TRANSMISSION PARAMETERS OF THE SOUND OF A FEMALE MOSQUITO

O.M. MAWEU, L.M. MUIA**, A.L. DENG****

*Physics Department, South Eastern University College, Kitui, Kenya,
e-mail: mawmant@yahoo.com
**Physics Department, Kenya Polytechnic University College, Nairobi, Kenya
***Zoology Department, University of Juba, Juba, Southern Sudan

Abstract. The audio spectra of three different species of female mosquitoes in flight were taped and analyzed. This work has established the modulating frequency (intelligence) to be at 97.7 Hz for all the species of mosquitoes studied, namely; *Culex pippen, Anopheles gambiae* and *Aedes egypti*. The signal carrier frequency is 488.3 Hz for all the species, except for the medically important *Anopheles gambiae* which is at 293 Hz. Bessel functions were used to determine the number of audio side bands or the bandwidth (BW). The bandwidth for the medically important *Anopheles gambiae* was found to be 781.6 Hz. The first order sidebands ($\pm f_1$) that is, (±97.7) were found to be the resonant frequencies occurring at 195.4 Hz and 390.6 Hz respectively, with an amplitude of 9.57 mV. Other species, i.e. *Aedes egypti* and a 'swarm' had a bandwidth of 1.36 kHz with resonant frequencies occurring at the second order sidebands ($\pm f_2$) or, 395 Hz and 786 Hz with an amplitude of 10.22 mV. The limits of the operational band created by the resonant frequencies enable the males to identify females of their kind.

Key words: Audio spectra, *Anopheles gambiae*, modulating index, resonant frequency, carrier frequency.

INTRODUCTION

Mosquitoes communicate with each other, specifically for mating purposes. These insects produce sound when in search of proteins needed for ovulation. In bioacoustics measurements, the carrier frequency of the frequency modulated acoustic signal [3] has been found in the ranges 150 Hz–500 Hz [4], which gives only one transmission parameter, i.e., the carrier frequency. Thus, there is need to establish other transmission parameters associated with this sound. Due to the low frequency range, this sound may be classified as classic or Chowning frequency modulation. This type of frequency modulation uses the sine wave, which produces

Received: August 2011;
in final form December 2011.

no other frequencies apart from its fundamental, as both the carrier wave and the modulating wave [2]. These types of frequencies (low) are associated with long wavelengths in the range of meters, and little is known of the insects' response to these wavelengths in the electromagnetic spectrum [1].

The aim of this study was to analyze the audio spectrum of a female mosquito in-flight and determine the transmission parameters, namely the amplitude, carrier frequency (f_c), modulating frequency (f_m), modulating index, (m_f) frequency deviation (δ), bandwidth (BW) and the wavelength (λ). *Anopheles gambiae,* and *Aedes egypti* mosquitoes were used in this study.

The formation of the spectrum is due to the modulating frequency being at the audio rate [2]. The spectrum contains the fundamental frequency, representing the carrier frequency and side bands occurring on either side of the carrier.

For a frequency-modulated wave, the equation for instantaneous voltage is [5]:

$$e = A\sin\left(\sin\omega_i + m_f \sin\omega_c\right) \tag{1}$$

where A, ω_c, and ω_i are the peak value of the carrier wave, carrier angular frequency, modulating signal angular frequency respectively. Further, $m_f = \dfrac{\delta}{f_c}$ is the modulation index for the frequency modulated wave.

Equation (1) can be written as:

$$e = E_c\left[\sin\omega_c t\cdot\cos\left(m_f \sin\omega_m t\right) + \cos\omega_c t\cdot\sin\left(m_f \sin\omega_m t\right)\right] \tag{2}$$

Evaluating (2) with help of Bessel’s expressions [9], we have:

$$\begin{aligned} e &= E_c \sin\omega_c t\left[J_0\left(m_f\right) + 2J_2\left(m_f\right)\cos 2\omega_m t + 2J_4 \cos 4\omega_m t\right] + \\ &+ E_c \cos\omega_c t\left[2J_1\left(m_f\right)\sin\omega_m t + 2J_3\left(m_f\right)\sin 3\omega_m t\right] = \\ &= J_0\left(m_f\right)E_c \sin\omega_c t + J_1\left(m_f\right)E_c\left[\sin\left(\omega_c + \omega_m\right)t - \sin\left(\omega_c - 2\omega_m\right)t\right] + \\ &+ J_3\left(m_f\right)E_c\left[\sin\left(\omega_c + \omega_m\right)t - \sin\left(\omega_c - 3\omega_m\right)t\right] \end{aligned} \tag{3}$$

From equation (3), the spectrum of FM consists of the carrier and infinite number of sidebands. The side frequency component extends above and below the carrier by an amount, etc. The side frequency pair differing from the carrier frequency by ω_m is the first order side frequency and that differing by $2\omega_m$ is the second order side frequency, etc.

MATERIALS AND METHODS

In practice, it is very difficult to tape the sound of a mosquito in-flight in an open room. Thus, captive and disease free mosquitoes obtained from a research institute (Kenya Pyrethrum-Board) were left unfed for a day. A single mosquito of each species was enclosed in a small mesh cage 12 cm^3.

An attractant was placed near the cage to ensure that the mosquito made continuous flights in search of food. The sound emitted by the mosquito was then recorded on a magnetic tape using a cord-less microphone.

Later a combination of all the species was put in the cage to form a 'swarm' and their sounds recorded. The taped audio signals were transferred to a combi scope (PM 3394 A) (Fluke cooperation, WA, USA) through a butter-worth filter to eliminate all the frequencies above 700 Hz [8]. The scope was set to auto-mode so as to capture the actual signal strength.

GENERATION OF THE FM SPECTRUM

Fluke-View combi-scope proprietary software for windows (Fluke cooperation, WA, USA) was used to transfer the data from the scope to a computer. Care was taken when selecting the band rate to ensure that sufficient data points were transferred to the computer so as to obtain a good frequency spectrum.

RESULTS

From Fig. 1, the maximum frequency component which can be transmitted, i.e., f_{max} is 488.4 Hz, the carrier component, f_c is 293 Hz. These two frequency components are important in determination of the transmission parameters as shown below:

Frequency deviation

$$\delta = f_{max} - f_c = 488.3 - 293 = 195.3 \text{ Hz},$$

The modulating index $m_f = \frac{\Delta f}{f_m} = \frac{195.3}{97.7} = 1.9$,

The bandwidth (BW) is given by $2 \times n \times f_m$, which is $2 \times 4 \times 97.7 = 781.6$ Hz and a wavelength of

$$\lambda = \frac{\nu}{f_c} = \frac{340}{293} = 1.16 \text{ m}$$

Where v is the velocity of sound in air, f_c is the carrier frequency and n is the number of side bands.

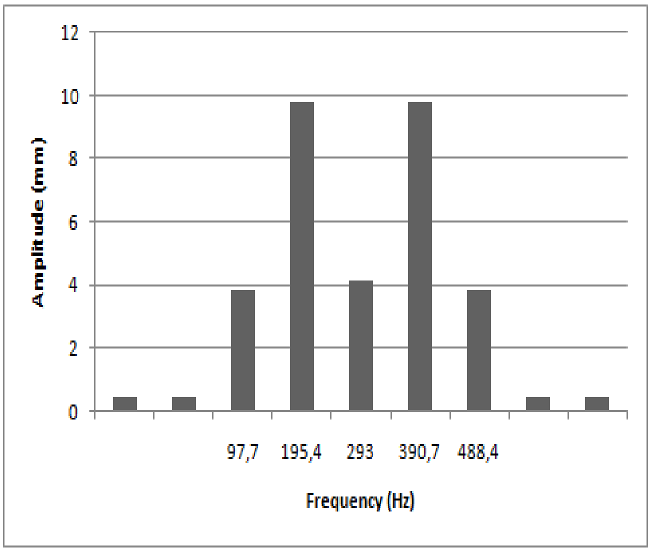

Fig. 1. Frequency spectrum of *Anopheles gambia.*

For the *Aedes egypti* spectrum the frequency deviation is

$$\delta = f_{\max} - f_c = 488.3 - 97.7 = 390.6 \text{ Hz}.$$

Modulating index m_f = 3.9, band width (BW) = $2 \times 7 \times 97.7 = 1.36$ kHz with a wave-length, $\lambda = \frac{340}{390.5} = 0.87$ m.

Table 1

Summary of transmission wave parameters of mosquitoes

Species	f_c (Hz)	BW(Hz)	δ (Hz)	λ (m)	m_f	n
Anopheles	293	781.6	195.3	1.16 m	1.9	8
Aedes	488.3	$1.3 \cdot 10^3$	390.4	0.87 m	3.9	14

DISCUSSION AND CONCLUSIONS

The medically important *Anopheles gambiae*'s sound spectrum (Fig. 1) shows the fundamental component has a frequency of 293 Hz. Besides this fundamental component, the spectrum contains eight side bands. However, out of the eight only four are transmitted. The rest four are not transmitted due to their low amplitudes. The modulation index is 1.9, which means these insects employ narrow band frequency modulation by using a small frequency modulation index. For the *Aedes egypti* the spectrum (Fig. 2) shows a fundamental component with a

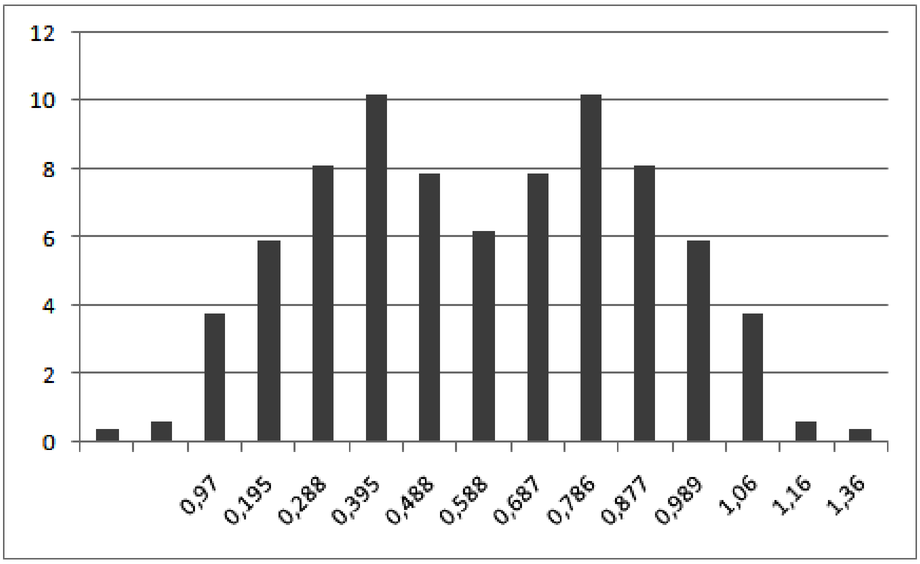

Fig. 2. Frequency spectrum of *Aedes egypti.*

frequency of 488.3 Hz (0.48 kHz) and more significantly is the higher value of modulation index at 3.9. This increases the number of sidebands to eleven and hence an increase in the bandwidth. Female mosquitoes emit sound, which is transmitted in air as frequency modulated wave [3] and it activates the antenna of conspecific male and provides directional indicators, which the massive sense organs, the Johnson's organ at the base of the antenna can resolve [6]. The male's antenna simply demodulates the fundamental component (carrier) to extract the modulating signal which bears the message. The modulating signal is the same for species, i.e., *Anopheles gambiae* and *Aedes egypti* at 97.7 Hz. This implies that the message sent to all the males is the same (mating), the only difference is the sender, who is identified through the size of the bandwidth, limits of the operational band created by the resonant frequencies and the modulation index. Maweu *et al*. [7], showed that if the transmission parameters obtained in this work were used to generate a pulse modulated wave and a bioassay set up, using a PM source and an FM source generated by the female mosquitoes, males were more attracted to the PM than the FM source [7]. Demodulation, the process of recovering the modulating wave from the carrier and consequently other transmission parameters such the bandwidth, modulation deviation, the wavelength and the modulation index plays a key role in understanding the mode of acoustic communication in these insects. With parameters that can be altered, it is possible to interfere with communication between these insects and possibly reduce the rate of malaria transmission if the contact between the male and the female is reduced [7].

REFERENCES

1. BAKER, G., Magnetic influence on the activity of termites and their directional behavior in building vertical galleries, *Mater.org*, 1979, **14**, 534–548.
2. CHOWNING, J., The synthesis of complex audio spectra by means of frequency modulation**,** *Journal of Audio Engineering Society*, 1973, **21**, 7–8.
3. CLEMENT, A.N., *Biology of Mosquitoes*, Chapman and Hall, U.K., 1992, pp. ix–xii.
4. EWING, A.W., *Anthropod Bioacoustics,* Edinburgh University Press, U.K, 1989, pp. 62–63.
5. GUPTA, K., *Hand book of electronics,* Pragati and prakashan publishers, India, 1966, pp. 1445–1475.
6. LANE, P.L., R.W. CROSSKEY, *Medical Insects and Arachnids*, Chapman and Hall, U.K. 1996, pp. 167–176.
7. MAWEU, O.M., A.L. DENG, L.M. MUIA, A comparative study of *Anopheles gambiae* male mosquito's response to frequency modulated [FM] and pulse modulated frequency modulated [FM] and pulse Modulated [PM] waves at different acoustic frequencies and distances*,* *Indonesian Journal of Physics,* 2009, **20**(4), pp. 81–84.
8. MILLMAN, J., C. HALKIAS, *Integrated electronics*, Tata McGraw-Hill, New Delhi, 1983, pp. 875–877.
9. RAJPUT, B.S., *Mathematical Physics,* Pragati and Prakashan Publishers, India, 1984, pp. 697–698.