AD-A248 557

CUMENTATION PAGE

2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
1 February 1992	Final Technical – 1 Oct 88 – 31 Dec 91

4. TITLE AND SUBTITLE

(U) Detecting Microwave Emissions from Terrestrial Sources: A Feasibility Study

5. FUNDING NUMBERS

PE – 61102F
PR – 2308
SA – CS
G – AFOSR 88-0257

6. AUTHOR(S)

Thomas C Ehlert and Thomas K Ishii

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Marquette University
Milwaukee, Wisconsin 53233

8. PERFORMING ORGANIZATION REPORT NUMBER

AFOSR-TR. 92 0237

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFOSR/NA
Building 410
Bolling AFB DC 20332-6448

DTIC
ELECTE
APR 16 1992
S D
D

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

A Dicke receiver has been designed and constructed in our effort to detect the 22 GHz spontaneous emission from water vapor. The receiver compares the brightness temperatures of two waveguides, one containing gaseous H_2O at low pressure, the other containing dry air. Each waveguide is terminated with polished brass, which provides a low background brightness temperature, at one end and connects to the input of the receiver at the other end. The system is capable of detecting a brightness temperature difference of about 0.2°K. In this experiment, the radiation from water vapor produced the brightness temperature difference between source and reference of 0.28 to 0.33°K. The experimental results proved that emission from water vapor was being detected.

92-09755

14. SUBJECT TERMS				15. NUMBER OF PAGES
Microwave Dicke Absorption Heterodyne Waveguide				14
				16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

SUMMARY

In the beginning of this research, we attempted to set up a heterodyne receiving system based on a spectrum analyzer to detect the emission from steam at 22 GHz, using two reflecting antennas, one at the transmission end with steam passing through the focus of the antenna as the emission source and the other one at the receiving end. These initial attempts to see the analog signal levels changing with and without steam presenting at the transmission antenna were unsuccessful. As another attempt to build a detection system around the spectrum analyzer, a pulse counting technique was used as a means for improving sensitivity. These experiments gave a 25 dB improvement in the sensitivity and indicated an increment in the normalized pulse counting rate of 0.097% when the steam was fed into the transmission antenna.

In analyzing the experimental data, several questions arose: 1. how much power is due to the emission from the steam; 2. how sensitive must the heterodyne receiver be in order to detect the signal directly; 3. how can the signal be extracted from the system noise? In order to answer these questions, methods used in radioastronomy were investigated. A Dicke receiver was designed and built for the further research. This receiver alternately looked at two waveguides, one filled with water vapor as an emission source and the other one filled with dry air as a reference. Both waveguides were gas tight so that the pressure and gas content in the waveguides could be controlled. The receiver compared the

brightness temperatures of the two waveguides. By controlling the gas content in the waveguides and the water vapor pressure of the source waveguide, the experimental results proved that radiation from water vapor was being detected.

OBJECTIVES

The objective of this research was to determine the feasibility of detecting discrete, spontaneous microwave emissions from terrestrial sources.

<u>The specifications</u>:

<u>terrestrial</u> distinguished these experiments from the accomplishments of radio astronomers who routinely detect such emission from astronomical sources;

<u>microwave</u> distinguished the experiments from the accomplishments of spectroscopists who routinely observe emissions in the infrared, visible, and ultraviolet spectral regions;

<u>emission</u> distinguished these experiments from microwave absorption spectroscopy, a well-developed methodology;

<u>spontaneous</u> distinguished these experiments from the accomplishments of researchers who obtain discrete microwave emissions from laboratory sources through the application of electric fields; and

<u>discrete</u> indicated that these experiments concern emission at certain frequencies rather than the continuum emitted by hot solids, liquids, and dense gases.

2

STATUS OF RESEARCH

A Dicke receiving system has been designed for the detection of spontaneous microwave emission from water vapor at 22 GHz. A block diagram of the receiving system was shown in Fig. 1. The receiver compared the brightness temperatures of two waveguides, each 8.8 meters long, one containing water vapor as the emission source, the other containing dry air as a reference. Each waveguide was terminated by a brass plate. Both waveguides were connected to a single pole double throw switch (SW), followed by a 22 GHz low noise amplifier (LNA), a mixer, a local oscillator (LO), a 30 MHz itermediate frequency (IF) amplifier, a detector, and a lock-in amplifier. The output data of the lock-in amplifier was collected by a data acquisition system. The output signal level of the lock-in amplifier represented the difference in brightness temperatures of the source and reference chambers.

The emissivities of the brass plates were measured as 0.0869 (source) and 0.0805 (reference), respectively. At room temperature (290 K), the brightness temperatures of the brass plates can be calculated as 25.20 (source) and 23.35 (reference) K, respectively. The brightness temperatures at the input of the LNA were calculated using radiative transfer equation

$$T_o = T_B \exp(-\alpha \cdot l) + T_m [1 - \exp(-\alpha \cdot l)] \qquad (1)$$

where T_o is brightness temperature of a background with brightness

temperature T_g passing though a medium with path length l and absorption coefficient α. The absorption coefficients of the water vapor-filled waveguide (source) and dry air-filled waveguide (reference) are, respectively

$$\alpha_S = \alpha_W + \alpha_{WV}$$
$$\alpha_r = \alpha_W$$

(2)

where α_s is the absorption coefficient of source chamber and α_r is the absorption coefficient of reference chamber. α_w is the absorption coefficient of the waveguide; which includes the insertion loss of the adapters, the waveguide itself, cables and the switch. α_{wv} is the absorption coefficient of water vapor. Our experiments showed that the measured α_w for the reference chamber at f=22.37 GHz was between -7.14 dB and -8.89 dB and for the source chamber was between -7.47 dB and -8.58 dB. α_w is given in ranges because the observed values changed when the coaxial cable position or shape was changed.

The absorption coefficient α_{wv} can be calculated by Eqs.(3) and (4)

$$\Delta v = 2.58 \times 10^{-3} (1 + 0.0147 \frac{\rho_v T}{P}) \frac{P}{(T/318)^{0.625}}$$

(3)

$$\alpha_v = 3.24 \times 10^{-4} \exp(-644/T) (\frac{vP\rho_v}{T^{3.125}})$$
$$\times [\frac{1}{(v-v_o)^2} + \frac{1}{(v+v_o)^2}] + 2.55 \times 10^{-8} \rho_v v^2 \frac{\Delta v}{T^{3/2}}$$

(4)

where α_v is absorption coefficient of water vapor at frequency v in

4

cm^{-1}, $\Delta\nu$ is half-level-line width in GHz, ν is the observation frequency in GHz, T is the path-medium-temperature in K, P is the total pressure in millibars, and ρ_v is the water vapor density in grams per cubic meter. For ν=22.34 GHz (subtract the IF frequency 30 MHz), T=290 K, P=19 mmHg, ν_o=22.235 GHz, the absorption coefficient of α_{wv} is 7.73E-6 cm^{-1}. Using Eqs. (1) and (2) the brightness temperature of reference chamber was between 238.48 and 255.57 K. The brightness temperatures of source chamber were between 242.58 and 253.28 K without water vapor in the waveguide and between 242.91 and 253.52 K with water vapor in the waveguide. Therefore, emission from water vapor can increase the brightness temperature by 0.28 to 0.33 K.

The sensitivity of the designed Dicke receiving system can be calculated by

$$(\Delta T)_{min} = 2\frac{T_{sys}}{\sqrt{t_{LF}\nu_{HF}}} \qquad (5)$$

where, $(\Delta T)_{min}$ is the sensitivity of the receiver in K, T_{sys} is the equivalent noise temperature of the system which includes the input brightness temperature and the effective noise temperature of the receiver, t_{LF} is the time constant of the low pass section of the lock-in amplifier, and ν_{HF} is the bandwidth of IF amplifier. For this designed receiver with an LNA (noise figure 4.8 dB and gain 30 dB) at the front end, the effective noise temperature was about 585.79 K. For an input brightness temperature of 250 K, T_{sys} was about 835.79 K. The IF bandwidth was 1 MHz, and the time constant

5

of the low pass section was measured to be 72 seconds. The sensitivity of the receiver was calculated to be 0.2 K.

The output signal levels of the lock-in amplifier vs. time with water vapor in the source chamber and dry air in the reference chamber is plotted in Fig. 2. In this experiment, initially, both chambers were filled with dry air. From time 0 to 120 seconds, the phase shifter of lock-in amplifier was adjusted to produce zero output. From time 120 to 420 seconds the phase shifter of lock-in amplifier was increased 90 degrees, and the output of the lock-in amplifier was no longer balanced. This signal level was due to the original brightness temperature difference between the source chamber and the reference chamber because of the different α_w and T_B of both chambers. From time 420 to 720 seconds the source chamber was filled with water vapor, and the pressure of the water vapor was at 18.9 mmHg. The magnitude of the output signal level increased because the emission from the water vapor increased the brightness temperature of source chamber. From time 720 to 960 seconds the phase shifter was reduced by 90 degrees, and the output of lock-in amplifier returned to zero. From time 960 to 2880 seconds the same process was repeated twice. The output signal level of the lock-in amplifier vs. time with the water vapor in the reference chamber and dry air in the source chamber is plotted in Fig. 3. The original brightness temperature difference between the two chambers was decreased due to the emission from water vapor increasing the brightness temperature of the reference chamber, as seen in Fig. 3.

The observed signal level difference between two chambers with water vapor pressure in the source chamber varied is plotted in Fig. 4. Also, the theoretical absorption coefficient of water vapor vs water pressure is plotted in Fig. 5. It is clear that the figures have similar tendencies.

PUBLICATIONS

1. "Digital Video Integrating Technique for Faint Signal Measurement", *The proceeding of 33rd Midwest Symposium on Circuits and Systems*, Aug. 1990.

2. "Pulse-Counting Technique Enhances Receiver Sensitivity", *Microwave & RF*, Apr. 1991.

PERSONNEL

Thomas C. Ehlert, Ph.D. 1963, "Mass Spectrometric Studies at High Temperature".

Thomas K. Ishii, Ph.D. 1959, "Cascaded Reflex Klystron Amplifier".

Shuming T. Wang, MS. 1988, "Design of Microwave Down Converter".

INTERACTIONS

1. Paper presented: "Digital Video Integrating Technique for Faint Signal Measurement", at the 33rd Midwest Symposium on Circuits and Systems, Aug. 12-14, 1990, Calgary, Canada.

DISCOVERIES AND INVENTIONS

The papers published in Midwest Symposium and Microwave & RF describe a new technique called "Digital Video Integrating Technique". This technique can improve the sensitivity of conventional heterodyned receiver up to 35 dB.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

Although the experimental results have shown that it is feasible to detect discrete, spontaneous emission of 22 GHz radiation from water vapor in a laboratory, it is important to understand that such experiments need not to be limited to water vapor, nor to the 22 GHz region, nor to waveguide-confined samples, nor to a particular pressure. In our experiment, in order to prove the signature of radiation from water vapor, the receiver was tuned slightly away from the center radiation frequency (22.235 GHz) at 22.34 GHz so that the pressure dependency of the radiation signal can be seen. For the receiver tuned at center radiation frequency, decreasing the pressure of the water vapor will not significantly reduce the detection sensitivity.

The designed Dicke receiver can reach a sensitivity of 0.2 K. The sensitivity can be further improved by increasing the bandwidth of the IF amplifier and reducing the insertion loss of components such as the coaxial cable.
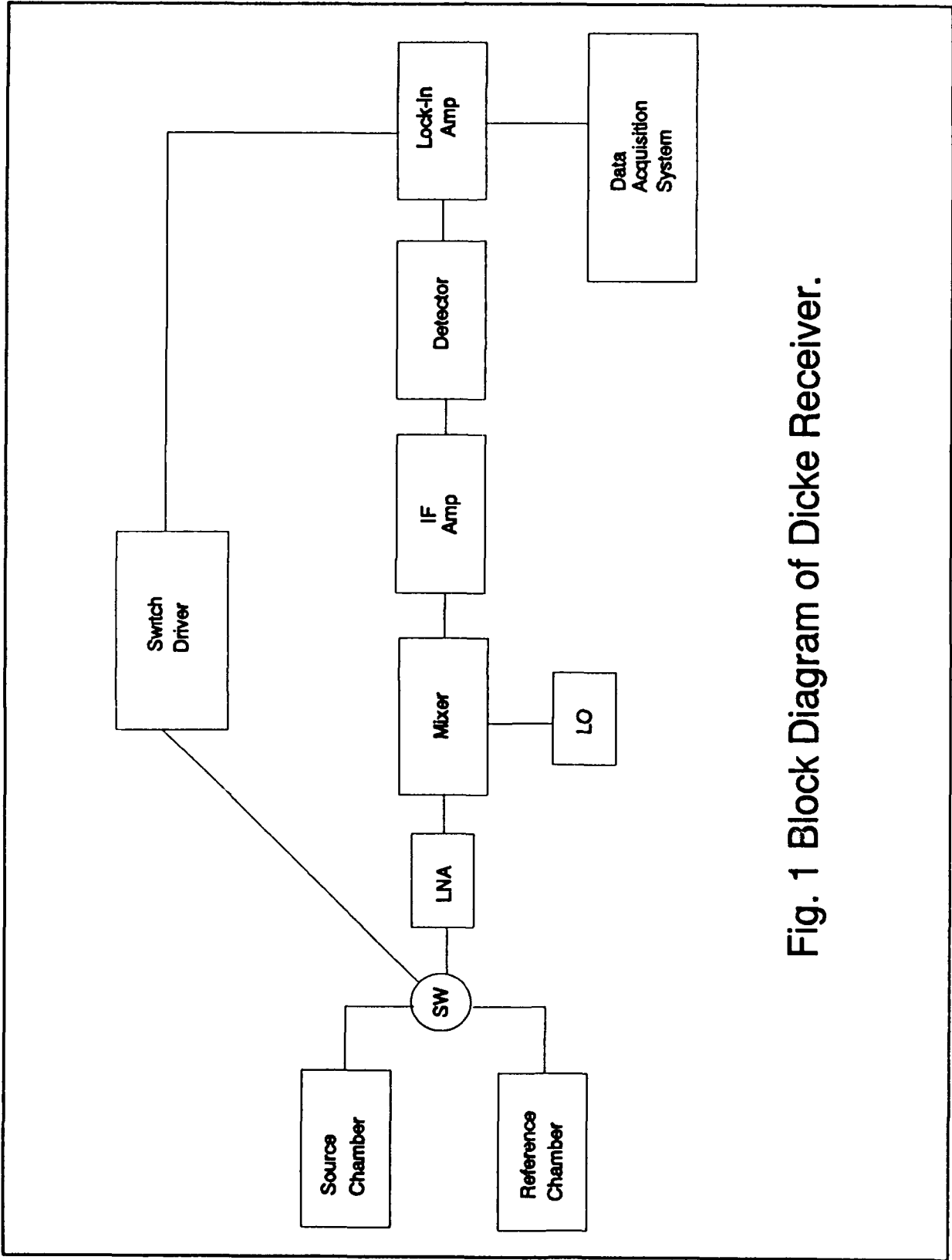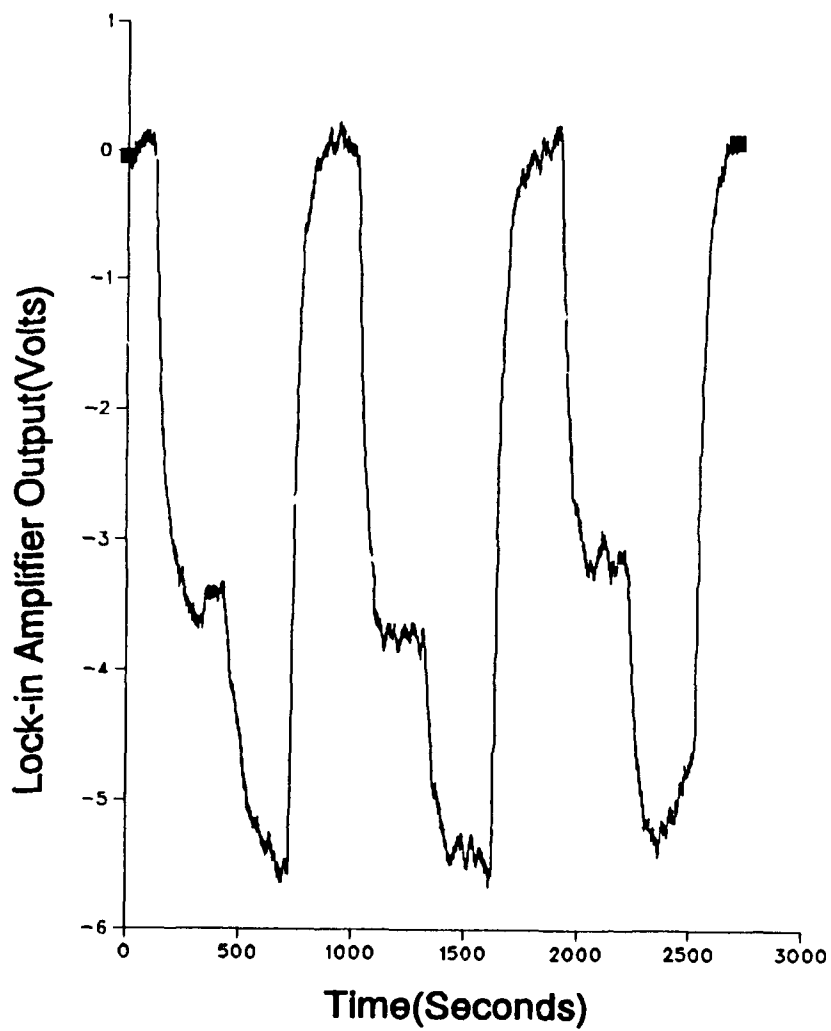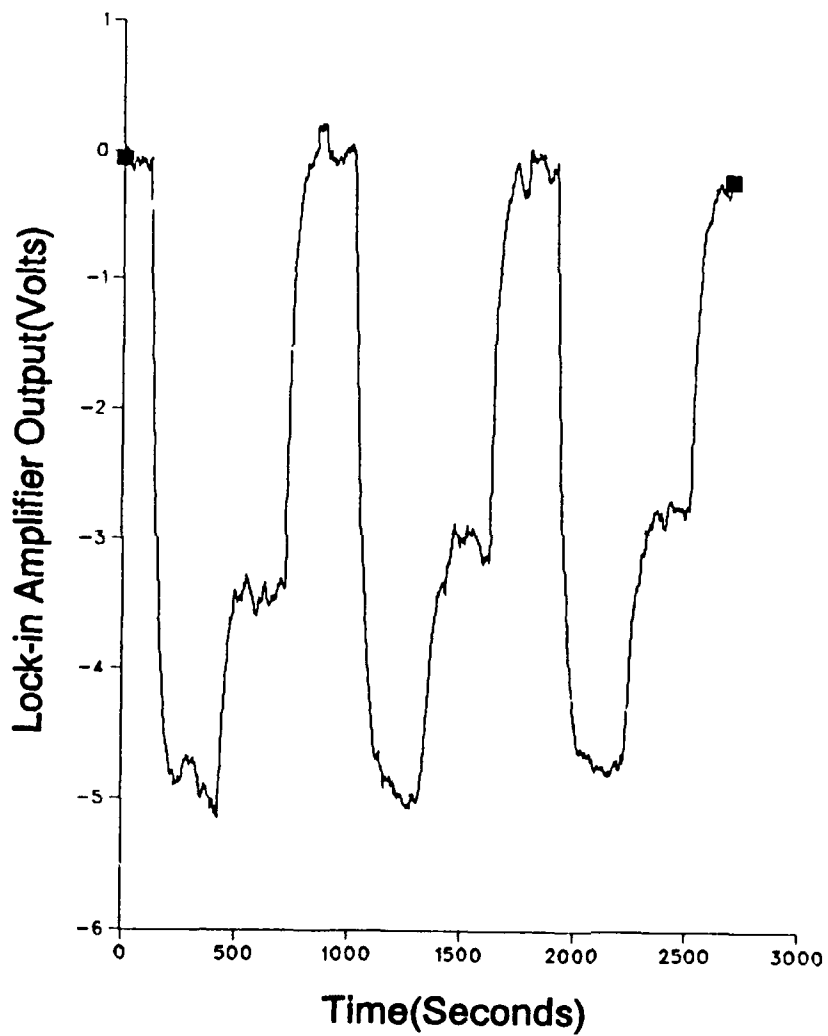
Fig. 1 Block Diagram of Dicke Receiver.

Fig. 2 Lock-in Amplifier Output vs. Time.
Source Chamber: H$_2$O Pressure=18.9 mmHg.
Reference chamber: Dry air.

Fig. 3 Lock-in Amplifier Output vs. Time.
Source Chamber: Dry air.
Reference Chamber: H_2O Pressure=19.1 mmHg.

Fig. 4 Magnitude of Lock-in Amplifier Output
Difference vs. Water Vapor Pressure.
Source Chamber: Water vapor.
Reference Chamber: Dry air.
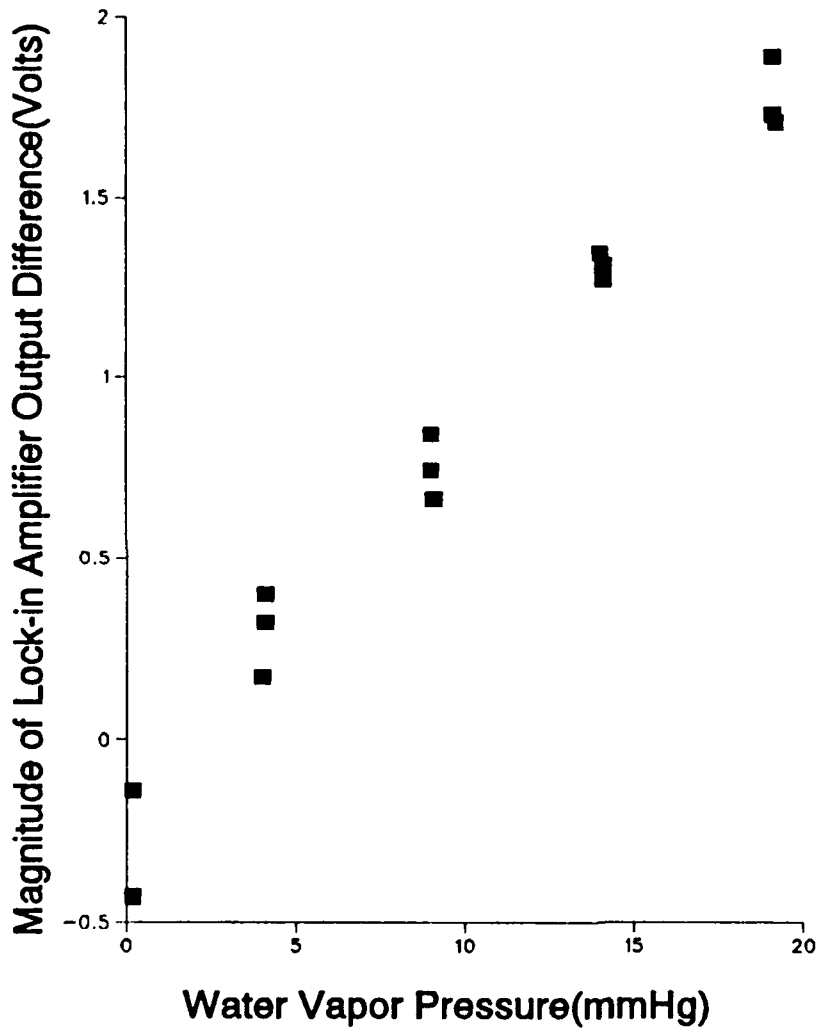
Fig. 5 Water Vapor Absorption Coefficient vs. Pressure
f=22.34 GHz.