The Radar Microphone: A New Way of Monitoring Honey Bee Sounds

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***Abstract*— This paper describes a radar microphone for studying incidental and deliberate insect sounds. It was specifically designed to record the sounds coming from honey bees inside a beehive.**

The sensor is based on a Doppler radar measuring the vibrations of a high dielectric object, such as a bee. It is shown that if the vibrational amplitude is much less that the radar wavelength, the frequency of the mechanical vibration and the frequency of the phase modulation in the reflected radar signal are the same. The instrument was implemented safely and inexpensively with readily available 5.8 GHz wireless components.

The output of the radar microphone is a signal no different from the signal that might be recorded with an acoustic microphone. As such the same data collection and processing techniques can be applied.

Examples are given of vibrations and airborne sounds from bees inside an observation hive.

I. INTRODUCTION

Since honey bees appear to communicate by vibrations, the bee sounds that we hear are likely to be only incidental to their activities [1-3]. Nevertheless, the relation between the health of a bee colony and the buzz coming from the hive is well known. Several patents have been granted for instruments to analyze bee sounds [4-6]. For instance, honey bees emit a characteristic buzz at 120 to 250 Hz. If the frequency increases to 285 Hz swarming may be imminent [4]. However, bees will also make different sounds when the hive is disturbed [7]. Therefore, a non-intrusive technique for monitoring bee sounds is required.

Acoustic methods depend upon inserting a microphone into the bee hive which is disruptive to the bee colony. Acoustic microphones also lack directionality at low frequencies to discriminate against environmental noise.

The proposed technique is based on a Doppler radar measuring the radio frequency modulations due to small mechanical vibrations of otherwise stationary dielectric objects. Radars at 25 GHz and 34 GHz have been developed for detecting surface vibrations with a heterodyne receiver [8, 9]. The present radar uses a much simpler homodyne receiver and operates at a much lower frequency of 5.8 GHz in order to penetrate a wooden box and detect the vibrations of bees inside the hive.

II. THEORY

Consider a continuous-wave Doppler radar as shown in Fig. 1, transmitting an unmodulated signal at frequency ω_o and corresponding wavelength λ_o. We assume that the radar return consists of a large stationary background clutter with amplitude A_1 from a distance R_1, and a small bee with amplitude A_2 from a distance R_2. The bee is assumed to vibrate with frequency ω_m and modulation amplitude m. The input to the radar receiver is then given by

$$s(t) = A_1 \cos(\omega_o t + \phi_1) + A_2 \cos(\omega_o t + \phi_2) \tag{1}$$

where $\phi_1 = 4\pi R_1/\lambda_o$, $\phi_2 = (2\pi m/\lambda_o)\cos(\omega_m t) + 4\pi R_2/\lambda_o$.

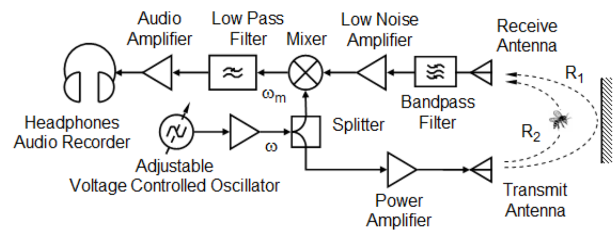

Fig. 1. Radar Microphone Block Diagram

After low-pass filtering the output of the homodyne receiver contains a DC component and an AC component at the modulation frequency

$$\begin{aligned} B(t) \approx \quad & (A_1/2)\sin(4\pi R_1/\lambda) \\ & +(A_2/2)\sin(4\pi R_2/\lambda)(4\pi m/\lambda)\cos(\omega_m t). \end{aligned} \tag{2}$$

Here we have assumed that $A_2 << A_1$ and $m << \lambda_o$.

The DC component in (2) is of no concern provided that it does not degrade the mixer performance. We note that the amplitude of the AC components is proportional to the modulation amplitude, but has nulls spaced $\Delta R_2 = \lambda_o/4$ apart. The nulls can be avoided at the expense of additional hardware, for example, by using an in-phase and quadrature receiver [10]. However, they can also be avoided by judicious adjustment of the radar operating frequency.

III. EXPERIMENTAL RESULTS

Our radar microphone resembled the Doppler radar described in [11] except that it operated in the Industrial, Scientific and Medical (ISM) band from 5.725 to 5.875 GHz and used printed circuit patch antennas. The range window $\Delta R_2 \approx 7.5$ cm adequately accommodated minor bee movements. The operating frequency was manually adjusted to maximize the AC signal. This is a one-time adjustment for any particular radar location.

At low frequencies an acoustic microphone has a more or less omnidirectional pattern. The directionality of our radar microphone does not depend on the frequency of the audio signal. Its beamwidth of about 12 degrees is determined by the combined transmit and receive patch antenna patterns at 5.8 GHz.

The frequency response of the radar microphone was measured with an acoustic vibration speaker with an advertised frequency response of 10 - 1,000 Hz. Compared to a condenser audio microphone, the radar microphone has excellent frequency response below 500 Hz, which is the frequency range of interest, as shown in Fig. 2.

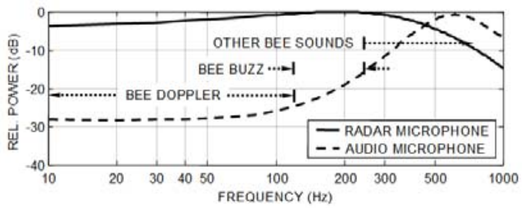

Fig. 2. Frequency Response of Microphones

Radar and acoustic microphone signals from a bee colony in an observation bee hive were recorded at a distance of 15 cm as illustrated in Fig. 3. Normally, the observation window was covered with an 7 mm thick plywood panel. The example of acoustic and vibrational spectrum of a quiescent hive in Fig. 4 suggests that an acoustic microphone might confuse harmonics with the fundamental frequency.

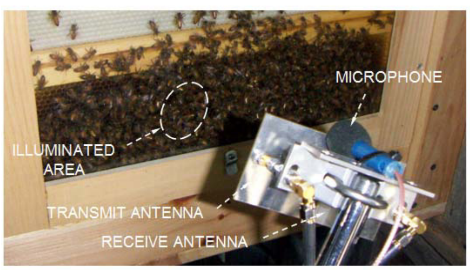

Fig. 3. Observation Hive with Cover Removed

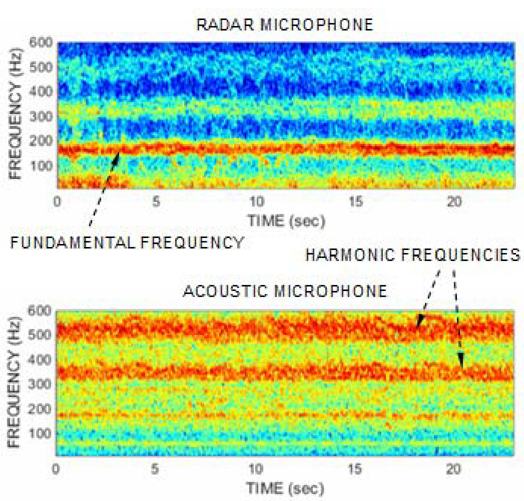

Fig. 4. Bee Sounds of a Quiescent Hive

In Fig. 5 we give an example of sounds made by queen bees [12]. Apparently, there are two queens in this hive. Unless the bee keeper intervenes, there will be a fight and the colony may not survive.

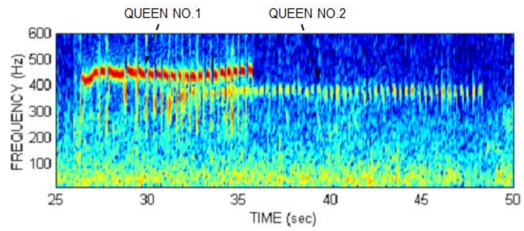

Fig. 5. Queen Bees Tooting and Quacking

IV. CONCLUSIONS

An alternate method of recording bee sounds has been presented. This technique can penetrate the bee hive walls without disturbing the bee colony. It is insensitive to environmental noise and has excellent directivity and low frequency response. It offers a compact and inexpensive instrument for monitoring bee sounds in the field.

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