



Scanning Terahertz Heterodyne Imaging Systems

These systems could reveal a wealth of information on biological and material specimens.

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Scanning terahertz heterodyne imaging systems are now at an early stage of development. They were recently conceived as means of probing biological specimens and samples of materials to obtain information complementary to that obtainable from imaging systems that utilize other parts of the electromagnetic spectrum (e.g., visible light or x rays). Emerging applications for scanning terahertz heterodyne imaging systems include studies of terahertz contrast mechanisms in biological samples, pump-probe excitation of phonon modes in liquids and solids, studies of effects of terahertz irradiance on functions and forms of living cells, and studies of spectral signatures indicative of binding and structures of protein molecules.

Scanning terahertz heterodyne imaging systems using continuous-wave (CW) radiation offer the wide dynamic ranges and high signal-to-noise ratios characteristic of narrow-band high-spectral-resolution systems. As such, they also invite comparison with other terahertz imaging systems that utilize short-pulse time-domain spectroscopy (TDS), which is extremely powerful as a diagnostic technique but typically involves limitations in dynamic range and spectral resolution. One especially notable result of these differences is that in wet tissues, terahertz TDS systems are limited to penetration depths of the order of microns, while terahertz heterodyne systems can reach depths of the order of millimeters. Because the capabilities afforded by the terahertz heterodyne concept are partly complementary to those afforded by the terahertz short-pulse TDS concept, imaging systems based on these concepts could be used as complements to each other to obtain more information than could be obtained by use of either system alone.

In a basic scanning terahertz heterodyne imaging system, (see Figure 1) two far-infrared lasers generate beams denoted the local-oscillator (LO) and signal that differ in frequency by an amount, denoted the intermediate fre-

quency (IF), chosen to suit the application. The LO beam is sent directly to a mixer as one of two inputs. The signal beam is focused to a spot on or in the specimen. After transmission through or reflection from the specimen, the beams

are focused to a spot on a terahertz mixer, which extracts the IF outputs. The specimen is mounted on a translation stage, by means of which the focal spot is scanned across the specimen to build up an image.

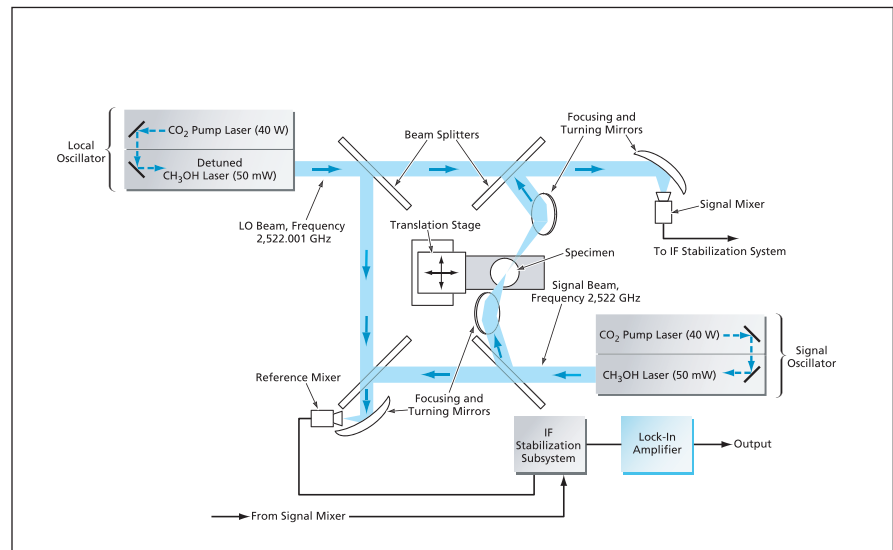


Figure 1. This Scanning Terahertz Heterodyne Imaging System incorporates an IF stabilization subsystem. This system is capable of a dynamic range of 10^9 , a penetration depth of 5 mm, a stability of 0.1 dB, and a resolution of 0.4 mm. The image-acquisition speed — about 30 pixels per second — is limited by the speed of the translation stage.

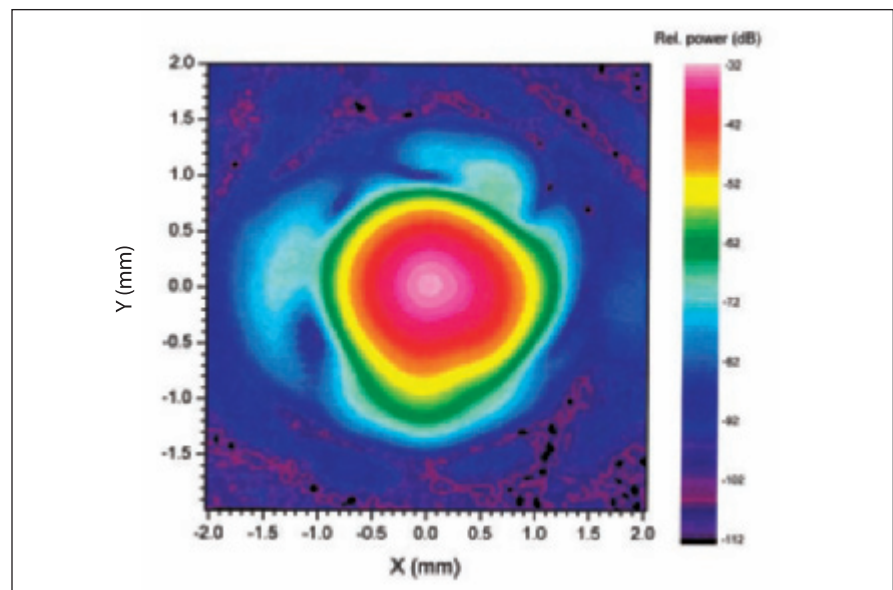


Figure 2. A 2.5-THz Laser Beam is imaged through a 150-micrometer diameter pin hole. Noise floor is -100 dB below peak detection level (0 dB).

The performance of the basic scanning terahertz heterodyne imaging system is limited by a number of factors, the most prominent one being frequency instability of the lasers. The figure depicts a more complex prototype system that incorporates an IF stabilization subsystem that increases the achievable frequency stability and dynamic range. This system utilizes two mixers denoted the reference and signal mixers, and the signal from each laser is split into two beams denoted the reference and signal beams. One of the lasers is slightly detuned so that their frequencies differ by an IF between 1 and 3 MHz. The IF outputs of the two mixers are equal in frequency; however, they differ in amplitude and phase because of the loss and phase shift suffered by the signal beam that passes through the

specimen and impinges on the signal mixer.

The IF output of the signal mixer becomes one of two inputs to a third mixer that is part of the IF stabilization subsystem. In a fourth mixer that is also part of the IF stabilization subsystem, the IF output of the reference mixer is mixed with a stable 14.6-MHz oscillator signal, and the resulting signal becomes the other input to the third mixer. The output of the third mixer and thus the output of the IF stabilization subsystem is a signal that has a stable frequency of 14.6 MHz but exhibits variations in amplitude and phase according to the loss and phase shift of the signal beam passing through the specimen. An improved system with an IF of 24 GHz has now been completed with a dynamic range of 100 dB

(Figure 2), 100 pixels/second, and penetration of 25 mm.

This work was done by Peter Siegel and Robert Dengler of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

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Master Clock and Time-Signal-Distribution System

This system has a modular, flexible architecture and is user-friendly.

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A timing system comprising an electronic master clock and a subsystem for distributing time signals from the master clock to end users is undergoing development to satisfy anticipated timing requirements of NASA's Deep Space Network (DSN) for the next 20 to 30 years. The developmental system is intended to supplant the aging DSN frequency and timing subsystem (FTS), which, while historically reliable, is complex, has limited distribution capacity and has become increasingly difficult to operate and sustain. This system has a modular, flexible, expandable architecture that is easier to operate and maintain than the present FTS. Replicas of this system could be useful in laboratories and other facilities in which there are stringent timing requirements that could include requirements to distribute precise time signals over long distances.

The system [to be installed in each Deep Space Communications Complex (DSCC) in the original DSN application] includes three major hardware assemblies interconnected by an infrastructure of fiber-optic cables (see figure). One major hardware assembly is the master clock assembly (MCA), wherein time signals are generated in synchronism with a 100-MHz reference signal from an atomic frequency standard, denoted the "online" standard.

The MCA is set to Universal Coordinated Time and generates a system time code (STC) for distribution of time-of-day and timing-rate information to the entire DSCC. The STC is sent, via fiber-optic cables, to a distribution assembly (DA). The DA contains 10 distribution modules (DMs), each of which reconstitutes the STC and transmits the signal, either to a second-stage DA for additional fan-out or to a time-code translator (TCT), which serves as a timing reference interface for an end user. The TCT compensates for transmission delays from the MCA and can generate a variety of time codes and pulse rates as required.

The MCA, the DAs, and the TCTs reside in standardized chassis that are hot-swappable and include dual redundant power supplies. The MCA and DA chassis are identical; the TCT chassis are different and match those of the TCTs of the FTS. The back of each TCT can accommodate four plug-in modules to provide different time-code and pulse rate outputs.

For high reliability, the system includes, from the perspective of each end user, two flywheel oscillators. One flywheel oscillator is part of the MCA. The main purpose of this flywheel oscillator is to maintain MCA time in the event of loss or interruption of the reference sig-

nal from the online standard. While the timing performance slowly deteriorates in the absence of the reference signal, the complex remains operational until the reference signal can be restored. A second flywheel oscillator is part of each TCT. This oscillator enables the TCT to continue to generate time-code and pulse-rate outputs in the event of interruption of time signals anywhere in the distribution infrastructure. The TCT flywheel oscillator is allowed to run for a holdover interval up to 12 hours — more than enough time for diagnosis and repair.

This system is designed to be user-friendly, requiring minimal expertise and minimal human intervention for clock setup and diagnosis of faults. In the original DSN application, operators already have an overabundance of status and fault information to analyze. In this system, the only status or fault information provided to operators is that which facilitates isolation of a failure to the module level. Local alarm indications in a TCT, visible as lighted front-panel light-emitting diodes (LEDs), are summed together and communicated back to the applicable DA by simply blanking one pulse of a 1-pulse-per-second monitor return signal. A missing-pulse detector circuit in each DM in each DA responds to a