Receiver control for the Submillimeter Array

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ABSTRACT

Efficient operation of a submillimeter interferometer requires remote (preferably automated) control of mechanically tuned local oscillators, phase-lock loops, mixers, optics, calibration vanes and cryostats. The present control system for these aspects of the Submillimeter Array (SMA) will be described. Distributed processing forms the underlying architecture. In each antenna cabin, a serial network of up to ten independent 80C196 microcontroller boards attaches to the real-time PowerPC computer (running LynxOS). A multi-threaded, gcc-compiled program on the PowerPC accepts top-level requests via remote procedure calls (RPC), subsequently dispatches tuning commands to the relevant microcontrollers, and regularly reports the system status to optical-fiber-based reflective memory for common access by the telescope monitor and error reporting system. All serial communication occurs asynchronously via encoded, variable-length packets. The microcontrollers respond to the requested commands and queries by accessing non-volatile, rewriteable lookup-tables (when appropriate) and executing embedded software that operates additional electronic devices (DACs, ADCs, etc.). Since various receiver hardware components require linear or rotary motion, each microcontroller also implements a position servo via a one-millisecond interrupt service routine which drives a DC-motor/encoder combination that remains standard across each subsystem.

Keywords: Submillimeter receiver, microcontroller, interferometry, Gunn oscillator, multiplier, DC servo motor, digital PLL

1. INTRODUCTION

The Submillimeter Array (SMA) is a collaborative project of the Smithsonian Astrophysical Observatory (SAO) and the Academia Sinica Institute of Astronomy & Astrophysics of Taiwan (ASIAA). The array consists of eight six-meter diameter antennas with receivers operating from 200-900 GHz and a digital correlator with 2 GHz bandwidth. Many design aspects of the array are analogous to the lower-frequency millimeter interferometers completed in the last decade (Owens Valley,[1] BIMA,[2] IRAM[3] and Nobeyama[4]). Located on Mauna Kea, Hawaii, the primary elements of the SMA interferometer can be reconfigured across 24 pads which provide baselines of 8 to 500 meters. The surface accuracy of each dish is optimized and periodically monitored via interferometric holography measurements.[5,6] Further general details on the array can be found in a summary paper.[7] Descriptions of the low-noise superconductive (SIS) receivers[8] and their associated cryostats and optics[9] have been previously published. In this paper, we describe the electrical and mechanical hardware and software that remotely controls these instruments. We provide a progress report on the deployment of this system.

2. COMPONENTS TO BE CONTROLLED

A submillimeter interferometer presents a daunting number of hardware components to be controlled and monitored to ensure the integrity of the desired observations. Since much of the equipment must be duplicated in each individual antenna, reliable remote control of these components is essential. Furthermore, automated control is desirable whenever possible in order to ease the demands on the telescope operator. In this section, we present a brief list of the major receiver-related hardware components that we are controlling for the SMA.

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2.1. Optical components

The first concern for a tracking interferometer is the pointing of the primary dish and subreflector. Beyond these elements, there are several additional optical components in the system. The SMA is designed to operate in (up to) two receiver bands simultaneously. The mechanism for selecting receivers is a combination of a polarization-splitting wire grid and a flat mirror. Located inside the receiver cabin (which does not tip in elevation), these components are rotated into specific orientations in order to illuminate the desired pair of receivers. Accurate positioning of their mechanical stages is required to provide consistent and identical pointing of the two feeds on the sky. For observations requiring the measurement of full Stokes parameters, a mechanism for inserting a waveplate into the beam must be present. Finally, thermally-controlled calibration vanes coated with millimeterwave absorbers must be moved in and out of the receiver beam at regular intervals to provide system temperature measurements, thereby improving the amplitude calibration of the observations.

Table 1. List of hardware items to be controlled and automated in the SMA receiver system.

	Hardware	**Required Function(s)**
Optics	Polarizing wire grid	Rotate to select low-frequency band receiver
	Combiner mirror	Rotate to select high-frequency band receiver
	Quarter wave plate	Move in and out of beam
	Hot calibration vane	Move in and out of beam, record temperature
	Cold calibration vane	Move in and out of beam, record temperature
Mixer	SIS mixer selection	Activate bias circuitry for selected pair of receivers
	SIS mixer bias V and I	Provide set points and sense lines from bias circuitry
	SIS mixer magnetic field	Provide set points and sense lines from bias circuitry
	SIS total power detector	Monitor continuum levels, measure system temperature
	FET switch	Select IF signals to output from cryostat
LO	Gunn oscillator	Tune two actuators to acquire and maintain phase-lock
	Harmonic mixer	Adjust YIG reference oscillator power for best mixing
	Waveguide attenuator	Adjust actuator for optimal receiver sensitivity
	Frequency multiplier	Tune two actuators for optimal LO power
	Martin-Puplett diplexers	Adjust mirror spacing for maximum LO injection
	Digital PLL	Enable/disable Gunn, set locking sideband, loop gain, monitor phase-lock status
Cryostat	Vacuum	Monitor pressure with Pirani and cold cathode devices
		Start/stop turbopump, monitor the RPM
	Refrigerator	Monitor refrigerator stages and receiver cold plates
		Adjust J-T needle valve to achieve 4 Kelvin

2.2. Receiver components

The frequency coverage of the SMA receivers is divided into six bands from 200-920 GHz. The first generation of receivers now on the telescope include the 230, 345 and 690 bands. Each receiver employs a single niobium SIS mixer. Each mixer requires a junction bias voltage and a magnetic field bias voltage to be present and tunable. In addition, a local oscillator (LO) signal must be combined with the sky signal to make the receiver sensitive to radiation. Each LO contains a chain of waveguide devices (Gunn oscillator, attenuator and multiplier) which require mechanically-tuned actuators to achieve the desired operating frequency. A phase-lock loop (PLL) circuit[10] maintains the phase and frequency of the LO signal in agreement with the master reference generator (MRG) distributed to each antenna via fiber optics. Detailed laboratory calibration of the individual LO chain devices is an essential step for reliable tuning and operation of the receivers. Feedback from the receiver continuum (total power) detector is essential to measure the receiver sensitivity (via the Y-factor method) and thereby automate the tuning of all these items.

2.3. Cryostat components

Since the SIS receivers must be operated continuously at 4K, they are housed in an evacuated cryostat cooled by a three-stage mechanical refrigerator utilitizing the Joule-Thomson (J-T) effect. Full control of the cryostat temperature and pressure requires a turbopump, vacuum gauge, a suite of diode thermometers, and a J-T needle valve. In addition, a cold FET switch must be controlled to select the appropriate pair of receiver intermediate frequency (IF) signals to be output from the cryostat.

3. HARDWARE ELECTRONICS

3.1. Design goals

All of the items discussed in section 2 reside inside the antenna receiver cabin. In principal, all of the functions described so far could be accomplished by a single computer. However, this arrangement would require a large number of (potentially) long wires containing sensitive signals prone to noise pickup. Instead, we have chosen the principal of *distributed processing*, in which the system logic is spread between a larger number of simpler computers located physically close to the item for which they are responsible. There are many advantages of distributed processing, primarily the greater modularity in each device. Both the hardware and software component of a device can be quickly and simultaneously replaced with a spare, which is an important quality at a remote site with many copies of the same hardware (i.e. an interferometer). Also, hardware specific information (such as calibration tables) can be stored at a low-level rather than being edited and propagated down from a large, high-level storage area. The main disadvantage of distributed processing is the greater number of computers which must communicate in a sensible and cooperative way. Also, global software updates must be propagated to many more devices. In a sense, distributed processing moves the complexity from the wiring to the software, which is more feasible to debug and augment from a remote location.

3.2. Microcontroller circuit boards

The design of the principal set of microcontroller circuit boards began in 1995, and production and testing has been ongoing since then. The set of boards is divided into three categories: LO control board, mixer control board and optics control board. Each microcontroller board includes an Intel 80C196KC 16-bit microcontroller running at 20MHz with an 8-bit bus, along with additional hardware specific to the board's function. This microcontroller is a versatile device that can address up to 64 kilobytes of memory using a von Neumann architecture. In our case, the boards each contain a 32 kilobyte EPROM and two banks of 8 kilobyte nonvolatile static random access memory (NVSRAM). Each antenna is outfitted with a single mixer board and optics board, and up to 8 LO control boards. Using multi-layer surface-mount technology, the boards measure only a few inches on a side. All of them reside on a single RS485 serial bus managed by a multi-threaded master program running on the antenna computer–a diskless PowerPC controller (Motorola MVME2700) with a commercial real-time Unix operating system (LynxOS). A related microcontroller board, called the servo control board, employs the same 80C196KC device to run the velocity servo loop and system status monitor of the main antenna drive motors. The SMA servo control board provides a good example of distributed control. Additional details have been presented elsewhere[11] and will not be further discussed here.

3.2.1. Local oscillator control board

The LO control board contains motor driver circuits for up to eight DC motors. The eight channels are allotted as follows: two for the Gunn oscillator, one for the attenuator, up to four for the multiplier(s) and one for a Martin-Puplett diplexer (to provide optimal LO injection in the high frequency bands). Each motor has a rotary encoder read by a quadrature decoder/counter interface on the LO control board. Associated with each LO control board is a digital PLL (DPLL) circuit and a thermoelectric controller (TEC) to power and control the Gunn oscillator.

3.2.2. Digital phase-lock loop

The DPLL is based on a high-gain second-order loop with an active filter. The IF signal from the harmonic mixer is first amplified by 60dB (across a bandwidth of 0-500MHz) and then passed to an Analog Devices AD96687 Ultrafast ECL Dual Comparator which converts the sinewave to a squarewave. Zero crossing detection is used in the comparator in order to avoid an automatic gain control (AGC) circuit in the IF amplifier. By biasing the comparator above the peak value of the IF signal, the microcontroller can disable the loop. The digitized signal output from the comparator enters the Analog Devices AD9901 ultrahigh speed phase/frequency discriminator. An AD817 high speed, low-power wide supply range amplifier provides the loop integrator. We implement a loop gain control by controlling the current in the AD9901 via the 8-bit DAC in the microcontroller. A second AD817 monitors the Gunn bias voltage and, along with a diode pair, keeps it within a diode drop (± 0.6 V) of the target bias voltage set manually via a potentiometer. The DPLL provides a high loop bandwidth (a few MHz) in order to reacquire lock after each phase switch in the 109MHz reference signal due to the interferometer Walsh cycle[12] generated by the direct digital synthesizer (DDS). The eight-channel 10-bit ADC in the LO microcontroller is used to monitor the Gunn bias, a temperature sensor and the power supply voltages. The high speed output of the microcontroller is used to control the on/off state of the Gunn oscillator and DPLL, the sideband of the DPLL, and a heater resistor to keep the diplexer section of the DPLL warm when the Gunn oscillator is not in use (thereby avoiding initial phase drifts at startup).

3.2.3. Optics control board

Like the LO boards, the optics control board has motor driver circuits for up to eight motors, two of which are higher current capacity drivers (for the grid and combiner mirror). The board also contains eight digital inputs attached to the optical breaks which provide home positions for the various rotating and translating stages. The eight-channel 10-bit ADC inside the microcontroller is used to monitor the calibration vane temperatures.

3.2.4. Mixer control board

The mixer control board contains four 12-bit DACs to provide the mixer bias and magnetic field command voltages to the active pair of receiver bias circuits, and a ten-way multiplexed 12-bit ADC to monitor the mixer bias, mixer current, magnetic field, receiver total power and other voltages. A set of digital outputs is used to select the two active receivers, which includes activating the appropriate quadrant of the mixer bias circuitry and setting the cryogenic FET IF switch. The next revision of the board will also contain a motor driver for the cryostat J-T valve.

3.3. Other devices

In contrast to the receiver and optics components, the cryostat instrumentation (turbo pump, vacuum gauges and thermometers) is controlled by commercial RS-232 interface units sold by the individual manufacturers (Varian, Balzers and Lakeshore). Each of these discrete units is managed by a separate monitor program running on the antenna computer.

4. ONLINE SOFTWARE

The online software structure of the SMA contains many levels of monitor and control functions. A central element in the organization is a fiber-linked hardware reflective memory (RM) system (VME Microsystems International Corporation). Critical monitor points are regularly logged to predefined locations in RM by various low-level programs running in the antenna computers, correlater crate computers, etc. The RM variables are read by higher-level status display programs (both text-based and graphical) and the error reporting system. For the most part, control commands are sent from the central computer (hal9000) to individual antenna computers via the remote procedure call (RPC) protocol,[13] in some cases bundled into Perl scripts. In the case of the receiver system, these commands are served by two layers of programs: a master server program on the antenna computer, and the set of programs running on the microcontrollers that it manages (see Figure 1). All programming is done in C, using a cross-compiler running on Solaris (or Linux) for the PPC-LynxOS code and the Tasking Inc. compiler running on Solaris for the Intel microcontroller code.

4.1. Antenna computer master program

A master server program (called tune6) runs on each antenna computer and talks to each of the microcontroller boards described in section 3.2. Tune6 has matured into a powerful, multi-threaded program. At startup time, it probes the RS485 serial bus to discover which boards are present, and thereby what capabilities are available to the user. In addition to the RPC server thread, it has an optional interactive command-line thread that is

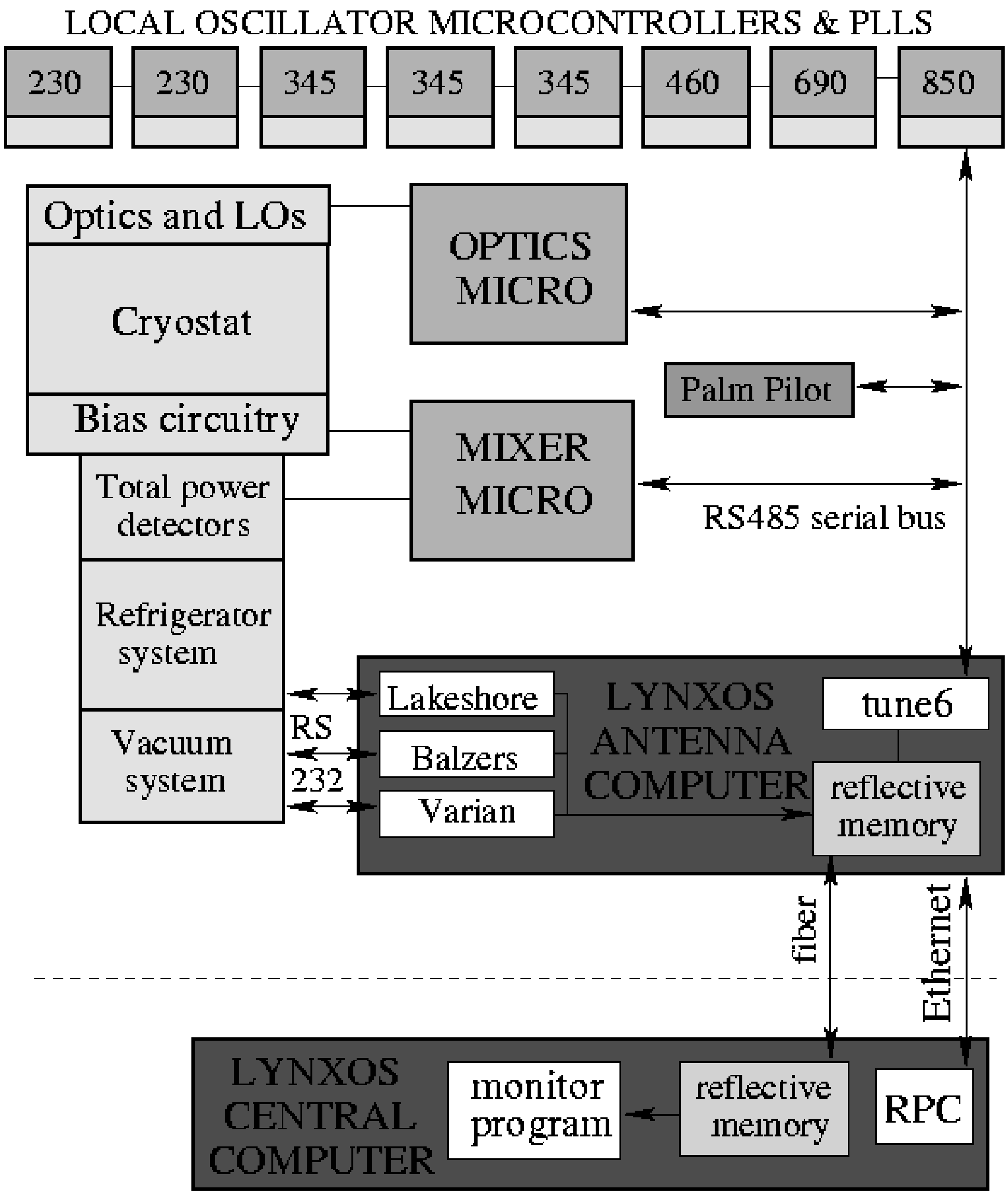

Figure 1.
Layout of the SMA receiver control system. Commands come from the central computer via Ethernet, either in RPC format or from an interactive console option. To fulfill these commands, the master server program "tune6" dispatches appropriate sub-commands to the microcontroller boards via a common RS485 bus, while constantly logging the system status to reflective memory.

used primarily in laboratory situations for hardware calibration functions, but is also quite useful in debugging problems on-site. A separate thread monitors critical values on each of the microcontroller boards into reflective memory at several Hertz. Access to the serial line amongst the threads is regulated by a mutex. In addition to the serial line, tune6 can talk to a dozen different GPIB devices (spectrum analyzer, synthesizer, multimeter, function generator, power meter, etc.). Tune6 can trigger resets of the microcontroller boards via a digital I/O card. It also controls the output power of the YIG oscillators and the RF switches that direct the YIG signal to the various receivers. It can acquire and simultaneously display current vs. voltage (I/V) and power vs. voltage (P/V) sweeps to any IP address via Tcl/Tk scripts[14] and the wish shell, without the need for either Xwindows or Motif on the antenna computer.

An alternate master program running on a Palm pilot can also control the bus in a "local mode", similar to the one on the antenna motor drive system. Because it resides on the same serial bus, it can eavesdrop on all the packets and provide a visual display of the system status even when the the antenna computer is in control. We use gnu prc-tools to generate the Palm pilot executable.[15]

4.2. Microcontroller slave programs

The goal for the microcontroller software is to implement hardware specific functions that can be called in succession when needed by tune6. Most of the embedded microcontroller code resides in the EPROM. The board type identifier is stored here along with the communication subroutines, which are a common object module to all boards. Since each board sees all packets on the RS485 bus, the packets contain the source and destination addresses, thus they are ignored by all boards except the target. (See appendix A for a detailed description of the packet protocol.) Each packet is encoded with a cyclic redundancy check (CRC) so that transmission errors can be identified. In practice, the low bandwidth used (38.4kbaud) makes errors very rare. The "operating system" running on the microcontroller boards is a simple command dispatcher, with essentially zero boot time. There are no priorities assigned to jobs–they are completed in the order received. A board which has received a command essentially has "control" of the RS485 bus until it has completed its command and issued an appropriate response to the caller, which is typically tune6, but can be another board previously commanded by tune6.

The lower section of NVSRAM is used for data tables. All hardware specific data, such as frequency tuning lookup tables and rotary stage positions, are stored here, but can be easily reloaded or modified by tune6 commands. In the case of the LO boards, the board sub-type (i.e. the frequency band) is stored here. This section of memory is automatically stored at power-down, and restored at power-up. The higher section of NVSRAM is used for additional embedded program code. New software features are generally programmed into this area first for debugging prior to being moved to the permanent EPROM.

4.3. DC motor servo

The LO and optics microcontroller board software each contain an identical interrupt-driven servo. The hardware allows two of the eight motors can be active at a time, though for software simplicity we run only one of them at a time. When a new position is commanded, the calling function on the microcontroller waits until the position has been acquired. We use the microcontroller software timer to trigger the interrupt service routine every millisecond. The encoders are read and the velocities during the past millisecond are calculated. The present position error is computed and adjusted by velocity feedback. If the position error changes sign, the motor direction is reversed. If the position error is zero, the motor current is stopped. As soon as the position error remains below 2 encoder counts for 20 consecutive cycles, the calling function proceeds.

5. CALIBRATION SOFTWARE

A large portion of the effort in this project has gone into developing automated calibration software for the various components of the system. Detailed laboratory calibration of millimeter oscillator hardware is particularly crucial in order to achieve reliable operation at the telescope.[16]

5.1. LO boards

In our system, the microwave LO chain hardware requires the largest amount of calibration effort. On the Gunn oscillator, attenuator and multiplier, the manual micrometers are first removed and replaced by linear actuators. The Klinger actuators (Figure 2) are comprised of a MicroMo rotary motor with an encoder and a leadscrew attached through a flexible coupling. Appropriate width washers are machined until the throw of the actuator matches the micrometer. The fully extended position is used as the reference hard stop for the encoder. A teflon washer is included to prevent the actuator from jamming at the hard stop. The applied motor torque heading toward the stop is reduced using a zener diode on the voltage drive line. With 64 pulses per revolution, a 141:1 gear ratio and a screw pitch of 2 threads per millimeter, the resolution of the encoder corresponds to a linear motion of .05 micron. When the servo acquires a specified rotary encoder position from opposite directions, the achieved linear position exhibits a consistent difference of about 5 microns. In repeated motions, the relative position change is better than 2 microns.

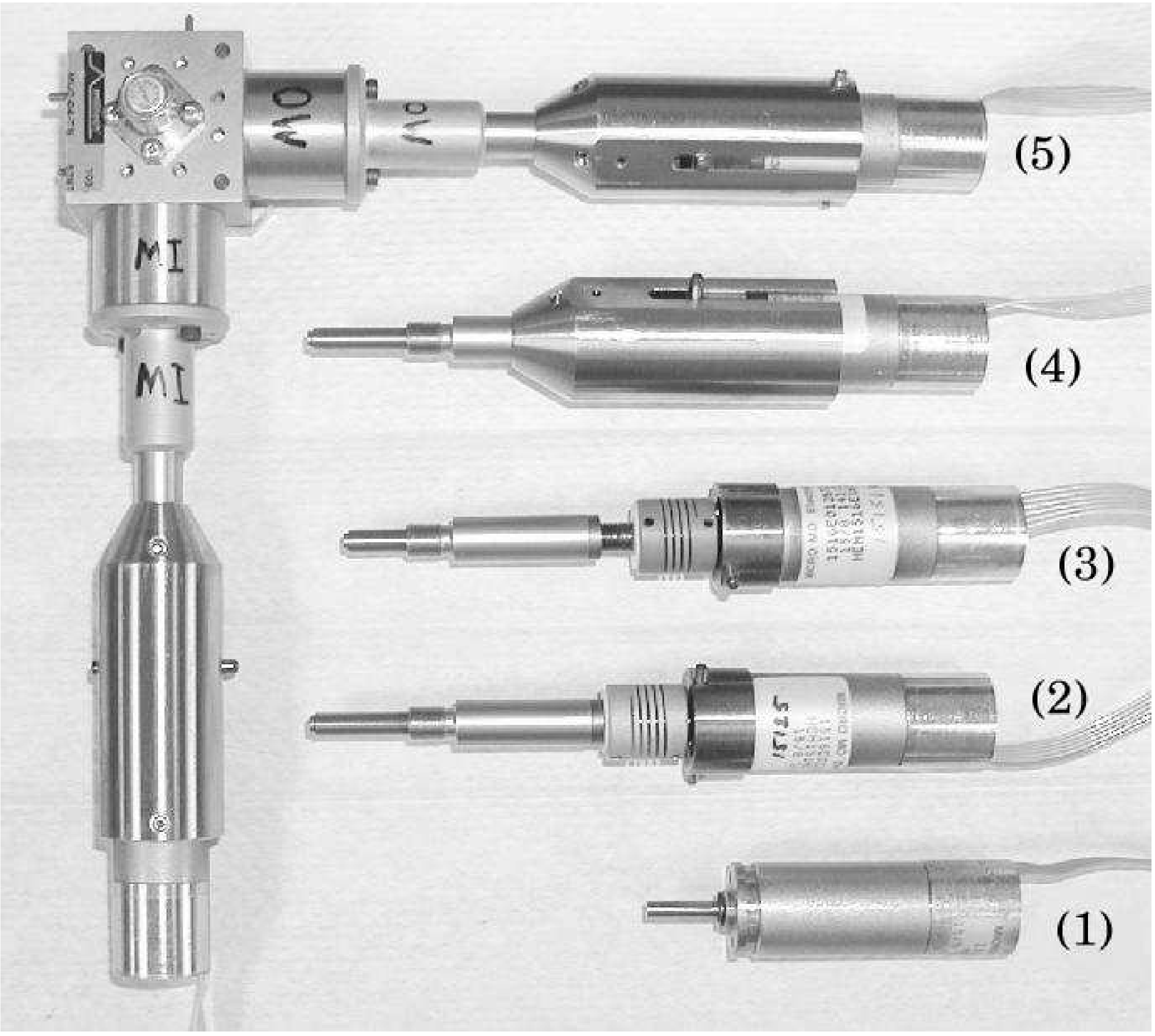

Figure 2. The linear actuator used to tune the spring-loaded waveguide plungers in the Gunn oscillator, attenuator and multiplier consists of a rotary DC motor with an encoder and a flexible coupling to a leadscrew. (1) DC motor and encoder unit, (2) Actuator in the fully-extended state, with the bearing against the teflon washer hardstop, (3) Actuator in a partially-retracted state, (4) Actuator assembled with shell, (5) Two actuators on an assembled multiplier.

5.1.1. Gunn oscillator calibration

The frequency output of a Gunn oscillator depends on both the applied bias voltage and the length of a mechanical tuning cavity.[17] The calibration sequence of the Gunn oscillator (see Figure 3) begins with a fixed bias voltage applied. The tuner and power backshort actuators are scanned, with the signal identification function running on a spectrum analyzer equipped with an external mixer. An initial tuning table of tuner motor position vs. frequency is thus generated. If a programmable power supply is available, the Gunn modulation sensitivity (typically $\sim 100-400$MHz/volt) is also measured during this procedure at each frequency by applying a small change in voltage and observing the change in frequency. It is important to identify any frequencies where the sensitivity approaches zero as they will be difficult (or impossible) to phase lock. The Gunn tuning table can be typically fit quite accurately with a monotonic segment of a fifth-order polynomial. The series of backshort settings that generate a local maximum in output power is analyzed by an algorithm which tries to select a sensible, continuous mode. Frequencies at which insuffcent power is available to drive the multiplier are identified as holes in the tuning table. The tuning table is then downloaded to the microcontroller and a automatic tuning test of 100 random frequencies is initiated, using the phase-lock search algorithm.

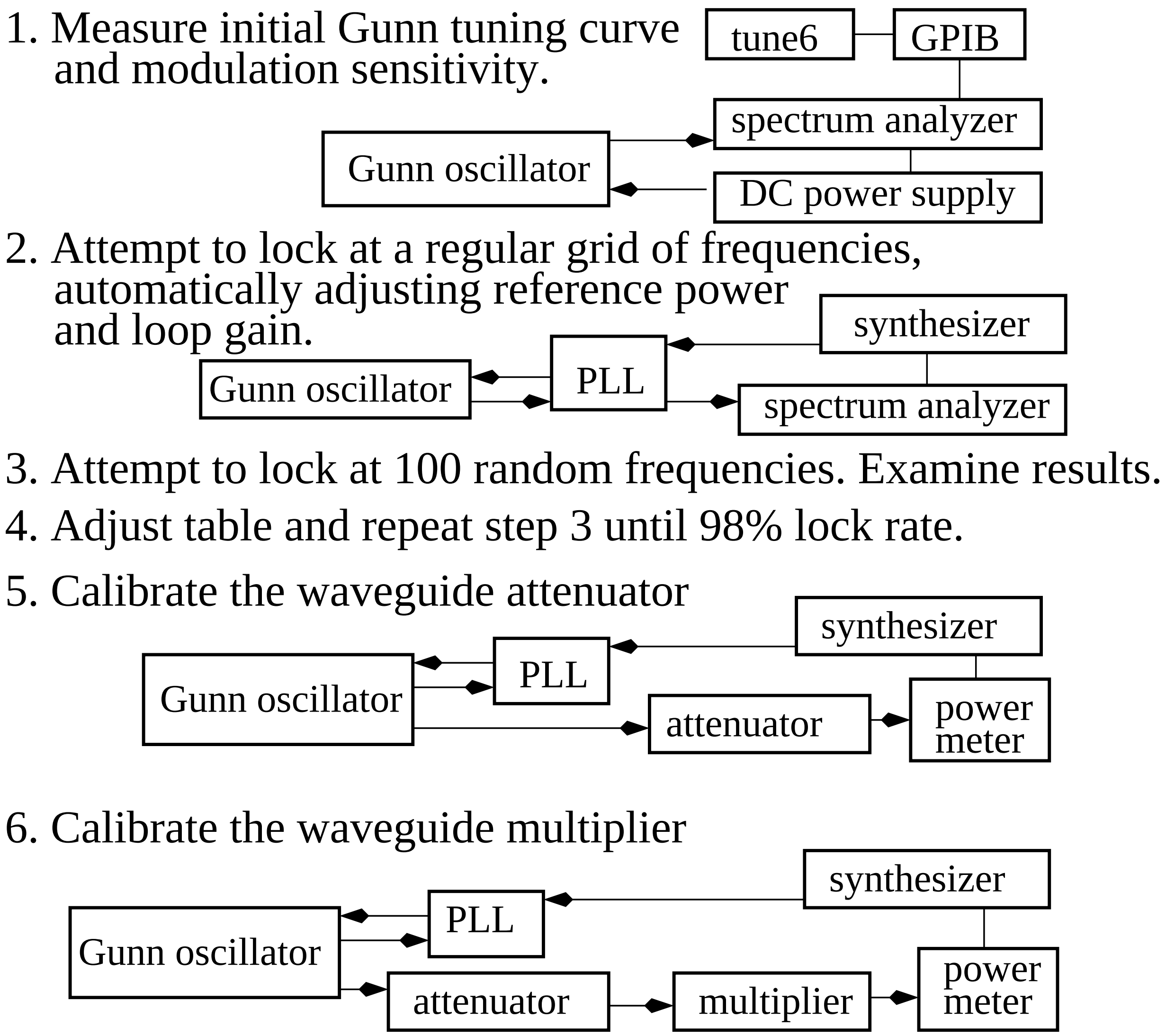

Figure 3. Major calibration steps for a motorized submillimeter local oscillator chain.

5.1.2. Phase-lock search algorithm

When a frequency command is given to the tune6 server, it is passed to the appropriate LO control board which examines its local lookup table and computes interpolated positions for the Gunn and multiplier backshorts. Once the actuators reach these positions, the DPLL voltages are examined. If there is no phase lock, a search mode begins. The Gunn tuner is scanned across the expected position. By the nature of the DPLL design (section 3.2.2), phase lock is indicated whenever the Gunn bias voltage lies between the two voltage limits established by the diode pair. However, if the IF amplifier is being overdriven, it is possible to "lock" on a harmonic of the IF. To reject these false "locks", two LC circuits are included which provide a simple yet powerful analysis of the IF spectrum to the tuning software. A portion of the IF signal is tapped and sent through a notch filter tuned to 109 MHz and on to a Schottky diode pair. A similar circuit implements a bandpass filter tuned to the same frequency. The Gunn bias and the voltage outputs of both filter circuits are digitized by the microcontroller board and used in the automated phaselock algorithm. Proper lock is indicated by a large ratio of bandpass to notch power combined with a Gunn bias that is less than a diode drop from the target. Once the Gunn is locked, the bias voltage may slowly drift as the PLL compensates for any residual thermally-induced changes in the tuner cavity length. Whenever the voltage drift exceeds half a diode drop from the target value, the mechanical tuner is automatically adjusted to recenter the bias. This feature maintains lock during astronomical observations.

5.1.3. Tuning table generation

During the calibration tests of a new Gunn, the initial lock search takes place using default values for the reference power and loop gain. If the search fails, these values are adjusted automatically and the search begins again. At all frequencies where lock is ultimately achieved, the power and gain settings are stored. The signal to noise of the IF trace is also recorded as a function of the reference signal power and the loop gain. With this information, a better tuning table can be constructed in which the reference power and gain vary with frequency. The varying reference power requirement is due to the variation of the harmonic mixer efficiency as a function of both frequency and applied power. The varying gain requirement results from the variation of the modulation sensitivity of the Gunn with frequency. After a few appropriate adjustments are made to the tuning table, the test is repeated until 99 percent success rate is achieved. There are tune6 commands to convert an ASCII-delimited tuning table to Intel hex format suitable for download to the microcontrollers. Commands to upload and plot the existing tables also exist. Single line changes to the table entries can also be applied directly to the on-line microcontroller memory. The frequency increment between entries need not be constant throughout the table, though we find that 1 GHz is usually sufficient.

5.1.4. Attenuator calibration

The attenuator calibration is quite simple as it requires only a Gunn oscillator and a W-band power meter. The attenuation is recorded in a single scan of the attenuator motor and the resulting table is resampled into the minimum number of points (typically a dozen) from which a linear interpolation will yield less than a specified error (e.g. 0.5 dB) in the achieved value. The resampled table is stored in the microcontroller NVSRAM immediately following the Gunn tuning table. All of the tables have variable lengths with computed pointers to the various component sections.

5.1.5. Multiplier calibration

The frequency multipliers are operating with passive, self-bias to protect them from static discharge, and to simplify the tuning. The calibration sequence of a multiplier requires either a high-frequency total power detector or an operating SIS receiver with a total power detector. First, the Gunn is tuned to the highest available frequency, and the multiplier backshorts are individually scanned through their full range. When the peak power is identified, the Gunn frequency is lowered to the next setting and a local maximum is found on both multiplier backshorts. The results of this procedure form the lookup table for the multiplier (see Figure 4). This table is stored in memory after the attenuator table. In practice, the final optimization of multiplier output power is done with feedback from the receiver total power detector.

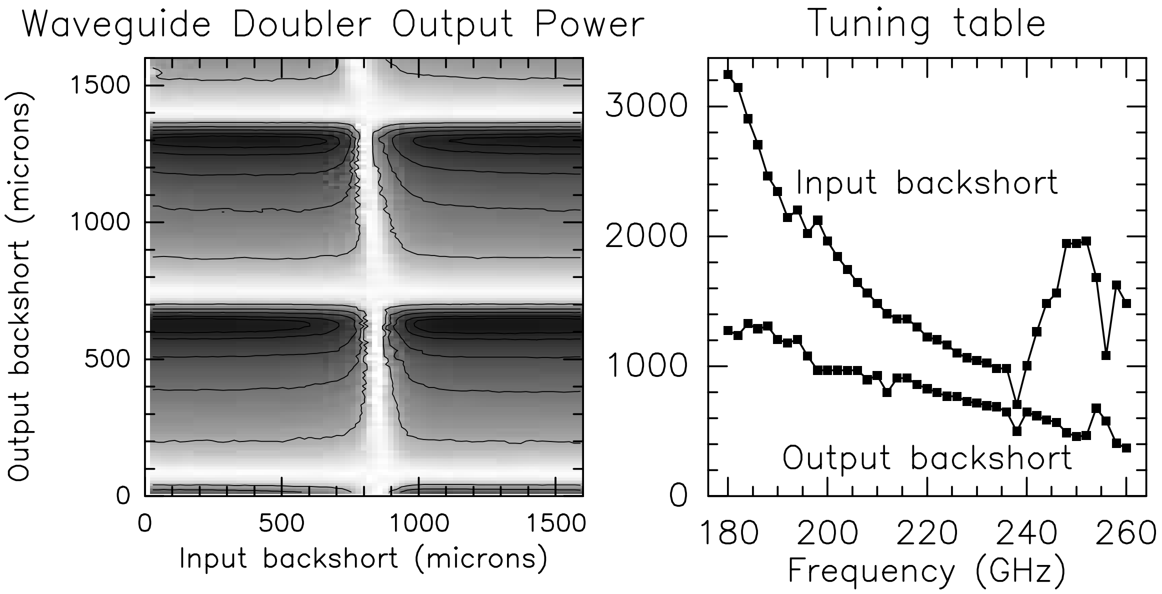

Figure 4. Left panel: Multiplier output as a function of backshort position at a single frequency (246 GHz). Contour levels: 20,40,60,80,90%. Right panel: Optimum backshort positions as a function of frequency.

5.2. Optics board

Some of the optical components in the SMA require precise positioning while others need only coarse motion. The polarization-splitting wire-grid and the combiner mirror are two elements that are critical to the receiver alignment. In each case, the alignment is carefully measured in the lab and a mechanical detent is placed at each receiver port so that the rotating stage can be locked into place manually. Once the motor drive gear has been engaged, the same detent is used by the automatic drive system. Like the LO chain motors, the grid motor has an encoder attached. In this case, one encoder tick corresponds to a 9.5 arcsecond rotation of the grid stage. For the calibration sequence, the stage is driven in small steps until the detent is engaged. The encoder position is noted at the position of each detent and stored in memory. When the optics board receives a command to select a new receiver, the servo drives the grid motor until the stored encoder position is achieved. As soon as the motor is depowered, if the stage is within a millimeter of the detent center, the mechanical force of the detent pulls the stage into position. Once a good encoder position is found for each detent, this limited feedback system works reliably. A single optical break, triggered by a fixed mechanical flag, is sufficient to provide a known absolute position for the encoder. Since the stage is rotated in only one direction, this break is triggered once per rotation, therefore no encoder drift can build up, and the system will automatically restablish the rotary coordinate system after any manual moves.

The other item presently under control of the optics board is the first generation of the SMA receiver calibration system. It consists of a single, ambient-temperature vane nine square inches in size that is moved in and out of the receiver beam by a rotary motor with a slip clutch. A hardstop defines the “in” and “out” positions. Due to the non-precision nature of the motion, a potentiometer on the motor (rather than an encoder) is sufficient to determine when one of the two positions is reached at which point the motor is turned off. A self-calibration sequence can quickly remeasure the two positions if the unit senses any mechanical drift.

5.3. Mixer board

The DAC and ADC zero offsets for the mixer bias control and feedback lines can be measured and stored in the microcontroller memory. This feature ensures symmetry about the origin of the I/V curves. The I/V curves are not stored on the mixer board, but rather are sent to a hard drive in the control building that is mounted by the antenna computer. A modelling subroutine fits the various regions of the I/V curve to determine the junction temperature, gap voltage and contact resistance. The noise temperature of the first stage amplifier is determined from the P/V curve. Commands exist for the mixer board to optimize the receiver total power output as a function of the mixer bias and LO attenuation. The magnetic field bias can also be scanned to minimize the area under a specified region of the P/V curve to maximize the receiver stability. The mixer board NVSRAM contains a table to record the optimal mixer bias, magnetic field and LO attenuation settings versus sky frequency. These can be measured and recorded in situ at the telescope as new frequencies are observed for the first time.

6. PRESENT DEPLOYMENT STATUS

As of August 2002, seven SMA antennas are present on Mauna Kea and four of them are undergoing routine test usage on the sky. The optics control board is present in all four of these antennas and is controlling the ambient temperature calibration vane and the wire grid rotation stage. The mixer control board is present in all four antennas and is fully functional. The receiver can be tuned interactively by computer commands and characteristic I/V curves are routinely obtained and displayed remotely. There are three LO control boards and DPLLs in each antenna, one each for the 230, 345 and 690 GHz receivers. Only the 230 GHz LO chains are motorized at this time. The other bands must still be tuned manually. Most of the development work is presently aimed at motorizing and fully automating the 345 GHz LO chains. The Palm pilot software is partly developed and is in use only in the laboratory. Further work on this software will resume once more of the higher priority LO chain hardware work is completed.

7. FUTURE REVISIONS

The main circuit board revision to be undertaken is an upgrade of the mixer control board. New functionality will be added to control the cryostat J-T valve. Also, a total power stabilization servo will be implemented by reading the receiver temperature and adjusting the HEMT bias accordingly. This feature will require higher precision ADCs and DACs than are presently on the board. An LED status board will be added to provide a simple description of the present state of the receivers to personnel entering the antenna cabin. Other revisions may be necessary to the connector portion of the LO control board to accomodate the geometry of the higher frequency LO chains. Software control of the Martin-Puplett diplexer on the 690 GHz LO chain also remains to be implemented. The waveplate mechanism and the next generation of calibration vanes (to provide a more accurate two-temperature calibration) are still under hardware design. Finally, some modifications to the tune6 software are being undertaken to streamline the system for dual-frequency operation in the near future. The ultimate goal for this software is to have all of the various receiver tuning commands to be triggered by a single command, the response to which will be the receiver temperature achieved.

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APPENDIX A. SERIAL PACKET PROTOCOL

The antenna computer communicates with the series of microcontroller boards via variable-length serial packets transmitted over an RS485 bus. Here we give a description of the packet protocol. The first two bytes in each packet constitute the packet header. The first byte of the packet header presents a unique pattern: it is the only byte in which the two most significant bits (MSB) are high. The next two bits are unused, while the four least significant bits (LSB) define the target address. The second byte of the packet header contains the source address in the four LSB. The third MSB is also set high in order to distinguish all bytes sent from board address 10 from the terminating character. The other three bits are unused. The packet type byte plus (up to) 32 bytes of content (aside from the header, terminator and extra encoding bytes) may be transmitted in a single packet. This provides space for eight long integers (in particular, eight motor encoder values). A global enumeration of packet types is shared by all boards, although not all boards are programmed to respond to all packet types. Following the (encoded) packet type and content bytes is the cyclic redundancy check (CRC) word (a two-byte short integer). Once the packet has been assembled, the packet data are encoded, beginning with the third byte and continuing through the CRC word. The CRC is performed over the entire packet, including the first two bytes which are not encoded. The first two bytes of the packet are not encoded so that each board on the bus can immediately discern to whom the packet is destined without having to decode it. The encoding proceeds as follows: for each byte, the sign bit is removed (and stored), and 0x20 is added to the value. After six such bytes, a byte containing the sign bits is constructed and placed prior to the six content bytes in the data stream. The value of this "sign byte" is 0x40 plus the sign bits which reside in the six LSB. The sign bit of the first byte resides in the third MSB. The sign bit of the second byte resides in the fourth MSB, etc. This cycle repeats for the rest of the data, including the CRC word. The final byte of the packet is the terminator character (a "newline" in C code = 0x0a = 10 = 00001010). In general, the response to a packet has the same packet type as the initiating packet. The contents vary as a function of the packet type. As far as addressing goes, three address dipswitches are located on each microcontroller board. The LO microcontrollers use the address range 0-7. Using a software implied "8"-bit, the mixer and optics boards can use any two unique addresses from 8-13. The antenna computer program (tune6) uses address 15 and the Palm pilot controller program uses address 14.