The PicoScan Quad RF Switch Module

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• Introduction

This document describes a four-channel RF switch module designed to work with the PicoPak clock measurement module. It is powered and controlled via a USB interface, and is packaged the same type of extruded aluminum enclosure as the other PicoPak family of instruments. The switching arrangement comprises one common 50-ohm port that can be connected to one or more of four I/O ports. The most common application is to switch one of four 5-15 MHz RF signals into the Signal input of a PicoPak clock measurement module. But it can be used at any frequency from DC to above 50 MHz, including switching of 1 PPS clock pulses. A photograph of the PicoScan Quad RF Switch module is shown in Figure 1.

Figure 1. PicoScan Quad Switch Module

• Block Diagram

A block diagram of the PicoScan Quad RF Switch is shown in Figure 2.

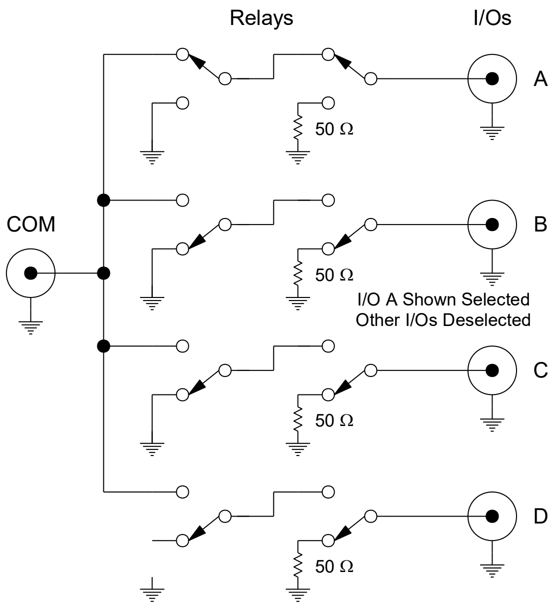


Figure 2A. Switching Logic

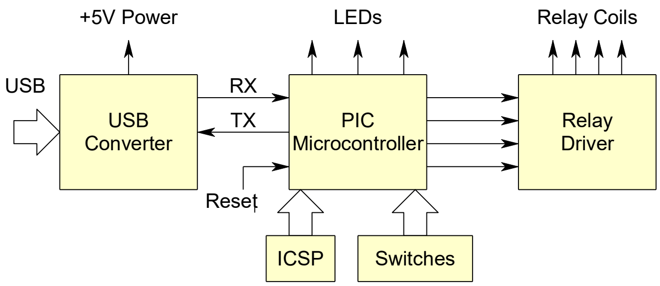


Figure 2B. Control Logic

• Schematic

Schematic of the PicoScan Quad RF Switch RF and Logic sections are shown in Figures 3 and 4. It comprises four DPDT relays, a Darlington relay driver chip, a PIC microcontroller, and USB interface device. Four DIP switches manually set the relay states, and LEDS serve as monitors showing their settings. The cascaded RF switch sections improve the channel isolation.

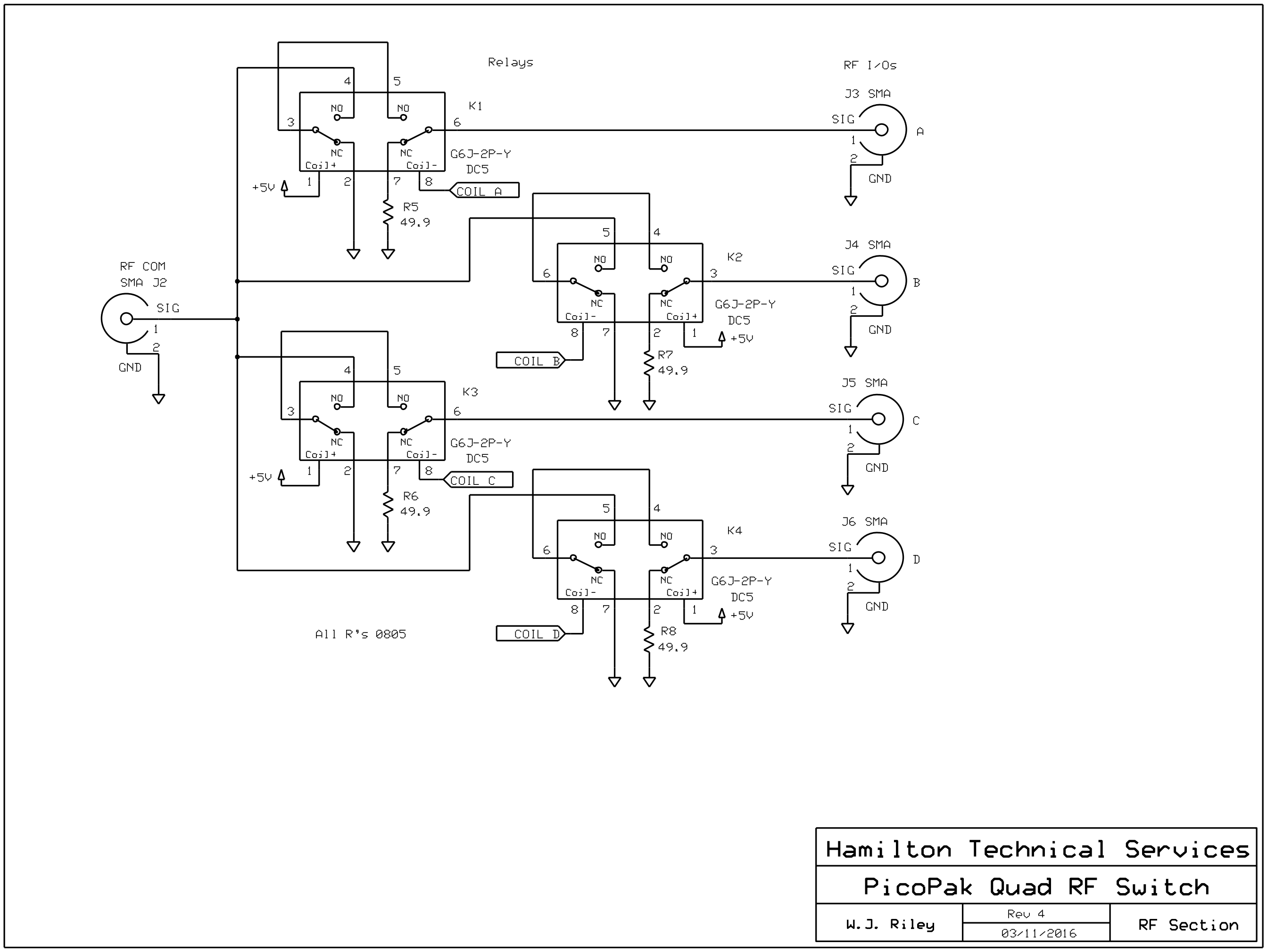


Figure 2. PicoPak Quad RF Switch Schematic – RF Section

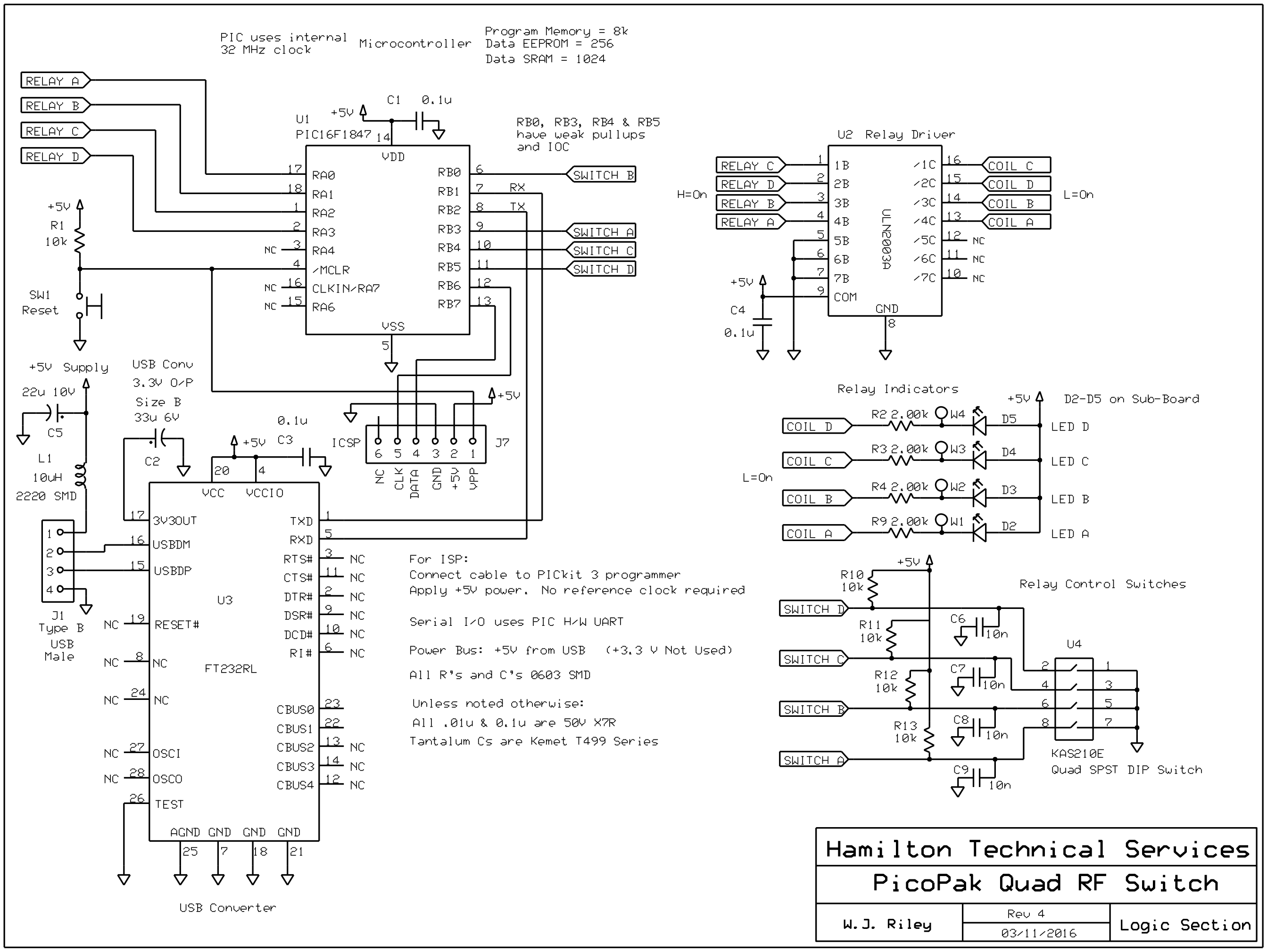


Figure 3. PicoPak Quad RF Switch Schematic – Logic Section

• Board Layout

The layout of the 50 mm x 80 mm nominal PicoScan Quad RF Switch circuit board is shown in Figure 5. The four RF I/O port SMA connectors are on the front end of the board, and the common RF port SMA connector, USB Type B jack and DIP switches are on the back. Besides the devices mentioned above, the board has a 6-pin ICSP programming connector and a reset button for the microcontroller. 50-ohm microstrip lines are used for the RF traces.

The four LEDs are on a small sub-board (not shown) that is mounted directly above the four SMA connectors behind the front panel.

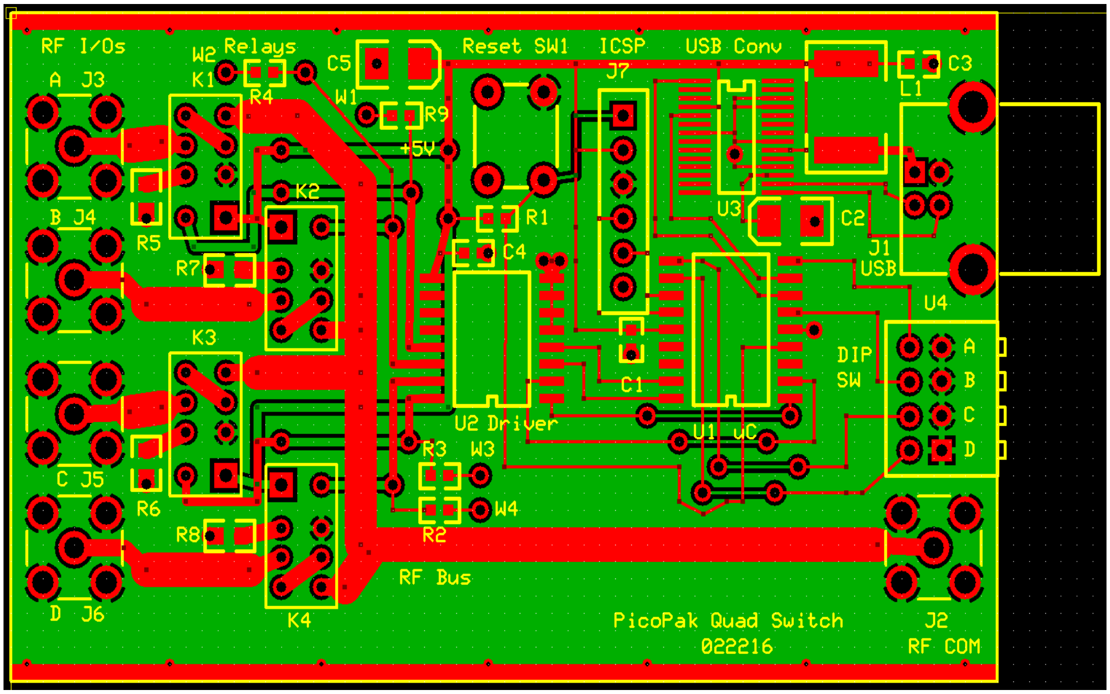


Figure 4. PicoScan Quad RF Switch Schematic – Board Layout

- **Quad RF Switch Board**

A photograph of the Quad RF Switch Module is shown in Figure 5. The four LEDs are visible on their sub-board above the SMA connectors on the front panel at the left. The large white components are the relays, and the relay driver chip is in the middle below the reset switch. The 6-pin header is for in-circuit programming of the PIC microcontroller (the largest chip) and the USC converter is located above it. The USB connector, DIP switches and common RF SMA connector are at the right, and slide into the rear panel.

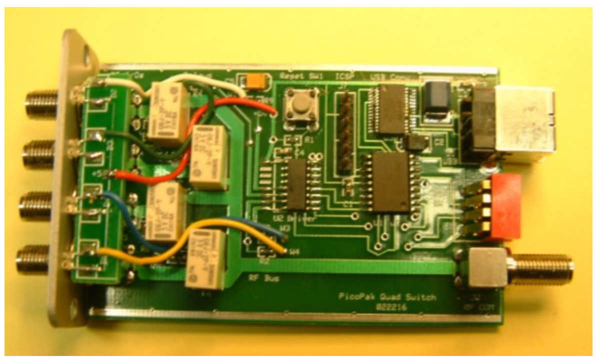


Figure 5. Quad RF Switch Board

- **Manual Switch Controls**

The four RF switches can be controlled manually by means of the four DIP switches on the rear panel. They are arranged to match the position of the front panel SMA connectors, and go from D to A (left to right looking at them from the rear of the module). The switched are on when the switch is up. These switches eliminate the need to connect the module to a computer and use control software, and, of course, have mechanical "memory" for their settings. The RF switches are initially set according to the rear panel DIP switches after applying power to the module or resetting its microcontroller.

• **LED Monitors**

There are four LEDS above the SMA connectors on the front panel that show the state of their corresponding switching relays (Lit=On, Unlit=Off. The four LEDs flash for a half-second when the module is powered up or its microcontroller is reset.

• **Commands**

The quad switch can also be computer-controlled via a terminal program such as TeraTerm, and accepts the following commands:

Cmd	I/O	Description	↵	=	?	Pneumonic	Format	Reset State	Remarks
A	Cmd	Turn Switches On				All			All switched on (closed)
D	Cmd	Read DIP Switches				DIP Switch		Auto Read	
L	Cmd	Flash LED				LED		Flash	Single L entry = 1s flash
N	I/O	Serial Number	√	√	√	Number	4 hex chars	Previous	Stored in EEPRPM
O	Cmd	Turn Switches Off				Off			All switches off (open)
R	Cmd	Reset PIC				Reset			Same as reset button
S	I/O	Get/Set Switch State	√	√	√	Switch	4 hex chars	0000	0 or 1 allowed (0=off)
V	I/O	Get/Set Verbose Mode	√	√	√	Verbose	1 hex char	0	0 or 1 allowed (0=off)
1	Cmd	Open Switch A							
2	Cmd	Open Switch B							
3	Cmd	Open Switch C							
4	Cmd	Open Switch D							
5	Cmd	Close Switch A							
6	Cmd	Close Switch B							
7	Cmd	Close Switch C							
8	Cmd	Close Switch D							
?	Cmd	Display Command Help				Question			Single ? entry

These commands are of the form C, C↵, C=# or C?, where C is the command letter code; immediately where appropriate or along with, ↵ to display a value with textual information, = to set a value and ? to read it. No carriage return is entered, and the commands are not echoed by the module. They are not required when using the Windows® software to control the switch module (see below).

The main commands are S=# or S? to set or read the switch state, where # is a 4-character code representing channels ABCD where 0=Off and 1=On, e.g, 0000 (all off) through 1111 (all on). For example, to turn on switches A and B, the command is S=1100.

The RF switches are initially set according to the rear panel DIP switches after applying power to the module or resetting its microcontroller. If the unit is then connected via its USB port to a computer running a terminal program, the RF switch states can be changed by external commands (the DIP switches will not, of course, change).

These commands can also be used to implement a custom control program such as to implement a 4-channel scanned clock measuring system along with a single PicoPak module.

• The PicoScan Clock Measuring System

The PicoScan clock measuring system comprises one PicoPak module and one PicoScan module and the PicoScan Windows® control software. The main characteristics of this system are as follows:

1. The system makes zero dead time phase measurements with the full PicoPak resolution.
2. All of the sources under test must be at the same nominal frequency within about ±2.5e-9 so that the PicoPak can maintain lock at a fixed DDS frequency (See Items 3 and 5).
3. The PicoPak DDS frequency cannot be changed during measurements so that continuous phase data are obtained.
4. The system must use the "absolute" PicoPak data stream #5 so that phase continuity is maintained between scanned measurements.
5. The measurement interval must not exceed that necessary for unambiguous phase data. At 10 MHz, that limit is 50 ns, and, for a frequency offset of ±2.5e-9, that sets a maximum measurement interval of 20 seconds. The allowable frequency offset is the combination of the source and DDS. At exactly 10 MHz, the DDS offset is about -9.3e-10, so the source offset cannot exceed about -3.4e-9 to +1.6e-9.
6. The 20 second measurement interval limit sets the maximum dwell time for a 4-channel system as 5 seconds. The minimum dwell time is that necessary for the PicoPak to re-stabilize between channels, about 2 seconds. A fixed 5 second dwell is used because it allows "even" 5, 10, 15 and 20 second measurement intervals that can be averaged to tau values like 1 minute, 100 seconds, 15 minutes, 1000 seconds, 1 hour, etc.
7. The number of channels sets the measurement interval, and cannot be changed during measurements because the data tau must remain the same.
8. Subject to the fixed measurement interval set by channel activation at measurement startup, individual channels can be stopped and restarted during scanning.
9. PicoScan timetagged phase data are stored in separate channel disk files, and also in the optional PicoPak PostgreSQL database.
10. The PicoScan user interface includes monitoring features to show 12-digit frequency values and either phase or fractional frequency plots for the 1-4 active channels.

• A PicoScan 4-Channel Clock Measuring System Test

A PicoScan 4-channel clock measurement system comprises a PicoPak clock measurement module and a PicoScan quad RF switch. One to four clock signals are scanned into the PicoPak by the PicoScan and timetagged phase measurements are made sequentially at 5-second intervals. As a test of that system, a PicoAmp quad RF amplifier was used to drive the PicoSwitch inputs coherently with the common reference as shown in Figure 6. This setup produces 4-channel phase data at a 20 second sampling interval and has a resolution and noise floor essentially identical to a basic PicoPak (see Figure 7). It is controlled by the PicoScan Windows® shown below and writes its data to both disk files and an optional PicoPak PostgreSQL database.

Figure 6. Coherent Test Setup for a 4-Channel PicoScan Clock Measurement System

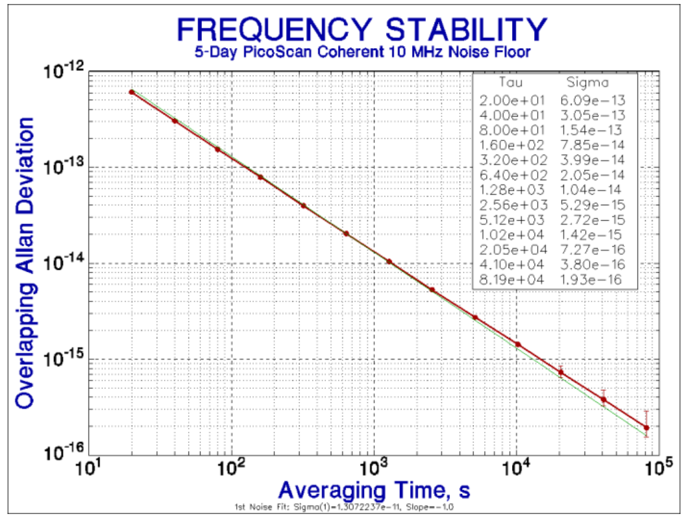
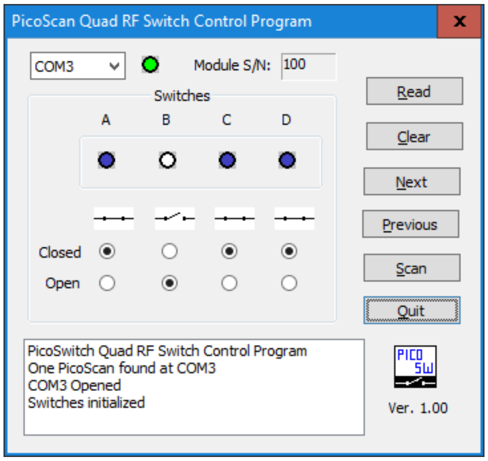


Figure 7. Coherent Noise Test of a 4-Channel PicoScan Clock Measurement System

• **Windows Software**

The PicoScan quad RF switch module comes with a Microsoft Windows® application to control it, as shown in Figure 8. Multiple instances of the program can be used to control multiple switch modules. This program is simply a graphical user interface that uses the same command set, and those commands take precedence over the DIP switch settings.

The PicoScan package also includes Windows® software for using it along with a PicoPak module as part of a 4-channel scanned clock measurement system, as shown in Figure 9. That program supports scanned phase measurements for 1-4 channels with a 5 second dwell time and sampling intervals of 5, 10, 15 and 20 seconds respectively. After opening serial communications with the PicoPak and PicoScan modules, and setting the common nominal frequency (e.g., 10 MHz), the actively scanned channels arfe selected and their individual parameters (source name, measurement description and data file name) can be set, and their optional PicoPak PostgreSQL database use configured. Then measurements can be started and stopped for individual or all channels. During measurements, the measured frequency is displayed, and data listings or a phase or fractional frequency plots are shown for each channel as it is scanned and measured. The resulting data files and database entries are identical to those of the basic PicoPak, and can be analyzed on-the-fly or afterwards with Stable32 and/or the PicoMon and PicoSQL programs.



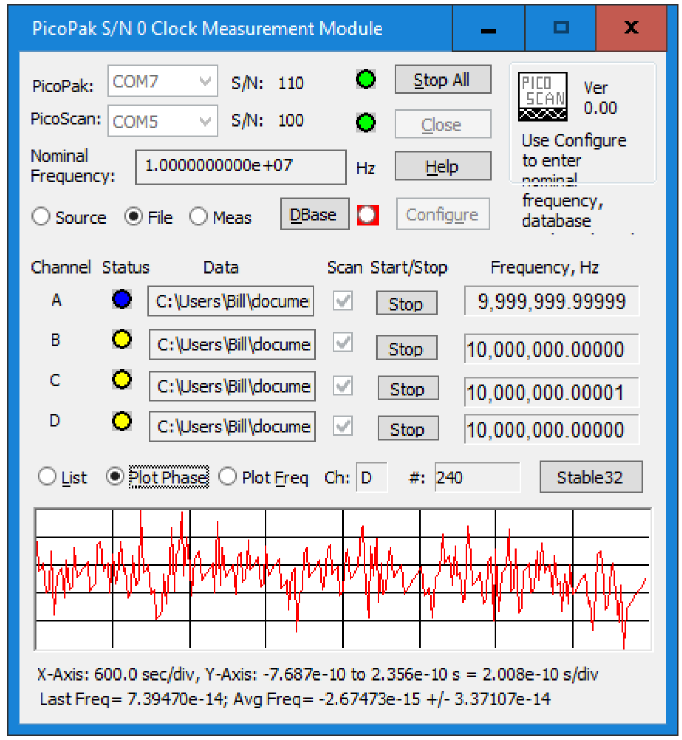


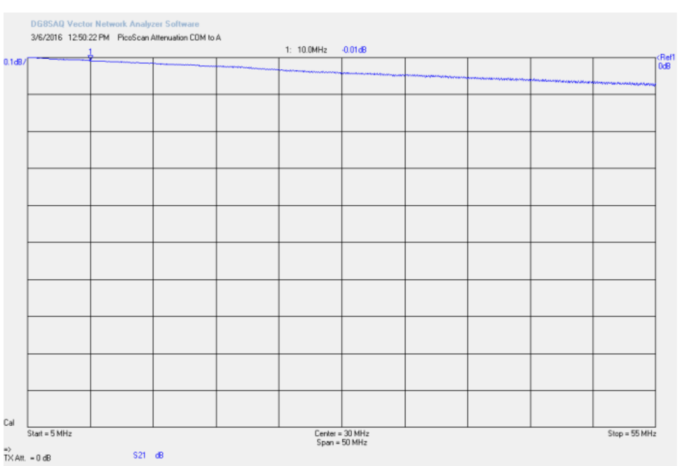
Figure 8. PicoSwitch Program Screen

Figure 9. PicoScan Program Main Screen

- **Performance**

The main performance attributes are switch insertion loss, isolation and impedance match. Preliminary measurements with an RF spectrum analyzer/tracking generator indicated an acceptable insertion loss (≈ 0.07 dB) and reasonable isolation (-71 dB) at 10 MHz. With all four inputs driven coherently, the Common output level changed from +10.4 dBm with all switches on to -60.4 dBm with all switches off.

Representative measurements with an RF network analyzer are shown in Figures 6-9.



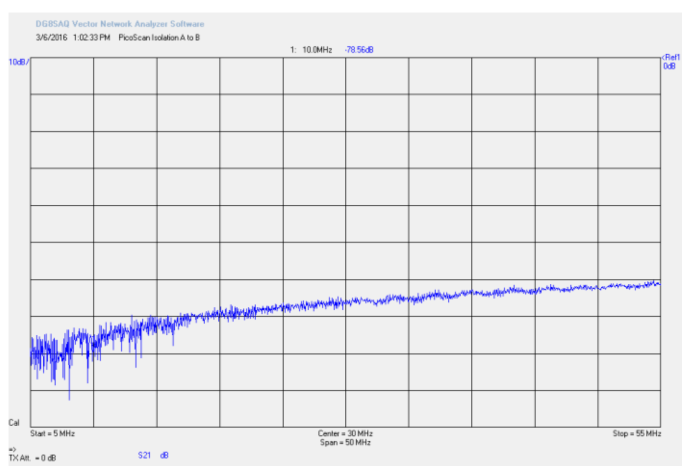


Figure 6. Insertion Loss – COM to Channel A

Figure 7. Isolation – Channel A to Channel B

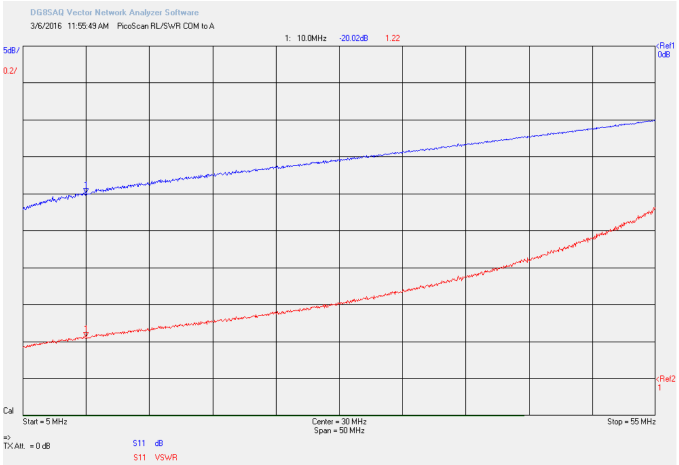


Figure 8. Input Impedance – COM Port with Channel A Selected and Terminated

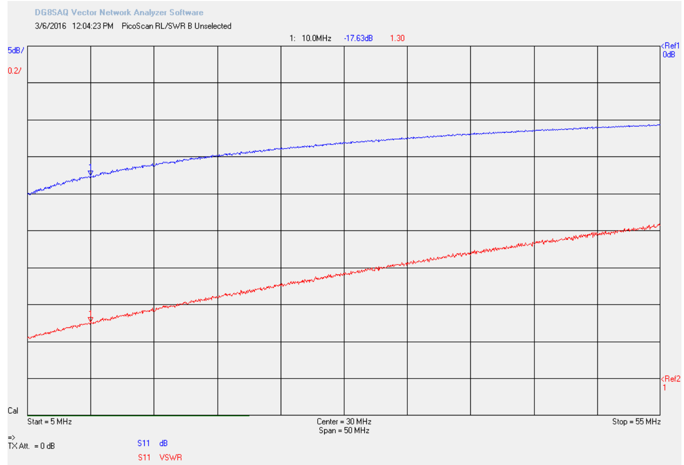


Figure 9. Input Impedance – Channel B Unselected

Referring to Figure 6, the insertion loss was a negligible 0.01 dB at 10 MHz.

Referring to Figure 7, the isolation was a very good 78 dB at 10 MHz.

Referring to Figures 8 and 9, at 10 MHz, the input impedance seen at the Common port with Channel A selected and terminated into 50 Ω had a return loss of 20 dB and a SWR of 1.22, and the input impedance of the unselected adjacent Channel B has a return loss of about 18 dB and a SWR of 1.30.

These parameters are discussed in more detail below.

<u>Insertion Loss</u>

The insertion loss between the common port and a selected I/O port is very small at its commonly-used HF frequencies, and is not a particularly critical aspect of clock measurements.

<u>Isolation</u>

The isolation between the common port and any unselected I/O port is an important parameter to avoid inter-channel crosstalk. The isolation will degrade toward higher frequencies, and that is probably the limiting aspect of a device of this type.

An estimate of the required isolation is as follows: The worst case is when the interfering signal is in phase with the desired signal and is at nearly the same frequency so that it produces a slow beat note, while it has no effect if it is in quadrature. Ninety degrees corresponds to 25 ns at 10 MHz. The PicoPak noise floor is about 10 ps, a ratio of about 2500 or 68 dB. So the inter-channel isolation should be at least 70 dB at 10 MHz.

The first isolation tests measured > 80 dB isolation between two adjacent I/O connectors, first without the relays installed, and then with inactivated relays. Isolation tests on the completed module showed an adjacent channel isolation of 78 dB at 10 MHz, which should be quite adequate for the intended clock measurement application.

Impedance Match

The impedance match presented by the common port when a selected I/O port is terminated into a 50 ohm load can be of some importance for avoiding transmission line reflections, as could possibly the match presented by any unselected I/O port. These attributes were also acceptable at 10 MHz.

Power Consumption

The power consumption of the quad switch is dominated by that of its relay coils, and therefore depending directly on the number of active switches. With all four relays activated, the 5 V USB current was 130 mA.

RF Power Rating

The expected switch usage does not involve RF powers above about +10 dBm (10 mW). A loss of 1 dB (≈12%) with a 1 W signal would correspond to a dissipation of 120 mW, mainly in the relay and board traces (mostly the latter), which seems entirely reasonable. The relay contacts are rated 1 A so that is not an issue. They have a maximum resistance of 0.1 Ω (2% loss in a 50 Ω system) and a rated dissipation of 100 mW, allowing a 5W signal.

A more serious power limit is imposed by the 0805 terminating resistors in the current design that are rated for only 125 mW at +70 °C. If derated by half, that sets a +18 dBm limit for the PicoScan inputs.

Switching Speed

The relays have a maximum on or off response time of 3 milliseconds (typically 1.6 ms on, 1.0 ms off).

Endurance

The relays are rated for 50 million operations. If used to make 4-channel scanned clock measurements at a 5 second/channel rate, each relay will be cycled on and off 3 times/minute, and the relays should therefore last for over 30 years.

• **Other Tests**

A test for interference due to PicoScan switch leakage was mode by driving a PicoPak clock measurement module from the common output of a PicoScan switch with one coherent 10 MHz test channel selected and a slightly-offset (-9.31×10^{-10}, corresponding to a beat period of 107 seconds) signal either not applied or applied to its three unselected channels, all at a nominal level of +5 dBm. Phase data, Dynamic Allan deviation and ADEV plots for the results are shown in Figures 10 and 13. The interfering signal was applied at the middle of the run. There was a phase offset of about -16 ps (perhaps due to moving the cables), but no obvious interference or change in noise level.

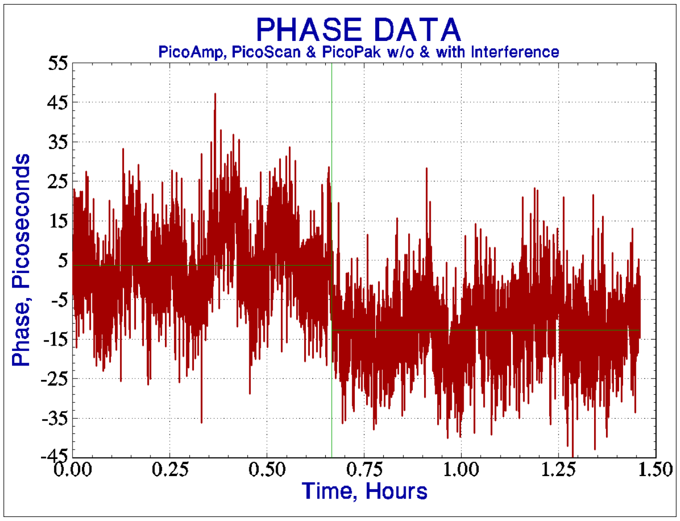


Figure 10. Phase Plot w/o and with Interference

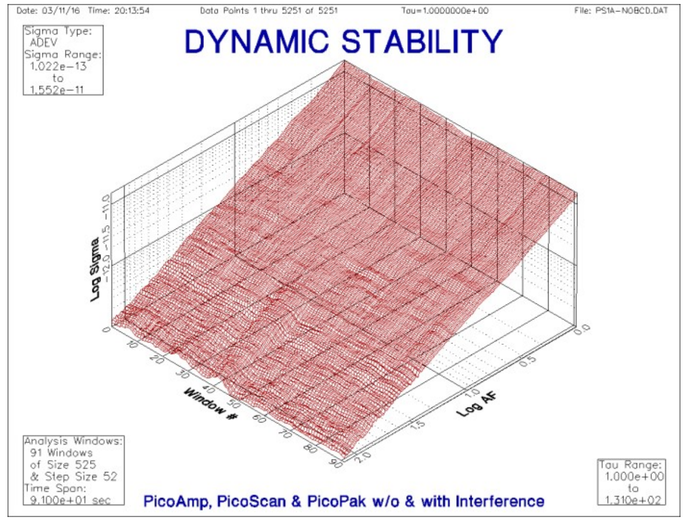


Figure 11. DADEV Plot w/o and with Interference

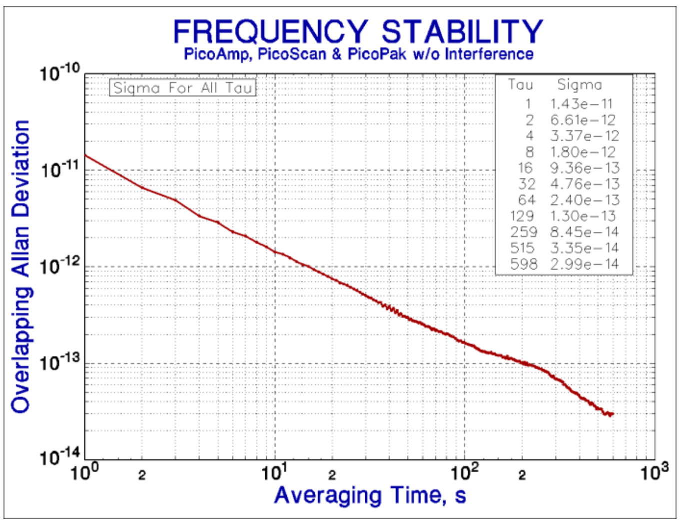


Figure 12. ADEV Plot w/o Interfering Signal

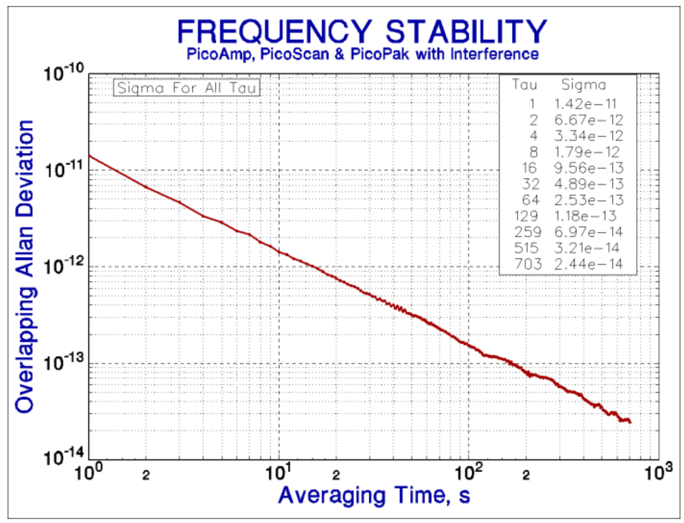


Figure 13. ADEV Plot with Interfering Signal

A test was conducted to measure the scan dwell time of PicoScan module controlled by the PicoSwitch program. One channel input was connected to a 1 VDC source (within the rating of the 50 Ω internal terminating resistor) and the module was scanned between that and another channel at a nominal 5-second dwell time. The actual dwell time was measured with a time interval counter in DC-coupled common start-stop positive-negative edge mode with a 0.5 VDC trigger threshold. The resulting dwell time was varied slightly (presumably due to Windows® operating system latency differences), but was always within 0.2% of the nominal value.

A test was conducted using the combination of a PicoAmp quad distribution amplifier, a PicoScan quad RF switch and a PicoPak clock measurement module. A laboratory DDS synthesizer was set to the same clock frequency and control word as the internal PicoPak DDS, and it and PicoPak were both referenced to the same 10 MHz source, thereby producing a nearly constant-phase coherent source that was fed via the PicoAmp to the four PicoScan inputs, which were scanned into the PicoPak with 100 second dwell times. The resulting "absolute" phase data stream was captured with TeraTerm, converted to decimal form in Excel, and plotted by Stable32 as shown in Figure 14.

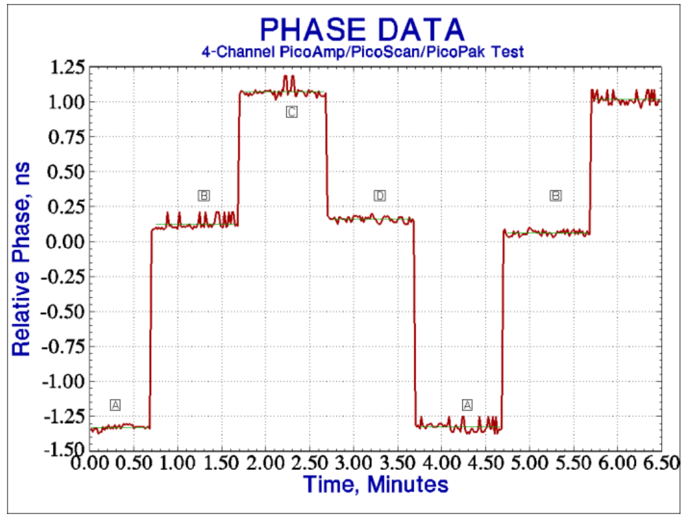


Figure 14. 4-Channel Scanned Coherent Phase Plot

The switching transitions are smooth and occur within one 1-second sampling interval, and the phase values reproduce between samples. The phase differences are presumably due to different phase shifts between the PicoAmp and PicoScan channels since the cable lengths were normally the same. The phase readings remained essentially unchanged over several hours of observation.

Another test was conducted using the combination of a PicoAmp quad distribution amplifier, a PicoScan quad RF switch and a PicoPak clock measurement module. The PicoPak reference input and the PicoAmp input were driven from the same 10 MHz Rb oscillator, the four PicoAmp outputs were connected to the four PicoScan inputs, and the PicoAmp common output drove the PicoPak signal input, thereby producing four scanned coherent 10 MHz sources that were scanned into the PicoPak with 60-second dwell times. This setup was used as follows:

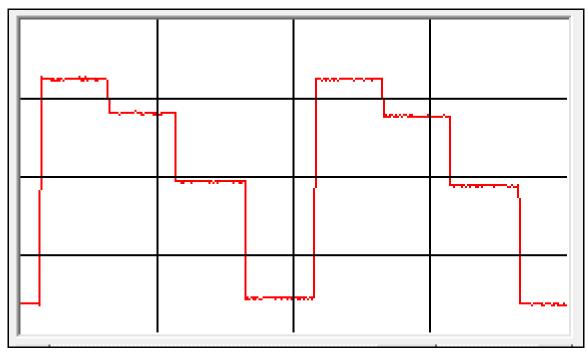


Figure 14. 4-Channel Scanned Coherent Phase Data Plot for Two Scan Cycles with 1 Minute Dwells Channels D,A,B,C,D,A,B,C,D, 1 ns/Division

The PicoPak has an "undocumented" UnlockStop flag that can be put into the [Preferences] section of its configuration file; normally 1, it can be set to 0 to allow a measurement to continue after loss of phase tracking. Thus it can continue making scanned measurements after the momentary signal loss during PicoScan channel switching. Because the standard PicoPak Windows® application uses incremental phase data, this does not provide phase continuity between scanner cycles, and the resulting frequency data have much dead time. It nevertheless does show that such scanned measurements are possible, as shown in Figure 14.

The PicoScan Windows® application uses "absolute" phase data (its DDS phase offset word) to overcome this issue and provide phase continuity during scanned measurements.

• Applications

The main PicoPak Quad RF Switch application is to switch between one of four 5 MHz to 15 MHz PicoPak clock measurement system input signals, or between one of four 10 MHz references, before starting a measurement run. The quad switch can also be used to switch 1 PPS inputs to a time interval counter. In particular, the switch can be used as a multiplexer for making multi-channel phase measurements since they can remain unambiguous and have zero dead-time. The PicoPak can operate in that way by switching its RF signal input to make multi-channel measurements for purposes like long-term aging or temperature sensitivity.

• Conclusion

The PicoScan Quad RF Switch module is a useful addition to the family of PicoPak time and frequency measurement instruments.

• References

The following references apply to the PicoScan Quad RF Switch module.

1. Data Sheet, Omron G6J-2P-Y DPDT Relay
2. Data Sheet, Microchip Technology PIC16F1847 Microcontroller
3. Data Sheet, FTDI FT232RL USB Converter
4. Data Sheet, TI ULN2003A Darlington Transistor Array
5. Data Sheet, Hammond 1455C801 Extruded Aluminum Enclosure

Appendix I

PicoScan Quad RF Switch Module Specifications		
Parameter		**Specification**
Switching Arrangement	Channels	4
	Type	RF, Coaxial, Relay Switched
	Configuration	1 Common connected to 0-4 Input/Outputs
	Impedance	50 ohms nominal
	VSWR	≤ 1.5:1 between 5 to 15 MHz (All ports, all conditions)
RF Signals	Frequency	0 to 50 MHz (10 MHz nominal)
	Waveform	Any (Sinusoidal RF, 1 PPS, etc.)
	Level	≤ +18 dBm
Attenuation	Selected Channel	≤ 0.3 dB at 10 MHz
Isolation	Between Channels	≥ 70 dB at 10 MHz
Control	Manual	Four DIP switches on rear panel
	USB	Computer control of all functions
Applications	PicoPak	Signal or Reference selection, scanned 4-channel clock measurements
	General	Any application requiring four-way HF RF switching
Switching Time	Relay on/off	2 ms typical
Endurance	Relay life	50 million cycles
USB Commands	Alphabetic ASCII Characters	Proprietary documented commands to control PicoPak from PC
Power	Voltage	5 VDC from USB
	Current	≤ 150 mA (130 mA typical with all relays activated)
Connectors	USB	Type B Male on rear panel
	RF Common Port	SMA Female on rear panel
	RF I/O Ports	Four SMA Females on front panel
	Programming	Internal 6-Pin 2 mm header for Microchip PICkit-3 (factory use only)
Indicators	Monitor	Four LEDs on front panel
Other Controls	Reset	Internal pushbutton
Physical	Size (LxWxH)	3.28”x2.25”x1.03” (excluding connectors, feet and trim)
	Weight	≤ 5 oz (extruded aluminum case)
Accessories (Included)	Cable	5’ USB Type A plug to Type B plug with ferrite choke
	Software	PC application to control PicoScan PS1 module
	Documentation	Paper describing PicoScan design and use, PC application help file

Note: These specifications are preliminary and subject to change without notice

Appendix II

PicoPak PostgreSQL Database with a PicoScan Clock Measuring System

The PicoPak PostgreSQL database was made compatible with a 4-channel PicoScan clock measuring system by adding provisions for storing data for the four channels as separate module S/Ns. These integer S/Ns were made negative to indicate that they apply to multi-channel scanned measurements, and are given by the expression (-4·S)+C where S is the PicoPak S/N and C is the channel # (A=0 through D=3). So, for example, the data for PicoPak S/N 110, when used in a 4-channel PicoScan clock measuring system, are stored with the pseudo S/Ns -440 through -437 for channels A through D respectively. These negative S/Ns appear in the sn columns of the `measurement_modules`, `measurement_list` and `measurements` database tables, but are expressed as 110A through 110D on the PicoMon and PicoSQL program screens. They therefore need to be considered only when performing direct `psql` database queries.

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