RANGE MEASUREMENT OF NONREFLECTING AND REFLECTING TARGETS USING INTERACTION OF ULTRASOUND AND MICROWAVES

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ABSTRACT

A new measurement technique for simultaneous remote range and temperature determination is reported, which utilizes the microwave (10.0 GHz) backscatter from a travelling ultrasound wave (about 22 KHz) /1/. For the first time, such a system is operated in a closed environment which suffers from clutter echoes. Maximum range in the order of 30 m can be measured with an accuracy of better than 1%. Multiple targets are detectable with a resolution of at least 2%. The air temperature profile along the path can be determined with the same local resolution and with an accuracy of better than ± 0.10° C.

INTRODUCTION

Noncontacting distance measurement at close range is a problem which is often encountered in industry or traffic surveillance. Standard solutions to this task are the application of ultrasonic pulse radars or microwave FMCW-radars. However, if more than one target is involved or multipath transmission due to specular reflections in various directions takes place, the target echo is distorted and the range measurement often fails.

Sometimes, the wanted echo completely disappears due to absorption or destructive interference at the target. All measurement principles which rely on target reflections fail in the above mentiond situations. In this paper, a new measurement technique and instrumentation is described, which overcomes the above mentioned problems, and experimental results are given.

SYSTEM OUTLINE

System operation
In order to be independent from uncertain target reflections, the system utilizes the microwave backscatter from a travelling ultrasonic pulse as an artificial reflector. The presented measurement set-up operates at a microwave frequency of 10.0 GHz with an ultrasonic frequency of about 22 KHz. Preliminary results have been reported in /1/. Similar measurement principles have been used previously for meteorological purposes /2/, /3/ at much lower frequencies (1 KHz sound and 500 MHz RF) for the measurement of the temperature profile in the lower troposphere.

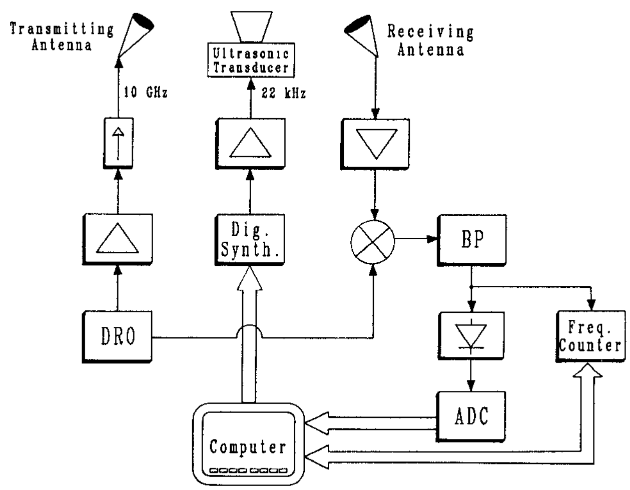

Fig. 1: Block diagramm of the measurment system.

A block diagram of the measurement system is shown in Fig. 1, and a photograph is presented in Fig. 2. The fundamental concept employed is the tracking of ultrasonic pulses by a doppler radar. This is possible, because the compression and rarefaction of air by an ultrasound wave forms a travelling grid pattern formed by a modulation of the refractive index. A power piezo-transducer /4/ is used as an acoustic antenna to meet the special requirements of the sounding system. This antenna has a narrow beamwidth of approximately 5° and good efficiency. Fig. 3 shows the measured pressure-pattern. In order to increase the useful measurement range, the transmitted acoustic power has to be maximized. However, an upper limit is given by the possible generation of shockwaves, which can be avoided by using a sufficiently large transducer surface.

The microwave antennas are arranged such, that the microwave backscatter signal returned by the spherical acoustic wavefronts is focused into the receiving antenna. The ultrasonic wavelength is tuned to be exactly half the electromagnetic wavelength in order to maximize the backscatter amplitude /2/. The transmitted microwave power of 1 W is generated by a FETDRO, followed by a power amplifier. The suppression of the oscillator FM-noise is important because, if the system is operated in a closed environment, a strong direct microwave reflection from the target may exist. The FM-noise of this signal will be discriminated, and will appear at the IF-output of the mixer. The measured spectrum of the received signal is shown in Fig. 4. A strong spectral line at the center frequency represents the direct microwave reflection from a target at 4.5 m distance. At a frequency offset of 22 KHz the wanted doppler information is present, which is well above the noise of the main reflection, hence indicating, that the stabilization of the oscillation frequency is sufficient.

Experiments show, that the maximum range, at which the doppler return exceeds the noise level, is about 30 m in a closed room, and approximately 40-50 m in the open air, where direct reflections disappear. The received signal is bandpass-filtered, rectified, A/D-converted and then processed in a desktop computer.

The actual velocity of sound is crucial, since range information is derived from travelling time. For this purpose the described system determines the spatial velocity distribution. From that, the correct range can be calculated. As an additional information the temperature profile can be found.

Assuming an ideal gas, speed of sound is given by /5/

$$V_s = \left(\frac{\tau R T}{M}\right)^{\frac{1}{2}} = K_d \, T^{\frac{1}{2}} \quad ,$$

where τ is the ratio of the specific heats, R is the gas constant, M the apparent molecular weight, and T the temperature in K. The coefficient K_d varies slightly with humidity (in dry air, K_d = 20.0528 $m \cdot sec^{-1} \cdot deg^{-1/2}$). Thus, information about the combination of these quantities is contained in the doppler-frequency f_d, which is related to the speed of sound by

$$f_d = \frac{2 V_s}{\lambda_e} \quad ,$$

where λ_e is the electromagnetic wavelength.
In order to measure the doppler frequency, a frequency counter at the IF-output is used. The transmitted ultrasonic wave is generated by a highly stable digital-synthesizer and gated under control of the computer, to give an integer number of entire cycles per pulse. A similar gate is created, which can be varied in length and positioned anywhere across the travelling time of the pulse in order to trigger the frequency counter. Hence temperature can be measured at any required position with high spatial resolution and high accuracy, by averaging the counted frequency over a certain period of time.

EXPERIMENTAL RESULTS

Experiments were performed in closed laboratory rooms with calm air. To our knowledge, the work described here is the first successful attempt to demonstrate ultrasonic and microwave interaction of waves in a closed environment.

Range measurements

In order to maximize the backscatter signal, the frequency of the transmitted ultrasound was adjusted to be equal to the doppler frequency. Between 5 and 50 acoustical cycles were used, corresponding to a range resolution between 0.08 and 0.75 m. Measurement results are displayed in Fig. 5. The antennas are directed perpendicular to the endwall of a laboratory room. As already mentioned, in this case the direct microwave reflection is maximum. Considering trace (A), the sound reaches the target after a travelling time of 13.66 ms, corresponding to a distance of 4,70 m (temperature 21.8° C, V_s = 344.28 m/s). Traces (B) and (C) show the same measurement, where a solid reflector (0.5 x 0.5 m) was brought into the antenna beams as a subtarget at different positions. The capability of the measurement-system for multi-target detection and the insensibility against clutter is clearly demonstrated. It shall be mentioned, that the range measurement could operate even if the targets would be absorptive for sound and microwaves. The differentiated trace of Fig. 5B is shown in Fig. 6. Positions of the subtarget and the target can clearly be detected.

Temperature measurements

The same number of ultrasonic cycles as for range measurements was used for temperature determination. Hence a similar accuracy for the localisation of a temperature profile is obtained. The local resolution capability is demonstrated by Fig. 7. A hot plate was installed at a certain position 1 m below the antenna beam, and trace (A) was recorded with the plate at ambient temperature (20,2° C). Then the plate was gradually heated up. The increase of the air temperature leads to a decrease in backscatter amplitude as can be seen from traces (B) and (C), taken after 5 min (23.5°), and 10 min (25.6° C), respectively.

Measurement accuracy for temperature depends on signal amplitude and averaging time, which was varied between 10 s and 10 min. Under optimum conditions an accuracy of ±0.05° C can be reached, limited by the stability of the oscillators and the frequency counter. Under more practical circumstances, the accuracy is ±0.25° C for the worst case.

CONCLUSIONS

The possibility of simultaneous range and temperature measurements in a closed environment is demonstrated, using microwave backscatter from a travelling ultrasonic pulse as a sounding signal. An experimental system is described and measured results are given. Special features of the system are high insensibility against clutter echoes, multitarget-measurement-capability and good range accuracy and resolution.

ACKNOWLEDGEMENT

This project has been supported by the Deutsche Forschunsgemeinschaft under grant kn 253/1-2.

REFERENCES

/1/ Daas, M., Knöchel, R.: Compact Sounding System Using Microwaves and Ultrasound. IEEE MTT-S Digest, 1989, Long Beach, pp. 257-260.

/2/ Marshall, J.M., Peterson, A.M., Barnes, A.S.: Combined Radar Acoustic Sounding-System. Applied Optics, vol. 11, 1972, pp. 108-112.

/3/ Frankel, M.S., Chang, N.J.F., Sanders, M.J.: A High Frequency Radio Acoustic Sounder for Remote Measurement of Atmospheric Winds and Temperature. Bull. Am. Met. Soc., Vol. 58, 1977, pp. 928-934.

/4/ European Patent Application 039986, G10K 11/02.

/5/ Gray, D.E., Ed., 1963: American Institute of Physics Handbook, 2nd Edition. New York, McGraw-Hill, pp. 3-64.

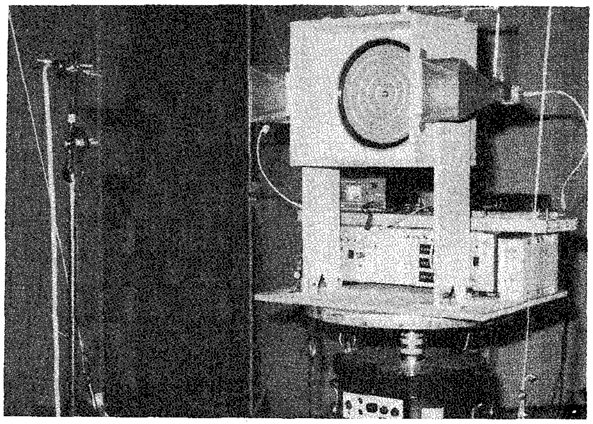

Fig. 2: Photograph of the system

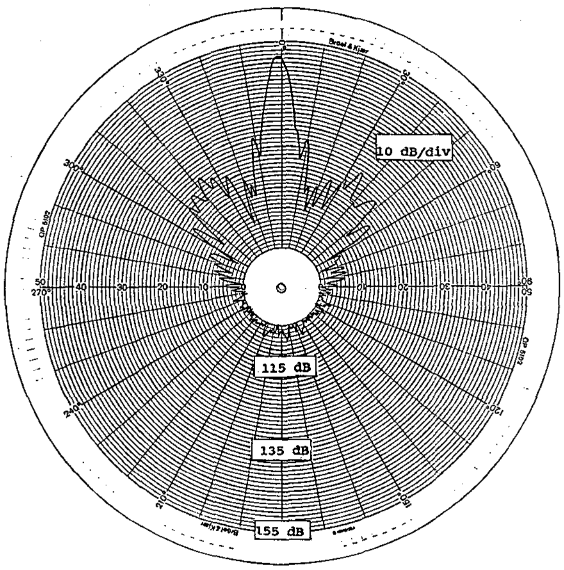

Fig. 3: Pressure-pattern of the transducer

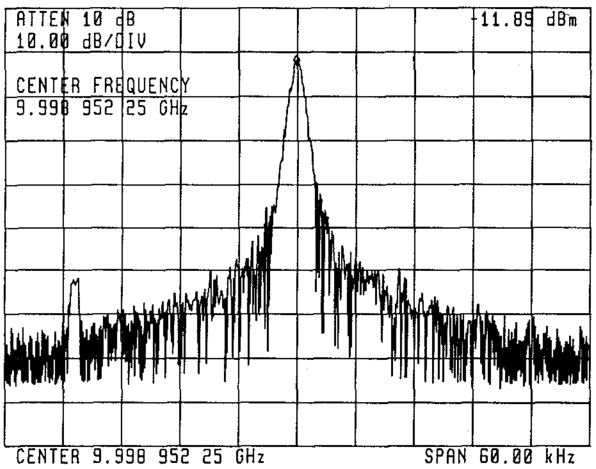

Fig. 4: Spectrum of the received signal

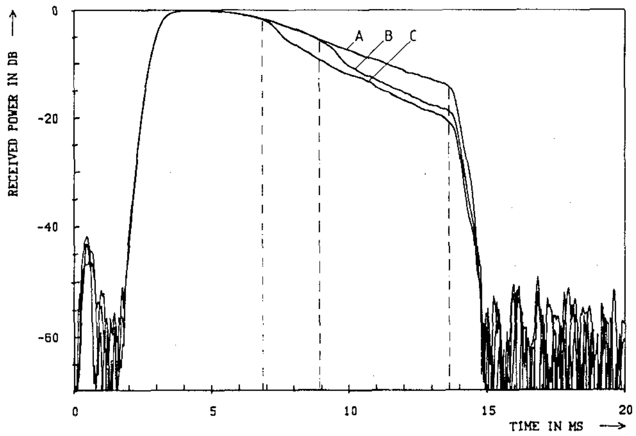

Fig. 5: Range measurement in a closed laboratory room, using the endwall as the target (A), and with a subtarget at various positions (B) and (C)

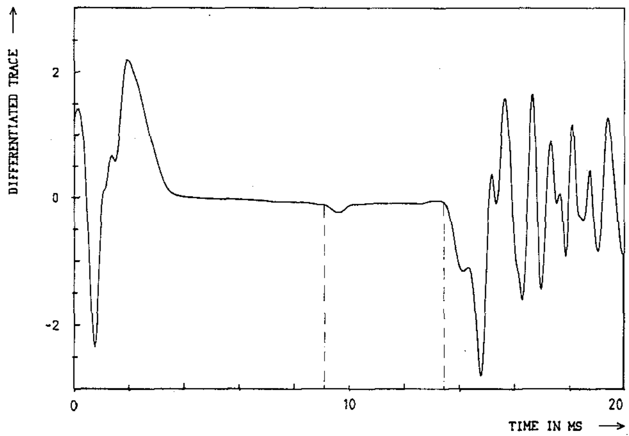

Fig. 6: Differentiated trace of Fig. 5B. Positions of the subtarget and the target can clearly be detected

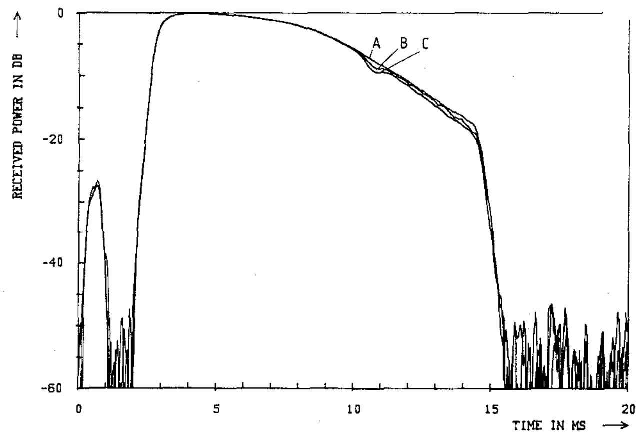

Fig. 7: Local resolution for a temperature measurement (a hot plate)