EM Cancer Detection by Means of Non-Linear Resonance Interaction

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A new electronic instrument allows for very easy *in vivo* cancer detection. It is sufficient, indeed, to bring a handy probe close to the organ that should be tested, without even touching the body. The probe contains batteries, an electronic circuit and a small antenna, emitting a very weak EM wave that has several frequency components (at 450, 900 and 1350 MHz, for instance). Their intensities are displayed as spectral lines on the screen of a spectrum analyser, intercepting the wave about 2 m away from the probe. The height of one or several of these lines can be strongly reduced, however, according to the pathological state of the tested biological tissue. We show that these properties result from the fact that malignant and normal tissues have different electric properties and that these modifications are efficiently revealed through *non-linear resonance interaction.*

The response of any material to oscillating electric fields is defined by two frequency dependent functions: the dielectric constant ε (relative to vacuum) and the conductivity σ. Schwan[1], Foster and Schwan[2,3] reviewed basic concepts and the main experimental results for biological tissues, while Pethig and Krell[4] discussed possible applications. They include the prospect of EM cancer detection, since ε and σ display significant differences for malignant and normal tissues. We will show that these modifications are understandable and that they can be exploited in a very simple way for diagnostic purposes.

Fricke and Morse[5] compared already in 1926 the electrical properties of malignant tumours of the human breast to those of normal tissue and benign tumours taken from the breast. Their measurements were only performed at *20 kHz,* but it appeared very clearly that ε was on the average about 10 times larger for actively growing tumours than for normal tissue. Benign or degenerated tumours did yield intermediate results, while σ had always nearly the same value. These features have to result from *membrane effects,* since they are predominant in biological tissues between 3 kHz and 30 MHz. An electric field that polarizes different media will create, indeed, *surface charges* at the interface or on both sides of cell membranes. These surface charges produce a secondary electric field that acts on all charges like an elastic restoring force, and this accounts for the appearance of resonance effects[6].

The increase of ε for *actively growing* malignant tumors can thus be attributed to an increased proportion of membrane surfaces per unit volume. The most probable modification concerns *intracellular membranes,* associated with the intensified energy household (in mitochondria) and protein synthesis (at the endoplasmic reticulum). Since cancerous cell proliferation is known to be accompanied by angiogenesis[7,8], we may also have to consider the membranes of capillaries, the high polarizability of the adjacent fluid and the effect of red blood cells.

Chaudhary et al.[9] measured ε and σ of breast carcinoma and homologous normal tissue *between 3 MHz and 3 GHz.* They found that ε and σ are always greater for tumours in this frequency domain, but ε increases towards lower frequencies (below 30 MHz), while σ is growing in the direction of higher frequencies (especially above 300 MHz). The first effect can again be attributed to membranes, but the second effect has to result from *reorientations of dipolar particles.* It has thus been attributed to the increased water content of tumours[10,11]. Joines et al.[12,13] confirmed that from 30 MHz up to 2 GHz, EM energy absorption is sensibly higher in malignant tumours of various origin than in normal tissues, but they found a broad maximum between 100 and 800 MHz, centred at about 400 MHz. Since the resonance frequency for *free* water molecules is 25 GHz at 37°C, these particles could only account for increased energy absorption above 1 GHz. It was therefore assumed that "bound water" and perhaps even "proteins" are responsible for the increased response at lower frequencies.

Greater inertia and hindering, resulting from bonds, will slow down the orientation of dipolar particles in an oscillating electric field, but why do *malignant* tissues exhibit stronger energy

absorption at frequencies as low as 400 MHz? It is known that proteins acquire more surface charges in malignant tumours[14]. Since these charges attract water molecules, they can explain the presence of more "bound water". We believe, however, that it is also necessary to take into account the fact that cancerous cells are characterized by dramatic changes of their metabolism, intercellular communication and adhesion properties. This means that the number and nature of *membrane proteins* has to be modified, but membrane proteins carry dipolar parts, sticking out of the membrane. These dipoles can be reoriented by an oscillating electric field[15]. Besides its practical applications, the "bioscanner/trimprob" could thus provide a motivation and a tool for closer examination of certain physiological phenomena.

The existence of significant differences between the electrical properties of malignant and normal tissues was confirmed by other empirical results[16-18], but this was to no avail for cancer diagnosis as long as ε and σ had to be determined by sophisticated *in vitro* measurements. There have been several attempts to simplify this procedure, in particular by pressing *an open-ended coaxial line* against the body surface[19,20], to measure the amplitude and phase of the reflected wave, so that ε and σ could be determined by model calculations. The *bioscanner* allows also for *in vivo* measurements, but its working principle is completely different. It can be explained by considering the equivalent circuit diagram of figure 1.

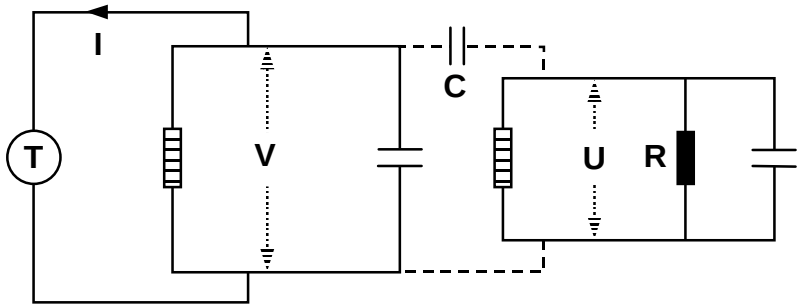

Figure 1: The equivalent electric circuit of the coupled active and passive oscillators.

The left part stands for the probe and the right part for the tested biological tissue, while the coupling is represented by (virtual) interrupted lines. Inside the probe, the transistor T activates an electric circuit, which has a natural frequency of oscillation f_1 that is determined by the self and the capacity of this circuit. But the current I passing through T is a *non-linear* function of the potential difference V. Actually, $I = -\alpha V + \beta V^2 + \gamma V^3$, where α defines a "negative resistance". It results from a positive feedback, mediated by magnetic coupling with the self of the first circuit. This non-linear system produces stationary oscillations of well-defined amplitude, but when the probe is brought close to the tested biological tissue, it becomes an "active oscillator" that interacts with a "passive oscillator".

Although the biological system contains various subsystems that could be set in forced oscillations, their mutual interactions are negligible. It is therefore sufficient to consider the effects of the active oscillator on one particular passive oscillator of given resonance frequency f_2. We can even imagine a circuit, where the self and capacity determine the frequency f_2, while the resistance R defines energy absorption.

The probe is about 30 cm long and can easily be held in one hand. It contains a tuneable, autonomous oscillator and a quarter wavelength antenna, axially centred in a partially reflecting cylindrical cavity[21]. The emitted wave is very weak, since the receiving antenna of the spectrum analyser catches only 1.58 μW at 200 cm from the probe. The biological tissue is situated in the near field, where retardation effects are negligible. The antenna acts there like an "open capacity" and the tested biological tissue is subjected to the resulting electric field. This type of coupling is unusual. It involves a capacity C that increases when the probe approaches the tested tissue. Since this capacity favours the passage of high frequency currents, we can call this a *dynamic* coupling.

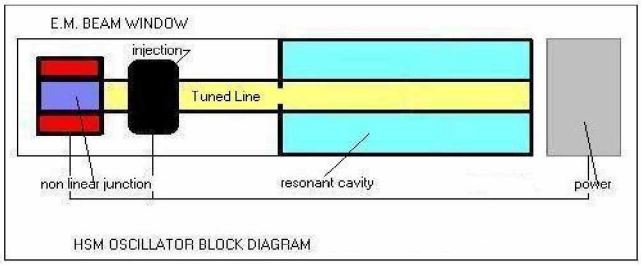

Figure 2 : The oscillator probe block diagram.

All these features are taken into account by *two coupled differential equations,* describing the possible variations of the potential differences V and U. The detailed mathematical treatment is available on Internet[23], but the basic ideas can be expressed in simple terms. Let us consider the particular case where the active oscillator is unperturbed (C = 0). The equation for V reduces then to the well-known *van der Pol* equation[22], initially introduced to account for the possible actions of a triode. Even when the amplification coefficient α is very small, the rest-state (V = 0) will be unstable. The slightest perturbation will be amplified and the capacity will accumulate charges, but when they increase, there will also be a greater tendency towards discharging. The system will end up with a stationary harmonic oscillation of frequency f_1 and given amplitude for the potential difference V. For larger values of α, there will appear higher *harmonics,* since the equation for V contains terms that vary like V^2 and V^3. This remains true when the active oscillator is coupled to a passive oscillator.

We can thus adopt a solution for V that accounts for the existence of oscillations at a fundamental frequency f and its harmonics, 2f and 3f. The value of f, as well as the amplitudes and phase factors of all these components can only be specified, when we take into account the fact that V produces forced oscillations for U and that this has an effect on V, because of C. The result can be summarized in the following way: The active oscillator is able to "feel" what happens inside the tested biological tissue, since *it has to transfer energy* to the passive oscillator to produce forced oscillations of the hidden entities. The active oscillator is also able to "tell" us how the passive oscillator is responding, since the amplitude of its own oscillations is strongly reduced when there is a large energy transfer. This is revealed, indeed, by a reduction of the amplitude of the emitted wave, displayed on the screen of the spectrum analyser. The mathematical treatment reveals that the active oscillator draws more energy from the batteries when resonance is achieved, but its own energy is reduced, as if it had to make a "big effort". This mechanism is the essence *non-linear resonance interaction.*

It is a peculiar process, with several remarkable properties. Although the values of f_1 and f_2 are fixed, it is possible to achieve or at least to approach *ideal resonance* where the "dip" of a given spectral line is strongest, by changing the value of C through a modification of the distance between the probe and the tested tissue. The first spectral line is very sensitive to the existence of a resonance, when the negative resistance α is small, but a higher value will allow for a simultaneous search of resonance phenomena at the fundamental frequency f and its harmonics 2f, 3f, …

The effect of this interaction it is easily detectable by means of a spectrum analyzer feed by a small antenna. At the resonance on one, or more of the spectral lines, two effects are detectable: the first is related to the transfer of an amount of radiofrequency from the generator probe to the diseased tissue, that absorb a part of the signal on the proper frequency line (dynamic resonance), The second effect it is related to the deformation of the electromagnetic pattern emitted by the probe, due to the interaction with a resonating agglomerated of cells, as above described, that produces in the "near field" a sort of parasitic resonating element able to deflect, on other spatial direction the waves, in the same way like the beam antennas for radio communications works.

The second and third lines are easily affected and a very strong depression of these lines can be sufficient to depress also the first line. Even this can be helpful for diagnostic purposes, when sufficient experience has been acquired.

The bioscanner can be tuned for optimal cancer detection in particular organs and for a better discrimination of inflammations, joint and bone diseases or vascular disorders, for instance. Medical testing by experts, with the approval of ethical commissions, did yield encouraging results. They will be reported elsewhere and have to be continued. We mention here only that malignant prostate cancer was detected with a sensitivity of 94%, under biopsy control[21]. We hope that this user-friendly and relatively inexpensive system can contribute to mass screening and sufficiently early detection of malignant tumours, to allow for efficient treatment before metastasis formation.

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