A progress update on SuperCam: A 345 GHz, 64-pixel heterodyne imaging spectrometer

Jenna Kloosterman[*], Christopher Groppi[†], Craig Kulesa[*], Christopher Walker[*], Tiara Cottam[*], Elliott Liggett[*], David Lesser[*], Michael Borden[*], Paul Schickling[*], Dathon Golish[*], Christian d'Aubigny[*], Sander Weinreb[‡], Glenn Jones[‡], Joseph Barden[‡], Hamdi Mani[†], Tom Kuiper[§] Jacob Kooi[‡], Art Lichtenberger[¶], Thomas Cecil[¶], Patrick Puetz[‖], Gopal Narayanan[**], Abigail Hedden[††], Xiaoying Xu[*]

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[*]University of Arizona, Tucson, AZ 85721

[†]Arizona State University, Tempe, AZ 85287

[‡]California Institute of Technology, Pasadena, CA 91125

[§]Nasa Jet Propulsion Laboratory, Pasadena, CA 91109

[¶]University of Virginia, Charlottesville, VA 22908

[‖]KOSMA, University of Cologne

[**]University of Massachusetts, Amherst, MA 01003

[††]Army Research Laboratory

Contact: jlkloost@email.arizona.edu

***Abstract*—SuperCam is a 345 GHz, 64-pixel heterodyne imaging spectrometer being prepared for installation on the Heinrich Hertz Submillimeter Telescope (HHSMT). In the Fall 2011 the receiver will begin its survey of 500 square degrees of the Galactic plane in ^{12}CO J=3-2. This large-scale survey will help answer fundamental questions about the formation, physical conditions, and energetics of molecular clouds within the Milky Way. The data set will be available via the web to all interested researchers. By integrating SIS mixer devices with LNAs in 8- 1x8 modules, the size needed for the cryostat and the complexity of internal wiring is significantly reduced. Here we briefly describe SuperCam's operation and report on its status.**

I. Introduction

SuperCam is a 64 pixel, Superheterodyne Camera designed to operate in the 345 GHz atmospheric window. Its development was motivated by the need to perform large scale, high spectral resolution submillimeter spectroscopy of the interstellar medium (ISM). All 64 pixels have been installed in the cryostat. The cryostat, bias system, IF down-converters and spectrometer are in their final stages of integration. Previously, noise temperature measurements from 32 out of 64 pixels have been presented (1; 2). Here we summarize the instrument design and give an update on SuperCam's progress.

II. Science

SuperCam will map 500 square degrees in the Galactic plane between $0° < l < 90°$ and $-1 < b < +1$ and all major star-forming regions visible from the HHSMT with 22" spatial resolution and 0.3 km/s velocity resolution. This survey has been outlined in black in Figure 1. By combining the results of SuperCam surveys in ^{12}CO J=3-2 and ^{13}CO J=3-2 with existing CO J=1-0 surveys, a complete excitation temperature map of the survey region can be constructed. Additionally, the SuperCam survey will improve upon the spatial resolution of existing Galactic Plane surveys by a factor >10. The depth of the survey is sufficient to detect CO to a level consistent with $A_\nu \sim 1$, detecting all CO that has formed in-situ (1).

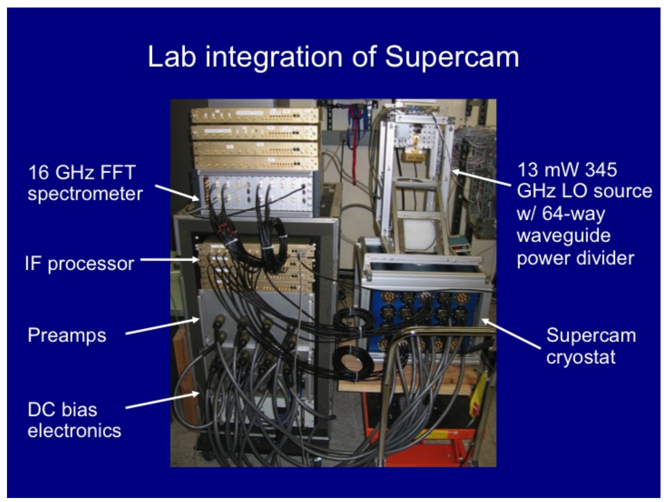

Fig. 2. Photograph of SuperCam cryostat, LO, and electronics for all 64 pixels.

III. Instrument Description

SuperCam is composed of several subsystems; optics, cryogenics, and electronics. A recent photograph of SuperCam is show in Figure 2. A block diagram of the instrument is provided in Figure 3. Each subsystem is discussed below.

A. Cryostat

The cryostat was constructed by Universal Cryogenics in Tucson, AZ. Light passes through an AR coated crystalline quartz vacuum window and 40K GoreTex GR IR filter before

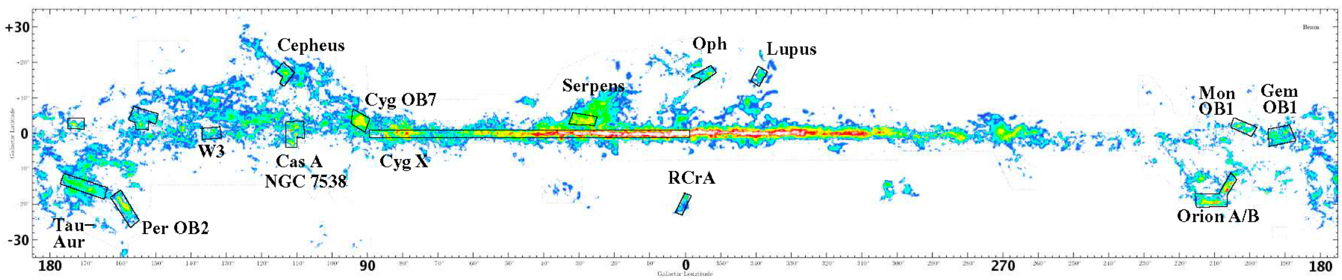

Fig. 1. The 500 square degree SuperCam Galactic Plane Survey from the HHSMT has been outlined in black. The survey will Nyquist sample the galactic plane from $0^\circ < l < 90^\circ$, -1$^\circ < b < +1^\circ$ and all major star forming regions visible from the HHSMT.

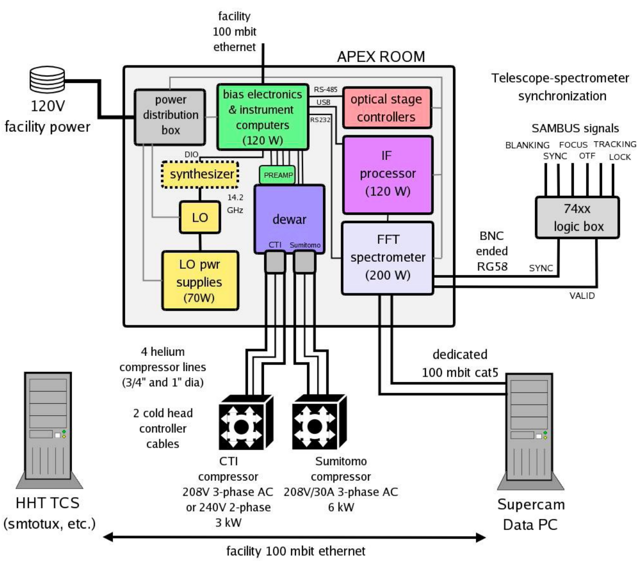

Fig. 3. A block diagram of SuperCam. The cryostat, pre-amplifier electronics, bias electronics, LO, IF downconverters, spectrometer, power supplies, control computers will reside in the HHSMT's Apex room, located just behind the 10 m dish.

illuminating the 4K mixer array. SuperCam uses a CTI-350 coldhead and a Sumitomo SRDK-415DP cryocooler. The CTI-350 supplements cooling of the 40K shield and provides 12K heat sinking for the 64 stainless steel semi-rigid IF cables leading from the mixer array to the vacuum bulkhead. The Sumitomo refrigerator cools the eight, 1x8 mixer array blocks to 4K (1).

B. Mixer Arrays

SuperCam uses eight 1x8 mixer modules made of 145 copper alloy, shown in Figure 4. The mixer modules were fabricated at the University of Arizona with a Kern MMP micromilling machine. Each module integrates 8 SIS devices with LNAs. The SIS devices have been optimized to work between 320-380 GHz. The modules use stainless steel guide pins and screws for proper alignment and thermal conductivity. A diagonal feedhorn array bolts to the front (2).

Inside each pixel, waveguide directs the incoming signal around a 90° curve to the SIS junction suspended above the stripline channel. Its design includes a quarter wave backshort.

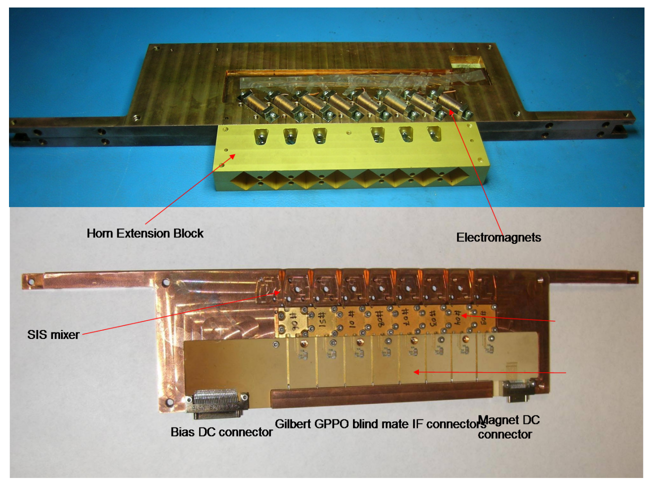

Fig. 4. A fully assembled mixer module (top) and a mixer module with the top covers removed (bottom).

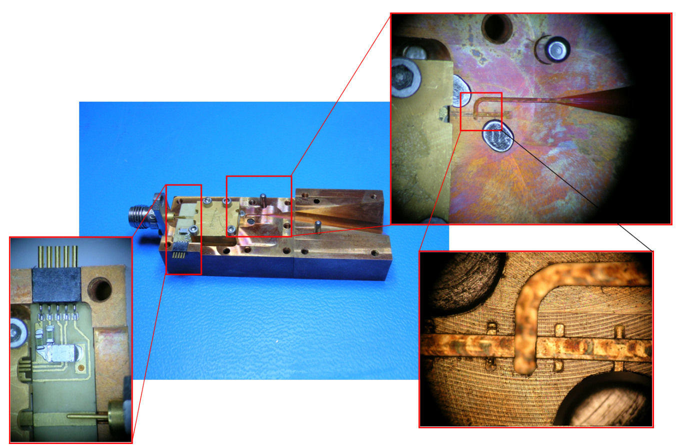

Fig. 5. A single pixel showing an enlarged SIS device and MMIC amplifier.

The output 5 GHz IF signal of each SIS device is immediately directed into a MMIC LNA. One pixel is shown in Figure 5. The amplified IF signal is then conveyed via semi-rigid coax to a vacuum flange. Outside the dewar each IF signal is downconverted to baseband in an IF Processor Box. Each of the 8 IF Processor Boxes downconverts the IFs from a 1x8 mixer array. Both the MMIC modules and IF downconversion boxes were designed and built at Caltech by Sander Weinreb's

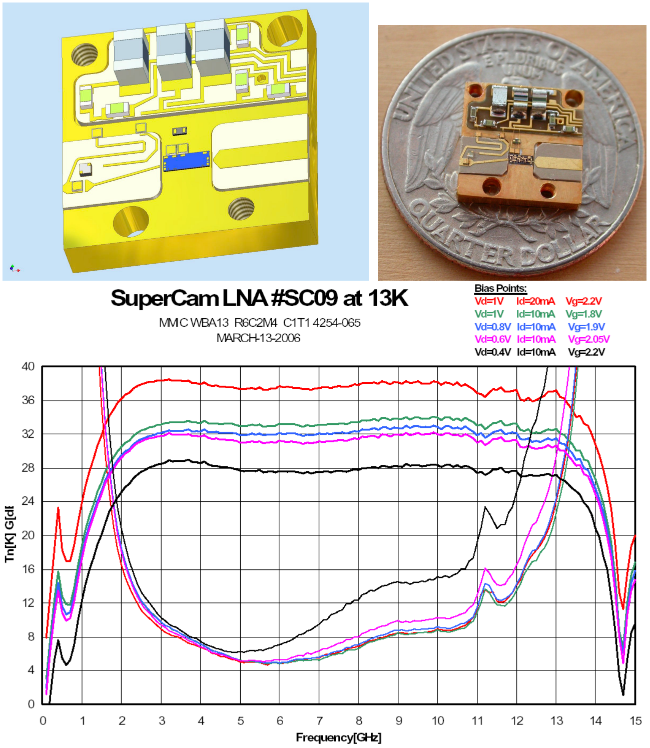

Fig. 6. A CAD drawing of MMIC amplifier drawing alongside its photograph (top) and its measured performance in a 13 K bath temperature along several bias points (bottom).

group. Figure 6 contains a CAD drawing of a MMIC amplifier in the top left panel. In the top right panel a photograph of an actual MMIC is shown with a quarter that has been placed for size comparison. The bottom figure shows the performance of a typical MMIC with measured gain and noise data at 4mW through 20mW power dissipation. The noise is remains unchanged down to 6mW (1; 2). Tests have shown that these amplifiers are stable in the integrated configuration and do not overheat the SIS devices (3). With only 8mW of power, the IF modules achieve a ∼5 K noise and 32dB of gain (1; 2).

C. Local Oscillator

A Virginia Diode, Inc. multiplier chain consisting of a chain of a single quadrupler and three subsequent doublers provides LO signal to the mixers. The output power of the multiplier chain is divided into 64 beams using a waveguide power divider and transmitted via an array of 64 diagonal feedhorns to an identical feedhorn array attached to the mixer modules in the cryostat. The LO power divider was machined at the University of Arizona using a Kern MMP micromilling machine. The signal is uniformly spread to each pixel on the ∼10% level (1; 2).

D. IF Bias System

The IF bias system controls the SIS bias voltage, electromagnetic current, and the biasing of the LNA gate and drain stages. The electronics are contained in two boxes, the pre-amplifier box and the bias box as seen in Figure 2. The pre-amp box was designed and built at the University of Massachusetts. The bias box was designed and constructed at the University of Arizona.

There are 8 bias cards. Each card provides all the required bias signals for a 1x8 mixer subarray. Each card has its own Technological System TS-7200 single-board-computer. The TS-7200 runs a TCP/IP socket server that provides all I/O to each board via Ethernet. To connect to the socket server a variety of clients can be used; including a graphical user interface (GUI), a script interface, or an interactive command line.

E. IF Processors

The warm IF Processor boxes downconvert each SuperCam IF signal to baseband for input into the spectrometer. The system consists of 8 printed circuit boards, each handling 8 SuperCam channels. There are switchable filters for the 250 MHz and 500 MHz bandwidth modes of the spectrometer (1; 2)

F. Spectrometer

Recent advances in the speeds of analog-to-digital converters (ADCs) and field programmable gate arrays (FPGAs) have enabled Omnisys AB of Sweden to build the SuperCam spectrometer in a single box. These advances have driven down the costs of spectrometers, which would have consumed the entire instrument budget in the past. A total of 8 boards are used each constructed with 4 ADCs that feed into a single Virtex 4 SX55 FPGA. A single board is shown in the top left of Figure 7. Each board can process either four 500MHz bandwidth signals or two 1GHz bandwidth signals in real time. Power consumption is 25 W per board. The FPGAs are easily reconfigurable and the spectrometer can be expanded to increase bandwidth. The spectrometer connects to the outside world via Ethernet (1; 2).

In its current configuration the spectrometer can process 64x250 MHz IF signals, 32x500 MHz IF signals, or 16x1 GHz IF signals. In the 64x250 MHz configuration the upper and lower sidebands signals are power combined. The Allan time with the IF downconverters is ∼ 250s, top right of Figure 7 (1; 2). The bottom of Figure 7 is a picture of the spectrometer in its entirety.

G. Optics

The SuperCam optics were designed to convert an f/13.8 beam, the beam after the HHSMT secondary mirror, to a ∼f/6 beam. Smaller f/#'s reduce the overall size of the instrument. The optics will be mounted in the Apex room of the HHSMT along with the cryostat and all of the electronic equipment (1; 2).

The optics system consists of 7 mirrors; 5 flat mirrors and 2 curved mirrors mounted to a steel support structure. The mirrors are made from nickel plated, aluminum. They were polished to near-optical quality to permit laser alignment. The polishing process utilized smaller and smaller grit sizes (down to 1μm) until a laser beam could be reflected with minimal speckling.

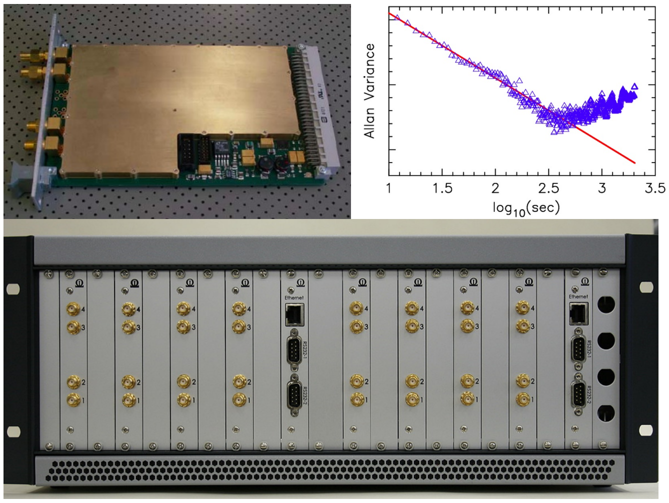

Fig. 7. A single spectrometer board (top left), the Allan Variance (top right), and the total SuperCam spectrometer (bottom).

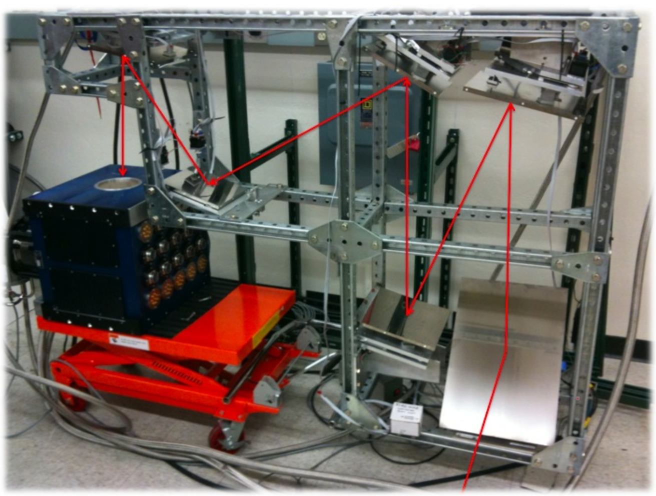

Fig. 8. The optical support structure in the lab at the University of Arizona with the optical path of the light drawn in. Mirror 1 is the pickoff mirror from the tertiary and is not pictured.

Initial alignment of the mirrors is performed mechanically with a FARO portable coordinate measuring arm (to be discussed in a separate paper) and then by laser. To facilitate alignment, each of the mirrors is mounted on a motorized, tip-tilt stage. A photograph of the optical system is provided in Figure 8. The optical path is indicated in red.

IV. Laboratory Results and Current Status

We have completed the fabrication and full assembly of all 64 pixels. These are installed in the SuperCam cryostat, shown in figure 9 with their diagonal feedhorns. After cooling the cryostat to 4 K, there are currently 52 live devices, 64 working LNAs, and 59 working magnets. The bias and preamp boxes have been fully tested and all 64 channels are working. The aluminum mirrors have been nickel-plated and polished to optical quality. Additionally, the optical support structure has been assembled with all mirrors and is currently undergoing alignment. The LO has been attached and is being aligned to provide power evenly to all 64 pixels. An end-to-end test has been performed on 8 pixels using a 345 GHz test signal. Each pixel simultaneously detects the tone. These results are shown in Figure 10. Preparations in the apex room of the HHSMT are underway for SuperCam to be installed this coming fall.

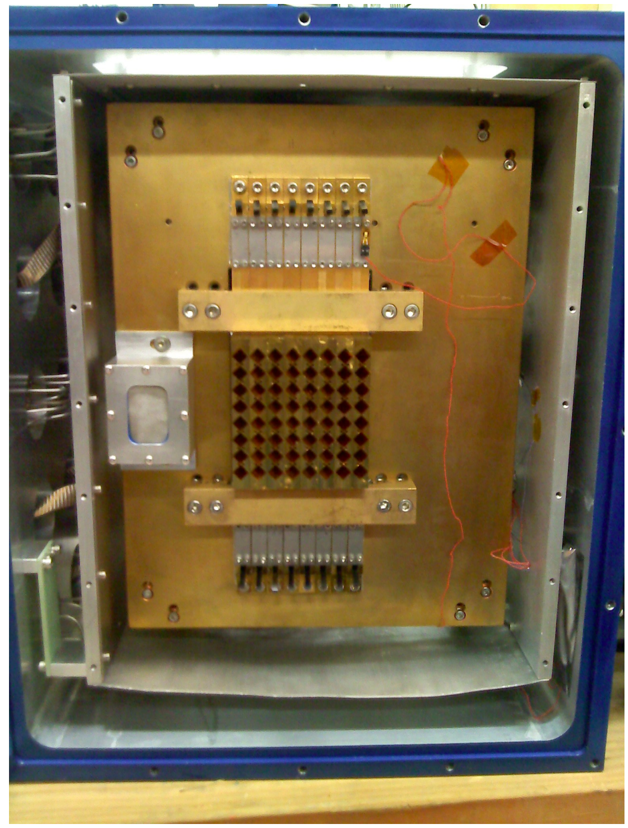

Fig. 9. All 64 pixels installed in the SuperCam cryostat.

V. Conclusions

SuperCam is a leap forward in the realization of a fully integrated heterodyne array for THz astronomy. The 64 pixel SuperCam imaging spectrometer is now fully assembled and is undergoing performance tests. SuperCam will be installed on the HHSMT in Fall 2011. Once installed, SuperCam will be initially used to survey the Milky Way in the ^{12}CO J$=3\rightarrow2$ line. These maps will provide new, valuable insights into the life cycle of the ISM and the inner working of our Galaxy.

Acknowledgments

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References

[1] C. Groppi, C. Walker, C. Kulesa, D. Golish, J. Kloosterman, S. Weinreb, G. Jones, J. Bardin, H. Mani, T. Kuiper, J. Kooi, A. Lichtenberger, T. Cecil, P. Puetz,

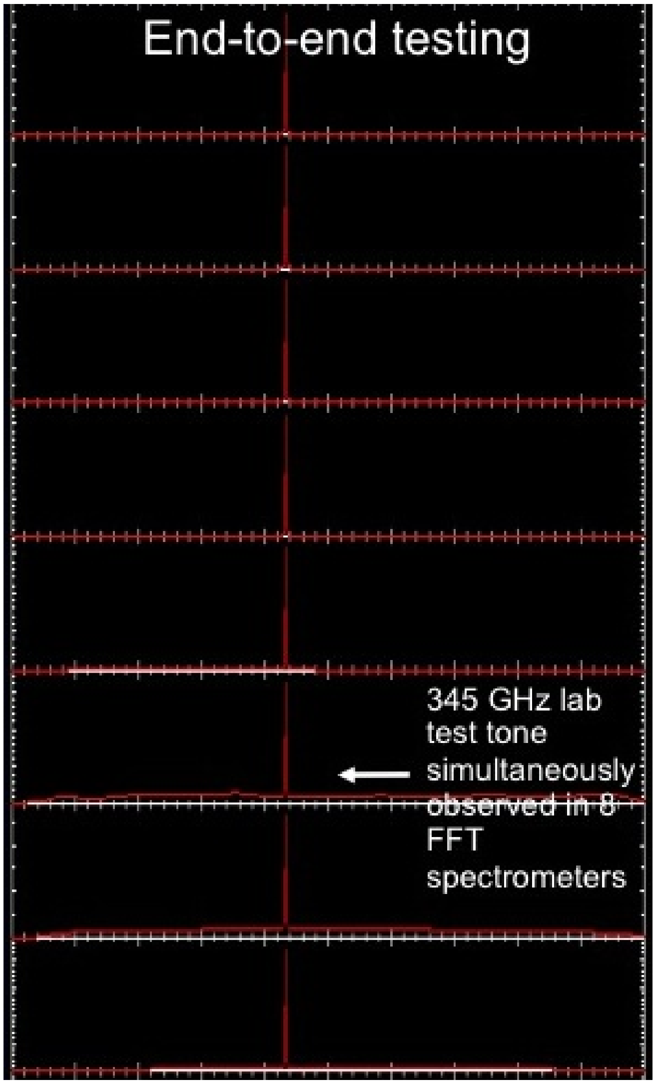

Fig. 10. 8 simultaneous spectra from an end-to-end test using a 345 GHz test signal.

G. Narayanan, and A. Hedden, “Test and integration results from SuperCam: a 64-pixel array receiver for the 350 GHz atmospheric window,” in *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, ser. Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference, vol. 7741, Jul. 2010.

[2] C. Groppi, C. Walker, C. Kulesa, D. Golish, J. Kloosterman, S. Weinreb, G. Jones, J. Barden, H. Mani, T. Kuiper, J. Kooi, and A. Lichtenberger, “Testing and Integration of Supercam, a 64- Pixel Array Receiver for the 350 GHz Atmospheric Window,” in *Twenty-First International Symposium on Space Terahertz Technology*, Mar. 2010, pp. 368–373.

[3] P. Pütz, A. Hedden, P. Gensheimer, D. Golish, C. E. Groppi, C. Kulesa, G. Narayanan, A. Lichtenberger, J. W. Kooi, N. Wadefalk, S. Weinreb, and C. K. Walker, “345 GHZ Prototype SIS Mixer with Integrated Mmic Lna,” *International Journal of Infrared and Millimeter Waves*, vol. 27, pp. 1365–1379, Oct. 2006.