A High-Resolution Time Interval Counter Using the TAPR TADD-2 and TICC Modules

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• Introduction

This paper describes a high-resolution time interval counter suitable for measuring the relative phase between a pair of precision frequency sources based on the Tucson Amateur Packet Radio Corporation (TAPR) TADD-2 Mini and TICC modules [1, 2]. The TADD-2 is a small 10 MHz to 1 PPS divider while the TICC is a daughter board mounted on an Arduino microcontroller. The device can compare the relative phase between two 10 MHz sinewave inputs with a resolution below 100 ps. The assembly is packaged in a small metal enclosure as shown in Figure 1, which also includes an optional Raspberry Pi computer to capture the resulting clock data.

Figure 1. TADD/TICC Time Interval Counter
(Shown with optional Raspberry Pi Computer)

• TADD-2

As described on the TAPR web site, the TADD-2 Mini is a divider that accepts a 5 or 10 MHz input signal and generates output frequencies in decade steps from 1 pulse-per-second ("PPS") to 10K PPS. The pulse train can be synchronized to an external source (such as a GPS receiver). The TADD-2 has six low-impedance outputs that deliver greater than 3.5 volts into a 50 ohm load, with a rise time of less than 3 ns. The pulse rate of each output can be individually set, along with the output polarity. A wide-range input circuit accepts signal levels as low as -10 dBm. The input can be terminated in 50 ohms or a high impedance load. The TADD-2 Mini is powered from 9 to 15 volts and the current draw ranges from 20 to 50 mA depending on the output load. It uses a PIC microcontroller chip as the divider.

• TICC

Also described on the TAPR web site, the TICC is a two-channel timestamping counter with better than 60 picosecond resolution and less than 100 picosecond typical jitter. It has an Allan deviation noise floor below $1x10^{-10}$ for a one second measurement.

The TICC designed to measure low-rate time intervals, such as the pulse-per-second signal from a clock or GPS, with very high resolution. The TICC hardware is a "shield" that mounts on an Arduino Mega 2560 processor board, and the TICC software runs on the Arduino. Data are sent via USB to a host computer for logging and analysis. The TICC can perform over 100 measurements per second, and the TICC can output timestamp data for each channel, or the time interval between the two channels. The channel inputs trigger with about 1.7 V and are safe to 5 V with a 1 megohm input impedance. The TICC requires an external 10 MHz reference clock at a nominal +3 dBm, though the input circuit operates over a wide amplitude range. The TICC is powered by the Arduino, which in turn can be powered by the USB cable from the host computer.

The TICC software is open source and available from www.github.com/TAPR/TICC. The repository also includes documentation, data sheets, and other information on some of the hardware components. The TICC phase data can be captured by a terminal program or with a custom software application (see below).

• Enclosure

The two TADD-2 Mini boards and TICC/Arduino assembly are housed in the inexpensive 5.3”Wx3.0”Hx5.9”D metal case (Jameco P/N 208911) shown in Figure 2. The small 0.75”Wx2.0”L TADD-2 Mini boards are assembled without output connectors and are mounted on the front panel, supported by their BNC 10 MHz input connectors. The 2.1”Wx4.0”L TICC/Arduino module is mounted on nylon spacers at the bottom rear of the enclosure (see Figure 3 for its mounting dimensions). They are therefore attached to the same “U”-shaped piece and can easily be interconnected. Short SMA coax cables are hard-wired from the TADD 1 PPS signals to the TICC.

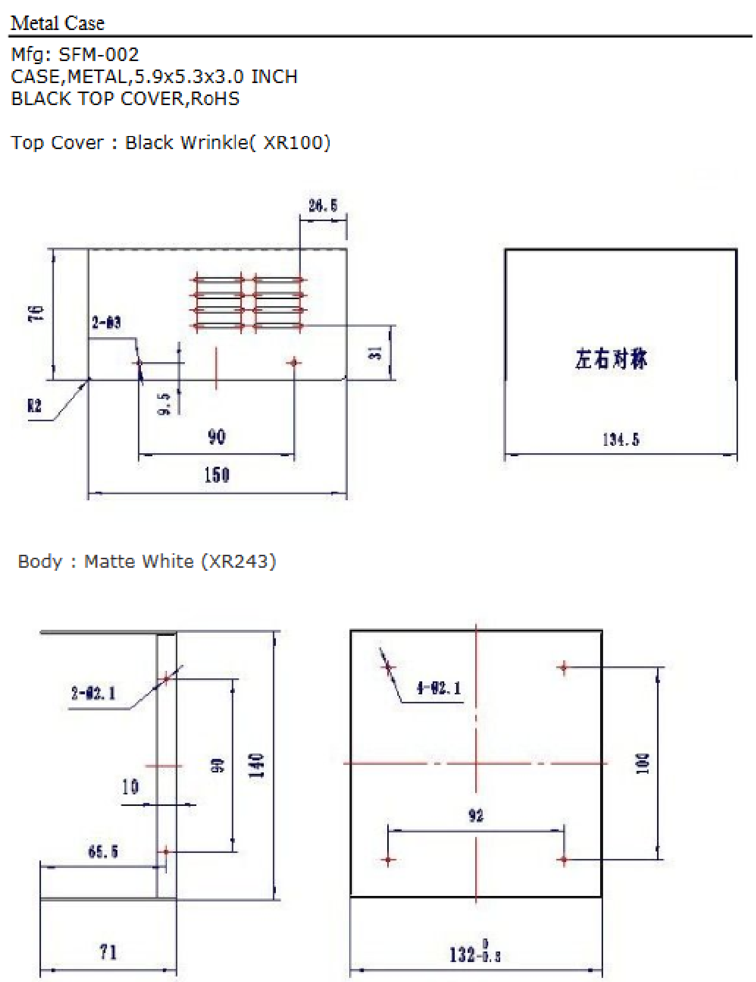

Figure 2. TADD/TICC Enclosure

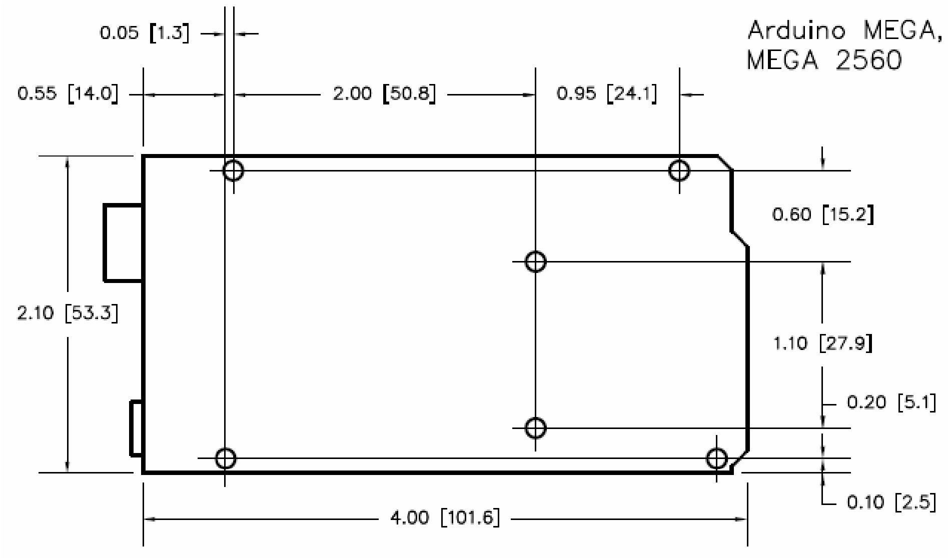

Figure 3. Arduino Mega 2560 Mounting Dimensions

• Construction

The TADD/TICC system (see Figure 4) is constructed as an evaluation unit, not a polished assembly (see Figures 1, 5 and 6), and was based on an earlier version that used a different time interval counter. An optional Raspberry Pi Model 3 computer is mounted outside on the top of the enclosure with double-sided foam tape. The TICC A and B 1 PPS inputs are wired in parallel with their corresponding BNC output connectors on the rear panel, and an opening in the side of the cover allows a short USB cable to be attached between the TICC/Arduino and the Raspberry Pi, whose external location allows for good Wi-Fi communications. Another BNC connector is located on the rear panel to bring in the 10 MHz reference to the TICC. The TICC and Arduino are powered by its USB connection, the Raspberry Pi is powered normally, and the TADD dividers are powered by an external 12 V supply. LEDs on the front panel show DC power and the 1 PPS signals, and momentary pushbutton switches allow the 1 PPS signals to be synchronized.

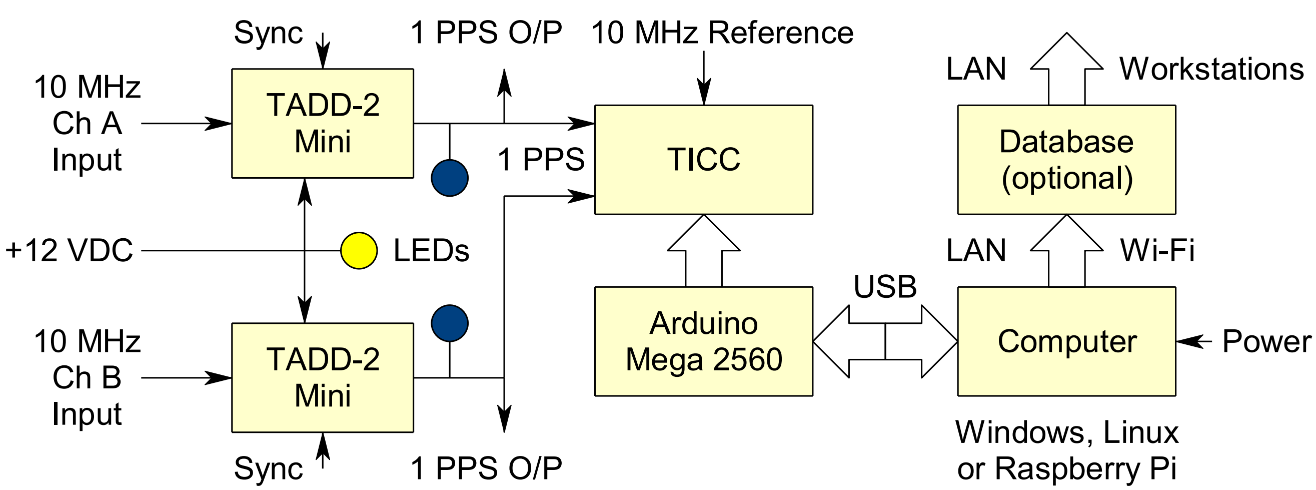

Figure 4. TADD/TICC System Block Diagram

This arrangement is quite flexible and allows the two TADD-2 Mini boards to be used separately as 10 MHz squarers by installing jumper headers in the PIC sockets, without them to use the 1 PPS outputs as inputs, or as 1 PPS dividers with the PICs. Either the TICC/Arduino or the Raspberry Pi can be used separately, or the entire assembly can be used as a complete clock measurement system with either the Raspberry Pi or another computer.

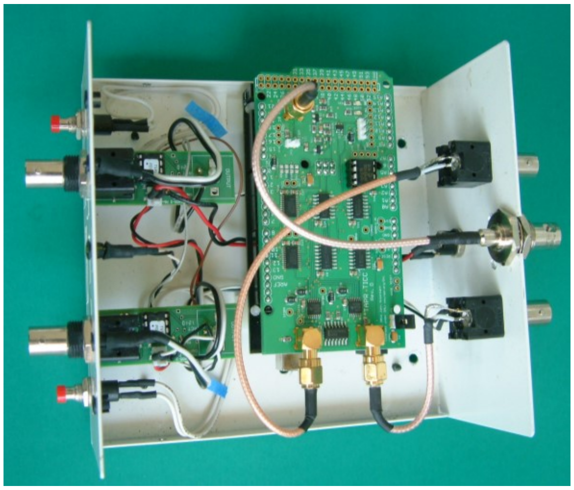

Figure 5. Interior of TADD/TICC Assembly

Figure 6. Rear Panel of TADD/TICC Enclosure

- **Performance**

The plots in Figures 7 and 8 show the results of an overnight noise floor run for a TAPR TICC driven by two TADD-2 1 pps dividers. The rms white phase noise is 77 ps at a 1-second averaging time.

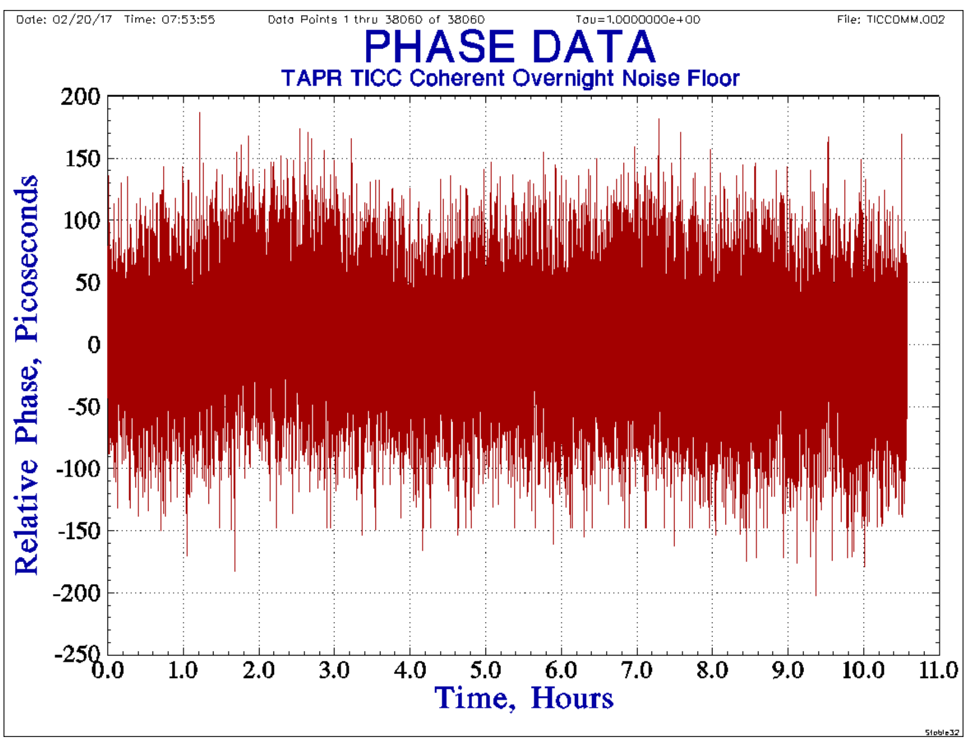

Figure 7. Phase Record for TADD-2/TICC Coherent Noise Test

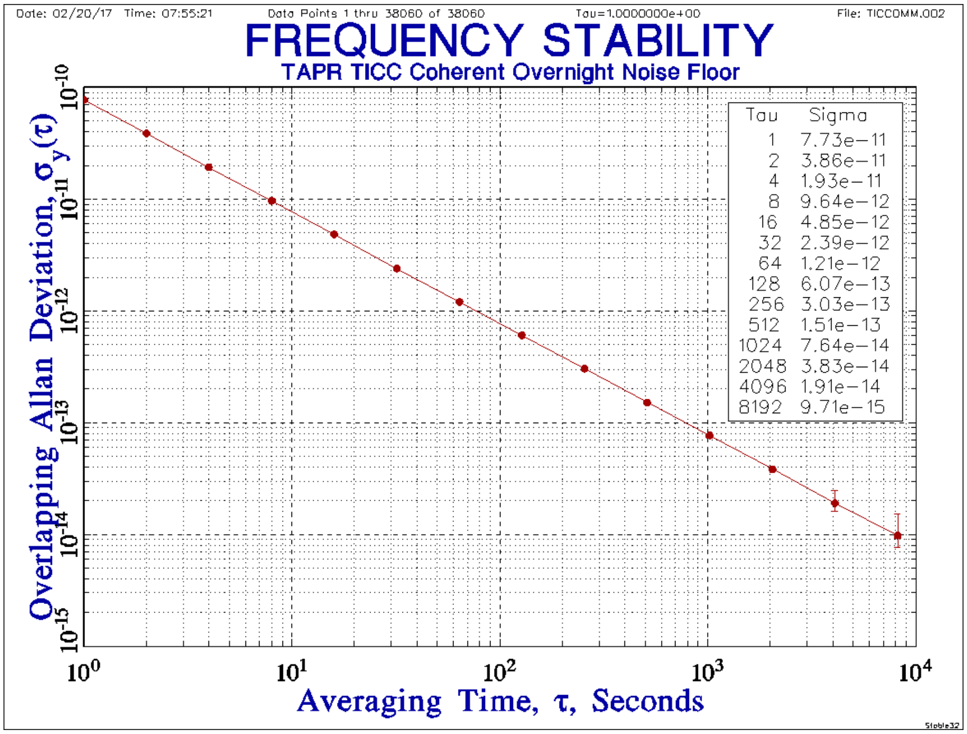

Figure 8. Stability Plot for TADD-2/TICC Coherent Noise Test

• User Interface Software

The TADD-2/TICC time interval counter phase data can be captured to a file by an ordinary terminal program such as TeraTerm under Microsoft Windows® or GtkTerm under Linux. However it is more convenient to use a custom user interface that can not only set the COM port and data filename, but also support downsampling the phase data to a longer averaging time, monitor the numeric, phase and frequency data stream, and even store the data to a database for archiving and retrieval. An example of such an application is shown below [3], running under both Windows® (Figure 9) and Ubuntu Linux [4] (Figure 10).

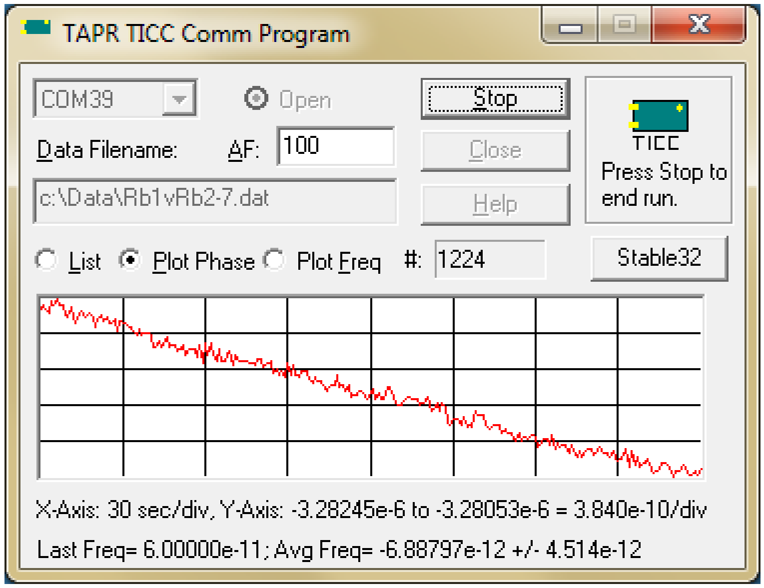

Figure 9. TICComm Screen under Microsoft Windows®

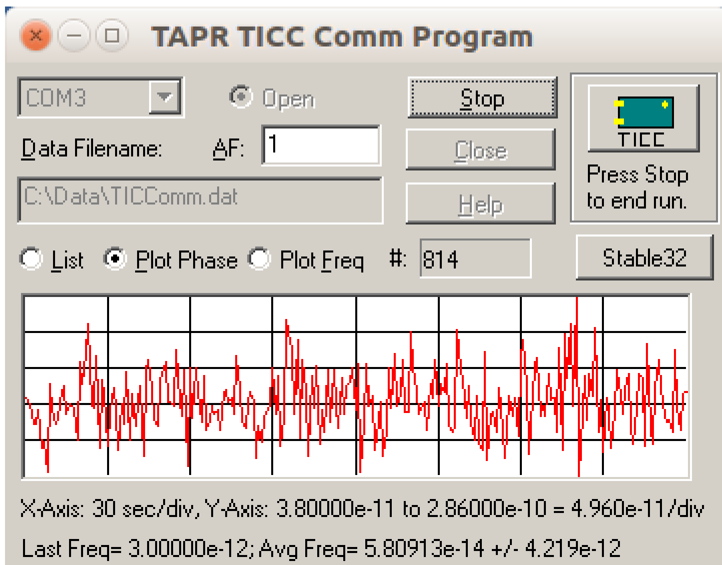

Figure 10. TICComm Screen under Ubuntu Linux

- **Measurement Example**

An example of a TAPR TICC measurement is shown in Figures 11-14 where the TICC phase data are stored in a PicoPak PostgreSQL database [5], observed with the Windows® and Web PicoPak monitor programs, and retrieved with the PicoSQL clock data access program [6]. The sources were an SRS PRS-10 Rb versus a Datum LPRO Rb. After short initial run, an external 1 PPS reference from a Thunderbolt GPSDO was applied to the PRS-10. Then, after about 1 day for PRS-10 synchronization and syntonization, the GPS 1 PPS reference was removed, which reduced the short-term frequency fluctuations. The TAPR TICC noise is low enough at the 100 second tau to resolve this difference in stability. After 1 PPS reference removal, the combined TICC and two Rb instability is about 1.7×10^{-12} at 100 seconds which improves down to a flicker floor of about 2.8×10^{-13} at around 1 hour where Rb thermal sensitivity becomes a factor.

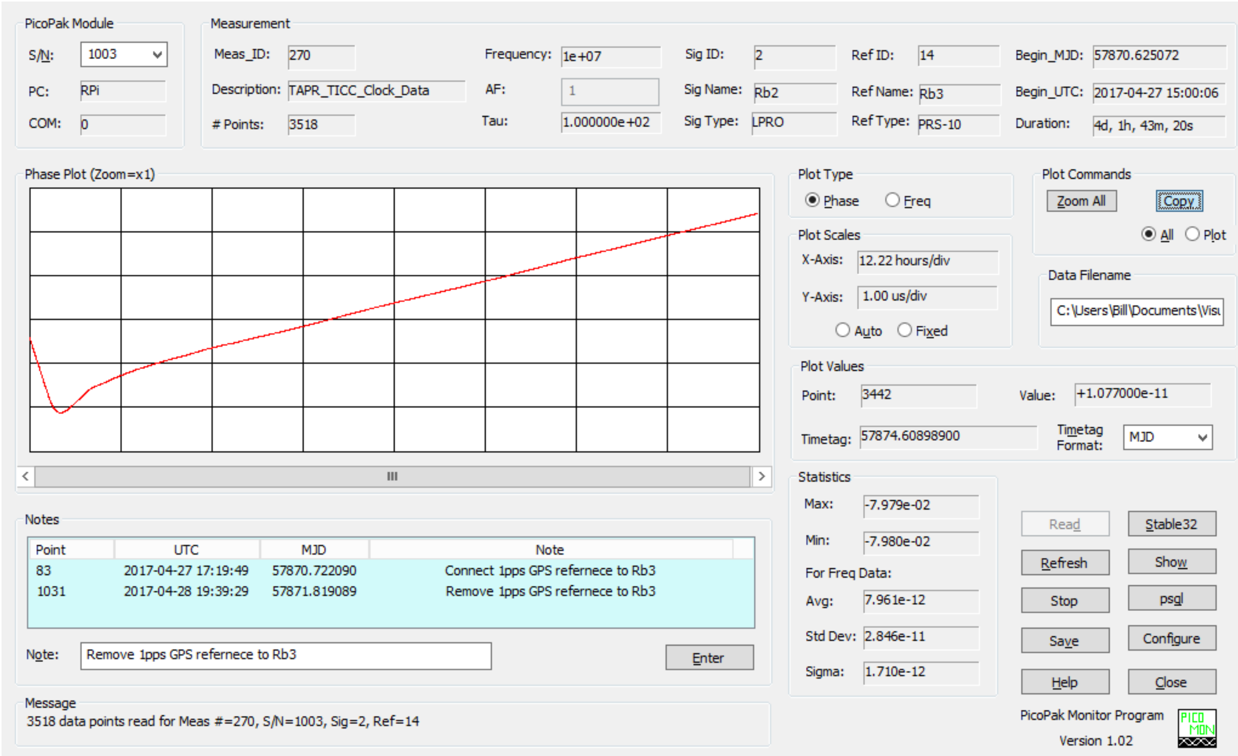

Figure 11. TAPR TICC Phase Data Record Using PicoPak Database and Monitor Program

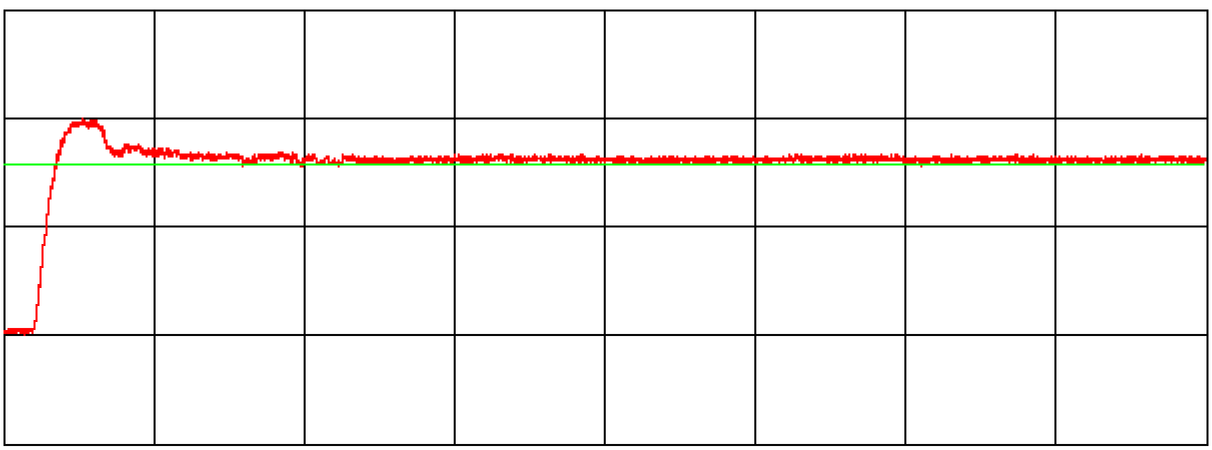

Figure 12. TAPR TICC Frequency Data Plot Using PicoPak Database and Monitor Program
Vertical Scale=1×10^{-10}/div, Horizontal Scale=12.22 hours/div
Measurement Tau=100 s, Record Duration≈4 days, 2 hours

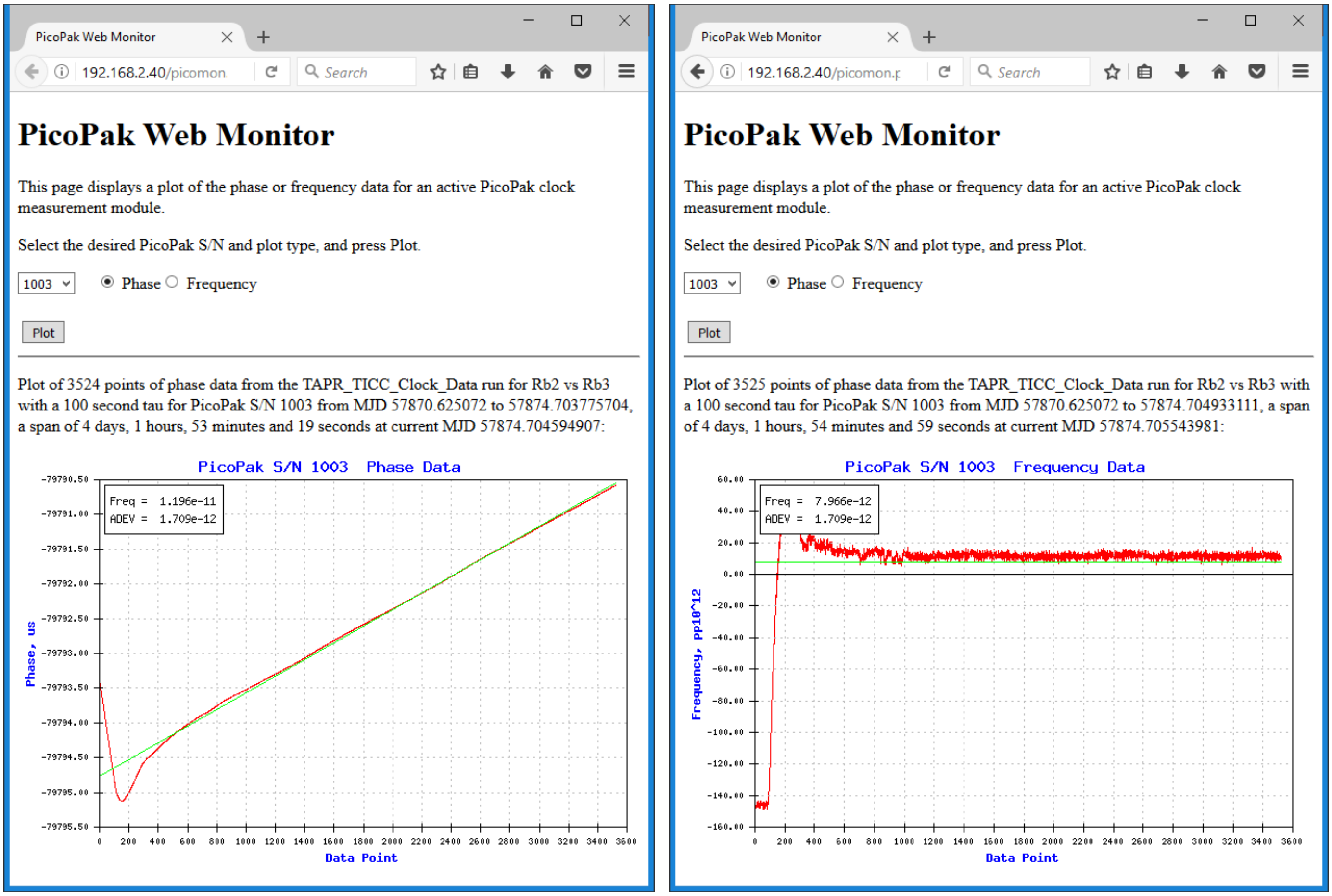

Figure 13. TAPR TICC Phase and Frequency Records Using PicoPak Database and Web Monitor

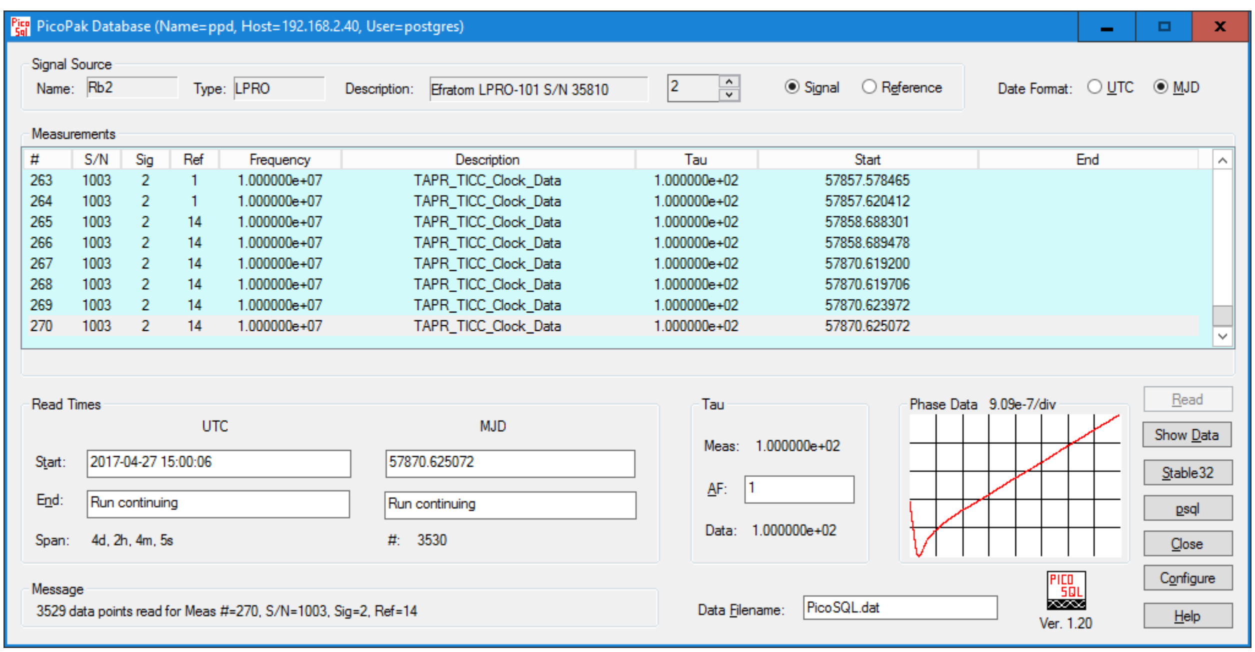

Figure 14. TAPR TICC Phase and Frequency Records Using PicoSQL Clock Data Access Program

• References

1. TADD-2 Assembly and Operation Manual, Tucson Amateur Packet Radio Corporation (TAPR), July 2009.
2. TAPR TICC Timestamping Counter Operation Manual, Tucson Amateur Packet Radio Corporation (TAPR), March 2017.
3. The TICComm program is available as a free download.
4. W.J. Riley, "Running the TAPR TICC with a Raspberry Pi", Hamilton Technical Services, March 2017.
5. W.J. Riley, "A PostgreSQL Database for the PicoPak Clock Measurement Module", Hamilton Technical Services, November 2015.
6. W.J. Riley, "PicoPak Software Overview", Hamilton Technical Services, August 2016.

File: A High-Resolution Time Interval Counter Using the TAPR TADD-2 and TICC Modules.doc
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March 13, 2017
Rev A, May 2, 2017
Rev B, May 3, 2017