange difference obtained by common view between the receiver and the simulator with or without cable insertion;

τ_{int}: Internal hardware delay of the receiver;

τ_{ref}: Delay between the receiver clock and the external reference clock;

t_{RFcable}: Delay of the cable on the RF path;

t_{CUT}: Delay of the cable under test;

t_{SD}: Internal hardware delay of the simulator.

Thus, it is feasible to obtain the cable delay by measuring the Δpr_1 when inserting a cable under test into the RF path of the experiment setup, and deducting Δpr_0 observed without the cable insertion then.

III. Measurement Methods and Results

A. The TIC Method

The TIC used in this paper was a Stanford Research Systems SR620. There are two ways in general to measure cable delay via a SR620, that is, by using the REF output of the SR620 at which a 50 % duty cycle square wave (1 kHz) is available, or with the aid of an external PPS source and a pulse distribution amplifier as shown in Fig. 4. In the second arrangement, the total delay value with and without the insertion of the cable under test will be measured separately, and the cable delay will be considered as the difference of two measurement results above.

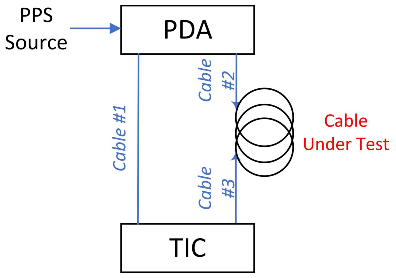

Fig. 4. Scheme of TIC measurement with a PDA.

For measurements involving PPS using a TIC, the main uncertainty contribution may derive from the wave distortion of the generated signals at the end of the cable under test due to attenuation and dispersion [4], which will cause overestimation in results with the growth of trigger level. Same situation could happen and could be even worse in square-wave measurements as shown in Fig. 5.

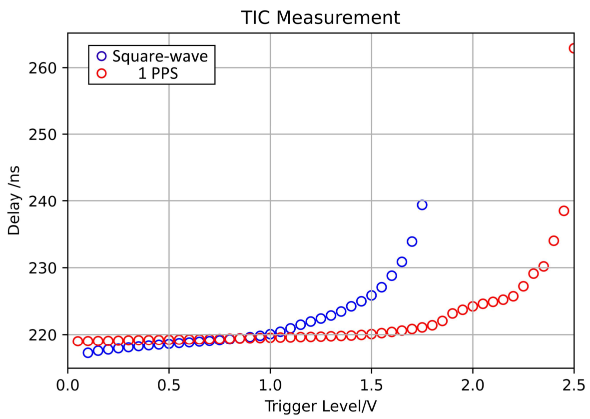

Fig. 5. Delay overestimation with the growth of trigger level.

Besides, depending on the distortion, a typical 1.0 V trigger under 50 ohms prescribed in the BIPM calibration guideline [5] may not necessarily be the one that best avoids the introducing of measurement uncertainty according to Fig. 6.

It can be noted that a lower trigger level may be more appropriate as it is less susceptible due to a slower slope, when the PPS pulses observed before and after passing through the cable under test are aligned at their starting points. Finally, a trigger level of 0.5 V for both Start and Stop ports was selected for the TIC measurement. The final results obtained by the PPS method is 219.21 ns and the square-wave method 218.60 ns.

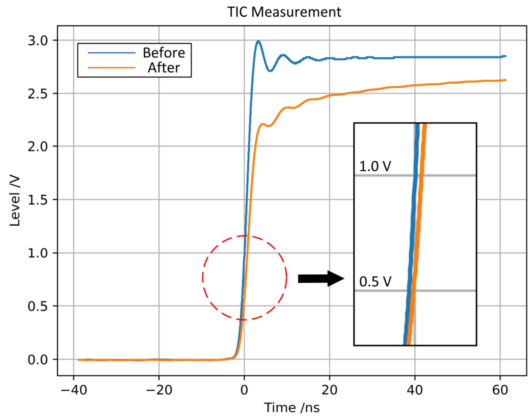

Fig. 6. PPS pulses observed before and after passing through the cable under test. The images were both captured by an oscilloscope under 1.0 V trigger level and were re-aligned manually. They thus do not indicate the phase relationship of the pulses in actual measurement.

B. *The VNA Method*

This method requires that both ends of the cable under test be connected respectively to the test ports of the VNA after a 2-ports calibration as shown in Fig. 7. The VNA used was a Keysight E5061B. Another VNA, model Transcom T5260C has also been employed as a validation.

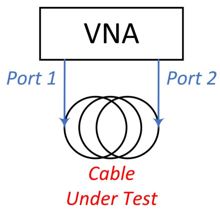

Fig. 7. Scheme of VNA measurement.

Specifically, we selected an IF bandwidth of 1 kHz to balance the measurement dynamic range with a moderate sweep time. A span of (1~2) GHz was selected to cover all the available GNSS carrier frequencies at present, and the frequency resolution was determined at 801 as a compromise between accuracy and sweep time. Finally, the smoothing function was set off in order to relieve the aperture effects mentioned in section II as possible. More detailed configuration is shown in Table II.

TABLE I. PARAMETERS AND VALUE OF THE VNA MEASUREMENT

Parameters	Value
S-parameter	S21
Format	Group Delay
Average factor	16
Smoothing	off
Frequency span	1GHz to 2GHz
IF Bandwidth	1 kHz
Sweep Points	801
Power level	-20 dBm

The raw results are presented in Fig. 8, where the Transcom measurement has been shifted for better view. The final measurement results of the two VNAs are obtained by the data averaged over two frequency bands around (1.16~1.31) GHz and (1.52~1.62) GHz respectively, which are able to cover all present GNSS carrier frequencies, as shown in Table III.

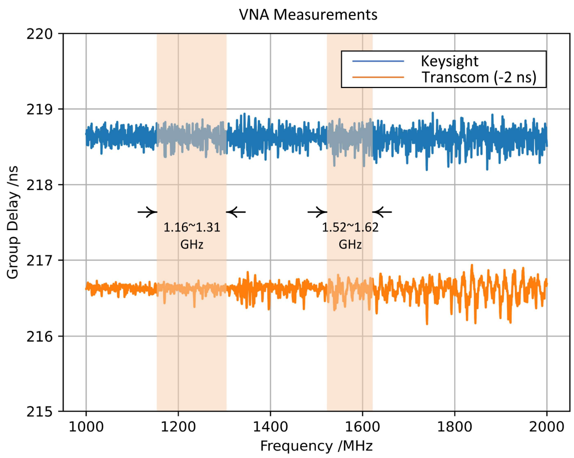

Fig. 8. Cable delay measured with two VNAs.

TABLE II. ANTENNA CABLE DELAY MEASURED BY VNA

Manufacturer	Cable Delay (ns)	
	1.16~1.31GHz	1.52~1.62GHz
Keysight	218.62	218.61
Transcom	218.63	218.62

The uncertainty sources from VNA calibration, cable deformation, temperature effects and connectors, which is estimated at 360 ps, surpassing the TIC method.

C. *The GNSS Simulator Method*

The experiment setup is depicted in Fig. 9, where we used respectively a MATRIX GNS8330 and a Spirent GSS8000 in turn to provide GNSS-like signals in BDS B1I, B3I, B1C, B2a and GPS L1C/A. The receiver we used here was a self-developed TLab-TFS-G1 coded TL06, which would generate continuous RINEX files during both scenarios with and without the cable insertion. Note that to ensure the power level at the receiver RF input to be identical, we calibrated with a spectrum meter and fixed it at the same value for all available carrier frequencies.

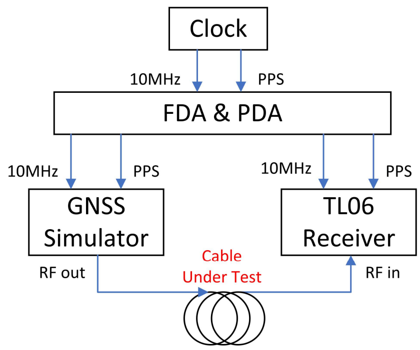

Fig. 9. Scheme of pseudorange difference measurement.

The period of observation was set to 1h after a 30-minutes warming up for all instruments, and the epoch interval of RINEX conversion to 1s. By differentiating the original data at the corresponding moment recorded in the simulator, the final results were obtained and presented here in Table IV.

TABLE III. ANTENNA CABLE DELAY MEASURED BY GNSS SIMULATOR

Carrier Frequency	Cable Delay (ns)	
	MATRIX GNS8330	Spirent GSS8000
BDS B1I	218.57	/
BDS B3I	218.56	/
BDS B1C	218.82	/
BDS B2a	218.64	/
GPS L1C/A	/	218.64

IV. CONCLUSIONS

In this paper, we mainly discussed three measurement methods for GNSS antenna cable delay as looked at their principles. The TIC method has been the most accessible and flexible among many timing laboratories, while an uncertainty of over 500 ps might nevertheless be introduced under some trigger levels. The main advantage of VNA method is its lower contribution to overall uncertainty, making it a more applicable technique to be carried out during precise measurement scenarios. We have also conducted measurement using GNSS simulators, which utilizes artificial GNSS signals and is considered optimal thanks to its similarity in real scenarios. Finally, the measurement results under three different methods showed sub-nanosecond consistency. For typical coaxial short cables to be deployed e.g., in time distribution systems, the same methods can also be adopted.

However, the VNAs as well as GNSS simulators may not be available due to the high cost or inflexibility, further work shall concentrate on the more accessible methods based on the TICs, as to match the results obtained via the VNAs and the GNSS simulators, which are regarded with better accuracy and lower uncertainty, including evaluation on PPS sources with different rise times and amplitude, measurements on coaxial antenna cables with different lengths and structures.

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REFERENCES

[1] Garbin, E., Defraigne, P., Krystek, P., Piriz, R., Bertrand, B., & Waller, P. (2018). Absolute calibration of GNSS timing stations and its applicability to real signals. Metrologia, 56(1), 015010.

[2] Valat, D., & Delporte, J. (2020). Absolute calibration of timing receiver chains at the nanosecond uncertainty level for GNSS time scales monitoring. Metrologia, 57(2), 025019.

[3] Rovera, D., Abgrall, M., Uhrich, P., & Siccardi, M. (2015, April). Techniques of antenna cable delay measurement for GPS time transfer. In 2015 Joint Conference of the IEEE International Frequency Control Symposium & the European Frequency and Time Forum (pp. 239-244). IEEE.

[4] Siccardi, M., Rovera, D., & Romisch, S. (2016, May). Delay measurements of PPS signals in timing systems. In 2016 IEEE International Frequency Control Symposium (IFCS) (pp. 1-6). IEEE.

[5] ftp://ftp2.bipm.org/pub/tai/publication/gnss-calibration/guidelines/