HYPOTHESIS OF NATURAL RADAR TRACKING AND COMMUNICATION DIRECTION FINDING SYSTEMS AFFECTING HORNETS FLIGHT

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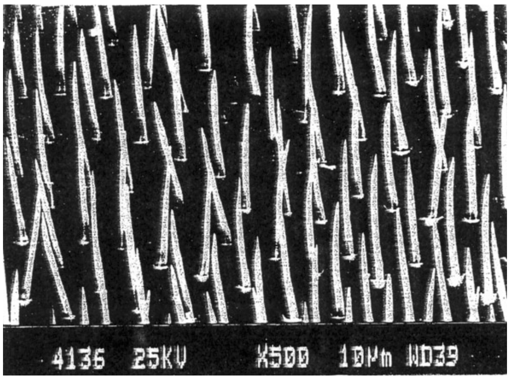
1. INTRODUCTION

We have presented the development of a new hypothesis concerning a natural sophisticated Radio Detection And Ranging (RADAR) navigation system affecting hornets flight. [1,2]. The hypothesis was derived following an investigation of the complex arrays of numerous spikes elements revealed on vespan cuticle (hornet skin) by electron microscopy. [3]. The occurrence of three different lengths of spikes and dispositions of these elements on the hornet vespan cuticle have led to consider them analogous to antennae associated with radio and RADAR theory and practice [4,5]. Thus, we can reach the hypothesis that the different length of spikes represent three transmitting and receiving phased arrays operating at three different frequencies in the sub-millimetric wavelength range, considering the length of the spikes (see Fig. 1) [1,6]).



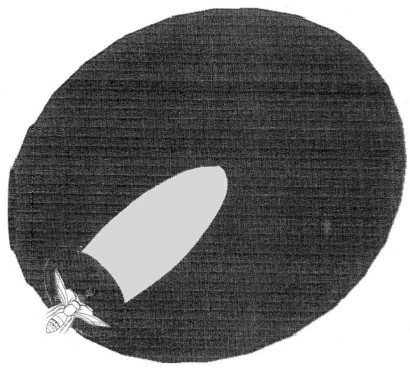


Fig. 1 The denser phased array. As can be seen the spikes are about 55 µm long and at 20-25 µm distance from each other. Those spikes were photographed worker hornet on abdominal segment

Fig 2 .Three Mode Tracking Mechanism of Hornets Natural; RADAR SYSTEMS

The photovoltaic and piezoelectric generation of energy in hornets, reported previously, could provide the Radio Frequency (RF) energy required for the operation of such a natural RADAR system [1,3]. A comparison was made between the well known sophisticated sonar tracking and navigational system of bats vis-a-vis the mode of operation and main parameters of the oriental hornet cuticle spike arrays [2;4].

2. THE NATURAL HORNET RADAR SYSTEM TRACKING ANALYSIS

The three influent frequency ranges fs_n of the oriental hornet workers spikes are: 535, 1365 and 2500 GHz all in the submillimetric wavelenghts. The natural RADAR hypothesis can be strengthened by the facts that under bad weather conditions the hornets activity is very limited due to signal attenuation and in the dark, at night they are not active at all due to the lack of photo electrical energy mandatory for the natural RADAR system operation. [2]

At millimeter waves and lower one the atmosphere has in addition to the Line of Sight (LOS) dispersion, molecular frequency resonances and air moisture losses.
The maximum operation range Rmax can be computed using the equations and simulations methods described in [2] following classical RADAR equation [8]. If we introduce in the realistic values in the equation for different targets RADAR Cross Section (RCS) areas $\underline{\sigma}$ [8]

$$R_{\max} \simeq 50[\sigma]^{1/4}\,\mathrm{m} \qquad (1)$$

Thus about 50m for a person and 5m for an insect.
In case of a frequency switching mode it is logical that the lowest frequency range array with the less directivity and higher operation range is operated first. If the signal reflected from the tracked target exceeds a threshold power level, when the hornet approaches the target, the more directive array at 1365 GHz is switched. When the target is very near the natural RADAR system switch to the highest frequency range as presented in fig. 2 [1].

3. **HORNETS COMMUNICATION DIRECTION FINDER INVESTIGATION AND SIMULATIONS**

Recently it was discovered by a graduate student of Professor Ishay that the two antennae of the oriental hornet are also densely covered by numerous spikes of a few different lengths.
The measured photo-voltaic energy of the hornet antennas is also significantly high and piezoelectrical energy can be generated under flight conditions [9]. Thus, the hornet two antennae, together with the body cuticle provide three different sources of RADAR radiation and reception for detection, localization and tracking of targets as shown in fig. 3.
The measured values of hornet antennae spike elements dimensions results are presented in table 1 which include 4 spikes length species for hornets workers as presented in fig. 4 Table 1 includes the spikes average length l_s in (μm), the respective expected wavelength in (μm) and frequency ranges in (GHz) obtained from the derived relations

$$f_{s_n} \leq 3.10^5 / 4.\,l_{sn} \text{ in GHz} \qquad (2)$$

Also given is the relative number of spike elements with a base of 100 units.

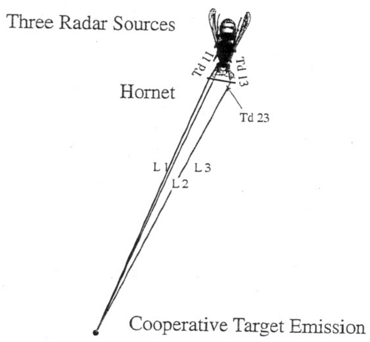


Fig. 3 The Hornet Direction Finding Technique
For Remote Target Detection and Localization

Table 1 : Parameters of the various spines present on the antennae of Oriental hornet workers

A. Workers :

Name of array	Length L_{sn} (μm)	Wavelength Range λ_{sn} (μm)	Frequency Range f_{sn}(GHz)	Base Diameter (μm)	Tip Diameter (μm)	Relative Number ❖
Trichoid	22.6	89.4	3340	2.4	Spine-like	100
Placoid	24.7	98.8	3030	4.6*	-	20

Campaniform	11.9	47.6	6300	7	3.3	5
Agmon	8.9	35.6	8430	3.7	Spine-like	2

The Oriental hornets workers antennae phased arrays frequency ranges are from 3030 to 8430 GHz, and the males from 295 to 9150 GHz, where the lowest frequency array at 295 GHz, with the lowest number of spikes, provide the highest distance operation with the less directivity for the first orientation process as presented in fig. 2. [3]. The fixed distances between the hornet radiating body two antennae and the radiating cuticle enable a new hypothesis of a Direction Finder (DF) technique [10]. The DF technique allow a precise and fast localization and tracking of cooperative targets and extend significantly the operation range of hornets, up to a few thousand of meters using a communication instead of a RADAR system. Thus, the dispersion losses reducing the received signal power level and the distance operation range increase only at a d^2 rate under Line of Sight (LOS) conditions instead of d^4 for the previous RADAR System.[7,8]
Nowadays, the most popular and sophisticated man made DF technique is the Global Positioning Satellite (GPS) system. The GPS provide very precise and fast three dimensions positioning localization by receiving simultaneously microwave signals from at least 3 orbiting satellites [11]. For hornets, the DF technique differ by localizing cooperative targets transmitting a submillimeter signal received by distant three phased array sources located on the searching hornet cuticle body and on the two antennae at fixed distances between themselves.

The DF communication hypothesis enables us to explain how males from remote nests can track and localize queen hornets for mating purposes. The DF communication operation range can be computed using the LOS free space communication link equation (2) using frequencies instead of wavelengths.
where respectively: P_r and P_t represent the power at the receiver antenna input and radiated at the transmitter antenna output in W., G_t and G_r the transmitter and the receiver antenna gain in absolute values. *c* is the light propagation velocity in m/sec, *f* is the radiated frequency in GHz .

$$d = \left[\frac{P_t \cdot G_t G_r \cdot 9 \cdot 10^{-2}}{P_r \cdot 160 \cdot f^2_{(GHZ)}} \right]^{0.5} \qquad (3)$$

The maximum operation range is obtained for the non directive minimum frequency band of f=295GHz for the initial detection position of the queen by the males . Realistic values are: $P_t = 10^{-5}$W, $P_r = 4.10^{-15}$W as shown previously for clear atmospheric conditions $G_t \simeq G_r \simeq 200$. Thus, from equation (7) $d \simeq 800$m.
Due to the diversity technique from the simultaneous detection of different frequency bands by the male hornet the operation range of detection and DF by the male is extended and can exceed 1 km.
The communication DF hypothesis can also explain the localization and the return to their nest of distant hornet workers. It is known that several worker hornets ventilate simultaneously their wings as a group near the nest may be to generate energy and radiate their submillimeter signals similar to a lighthouse beacon function . These multiple radiation sources can be received by the hornet 3 reception centers phased arrays of a remote hornet which provide the DF indications necessary to locate and reach their nest. [8, 10].It was shown that the most efficient radiation is at the worker hornets lowest frequency range of f=535GHz as [3]. If we suppose $P_t = 5.10^{-5}$W, $P_r = 4.10^{-15}$W $G_t = G_r = 500$, we obtain $d_{max} \simeq 2.0$ km.

4. **PRELIMINARY EXPERIMENTAL TESTS AND DISCUSSION**

The German hornets (Paravespula Germanica) have shown that their spikes length around 0.5 mm, correspond to a frequency range of 150 GHz. The existence of these extremely long spikes may be the results of their ecology environment with higher rain quantity, clouds and foliage in central Europe. These lower frequency range enable better Radar tracking and longer distances communication direction finding systems at the 150 GHz millimeter rather than at the submillimeter waves. The one & only suitable laboratory in Israel which could help us to test our hypothesis is the Mm Waves Measurement Lab. of the Electro Optic Research Company at the Technion Research Center in Haifa (Israel). The lab. facilities include a mm waves anachoid chamber and two accurate measurement receivers at 140 and 220 GHz.
Last year we brought to the lab. two wooden and glass covered boxes: the first including about 50 German hornets and in the second tens of Oriental workers and 6 males.
The German type hornets box was installed in the dark anachoid chamber which was illuminated for a period of a few minutes in order to enable them to radiate mm waves. For all the experiments with the 140 GHz receiver the ratio of the received to the background radiation intensity showed an increase of about 1% in light compared to conditions in the dark. However in some cases with 220 GHz receiver the intensity ratio decrease in light conditions. These results are correlated to the estimated hornets radiation frequency of 150 GHz. In comparison, the ratio intensity measurement

results with the Oriental hornets show contradictory results for both 140GHz and the 220 GHz receiver cases. This may be due to the significant frequency differences related to the real hornets radiation frequencies.
The main conclusions from the preliminary experimental results are:

1. The affirmative results obtained with the German hornets at 140 GHz are encouraging but not sufficient for a conclusive proof of our hypothesis.
2. A mm frequency sweeper from 140 to 220 GHz is required to detect a reception peak at the precise main frequency radiation of the German hornets. This sweeper may be supplied next year.
3. The mm wavelength bands equipment with the sweeper will be sufficient to prove the hypothesis of mm waves radar tracking for the German, but not for the investigated Oriental hornets operating at significantly higher frequency ranges, where submillimeter waves chambers and detectors are required.

The proof of our hypothesises could open new horizons in the investigation of hornets flying insects and animals and on novel low wavelength mm and submillimeter systems. If our hypothesis is accurate many new Applications can be developed.

5. **CONCLUSIONS**

The hornets natural RADAR and DF systems wavelength bands are shorter than the nowadays usable radio millimeter waves and longer than the usable Infrared optical bands. Therefore, the probability of hornets radiation detection is very low, quite inexistant.

The simulations results from our hypothesises show that the RADAR tracking and detection operation range similar to bats is limited to tenths of meters only, even for large RADAR Cross Section (RCS) areas. The possibilities of hornet males tracking the queens and of the workers localizing their nest at distances up to a few kms are analysed using the new concept of a natural communication Direction Finder (DF) System. These hypothesizes about hornets have yet to be confirmed by precise measurement results ascertaining the parameters of the submillimetric power sources. This remains a difficult task, considering the absence of man-made RADAR and communication systems for the submillimeter wavelength and also the scarcity and extremely high cost of radio sources and detectors for these frequency bands.

However in a few months we shall try to continue the measurements which may bring to new interressing applications.

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