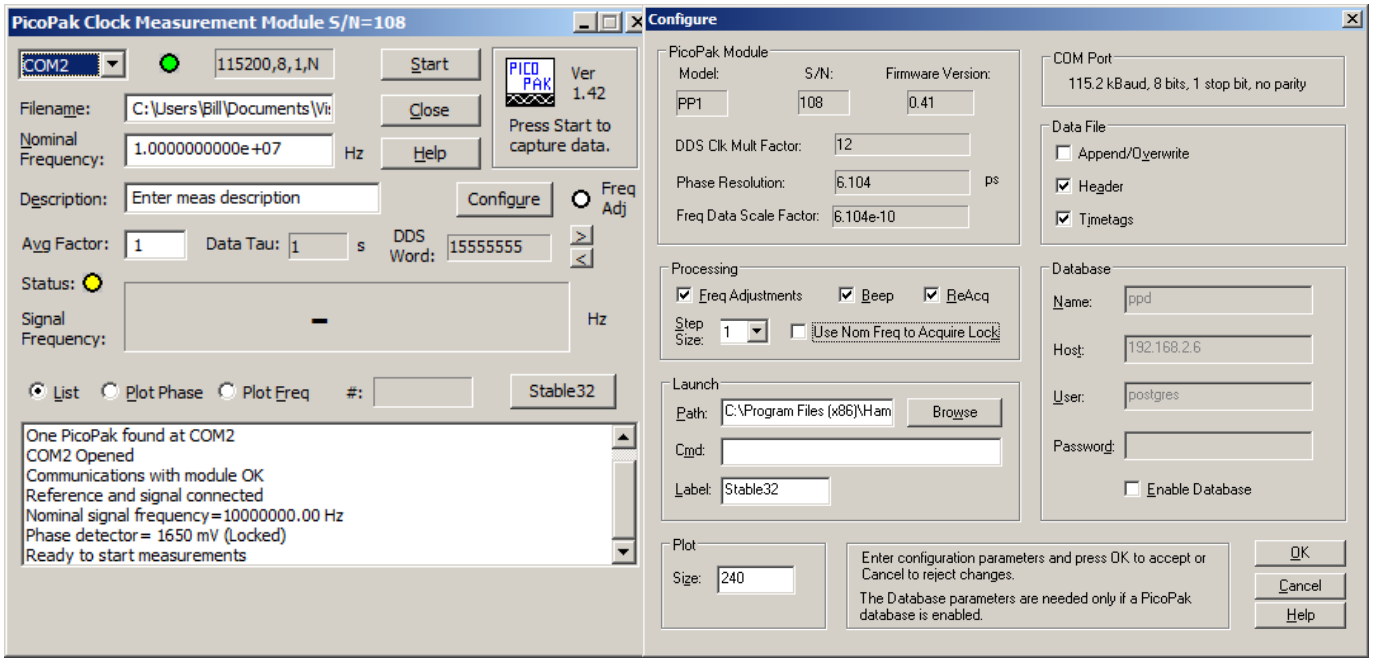
PicoPak Operating Hints

W.J. Riley
Hamilton Technical Services
Beaufort, SC 29907 USA
bill@wriley.com

• Introduction

The PicoPak clock measurement module uses a unique and somewhat unfamiliar principle to make its measurements. This is an effective technique, but it does impose some limitations regarding its operation. These hints are intended to aid in understanding and using the module. Screen shots of the PicoPak main and configure screens are shown below as references for the information below. We will begin with PicoPak operation without its optional PostgreSQL database.



PicoPak Main Screen at Startup PicoPak Configure Screen with Typical Settings

• COM Port

The PicoPak must establish a connection to its PC user interface via a USB-based virtual COM port. This can be more difficult that it should be, mainly because of the behavior of the Windows operating system. Once established, the system will remember the module and its COM port and reestablish its connection to that COM port regardless of which USB port it is plugged into. That is convenient, but if it is necessary to change that relationship it may be necessary to delve into the operating system settings. The PicoPak user interface searches for PicoPak modules when it is launched (see the "One PicoPak found at COM2" on the first status message line), and that can be repeated by pressing F3 at any time when measurements are not being made (which will produce "# Available PicoPaks=1" and "S/N=108, Port=COM2" in this case). The Enumerate command line program supplied with the PicoPak system will also do the same thing. Multiple PicoPak modules can be connected to separate COM ports and used to make simultaneous measurements (although things do get a bit more complicated). See "The PicoPak Virtual Serial Port USB Interface" and "Multiple Instances of the PicoPak Clock Measurement Module and Windows User Interface Program" for more information.

• **Nominal Frequency**

The nominal frequency of the signal should always be entered into its edit box. That value is used for calculating fractional frequency values $(f-f_0/f_0) = \Delta f/f_0$. It is usually a standard value like 10.000000 MHz, and does not necessarily have to be exactly equal to the actual signal frequency. But if it is used to set the PicoPak DDS (see below), then it does indeed have to be nearly exactly equal to it.

• **Averaging Factor**

The desired averaging factor for the stored phase data must be entered into its edit box. This, of course, has to be an integer. It doesn't affect the rate at which the PicoPak takes measurements, that is always exactly 1/s determined by the reference 10 MHz input.

• **Other Main Screen Settings**

The other main screen settings are either optional or will be discussed below. It is very desirable to enter a measurement description, which will be included in the data file header (that is especially important if the optional database is used). The data filename will be the same as the previous one, which will be either overwritten or appended to, and it is likely that you will want to enter a new name for the new measurement.

• **Lock Acquisition**

The PicoPak module must acquire frequency and phase lock before beginning a measurement. The main aspect of that is setting the frequency of its internal DDS frequency synthesizer very close that of the signal under test. That can be accomplished either by manually entering the nominal signal frequency to within $\pm 2 \times 10^{-9}$ of its actual value, or automatically by the PicoPak user interface, as determined by whether or not the Use Nom Freq to Acquire Lock checkbox on the configure screen is checked. If you know the exact signal frequency, then it is better to enter it and check the box, since that avoids the need for the system to determine it.

When you enter the nominal frequency, the corresponding hex DDS tuning word is displayed in its box (e.g., 15555555 for 10 MHz). That value is the one used when the Use Nom Freq to Acquire Lock checkbox is checked. Otherwise, the automatically measured one is used and displayed. If, after an automatic nominal frequency determination, the DDS hex word is not exactly the correct one (e.g., 15555556 instead), it is desirable, but usually not necessary to adjust it with the > and < buttons.

• **Automatic Frequency Measurement**

The automatic frequency measurement is a two-step process. First, a coarse frequency count is made to determine the signal frequency to within a few Hz. Then, a 100 Hz nominal beat note is established between the signal and DDS, and a period measurement is made to determine the signal frequency to within about 10 mHz (1×10^{-9} at 10 MHz). Information is displayed about these frequency measurements, and, if the Beep checkbox is checked, an "exclamation" beep will sound if one of the period measurements is rejected. They are almost always accurate enough to allow the module to lock. If it doesn't, the process will have to be repeated. If you mostly measure 10 MHz atomic frequency standards, set the nominal frequency to that and use it. If you are measuring crystal oscillators at various frequencies, then use the automatic frequency determination.

• **Lock Acquisition (Con't)**

The PicoPak module uses a phase tracking loop that will naturally acquire lock once the DDS frequency is set. The phase acquisition is speeded up by using larger DDS phase increments during the process. Phase lock is sensed by using an ADC to read the phase detector DC output voltage, which must be at the center of its range (equal to its 1644 mV comparator reference voltage) for the proper quadrature condition. This check is performed several times to insure that it is constant. The phase detector voltage and condition (locked or unlocked) is reported in the PicoPak main screen message box. When it is within the proper range (1600 mV to 1728 mV), the module is ready to make measurements. See "The PicoPak Lock Acquisition Process" for more information.

There is a ReAcq checkbox on the configure screen that determines whether or not a full reacquisition is done when a measurement run is restarted. This should generally be checked, but if the same or similar high-stability source is being measured again, this can speed up the reacquisition process.

• **Status Indicators**

The "LED" at the top of the main screen indicates whether or not the COM port is opened (red=not opened, green=opened). The "LED" Status indicator is grey at startup, yellow when the module is ready to start a measurement, green during a run, and red if there is an error. Text in the message box provides additional status information. It is particularly important that the communication between the PicoPak user interface program and the module are OK. If not, a hardware reset or USB disconnect/reconnect may be required.

• **Measurement Processing**

PicoPak measurement processing involves receiving incremental phase, frequency adjustment and phase correction values from the module once per second, applying scale factors, DDS frequency offset and other corrections, and then displaying the resulting fractional frequency, plotting the integrated phase or fractional frequency, and writing timetagged integrated phase data to a disk file. The user has several ways to control that process via setting on the PicoPak configure screen.

The PicoPak phase tracking loop must remain within its dynamic range at all time during a measurement. This may require that the DDS frequency is adjusted to follow the signal frequency, but many highly-stable sources remain within the ±2 to ±3 parts per billion ($pp10^9$) frequency tolerance that the PicoPak phase tracking loop can handle. Therefore, for highly-stable sources, frequency adjustments can be turned off by unchecking the Freq Adjustments checkbox on the configure screen. The state of the frequency adjustments is shown by the Freq Adj indicator on the main screen. If not, frequency adjustments can be enabled, and their size (1, 2 or 3 DDS frequency tuning increments) can be set with the Step Size box. The Beep checkbox determines whether or not an "OK" beep is sounded when a frequency adjustment is made. The main consideration is for fast frequency slew, which is limited to about $\pm 3 \times 10^{-7}$/s, a fundamental limitation of the PicoPak measurement concept. See the paper "PicoPak Phase and Frequency Tracking Dynamics" for more information.

• **Data Listing**

During a run, the message area shows a listing of the data. This information is the data point #, the hex data, and the incremental phase error over the last second (also equal to the fractional frequency error). The hex data comprises 4 characters for the phase count, 2 characters for the frequency adjustments and 2 characters for the phase corrections. These characters represent signed integers. Without frequency adjustments, the last 4 characters are zero.

- **Plot Size**

The size (# of points, 1point/s) of the phase or frequency plot on the main PicoPak screen can be set with an edit box on the configure screen. The plot fills up to this size and then scrolls as more data is obtained. It should be set to a multiple of eight because there are eight horizontal plot divisions; there is little reason to use a value other than the default 240, and the data listing holds about that number of points.. Phase data is plotted point-to-point, while frequency data is plotted as horizontal line segments depicting the 1 second sampling time.

- **Plot Annotations**

The annotations below the phase and frequency plots show the x and y scale factors, the average frequency over the visible plot, and its standard error (a measure of the frequency stability). The green line on the frequency plot shows its average value.

- **Input Level**

The nominal level of the signal and reference inputs is +7 dBm. The module will work over a range of at least -10 dBm to +10 dBm, and the inputs should be low-distortion sinewaves. The inputs present a good 50 Ω impedance match so reflections should not be a problem. It is important that the cables and connections are mechanically sound to avoid erratic phase readings. RF isolation transformers may be helpful in some cases for eliminating ground loops. Operating all parts of a measuring system from the same power strip is also advisable.

The lowest noise floor occurs with a signal level somewhat below nominal, say +3 dBm. The reference level is less critical.

- **Data File**

Besides the data file name on the main screen, the PicoPak configure screen allows a choice of whether or not a header is written at the top of the file, and whether timetags are written along with the phase data. These options should be left on unless there is a reason to do otherwise.

There is another choice as to whether or not to show a data file Append/Overwrite box when a run is started. Uncheck this box for the data file to always be overwritten.

- **Launch**

The launch parameters on the configure screen are used to set up the launch of a frequency stability analysis program with a button on the main screen. The full path to that program is entered in its edit box with the help of the browse button. The label for the launch button on the main screen is entered in its edit box. This feature is provided mainly for the Stable32 program, which will automatically open the PicoPak phase data file with the appropriate sampling time (tau) value, and there are provisions for entering additional command line arguments such as skipping the Stable32 file read screen with –o skip. Please see the Stable32 User Manual and Help file for more information about that and automating Stable32 analyses.

- **Data**

The PicoPak module supports five data formats, but only one of those, the most complete 1-second stream, is used by the PicoPak user interface. That data stream provides incremental phase count,

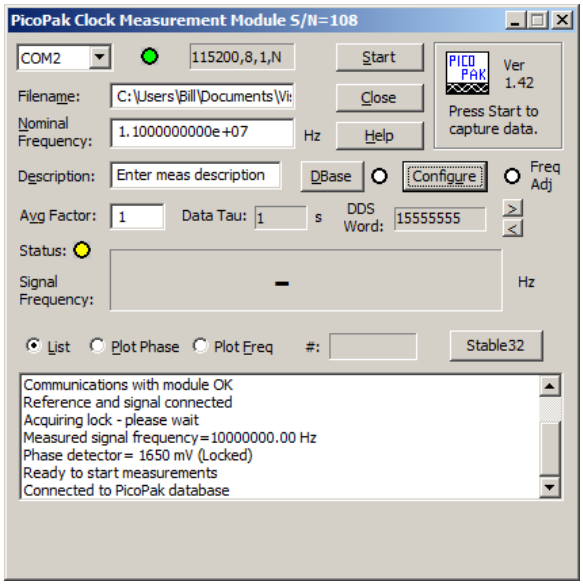
frequency adjustment count and phase correction information that is processed by the user interface to obtain integrated phase values in seconds.

The scale factor of the incremental phase count is determined by the DDS frequency (its period divided by 2^{16}), and the incremental phase count is multiplied by that to obtain its value in seconds. The frequency adjustment count represents any change made to the DDS tuning word during the measurement interval. The incremental phase value is then corrected for the effect of the frequency offset between the DDS and nominal frequencies, and for the effect of any DDS frequency adjustments made during the measurement interval. Because the measurement interval is 1 second, the corrected incremental phase value is also the fractional frequency reading. Finally, the corrected incremental phase value is added to the integrated phase to obtain the phase data point.

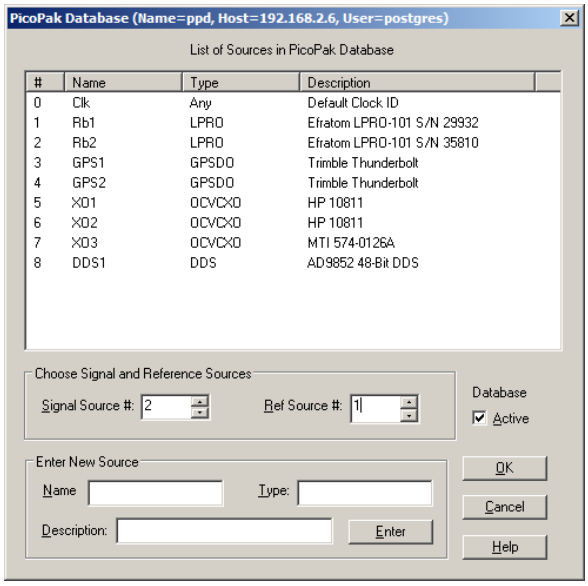
MJD timetags with millisecond resolution are optionally added to the data that are written to the disk file each second. Those are obtained from the PC system clock, which should therefore be accurately set by some means such as an internet-based NTP time client like Meinberg (see: meinbergglobal.com).

- **Database**

The PicoPak system also supports an optional PostgreSQL database to store and access its clock data. This functionality is enabled with the Enable Database checkbox on the configure screen, which adds a DBase button and status indicator to the main screen. The Dbase button is activated when a database connection has been made, and pressing it brings up the Database screen shown below.



PicoPak Main Screen with Database Enabled



PicoPak Database Screen with Typical Settings

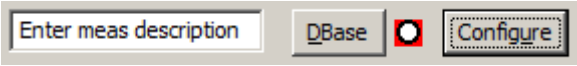
Information about installing and using the database can be found in the paper "A PostgreSQL Database for the PicoPak Clock Measurement Module".

To use the database, its logon credentials must be entered on the configure screen, and a connection made to it by checking the Enable Database checkbox. To activate it for a particular measurement run, check the Database Active checkbox on the Database screen. If the database is deactivated, the background color of its indicator on the main screen is red. The database status settings are shown below:

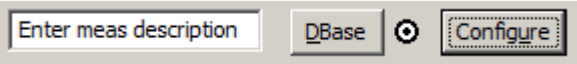
Database disabled:

Database enabled but not connected:

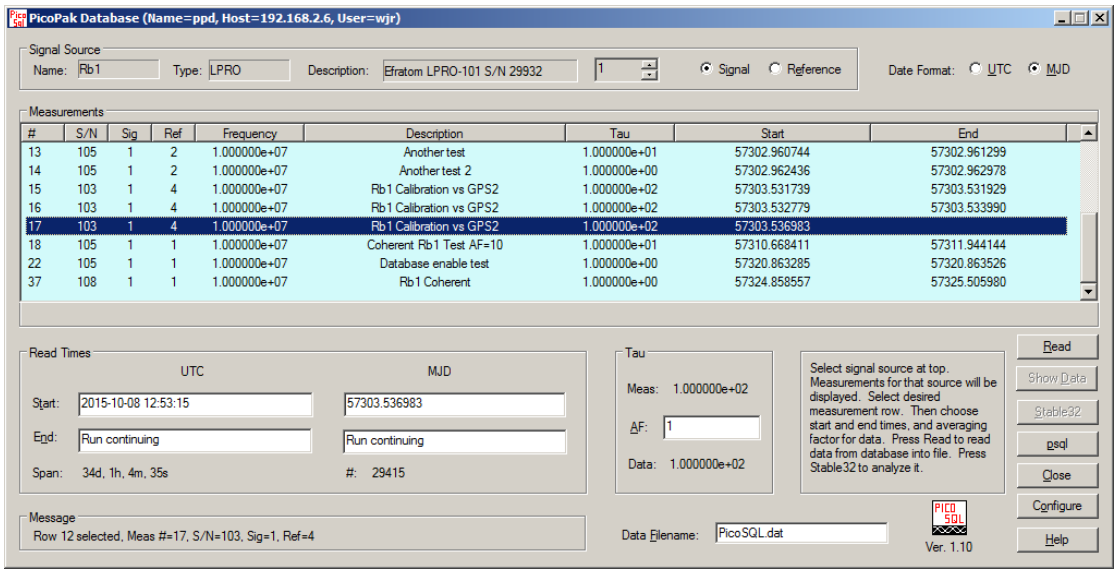
Database enabled and connected but inactive:



Database enabled, connected and active:



Before beginning a run with the database, one should not only enter a description of the measurement on the main screen but, more importantly, select the signal and measurement clocks on the Database screen, which will put that information into the database to allow easier access to the data. New clocks can be added by entering their Name, Type and Description on the Database screen. Database access is supported by the PicoSQL user interface program, whose main screen is shown below. Note that the size of the Description field is limited to 30 characters. Dragging the Database window to the edge of the screen, or pressing the left mouse button in the plot area, will refresh the plot without re-reading the data.



PicoSQL Database Access Program Main Screen

- **Database Security**

The PicoPak and PicoSQL programs hide the database user password on their screens and encrypt it in their configuration files. But, as presently implemented, the stored password is read, decrypted and reapplied when either application is opened. There is therefore no real database security since anyone can open the program and access the database (although they can't learn the password itself, which could be entered only once by the by the system administrator. It would be easy, but inconvenient, to require that the user enter his/her password each time the program is opened. Since there is no obviously secure way to make that a program option, it would have to be rebuilt with that option. Perhaps the main security issue is the ability to launch psql from within PicoSQL, which allows just about any change to be made to the database. Fortunately, connecting to the database via psql requires a separate password entry if one is imposed by the database access settings.

• Limitations, Problems, Anomalies and Hints

The PicoPak module user interface program is a work in progress, so problems and anomalies are still being resolved. The PicoPak operating concept presents several issues that are different from traditional phase and frequency measurements, and to some extent are intrinsic to its small, low cost hardware and associated firmware.

The PicoPak is limited to measuring precision and semi-precision frequency sources between 5 MHz and 15 MHz. It has a 1-second ADEV noise floor of about $1x10^{-11}$ that improves with tau down to the $pp10^{16}$ range where thermal and other considerations apply. It can also serve as an 11 digits/s counter.

We already mentioned the need to set the internal PicoPak DDS frequency to agree with that of the signal under test in order to successfully acquire lock, and that that setting is also used for calculating fractional frequency values. We also mentioned that there is a limit on the size of the frequency slew rate that can be handled, which precludes measuring low-stability devices or things like OCXO warmup.

If either the reference or signal (or both) are removed, the module will stop measuring, but in somewhat different ways than might be expected. Generally, if either the signal or reference input is lost, the user interface will detect it, sound an "asterisk" beep, stop the measurements, and close the data file. When the signal or reference is restored, measurements can be restarted by pressing the Start button. Generally, if both the signal and reference inputs are lost (as for a coherent run), the measurement stream will continue while indicating No Data. When the inputs are restored, either valid measurements will begin again or the user interface will report their loss, sound a "hand" beep, stop the measurements, and close the data file. That inconsistent behavior is due to the use of the phase detector DC output as an unlock detector which is ambiguous since no input produces the same output as correct quadrature conditions, and unlock detection depends on its output transient. In any case, signal or reference loss ends the usefulness of a run. The subsequent restart inconsistency is best managed by doing a complete restart of the user interface.

If you are getting strange fractional frequency values, check that the nominal frequency is correct. If you are getting strange readings that are off by several $pp10^{9}$, check the DDS hex word and cycle it up and down to resynchronize it between the module and user interface.

One way to force a re-initialization of the user interface is to select another COM port and then reselect the proper one.

There may be times when the module must be reset, for example when the communications link between the PC and PicoPak firmware fails. That can be done by either pressing its reset button or by removing and reinserting its USB cable at either the PC or module.

The data file allows sharing so it can be read at any time by another program. The data file buffer is flushed to disk after every measurement so new points are immediately available.

There is an "undocumented" Verbose flag that can be manually set (Verbose=1) or reset (Verbose=0) in the [Preferences] section of the PicoPak.ini configuration file that reports several additional items in the PicoPak main screen message box.

The PicoPak module S/N is shown in the dialog box title bar, and the user interface version # is shown next to the icon on the main screen. The module model, S/N and firmware version is shown on the PicoPak configure screen. The main screen may be minimized, and its position changed in the usual Windows fashion. The position is saved and restored when the program is closed and reopened.

With the database, you can use the Stable32 button on the main PicoPak user interface screen to examine the data during a run, and the Stable32 button on the main PicoSQL screen at any time afterwards without having to rename either the PicoPak or PicoSQL data file.

Most of the controls are disabled during a PicoPak measurement run. Press Stop to stop the run before trying to close the program.

After measurement data is read in PicoPak, the Read button is disabled so that it cannot be read again without reselecting the measurement run and updating the number of points.

It is recommended that some form of connector saver be used on the two SMA RF connectors, either an SMA M/F or an SMA M to BNC F. An SMA attenuator can be used on the signal input, which may also reduce the noise floor. The SMA connectors should be installed with a 5 to 7 in-lbs (0.6 N-m) torque wrench. Proper connector torque is important for both their life and to assure a solid, phase-stable connection. Quality cables are also recommended, and can avoid much frustration.

Long-term measurement runs require precautions against their interruption, including powering the signal and reference sources, reference distribution, measuring system computer and optional database server from an UPS. It is preferable to disconnect those computers and their LAN from the internet; if connected to the internet, automatic updates should be disabled. It is also preferable that the measurement and optional database computers be dedicated to those purposes, with data analysis performed on another workstation. The environmental conditions in the test area should be as stable as possible, and any disturbances should be noted in a log. The optional database should be backed up regularly.

It is essential that the PicoPak programs and their users have full read/write access to the folders where they are launched and their data is stored. To allow full user control of the C:\Program Files (x86)\Hamilton Technical Services\ folder:

1. Navigate File Explorer to that folder.
2. Click on Properties.
3. Select the Security tab.
4. Press Edit.
5. Select Users.
6. Check Allow/Full control and then press Apply.
7. Press OK and then OK again to close the dialog boxes.

The Hamilton Technical Services folder(s) can now be written to by their users.

It is important that the various computers used for PicoPak data acquisition and storage all have their clocks synchronized, preferably to UTC using a GPS reference or NTP server. This is essential for the refresh and monitoring functions of the PicoMon program.

It can be an advantage that the database server has a fixed rather than a dynamic (DHCP) network address so that the configuration of the various PicoPak programs and measurements does not change.

It is wise to confirm that all elements of a clock measuring system (source, reference, distribution amplifiers, measurement module, database server, etc.) have uninterruptable power before starting a long, important measurement run.

File: PicoPak Operating Hints.doc
W.J. Riley
Hamilton Technical Services
December 27, 2015