Frequency Domain Terahertz Spectroscopy

David S. Kurtz, Thomas W. Crowe, Jeffrey L. Hesler, David W. Porterfield
Virginia Diodes Inc.

Abstract

A frequency domain terahertz spectroscopy system was developed to operate from 210-270 GHz. A multiplier chain ending with a broadband sextupler provides several milliwatts of power, and a heterodyne receiver measures the transmission through materials under test with better than 0.5% accuracy.

Introduction

Chemists have long measured the absorption of molecules to study their structure and to identify the composition of unknown samples [i]. Advances in submillimeter-wave technology are enabling the development of improved spectrometers in this spectral region with the possibility of providing compact systems for detection of chemical and biological warfare agents [ii]. A coherent all solid state spectroscopy system operating from 210-270 GHz was developed that provides extremely high resolution and better than 0.5% accuracy. This system is potentially very compact and affordable and the fundamental technology will be extended to achieve full waveguide band coverage throughout 100 – 1,000 GHz frequency range.

I. The Transmitter and Receiver

The 210-270 GHz spectroscopy system, sketched in figure 1, uses heterodyne detection to accurately measure the transmitted signals through a material under test. The all-solid-state source consists entirely of commercial products that yield several milliwatts from 210-270 GHz. A voltage controlled YIG oscillator is used to generate the initial signal. The signal is then multiplied by a factor of four and amplified by a Spacek [iii] active quadrupler to yield several hundred milliwatts from 35-45 GHz. An integrated VDI multiplier (WR-4.3x6) is then used to increase the frequency by a factor of six with an output power of several milliwatts. All of the components are broadband and thus the source can be rapidly swept across the entire frequency range from 210 to 270 GHz simply by changing the control voltage.

The transmitted signal mixes with a Local Oscillator (LO) in a VDI subharmonic mixer (wr3.4SHM). The resulting Intermediate Frequency (IF) at 1.7 GHz is then amplified, detected, and read by a computer. Due to the fixed, narrow bandwidth of the IF amplifier, the LO is locked to the transmitter. This was accomplished using a sideband upconverter to produce a slightly offset sideband of the signal from the YIG oscillator. This sideband is filtered by a YIG, amplified by a Spacek 35-45 GHz active quadrupler, and multiplied by a VDI tripler (WR-8x3) to provide the LO for the subharmonic mixer so that the IF is set at 1.7 GHz.

Although our earlier systems successfully used direct detectors to measure the transmitted signal, the heterodyne system provides more dynamic range which allows faster, more accurate measurements.

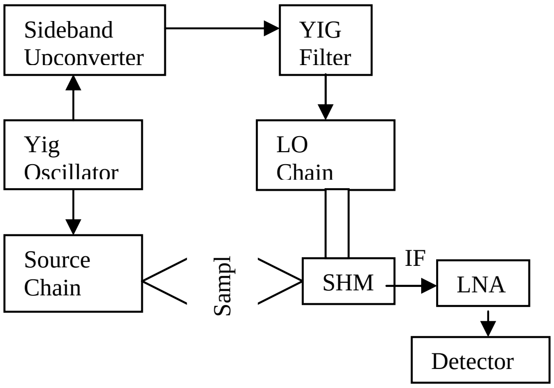

Fig. 1: Spectroscopy system block diagram.

II. The System Optics

The spectroscopy system was designed to measure TEM mode transmission through material films in free space. The signal radiated into free space using a horn antenna on the rectangular waveguide output of the VDI sextupler. Two off-axis parabolic mirrors collimate and then focus the beam through the material under test. Two other off-axis parabolic mirrors collimate the transmitted signal and focus onto the receiver.

Reducing standing waves is a necessary challenge in order to obtain accurate measurements. For the measurements reported in this paper blocks of absorber were used on either side of the material-under-test to reduce standing waves by attenuating the reflected waves. The absorber blocks were placed at angles 45° to the incident beam s that their reflections were not coupled into the system.

III. Measurements

Transmission through a sheet of 2 mil thick mylar, a mesh filter, and Salmon DNA were measured from 210-270 GHz. Repeatability was improved by averaging each frequency point for 5 seconds. Also, it is necessary to measure with and without the sample in order to calculate the percent transmitted. A sweep of 20 points would require 100 seconds for the entire sweep. Unfortunately, the source power level can drift over this time period introducing errors into the measurement. Therefore, a motor was used to move the sample in and out of the beam for each frequency measured. A computer was used to change the YIG frequency, move the sample in and out of the beam, and then measure and graph the results. Figure 2 shows the transmission through mylar compared to simulated results demonstrating the accuracy of the system.

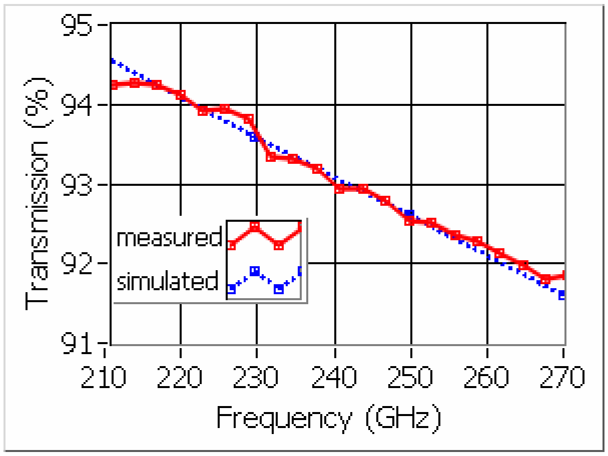

Fig. 2: Measured transmission through 2 mil thick mylar compared to simulation.

Figure 3 shows measurements of Salmon DNA provided by Dr. Tatiana Globus from the University of Virginia [iv]. The material was spread thinly onto saran wrap held by a 2 inch diameter washer. Figure 4 shows a 1.5 inch diameter mesh filter [v] that achieves maximum transmission near 223 GHz.

IV. Conclusion

A solid state heterodyne spectroscopy system operating from 210-270 GHz was developed and used to measure various materials. These initial measurements demonstrate the accuracy and usefulness of the system. Although this spectrometer was developed on a laboratory bench, the basic design is suitable for applications requiring portability. Also, more sophisticated optics will be implemented to provide greater control over the beam and thereby improve measurement accuracy. We are also developing systems with greater tuning bandwidth throughout the 0.1 – 1.0 THz frequency range.

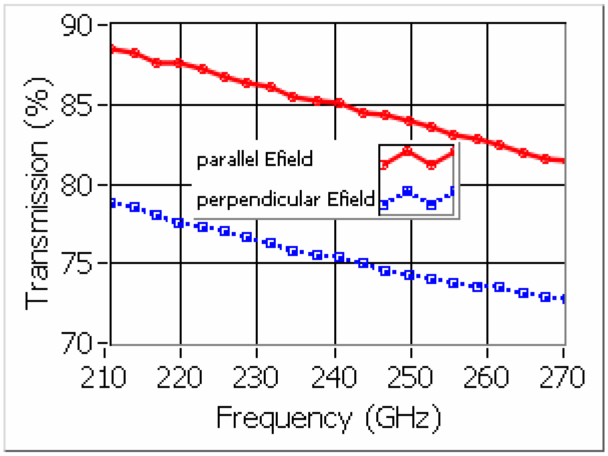

Fig. 3: Transmission through Salmon DNA with the electric field aligned parallel and perpendicular to the fibers.

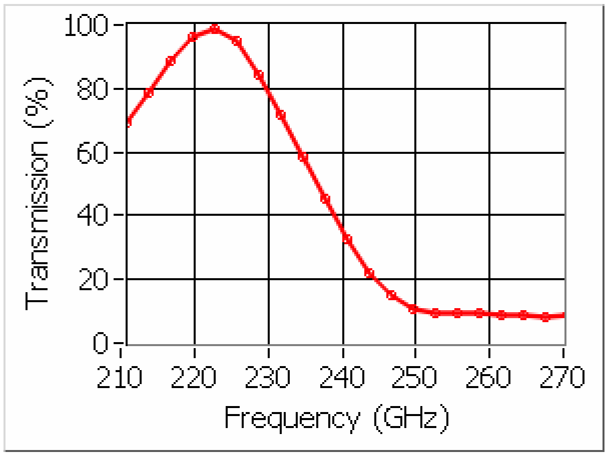

Fig. 4: Transmission through a 1.5 inch diameter metal mesh filter.

Acknowledgement

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References

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