COMPACT SOUNDING SYSTEM USING MICROWAVES AND ULTRASOUND

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ABSTRACT

A compact sounding system is described that uses the radar return from a transmitted pulse of ultrasound (22 kHz) for temperature determination and for range measurement of targets. The targets may be nonreflective for ultrasound or microwaves or may show reflections, which can not be used in conventional radars. Technical details are given and experimental results are described for temperature profiling and range determination.

INTRODUCTION

Radar-Acoustic Sounding Systems are sometimes used in meteorology for the remote measurement of temperature profiles in the lower troposphere [1], [2]. Typically such sounding systems are designed to reach heights up to several thousands of meters and therefore are operated with radar frequencies between 40 MHz and 500 MHz, corresponding to acoustic frequencies between 100 Hz and 1 kHz. The reason for this is, that only low acoustic frequencies can propagate in the atmosphere over a long distance without too high attenuation. The long range, that is reached, is accompanied by a coarse range resolution, and, due to the low acoustic frequencies, very large acoustic arrays are needed in order to transmit the sound wave. Due to the huge size of such an array of acoustical sources, the systems are not mobile. In addition, they do not work below a height of approximately 100 m.

This paper deals with a sounding-system which operates at X-band and uses a pulse of ultrasound (22 kHz) as an acoustical signal. It is a very compact measurement system, that can readily be transported, and, therefore, can conveniently be installed in vehicles or, for instance, at a mast or tower. It is an experimental system, which is investigated for two applications:

- measurement of the temperature stratification in the nearby range,

- range-measurement up to several tens of meters without needing a reflected signal of the target.

Besides of an application in meteorology, such a small and compact measurement system, although only suitable for narrow ranges, could be useful in industry and possibly in pollution control. It could be used for remote monitoring of thermic emissions, for instance to find leakages in pipelines.

PRINCIPLE OF OPERATION

Since the principle of radar-acoustic sounding is not very well known, it will be described shortly. The basic system arrangement is sketched in Fig. 1. A loudspeaker (array fo 3x3 piezo-transducers, 30x30 cm size) is emitting a strong sound wave (20 W acoustical power), which, after a distance, forms a spherical sound wave. This sound wave, which is propagating, of course, with sound velocity, consists of compressed and expanded air, and hence forms a moving modulation of the refractive index of the atmosphere. In principle, this variation of the dielectric constant can be "seen" by a doppler radar, which is part of the measurement system.

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The doppler radar consists of a dielectrically stabilized FET-oscillator (DRO) at about 10 GHz and a power amplifier, which feeds approximately 0.5 W of power to the transmitting horn antenna (20 dB gain). The receiving antenna (same type of antenna) is coupled to a low noise FET amplifier (NF = 1.8 dB, 40 dB gain), which is connected to a double balanced mixer (DBM, Conv. loss 6 dB). The mixer converts down the received signal, using the DRO signal as the LO. The received signal is filtered, evaluated and then displayed.

The doppler signal normally is very small. However, it can be increased considerably by two steps:

- The acoustical array and the microwave antennas have to be arranged confocally; the transmitted microwave power, reflected by the sound is then focused to the receiver;
- the microwave-wavelength is tuned to be twice the acoustical wavelength; then the microwave reflections add coherently, i.e. the well known Bragg-condition is fulfilled.

It turns out, that the frequency shift of the microwave signal, detected by the doppler radar, is approximately equal to the transmitted acoustical frequency. Hence, in order to measure temperature, the frequency-shift of the return signal is determined. The acoustical wavelength in air is a measure for temperature ϑ, because the velocity v of sound depends on temperature via

$$v(\vartheta) = 331.4 \sqrt{\frac{\vartheta/^{\circ}C + 273}{273}} \; {}^{m}/_{s}$$

A range resolution is obtained by pulsing the acoustical signal. The received signal then decays with time, depending on the acoustical attenuation in air and on the local match between the electrical and acoustical wavelength. Hence temperature information can be resolved over range. Between 10 and 200 acoustical cycles are used, corresponding to a range resolution between 15 and 300 cm. The received amplitude depends of course on the number of acoustical cycles. The signal-to-noise ratio can be improved by averaging over many pulses.

EXPERIMENTAL RESULTS

System operation

Fig. 2 shows the shape of the transmitted signal at 22 kHz: The upper trace shows the transmitted signal, whereas the lower signal illustrates the radar return. After transmission of the acoustical pulse, it takes 9 ms until the radar return appears. This indicates, that for the chosen hardware configuration, the beams of the transmit and receive antennas overlap at a height of approximately 3 m. After that, the return signal decays due to beam spreading and attenuation of the acoustical signal as well as temperature changes.

Fig. 3 shows the rectified return signal, as it is used in the system, where the antennas look vertically into the air.

Fig. 4 shows an example of the same signal, which is digitized with an oscilloscope. The amplitude is normalized to its maximum, and data are converted to their logarithmic value. Then the signal decays linearely with time or distance, if the temperature is constant across the range. As can be seen, this is approximately true in Fig. 4. The maximum range corresponds to about 26 m.

Temperature measurement

The temperature has been measured at a height of 8 m on 22nd of November 1988. Results are depicted in Fig. 5. Measurements were made between houses with a height of approx. 8 m, which gave the possibility to measure a reference temperature with a thermometer.

Distance measurement

Besides of the temperature measurement capability, and as a novel application, the microwave-ultrasound sounding system can be used for range measurements of targets, which may be non-reflective or which show a specular reflection under a certain angle, where the reflected beam does not meet the receiving antenna. Here the feature is used, that a received signal is only present, as long as a sound wave is traveling towards the target and as long as the focusing condition is fulfilled. That means, when the sound wave hits the target, the Bragg-reflection of the microwave and hence the received doppler signal disappears. This information can be used for range determination. An eventually existing reflected sound wave has wavefronts, which do not fulfill the focusing condition, therefore the received signal will be small. The reflected microwave signal, even if doppler shifted by an existing movement, will be outside the evaluated frequency range (i.e. 22 kHz) when received.

Fig. 6 shows the radar return, when the microwave--ultrasound signal is directed towards a wall under an angle of 60°. No direct reflection would reach the receiving antenna, i.e. the target could not be measured using a conventional ultrasound or microwave distance meter.

The sound wave reaches the wall after a travelling time of 37 ms, corresponding to a distance of 12.38 m (Temperature 5.5° C, $v_{sound} \cong 334.72$ m/s). The return signal then steeply decays as the sound wave (length 10 ms) is reflected by the wall. A more elaborate signal processing is needed, to extract more information from the signal. The curvature of the received signal (compared to a linear decay) indicates, that the temperature obviously is not constant across the range. However, this temperature deviation could be derived from the signal and corrections for the sound velocity could be made.

Fig. 7 shows a similar range measurement, but with a steeper incidence of the signal at the wall (~ 80°). The time scale of the measurement starts at 20 ms. The transmitted ultrasound pulse appears as a spike due to crosstalk within the system. After a flying time of 36 ms the target is reached. Temperature was 4,5° C corresponding to v_{sound} = 334.1 m/s, i.e. the distance of the target was 12.03 m.

CONCLUSION

A compact sounding system using interaction of microwaves at 10 GHz and ultrasound at 22 kHz has been introduced. Besides the possibility of measuring temperature, the measurement of range has been presented as a novel application. Results are still preliminary, but the interesting feature is demonstrated, that the system is still operational at small distances where conventional distance meters cannot be used.

ACKNOWLEDGEMENT

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REFERENCES

[1] J.M. Marshall, A.M. Peterson, A.S. Barnes: Combined Radar-Acousting Sounding-System. Applied Optics, vol. 11, pp.108-112, 1972.

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

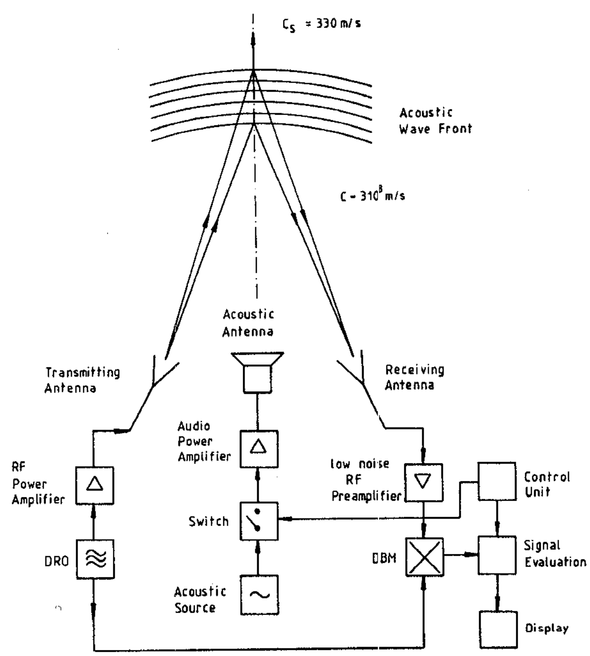

Fig. 1: System arrangement

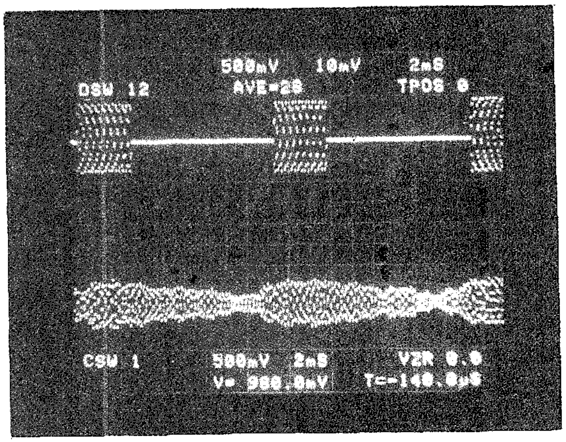

Fig. 2: Shape of the transmitted signal (upper trace) and radar return (lower trace)

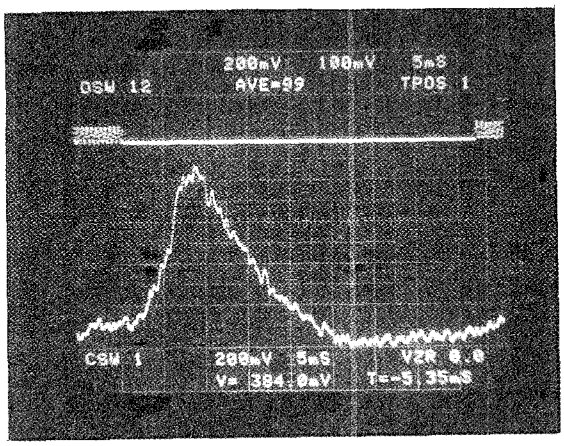

Fig. 3: Rectified radar return

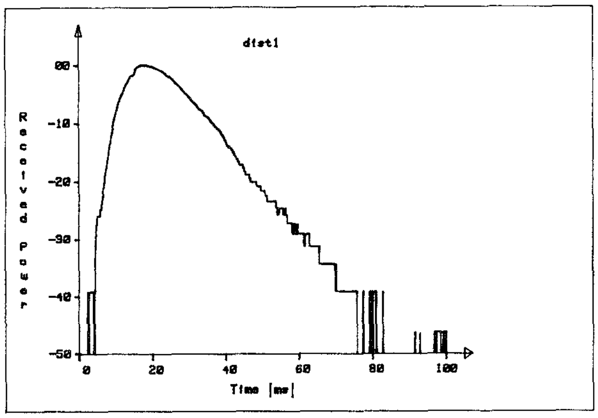

Fig. 4: Normalized Radar return
τ_{pulse} = 10 ms

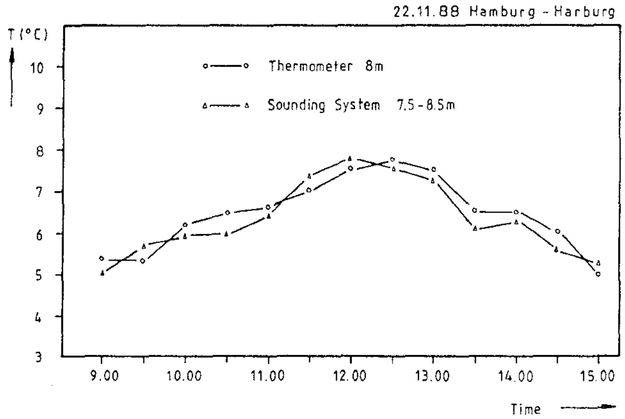

Fig. 5: Comparison of the sounding system data and directly measured temperatures (10 min. av.)

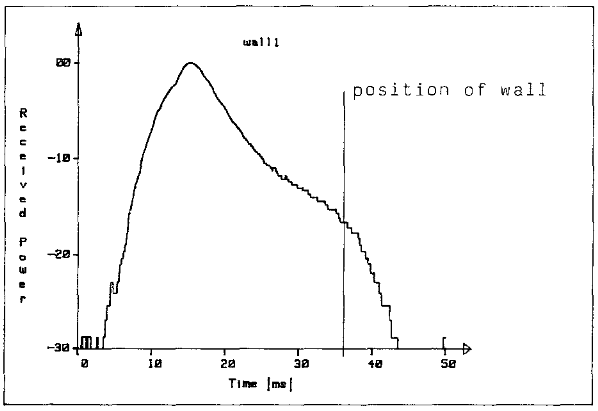

Fig. 6: Range measurement of a wall under an angle of 60°.
τ_{pulse} = 10 ms, v_{ac} = 334.72 m/s

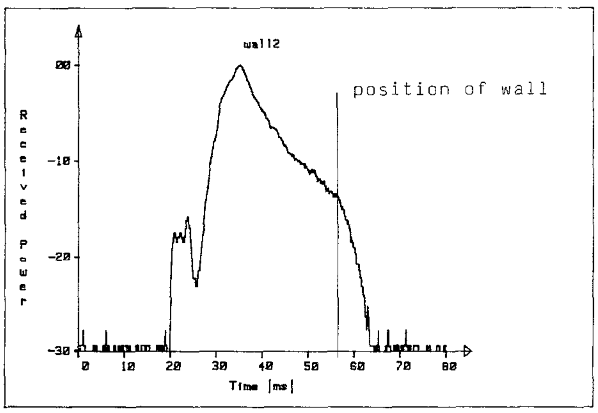

Fig. 7: Range measurement of a wall under an angle of 80°
τ_{pulse} = 10 ms, v_{ac} = 334.1 m/s