Americana Cockroach Guidance and Control with Electromagnetic Waves

Gh. Rezaii rad, Fateme S. Arzanforoosh and A. Cheldavi

***Abstract*—nowadays, taking advantage of insect's driving force and steering capabilities by direct or indirect stimulation has turned into an important research topic. Conducting cockroaches by electromagnetic waves is the main issue presented here. In a series of experiments conducted on Americana Cockroach, we confirmed that cockroaches entering a U shaped tube will chose their path randomly, but most of them that chose the electromagnetic-wave enabled path would eventually go back to the path with little or no trace of magnetic waves. Returning time would decrease with the increasing of the wave's frequency. We also pointed out the importance of cockroach's antenna in perception of electromagnetic waves, by removing one and then both of the antennas and analyzing the cockroach's behavior in the same tube. To confirm the results obtained from the experiments we modeled cockroach's antenna with an impedance based system containing one resistor and capacitor. We thoroughly inspected the effect of electromagnetic wave on this impedance-based model that leads to insect's specific behavior.**

***Index Terms*— cockroach's antenna, impedance spectrum, electromagnetic wave, charged chamber, behavior.**

I. Introduction

ROBOT design and implementation for better human life has been under development for years; in recent years a new interest is developing for small size robots, and as a result some attention has been paid to the benefit of controlling small size insects for specific purposes [1,2]. Bio-robotic is a new developing field to explore and employ new concepts in this area. First, researchers started with stimulating small insects like *cockroaches* for their special capabilities [3,4]; it was first begun with direct stimulation with special electrodes to investigate the response from insect. Direct stimulation has led to designing a chip controller which is attached to the back part of the cockroach's body [5]. This method has its own drawbacks like the heavy weight of the chips for some kinds of insects, falling off the back of the cockroach and short battery life. Therefore, indirect control and stimulation became of interest soon.

Constant electric and magnetic field stimulation along with radio frequency electromagnetic wave control of insects [6,7], have been employed by a number of research groups. Animals show a variety of behavioral responses to electrical fields that are dependent to the type of electric field and species involved [8, 9]. Past researches have shown that cockroaches are able to detect static electrical fields and avoid them [6]. They do not do this with a specialized detection system but by virtue of having long antennas that are easily charged and displaced by electric fields.

Years ago microwaves energy was used for killing insect. The energy densities is what that will kill Colorado potato beetles or damage potato plant [10]. The microwave energy required to kill Colorado potato beetles is 1230 J/cm in the first larval stage whereas 390 J/cm are enough to kill adults.

Examining the effectiveness of microwave energy for control of the Colorado potato beetle in potato crops begins with an investigation of the dielectric properties of the insect and plant. At previous rummages presented the measured complex permittivity of the Colorado potato beetle and potato plant over the frequency range 100MHz to 26.5 GHz obtained using coaxial probes and an automatic network analyzer [11]. The results indicate that real relative permittivity of Colorado potato beetle was decreased with increasing frequency at constant temperatures and imaginary relative permittivity remains unchanged with increasing frequency [12].

In the present study we have analyzed cockroach behavior in response to electromagnetic wave, and then we obtained the impedance spectrum of cockroaches' antenna to investigate how they detect electromagnetic wave.

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II. Experimental

A. Materials and method

We used adult cockroach Periplaneta Americana during all experiments. They were kept in translucent wet box in a a 12h:12h light:dark regime for one week before the experiments.

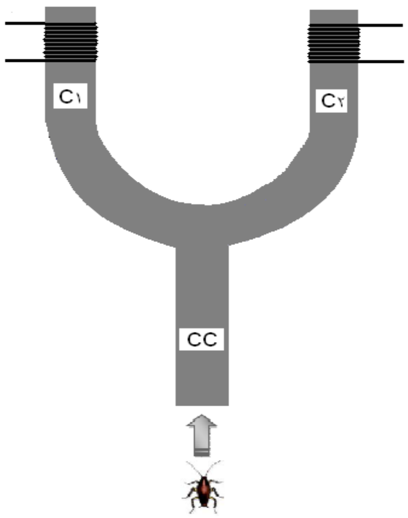

Fig. 1. Photogragh of U tube apparatus shown the central chamber (CC), Chamber1 (C1) and chamber2 (C2).

In addition, water and biscuit were provided to them during this time. Experiments were carried out at 9:00 till 12:00 every day. The light of testing room in the center was adjusted so that its intensity was 0.70 Wm^{-2} and room's temperature was kept in 22±1ºC.

The experimental tube was built from three chamber, central chamber, chamber1 and chamber2 (shown in Fig. 1) by silicon glass with 2mm thickness. The diameter of all over the tube was 30mm and the length at the each side was 25cm. Near the end of chamber 1 and chamber 2 copper wires with 2mm thick 30 times was curled around each chamber. The vertical tube should have vertical symmetry, it means chamber1 and chamber2 should be quite similar.

Two cupper wires end of C1 and C2 is connected to a signal generator to produce electromagnetic waves with frequencies from 100 to 500 MHz. This variable electromagnetic field has an amplitude of 50 milli-T in the same direction as the tube. Earth's magnetic field in this direction is measured 18.5 micro-T that can be easily ignored.

B. *Experimental setup*

At first step of the test, the box and cockroaches were placed into a refrigerator for 30 min before the test. This will make the cockroach to be unmoving and ease handling them. At one of chamber1 or chamber2 the electromagnetic wave was set at 100MHz. Cockroach is allowed to experimental tube from central chamber side and for the next 30 minutes it's behavior is carefully investigated. Then it is removed eighter from chamber1 or chamber2. Then the tube is washed with hot water and acetone to remove possible pheromone deposits and then tube is dried. Afterward, the second sample is got into the tube and we continue so until all samples are finished. The activated chamber is altered after each trial to control for natural bias. In the second step the frequency is adjusted to 300 MHz, then all the experiment is repeated all over again. Finally we investigated cockroach behavior at the frequency 500MHz. The web camera keeps film taking while the cockroach is inside the tube.

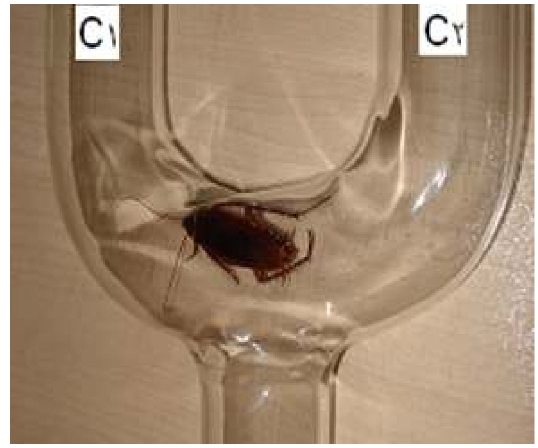

Fig. 2. Cockroach choose pathway in the experimental tube

C. *Results*

Electromagnetic wave with 100MHz frequency was applied to the one part of experimental tube to examine behavior of cockroaches facing electromagnetic wave. At the first step all cockroaches selected one pathway and so it was no significant preference for cockroaches to take either the treated or untreated pathway. In this case 28 cockroaches from 50 tested cockroaches chosed treated chamber and other entered to untreated chamber.

When cockroaches arrived under the wire, all of them would stay in this part because they like dark places, then 25 cockroaches of 28 cockroaches that chose treated chamber after 22.1 minute left the place and went to untreated chamber but another group stay in free chamber till end of the test. Fig.3A. shows mean durations that these 25 cockroaches endured electromagnetic wave with 100MHz frequency in the treated chamber.

Similarly this case occurred when the frequency adjusted in 300MHZ and 500MHZ. However, in these cases the time that cockroaches stayed in the treated chamber is longer than before. We can see this point in Fig. 3A clearly. Furthermore, we can see when the frequency is 300 MHz, 24 number of cockroaches went to treated tube and just 2 cockroaches did not leave the treated chamber till end of the test. But, in the case that frequency is 500 MHz, 22 numbers of cockroaches

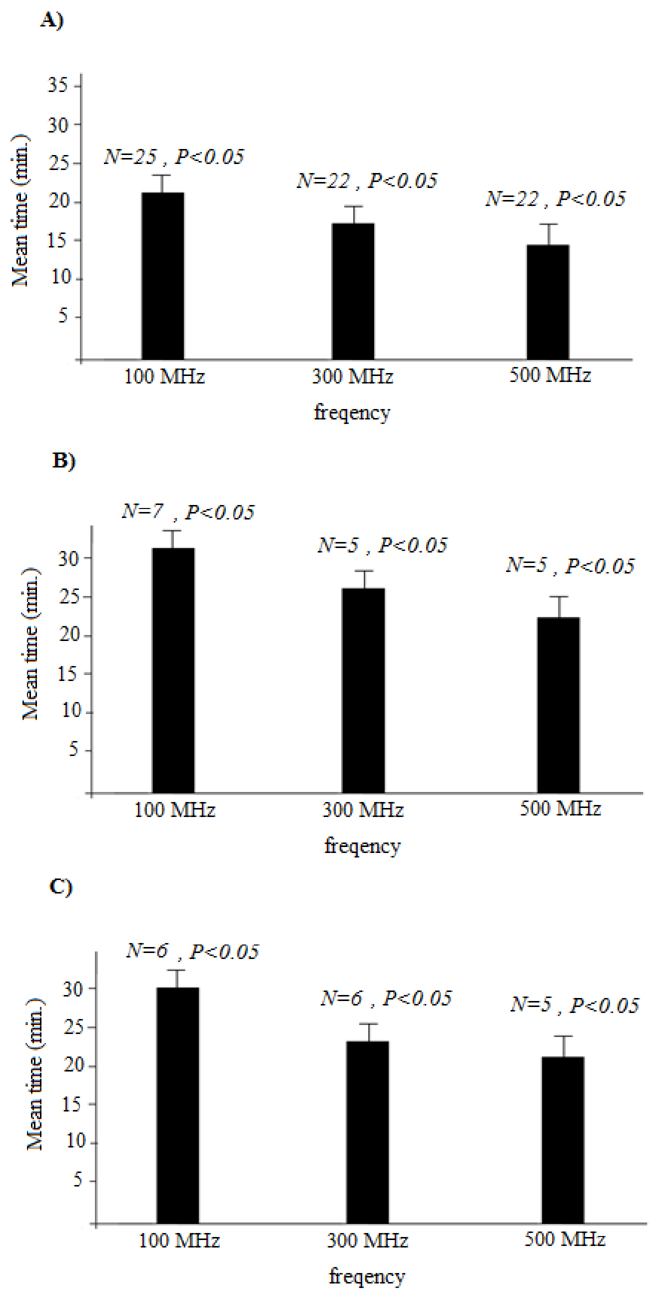

Fig. 3. duration time that cockroaches stayed under the treated chamber. (A) Cockroaches with two antennas; (B) cockroaches with just left antenna; (C) cockroaches with just right antenna.

chosed charged tube and no one stayed there for ending the test. We can see in Fig.2A. that mean time cockroaches endured electromagnetic wave in the frequency 300 MHz is 17.2 minute and 500 MHz is 15.1 minute ($p<0.05$ in all the cases, William Sealy Gusset T-Test).

Afterward to enquire function of antenna in this behavior and avoidance of cockroaches, we tested them without antennas or just with one antenna.

First, we chosed 10 cockroaches and separated their right antenna and put them in the experimental tube. At 100 MHz frequency seven cockroaches, at 300MHz and 500MHz five

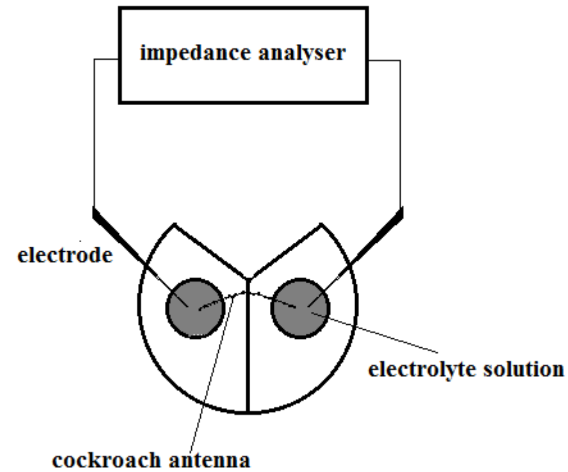

Fig. 4. Experimental set-up of the impedance spectroscopy measurements. The cockroach antenna and electrodes are connected with electrolyte solution.

numbers of 10 cockroaches preferred to go in the treated tube. Similarly, after specific time they went to untreated tube. Fig.3B. shows the mean time that they stay in the treated tube. This mean time is: at 100 MHz frequency, 31.2 minute, at 300MHz frequency, 25.7 minute and at 500 MHz frequency is 22.6 minute.

We can see that mean duration time for the cockroaches with two antennas is less than duration time for the cockroaches that have just left antenna. It means that lost right antenna caused low speed in the realization of electromagnetic wave.

On the contrary, left antenna of 10 cockroaches is parted then they are paced in experimental tube. In this posture at 100MHz and 300MHz frequency 6 cockroaches and at 500 MHz, 5 cockroaches opted charged chamber and other went to uncharged chamber. According our expectation, cockroaches with only right antenna stayed more in treated tube (Fig. 3C). In This case when frequency is 100 MHz duration time is 30.5 at 300 MHz it is 24.1 and at 500 MHz it is 21.6.

Finally we parted both antenna of 20 cockroaches and tested them with electromagnetic wave in the experimental tube. Then we can see that 12 numbers of them chosed treated chamber, but they did not came out till end of test. Probably it means cockroaches without antennas cannot sense electromagnetic wave at all. Second result is that left antenna is more important than right antenna.

III. MODELING

A. *Impedance spectroscopy*

For the more analyzing this behavior of *Periplaneta americana*, cockroach's antenna was characterized by means

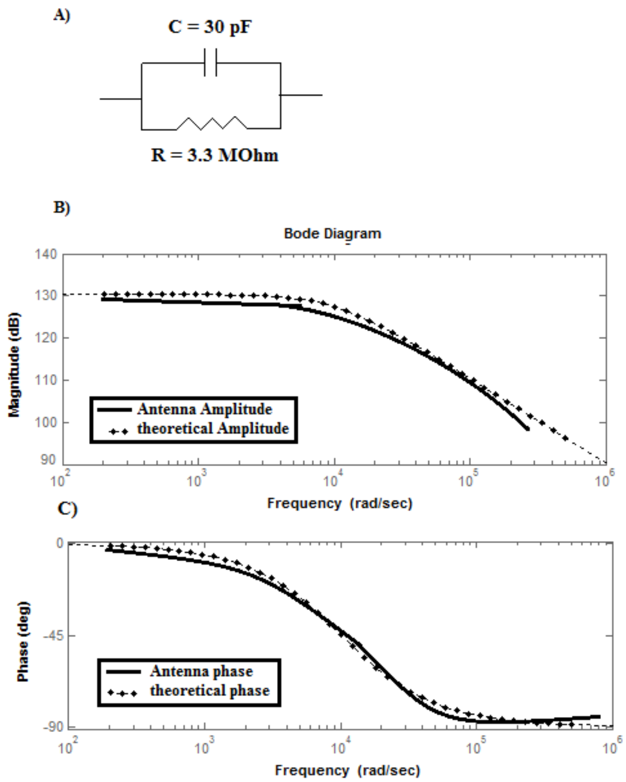

Fig. 5. (A) Equivalent circuit of the *Periplaneta americana* cockroach's antenna consisting of the capacitance and resistance in parallel. (B) Typical magnitude of impedance spectrum of *Periplaneta americana* cockroach's antenna between 100 Hz and 1 MHz. The magnitude of impedance spectrum of the respective equivalent circuit is also depicted. (C) Typical phase of impedance spectrum of *Periplaneta americana* cockroach's antenna between 100 Hz and 1 MHz. The phase of impedance spectrum of the respective equivalent circuit is also depicted.

of impedance spectroscopy. We conducted the same experiment that P.Schroth did on cockroach's antennas but we chosed Americana cockroach antenna in this case [13]. The antenna holder was built and cockroach antenna was mounted on it and connected with an electrolyte solution (Fig. 4). The impedance analyser applied a bias voltage and alternating voltage with 100 mV amplitude and 100 Hz and 1 MHz to the antenna through the electrodes and measured the alternating current that was following in the circuit.

We prove that impedance spectrum has good agreement with circuit shown in Fig. 5A. This is clearly shown in Fig. 5B and Fig. 5C. In those figures typical impedance spectrum for *Periplaneta americana* cockroach's antenna is shown. First diagram presents amplitude and second diagram is for phase of complex impedance. We can see obviously that this impedance spectrum is completely similar to impedance spectrum of resistance and a capacitance, being arranged in parallel. The resistance is 3.3 MΩ and the capacitance is fitted to 30pF (Fig. 5A). The impedance spectrum of equivalent circuit is also shown in Fig. 5B and Fig. 5C. shows phase of impedance spectrum of cockroach's antenna and equivalent circuit. same.

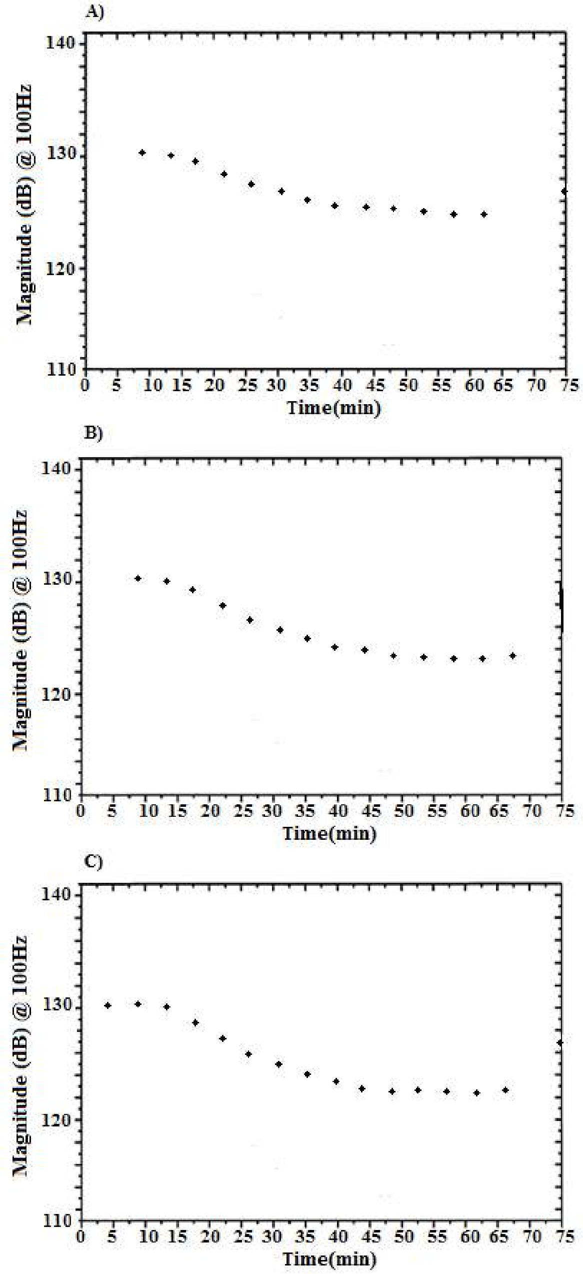

Fig. 6. (A) Impedance amplitude of cockroach's antenna at 100 Hz decrease when electromagnetic wave with 100 MHz is radiate to cockroach antenna. (B) Impedance amplitude of cockroach's antenna at 100 Hz decrease when electromagnetic wave with 300 MHz is radiate to cockroach antenna. (C) Impedance amplitude of cockroach's antenna at 100 Hz decrease when electromagnetic wave with 500 MHz is radiate to cockroach antenna.

B. Change antenna magnitude on the electromagnetic wave

Fig. 5B. shows that antenna impedance amplitude at 100 Hz frequency is 130 dB. For examining the effect of electromagnetic wave on impedance amplitude of cockroach antenna, electromagnetic wave was radiated to the antenna. At first step frequency of electromagnetic wave is adjusted at 100 MHz, and then impedance amplitude of cockroach antenna is recorded. In this case we can see after 25 min. that impedance

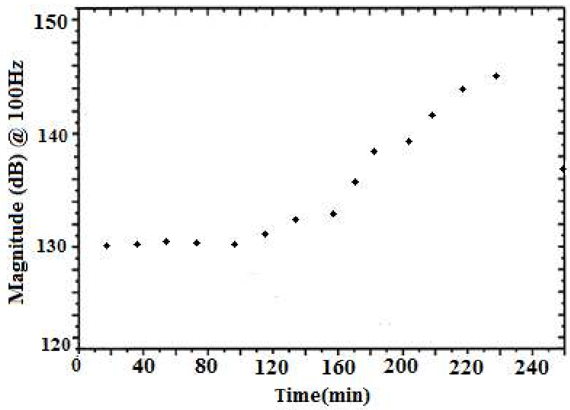

Fig. 7. Time dependence of the low-frequency impedance amplitude of a *Periplaneta americana* cockroach's antenna.

amplitude of cockroach antenna is decreased to 120 dB and stay fix there (Fig. 6A).

When the frequency was changed to 300 MHz the same thing happened to impedance amplitude of cockroach antenna but in this frequency its impedance amplitude reduced to 124 dB, that it longed 25 min. and at first 20 min it got to 126 dB (Fig. 6B).

Next, frequency of electromagnetic wave is regulated at 500MHz and again we can see that impedance amplitude of cockroach antenna is changed to 122 dB at almost 25 min. noticeable point is that in this case at first 15 min. its impedance amplitude arrived to 126 dB (Fig. 6C).

As we see electromagnetic wave on cockroach's antenna has led to reduction of impedance amplitude. This effect could be explained by the opening of channels in cell members that allow cockroaches to sense electromagnetic wave [13]. Higher frequency leads to opening more channels and as a result less impedance amplitude.

At final step we investigated on the behavior of separated cockroach antenna on the longer time scale of about 200 minute (Fig. 7). As we see, impedance amplitude did not change in the first 120 min, but then increased linearly. This observation proves that mean lifetime of separated cockroach antenna is almost 2 hours.

IV. Conclusion

In this paper we have investigated the effects of electromagnetic waves on cockroach guidance. We have shown that when cockroaches were exposed to electromagnetic waves, they tried to avoid it after a time delay. This time delay is reduced with the increase of the frequency of the electromagnetic wave.

It is observed that this time delay for cockroaches with just one antenna is longer than time delay for the ones with two antennas, since the cockroach had lost one of its sensory organs. Also, we have proved that the mean time delay for cockroaches without right antenna is longer than time delay for cockroaches without left antenna. As a result, it can be concluded that right antenna has more sensory organs and elements on it.

At the final stage of this experiment, both antennas of cockroaches were detached, and then these cockroaches were exposed to electromagnetic waves. In this case, no signs of impression by waves were found in cockroach's behavior, which means cockroaches without antennas, do not sense electromagnetic waves at all.

In addition, to examine the function of antennas more accurately, we derived the impedance spectrum of antennas that is equal to the impedance spectrum of a paralleled resistance and capacitor. Amplitude of impedance spectrum increased when cockroach's antenna is exposed to electromagnetic wave. This could be a result of the change in the cockroach's antenna dielectric, which leads to the change in the capacitance value of the equivalent capacitor, which in turn makes the cockroach to run away from this environment. Any further frequency increase results in higher amplitude of the impedance spectrum and lower phase of the impedance spectrum; this reduces the amount of time that a cockroach can bear the electromagnetic wave.

The novel approach of this research is to offer a way for insect guidance with electromagnetic waves, which does not need to install a transceiver on the insect. We just need to employ the electromagnetic sensors on their bodies for our goals.

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