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

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Abstract—The hypothesis of a natural sophisticated RADAR tracking system affecting hornets flight was described, analyzed and developed in previous papers [1, 2] considering their (cuticle) skin complex spike elements arrays shown by electronic microscope pictures. The existence of different spike length arrays and their disposition lead, by analogy with antenna, and radio theory and practice, to the hypothesis of transmitting and receiving phased arrays antennae operating at three different wavelengths in the sub-millimetric bands.

The natural photo-and piezo electric generation of energy in the hornets reported previously explain how is generated the Radio Frequency (RF) energy required for the operation of the sub-millimeter wavelength natural RADAR system. However, similar to bats, new computation results show that the operation range of hornets RADAR system is limited to less than 100 m.

Recently, investigations have shown that also in the hornet two antennae are located hundreds of spikes which may radiate and detect significant radio energy from their internal photo electric sources and piezoelectric effect.

Thus, the existence of three separate sources of radiation and detection enable the application of Direction Finding (DF) communication additional hypothesis. The DF concept can contribute to explain how male hornets track the queens and how workers can be guided to their nest even for operation distances up to a few kms.

It is possible that the results of the proposed investigations will provide tools to improve real tracking and DF systems performances especially in the yet not sufficiently explored submillimeter wavelength ranges and to find applications to this novel hornet property. Soon will be published results and analysis of experiments contributing to prove this fascinating hypothesis.

1. INTRODUCTION

Two recent publications [1, 2] have presented the development of a new hypothesis concerning a natural sophisticated Radio Detection And Ranging (RADAR) navigation system affecting hornets flight. 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].

The natural 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]. A comparison was made between the 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, 7].

for instance, at a LOS distance of $d = 10\,\mathrm{m}$ from the hornet the sparsed phased array at wavelength λ_{S3} will cause a one way $A \simeq 107\,\mathrm{dB}$ and a minimum two way space attenuation of $2A \simeq 215\,\mathrm{dB}$. This significant high attenuation levels require sensitive receiver

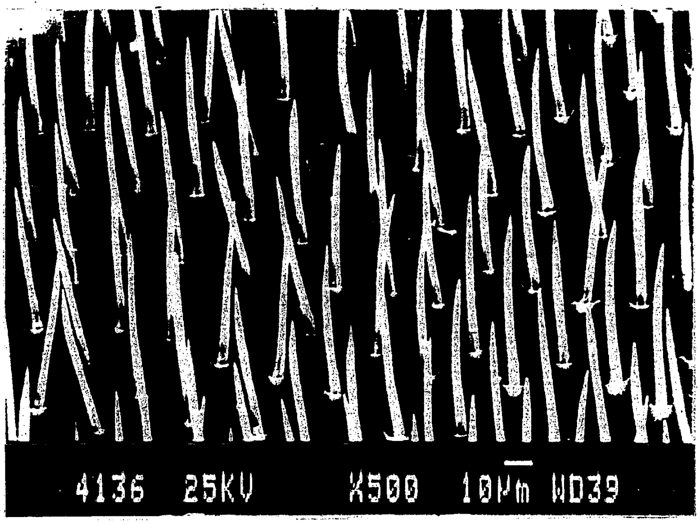

Figure 1. The denser phased array. As can be seen the spikes are about 55 μm long and at 20–25 μm distance from each other. Those spikes were photographed worker hornet on abdominal segment.

systems and high directivity and gain of the natural spikes antennae arrays to achieve high detection probability of targets for distances exceeding ten meters [2].

At millimeter waves and lower one the atmosphere has an additional attenuation in function of the molecular frequency resonances and the moisture of the air. The mean measured atmosphere attenuation in $\frac{dB}{m}$ are obtained from the International Telecommunication Union Radio (ITU-R) [8] and Jet Propulsion Lab. (JPL) measurement results [11]. The medium attenuation factor α_A at sea level under clear atmosphere conditions and α_B at sea level with heavy status cloud conditions are also presented for the three hypothetical frequency ranges [2, 11].

For instance, at a distance of 10 m from the hornet at clear atmospheric sea level conditions the minimum attenuation for the medium phased array return double way signal will be about 4 dB and for the sparser phased array return signal around 535 GHz less than 0.3 dB as shown in Fig. 2. Thus, it is possible to neglect the atmospheric losses in comparison to the LOS propagation dispersion losses which are dominant.

In adverse weather conditions the atmospheric radio waves absorption is significantly higher and therefore the operational range

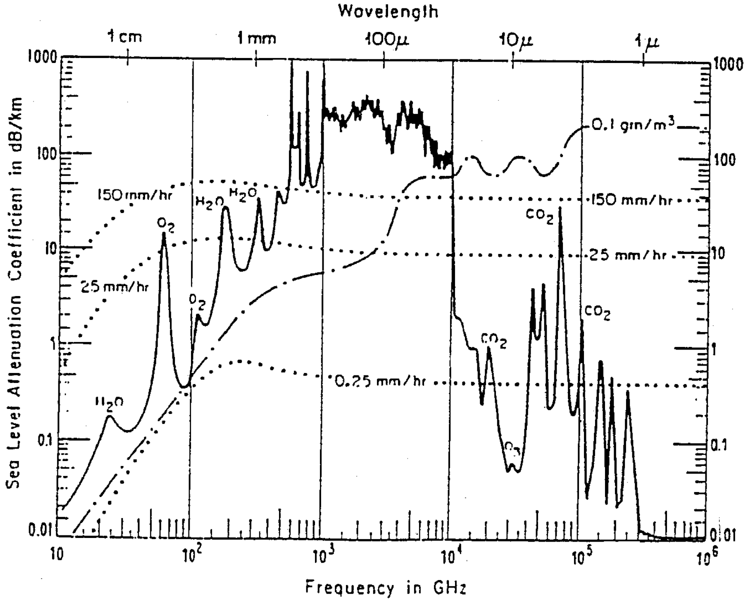

Figure 2. Sea level attenuation coefficients, in decibels/kilometer, versus frequency for: the gaseous atmosphere (continuous line curves for 20°C temperature and water vapor density of 7.5 gr/m^3), clouds or fog (the dot-dash curve for water droplets 0.1 gr/m^3), and various rainfall rates (the dotted curves).

of the RADAR system is very limited [9]. The natural RADAR hypothesis receives additional plausibility from the facts that in unfavorable climatic conditions the activity of hornets is very limited owing to signal absorption, while in the dark, at night, they are not active at all due to the lack of photoelectrical energy mandatory for the natural RADAR systems operation [10].

Actually these sub-millimeter wavelength ranges at frequency bands exceeding 500 GHz, are generated and detected only in advanced research laboratories, and not yet used for operating radio systems. Nowadays, 600 GHz is the highest frequency used in radio astronomy and remote sensing applications. The atmospheric window frequency range of 135 GHz is the highest frequency range used for tracking military missiles and anticollusion vehicular radars operate at 77 GHz [5, 11].

These $120 \leq \lambda \leq 560\,\mu$m submillimeter wavelength ranges differ also much, by (more than one decade distance) from the classical Infra Red LASER wavelength of Nd Yag 1,06 μm and of CO_2 10,6 μm [12, 13]. Thus, the supposed hornet natural frequency ranges are not yet occupied by man made systems except in radio astronomy.

The operation space distance range of the hornet biological navigational system depend on the transmitted power level, and also on the space propagation attenuation.

The maximum operation range $R_{\max}$ can be computed using the following classical RADAR equation [9]:

$$R_{\max} = \left[\frac{P_t G_t Ae \sigma}{(4\pi)^2 \cdot S_{\min}} \right]^{1/4} \tag{1}$$

where realistic values are:

The transmit power $P_t = 10\,\mu\text{W}$

The antenna gain $G_t = 4.10^3$ (36 dBi)

The isotropic Radar Cross Section (RCS) area σ

Typical values of σ: an insect $10^{-4}\,\text{m}^2$, a bird $10^{-2}\,\text{m}^2$ and a man around $1\,\text{m}^2$ [8, 9]

The receiver antennae's effective area $Ae = 4 \cdot 10^{-4}\,\text{m}^2$.

For frequency ranges up to 4000 GHz the thermal system internal noise "P_n" is still dominant over the quantic Plank noise and limits the minimum detectable signal.

$$P_n = FKTB \tag{2}$$

Where K is the thermodynamical Boltzmann constant at ambient temperature [5]

$$T \simeq 290^\circ K, \text{so we obtain } KT \simeq 4 \cdot 10^{-21} \text{ Joule} \tag{3}$$

A realistic value for the bandwidth B is 25 KHz for pulse transmission and the noise figure F is taken as 4 (6 dB).

From equations (2) and (3) we obtain $P_n \simeq 4 \cdot 10^{-16}\,\text{W}$. Thus, for an adequate Signal to Noise and Clutter of 10 (10 dB) in clear atmospheric conditions $S_{\min} \simeq 4 \cdot 10^{-15}\,\text{W}$

If we introduce the realistic values in equation (1) we obtain for different targets RADAR Cross Section (RCS) areas $\underline{\sigma}$ [9]

$$R_{\max} \simeq \left[\frac{10^{-5} \cdot 4 \cdot 10^3 \cdot 4 \cdot 10^{-4} \sigma}{160 \cdot 4 \cdot 10^{-15}} \right]^{1/4} \simeq 70[\sigma]^{1/4}\,\text{m} \tag{4}$$

Thus, the natural Radar maximum operation range for a flying hornet to detect and track a man is about 70 m and for an insect about 7 m.

However, if the hornet brain control system can generate a signal pulse integration process, similar to the case of bats [1, 7]. For an adequate probability of detection and low false alarm rate the operation distance range can be enhanced to

$$21 < R_{\max} < 210 \text{ m} \tag{5}$$

In comparison it is known that for bats the navigation system operational range extends from a few cm up to 30 m [7]. However the extremely high Radio frequency (RF) emission of hornets provides significantly more probability of prey detection and tracking accuracy especially for small targets [15].

In case of frequency switching mode it is logical that the lowest frequency range array with the less directivity is operated at first. If the signal reflected from the tracked target exceeds a threshold power level, when the target is very near and the reflected signal exceeds a bigger threshold level, the natural RADAR system switch to the most accurate tracking mode at the highest frequency range as presented in Figure 3 [1].

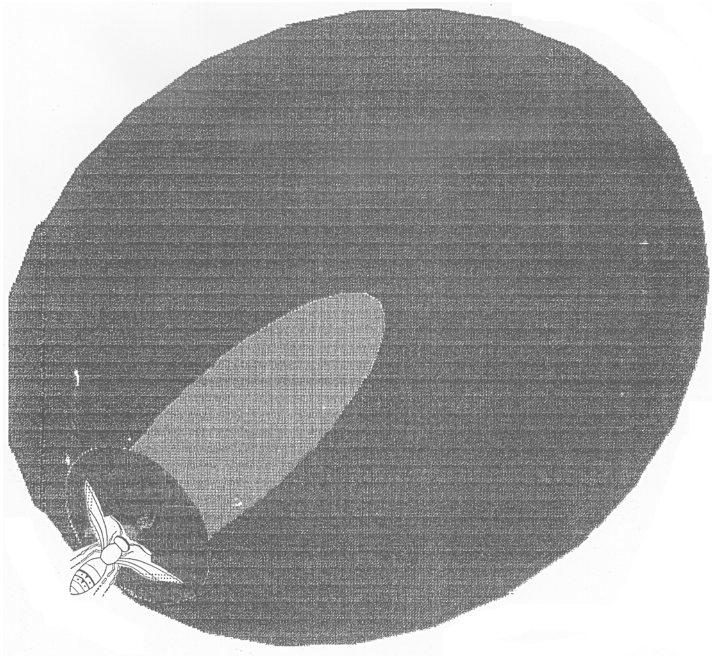

Figure 3. Three mode tracking mechanism of hornets natural RADAR systems.

In case of operation mode of the three arrays simultaneously, the operation range $R_{\max}$ is enhanced due to the applied diversity technique [5].

2. HORNETS COMMUNICATION DIRECTION FINDER INVESTIGATION GENERAL CONCEPTS

The two antennae of the oriental hornet are also densely covered by numerous spikes of a few different lengths. The two hornet antennae measured photo-voltaic energy generated by light is significantly high in comparison to the hornet cuticle energy and also piezoelectrical energy can be generated in the antennae under flight conditions [10]. Thus, the hornet two antennae, together with the cuticle provide three different sources of RADAR transmission and reception for detection, localization and tracking of targets echoes as shown in Figure 4.

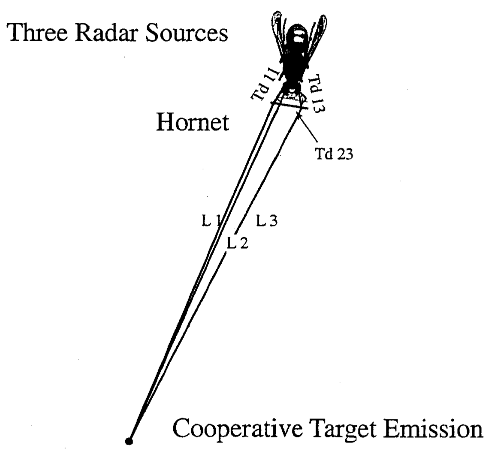

Figure 4. The hornet direction finding technique for remote target detection and localization.

The measured values of hornet antennae spike elements dimensions results are presented in Table 1 which includes 4 spikes species for hornets workers as presented in Figure 5 and 5 species for (drones) males as presented in Figure 6. Table 1 includes the spike species average length l_s in (μm), the respective expected wavelength in (μm) and frequency ranges in (GHz) obtained from the derived relations

$$\lambda_{sn} \geq 4l_{s_n} \tag{6}$$

Table 1. Parameters of the various spines present on the antennae of workers and males of the oriental hornet.

A. Workers:

	Length	Wavelength Range	Frequency Range	Base Diameter (μm)	Tip Diameter (μm)	Relative Number †
	L_{sn} (μm)	λ (μm)	f (GHz)			
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

B. Males:

	Length	Wavelength Range	Frequency Range	Base Diameter (μm)	Tip Diameter (μm)	Relative Number *
	L_{sn} (μm)	λ (μm)	f (GHz)			
Trichoid	20	80	3750	3.5	Spine-like	100
Placoid	27.1	108.4	2770	8.8	3.6	5
Campaniform	11.7	46.8	6400	3.4 *	-	20
Agmon	8.2	32.8	9150	3.3	Spine-like	2
Tyloid	253.6	1014.4	295	72.3 *	-	1 ‡

* Width
† On a relative scale of 1 to 100
‡ First and second segment — none, third segment — one, fourth through thirteen segments — two on each one.

and

$$f_{s_n} \leq \frac{3 \cdot 10^5}{4 \cdot l_{s_n}} \text{ in GHz} \tag{7}$$

Also give in Table 1 are the spike elements base and tip diameters in μm and the relative number of spike elements with a base of 100 units. The photoreceptor elements are not considered owing to their scarcity and the difficulty in measuring the permittivity ε_r and the operation frequency ranges of this stripline configuration.

The Oriental hornets workers antennae phased arrays frequency ranges are from 3320 to 8430 GHz. Most of the spike elements belong to

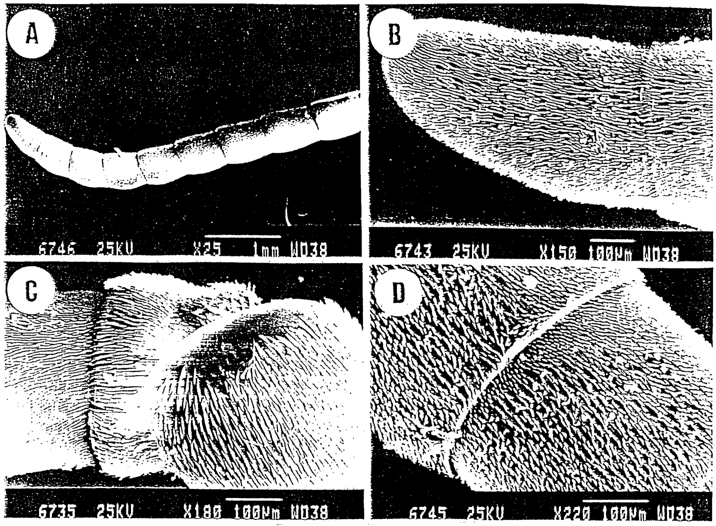

Figure 5. Worker hornet antenna.

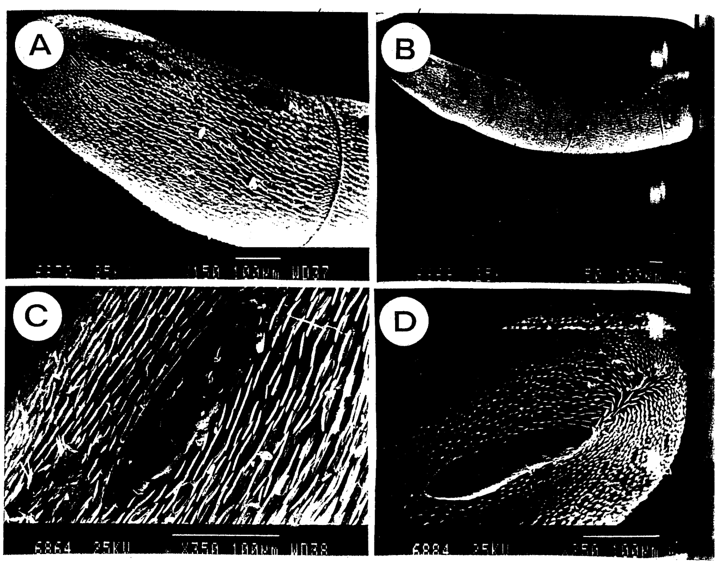

Figure 6. Male hornet antenna.

the two lower frequency range phased arrays which provide the highest accuracy for shorter operation ranges and the two antenna frequency ranges of significantly less spikes provide the highest distance operation [16].

The Oriental hornets males antennae phased arrays frequency ranges are from 295 to 9150 GHz, where the lowest frequency array at 295 GHz with the lowest number of spikes provide the highest distance operation but with the less directivity for the first orientation process. The highest number of spikes and directivity are operating at the median frequency ranges of 2750 and 3750 GHz and the highest accuracy for short distance operation at the highest frequency range of 9150 GHz [16].

It has been shown previously [1, 2] that the RADAR detection and tracking operation range is limited to tens of meters only due to the extremely high frequency attenuation increasing at a d^4 rate. However, the fixed distances between the hornet radiating two antennae and the radiating cuticle enable a new hypothesis of a Direction Finder (DF) technique [17]. The DF technique allow the 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 attenuation 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 [14].

The hypothesis of insect radio communication using microwave or infrared wavelength is not new and were published in a few papers [18, 19] concerning night flying moths which locate mating partners via a natural radio link. However, the hypothesis of submillimeter Radio Communication links and a DF technique applied to hornets is quite new.

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 [20]. 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 and on the two hornet antennae at fixed distances between themselves.

3. HORNETS DIRECTION FINDER TECHNIQUE APPLICATIONS AND SIMULATIONS

The DF communication hypothesis enables us to explain also 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 (9) considering that for the extremely short waves transmitted by the hornets, more than 60% of the first Fresnel ellipsoid of the link is generally free of obstacles [5].

$$P_r = P_t G_t \cdot G_r \left(\frac{\lambda}{4\pi d}\right)^2 \tag{8}$$

or using frequencies f

$$\frac{P_r}{P_t} = \frac{G_t G_r c^2}{16\pi^2 f^2 d^2} \tag{9}$$

where P_r and P_t are respectively the power at the receiver antenna input and radiated at the transmitter antenna output in W, G_t and G_r are respectively the transmitter and the receiver antenna gain in absolute values. c is the light propagation velocity in $\frac{m}{sec}$, f is the radiated frequency in GHz and d the operation distance in m.

From equations (8) and (9) we obtain [that]:

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

The maximum operation range is obtained from the non directive minimum frequency band of $f = 295\,\mathrm{GHz}$ for initial detection of the queen position by the males. Realistic values are: $P_t = 5 \cdot 10^{-5}\,\mathrm{W}$, $P_r = 10^{-15}\,\mathrm{W}$ as shown previously for clear atmospheric conditions and $G_t \simeq G_r \simeq 50$.

From equation (10) we obtained a value of $d \simeq 900\,\mathrm{m}$.

Due to the diversity technique from the simultaneous detection of four 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 DF hypothesis can also explain the localization and the return to their nest of distant hornet workers. Using the former natural RADAR detection and tracking techniques the maximum hornet operation range is limited only to around 100 meters and it is well known that hornets can find directly their way to their nest up to a distance of a few kms. To enable detecting and tracking the localization of the nest, even from far distances, several worker hornets ventilate simultaneously their wings as a group near the nest 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 different reception centers phased arrays of the remote hornets which are DF indications which are required to locate and reach their nest [9, 17].

The DF communication maximum distance "d" of remote hornets from their nest can be computed using equation (10). It was shown that the most efficient radiation is at the worker hornets lowest frequency range of $f = 535\,\text{GHz}$ as shown in [1, 2]. If we suppose $P_t = 5 \cdot 10^{-5}\,\text{W}$, $P_r = 4.1\ 10^{-15}\,\text{W}$, $G_t = G_r = 500$, we obtain $d_{\max} \simeq 2.0\,\text{km}$. The diversity technique achieved by the common radiation of up to 10 hornets at different frequencies and integration of pulses transmission can still enhance the operation range by about a factor of 3 [15].

4. CONCLUSIONS

Attempts to investigate the function of the hornet spikes on their cutile observed from electronic microscopy studies has led to the hypothesis of a natural complex and sophisticated RADAR navigation system.

The natural RADAR system wavelength bands are far beyond the nowadays usable longest radio millimeter waves radio and shorter Infrared optical bands. Therefore, the effects of man made noise and the interference from existing radio systems on the hornets detection and tracking systems are negligible to day and in near future. Also today the probability of hornets radiation detection is very low quite inexistent.

However, the computation results show that the RADAR tracking and detection operation range is limited to tenths of meters only even for large RADAR tracking detection operation range is limited to tenths of meters only even for large RADAR Cross Section (RCS) areas. In comparison the hypothesis of the hornet males tracking the queens and of workers localizing their nest at distances up to a few kms are developed here, This become possible after one proves the possibility of submillimeter waves radiation towards three transmitting and Receiving Radio Communication radiation and detection centers included on a single hornet. This enables Direction Finding (DF) communication technique possibility up to an operation distance of a few kms. These fascinating hypothesis of hornets RADAR and DF communications systems, which could explain the hornet's astonishing three dimensional long range guiding and localization abilities 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 THz frequency ranges and also the scarcity and extremely high cost of radio sources and detectors for these frequency bands. However, with the promised assistance of state-of-the-art laboratories we hope to proceed with the experimental stages of this novel investigation.

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