Miniature Atomic Clock (MAC) SA5X User's Guide

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Preface

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All documentation becomes dated, and this manual is no exception. Microchip tools and documentation are constantly evolving to meet customer needs, so some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our website (www.microchip.com) to obtain the latest documentation available.

Documents are identified with a "DS" number. This number is located on the bottom of each page, in front of the page number. The numbering convention for the DS number is "DSXXXXXXXXA", where "XXXXXXXX" is the document number and "A" is the revision level of the document.

For the most up-to-date information on development tools, see the MPLAB® IDE online help. Select the Help menu, and then Topics, to open a list of available online help files.

PURPOSE OF THIS GUIDE

The MAC-SA5X User's Guide provides basic recommendations for designing products to use Microchip's Miniature Atomic Clock (MAC) SA5X. The guidelines in the document are generic because specific product requirements vary between applications.

This material consists of a brief description of SA5X design supported by block diagrams, description of environmental issues, installation guidelines, and unit operation.

WHO SHOULD READ THIS GUIDE

This document is intended for engineers and telecommunications professionals who are designing, installing, operating, or maintaining time, frequency, and synchronization systems that require a low profile and highly precise frequency generator.

To use this document effectively, you must have a good understanding of digital telecommunications technologies, analog frequency generation, and synthesis techniques.

DOCUMENT LAYOUT

This guide contains the following sections and appendixes:

- **Chapter 1. "Product Overview"**: Provides an overview of the product, describes the major hardware and software features, and lists the system specifications.
- **Chapter 2. "Installation"**: Contains procedures for unpacking and installing the system, and for powering up the unit.
- **Chapter 3. "Operation"**: Describes procedures for frequency adjustment and toggling on/off various features.
- **Chapter 4. "Command Line Interface"**: Describes the CLI command conventions, functions, and features.
- **Chapter 5. "Maintenance and Troubleshooting"**: Contains maintenance and troubleshooting procedures for the product. Also contains procedures for returning the MAC.
- **Appendix A. "Principle of Operation"**: Briefly explains Atomic Interrogation and

Coherent Population Trapping

- **Appendix B. "Legacy Command Set (SA.3Xm)"**: Describes the Legacy CLI command conventions, functions, and features. For backwards compatibility.
- **Appendix C. "Reference Designs"**: Provides generic sample schematics for converting MAC input/output signals.
- **Appendix D. "Evaluation Kit"**: Describes the evaluation kit for use with the MAC.
- **Appendix E. "Software License Agreements"**: Describes the open source software that portions of the SA5X software makes use of.

CONVENTIONS USED IN THIS GUIDE

This manual uses the following documentation conventions:

- Acronyms and Abbreviations: Terms are spelled out the first time they appear in text. Thereafter, only the acronym or abbreviation is used. This guide uses "SA5X" and "MAC" interchangeably. SA5X is the latest generation of Miniature Atomic Clock (MAC).
- Unless explicitly labeled with Hz, MHz, etc, all references to "frequency offset" throughout this document imply the industry-standard fractional frequency $\Delta f/f$, where "Δf" is the difference between nominal and measured value (in Hz), and "f" is the nominal frequency (in Hz).

WARNINGS, CAUTIONS, RECOMMENDATIONS, AND NOTES

Warnings, Cautions, Recommendations, and Notes attract attention to essential or critical information in this guide. The types of information included in each are displayed in a style consistent with the examples below.

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Note: All notes use this style. Notes contain installation, operation, or maintenance procedures, practices, conditions, or statements that alert you to important information that may make your task easier or increase your understanding.

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DOCUMENT REVISION HISTORY

Revision A (November 2019)

- Initial release of this document as Microchip DS50002938A.
  - Under Microsemi’s literature system, this document is number 900-44500-000, Rev. A.

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Table of Contents

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Chapter 1. Product Overview

1.1 MAC-SA5X OVERVIEW

The MAC is a source of stable output frequency. Because it relies on the Atomic resonance of Rubidium Isotope 87 (87Rb) gas to generate the RF output, it is less susceptible to instabilities produced from the mechanical and thermal stresses inherent in Quartz oscillators, enabling superior mid- to long-term accuracy. This stability makes it suitable as a holdover reference in GPS denied environments. Frequency errors can be corrected by applying a digital command or external correction voltage to the MAC. (See Frequency steering and **Section 3.2 "Analog Tuning"**). Frequency drift (Aging rate) can also be corrected by implementing the 1PPS disciplining feature of the MAC. When combined with a GNSS receiver, this feature allows the system designer to combine the short-term stability of a Rb reference with the long-term stability of the GNSS, approaching the performance of laboratory-grade Cesium Beam Tube frequency standards (see **Section 3.4 "1PPS Disciplining"**).

The Miniature Atomic Clock (MAC) SA5X is Microchip's seventh generation gas cell atomic oscillator technology product. It was designed to accommodate a variety of timing applications as well as to replace several legacy Rubidium products (SA.22c, x72 and MAC-SA.3Xm). The footprint is compatible with the SA.3Xm, but with several advancements in technology and features. Users of the previous generation (SA.3Xm) can now expect improvements to frequency stability, warm-up time, input voltage range, and operational temperature range. Additionally, 1PPS disciplining and USB connections via a new embedded Molex™ connector allow greater design capabilities. The 1PPS input allows users to quickly calibrate frequency and phase of the MAC to a primary clock such as GPS, while the RF and 1PPS outputs provide highly stable holdover references.

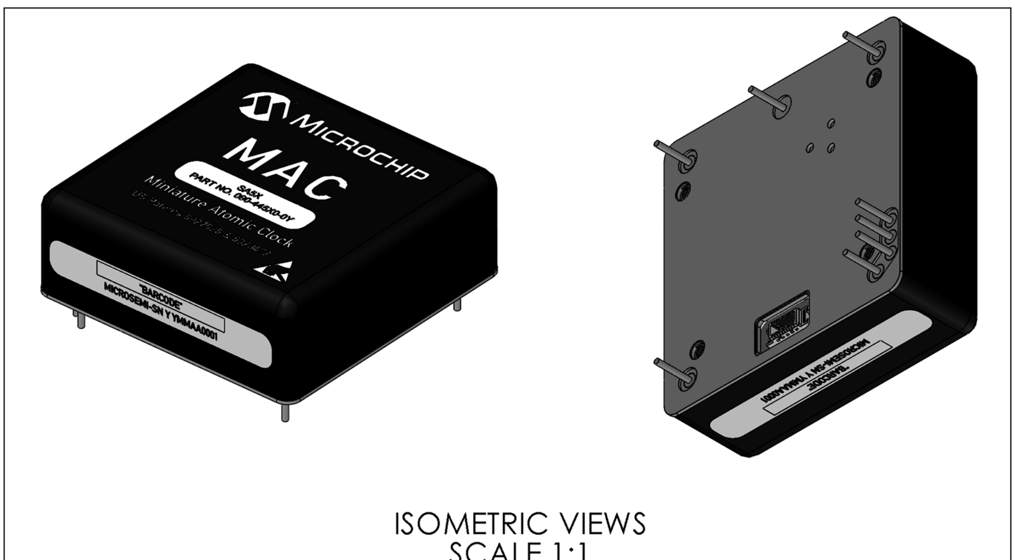

FIGURE 1-1: The Miniature Atomic Clock (MAC) SA5X.

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The MAC reflects significant advances in physics miniaturization and atomic interrogation algorithms that serve to reduce size and power while providing a stable reference frequency that is resistant to environmental perturbation. The SA5X comes in several performance levels to meet a range of system requirements. The SA5X offers a low height (18.3 mm/0.72 in), a small footprint (50.8 mm × 50.8 mm, or 2 in × 2 in), and an industrial operating temperature range of –40°C to +75°C (measured at the baseplate). It is refined for cost effective mass production and can be easily integrated into time, frequency, and synchronization systems. The SA5X requires a single supply voltage and can be mounted directly onto a circuit board as a component of a module used in 20 mm (0.8 in) wide card slots. The design produces a stable frequency with good short and long term stability, and excellent phase noise performance.

This user guide provides engineering information for use of the SA5X. It also provides supporting information for use of the Evaluation Kit (p/n 090-44500-000). Furthermore, the design details of the Evaluation Kit can be used to assist with host system design (for example, power conditioning, signal buffering, and so on). This user guide must be used in conjunction with the current data sheet for the SA5X, which is available on the Microchip web site.

1.1.1 Key Features

- 10 MHz CMOS Output
- 1PPS Disciplining
- 1PPS LVDS Inputs and Output
- –40°C to +75°C Operating Temperature (Baseplate)
- –55°C to +100°C Storage Temperature
- USB 2.0-Compatible Communication Pins
- Wide Range Allowable DC Input (4.5 to 32V)
- Fast Warm-Up Time (<7 Minutes from –10°C to +75°C)
- <$5x10^{-11}$ Monthly Aging Rate (On for 30 Days Prior)
- <100 ns Time Error in 24 hrs (Calculated Based on $5x10^{-11}$/mo. Aging Rate, Assuming Zero Initial Phase/Frequency Offset, Static Environment, On for 30 Days Prior to Holdover)
- Serial/USB Interface for Digital Steering, Configuration, and Diagnostics

1.2 PHYSICAL DESCRIPTION

Labels will contain information about the part number and the serial number. The serial number indicates the initial time of manufacture in the following manner. The first two digits of serial number indicate the year of manufacture (18 = 2018). Digits three and four indicate the month of manufacture (01 = January).

The MAC consists of a 2 in x 2 in x 0.7 in PCB-mountable chassis, consisting of a Nickel-plated Aluminum baseplate and black anodized Aluminum cover. All connections for the MAC are on the baseplate. Figure 1-2 shows the top cover on the left and the bottom baseplate on the right.

See Figure 2-1 for a complete mechanical drawing.

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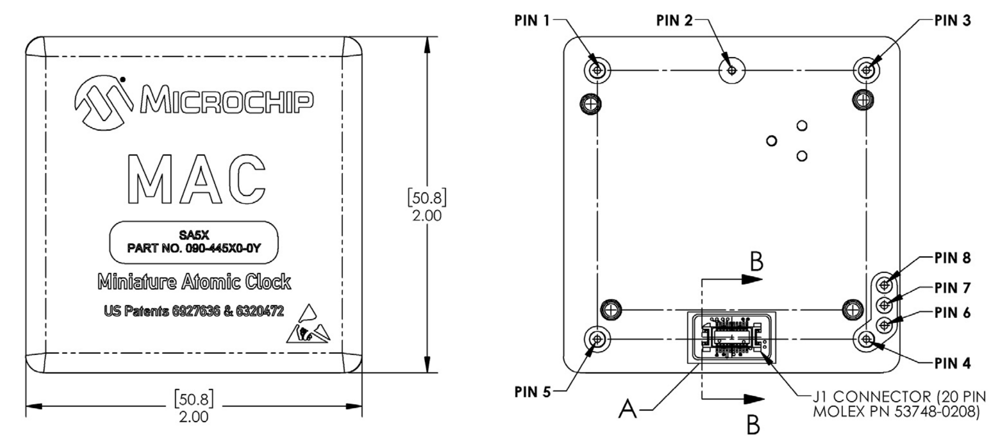
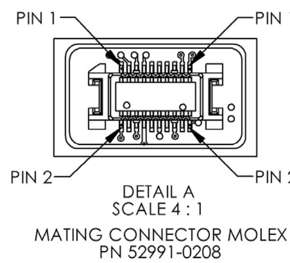


FIGURE 1-2: *Top Cover and Bottom Baseplate.*

The baseplate consists of eight backwards-compatible gold-plated pins and recessed 20-lead Molex™ connector for new features (1PPS, USB, etc).

J1 CONNECTOR PINOUTS			
PIN NO.	FUNCTION	PIN NO.	FUNCTION
1	PPS-IN 1+	2	USB DATA +
3	PPS-IN 1-	4	USB DATA -
5	PPS-IN 0+	6	USB POWER
7	PPS-IN 0-	8	GND
9	GND	10	NC
11	NC	12	NC
13	NC	14	NC
15	GND	16	NC
17	PPS-OUT +	18	NC
19	PPS-OUT -	20	ALARM

NC - PINS THAT SHOULD HAVE NO CONNECTION. RESERVED FOR FACTORY OR FUTURE FUNCTIONS.



PIN NO.	FUNCTION
1	INPUT FREQUENCY CONTROL
2	CASE GROUND
3	RF OUTPUT
4	GND (SUPPLY & SIGNAL)
5	INPUT SUPPLY (+4.5 TO +32 VDC)
6	BITE
7	RS-232 TX
8	RS-232 RX

FIGURE 1-3: *Pinout.*

1.2.1 Communications Connections

The MAC is controlled either by the legacy serial port pins or with the high speed USB-compatible pins on the Molex connector.

- **Serial Console Port:** The serial port connection is made through pins 7 and 8 on the baseplate of the MAC. This port allows a user to connect to a terminal or computer using a terminal emulation software package. When connecting to this port, use an appropriate converter chip such as the TRS3122E or similar to attain the required LVCMOS levels. Figure 1-2 shows the serial port pins 7 and 8 in the lower-right region of the baseplate. The default speed is 57600 bps and higher speeds of 230400 bps and 921600 bps are available.
- **USB Port:** The USB port is capable of making high speed communication with the MAC though the Molex (J1) connector pins J-2, 4, and 6.

> **Note:** "Compatibility" commands are not supported when communicating via USB port. See **Appendix B. "Legacy Command Set (SA.3Xm)"**.

1.2.2 Input Connections

- **Analog Tuning:** Analog Tuning is available on pin 1 for steering the MAC output frequency by means of an externally supplied DC voltage. This method is for legacy applications that cannot steer the MAC digitally via the serial/USB interface.
- **1PPS Input (x2):** Two selectable LVDS 1PPS inputs can be provided on pins J1-5,7 (PPS0-IN) or J1-1,3 (PPS1-IN) for aligning the MAC's frequency and timing

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output with an externally applied 1PPS reference signal. The PPS input is selected via digital interface. Default input is PPS0-IN.

1.2.3 Output Connections

- **10 MHz RF Output:** One CMOS output is available on pin 3.
- **1PPS Output:** A single differential LVDS 1PPS output is available on pins J1-17, 19.
- **Built-In Test Equipment (BITE):** An active-low CMOS output on pin 6 signifies that the MAC has achieved atomic lock.
- **Alarm Output:** An active-low CMOS output on pin J1-20 indicates if an alarm condition is present. The user can read the Alarm bits through the USB/Serial interface to determine which alarm was triggered.

1.2.4 Power and Ground Connections

The MAC is not equipped with a power switch. DC power is applied on pin 5 with ground pins located on pins 2 and 4. If the J1 connector is used, pins J1-8, J1-9, and J1-15 should be grounded. Remaining pins should remain as “No Connect” (NC) unless indicated otherwise in Figure 1-3. If J1 connector is unused, all pins should remain as “No Connect”.

> **Recommendation:** It is recommended to tie ground (Pin 4) to same node as the baseplate ground Pin 2.

1.3 FUNCTIONAL DESCRIPTION

Communication Ports

These ports can be used to configure the MAC with Microchip's C3 software commands using a terminal or a computer with terminal emulation software. The default settings for the serial port are:

- Baud = 57.6K
- Data Bits = 8 bits
- Parity = None
- Stop bits = 1
- Flow Control = None

Commands allow the user to:

- Turn Analog tuning on or off
- Digitally adjust the output frequency
- Configure 1PPS Disciplining settings
- Query the MAC's health/lock/alarm status
- Configure the Time of Day

Analog Tuning Input

Analog tuning is a means of steering the MAC's output frequency by applying a DC tuning voltage to Pin 1. This is useful for legacy applications where digital frequency steering is not possible.

1PPS Inputs

The MAC offers two selectable 1PPS inputs for use in steering the output RF (and 1PPS Output, simultaneously). PPS_Input_0 (pins J1-5,7) and PPS_Input_1 (pin J1-1,3) are selectable with the `PpsSource` parameter. Their 1PPS Disciplining set-

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tings can be adjusted independently, however, the MAC can only discipline to one input at a time. If a valid PPS signal on the selected input is present, then the parameter `PpsInDetected` = 1. See **Section 3.4 "1PPS Disciplining"** for more details.

CAUTION
An LVDS square wave 1PPS is the allowable input.

10 MHz Output

The 10 MHz RF output appears on Pin 3 as soon as the MAC is switched ON and is always present, regardless of the lock status. When the MAC is out of lock (`Locked` = 0/Logic-High BITE pin), the output frequency is provided by the free-running TCXO, which has frequency accuracy specification of ±2 ppm over its operating range. The output format is 3.3V LVCMOS compatible.

Note: If a high-level (high-power) output driver is required, a driver circuit must be implemented external to the MAC.

1PPS Output

An LVDS 1 pulse-per-second (1PPS) square wave output is available on pins J1-17,19 upon power-up. The 1PPS output is derived by digital division of the RF reference frequency and cannot be de-coupled. Therefore, the 1PPS and 10 MHz outputs are always synchronized (within ±50 nanoseconds, regardless of Lock status).

PPS output timing relative to average PPS input timing is adjustable via the digital interface with 10 ns steps using `PpsOffset` parameter.

Default PPS Pulse Width is 20 µs. Pulse width may be modified via the `PpsWidth` parameter.

BITE Output

The SA5X provides an active logic low indication through Pin 6, the BITE signal, when the internal quartz oscillator is frequency-locked to the rubidium atomic resonance. As long as the BITE signal is low, the user can be assured that the short-term stability specifications are satisfied. The lock status is also available through the C3 Protocol `Locked` parameter.

If the BITE signal is high (`Locked` = 0), then atomic Lock is not attained (or is lost) and the SA5X is in its start-up sequence. During this sequence, signal output amplitude is maintained but the stability performance is driven by the internal TCXO. Lock acquisition typically takes 5 minutes at room temperature.

Alarm Output

The Alarm Output provides an indication if an alarm is present (active logic low). It will persist until cleared with the `ackalm` software command. A user can learn the exact alarm condition from the value of the `Alarms` parameter (See **Section 4.4.3 "Alarms Parameter"**).

1.4 CONFIGURATION MANAGEMENT

The Command Line Interface can be used to control specific functions of the MAC from a terminal connected to the RS-232 serial port or the USB port.
Refer to **Chapter 4. "Command Line Interface"** for further details.

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1.5 ALARMS

The MAC uses alarms to notify the user when certain conditions are deteriorating below specified levels or when issues arise, such as failure to acquire Lock or temperature warning. These alarms are indicated by CLI status and the alarm pin. For more information, see **Section 3.5 "Device Information and Status"** and **Section 4.4.3 "Alarms Parameter"**.

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Chapter 2. Installation

2.1 HANDLING CONSIDERATIONS

CAUTION
To avoid electrostatic discharge (ESD) damage, proper ESD handling procedures must be observed in unpacking, assembling, and testing the MAC.

The MAC is delivered in ESD-safe packaging. The MAC must be removed from the ESD-protective bag in an ESD-safe environment. Once installed on the test fixture, it is recommended that the entire assembly be treated as ESD-sensitive.

Retain the original MAC ESD-safe packaging material in the event that the device needs to be returned to Microchip for service.

2.2 MOUNTING CONSIDERATIONS

For initial testing and evaluation, it is recommended that the pins not be modified or soldered to a PCB. The recommended socket for PCB attachment is Mill-Max 0332-0-43-80-18-27-10-0. After evaluation, the pins can be hand-soldered to a PCB.

Below is the mechanical drawing (ICD). Contact Microchip for latest revision.

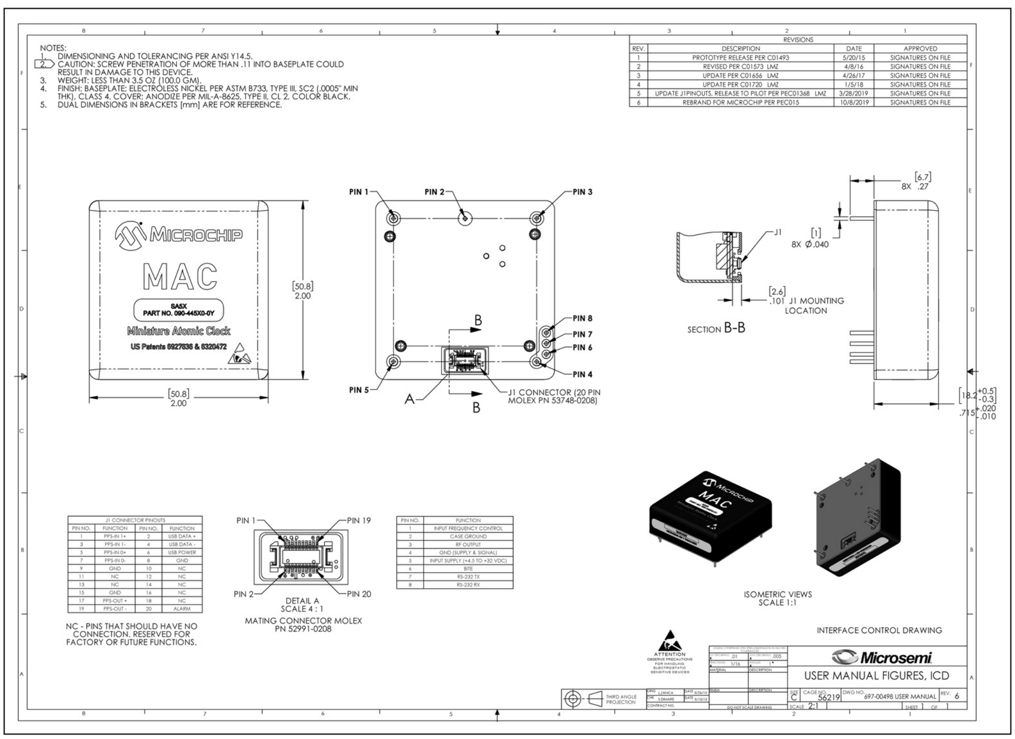

FIGURE 2-1: *ICD 697-00498-000 for MAC.*

Solder

The MAC is a lead-free device. See the data sheet for RoHS compliance. Use SAC305 solder Sn96.5/Ag3.0/Cu0.5 or similar for hand-soldering to a PCB.

Heat Sink and Thermal Management

To allow the highest ambient operating temperature for the SA5X, it is recommended that the bottom (baseplate) of the SA5X have good thermal contact with the mounting surface (no air gap between baseplate and external PCB/heat sink etc). To ensure good thermal contact, Microchip recommends that the SA5X is secured using (4) 2-56 screws. The location of the four screw holes is shown in Figure 2-1.

If the baseplate temperature rises above +75°C, the physics package heater shuts down as control point temperatures are exceeded and the unit temperature coefficients increase. The unit eventually loses lock above +75°C.

When practical, it is recommended to monitor the baseplate temperature with a thermocouple to ensure it remains below +75°C. Alternatively, one may query the telemetry parameter `Temperature` to get a rough estimate of the external baseplate temperature. The `Temperature` parameter is measured internally on the PCB and is generally ~10°C to 15°C warmer than the actual baseplate temperature.

It is also important to maintain a uniform temperature into the baseplate of the SA5X through its mounting points. A thermal pad or thermal grease may improve thermal conductivity between a heat sink and the MAC's outer case. Figure 2-2 shows the mechanical drawing for a thermal pad.

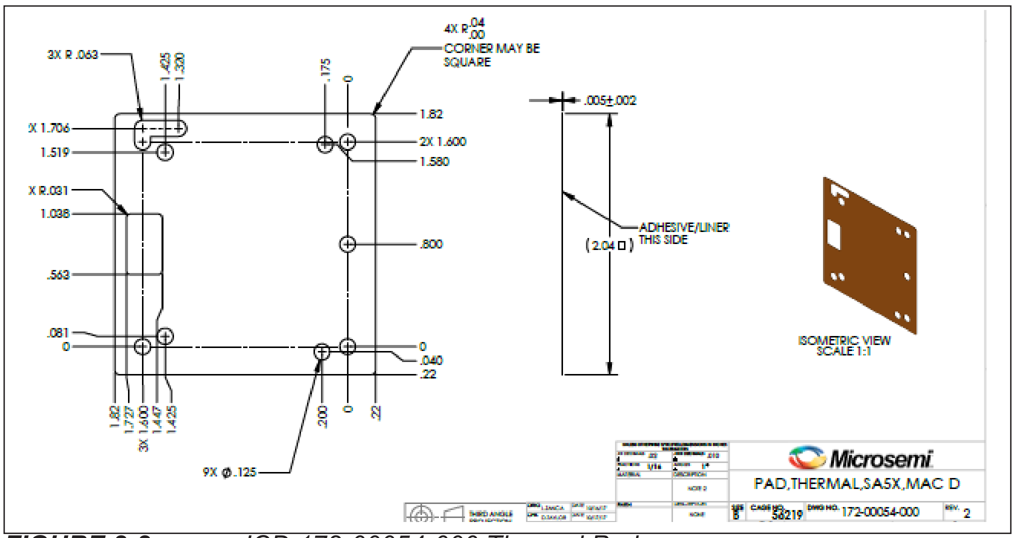

FIGURE 2-2: *ICD 172-00054-000 Thermal Pad.*

CAUTION
To avoid damage to the SA5X, the mounting screws must not penetrate the unit by more than 0.11 in. (2.79 mm).

WARNING
To avoid the possibility of a burn, mount the SA5X to a heat-dissipating surface. The SA5X operates at a temperature that is hot to the touch and may cause handling distress.

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RF Noise Mitigation

If the system that the MAC is designed into is sensitive to RF or microwave frequencies (especially 3.417 GHz and its harmonics), care must be taken to dampen those frequencies at locations that might be adversely affected. One way to do this is to determine the appropriate capacitor that has its "zero-ohm" characteristic at the frequency of interest and use that capacitor to effectively short that frequency to ground where it might a problem. For example, it has been determined that at 3.417 GHz, the "zero-ohm" capacitor value for an 0603-sized SMT component is 4.3 pF; for an 0402-sized capacitor, the value must be 6.8 pF; and for an 0201-sized capacitor, 8.2 pF is ideal.

From this, it is recommended to place the appropriate-valued capacitor at the node of interest. It is important that this cap be exactly on the node where the noise must be squelched, and is grounded right at the cap as well. In addition, a good RF ground plane is required, otherwise the improvement can be nullified.

The nulling capacitors are placed as close to the MAC I/O pins as possible. Because the 3.417 GHz frequency is used within the MAC, the above mentioned nulling capacitors are recommended to be installed on pins 1,3,5-8.

EMI and Noise Considerations

When a user has an application where the phase noise and spur integrity are crucial, the SA5X must be provided with a clean source of DC power (free of spurious current or voltage noise). Connecting fans, heaters, and other switching devices to the DC supply powering the SA5X can result in degraded performance.

This noise is coupled through the power line to cause modulation spurs on the output signal. Special care must be taken to avoid noise at 100 Hz and its harmonics (roughly up to the tenth harmonic).

If power line filtering is added at the power input pin of the SA5X, this filtering cannot have any resonance points greater than the specified impedance of less than 0.1Ω from DC to 100 kHz in order to avoid the potential for noise peaking or oscillations in the internal power regulators.

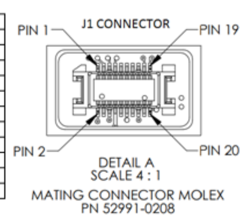
In addition, the input operating voltage range specified for the SA5X during turn-on must continue to be met during operation of the unit. For example, using a 0.3Ω DC source resistance for the input supply line may not be appropriate because the voltage drop resulting from this resistance (caused by the turn-on current or quiescent operating current) could cause the input voltage to drop below the specified allowable value.

Signal Connections

The SA5X pinout is shown in Figure 2-3.

J1 CONNECTOR PINOUTS			
PIN NO.	FUNCTION	PIN NO.	FUNCTION
1	PPS-IN 1+	2	USB DATA +
3	PPS-IN 1-	4	USB DATA -
5	PPS-IN 0+	6	USB POWER
7	PPS-IN 0-	8	GND
9	GND	10	NC
11	NC	12	NC
13	NC	14	NC
15	GND	16	NC
17	PPS-OUT +	18	NC
19	PPS-OUT -	20	ALARM

NC - PINS THAT SHOULD HAVE NO CONNECTION. RESERVED FOR FACTORY OR FUTURE FUNCTIONS.



PIN NO.	FUNCTION
1	INPUT FREQUENCY CONTROL
2	CASE GROUND
3	RF OUTPUT
4	GND (SUPPLY & SIGNAL)
5	INPUT SUPPLY (+4.5 TO +32 VDC)
6	BITE
7	RS-232 TX
8	RS-232 RX

LEGACY OCXO-STYLE PINS

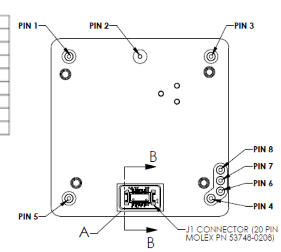


FIGURE 2-3: *Pinout.*

The electrical function of each pin is shown in Table 2-1.

TABLE 2-1: PIN FUNCTION TABLE

Connector	Pin Number	Function	Range/Format	Note
OCXO Style	1	Analog tuning input	0V to 5.0V	Note 1, Note 2
OCXO Style	2	Baseplate	—	Note 3
OCXO Style	3	RF output	CMOS 3.3V_{PP} nominal	Note 4
OCXO Style	4	GND	—	Note 5
OCXO Style	5	Supply voltage (V_{CC})	4.5VDC to 32VDC (5VDC recommended)	—
OCXO Style	6	Built-In Test Equipment (BITE)	CMOS: Logic_H > 3V, Logic_L < 0.3V	Note 6
OCXO Style	7, 8	Serial communication	2.8V < Logic_H < 3.8V 0V < Logic_L < 0.3V	Note 7
J1 Molex	1, 3	PPS1-IN	LVDS	—
J1 Molex	5, 7	PPS0-IN	LVDS	—
J1 Molex	8, 9, 15	GND	—	—
J1 Molex	17, 19	PPS-OUT –,+	LVDS square wave, 4 ns, 100Ω	—
J1 Molex	20	Alarm	CMOS: Logic_H > 3V, Logic_L < 0.3V	—
J1 Molex	2, 4, 6	USB	USB	—

Note 1: Analog tuning input sensitivity is 0V to 5V into 5 kΩ, 2.5V for no pull.

2: Analog tuning is disabled by default. Digital tuning is recommended instead.

3: Shall be connected to GND externally.

4: 10 MHz, CMOS square wave, VL < 0.3V, VH > 3V. Amplitude is dependent on load.

5: Signal and Supply. It is recommended to tie this ground to same node as baseplate ground Pin 2.

6: BITE output (active-low):
0 = Normal Operation
1 = Unlock Condition

7: If connecting to COM port of a computer, a TTL/RS-232 (or HCMOS/RS-232) adapter is necessary.

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2.2.1 Absolute Minimum and Maximum Ratings

Table 2-2 indicates the absolute minimum and maximum ratings to which the MAC can be subjected without permanent unrecoverable damage.

Note: The MAC cannot be expected to perform normally when operated outside of the recommended operating conditions noted on the product data sheet. All ratings apply at +25°C, unless otherwise noted.

TABLE 2-2: MINIMUM AND MAXIMUM RATINGS

Parameter	Rating
Supply Voltage (V_{CC})	0VDC to +32VDC
1PPS Inputs	–0.5V to +3.6V
Analog Tuning Voltage	0V to +5V (into 5 kΩ)
Maximum Current Draw	RS-232, BITE, Alarm: ±8 mA RF output: ±8 mA
Storage Temperature	–55°C to +100°C

2.3 START-UP SEQUENCE

CAUTION

To avoid severe damage to the unit, do not apply power to the incorrect terminals. The SA5X does not have reverse voltage protection.

When the MAC is initially powered on, it performs an acquisition sequence, which includes stabilizing the temperature of the physics package, optimizing physics package operating parameters, and acquiring frequency lock to the atomic resonance.

A typical warm-up sequence is shown in Figure 2-4. When power is connected to the MAC, its RF and 1PPS output signals (orange dashed line) will appear immediately. The short-term stability specification of these signals will not be satisfied until the Lock sequence is completed (after ~300 seconds in this example). Prior to Lock, the output signal will have an inaccuracy of several ppm and drift per the MAC's internal TCXO.

All MAC's have their (Locked) output frequency calibrated to within $\pm 5 \times 10^{-11}$ Hz/Hz prior to shipment. However, environmental conditions and transit time will affect the calibration to an unknown degree. Therefore, some additional frequency offset should be expected when the MAC is first powered on by the user. Offsets may be corrected, as explained in the Frequency Steering section. The re-trace specification provides some guidance for frequency offsets due to powering off the unit; however, the specification is not comprehensive.

Power consumption is displayed as a solid black trace. Initially, the power consumption will draw >10W to bring the internal unit temperature up to operational level. Once the temperature has stabilized, the steady state power consumption will drop to ~6W. Steady state power consumption will be higher for colder ambient temperatures because more heating will be required to maintain the correct internal temperature. Similarly, the duration of the heat-up period (maximum power consumption) will be longer for colder ambient temperatures.

The baseplate temperature (solid orange trace) will generally rise ~15°C during the start-up sequence, but this varies greatly with thermal management (heat sink, airflow, etc). Generally, the temperature rise will be smaller at warmer temperatures, larger at colder temperatures.

Care should be used to ensure that the maximum operating temperature is not violated. For instance, a MAC that is powered up in a 70°C ambient environment will likely rise above the maximum operating temperature during the start-up period unless careful thermal management is employed. (See **Section 2.2 "Mounting Considerations"**)

The `LockProgress` parameter (not pictured) will reveal the Lock acquisition status in terms of percentage-complete. Once the unit finishes the sequence, the BITE pin (black dashed trace) will indicate Lock (logic low). Generally, Lock acquisition times will be shorter at warmer temperatures, longer at colder temperatures. If this sequence should fail, the `Alarms` parameter will signify "Acquisition Failed". If this should occur, check that the environmental specifications have not been violated (operating temperature, input voltage, magnetic field exposure, etc) and reboot the device. Contact Customer support if the alarm persists.

Note:	Sequence times and power levels vary according to environmental conditions, especially temperature.

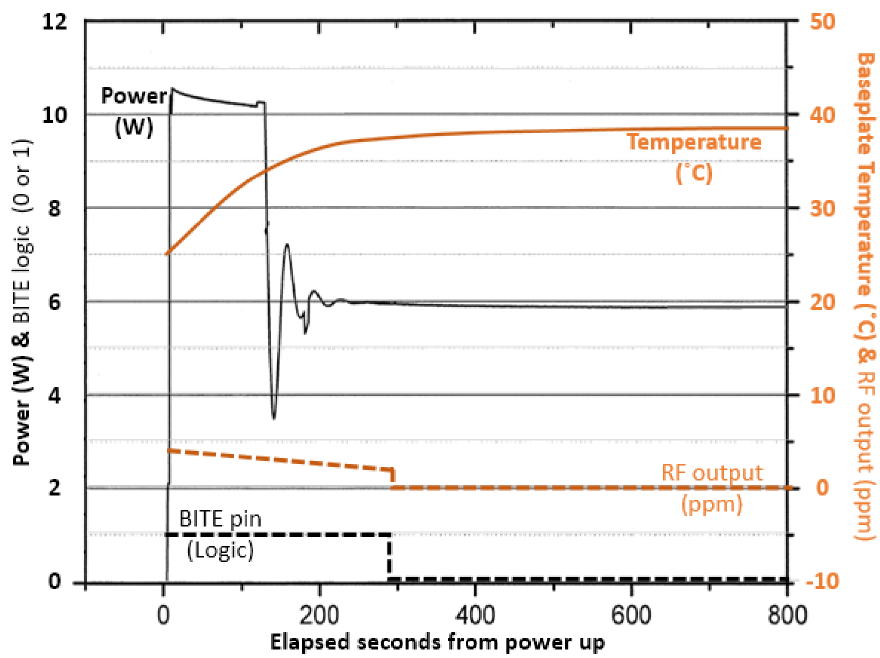

FIGURE 2-4: *Start-Up Sequence.*

Once power is supplied to the unit, it will output the following strings on the serial port:

```
[>Loading...]
[>Microchip SA5X]
```

After a typical warm-up time of 5 to 7 minutes, the oscillator is fully operational and the operator may choose to adjust the device parameters. The MAC meets all short-term stability specifications as soon as Lock is achieved. Long-term stability specifications (Monthly Aging frequency drift rate) is satisfied within 30 days of continuous power at room temperature. There are no maintenance procedures or adjustments needed, aside from frequency adjustment which is described in a later section.

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Chapter 3. Operation

This section will cover the following topics:

- Configure the Serial Port
- Analog Tuning
- Digital Frequency Adjustment
- Configure 1PPS Discipline Settings
- Query the MAC's Health/Lock/Alarm Status
- Configure the Time of Day

3.1 CONFIGURE THE SERIAL PORT

The default settings for the RS-232 interface are listed below.

- Speed: 57600 bps
- Data Bits: 8 bits
- Parity: None
- Stop Bits: 1
- Flow Control: None

The baud rate can be configured via the bootstrap loader (BSL). The following sequence illustrates how to query and set the baud rate. The following interaction sequence begins with the SA5X unit already powered on:

TABLE 3-1: BOOTSTRAP LOADER INTERACTION SEQUENCE

Serial Communication	Description
`{reset}`	User resets the CPU to access the bootloader.
`[>Loading...]`	After reset, BSL announces it is ready (waits 3 seconds).
`{bsl}`	User requests the BSL command mode (within 3 seconds).
`[=BSL]`	BSL confirms it is now in command mode.
`{baud?}`	User queries the currently configured baud rate (optional).
`[=57600]`*<CR><LF>*	BSL returns the configured baud rate.
`{baud,921600,now}`	User requests a new baud rate to take effect immediately. Omission of ",now" argument will defer the change until the next reset.
`[=921600]`	BSL confirms the newly configured baud rate.
`{reset}`	User resets the CPU for the new rate to take effect.
`[>Loading...]`	After reset, BSL announces its presence at 921600 bps.

See **Chapter 4. "Command Line Interface"** for reference on proper command syntax.

3.2 ANALOG TUNING

Analog tuning allows a user to correct the RF and 1PPS output frequency by applying a DC correction voltage. Analog tuning is an inferior approach compared to Digital tuning or 1PPS Disciplining because its resolution is only parts in 10^{11}. However, it has been carried forward to support legacy applications.

The analog frequency control is derived from the analog voltage applied to Pin 1. This voltage is digitized, scaled, and applied to the SA5X frequency servo. Analog tuning (AT) voltages above mid-point (2.5VDC) increase the output frequency, and, conversely, tuning voltages below midpoint decrease the output frequency. Because the tuning range is $\pm 1x10^{-8}$ from 0V to 5V, this corresponds to roughly $1x10^{-11}$ for every 2.5 mV change in AT voltage.

If the analog frequency tuning is disabled (by default), the analog frequency control value is zero. It may be enabled with the `AnalogTuningEnabled` Parameter. The Analog Tuning input voltage may be read via the `AnalogTuning` parameter, regardless if it is enabled or not.

> **Recommendation:** If Analog Tuning is the desired method, it is highly recommended that it be used exclusively. Do not try to implement Analog Tuning with Digital Tuning or 1PPS Disciplining simultaneously into one system.

3.3 DIGITAL TUNING

The MAC RF (and 1PPS) output may be adjusted by the user via the `DigitalTuning` parameter. Relative steering values are entered in (integer) units of parts in 10^{15}, though the resolution realized by the MAC hardware is approximately 1 part in 10^{14}. Digital adjustment is clamped to ±2 parts in 10^{8}. Consult **Section 3.3.1 "Calibration"** if a larger correction is desired.

> **Note:** Steering commands may be entered during acquisition (`Locked` = 0) but will not take effect until lock is achieved.

Frequency steering is volatile (unless the `store` command is used). Upon reboot, the MAC returns to its nominal (calibrated) frequency setting. To update the non-volatile calibration, see **Section 3.3.1 "Calibration"**.

3.3.1 Calibration

In the unlikely event that the adjustment range of `DigitalTuning` has been exhausted beyond the limits of $\pm 2x10^{-8}$ (perhaps due to cumulative frequency aging offsets) it may be desirable to update the calibration. When this is the case, manual calibration of the MAC is accomplished in the following manner. First, the MAC output should be compared to a superior Frequency Reference with a frequency counter or other suitable test equipment. Next, the MAC is steered onto frequency by adjusting the `DigitalTuning` parameter, (see **Section 3.3 "Digital Tuning"** or **Section 3.4 "1PPS Disciplining"**). Finally, the present value of the `DigitalTuning` parameter is summed into the non-volatile calibration register via the `latch` command. This command will simultaneously reset `DigitalTuning` to zero at the new center frequency. The user may then adjust the output $\pm 2x10^{-8}$ from its current value.

> **Note:** Once a calibration is overwritten, it cannot be recalled.

> **Note:** The `latch` command is only valid when the MAC is locked (`Locked` = 1).

> **Note:** Total net steering range is limited to $\pm 1x10^{-6}$. See data sheet for exact specification.

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3.4 1PPS DISCIPLINING

For further reduction of phase and frequency errors, disciplining can be enabled/disabled with the `Disciplining` parameter. The algorithm implements a high-resolution phase meter within the MAC to automatically correct the phase and frequency relative to a reference 1PPS input once per second with a resolution of 450 ps. The algorithm will simultaneously steer the phase and frequency to that of the external reference (1PPS input), ultimately achieving accuracies of <1 ns and 1×10^{-13}, respectively, depending on the stability of the 1PPS input and ignoring external cabling delays, etc (See **Section 3.4.5 “Cable Length Compensation”**).

3.4.1 Theory

The 1PPS input is user selectable from pins J1-5,7 or J1-1,3 via the `PpsSource` parameter. If a valid 1PPS is present on the selected input, `PpsInDetected` = 1 and the user will notice the `DigitalTuning` parameter automatically adjust, once `Disciplining` is enabled. The `LastCorrection` parameter will tell the user how much the MAC was digitally steered (in frequency) since its last correction; it is simply the difference between the last two successive `DigitalTuning` values. Similarly, the `Phase` parameter will report the most recent phase meter measurement to indicate the time-difference between input and output 1PPS signals.

The speed and effectiveness of the disciplining algorithm can be adjusted by the time constant “Tau”, which is user selectable through the `TauPps0` (or `TauPps1`) parameter. See **Section 3.4.2 “Selection of Disciplining Time Constant, “Tau””** for advice on choosing an appropriate time constant.

When disciplining is turned on, it will make a correction once per second based on its most recent internal phase meter measurement. The disciplining algorithm will attempt to dampen an initial phase and/or frequency error E_0 by ~63% after an elapsed time of one Tau, 99% after five Tau per the equation:

EQUATION 3-1:

$$E = E_0 \times \left(1 - e^{-\frac{t}{\tau}}\right)$$

Where:
E = The instantaneous error.
E_0 = The initial error calculated from the moving average of the previous errors observed over time duration τ, updated once per second.
τ = The user-selectable time constant, tau, in seconds.
t = Elapsed time, in seconds.

Any subsequent additional errors after E_0 will prolong the settling time of the algorithm.

In the event that the reference 1PPS input is removed from the selected input (pins J1-5,7 or J1-1,3) while disciplining, the MAC remains in holdover and preserves the most recent `DigitalTuning` value. If the 1PPS reference subsequently reappears, disciplining continues where it left off. The exception being if the measured instantaneous `Phase` > `PhaseLimit`, whereby a JamSync will be implemented and the Disciplining algorithm will start anew. (Phase outliers are ignored. See **Section 3.4.3 “JamSync”**)

The status of disciplining is indicated by the `DisciplineLocked` parameter in the telemetry. `DisciplineLocked` = 0 upon algorithm startup or when a valid PPS input signal is not detected. `DisciplineLocked` = 1 when magnitude of the phase mea-

surement is less than the `DisciplineThresholdPps0` setting for two time constants of duration (see **Section 3.4.2 "Selection of Disciplining Time Constant, "Tau""**).

The following state diagram provides the concept behind the disciplining and phase-metering algorithms. For more information on phase-metering, see **Section 3.4.4 "1PPS Phase Measurement Mode"**.

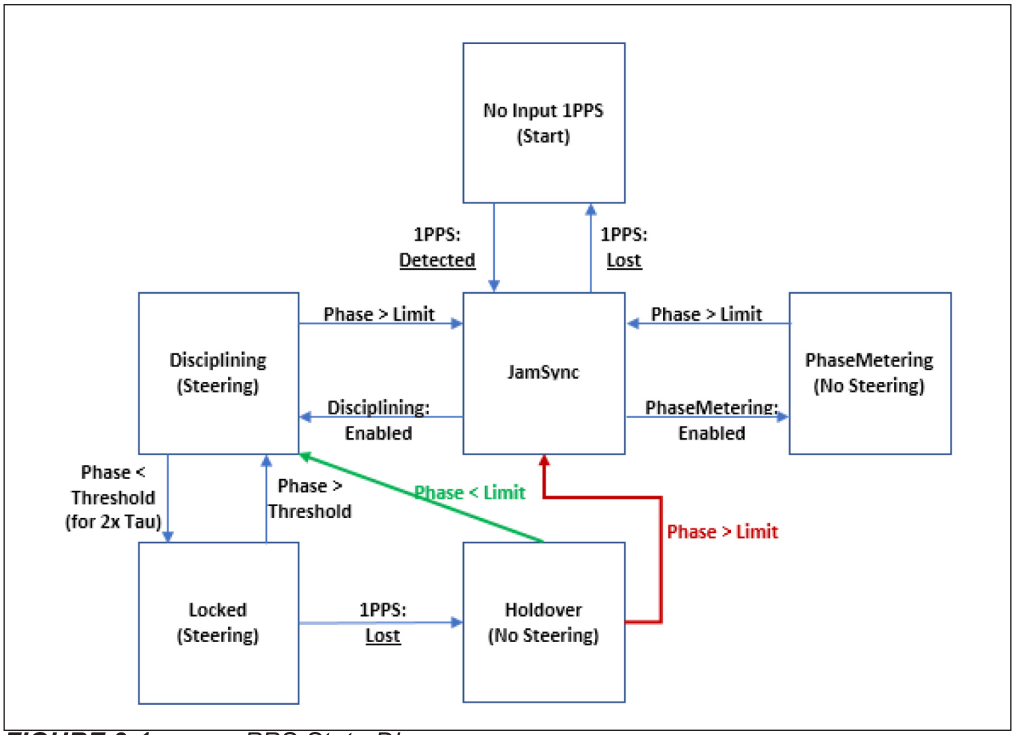

FIGURE 3-1: PPS State Diagram.

> **Note:** Discipline settings are volatile, that is, not preserved across power cycles unless the `store` command is used.

> **Note:** The user is allowed to adjust the `DigitalTuning` parameter while in Disciplining mode. However, this is discouraged because it could prolong and disrupt the disciplining algorithm.

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3.4.2 Selection of Disciplining Time Constant, “Tau”

Algorithm performance will be predicated on the selection of the disciplining time constant Tau. When possible, it is advisable to choose a Tau that corresponds to the “least noisy” averaging time of your 1PPS input source. Generally, a longer Tau is required for a noisy 1PPS input reference (such as a simple GPS receiver); shorter Tau is acceptable for stable lab-grade instruments (such as a Cesium Beam Tube). Furthermore, shortening the Tau may be necessary to quickly adjust the MAC if its inherent stability is under influence of external environmental conditions (such as g-forces, rapid temperature changes, etc.).

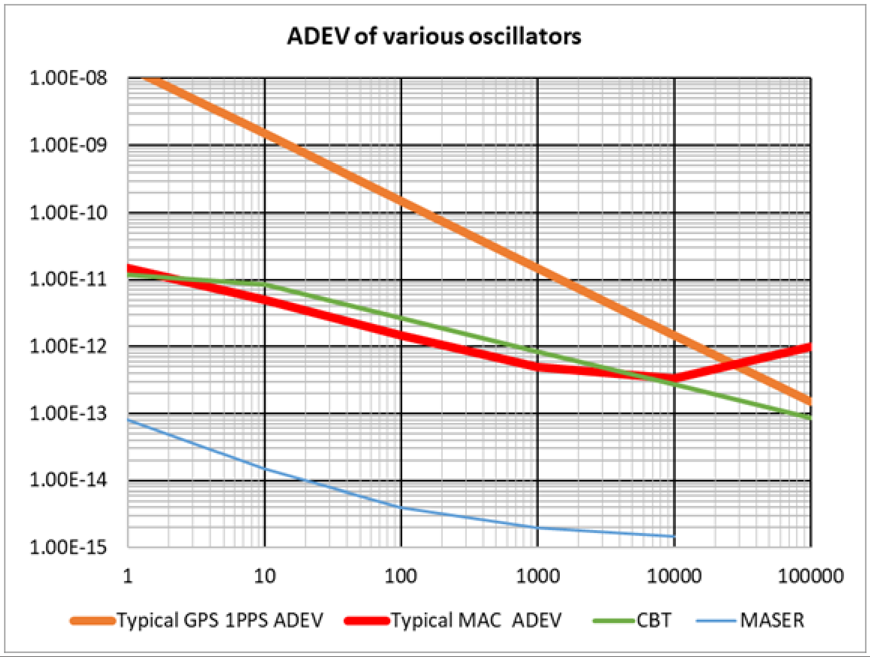

FIGURE 3-2: *Sample ADEV Curves.*

Figure 3-2 shows the performance of several frequency references. For optimum Disciplining performance when disciplining to a GNSS reference, a time constant should be selected where the MAC and GNSS ADEV curves intersect (τ = 25,000 seconds, in this example). In this way, the resulting performance of the Disciplined-MAC will have short and mid-term stability of a free-running MAC, combined with the long-term stability of GNSS.

Note:	The above set of curves is very generic and a designer should independently quantify the stability of their own GNSS source. Usually, ADEV information for GNSS receivers is not published because the stability will vary according to a variety of environmental conditions; the designer will have to generate this plot on their own. A rough approximation would be to measure the 1s ADEV performance of a GNSS and extrapolate the curve proportional to $1/\sqrt{(Tau)}$.

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NOTICE

Caution should be used when using a longer time constant. Initial frequency errors at the start of Disciplining produce phase errors that will grow proportionally with elapsed time. For slow (long Tau) Disciplining algorithms, the initial errors could grow outside the `DisciplineThreshold` or `PhaseLimit` settings before an adequate correction can be made by the algorithm, resulting in a JamSync and `DisciplineLocked` = 0. Generally, a good Discipline approach is to use a short Tau to make quick coarse corrections, then apply a longer Tau to further reduce the MAC's phase and frequency error.

3.4.3 JamSync

When Disciplining is first enabled, the algorithm will implement a JamSync (Observable with the `JamSyncing` parameter). It will also occur whenever the `Phase` is beyond the `PhaseLimit` parameter. A JamSync has the benefit of speeding up the disciplining routine by quickly synchronizing the output 1PPS after one clock cycle (phase is briefly aligned, but frequency is not). The disciplining algorithm can then continue onward by further refining the frequency and phase errors. However, the drawback of a JamSync is that the user will observe a phase "jump" during the JamSync, rather than a slow steer as predicated by disciplining alone. To avoid said "jump", the user can adjust the `PhaseLimit` parameter. This is particularly useful for long Disciplining time constants. However, the initial JamSync (when disciplining is initialized) cannot be avoided.

3.4.4 1PPS Phase Measurement Mode

Phase measurement mode does not steer or Discipline the MAC's output frequency. Rather, it makes use of the MAC's internal phase meter by reporting the time difference between the MAC's internally-generated 1PPS output (pins J1-17,19) and the externally applied reference 1PPS active input (pins J1-5,7 or J1-1,3) once per second. Measurement resolution is approximately 450 ps. The mode is enabled with the `PhaseMetering` parameter and the internal phase difference can be read via the `Phase` parameter.

Note:	Tau has no effect on the `Phase` parameter.

3.4.5 Cable Length Compensation

The zero point of disciplining can be adjusted to accommodate cable and other instrumentation delays (or advances) that impact the arrival time of the 1PPS at the MAC 1PPS input pin. The compensation value can be adjusted with the `CableDelay` parameter.

The maximum compensation adjustment is ±0.5 seconds, where the positive sign indicates phase advancement of the input 1PPS. For example, if there is 45 ns of delay (approximately 33 feet of RG-58 coaxial cable) between the on-time point and the MAC 1PPS input then the compensation value would be +45.

Note:	Compensation is implemented in the disciplining algorithm, not in the phase measurement itself. The phase measurement, as reported through telemetry, reports the actual phase measurement. That is, if the MAC is disciplined with +50 ns of compensation, the phase meter reports –50 ns of phase difference when disciplining is settled.

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3.4.6 PPS Quantization Error Correction

For use with certain GNSS receivers, the `PpsQErr` parameter may be used to correct known dynamic quantization errors due to the receiver itself. This is a picosecond adjustment to the next MAC 1PPS phase measurement to account for the error.

3.5 DEVICE INFORMATION AND STATUS

Consult **Section 4.4 “Parameters”** for a comprehensive list of all available device telemetry parameters. They provide insight into device settings, discipline/atomic lock status, time of day, and alarm conditions.

Several commands provide insight into hardware/software revision, device identification, environmental extremes, and estimated NVRAM health:

- `app?`
- `device?`
- `platform?`
- `describe?`
- `swrev?`
- `hwrev?`
- `serial?`
- `extremes?`
- `health?`

See **Section 4.5 “Commands”** for details.

3.6 TIME OF DAY (TOD)

The MAC maintains a TOD parameter `TimeOfDay` as a 32-bit unsigned integer, which is incremented synchronously with the rising edge of the 1PPS output. Until set otherwise, TOD begins counting from zero when the MAC is powered on.

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NOTES:

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Chapter 4. Command Line Interface

This section describes the communication interface provided by the Microchip MAC SA5X Rubidium Oscillator. The device supports the Microchip proprietary C3 protocol.

The C3 protocol provides read/write access to the device's parameters. The device's state is exposed through these parameters; modifying their values produces changes in state. The C3 protocol also provides access to flash memory operations, device identification functions, and device telemetry.

Key Features

Key features of the C3 protocol include:

- Text-based: Compatible across many architectures; avoids number representation issues.
- Orthogonal: All commands and responses share the same format.
- Parameter-based: Command set is based on exposing information and controls as a set of parameters.
- Error-detecting: With checksums, garbled commands/responses are more detectable.

Message Flow

For each command message sent to the device, one response message will be returned. In certain situations, such as device startup, announcement messages are sent asynchronously.

Note: Protocol is character case-sensitive.

4.1 COMMAND STRUCTURE

The structure of a C3 command follows:

`{command#XX,argument1,|CC}`

Where:

TABLE 4-1: COMMAND STRUCTURE

Field	Description	Required?
`{`	Signifies the beginning of a command.	Yes
`command`	The name of the command being issued.	Yes
`#XX`	The sequence number of the command. (XX = two hex digits).	No
`,argument1`	The start of the argument list, beginning with a comma and containing quoted or un-quoted arguments.	Per Command
`|CC`	The 8 bit checksum of the command message. (CC = two hex digits).	No
`}`	Signifies the end of a command.	Yes

The sequence number, arguments, and checksum fields are optional. If a command is entered incorrectly, MAC will reply with the appropriate error message (See **Section 4.2.1 "Error Responses"**).

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Note: Spaces are not used within the command structure.

4.1.1 Sequence Number

The optional sequence number is used to match a response to an earlier command. Commands issued with a sequence number between #01 and #FF will trigger a response message that includes the same sequence number.

4.1.2 Arguments

The argument list follows the command name (or the sequence number, if included), and always begins with a comma before each argument. Numbers and alphanumeric arguments can be written as-is, but arguments that may contain punctuation should be enclosed in double quotes to prevent ambiguity when parsing the command.

Within a quoted argument, the backslash character is a special escape character. It can be used to escape the following sequences (Any other sequences result in the removal of the backslash.):

TABLE 4-2: ESCAPE SEQUENCES

Escape Sequence	Resulting Character
`\r`	Carriage return.
`\n`	New line/line feed.
`\t`	Horizontal tab.
`\\`	Backslash.

4.1.3 Command Checksum

An optional 8-bit checksum provides a measure of reliability to commands and responses. If a checksum is included with a command, the response will also include a checksum for verification purposes.

The checksum of a command is calculated as a running XOR of all the characters between the opening '{' and the '|' checksum delimiter. It is a two-byte ASCII representation (in hexadecimal) of the XOR.

```
{command#XX,argument1,"argument2"|CC}
```

For example, the hexadecimal checksum of the `{device?}` command would be entered as:

```
{device?|27}
```

If the command is garbled in transmission, causing a mismatch between the contents and the checksum, the C3 response will be `[!3]` indicating a bad checksum error (See **Section 4.2.1 "Error Responses"**). The command should be re-sent.

4.2 RESPONSE STRUCTURE

The structure of a C3 response follows:

```
[#XX=value|XX]<CR><LF>
```

Where:

TABLE 4-3: RESPONSE STRUCTURE

Field	Description	Usage
`[`	Indicates the start of a response.	Always

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TABLE 4-3: RESPONSE STRUCTURE

Field	Description	Usage
`#XX`	The sequence number in the corresponding command (XX = two hex digits).	Only when a sequence command is sent
`=`	The response type. A normal response type is indicated by a ‘=’ character. An error response is indicated by a ‘!’ character.	Always
`value`	The response value. It may be a number, alphanumeric, or quoted string. The meaning of the value depends upon the command. Max Length is 4096 characters.	Always
`|CC`	The 8-bit checksum of the response message. (CC = two hex digits).	Only when a checksum command is sent
`]`	Indicates the end of a response.	Always
`<CR>`	A carriage return character.	Always
`<LF>`	A linefeed/newline character.	Always

A sequence number will be included in a response if one was provided in the command. Similarly, a checksum will be included in a response if a checksum was given for the command.

4.2.1 Error Responses

An error response indicates a problem with the command. It is identified by a ‘!’ character instead of ‘=’ following the optional message sequence number.

The following table lists all error numbers returned by the device:

TABLE 4-4: ERROR RESPONSES

Error Number	Error Message	Cause(s)
1	Invalid command	Unrecognized command name, invalid syntax.
2	Insufficient arguments	Not enough arguments provided for the command.
3	Bad checksum	Checksum does not match the message received.
100	Invalid parameter	The given parameter name or id is unrecognized.
101	Invalid argument	One of the command arguments was semantically invalid. See the command’s documentation for details.
102	Read-only parameter	The parameter’s value cannot be written by the user.
301, 303	Corrupt file contents	The firmware file contents are corrupted.
302	Bad file checksum	There was an error in the file transfer.
304	Incomplete file	The firmware file contents are incomplete.
310	Transfer failed – too many retries	The file transfer was aborted after too many retries.
311	Transfer failed – canceled by client	The client aborted the file transfer.
312	Synchronization error	A file transfer synchronization error occurred.
313	Transfer failed – Unsupported request	The file transfer was aborted due to an unsupported request.

TABLE 4-4: ERROR RESPONSES

Error Number	Error Message	Cause(s)
320	Erase failed	An error occurred while erasing flash memory.
321	Write failed	An error occurred while writing to flash memory.

For example, the response to the invalid command {type7} would be:

```
[!1]<CR><LF>
```

4.2.2 Response Checksum

The checksum of a response is calculated as a running XOR of all the characters between the opening '[' and the '|' checksum delimiter. See the double underlined portion of the response below:

```
[#XX=value|CC]<CR><LF>
```

For example, the checksum-response to the {device?|27} command would be:

```
[=sa5x|62]<CR><LF>
```

4.3 ANNOUNCEMENT STRUCTURE

The structure of a C3 announcement follows:

```
[>message|CC]<CR><LF>
```

Where:

TABLE 4-5: ANNOUNCEMENT STRUCTURE

Field	Description	Usage
[	Indicates the start of an announcement	Always
>	Identifies this as an announcement, versus a response or error.	Always
message	The announcement message. It may be alphanumeric or a quoted string.	Always
|CC	The 8-bit checksum of the announcement message. (CC = two hex digits)	Currently unused feature
]	Indicates the end of an announcement	Always
<CR>	A carriage return character.	Always
<LF>	A linefeed/newline character.	Always

Currently, announcements only occur immediately after applying power to the unit (or resetting the microprocessor):

```
[>Loading...]<CR><LF>
[>Microchip SA5X]<CR><LF>
```

4.4 PARAMETERS

The state of the device is exposed as a set of parameters: named values with semantic attributes. Certain parameters are readable/writable to allow the device to be controlled and configured, while other read-only parameters present useful status information.

Parameters are uniquely identified by either a numeric id (e.g. 769) or a name (e.g. PpsSource). The device provides a set of commands to indicate which parameters are available to the user and to describe each one, including name string, real world units, whether it's writable, etc.

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4.4.1 Parameter Index

The parameters provided by the device are listed in the table below.

TABLE 4-6: PARAMETER INDEX

ID	Name	R/W	Description	Units	Allowable Range (Note 1)
General Status Parameters					
256	`Alarms`	RO	Bitfield of all active alarm conditions.	Bitfield	32 bits
257	`PpsInDetected`	RO	A signal is detected on the selected PPS source.	Boolean	0 or 1
263	`Locked`	RO	The unit is in a locked and stable state.	Boolean	0 or 1
264	`TimeOfDay`	R/W	Time of day at the next 1PPS output pulse. This is a configurable second counter.	seconds	0 to 2,147,483,647
265	`DisciplineLocked`	RO	Disciplining servo is locked to the selected PPS source.	Boolean	0 or 1
Configuration Parameters					
512	`PpsOffset`	R/W	Offset of the output pulse. Default is 0 ns.	ns	±83,886,080 (10 ns step)
513	`PpsWidth`	R/W	Width of the output pulse. Default is 20,000 ns.	ns	0 to 83,886,080 (10 ns step)
515	`CableDelay`	R/W	1PPS input cable delay compensation. Default is 0 ns.	ns	±500,000,000
Disciplining Parameters					
768	`Disciplining`	R/W	Disciplining to 1PPS input is enabled. Default is false.	Boolean	0 or 1
769	`PpsSource`	R/W	Selected 1PPS input source: 0 = PPS Input 0, 1 = PPS Input 1. Default is 0.	—	0 or 1
770	`TauPps0`	R/W	Disciplining time constant when using PPS Input 0.	seconds	10 to 45,000
771	`PpsQErr`	R/W	Time error of the next input pulse due to quantization. For compatibility with GNSS receivers.	ps	±1,000,000
772	`PhaseLimit`	R/W	Limit of phase offset between 1PPS input and 1PPS output before jam syncing. Default is 1,000 ns.	ns	±1,000,000
773	`JamSyncing`	RO	A jam sync to remove phase offset is in progress.	Boolean	0 or 1
774	`Phase`	RO	Most recent measurement of phase offset between 1PPS input and 1PPS output.	ns	±500,000,000.0
775	`LastCorrection`	RO	Most recent frequency correction due to disciplining.	x 10^{-15}	±20,000,000
777	`TauPps1`	R/W	Disciplining time constant when using PPS Input 1.	seconds	10 to 45,000
778	`PhaseMetering`	R/W	Metering of 1PPS phase offset without corrections is enabled. Default is false. Cannot be enabled simultaneously with disciplining.	Boolean	0 or 1

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TABLE 4-6: PARAMETER INDEX (CONTINUED)

ID	Name	R/W	Description	Units	Allowable Range (Note 1)
779	`DisciplineThresholdPps0`	R/W	Phase threshold for determining a disciplining lock to PPS Input 0.	ns	1 to 1,000
780	`DisciplineThresholdPps1`	R/W	Phase threshold for determining a disciplining lock to PPS Input 1.	ns	1 to 1,000
Oscillator Parameters					
1293	`AnalogTuning`	RO	The measured analog tuning input voltage.	mV	0 to 5,000
1296	`Temperature`	RO	Ambient temperature of the unit.	m°C	–40,000 to 100,000
1300	`DigitalTuning`	R/W	Digital tuning of the oscillator frequency. Default is 0. Values are volatile (not preserved across a power-cycle).	x 10^{-15}	±20,000,000
1306	`PowerSupply`	RO	The measured voltage of the external power supply.	mV	0 to 36,300
1312	`AnalogTuningEnabled`	R/W	Analog tuning is enabled. Default is false.	Boolean	0 or 1
1321	`EffectiveTuning`	RO	Total effective digital frequency tune. This provides little insight to the user since its value will vary depending upon a number of constantly changing internal adjustments.	x 10^{-15}	±2,147,483,647
1332	`LockProgress`	RO	Progress toward acquiring lock.	%	0 to 100

Note 1: Allowable ranges are integer-only, unless indicated otherwise.

4.4.2 Parameter Attributes

Each parameter has a set of fixed attributes that describe semantic information about itself: read-only, stored to flash, etc. These attributes are represented as a 32-bit field, below.

TABLE 4-7: PARAMETER ATTRIBUTES

31-15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
—	Units					—	—	—	—	Persisted	—	Silent	Read-Only	—	—

- Read-Only: The parameter cannot be written by the user.
- Silent: Changes to the value are excluded from the upd command.
- Persisted: This parameter will be written to flash by a store command.
- Units: A 5-bit enumeration containing the parameter's real-world units.

Use the `browse` command to learn the attributes of each parameter.

4.4.2.1 PARAMETER UNITS ATTRIBUTE

The following table maps Units Attribute values to Parameter units:

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TABLE 4-8: UNITS ATTRIBUTE

Units Value	Parameter Units
0	None/No units
1	Picoseconds
2	Nanoseconds
3	Microseconds
4	Milliseconds
5	Seconds
6	Microvolts
7	Millivolts
8	Microamps
9	Milliamps
10	Millidegrees Celsius
11	$x\ 10^{-12}$
12	$x\ 10^{-15}$
13	Hertz
14	Kilohertz
15	Megahertz
16	Percent (%)
17	Boolean (true/false)
18	Millimeters
19	Millimeters/second
20	Meters
21	Meters/second
22	Degrees
23	Decibel Hertz (dBHz)
24	Microdegrees Celsius
25	dBm

For example, the command `{browse,attrs,PpsInDetected}` will return `[=17412]`. This maps to bits 10, 14 as a logic high (indicating a Units Value of “17” or “Boolean”) and bit 2 as a logic high (indicating that the parameter is “read only”).

4.4.3 Alarms Parameter

The Alarms parameter represents the device’s current alarm state as a bitfield. Each 1 bit represents an active alarm condition. The user is also notified of new alarm conditions via the device’s ALARM pin (J1-20). This pin is driven high when a new alarm condition occurs and it remains high until the condition is resolved or the user acknowledges it with the `ackalm` command. If multiple alarm conditions are unacknowledged by the user, the ALARM pin will remain high until each individual alarm condition has been acknowledged or resolved.

Alarm Bits

The bits of the Alarms parameter are described as follows:

TABLE 4-9: ALARM BITS 31-16

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
—	—	—	—	—	—	—	—	—	—	—	—	—	Disciplining Range Warning	No PPS Input	Temperature Warning

TABLE 4-10: ALARM BITS 15-0

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
—	—	—	—	—	—	—	—	—	Incompatible Firmware	Heater Fault	No External Oscillator	Acquisition Failed	Flash Fault	PLL Fault	FPGA Fault

TABLE 4-11: ALARM DESCRIPTIONS

Bit	Decimal	Alarm	Description
0	1	FPGA Fault	Hardware fault related to the internal FPGA.
1	2	PLL Fault	Hardware fault related to the internal PLL circuit.
2	4	Flash Fault	Hardware fault related to flash memory.
3	8	Acquisition Failed	The most recent attempt to acquire lock failed.
4	16	No External Oscillator	An external oscillator was expected and not detected.
5	32	Cell Heater Fault	Hardware failure within the Cell Heater.
6	64	Incompatible Firmware	The loaded firmware is not compatible with the unit's hardware.
16	65536	Temperature Warning	The clock is unable to maintain a stable internal temperature and performance is likely degraded. This alarm is only asserted when the `Locked` parameter is 1.
17	131072	No PPS Input	Disciplining is enabled but no 1PPS input is detected on the selected input.
18	262144	Disciplining Range Warning	Disciplining is enabled but the digital tuning adjustment needed to discipline the clock is outside the range of `DigitalTuning`. The user should issue a `latch` command when this alarm occurs.

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4.5 COMMANDS

The Microchip SA5X provides access to all device features, status, and measurements through the C3 command set.

In addition to these standard commands, backwards compatibility with the MAC-SA.3Xm line of Rubidium Oscillators is provided through a set of compatibility commands (See **Appendix B. "Legacy Command Set (SA.3Xm)"**). Only a subset of the device's functionality is available through the compatibility command interface; it is included to ease the design transition from the SA.3X devices to the newer C3 protocol.

4.5.1 Command Index

The following table contains the available C3 commands. Refer to the next section for detailed command usage.

TABLE 4-12: COMMAND DESCRIPTIONS

Command	Arguments	Description
Device Identification Commands		
`app?`	0	Returns a short string identifying the firmware application type.
`device?`	0	Returns a short string identifying the device type.
`platform?`	0	Returns a short string identifying the firmware platform of the device.
`describe?`	0	Returns a readable English description of the device.
`swrev?`	0	Returns the software revision.
`hwrev?`	0	Returns the hardware revision.
`serial?`	0	Returns the serial number of the unit.
`help`	0	Returns a list of available commands.
Parameter Commands		
`get`	1	Returns the current value of a parameter.
`set`	2	Sets the value of a parameter.
`add`	2	Adds to the current value of a parameter.
`browse`	1-2	Returns information about one or more parameters.
`upd`	0	Returns a list of all parameter values that changed since the last upd.
Alarms Command		
`ackalm`	1	Acknowledges an alarm, preventing it from contributing to the ALARM pin state.
Configuration Management Commands		
`store`	0	Stores the current configuration to flash memory.
`latch`	0	Latches the current frequency and clears the digital tuning parameter.
`load`	0	Loads the most recent configuration from flash memory.
Miscellaneous Commands		
`extremes?`	1	Returns the minimum and maximum measurements for certain parameters over the life of the unit.
`health?`	1	Returns health estimates of certain components.
`reset`	0	Resets the CPU.

4.5.2 Command Usage

This section contains command usage and details regarding each supported C3 command, listed in alphabetical order.

{ackalm,*alarm*}

Description	Acknowledges an alarm, or multiple alarms. The acknowledged alarm remains active but it will no longer contribute to the output of the ALARM pin as an outstanding alarm. The value of the `Alarms` parameter will not be affected; it always shows the active alarms, acknowledged or outstanding.
Arguments	Requires one argument: ***alarm*** – The decimal number of alarm bit(s) to acknowledge. Multiple alarm bits may be OR'd together, to be acknowledged simultaneously.
Returns	`[=1]`
Since	V1.0

{add,*parameter*,*amount*}

Description	Adds to the current value of a parameter.
Arguments	Requires two arguments: ***parameter*** – The numeric id or name string of the parameter to modify. Parameter must not be read-only. ***amount*** – The amount to add to the value (may be negative). Allowable range depends on parameter used.
Returns	The parameter's updated value. Error `[!100]` (Invalid parameter) if the parameter does not exist. Error `[!102]` (Read-only parameter) if the parameter is read-only.
Since	V1.0

{app?}

Description	Returns a short string identifying the firmware application type.
Arguments	None.
Returns	`[=clock]` in normal operation, or `[=bsl]` in the bootstrap loader.
Since	V1.0

{browse,*what*,*parameter*}

Description	Returns information about one or more parameters.
Arguments	Accepts two arguments (first is required): ***what*** – (Required) The type of parameter information being queried. Acceptable values for **what** are: • "id" – Browses numeric parameter ids. • "name" – Browses parameter name strings. • "value" – Browses current parameter values. • "attrs" – Browses parameter attributes. ***parameter*** – (Optional) The numeric id or name string of the specific parameter being queried.
Returns	A single item (if ***parameter*** is specified), or a list of items beginning with a comma and delimited by commas (if ***parameter*** is omitted). Returned lists are always the same length and in the same order. (e.g. Element N of `{browse,id}` matches element N of `{browse,name}`. Error `[!101]` (Invalid argument) if ***what*** value for the specified parameter does not exist.
Examples	`{browse,id}` – Returns all parameter IDs. `{browse,id,Alarms}` – Returns the numeric id of the Alarms parameter.

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Since	V1.0

{describe?}

Description	Returns a readable English description of the device.
Arguments	None.
Returns	A response similar to “Microchip SA5X”.
Since	V1.0

{device?}

Description	Returns a short string identifying the device type.
Arguments	None.
Returns	`[=sa5x]`
Since	V1.0

{extremes?,*parameter*}

Description	Returns minimum and maximum measurements for certain parameters over the life of the unit. The following parameters are supported: • `Temperature` • `PowerSupply` An example command would be `{extremes?,Temperature}`
Arguments	Requires one argument: ***parameter*** – The numeric id or name string of the parameter.
Returns	The minimum measurement followed by the maximum measurement, separated by a comma. Example response to the above command would be `[=-38389,83629]` …indicating a min and max temperature of –38389 m˚C and 83629 m˚C. Error `[!100]` (Invalid parameter) if the parameter does not exist.
Since	V1.0

{get,*parameter*}

Description	Returns the current value of a parameter.
Arguments	Requires one argument: ***parameter*** – The numeric id or name string of the parameter.
Returns	The parameter’s current value, as an integer or floating-point number. Error `[!100]` (Invalid parameter) if the parameter does not exist.
Since	V1.0

{health?,*component*}

Description	Returns the health rating of certain components within the unit. Currently, only the flash memory (NVRAM) write endurance is reported.
Arguments	Requires one argument: ***component*** – The name of the component to query. Currently, only the `nvram` component is supported.
Returns	The component’s health rating, from 0 to 100 (full health). For example `[=100]` Error `[!101]` (Invalid argument) if the component is not supported.
Since	V1.0

{help}

Description	Returns a comma-delimited list of available commands. Commands that are not accessible with the current authentication will not be included. Some factory-use commands may be included in the list, but are not described in this manual because they present no usable information/function to the user outside of the factory.
Arguments	None.
Returns	A comma-delimited list of command names. Example response is: `[=,ackalm,add,browse,chap,describe?,extremes?,get,health?,help,hwrev?,latch,load,reset,serial?,session,session?,set,store,swrev?,type?,upd]`
Since	V1.0

{hwrev?}

Description	Returns the hardware revision of the device.
Arguments	None.
Returns	The MAC's hardware revision, typically a single character.
Since	V1.0

{latch}

Description	Simultaneously latches the current output frequency and clears the digital tuning. This is used to center the output frequency at the current digital tuning value. The `DigitalTuning` parameter will be set to zero and the output frequency will be unaffected. Similarly, the `DigitalTuning` value will be subtracted from the current `EffectiveTuning` value. Note: The new latched value is preserved across power cycle.
Arguments	None.
Returns	`[=1]`
Since	V1.0

{load}

Description	Loads the most recent configuration from flash memory (Discipline settings, Analog tuning configuration, etc). The device configuration is loaded automatically on boot.
Arguments	None.
Returns	`[=1]` on success. `[=0]` if no stored configuration is available.
Since	V1.0

{platform?}

Description	Returns a short string identifying the firmware platform of the device.
Arguments	None.
Returns	`[=sa5x]`
Since	V1.0

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{reset}

Description	Resets the CPU. Any un-stored configuration will be lost. The device will reacquire lock on restart.
Arguments	None.
Returns	No response. Processor is immediately reset.
Since	V1.0

{serial?}

Description	Returns the serial number of the unit.
Arguments	None.
Returns	The unit's alphanumeric serial number as an 11 character text string.
Since	V1.0

{set,*parameter*,*value*}

Description	Sets the value of a parameter.
Arguments	Requires two arguments: ***parameter*** – The numeric id or name string of the parameter to modify. ***value*** – The new value, as a decimal integer or floating-point number, as allowed by the parameter.
Returns	The updated value of the parameter. Error `[!100]` (Invalid parameter) if the parameter does not exist. Error `[!102]` (Read-only parameter) if the parameter is read-only.
Since	V1.0

{store}

Description	Stores the current configuration to flash memory. The configuration will be loaded automatically on the next restart, or it can be loaded manually with the load command.
Arguments	None.
Returns	`[=1]` on success. `[=0]` on flash memory failure.
Since	V1.0

{swrev?}

Description	Returns the software revisions.
Arguments	None.
Returns	The revision strings as a comma-delimited list. The first element is the CPU firmware revision. The second element is the FPGA revision. Example response is `[=V1.0.4.0.5ADA4E31,V1.0]`
Since	V1.0

{upd}

Description	Returns a list of all parameter values that changed since the previous upd. This command is useful for collecting telemetry from the device without continuously polling each parameter. Only the values of the parameters that changed will be reported.
Arguments	None.

Returns	A list of parameter updates notifications, beginning with a comma and delimited by commas. Each notification is composed of two fields, also delimited by commas. The first field in a notification is the id of the parameter that updated. The second field is the parameter's new value. So, if three parameter values have changed since the previous upd command, the returned string will be a list with a total of six values (3 notifications * 2 fields), each preceded by a comma. For example, if the response is `[=,513,20000,515,25,779,20]` then the `PpsWidth`, `CableDelay`, and `DisciplineThresholdPps0` parameter values have changed to 20,000 ns, 25 ns, and 20 ns, respectively.
Since	V1.0

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Chapter 5. Maintenance and Troubleshooting

5.1 PREVENTATIVE MAINTENANCE

There are no maintenance procedures or adjustments needed, aside from frequency adjustment. See the product data sheet for environmental requirements.

5.2 ELECTROSTATIC DISCHARGE (ESD) CONSIDERATIONS

Maintenance personnel should wear ESD wrist straps when installing or working on the MAC.

CAUTION
To avoid electrostatic discharge damage, proper ESD handling procedures must be observed in unpacking, assembling, and testing the MAC.

5.3 TROUBLESHOOTING

If the MAC does not respond to user commands, check the following:

1. Ensure that the BAUD, flow, and syntax of your terminal interface are configured as described previously.
2. Check all physical connections.
3. Check that the MAC is not in "compatibility mode". Use the backslash character "\" to exit compatibility mode.

Note: The MAC enters compatibility mode whenever legacy MAC-SA.3Xm commands are entered. It stays in this mode until the user inputs the backslash character "\".

5.4 REPAIRING THE MAC

The MAC cannot be repaired in the field. It must be sent back to the factory for replacement.

5.5 UPGRADING THE FIRMWARE

As of the initial release of this manual, upgrading the firmware in the field is not supported. It must be sent back to the factory for any future upgrades, if applicable.

5.6 RETURNING THE MAC

You should return the equipment to Microchip only after you have exhausted the troubleshooting procedures described earlier in this chapter, or if Microchip FTS Services and Support has advised you to return the unit.

> **Note:** Please retain the original packaging for re-shipping the product. If the original packaging is not available, contact Microchip FTS Services and Support for assistance.

Repacking the Unit

Return all units in the original packaging. If the original packaging is not available, contact Microchip FTS Services and Support. Use standard packing procedures for products being returned for repair to protect the equipment during shipment. Connectors should be protected with connector covers or the equipment should be wrapped in plastic before packaging.

Equipment Return Procedure

To return equipment to Microchip for repair:

1. Contact Microchip per the guidelines on page 5 to obtain a return material authorization number (RMA) before returning the product for service.
   You can request an RMA on the internet at www.microsemi.com/ftdsupport
   Retain the assigned RMA number for future reference.
2. Provide a description of the problem, product item number, serial number, and warranty expiration date.
3. Provide the return shipping information (customer field contact, address, telephone number, and so forth.)
4. Ship the product to Microchip, transportation prepaid and insured, with the Return Material Authorization (RMA) number and item numbers or part numbers clearly marked on the outside of the container to the address given with the RMA.

Repaired equipment is returned to you with shipping costs prepaid by Microchip.

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Appendix A. Principle of Operation

The MAC is a passive atomic clock, incorporating the interrogation technique of Coherent Population Trapping (CPT) and operating upon the D1 optical resonance of atomic 87Rb to control the frequency of a quartz crystal oscillator via a frequency-locked loop (FLL). The FLL function block is shown in Figure A-1. The principal RF output from the MAC is provided by a Temperature-Compensated Crystal Oscillator (TCXO) and provided on the MAC output pin 3. The laser is mounted on a Thermal-Electric Cooler (TEC) for precise temperature control and is modulated by the microwave synthesizer at half the hyperfine frequency to produce sidebands in the laser spectrum. The light travels through the temperature-controlled Rb cell exposed to a magnetic "C-field" before hitting the photodetector that detects the transmitted CPT resonance signal. The photodetector current is used to generate a control signal with phase and amplitude information that permits continuous regulation of the TCXO frequency. Servos control frequency synthesis chain, laser current, TEC setpoint, C-field, and cell heater. Additionally, the microprocessor and FPGA provide precise 1 pulse per second functionality.

The main advantage of employing CPT is it allows the use of low power lasers allowing to construct low power, small size atomic clocks.

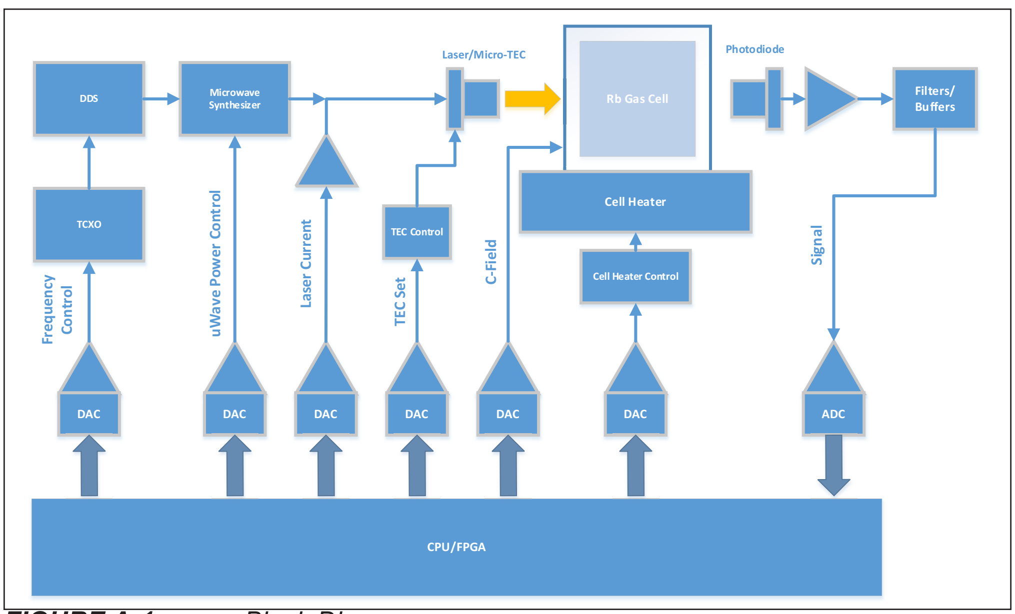

FIGURE A-1: *Block Diagram.*

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NOTES:

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Appendix B. Legacy Command Set (SA.3Xm)

This section describes the commands used in the Legacy MAC product: SA.3Xm. They have been carried forward to the SA5X product to accommodate legacy applications. These compatibility commands do not follow the aforementioned C3 command syntax; the response syntax is unique to each command. When a compatibility command is received, the Microchip SA5X serial command processor enters “compatibility mode.” An escape character ‘\’ is required to escape the mode before issuing any further C3 commands.

Generally, these commands are considered inferior to the C3 commands and are not recommended for new designs. All of the old commands may be used with the new product and will have the same intended functionality. However, you may see some minor changes in the MAC response to these commands (such as string length or additional data fields).

Any serial port terminal emulator program can be used to communicate with the MAC.

B.1 LEGACY COMMAND STRUCTURE

The legacy SA.3Xm communication protocol supports the following types of commands:

- Single keystroke: A carriage return is not required.
- Multiple keystroke: Requires a specific start (<) and end (>) character. Used for commands that require arguments. A carriage return is not required. All multiple keystroke commands return confirmation strings describing what action they have taken.

The MAC communicates exclusively with “printable” ASCII characters.

All commands produce a response from the MAC, which are human readable, with individual lines ending in a carriage return/line feed sequence. If an unsupported or improperly formatted command is received, the MAC responds with "?" followed by a carriage return/line feed sequence.

Note:	The remainder of this document abbreviates “carriage return/line feed” as “[CRLF]”.

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B.2 LEGACY COMMAND INDEX

Table B-1 summarizes the Legacy MAC SA.3Xm commands.

TABLE B-1: LEGACY COMMAND INDEX

Command	Description
A	Analog Tuning Enable
a	Analog Tuning Disable
c	Display Current Values
6	Return telemetry headers as comma-delimited string
^	Return telemetry as comma-delimited string
<NX0>	Disables analog tuning and persists the setting past power-off
<NX1>	Enables analog tuning and persists the setting past power-off
<FA>	Apply the Digital Adjustment value to the Center Frequency and zero out the Digital Adjustment value
<FS>	Save current DDS Center Frequency to Non-volatile memory (NVRAM)
<FCnnn>	Add nnn to the current DDS Center Frequency. (nnn is in pp 10^{12})
<FFnnn>	Add nnn to the current DDS Center Frequency. (nnn is in pp 10^{15})
<FDnnn>	Replace the Digital Adjust value with nnn. (nnn is in pp 10^{12})
<FGnnn>	Replace the Digital Adjust value with nnn. (nnn is in pp 10^{15})
<FEnnn>	Add nnn to the Digital Adjust value. (nnn is in pp 10^{12})
<FHnnn>	Add nnn to the Digital Adjust value. (nnn is in pp 10^{15})

B.3 LEGACY COMMAND USAGE

A

Enables analog tuning but does not persist the setting past power-off. This command also returns a confirmation string. See the <NX1> Analog Tuning command for a persistent version.

a

Disable Analog tuning. See <NX0> for a persistent version.

c

Returns a list of current telemetry values. Example Response:

```
   ...CURRENT VALUES...
BITE = 0
Version = V1.0.4
SerialNumber = 1801MX00041
TEC Control (mDegC) = 55177
RF Control (0.1mv) = 20184
DDS Frequency Center Current (0.01Hz) = 0
CellHeaterCurrent (ma) = 418
DCSignal (mv) = 1000
Temperature (mDegC) = 55024
Digital Tuning (0.01Hz) = 3
Digital Tuning (pp15) = 3000000
Analog Tuning On/Off = 0
Analog Tuning (mv) = 1450
```


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> **Note:** BITE = 0 is an indication of Atomic Lock (1 = un-Lock)
> Analog Tuning = 0 indicates that it is turned off (1 = on)

6

Retrieves the telemetry headers. Response is a comma-delimited string, suitable for importing into spreadsheet programs.

Example Response:

```
BITE,Version,SerialNumber,TEC Control (mDegC),RF Control
(0.1mv),DDS Frequency Center Current (0.01Hz),CellHeaterCurrent
(ma),DCSignal(mv),Temperature (mDegC),Digital Tuning
(0.01Hz),Analog Tuning On/Off,Analog Tuning (mv),Digital Tuning
(pp15)
```

^

Retrieves the telemetry values. Response is a comma-delimited string, suitable for importing into spreadsheet programs.

Example Response:

```
0,V1.0.4,1801MX00041,55173,20174,0,413,1000,55306,3,0,1450,3000
000
```

> **Note:** Similar functionality (comma-separated headers and values) is available with the C3 commands using `{browse,name}` and `{browse,value}`.

> **Note:** Maximum output string length = 128 characters.

<NX0>

The command disables analog tuning and persists the setting past power-off. See the `A` command for a non-persistent version.

<NX1>

The command enables Analog Tuning and persists the setting past power-off.

<FA>

This command has essentially the same function as the new `latch` command. Previously, for the legacy MAC-SA3x, the purpose of this command was to add the digital adjustment value into the current center frequency value so that the accumulated changes can be saved. The center frequency could then be subsequently saved using the `<FS>` command, if the changes were to be made permanent (this step is no longer necessary because `<FA>` now saves the value to NVRAM). Upon execution of `<FA>`, the digital adjustment will be re-set to zero.

<FS>

Save the current DDS center frequency to non-volatile memory (NVRAM). The `<FS>` command can be used to persist the setting of the DDS center frequency. However, there is no way to persist digital adjustment, per se. The recommend procedure to "persist" digital adjustment is to use the `<FA>` command to alter the DDS center frequency and set the digital adjustment to zero and then use the `<FS>` command to save the DDS center frequency. As the default value of the digital adjustment is zero, this effectively saves the value.

> **Note:** This command is redundant with the `<FA>` command when used on MAC-SA5X because the `<FA>` command also saves the value to NVRAM.

<FCnnn>

Command will increment or decrement the center frequency by the specified number interpreted as pp 10^{12}. The range of nnn for the `<FCnnn>` command is ±20000. Values outside of that range are clamped at the maximal excursion either positive or negative.

Example: `<FC-10>`

Functional Response: Center Frequency will decrement by -10×10^{-12}

Example Response: "`    ...Persistent Frequency Adjustment = -10`"

<FFnnn>

Command has identical function as `<FCnnn>` command, except it will increment or decrement the Center Frequency by the specified number interpreted as pp 10^{15}. The range of nnn for the `<FFnnn>` command is ±20000000. Values outside of that range are clamped.

> **Note:** `<FC?>` and `<FF?>` return the current Center Frequency in 0.01 Hz.

<FDnnn>

Command will replace the digital adjustment value with the specified number interpreted as pp 10^{12}. The range of nnn for the `<FDnnn>` command is ±20000. Values outside of that range are clamped at the maximal excursion either positive or negative.

Example: `<FD1000>`

Functional Response: digital adjustment set to 1000×10^{-12}

Example Response: "`    ...One Time Frequency Adjustment = 1000`"

<FGnnn>

Command will replace the digital adjustment value with the specified number interpreted as pp 10^{15}. The range of nnn for the `<FGnnn>` command is ±20000000. Values outside of that range are clamped.

> **Note:** `<FD?>` and `<FG?>` return the digital adjustment in pp 10^{12} and pp 10^{15}, respectively.

<FEnnn>

Command will augment the digital adjustment, whereas the commands in the previous section replaced the digital adjustment value. `<FEnnn>` will increment or decrement the digital adjustment by the specified number interpreted as pp 10^{12}. The range of nnn for the `<FEnnn>` command is ± 20000. Values outside that range are clamped at the maximal excursion either positive or negative.

Example: `<FE-500>`

Functional Response: digital adjustment will decrement by -500×10^{-12}

Example Response: "`    ...One Time Frequency Adjustment = -500`"

<FHnnn>

Command will increment or decrement the digital adjustment by the specified number interpreted as pp 10^{15}. The range of nnn for the `<FHnnn>` command is ±20000000. Values outside of that range are clamped.

> **Note:** `<FE?>` and `<FH?>` return the digital adjustment in pp 10^{12} and pp 10^{15}, respectively. They are redundant commands to `<FD?>` and `<FG?>`.

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Appendix C. Reference Designs

The following schematics are borrowed from the evaluation kit schematic diagram and may contain extra features that are not required by the end-user. Specific applications should modify these schematics according to each systems requirement.

USB Connection

This reference schematic maps a USB-micro connection to the MAC's USB pins J1-2,4,6.

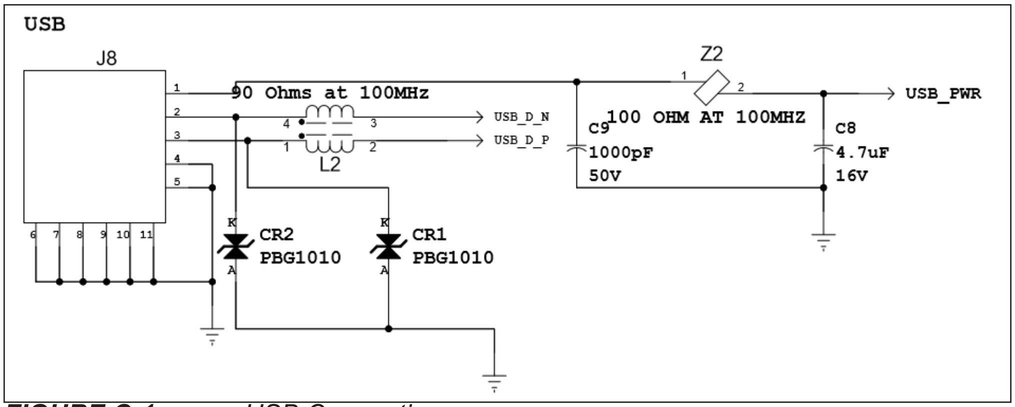

FIGURE C-1: USB Connection.

RS-232 Connection

This reference schematic converts USB-mini signals and maps them to the MAC's RS-232 pins 7 and 8.

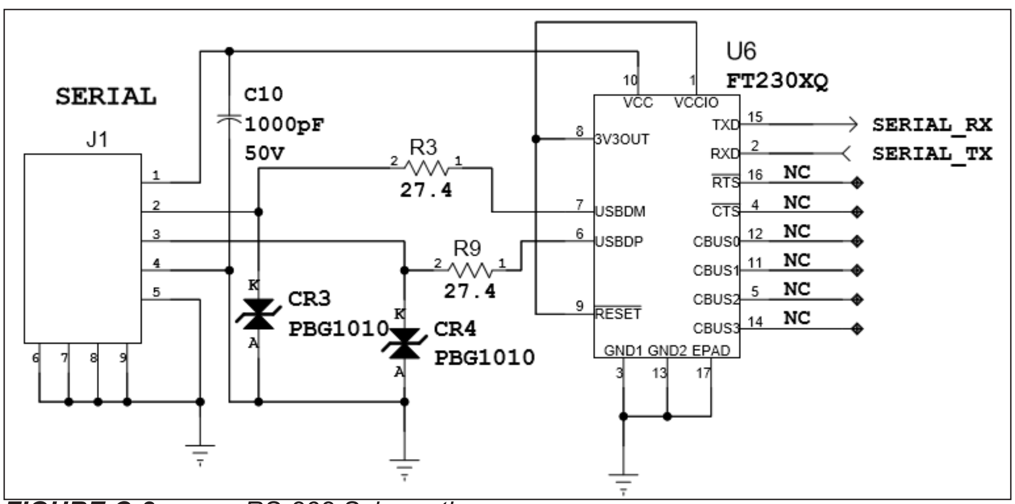

FIGURE C-2: RS-232 Schematic.

If a designer wants to use the RS-232 pins without a USB converter, a line driver such as the TI MAX202 or similar device is recommended (shown in Figure C-3). This schematic was implemented on the previous generation evaluation board and is not featured on the current design.

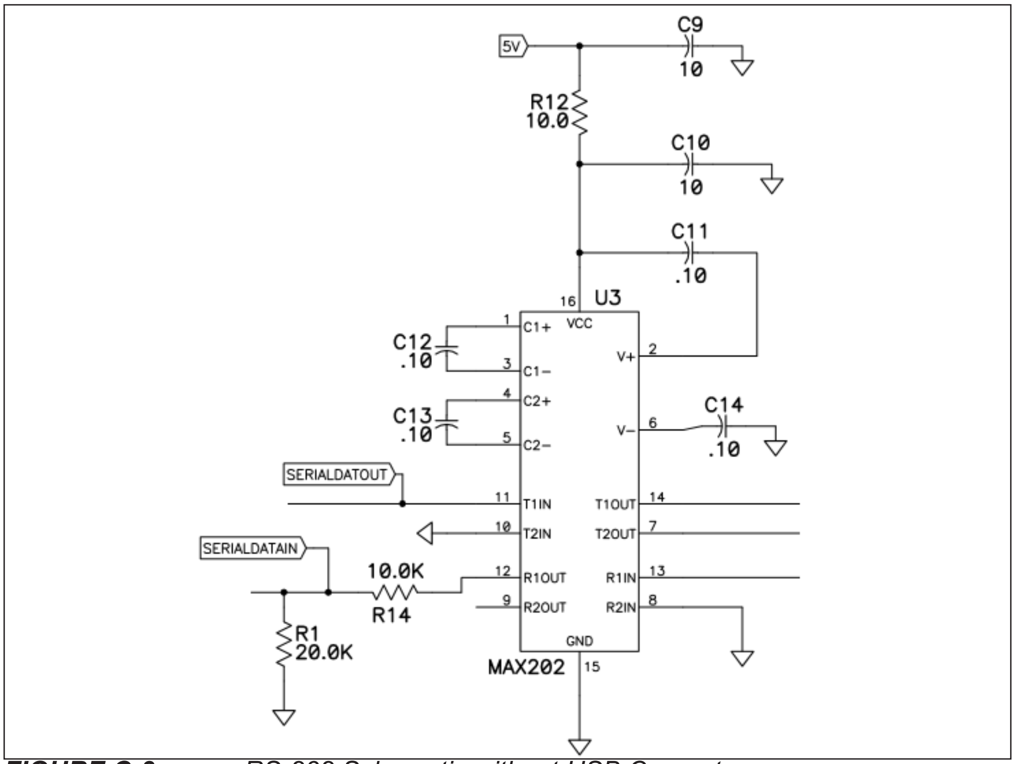

FIGURE C-3: *RS-232 Schematic without USB Converter.*

1PPS Input Connection

This reference schematic converts a single-ended (3.3V @ 50Ω) 1PPS signal to the differential LVDS format required by the MAC.

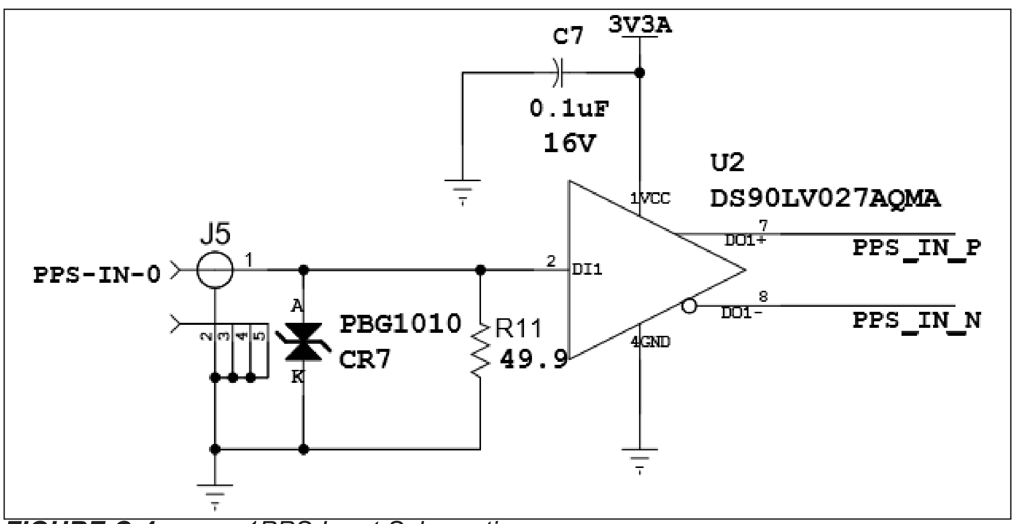

FIGURE C-4: *1PPS Input Schematic.*

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Analog Tune Input Connection

This reference schematic shows how the Evaluation kit maps AT voltages to the MAC.

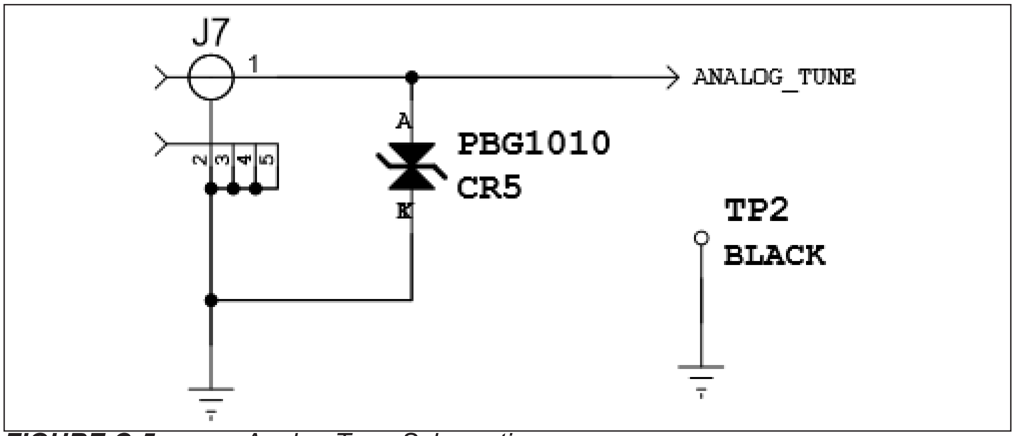

FIGURE C-5: Analog Tune Schematic.

1PPS Output Connection

This reference schematic converts the MAC's differential 1PPS LVDS output to a single-ended 3.3V signal and contains a driver circuit capable of driving a 50Ω coaxial cable.

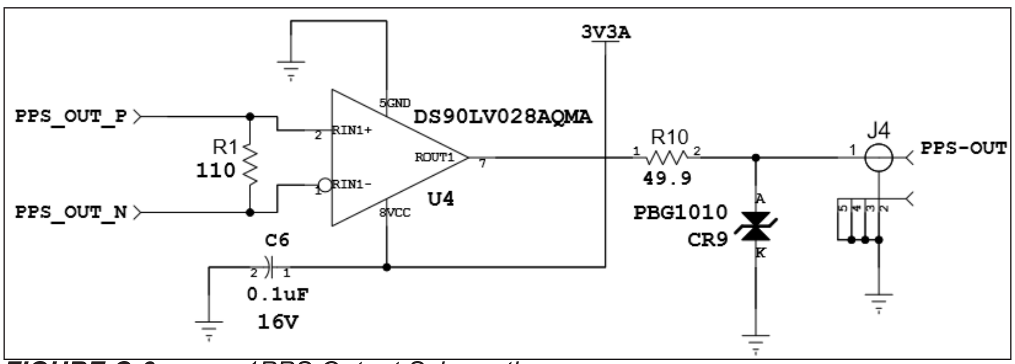

FIGURE C-6: 1PPS Output Schematic.

RF (10 MHz) Output Connection

This reference schematic buffers the MAC's RF output as a 50Ω, 3.3V signal on J2.

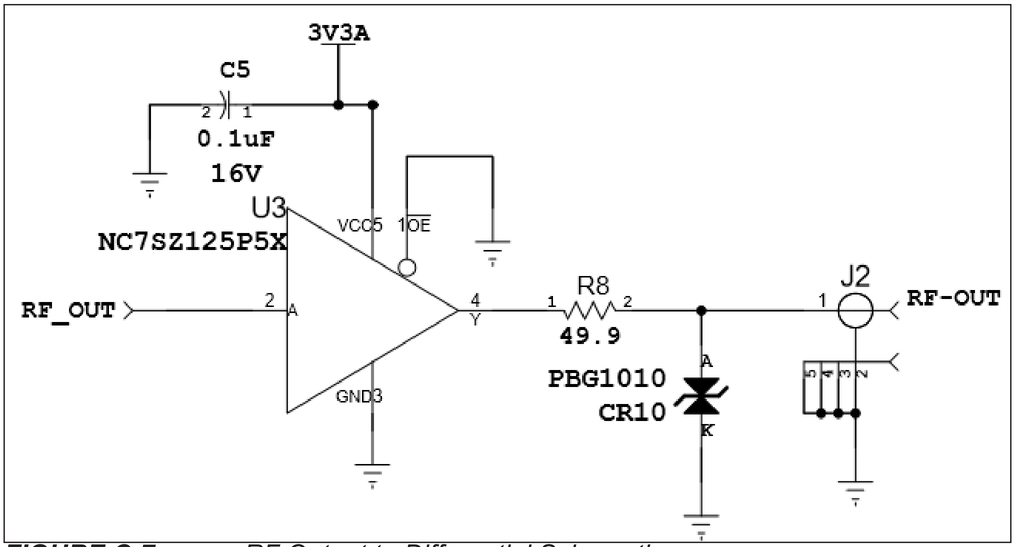

FIGURE C-7: RF Output to Differential Schematic.

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Appendix D. Evaluation Kit

The evaluation kit (p/n 090-44500-000) may be purchased separately and is provided as a means for a user to quickly test out the features of the MAC-SA5X. It is intended for static, bench-top use and is not designed for environmental testing.

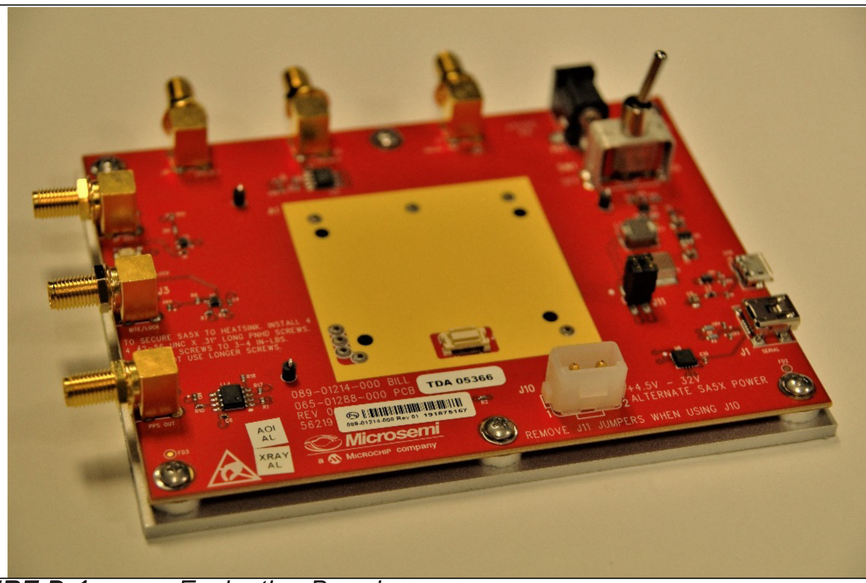

FIGURE D-1: Evaluation Board.

D.1 OVERVIEW AND KEY FEATURES

The Evaluation Kit has the following features:

- 10 MHz LVCMOS Output via SMA(f) Connector
- 1PPS Disciplining (Steering) via Two Selectable SMA(f) Connectors
- 1PPS LVCMOS Output via SMA(f) Connector
- –40°C to +75°C Operating Temperature (Baseplate)
- –55°C to +100°C Storage Temperature
- Interface for Digital Steering, Configuration, and Diagnostics via:
  - USB-mini Communication Port for Accessing RS-232 MAC Pins
  - USB-micro Communication Port for Accessing USB MAC Pins
- Wall-Plug Power Connector with On/Off Toggle Switch
- Alternate Wide Range Allowable DC Input (4.5V to 32V) Connector
- Heat Sink and Thermal Pad for Thermal Conditioning
- LED Status Indications for Power, Lock, and Alarm
- Insertable Socket Design to Quickly Plug in a MAC without Need for Soldering
- Analog Tuning via SMA(f) Connector

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D.2 PHYSICAL DESCRIPTION

The Evaluation Kit contains the following items:

TABLE D-1: EVALUATION KIT CONTENTS

Description	Purpose
#2-56UNC-2A X 31LG type screw (Qty = 4)	Fasten MAC-SA5X to Evaluation Board
Wall-mount power adapter US (90VAC to 264VAC) to 5VDC	Supply Power to the MAC and Evaluation board (PS1 connector)
USB 2.0(M) to USB-mini(M) cable	Connection from a PC to Evaluation board's serial-to-USB-mini adapter
Thermal Pad (p/n 172-00054-000)	Provide thermal interface between MAC and heat sink
PCBA/Baseplate Subassembly	Heat sink and PCBA receptacle containing all connections

The PCBA/Baseplate consists of a 3.9" x 5.1" aluminum heat sink/baseplate attached to a PCBA with six mounting screws. All connections are on the PCBA. The physical connections of the PCBA/Baseplate are highlighted in Figure D-2.

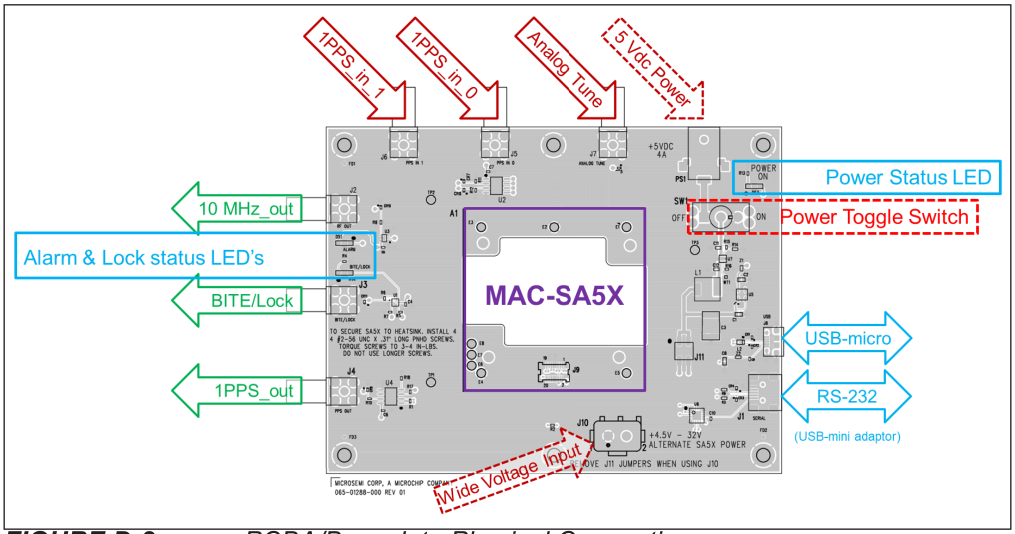

FIGURE D-2: PCBA/Baseplate Physical Connections.

- A power on/off toggle switch is within the red-dashed box.
- Power input connections are identified by red-dashed arrows.
- Input connections are identified by solid-red arrows and are accessible with SMA(f) RF connectors.
- Output connections are identified by green arrows and are also accessible with SMA(f) RF connectors.
- Blue arrows identify the communications ports (accessible with USB-micro and USB-mini).
- Blue boxes highlight the communications LEDs.
- A MAC-SA5X may be plugged into the purple box with its J1 connector oriented towards the bottom of the Evaluation board so that it mates with the Evaluation board's J9 connector.

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TABLE D-2: CONNECTIONS

Eval Board ID	Label	Function	Maps to MAC Pin
J7	Analog Tune	(INPUT) Accepts DC voltage for frequency steering	1
J5	PPS_in_0	(INPUT) Accepts a 1PPS (3.3V, 50Ω) signal for Freq/Phase Disciplining	J1-5,7
J6	PPS_in_1	(INPUT) Accepts a 1PPS (3.3V, 50Ω) signal for Freq/Phase Disciplining	J1-1,3
J2	10 MHz	(OUTPUT) Buffered MAC RF output (3.3V, 50Ω)	3
J3	BITE/Lock	(OUTPUT) MAC Lock status (CMOS, 1 MΩ)	6
J4	PPS_out	(OUTPUT) Buffered MAC 1PPS output signal (3.3V, LVCMOS, 50Ω)	J1-17,19
J1	RS-232	(COMM.) access the MAC's serial communication port	7, 8
J8	USB-micro	(COMM.) access the MAC's high-speed USB communication port	J1-2,4,6
PS1	5VDC Power	(POWER) accepts the 5VDC wall-mount power adapter for powering the Evaluation board and the MAC	5
J10	Wide Voltage Input	(POWER) accepts an alternate source of voltage for the MAC (only) if J11 jumpers are removed	5
SW1	Toggle Switch	(SWITCH) allows power to flow to the Evaluation board from the 5VDC supply	N/A
DS3	Power Status	(LED) illuminates when power is provided to PS1	N/A
DS1	Alarm Status	(LED) illuminates when an alarm condition is triggered	J1-20
DS2	Lock Status	(LED) illuminates when Atomic Lock is achieved	6

D.2.1 Communications Connections

The Evaluation board has two USB connections for communicating between a PC and a MAC-SA5X (blue arrows in Figure D-2). The "RS-232" connection accepts a USB-mini(M) connector that then passes to a serial converter on the Evaluation board and applies the appropriate levels on pins 7,8 of the MAC. A USB 2.0-to-USB-mini cable is provided in the kit.

The "USB-micro" connection accepts a USB-micro(M) connector that maps to pins J1-2,4 of the MAC. A cable is not provided in the kit.

Consult the main portion of the MAC-SA5X User Guide for advice on communicating with a MAC plugged in to the Evaluation board.

Three LEDs communicate status information to the user by illuminating under the following conditions:

- Power Status LED illuminates when power is provided to PS1.
- Alarm Status LED illuminates when an alarm condition is triggered.
- Lock Status LED illuminates when Atomic Lock is achieved.

D.2.2 Input Connections

Three input connections are available via SMA connectors on the top of the Evaluation board. The "Analog Tune" connector accepts a DC voltage (see **Section 3.2 "Analog Tuning"**) for steering the RF (and PPS outputs). This pin maps to pin 1 on the inserted MAC device.

Two 1PPS input connections are available ("PPS_in_0" and "PPS_in_1") for disciplining the MAC's output frequency. The Evaluation board accepts a 3.3V @ 50Ω LVCMOS 1PPS signal. See **Section 3.4 "1PPS Disciplining"** for details.

D.2.3 Output Connections

Three SMA(f) connectors provide outputs from the MAC's 10 MHZ, 1PPS_out, and BITE/Lock pins. The 10 MHz and 1PPS are buffered according to the schematics in Appendix D and designed to drive 50Ω, while the BITE/Lock pin maps directly to the SMA. See **Section 1.2.3 "Output Connections"** for more details.

D.2.4 Power Connections

The Evaluation board is supplied with a wall-mount power supply capable of powering the ICs on the board (through "PS1") as well as a MAC inserted into the board. The toggle switch "SW1" controls the flow of power to the board.

Alternatively, one may use the wide voltage range connector "J10" if they wish to test a MAC under variable voltage conditions.

> **Note:** The J11 jumpers must be removed in this mode of operation. Also, the 5V wall-mount supply must still be employed in order to power the other ICs on the Evaluation board.

D.2.5 Functional Description and Operation

CAUTION
To avoid electrostatic discharge (ESD) damage, proper ESD handling procedures must be observed in unpacking, assembling, and testing the MAC.

The MAC and Evaluation board are delivered in ESD-safe packaging. They must be removed from the ESD-protective bag in an ESD-safe environment. Once installed on the test fixture, it is recommended that the entire assembly be treated as ESD-sensitive.

Retain the original MAC ESD-safe packaging material in the event that the device needs to be returned to Microchip for service.

The Evaluation board accepts a MAC-SA5X device using sockets that do not require the use of solder. Four screws are provided to ensure the device remains properly seated on the board. Care should be afforded and the number of insertions should be minimized in order to maximize the lifetime of the sockets and the J9 connector. The Evaluation board is not designed for repeated production-type testing.

Once a MAC is inserted and the wall-mount power supply is connected, the toggle switch may be flipped to supply power to the MAC. The user should expect the "Power Status" LED to illuminate and the communication ports will become active. RF and 1PPS outputs are immediately available after supplying power.

A terminal emulation program may be used to configure and observe the MAC telemetry by connecting a PC to J1 or J8 of the Evaluation board (see **Section 3.1 "Configure the Serial Port"**). Once power is supplied to the MAC, it will

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behave as outlined in **Section 2.3 “Start-Up Sequence”**. After several minutes, the user should expect the “Lock Status” LED to illuminate, indicating that Atomic Lock has been achieved, and the short-term stability performance of the MAC will behave per the product specifications. Also, the BITE/Lock pin (J3) will flip to a logic zero once Lock is achieved.

Settings such as turning on/off Analog Tuning, Digital Tuning, and 1PPS disciplining can all be adjusted with terminal emulation software. See **Chapter 4. “Command Line Interface”** for appropriate syntax.

See the sections above regarding appropriate expected input/output signal levels from the Evaluation board. The levels in Appendix D take precedence over other sections of this User Guide that pertain to the MAC-SA5X only.

D.2.5.1 TROUBLESHOOTING

If an error should occur, the “Alarm Status” LED will illuminate. This pin is driven low when a new alarm condition occurs and it remains low until the condition is resolved or the user acknowledges it with the `ackalm` command. If an alarm cannot be cleared, contact the factory for guidance.

If communication cannot be achieved, ensure the MAC is properly seated and that the communication port settings are appropriate.

If the LEDs do not illuminate, check the power cable connector and toggle switch for damage.

If atomic Lock cannot be achieved, check that the environmental conditions are within product specifications and that the MAC is properly seated on the board.

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Appendix E. Software License Agreements

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