Recommended Calibration Intervals

for the

AARTS System

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Accel-RF Corporation specializes in the design, development, manufacture, and sales of accelerated life-test/burn-in test systems for RF and Microwave semiconductor devices. This white paper describes technical information related to the AARTS Hardware. For more information contact:

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1 Description

This documents Accel-RF's recommended calibration schedule for the AARTS system. Calibration comprises two levels of architecture: 1) instruments used in the system (e.g. the DVM); and 2) subsystem calibration (often defining relative calibration to external instrumentation). The system calibration procedures are documented in the Software Manual, and the instrument calibration procedures are defined in their associated manuals. This white paper describes some of the issues related to system performance, specific calibration recommendations, and rationale for the recommendations.

All parametric measurements in the system are made using commercially available instruments, typically manufactured by Agilent. Each of those instruments could be calibrated per their own recommended calibration schedule. However, two important issues exist in the context of reliability testing and the AARTS system. First, the primary interest for life testing purposes is detecting relative changes over time. Although it is important to maintain reasonable absolute accuracy, those values are of secondary concern as dictated by the customer-specific device-testing paradigm.

Second, all voltage-related measurements (e.g. DUT voltage, current, and temperature) are calibrated to external instruments. For example, the operator would calibrate DUT temperature by employing a metrology-grade thermal measurement device to measure the DUT surface-plate temperature and adjust a "calibration factor" within the system to make the system reading match the external reference. This means that internal instrument absolute accuracy is not of primary importance.

RF power and frequency measurements rely on the accuracy of their associated instruments. However, considering the testing expectations (e.g. frequency is only controlled via software to a ±1 MHz accuracy), true absolute accuracy is dictated by customer requirements.

All voltage measurements are made using an Agilent DVM. All RF power measurements are performed using an Agilent dual RF Power Meter. Frequency measurements utilize an Agilent frequency counter. The optional Semiconductor Parameter Analyzer (SPA) measurement accuracy is determined by the SPA performance.

Note: Accel-RF does NOT recommend removing instruments from the AARTS system during calibration. All calibrations should be done in-situ.

1.1 PCU Calibration

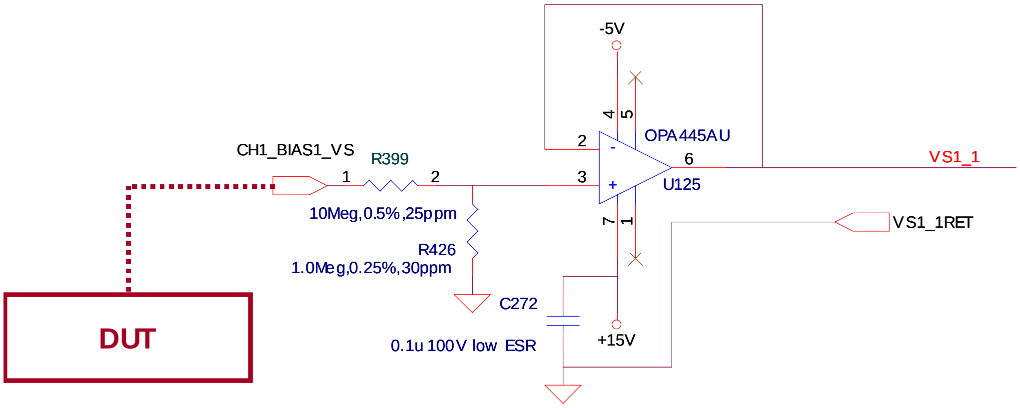
The Power Control Unit (PCU) sources two DC biases to each DUT. Bias1 is a high-power unipolar supply capable of sourcing ~0.5V up to 100V at 0 to 3A, dependent on model. Typically, it is used for the drain or collector supply of a transistor. Bias2 is bipolar and can source or sink current in both polarities. Its operating range is ±18.5 V at 150mA. Given the PCU operating range, there is a limit on accuracy, stability, and resolution as stated in the PCU specifications. This section describes some of these limitations and how the AARTS calibration maintenance can help maximize performance.

1.1.1 Voltage Cal Factors

The system employs an analog multiplexer (MUX) system to route a plethora of signals to a common DVM for measurement. The maximum voltage rating for the MUX system is ±12V; hence, in order to measure signals larger than 12V (e.g. 100V for the Bias1 supply), they must be scaled down to usable levels by voltage divider networks, as illustrated in Figure 1. These dividers employ precision low-Thermal Coefficient of Resistance (TCR) resistors and high-performance op-amps designed to minimize thermal drift and maximize system accuracy and stability.

The standard PCU box (+0.5 to +100V for Bias1; ±18.5V for Bias2) has a typical voltage reading accuracy and stability of ~4 to 8mV for both Bias1 and Bias2. Voltages are detected in the system by measuring the scaled version of the target and applying a calibration factor to the reading to obtain the actual value. The technique of determining the Cal Factor is described in the software manual. It employs an external “reference” meter as the basis for determining the factor. Hence, the absolute accuracy of the system meter is of minimal impact. Relative accuracy is more important.

Figure 1: Circuit used for Voltage Measurements



Voltage Cal Factors do not change much with time. Experience suggests that these factors are quite stable, even over a period of years. Considering the levels at which users typically run devices (1 to 50V magnitude range), the accuracy and drift performance is more than adequate for life testing purposes.

1.1.2 Current Cal Factors

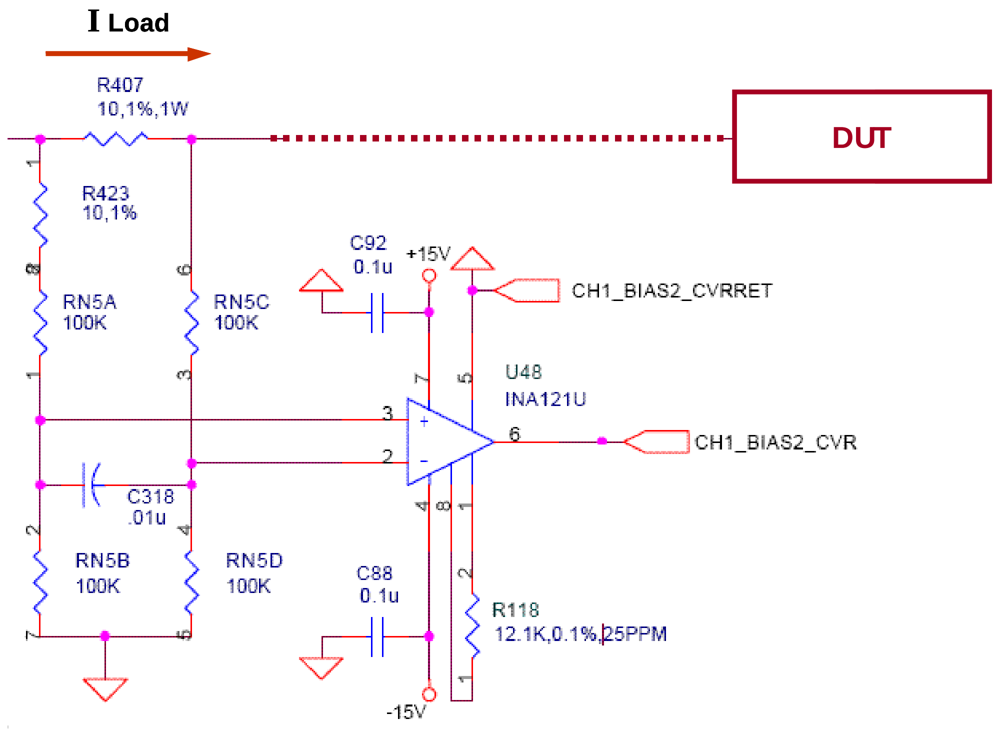
The standard PCU box (+3A for Bias1; ±150mA for Bias2) has a typical current reading accuracy and stability of ~1 to 3mA for Bias1 and ~1 to 10µA for Bias2. DUT current is ascertained by measuring the voltage drop created across a Current Viewing Resistor (CVR), contained in the power supply. The techniques of determining the cal factors are described in the software manual. They employ an external “reference” meter as the basis for determining the factors. Hence, the absolute accuracy of the system meter is of minimal impact. Relative accuracy is more important.

The current measuring circuitry is illustrated in Figure 2. The load current passes through a precision low-TCR resistor, the value of which is chosen to maximize the full-scale current vs. voltage range at the output of op-amp (U48) for the PCU model chosen (note: the voltage range at the CVR may be higher than the 12V MUX range; hence, the matched precision resistive divider network shown in the schematic is incorporated to scale the voltage down to acceptable levels). The CVR value, resistive divider values, and op-amp gain setting resistor are all chosen to maximize current measurement accuracy and stability.

Current calibration factors comprise two quantities: 1) current offset; and 2) current-to-voltage transfer gain. Current offset may be understood by considering the output voltage of the op-amp at zero current. If the load voltage happened to be 0V, then the input to the op-amp would as well be 0V. However, the output of the op-amp is not 0V due to input offset voltages and currents, present in all op-amps. Hence, a zero-current offset factor is involved in any measurement. Note that the effects of input offset voltage and current are a function of absolute voltage level. Further, since the “matched” resistive divider networks can never be perfect, the two voltages generated at the op-amp input are slightly different, and are a function of voltage. Hence, in the AARTS system, a transfer curve is created during current calibration that represents offset as a function of voltage over the entire usable voltage range. This factor is then subtracted from the voltage measurement prior to applying the gain factor to yield current.

The current-to-voltage transfer gain factor is determined by applying a load to the power supply output (at an appropriate voltage level) and measuring the resultant voltage at the op-amp output. Simultaneously, the actual current is measured using a metrology-grade current meter and the system is calibrated to that reference. The Gain Cal Factor is very stable and scales linearly as a function of load voltage.

Figure 2: Circuit used for Current Measurements



Experience suggests that current gain factor is quite stable, even over a period of years. However, zero-current offsets drift slightly with temperature, and hence test scenarios. The zero current drift is not continuous in one direction, but varies around an “average” value. Further, the drift is consistent with the specification of system performance. If very low current measurements are of importance to the test paradigm, it may be desirable to recalibrate the offsets periodically to optimize results. Practically, most users are quite satisfied recalibrating offsets between test runs. Fortunately, offset calibrations are very easy to perform using the LifeTest calibration procedures.

1.1.3 Voltage & Current Calibration Intervals

The correct calibration interval is driven by several factors. First, considering the context of the life testing paradigm, as compared to the PCU model being used for that testing, the inherent accuracies and stability may be more than adequate for long term intervals. For example, if a FET device under test experiences a Bias1 (drain) condition of 20V @ 1A, and the failure criteria of interest were 10% degradation, the accuracies of the standard PCU box (8mV for voltage and 3mA for current) would be more than sufficient to assure measured changes were caused by device degradation rather than test set drift. Second, life test paradigms are primarily interested in relative changes, as opposed to absolute accuracy. Therefore, an 8mV error in a 20V target is of little impact to the test condition. Finally, as explained in detail in the software manual, the setting of bias conditions are subject to iteration events, and their associated tolerance settings. In practice, the tolerance settings are much greater than the power supply accuracies and stability variations.

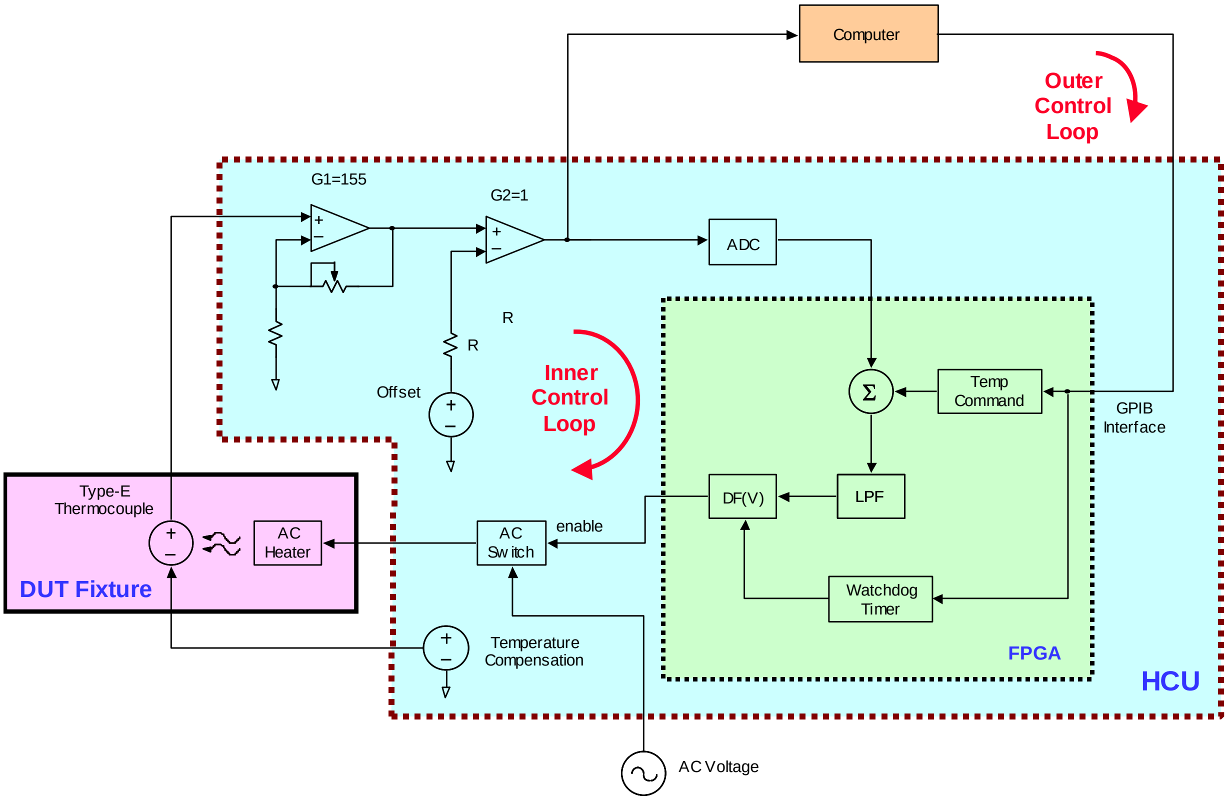
For most life testing scenarios, the default calibrations are more than adequate and re-calibration should only be required at yearly intervals. Nevertheless, for the absolute maximum accuracy, users may wish to calibrate voltages and currents more regularly and at the use conditions of the test. Since the calibration process is part of the standard test setup, and the calibration paradigm utilizes external metrology-grade instruments against which to set its calibration factors, the internal meter calibrations may be extended to a yearly cycle or longer.

1.2 HCU Calibration

The Heater Control Unit (HCU) controls the surface temperature of the DUT. A block diagram of the heater control loop is presented in Figure 3. As shown, a Type-E thermocouple is mounted ~50 mils below the top surface of the heater block, located roughly in-line with the RF signal path. A 2-stage chopper-stabilized amplifier chain amplifies the signal to manageable levels for routing through the MUX system. Functional operation of the control loop is described in the software manual, and is not required to understand calibration issues.

The key components related to calibration are the thermocouple, amplifier chain, and device mounting configuration. First, consider the thermocouple and amplifier chain. Note that an offset and gain adjustment mechanism exists in the HCU circuitry that allows optimizing the temperature range of the thermocouple against the operating range of the Analog-to-Digital Converter (ADC). These elements yield an equivalent Offset and Gain calibration factor that are used to determine thermocouple temperature.

Figure 3: Block Diagram of the Heater Control Loop



A second factor related to determining accurate device temperature is the way in which the device is mounted to the heater block. For instance, if a carrier plate and epoxy interface are employed, they each contribute some thermal resistance and radiative cooling effects. In the life testing paradigm, the most important temperature to know and/or control is the device channel temperature. There is a thermal gradient between the bottom surface of the device substrate and the channel, which is a function of the amount of power dissipated in the device. Many techniques may be employed to determine the temperature gradient; however, the most common and simplest approach is to assume a constant junction to case factor, known as θjc (in units of degC/Watt). By multiplying the total power dissipated in the device by θjc, an incremental temperature is added to the case, or surface, temperature to calculate channel temperature.

The key to calibration is that the system needs to accurately reflect the temperature as measured at the device “case”, or typically bottom surface. The device is usually mounted in some type of package or carrier plate. Hence, there must be some way to adjust the temperature calibration to reflect the correct temperature for both measurement and heater control. The technique employed in the AARTS system allows the user to calibrate the measured values against a known good metrology-grade instrument connected the appropriate point of interest, such as a thermocouple mounted to the top of a device carrier plate.

1.2.1 Temperature Calibration Intervals

The correct calibration interval is a function of the devices being tested and system accuracy desired. The channel Offset and Gain are calibrated at the factory using power supplies and external measurement instruments. The offset should never have to be calibrated in the field. All calibration factors are driven by the channel gain. The Gain factor is linear and calibration at a “use” temperature (typically higher than 200 °C) should yield adequate low-temperature readings. In the life testing paradigm, the stress temperature is most critical. Lower temperatures are typically only utilized to take control sweeps for reference, and temperature accuracy is generally not considered critical.

Accel-RF recommends a temperature calibration cycle of yearly, or whenever a new device structure is introduced. Typical life test temperature requirements only require accuracy to several degrees. Considering the specification for test set accuracy, and amount of variations typically experienced, temperature calibration at one temperature yields acceptable performance at other temperatures. Nevertheless, for the absolute maximum accuracy, users may wish to calibrate temperature more regularly and at the use conditions of the test.

1.3 RFU Calibration

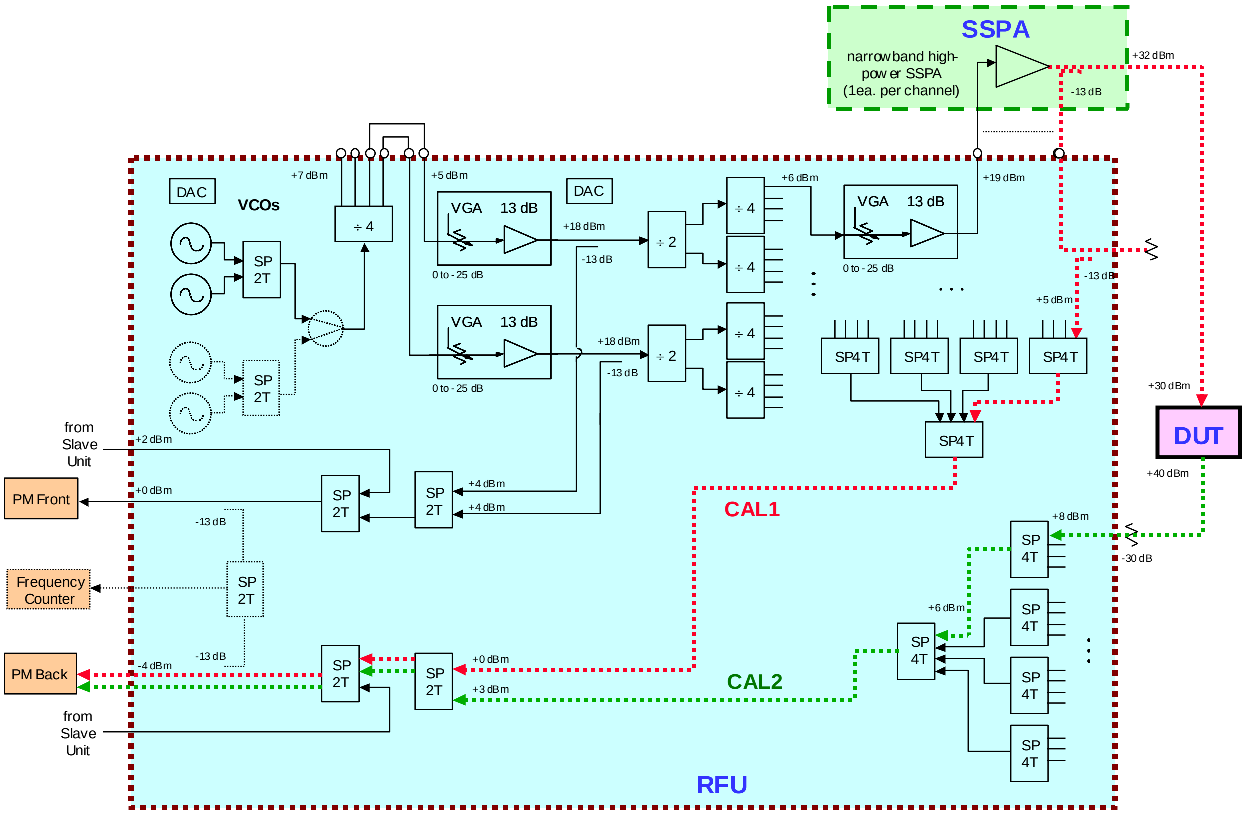
The RF Control Unit (RFU) generates RF stimulus for all devices. Only one frequency at a time may be generated and is global to all channels, unless an external source is utilized (see hardware and software manuals for splitting sources). Each DUT RF input power level may be controlled independently. Frequency and power level measurements are affected by system calibration.

A block diagram of the RF subsystem, including the RFU and SSPA, is presented in Figure 4. Frequency is set by measuring a sample of the VCO output with a frequency counter and adjusting the VCO control voltage using a Digital-to-Analog Converter (DAC) to achieve the target. DUT input and output powers are determined by routing appropriate signals through an RF switch matrix to an RF power meter head, and then applying a linear calibration factor to the reading to ascertain DUT RF level. RF power levels are DAC controlled by applying voltage to a Variable Gain Amplifier (VGA) control input.

1.3.1 Frequency Calibration

Frequency accuracy is determined by two factors: 1) the accuracy of the frequency counter; and 2) the tolerance defined in the iteration limits of the LifeTest software. That tolerance is user definable and is typically set to 1 MHz. The frequency counter accuracy and stability are much greater than anything the user might practically select as part of the system operating paradigm, and as such is not critical.

Figure 4: Block Diagram of the RFU



1.3.2 Frequency Calibration Interval

Frequency calibration is of secondary importance and the accuracy of the frequency counters are much greater than that employed in system operation or that is required by life testing paradigms. Therefore, Accel-RF recommends calibrating the frequency counter yearly, if not longer.

1.3.3 RF Power Level Calibration

RF power level accuracy is determined by three factors: 1) accuracy of the RF power meter; 2) accuracy of the Cal1 and/or Cal2 factors; 3) frequency measurement accuracy; and 4) the tolerance defined in the iteration limits of the LifeTest software. That tolerance is user definable and is typically set to 0.05 dB.

An important point related to RF power level measurement is that the Cal1 and Cal2 factors vary with frequency. Therefore, frequency must be known to properly determine the calibration factors. In fact, the RF power meter head also utilizes frequency information to correct for its own frequency-dependent characteristics. It is assumed that all components in the Cal1 and Cal2 paths are passive and linear. Therefore, calibrating at one power level is sufficient for use at all power levels.

The input RF power level calibration factor (Cal1) is determined by sampling a small amount of SSPA output power through a directional coupler, and routing it through an RF switch matrix to the RF power meter head. This allows extraction of a very small amount of signal energy, and the coupler's directivity helps mask the effects of poor input return loss of the DUT. However, the directivity is not perfect and some of the reflected energy from the DUT input could couple into the measurement system, thus affecting measurement accuracy. Fortunately, this error is small in comparison to the accuracies required and it remains essentially constant, therefore, not affecting relative gain degradation or output power measurements.

Output power is very insensitive to DUT output impedance mismatches. A 50-Ω coaxial transmission line routes RF energy through a large 50-Ω power attenuator (typically >20 to 30 dB) located at the RFU input. Hence, load impedance is very stable and well matched. Therefore, whatever power is launched into the transmission line is ultimately routed to the RF power meter head with virtually no loss of accuracy.

1.3.4 RF Power Level Calibration Interval

The primary contributors to accurate power level measurements are the accuracy of the RF Power Meter, and the accuracy of the Cal1 and Cal2 Factors. The RF power meter accuracy is inherently much greater than the tolerance typically employ in the iteration routines of the AARTS system, and hence, Accel-RF recommends calibration of the meter on a yearly basis, if not longer.

The Cal1 and Cal2 factors are generally very stable with time, but are highly frequency dependent. As explained in the software manual, these factors are calculated over a user-defined frequency range and number of points. It is important to define enough points that the calibration curves are smoothly varying with frequency. Further, re-calibration is required when a new test frequency falls outside of the calibration range. Otherwise, RF Cal1 and Cal2 calibrations should be performed at approximately 3-month intervals.

1.4 SPA Calibration

The optional Semiconductor Parameter Analyzer (SPA) is a stand-alone instrument in the context of the system and may be calibrated on its own recommended schedule. However, based on similar arguments related to life testing paradigms Accel-RF recommends calibrating on a yearly basis, or longer.