# USE OF AN ARTIFICIAL NEURAL NETWORK MODEL TO STUDY CELL INTERACTIONS IN THE PRESENCE OF EM RADIATION

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**ABSTRACT**

Electromagnetic radiation emitted by man-made sources has been a cause for concern in recent decades. It has been feared that the proliferation of electromagnetic devices may have a detrimental effect on biological organisms. For instance, numerous recent studies have focussed on the possible biological ill effects of EM radiation. This paper proposes a novel approach to the a priori assessment of the state of biological cell interaction when cells are exposed to EM radiation, doing so with the aid of an artificial neural network model.

## 1. INTRODUCTION

For at least two decades now, wide spread concerns have been expressed regarding the possible ill effects on living organisms of electromagnetic and electric fields [1]. Fears have been popularised especially with the common availability and use of mobile telephones. Many studies have been conducted to establish possible cause-effect relationships although to date no conclusive evidence seems to be forthcoming. Notwithstanding, interest in the effects of man-made electromagnetic fields on biological organisms is very much alive.

This paper seeks to make a contribution by presenting a new approach to the study of cell interactions in an ambience permeated by electromagnetic (EM) radiation. The method is based on the use of artificial neural network (ANN) techniques.

## 2. ANN-BASED CELL INTERACTION MODEL

It would seem logical that ANN techniques may be considered an obvious candidate for the study of biological cell interactions since the inspiration for ANN lies in the biological realm. An ANN has the capability for incorporating in a suitably formulated model both tangible physiological aspects and not so tangible psychological factors. For instance, Grossberg [2][3] used a Gated Dipole Model in the study of cell activation processes in the brain related to negative enforcement; a psychological phenomenon. Grossberg's model [3] employed a single cue input, ($J_1$), into the on-path.

In this paper we build on Grossberg's model [3] by introducing an additional cue input ($J_2$) toward developing a tool suitable for simulating the biological cell interaction process.

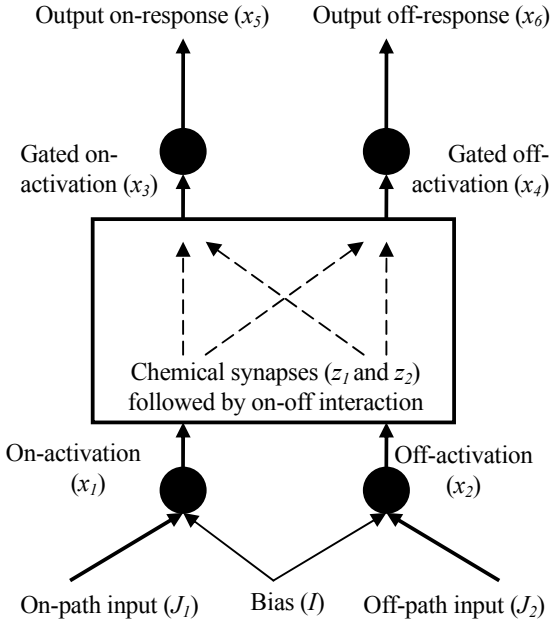


Figure 1. Enhanced Gated Dipole Model with two cue inputs and double bias

This second cue input is applied to the off-path along with bias ($I$) on both paths (Fig. 1). ($J_2$) is an unspecific cue input and represents the presence of EM radiation.

## 3. MODEL EQUATIONS

The following set of simultaneous equations, based on Fig. 1, constitute the mathematical model [3] representing biological cell interaction when cells are exposed to EM radiation. They will be used to simulate the interaction process.

$$\frac{dx_1}{dt} = -\alpha x_1 + I + J_1 \tag{1}$$

$$\frac{dx_2}{dt} = -\alpha x_2 + I + J_2 \tag{2}$$

$$\frac{dz_1}{dt} = -\beta(\gamma - z_1) - \delta[x_1(t-\tau) - \Gamma]^+ z_1 \tag{3}$$

$$\frac{dz_2}{dt} = -\beta(\gamma - z_2) - \delta[x_2(t-\tau) - \Gamma]^+ z_2 \quad (4)$$

$$\frac{dx_3}{dt} = -\varepsilon x_3 + \zeta[x_1(t-\tau) - \Gamma]^+ z_1 \quad (5)$$

$$\frac{dx_4}{dt} = -\varepsilon x_4 + \zeta[x_2(t-\tau) - \Gamma]^+ z_2 \quad (6)$$

$$\frac{dx_5}{dt} = -\eta x_5 + \kappa[x_3(t-\sigma) - x_4(t-\sigma)] \quad (7)$$

$$\frac{dx_6}{dt} = -\eta x_6 + \kappa[x_4(t-\sigma) - x_3(t-\sigma)] \quad (8)$$

where:

$J_1$ – existing input to the ANN;
$J_2$ – unspecific input induced by exposure to EM radiation;
$x_1$ to $x_4$ – relevant cell activations via on-path and off-path;
$x_5$ – output response due to on-path;
$x_6$ – output response due to off-path.

ANN parameters and time constants are represented by $\alpha$, $\beta$, $\gamma$, $\delta$, $\Gamma$, $\varepsilon$, $\zeta$, $\tau$, $\eta$, $\kappa$, $\tau$ and $\sigma$.

Chemical synapses ($z_1$) and ($z_2$), alluded to inside the block in Fig. 1 serve as transmitters with limited capacity, diminishing their capacity in due course. That is why they appear as negative terms in equations (3) and (4) [2][3][4].

## 4. CELL INTERACTION SIMULATION

Figs. 2 and 3 present the simulation results with a single cue input ($J_1$) and with two cue inputs ($J_1$+$J_2$) to the Gated Dipole Model respectively. It is noteworthy that removal of an aversive signal is associated with a positive response at the off-path, as highlighted with shading in Fig. 2. This response is what Grossberg [2] and others [5] have identified as the antagonistic rebound effect. Indeed, the *antagonistic rebound effect* is an effective means of behaviour correction due to its positive reinforcement.

Grossberg's [2] analysis of the Gated Dipole Model with one-input ($J_1$) is based on the property of antagonistic rebound effect. In the simulations here, the stimulus applied to the off-path causes the oscillation of the dipole field. In modelling terms, the process is significantly affected by the competition between the gated on-response ($x_3$ in Fig. 2) and the gated off-response ($x_4$).

Fig. 3 represents the situation when both stimuli, $J_1$ and $J_2$, co-exist. The regime depicted is that of the cue input $J_1$ being applied first, followed by the onset of the cue input $J_2$, then both $J_1$ and $J_2$ being removed simultaneously. Fig. 3 shows that the traces $x_3$ and $x_4$, corresponding to cell activations, run parallel to one another when $J_1$ and $J_2$ are present at the same time: this behaviour is termed *competition*. When both stimuli are removed, cell activation of the off-path, $x_4$, decays more slowly than that of the on-path, $x_3$. This leads to antagonistic rebound as evidenced by the gated off-cell response; $x_4$ exceeding (or *winning* over) the gated on-cell response!

With no input at all, both responses continue to decay tending toward zero. If however the input stimuli are reapplied the situation changes. Fig.3 illustrates this. This time $J_2$, representing the EM radiation in this case, precedes the onset of $J_1$. Remarkably, this causes the output off-response, $x_6$, to rise dramatically, reversing its polarity in the process. This behaviour is significant in that it is not encountered in the case of a Gated Dipole with a single cue input.

## 5. LINK TO EM RADIATION

As already mentioned, the unspecific cue input to the off-path, $J_2$, has been introduced here for the purpose of accounting for the presence of electromagnetic radiation. This has been done with the expectation that the ensuing model may be used to assess the ramifications for biological cells exposed to EM radiation.

The simulation results presented and discussed are promising in the light of observations made in a number of studies. For instance, simulations show that raising the level of the on-path stimulus leads to a larger on-path output response, constituting an *excitatory* behaviour.

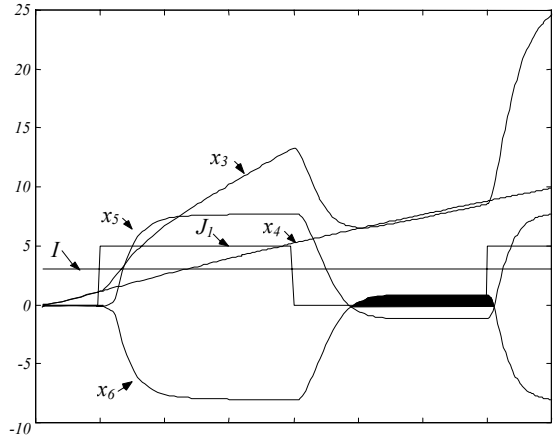


Figure 2. Cell responses with single input ($J_1$)

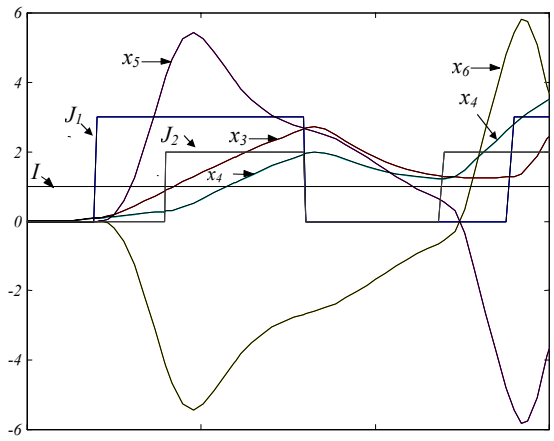


Figure 3. Cell responses with dual input ($J_1$ and $J_2$)

They also reveal that the presence of a stimulus on the off-path simultaneously with the on-path acts to alter the activation pattern of the neighbouring cell: raising the stimulus level competes with the on-path cell activation, eventually even reversing the trend. This counter action constitutes *inhibitory* behaviour. Both the excitatory and the inhibitory behaviours lead to the generation of non-linear output responses from the contiguous cells. This observation is in agreement with the findings of a study of cell membrane activities in the presence of EM radiation [6] which found that membranes exhibit strongly non-linear electrical properties due to EM radiation. The study suggests that this may be, at least partly, due to the effect of the electrical field on the proteins in the membrane or nearby, which assist the flow of currents through the membrane. It is also suggested that the cell membrane may act as a rectifier.

Further studies [7][8] have found that the presence of an electrical field causes the cells to be polarised in opposing directions.

In the simulated cell responses of Fig. 3, it is seen that the output response of the on-cells, $x_5$, and that of the off-cells, $x_6$, are symmetrically placed around the horizontal axis. This agrees with the findings of previous studies that biological cells are polarised when exposed to an oscillating electrical field. The consequences from the viewpoint of EM radiation are significant.

## 6. POSSIBLE ILL EFFECTS ON HEALTH

Various studies have linked exposure to EM radiation with possible ill effects on health [9][10][11]. For instance, Sarkar *et al* [12] have reported that mice exposed to 2.45 GHz radiation developed large-scale structural rearrangement of DNA brain cells. Similarly, Lai et al [13] reported an increase in the number of single-strand and double-strand DNA breaks in the brain cells of rats after being exposed for two hours to pulsed or continuous EM radiation at 2.45 GHz. Maybe surprisingly, another study [14] found no ill effects at all in hippocampal cells of the brain of rats exposed for two hours to 2.45 GHz radiation! Hence, it has been suggested that further studies need be undertaken for a better understanding [9].

Protein kinases, such as ornithine decarboxylase (ODC), are key enzymes that are normally activated as a result of the action of hormones, growth factors and lymphokines on receptors in cell membranes. ODC is the rate-limiting enzyme in the synthesis of substances called polyamines, which can trigger DNA synthesis, cell growth and cell differentiation [9]. Inhibition of ODC activity retards the growth of both normal cells and tumour cells [10]. ODC activity is modulated by membrane-mediated signalling events, and its activation is associated with the activity of mitogens (substances that cause mutation) and tumour-promoting agents of various types, such as the phorbol ester TPA, during carcinogenesis. Activation of ODC has been related to the "promotional" phase of cancer development, which is usually (but not always) correlated with proliferation (an increase in the rate of cell division) in the affected tissue [9]. The Royal Society of Canada [11], reviewing investigations of the effects of EM radiation on the level and activity of ODC, has reported modest increases in ODC activity only at low frequencies of about 10-65 Hz.

The effects of EM radiation on cognitive functions such as memory, attention and concentration, have been of further concern. For instance, considering the effects of exposure to high frequency EM radiation associated with mobile telephone usage, it has been suggested that even though the radiation levels may comply with existing exposure guidelines, such exposure may have biological effects that are of sufficient magnitude to influence cognitive behaviour [9].

## 7. POTENTIAL MITIGATION OF ILL EFFECTS

Simulation results presented in this paper - along with the findings of other researchers - point to potential mitigation techniques in combating the possible ill effects due to EM radiation. It is observed, as in Fig. 3, that equalising cue inputs into the on-cell path and off-cell path results in no output. This factor could possibly provide the basis for developing measures to mitigate the biological effects of EM radiation.

Considering the notion of antagonistic rebound [5], let us assume that the value of gated signals in the on-path is $S_1$, and in the off-path is $S_2$, with $S_1z_1 < S_2z_2$. When both inputs are present, the *competition* between the two paths produces an output off-response, the magnitude of which is proportional to

$$S_2z_2 - S_1z_1 = \frac{A^2B(J_2 - J_1)}{(A + I + J_1) + (A + I + J_2)} \tag{9}$$

With the onset of $J_2$, even before the onset of $J_1$, the off-path gets the larger signal ($S_1z_1 < S_2z_2$). If $J_1$ and $J_2$ are shut-off, then the cell-potential rapidly adjusts until new signal values reach $S_1^* = I$ and $S_2^* = I$. The rebound is transient because the same magnitude signals $S_1^* = S_2^* = I$ gradually equalise the $z_1$ and $z_2$ leading to shut-off for both outputs. Similarly, equalising $J_1$ and $J_2$ also results in shutting off both output responses as indicated by Equation (9).

Interestingly, experimental studies yield contradictory results since the effect of EM radiation does not appear consistent, sometimes with no effect at all [9]. The above equalising process may offer an explanation.

## 8. CONCLUSION

The Gated Dipole Model due to Grossberg [2][3], enhanced with the addition of a further cue input, applied to the off-path as discussed in the paper, constitutes an effective means of assessing the effects of EM radiation on biological cells.

The additional input represents the EM radiation incident on the cell structure. Simulation results obtained from the use of the Gated Dipole Model with dual input agree with practical observations made in a number of studies.

It has been shown that the cell interaction is subject to excitatory and inhibitory behaviour and the results may suggest a way to mitigate the possible ill effects of EM radiation.

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