SA.3Xm QUANTUM™ Miniature Atomic Clock

097-44300-00 User Guide

Microsemi®

Power Matters.™

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1 Preface

1.1 About this document

The SA.3Xm User's Guide provides basic recommendations for designing products to use Microsemi's SA.3Xm Miniature Atomic Clock (MAC). The guidelines in the document are generic because specific product requirements vary from one application to the other.

This material consists of a brief description of SA.3Xm design supported by block diagrams, description of environmental issues, installation guidelines, and unit operation.

1.2 Intended Audience

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

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

1.3 Warnings, Cautions, Recommendations, and Notes

Warning: To avoid serious personal injury or death, do not disregard warnings. Warnings are installation, operation, or maintenance procedures, practices, or statements, that if not strictly observed, may result in serious personal injury or even death.

Caution: To avoid personal injury, do not disregard cautions. Cautions are installation, operation, or maintenance procedures, practices, conditions, or statements, that if not strictly observed, may result in damage to, or destruction of, the equipment. Cautions are also used to indicate a long-term health hazard.

ESD Caution: To avoid personal injury and electrostatic discharge (ESD) damage to equipment, do not disregard ESD cautions. ESD cautions are installation, operation, or maintenance procedures, practices, conditions, or statements that if not strictly observed, may result in possible personal injury, electrostatic discharge damage to, or destruction of, static-sensitive components of the equipment.

Notes:

- Notes contain installation, operation, or maintenance procedures, practices, conditions, or statements that alert you to important information, which may make your task easier or increase your understanding.
- Microsemi offers training courses designed to enhance your knowledge of the SA.3Xm Rubidium Frequency Standard. Contact your local representative or sales office for a complete list of courses and outlines.

1.4 References

For additional information about the products described in this guide, contact your Microsemi representative or your local sales office. You can also contact us on the web at *www.microsemi.com*.

- *MAC Developer's Kit (090-44300-00)*
- *MACdemo software (084-01513-000)*

2   SA.3Xm Miniature Atomic Clock

2.1   SA.3Xm Overview

The SA.3Xm Miniature Atomic Clock (MAC) is Microsemi's sixth generation gas cell atomic oscillator technology product. It reflects significant advances in physics miniaturization and atomic interrogation algorithms which serve to reduce size and power while providing stable reference frequencies, which are resistant to environmental perturbation. The SA.3Xm comes in several performance levels for application to specific system requirements. The SA.3Xm offers a low height (18.3 mm / 0.72"), a small footprint (50.8 mm × 50.8 mm or 2 in × 2 in), and an industrial operating temperature range of -10°C to +75°C (baseplate temperature).

Figure 1 •   **SA.3Xm Rubidium Frequency Standard**

The SA.3Xm is refined for cost effective mass production and can be easily integrated into time, frequency, and synchronization systems. The SA.3Xm 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") 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 SA.3Xm. It also provides supporting information for use of the Developer's Kit (p/n 090-44300-00). Furthermore, the design details of the developer's 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 SA.3Xm, which is available on the Microsemi web site at *www.microsemi.com*.

2.1.1   Precautions

ESD 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.

2.1.2   Packaging

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

2.1.3 Absolute Minimum and Maximum Ratings

Table 1 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. All ratings apply at 25°C, unless otherwise noted.

Table 1 • **Absolute Maximum Ratings**

Parameter	Rating
Supply voltage (Vcc)	0 - 5.1 V
Analog tuning voltage	0 - 5 V
Maximum current draw	RS232, BITE: +/- 2 mA RF output: +/- 20 mA
Storage temperature	-55°C to +100°C

2.1.4 Mechanical Interface and Mounting Considerations

The physical dimensions of the SA.3Xm MAC are 2.0" x 2.0" x 0.72" H. Figure 2 shows the detailed dimensions and pin-out of SA.3Xm. Pins 2 and 4 are not connected internally.

Figure 2 • **SA.3Xm Dimensions and Pinout**
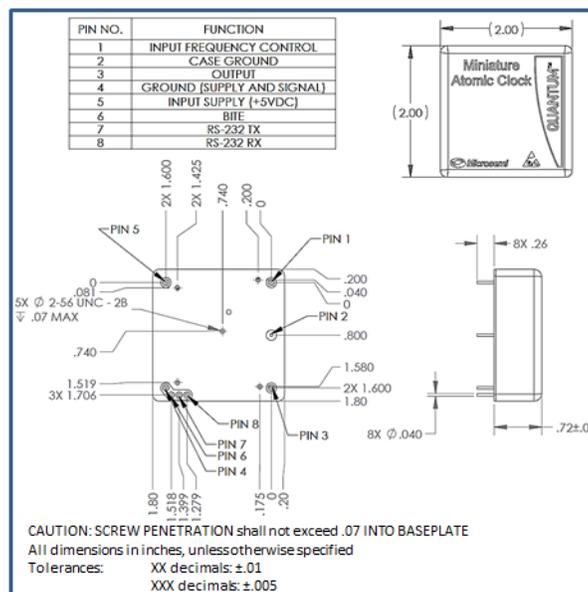
For initial testing and evaluation, it is recommended that the pins must not be modified or soldered to a PCB. The recommended socket for PCB attachment is Mill-Max 0332-0-43-80-18-27-10-0.

After evaluation, the pins can be hand soldered to a PCB using SAC305 solder Sn96.5/Ag3.0/Cu0.5.

2.1.5 Recommended Operating Characteristics

The SA.3Xm pin-out is shown in . The electrical function of each pin is shown in Table 2.

Table 2 • **Recommended Operating Characteristics**

Pin	Function	Range	Note
1	Analog tuning input	0 - 5.0 V	1, 2
2	Baseplate	–	3
3	RF output	3.8 Vpp, nominal	4
4	GND	–	5
5	Supply voltage (Vcc)	5.0 ± 0.1 VDC	–
6	Built-in Test Equipment (BITE)	Logic_H > 2.8 V Logic_L < 0.3 V	6
7/8	Serial Communication	2.8 V < Logic_H < 3.8 V 0 V < Logic_L < 0.3 V	7

Notes:

1. Analog tuning input sensitivity is, 0-5 V into 5 kΩ, 2.5 V 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, HCMOS square wave into 15 pF load. 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/RS232 (or HCMOS/RS232) adapter is necessary.

2.2 Functional Description

2.2.1 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 Rubidium Isotope 87. A complete description of passive atomic clocks, CPT, and the MAC architecture is beyond the scope of this user guide.

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.

Figure 3 shows a simplified block diagram of the MAC. The principal RF output from the MAC is provided by a Temperature-Compensated Crystal Oscillator (TCXO) and provided on the MAC output pin 3. In normal operation, the frequency of the TCXO is continuously compared and corrected to ground state hyperfine frequency of the Rubidium atoms, contained in the "physics package," to provide performance comparable to conventional Rubidium oscillators.

Figure 3 • **Simplified MAC Block Diagram**
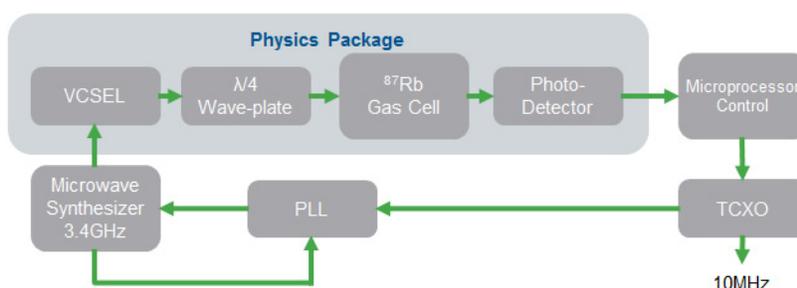
The Vertical Cavity Surface Emitting Laser (VCSEL) replaces the lamp of conventional Rubidium oscillators. The upside of the VCSEL is a reduction in size, weight, and power. The following describes a detailed description of the MAC:

1. Jinquan Deng, Peter Vlitas, Dwayne Taylor, Larry Perletz, and Robert Lutwak, "A COMMERCIAL CPT RUBIDIUM CLOCK" EFTF 2008 Toulouse, France.
2. R. Lutwak, et. al., "The MAC - A Miniature Atomic Clock", Proceedings of the 2005 Joint IEEE International Frequency Control Symposium and Precise Time & Time Interval Systems & Applications Meeting, August 29-31, 2005, Vancouver, BC.

2.2.2 Start-up Sequence

Caution: To avoid severe damage to the unit, do not apply power to the incorrect terminals. The SA.3Xm does not have reverse voltage protection.

When power is connected to Pin 5, the SA.3Xm unit begins its warm-up cycle. A typical warm-up sequence is shown in Figure 4 on page 11.

Note: A signal appears at the output immediately after power is applied to the unit. This output signal is not stable until the oscillator is locked (indicated by the BITE pin at CMOS_low).

Performance of the SA.3Xm unit varies according to the product version specified at the time of order. See the *SA.3Xm product Datasheet* for information on unit performance for the specific product version purchased.

Note: Sequence times and power levels vary according to environmental conditions, especially temperature. Figure 4 on page 11 shows the start-up sequence of MAC. It is representative of performance, but not a specification.

Figure 4 • **Start-up Sequence of MAC**
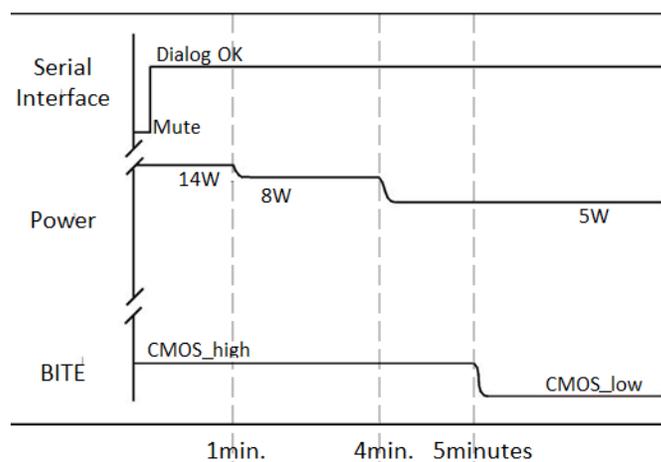
2.2.3 Built-In Test Equipment (BITE)

The SA.3Xm provides an active logic low indication that the internal quartz oscillator is locked to the rubidium atomic resonance through Pin 6, the BITE signal. As long as the BITE signal is low, once warm-up is completed, the user can be assured that the output frequency is locked to the rubidium atomic resonance. The lock status is also available through the RS232 commands "(c) Telemetry" on page 16.

If the BITE signal is high, atomic lock is not attained or is lost and the SA.3Xm enters Sweep Mode to reacquire lock. During the sweep, signal output amplitude is maintained but no reliance must be placed on signal accuracy or stability. Lock acquisition typically takes 5 minutes, but in Parameter Recovery mode, lock acquisition can take 2 hours.

Note: When not locked, BITE = 1 in the telemetry output string.

2.2.4 RF Output Characteristics

The 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 (BITE = 1), the output frequency is provided by the free-running TCXO, which has frequency accuracy specification of ±2 ppm over its operating range. The following shows the characteristics of RF output:

• 10 MHz 3.8 V CMOS square wave into a 15 pF Load
• Logic Level: VL < 0.5 V, VH > 2.7 V (15 pF load)
• Rise / Fail Time: <10 ns
• Duty Cycle: 50% ±10%

The RF Output is not designed to drive a 50 Ω load. However, a 50 Ω series resistor is installed on the output to minimize reflections if a relatively long line is used for this signal.

Note: If a high-level (high-power) output driver is required, a driver circuit must be implemented external to the MAC, such as the one implemented on the Evaluation Board (see "Reference Schematic For Evaluation Board" section on page 30).

2.2.5 Frequency Steering

The 10 MHz output frequency of the SA.3Xm may be changed by tuning the internal microwave synthesizer in two ways—a digital tuning command may be issued via RS-232 interface (preferred) or an analog DC tuning voltage may be applied to Pin 1 (if analog tuning is enabled). It is highly recommended that frequency control be implemented by only one of the two methods. Do not try to combine both approaches into one system.

The microwave synthesizer produces a 3.417 GHz signal used in locking the physics package to the atomic resonance of Rb. By adjusting the input to the microwave synthesizer, the 10 MHz output is steered. The equation governing the adjustment is:

Effective DDS Frequency = DDS Center Frequency + Digital Adjustment + Analog Tuning

EQ 1

where the different terms represent variables, which may be independently controlled by the user. This equation is recalculated based upon current values and applied to the frequency control servo at 100 ms intervals.

Note: "Effective DDS Frequency" is a frequency internal to the microwave synthesizer, and is not equal to 10 MHz. But adjusting its value will tune the 10 MHz output. See Figure 3 on page 10.

2.2.5.1 Frequency Calibration

The internal frequency calibration of the MAC is set prior to shipment. Its DDS center frequency is stored in NVRAM and is retrieved for active use at startup. It is sometimes desirable to update the calibration to remove cumulative frequency aging offsets.

Calibration of the MAC is accomplished in the following manner. First, the MAC output is compared to a superior Frequency Reference. Next, the MAC is steered onto frequency, through an external RS232 command (see "Digital Adjustment" section on page 13). Finally, the present value of Digital Adjustment is summed into the non-volatile calibration register via the RS232 <FA> command. This command will also reset Digital Adjustment to zero. The new DDS Center Frequency may be saved through the <FS> command.

Note: The <FS> command is only valid when the MAC is locked (BITE = 0).

Caution: It may be tempting to frequently overwrite the calibration in the event of unforeseen power outage. This is HIGHLY DISCOURAGED because the lifetime of the MAC's NVRAM is finite; updating it >10,000 times will DAMAGE it and render the MAC INOPERABLE. For example, a write once per 12 hours will allow an NVRAM lifetime of 10 years.

To demonstrate the functionality of the MAC, screenshots from Microsemi's PC-based graphical interface, "MACdemo" are shown in Figure 5 and Figure 6 on page 14. See "MACdemo Software Installation" on page 26 for more details.

Figure 5 • **Frequency Calibration with MACdemo**
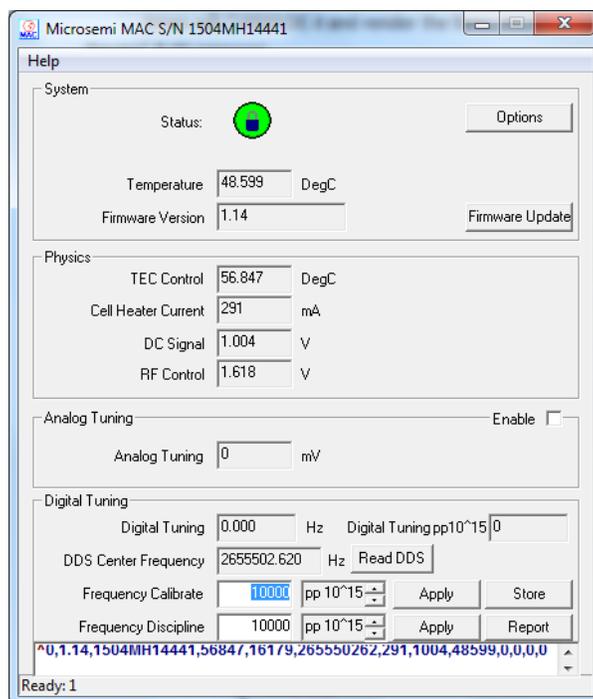
To adjust the Frequency Calibration, Enter the desired adjustment in the **Frequency Calibrate** text field and then click **Apply**; Notice that **Digital Tuning** will reset to zero. To use the new calibration across power-cycles, click **Store** to permanently save to NVRAM.

2.2.5.2 Digital Adjustment

Digital Adjustment is the preferred method for steering the MAC. The MAC internal microwave synthesizer may be adjusted by the user via the RS232 `<F_>` series of command's (see Frequency Steering in the "Programmers Reference" section on page 15). 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^{12}. Steering commands may be entered as either absolute steers (`<FD>` or `<FG>`) or as relative steers (`<FE>` or `<FH>`). In the case of an absolute steer, the contents of the steer register are replaced with the new value. In the case of a relative steer, the new value is summed with the existing value in the steer register. In either case, the maximum steer that can be entered in a single `<F_>` command is ±2 parts in 10^8 (±20000000 pp 10^{15}). If a larger correction is sent to the MAC, the maximum allowed steer is applied. There is no limit to the cumulative amount of steering that a user wishes to apply.

Figure 6 • **Frequency Disciplining with MACdemo**
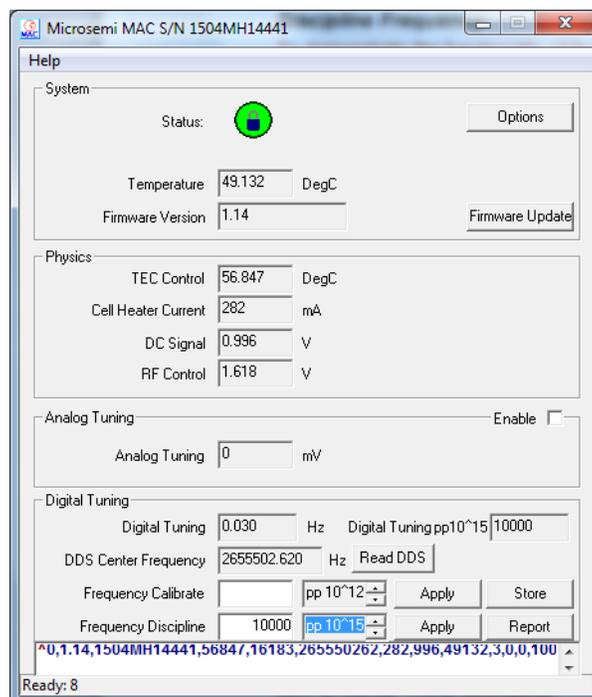
Using MACdemo, as in Figure 6, frequency can be adjusted in pp 10^{12} or pp 10^{15} through the **Frequency Discipline** box. The adjustment is displayed after the next poll in the **Digital Tuning** dialog boxes. The result can be observed on a frequency counter, for example, to determine if the steer tracked the RF output closer to 10 MHz or not.

Note: Steering commands may be entered during acquisition (BITE = 1) but will not take effect until lock is achieved.

Frequency steering is volatile. Upon reboot, the MAC returns to its nominal (calibrated) frequency setting. To update the non-volatile calibration, use the <FA> and <FS> commands (See "Frequency Calibration" section on page 12).

The current steering value appears in the telemetry string as "Steer".

Note: Steer reports the actual hardware steering, in units of pp 10^{12}, even though the software registers maintain resolution of pp 10^{15}, so that many small relative corrections are applied. As a result, the reported value may appear to disagree with the applied correction by one unit or so due to roundoff error.

2.2.5.3 Analog Adjustment

The analog frequency control is derived from the analog voltage applied to Pin 1. This voltage is digitized, scaled, and applied to the SA.3Xm frequency servo as indicated in EQ 1. Analog tuning voltages above mid-point increase the output frequency, and conversely tuning voltages below midpoint decrease the output frequency. If the analog frequency tuning is disabled, the analog frequency control value is zero.

Specifications for the analog tuning range (frequency range and applicable voltage) are provided on the *SA.3Xm Datasheet*; setting the mid-point of the analog tuning, for example 2.5 V, provides zero analog frequency control value.

2.3 Programmers Reference

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

- **Single keystroke**: A carriage return is not required.
- **Multi keystroke**: requires a specific start (<) and end (>) character. Used for commands that require arguments. A carriage return is not required.

See "Design Guide" section on page 19 for information on RS232 Hardware interface.

Microsemi provides two software packages to communicate with the MAC: MACdemo and Clockworks. However, any serial port terminal emulator program can be used.

2.3.1 Overview of Telemetry Interface

The MAC communicates exclusively with printable (non-binary) 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 shall abbreviate "carriage return/line feed" with "[CRLF]".

2.3.2 Command Summary

Table 3 summarizes the MAC commands.

Table 3 • **Command Summary**

Cmd	Description	Reference Section
A	Analog Tuning Enable	2.3.3.1
a	Analog Tuning Disable	2.3.3.1
c	Display Current Values	2.3.3.2
6	Return telemetry headers as comma-delimited string	2.3.3.3
^	Return telemetry as comma-delimited string	2.3.3.3
<NX0>	Disables analog tuning and persists the setting past power-off	2.3.4.1
<NX1>	Enables analog tuning and persists the setting past power-off	2.3.4.1
<FA>	Apply the Digital Adjustment value to the Center Frequency and zero out the Digital Adjustment value	2.3.4.2
<FS>	Save current DDS Center Frequency to Non-volatile memory (NVRAM)	2.3.4.3
<FCnnn>	Add nnn to the current DDS Center Frequency. (nnn is in pp 10^{12})	2.3.4.4
<FFnnn>	Add nnn to the current DDS Center Frequency. (nnn is in pp 10^{15})	2.3.4.4
<FDnnn>	Replace the Digital Adjust value with nnn. (nnn is in pp 10^{12})	2.3.4.5
<FGnnn>	Replace the Digital Adjust value with nnn. nnn is in pp 10^{15}	2.3.4.5
<FEnnn>	Add nnn to the Digital Adjust value. nnn is in pp 10^{12}	2.3.4.6
<FHnnn>	Add nnn to the Digital Adjust value. nnn is in pp 10^{15}	2.3.4.6

2.3.3 Detailed (Single Keystroke) Command Descriptions

2.3.3.1 (A and a) Analog Tuning

`A` enables analog tuning but does not persist the setting past power-off. This command also returns a confirmation string. See the (<NX0> and <NX1>) Analog Tuning command for a persistent version.

Similarly, `a` and `<NX0>` will disable analog tuning.

2.3.3.2 (c) Telemetry

Returns current operational values in a list formatted as follows:

`...CURRENT VALUES...`	**Note:**
`BITE = 0|1`	(Built-In Test Equip., 0 => MAC locked)
`Firmware Version n.nn`	
`SerialNumber = MMYYZZnnnnn`	(MMYY => month/year of manufacture, ZZ => model code, nnnnn => sequential number)
`TEC Control (mDegC) = nnnnn`	
`RF Control (0.1mv) = nnnnn`	
`DDS Frequency Center Current (0.01Hz) = nnnnn`	
`CellHeaterCurrent (ma) = nnn`	
`DCSignal (mv) = nnnnn`	
`Temperature (mDegC) = nnnnn`	
`Digital Tuning (0.01Hz) = nnnnn`	
`Digital Tuning (pp15) = nnnnn`	
`Analog Tuning On/Off = 0|1`	(0 => Off, 1 => On)
`Analog Tuning (mv) = nnnnn`	(This is only applied if the above is 1)

Note: Firmware versions 1.13, 1.14, and 1.15 are known to incorrectly display the number of digits for the "CellHeaterCurrent (ma)" value. Number of digits must equal three or less. The correct value can be obtained through the `6` and `^` commands.

2.3.3.3 (6 and ^) Telemetry

MAC supports two commands, `6` and `^` to retrieve the telemetry headers and values, respectively. Both responses are comma-delimited strings, suitable for importing into spreadsheet programs.

Example: Telemetry headers command: `6`

Unit Response: Comma-delimited string of identifiers ending in carriage return/linefeed.

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)" [CRLF]
```

Example: Telemetry data command: `^`

Unit Response: Comma-delimited string of telemetry data ending in carriage return/linefeed.

Example Response:

```
"0,1.14,1504MH14441,56847,16185,265550258,289,996,49156,0,0,0,0" [CRLF]
```

Note: Maximum output string length = 128 characters

2.3.4 Detailed (Multi- Keystroke) Command Descriptions

All multiple keystroke commands return confirmation strings describing what action they have taken.

2.3.4.1 (<NX0> and <NX1>) Analog Tuning

The command `<NX0>` disables analog tuning and persists the setting past power-off. See the "(A and a) Analog Tuning" on page 16 command for a non-persistent version. Similarly, `A` and `<NX1>` will enable Analog Tuning.

2.3.4.2 (<FA>) Apply Digital Adjustment to Center Frequency

The purpose of this command is to add the digital adjustment value into the current center frequency value so that the accumulated changes can be saved. The center frequency can then be subsequently saved using the `<FS>` command, if the changes are to be made permanent. Upon execution of `<FA>`, the digital adjustment will be re-set to zero.

2.3.4.3 (<FS>) Save Center Frequency to NV RAM

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.

2.3.4.4 (<FCnnn> and <FFnnn>) Add nnn to the current DDS Center Frequency

`<FCnnn>` 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: Augment DDS command: `<FC-10>`

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

Example Response:

`"   ...Persistent Frequency Adjustment = -10"`

`<FFnnn>` 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.

2.3.4.5 (<FDnnn> and <FGnnn>) Replace the Digital Adjustment with nnn

`<FDnnn>` 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: Replace digital adjustment command: `<FD1000>`

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

Example Response:

`"   ...One Time Frequency Adjustment = 1000"`

`<FGnnn>` 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.

2.3.4.6 (<FEnnn> and <FHnnn>) Add nnn to the Digital Adjustment

These commands 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: Augment digital adjustment command: <FE-500>

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

Example Response:

`"   ...One Time Frequency Adjustment = -500"`

`<FHnnn>` 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?>`.

2.4 Design Guide

2.4.1 The Art of Disciplining

Often, users of MAC wish to design hardware to accept an external reference and steer the MAC to synchronize with said reference. With the assistance of an external phase meter, disciplining can be utilized to calibrate the MAC frequency in the field, even if a reference source is only occasionally or sporadically available, thereby improving the long-term performance (phase and frequency drift) of the MAC. At the same time, the disciplined MAC may be used to "clean-up" the short-term stability of an accurate but noisy reference source, such as GPS.

Implemented incorrectly, however, disciplining may degrade the performance of the MAC.

A successful disciplining strategy involves understanding the noise properties of the MAC, the reference source, and the phase meter, to select the appropriate time constant that makes the best use of the available timing information.

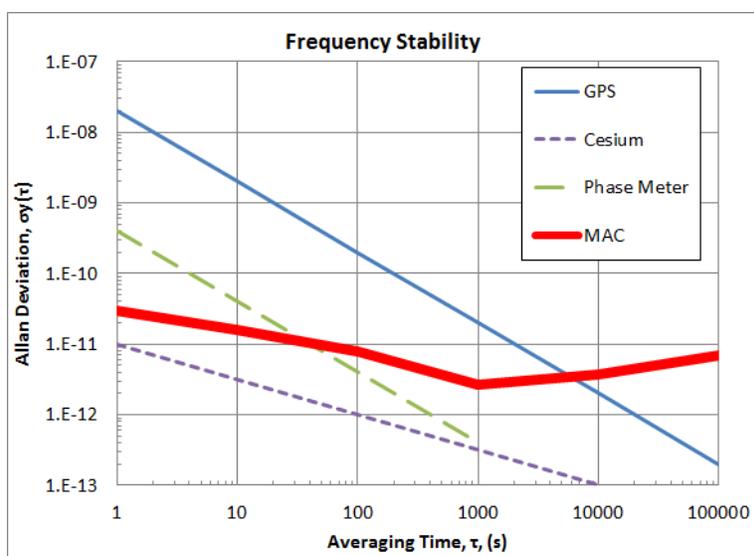*Figure 7 •* **Frequency Stability versus Averaging Time**

Figure 7 shows typical instability (Allan Deviation) of the MAC (in red), along with the noise floor of the Phase Meter (in green). Also shown are the instabilities of typical reference sources, GPS (in blue) and a high-performance Cesium Beam frequency standard (in purple). When disciplining, the stability of the output of the MAC at any averaging time reflects the noise properties of the dominant (most noisy) source.

For example, if disciplining the MAC to a GPS source, which is noisier than the MAC for averaging times < 5000 seconds, the disciplining time constant must be set to τ > 5000 seconds. In this way, one can leverage the benefits of the superior short-term stability of the MAC with the excellent long-term stability of the GPS reference.

On the other hand, consider the case where the MAC is disciplined to a high-performance Cesium Clock, which is more stable than the MAC on all time scales. The noise is dominated by the Phase Meter for τ < 30 seconds and by the MAC for τ > 30 seconds. In this case, the disciplining time constant could be set to τ = 30 seconds for optimal performance.

2.4.2 Thermal Considerations

To allow the highest ambient operating temperature for the SA.3Xm, it is recommended that the bottom (baseplate) of the SA.3Xm have good thermal contact with the mounting surface. To ensure good thermal contact, Microsemi recommends that the SA.3Xm is secured using (5) 2-56 screws. The location of the five screw holes is shown in Figure 8.

Caution: To avoid damage to the SA.3Xm, the mounting screws must not penetrate the unit by more than 0.07 in (1.8 mm).

It is also important to maintain a uniform temperature into the baseplate of the SA.3Xm through its mounting points. The SA.3Xm unit will operate normally without the use of thermal pad, but for some applications, a conductive thermal pad or tape may simplify customer system thermal design requirements.

Warning: To avoid the possibility of a burn, you must mount the SA.3Xm to a heat-dissipating surface. The SA.3Xm operates at a temperature that is hot to the touch and may cause handling distress.

As the baseplate temperature continues to increase, the unit eventually loses lock. Above a baseplate temperature of +75°C, the physics package heater shuts down as control point temperatures are exceeded and the unit temperature coefficients increase.

A thermal pad or thermal grease is recommended to provide the best thermal conductivity between a heat sink and the MAC's outer case. Figure 8 shows the mechanical drawing for the thermal pad used on the Evaluation board.

Figure 8 • **Thermal Pad**
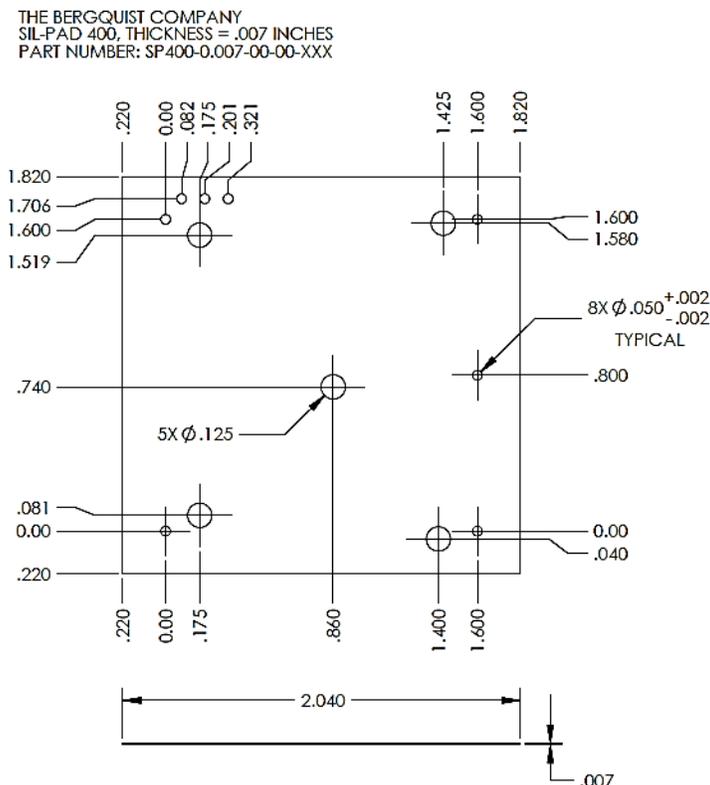
Note: The heat sink provided with the Evaluation board is designed to specifically address continuous high temperature/ zero airflow conditions. Generally, a much smaller heat sink or intermittent small fan is preferable if the designer anticipates MAC operation over a wide range of temperatures.

2.4.3 Electrical Interface

2.4.3.1 Input Power

The input power for the SA.3Xm is 5 +/- 0.1 V. Detailed specifications for operating ranges are provided in the *SA.3Xm Product Datasheet*.

2.4.3.2 RS232 and Communications Basics

The RS232 RX and TX signals are used to communicate with the SA.3Xm for the purpose of controlling and monitoring. The characteristics of both RX and TX are:

- 3.3 V ACMOS
- 3.3 V = idle state
- 0 V = active state

The data rate and word structures are:

- 57,600 Baud
- 8 bits character
- parity none
- 1-bit Stop

2.4.4 EMI and Noise Considerations

When a user has an application where the phase noise and spur integrity are crucial, the SA.3Xm 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 SA.3Xm 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 SA.3Xm, this filtering cannot have any resonance points greater than the specified impedance of less than 0.1 Ω 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 SA.3Xm during turn-on must continue to be met during operation of the unit. For example, using a 0.3 Ω DC source resistance for the input +5 V DC supply line would not be appropriate since the voltage drop resulting from this resistance (caused by the turn-on current or quiescent operating current) would cause the input voltage to drop below the allowable value.

2.4.5 RF Noise

If the design requires use of RF or microwave frequencies, care must be made to dampen those frequencies at locations that might be adversely effected. 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.

Figure 9 shows the example layout of PCB with nulling capacitors placed near MAC I/O pins. The nulling capacitors (C7 - C12) are placed as close to the MAC I/O pins as possible.

Figure 9 • **Example layout of PCB with nulling capacitors placed near MAC I/O pins**
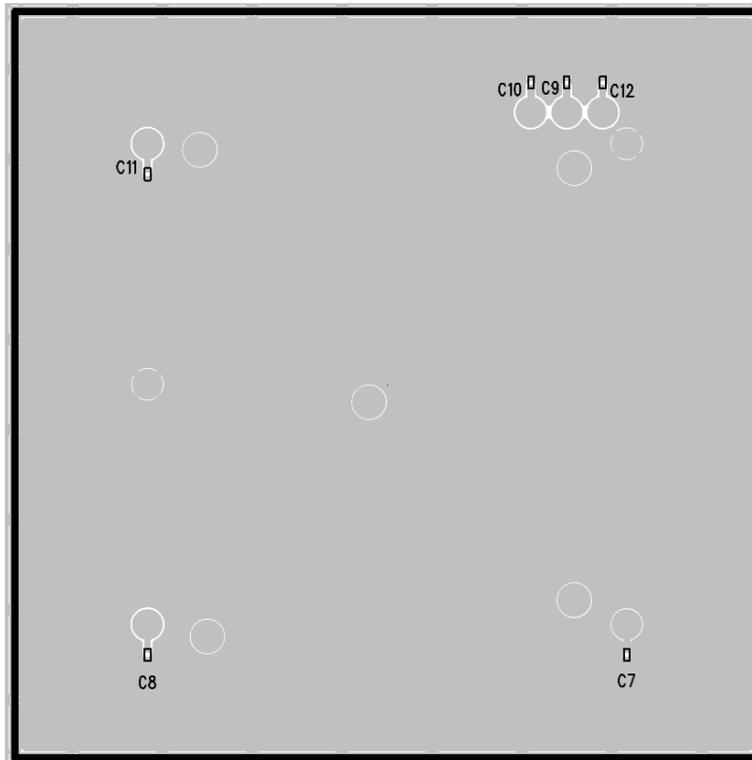
Note: Capacitors in Figure 9 are 6.8 pF, 50 V (Murata p/n GJM1555C1H6R8CB01D, AVX p/n 04025A6R8CAT2A).

2.4.6 SA.3Xm Reliability

The SA.3Xm is designed for more than ten years of operation without factory adjustment. To accomplish this, the major mechanisms impacting the need for maintenance have been addressed including adequate rubidium supply, sufficient adjustment range for the internal quartz oscillator, and sufficient dynamic range of the rubidium resonance control loop.

2.4.7 User Maintenance and Adjustments

The SA.3Xm is considered to be factory serviceable only. Aside from frequency steering, there are no user service adjustments or maintenance required.

If the unit fails to operate properly, or has reached the end of its' effective life, contact Microsemi Global Services for the return/disposal procedure.

2.4.8 Troubleshooting

If, after installation, the SA.3Xm fails to provide signal or communication outputs, or if the unit fails to achieve lock, verify the following:

• Is the external power supply providing power at the correct voltage at the input power pin?
• Is the external power supply current at expected levels for the operational mode (For example warm-up)?
• Is there excess humidity or moisture inside the operating area?
• Is the case temperature below -10°C or above +75°C? The unit will not start properly for temperatures outside this range.

2.4.9 Firmware and Software Notes

It is possible for firmware versions 1.03 and later to be upgraded. Contact technical support for guidance.

Digital steering commands do not affect the lifetime of the product. However, writing to Non-Volatile Memory (>10,000 times) will affect the lifetime.

Note: Generally, FE/FH are preferable to FC/FF commands because they affect the digital tuning component instead of the center component. The cumulative frequency adjustment can be seen in the response of the ^ telemetry command, in the Digital Tuning column.

2.4.10 Notes on Evaluation Board

2.4.10.1 Socket Lifetime

Socket lifetime is less than 20 insertions, so care must be taken while placing and removing the SA.3Xm.

2.4.10.2 Heat Sink

The heat sink used on the Evaluation board is larger than necessary for adequate heat sinking, and is not recommended as an example for user designs requiring lighter and smaller placements. The mechanical dimensions (inches) are provided below for reference.

Figure 10 • **Heat Sink on base of Evaluation Board**
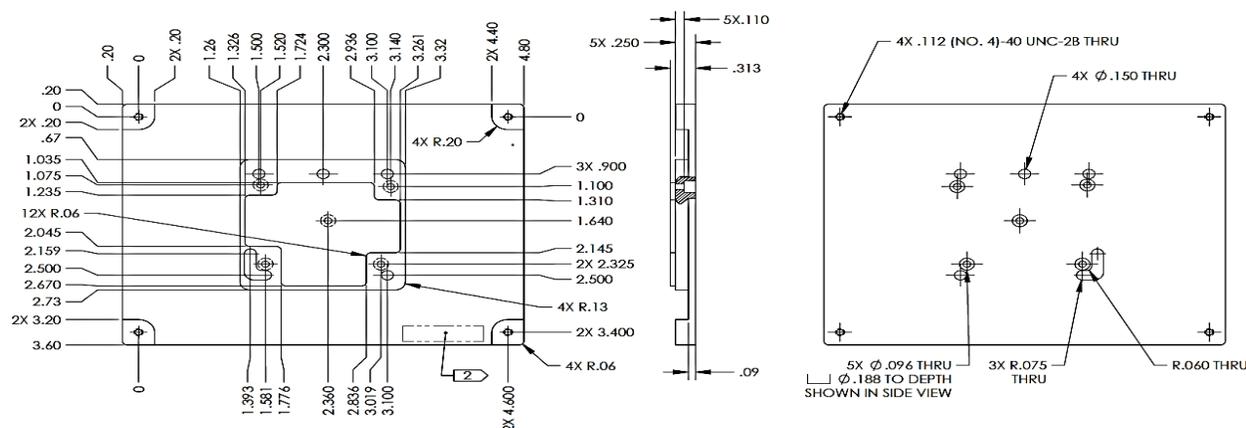
2.4.10.3 Vibration

The Evaluation Board is not qualified for mechanical shock and vibration testing. See *SA.31m, SA.33m and SA.35m datasheet* for SA.3Xm specification.

2.4.11 Mechanical Considerations

2.4.11.1 Drawings

The MAC housing, shown in does represent a fully assembled MAC. In reality, a small amount of silver epoxy is used to affix the MAC cover to the baseplate. Thus length, width, and height of the MAC are slightly larger than indicated.

2.4.11.2 Screw tolerance for the baseplate

For a #2-56unc-2b thread, the recommended torque for a stainless screw is 3.5 - 5.0 inch-lbs. Screw penetration shall not exceed 0.07 inches in to the baseplate.

3   Developers Kit

3.1   Package Contents

Table 4 lists the contents of MAC Developer's Kit (Part # 090-44300-00). Contact Microsemi if any of these items are missing.

*Table 4 •* **Contents of MAC Developer's Kit**

Item	Microsemi Part Number
Interface Printed Circuit Board Assembly	16455-501
Base/Heat Sink	16464-001
Power Cord Assembly, 100-240VAC/15VDC/2A	45-01775
Mounting Hardware	04000-701-04008 (Qty: 4) pan head, 4-40; UNC-2A X 0.25-inch long screws 04001-701-04008 (Qty: 4) #4, small pattern; 0.25-inch OD flat washers 04000-701-02008 (Qty: 5) pan head, 2-56; UNC-2A X 0.25-inch long screws
SA.3Xm of chosen performance level (if purchased with kit)	090-443XX-2X
Thermal Pad	16399-001

Caution: Screw penetration into the SA.3Xm housing shall not exceed 0.07 in.

3.2 Evaluation Board Overview

Detailed schematics of the evaluation board are provided at the end of this section under "Reference Schematic For Evaluation Board" section on page 30. Figure 11 shows the connections to the evaluation board.

Figure 11 • **Evaluation Board**
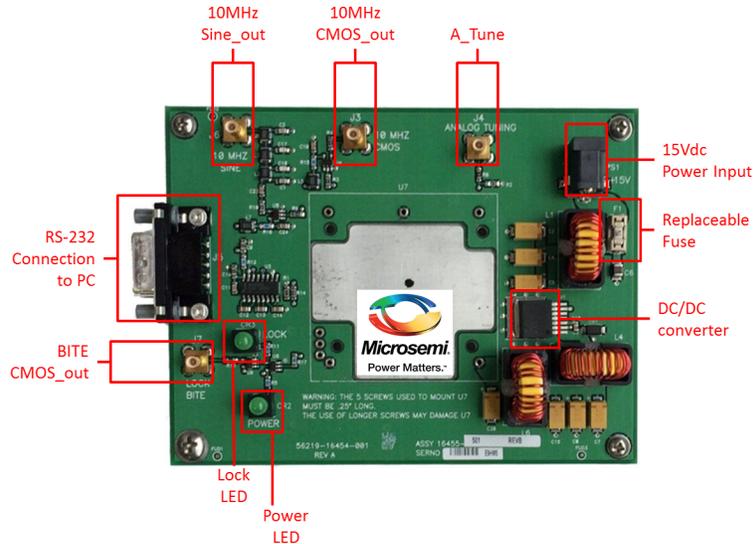
3.2.1 PCB and Power Supply

The Developer's Kit PCB and power supply consists of:

- **Socket (U7)** - To plug in SA.3Xm
- **10 MHz CMOS output (J3)** (SMB) - The MAC buffered output is an RF, CMOS 0-3.3 V DC waveform.
- **10 MHz SINE output (J6)** (SMB) - A high-speed buffer (U1) on the evaluation board converts the CMOS output to an AC-coupled output capable of delivering 10 dBm to a 50 Ω load.
- **15 V DC Input** – Input power to the evaluation board is provided on a 5 mm (center positive) coaxial connector (PS1). To avoid damage to the test fixture, it is recommended to use only the power adapter provided by Microsemi with the Developer's Kit. A DC/DC Converter (U1) is used to step down the 15 V to the 5 V required by the SA.3Xm
- **RS232 connector (J5)** - The evaluation board provides a level shifter (U3), which converts the MAC 0-5 V DC serial interface to the RS232 standard +/- 12 V for direct interface with a PC COM port. Connect the test fixture (J1) to a PC with a standard (non-Null) DB9F-DB9F RS232 cable. To avoid complication, use the proper cable which is provided by Microsemi with the Developer's Kit.
- **Lock Indicator LED** (SMB) - Indicates normal operation following initial acquisition of the clock signal.

Note: This is the logical complement of the BITE output (MAC PIN 6).

- **Power LED** - Indicates the state of the power on the board.
- **BITE Output (J7)** (SMB) - This is a buffered output from PIN 6 of the MAC.
- **Analog Tuning Input (J4)** (SMB) - This input is directly connected to Pin 1 of the MAC.

Note: This input is capacitively coupled to the level-shifting circuit on the evaluation board (see "Reference Schematic For Evaluation Board" section on page 30) and therefore the applied pulse width must be < 10 ms in duration.

- **DC/DC Converter (U1)** - To step down the 15 V to the 5 V required by the SA.3Xm
- **Replaceable Fuse** - Littel fuse Part No. 015401.5DRT
- **15 V power supply** - AC to DC (external, not pictured)

3.2.2 Base/Heat Sink

The Developer's Kit base/heat sink serves two purposes:

1. It provides a base with standoffs that allow easy use of the Developer's Kit PCB.
2. It serves as a heat sink for the SA.3Xm.

Drawings of the Base/Heat sink and Thermal Pad are provided in the "Thermal Considerations" section on page 20.
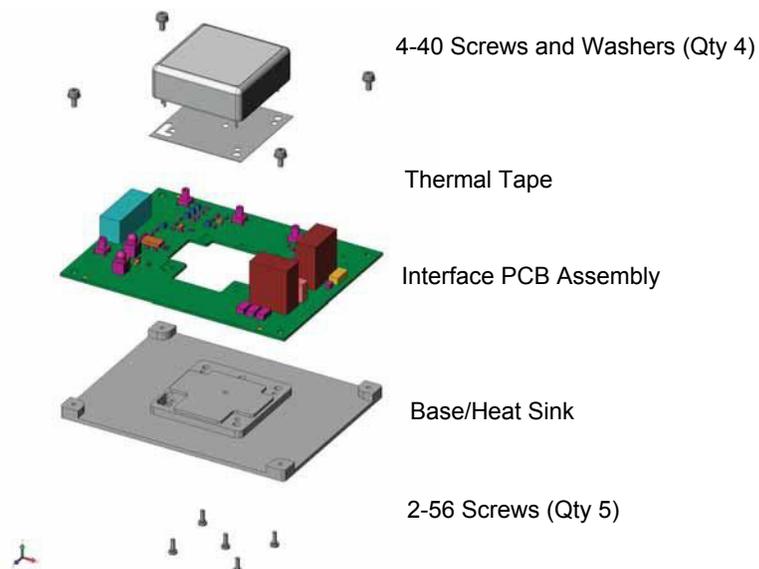
3.3 Installing the MAC on the Test Fixture

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

Remove the MAC and evaluation board from their ESD protective bags only in an ESD-safe environment.

Note: The SA.3Xm pinout is "keyed" (see Table 2 on page 9) so the MAC can only be inserted in the proper orientation. Gently insert the MAC into the socket on the evaluation board as shown in Figure 12

Figure 12 • **Installation of MAC Developer's Kit**

4-40 Screws and Washers (Qty 4)

Thermal Tape

Interface PCB Assembly

Base/Heat Sink

2-56 Screws (Qty 5)

3.4 MACdemo Software Installation

The Microsemi MACdemo software (Part # 084-01513-000) provides a convenient graphical user interface for monitoring and controlling the SA.3Xm MAC. MACdemo also is used for collecting and archiving monitor data from the MAC. It will install and run on any PC running Microsoft Windows XP/7/10 and having at least one available RS232 (COM) port.

Note: Multiple MACs can be monitored from a single PC, provided additional COM ports are available.

To install the MACdemo software, download from
http://www.microsemi.com/products/timing-synchronization-systems/embedded-timing-solutions/components/sa-31m-sa-33m-amp-sa-35m#downloads

If installation does not start automatically, browse to the download drive in Windows Explorer and double-click **setup.exe** in the root directory.

Upon accepting all of the default installation options (recommended), the MACdemo software is installed in c:\Program Files\Microsemi\MAC, a startup icon is added to the **Start > All > Programs > Microsemi > MAC menu**, and a MACdemo icon is placed on the desktop.

3.5 Cabling

Connect the provided RS-232 cable between the evaluation board and the COM port on the PC. On laptops without an available COM port, a USB-to-RS232 adapter, such as National Instruments USB-232, can be used.

3.6 Operation

3.6.1 Initial Power-On

Connect the RS232 to the Evaluation board as described in "Cabling" section. Connect the power assembly between the 15 V DC power input and a 120 V AC wall outlet.

MAC signal outputs are available from the evaluation board on connectors J3 (10 MHz CMOS output) and J6 (10 MHz SINE output). Connect either (or both) of these to your test equipment (frequency counter, spectrum analyzer, and so on.)

3.6.2 Establishing Communications

Double-click the **MACdemo** desktop icon on the connected PC.

When communications are successfully established, the MACdemo main window appears, as shown in Figure 13.

Figure 13 • **MACdemo communicating with MAC during warm-up**
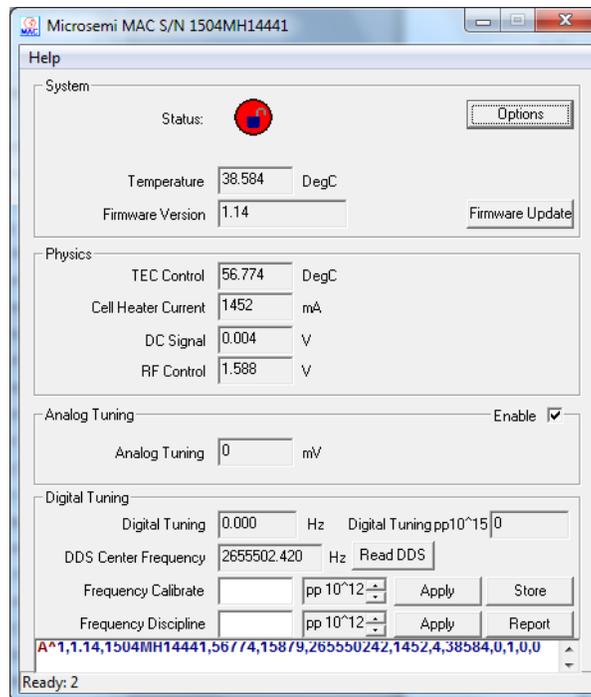
The title bar of the window indicates the unit serial number (here "1504MH14441"). The main body of the window shows most of telemetry values from the unit. Initially, upon power-up, the status indicator "🔴" reflects the MAC's unlocked condition (BITE=1). The "Ready" field of the bottom status bar indicates the number of seconds until the next poll (here "2").

In the event of communication failure, the status indicator appears as "🟡". In this case, check the cabling, power supply, and so on. If using a PC serial port other than "COM1," select the **Options** and select a different COM Port as shown in Figure 14. Select the correct COM port from the pull-down menu and click **OK** to re-attempt communications.

Figure 14 • **MACdemo Options... Panel**

3.6.3 Observing Acquisition

Initially, when the MAC is powered up, the lock LED on the Evaluation board will momentarily turn on then off once again. Acquisition takes < 7.5 minutes in a 25°C ambient (to achieve accuracy <1×10^{-9}). When acquisition is complete, the Lock LED on the evaluation board will illuminate, and the status indicator will change from "🔴" to "🟢".

Once locked, the main panel of MACdemo appears as shown in Figure 15.

Figure 15 • **MACdemo in locked condition**
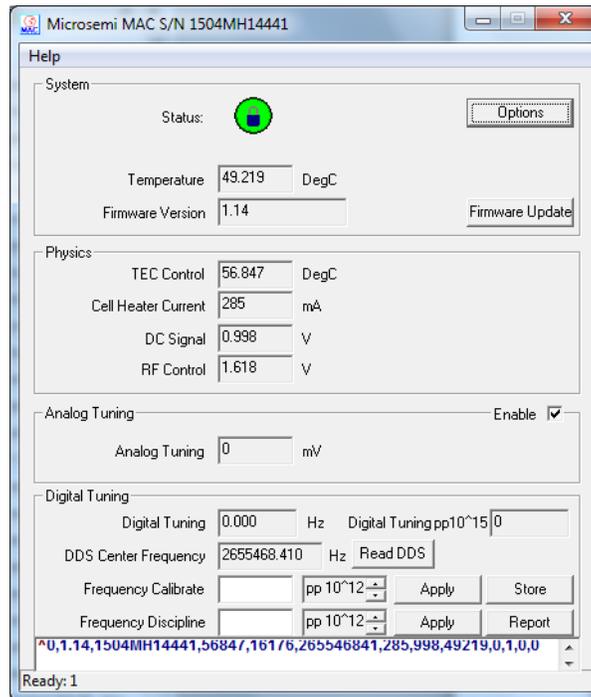
Figure 15 shows typical values for a normally operating MAC. In this case, the internal case temperature of the MAC is 49.219°C, and the Firmware version is 1.14. The physics package parameters in Figure 15 are fairly typical as well: TEC is ~57°C, Cell Heater Current is 285 mA, DC Signal is ~1 V, and RF Control is ~1.6 V. Analog Tuning is enabled with 0 mV present on Pin 1.

3.7 Data Acquisition with MACdemo

For long-term monitoring of the MAC, select **Options** to open the "Options…" Panel.

Choose a polling rate in seconds. For short-term (1 - 2 day) measurements, a polling rate of 10 seconds is optimal, and will accumulate data onto disk at a rate of about 1 MB/day. For longer term measurements (30 - 100 days), a longer polling rate, such as 60 seconds, reduces the growth of the data file to 150 KB/day.

Enable "**Save to Disk**" with the checkbox in the top right of the panel.

Click "**Browse…**" to select an existing directory in which to archive the MAC data.

Note: The user must have write permission to the selected directory.

Type file name for the data. Click **OK** to implement the new options or click **Cancel** to discard changes and exit the panel.

The data is stored in ASCII comma-separated-values (CSV) format, which allows for convenient import into most popular spreadsheet and analysis software. The first line in the file contains the column headers (see (6 and ^) Telemetry command). Subsequent lines contain the corresponding periodically-polled data. The first column in the file contains time stamps derived from the host computer's clock in mean-Julian day (MJD) format, referenced to universal coordinated time (UTC).

3.8   Reference Schematic For Evaluation Board

Figure 16 • **Evaluation Board schematic**
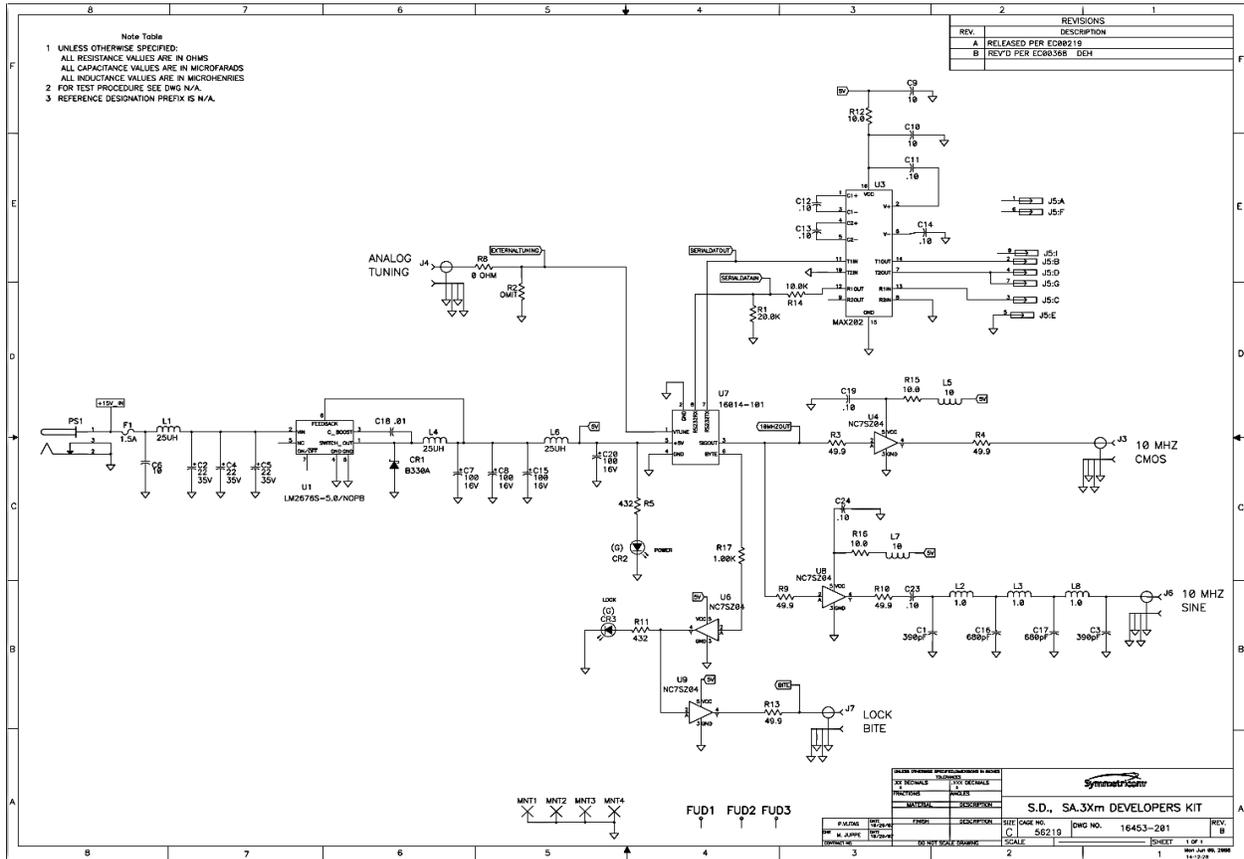
See "RF Noise" section on page 21 for comments on nulling filters.

4   Revision History

The following table shows important changes made in this document for each revision.

Revision	Changes
Revision D (April 2016)	Updated per EC11404. Updated mechanical drawings and Firmware command list. Added "Design Guide".
Revision C (August 2015)	updated per EC01977. Ported the document to the Microsemi template.
Revision B (November 2008)	Updated per EC01343. Updates to List of Command and minor updates to the reference guide
Revision A (June 2008)	Updated per EC00655. Initial release.

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