Ultra High Frequency and Microwave Non-linear Interaction Device for Cancer Detection and Tissue Characterization

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Abstract

The spectrum analysis of interactions between biological tissues and the signals emitted by a specially designed electronic apparatus that incorporates a hybrid-state microwave stimulated emission amplifier-oscillator are described. The biological tissue provides an electromagnetic signature that could be used to investigate cases suspected disease or cancer. This methodology provides a structural characterisation of biologic tissues in support of modern diagnostic imaging techniques. Further to existing literature describing methods for cancer detection by means of electromagnetic field, this technology represents an additional innovation.

Interaction of the electromagnetic fields with the living matter

In the past century, a great number of researchers have made their contribution to the study of the interactions between biological matter and electromagnetic fields. Many investigated the dielectric properties of living matter. Some analysed the differences between a cancerous agglomerate of cells and homogenous or ‘normal’ tissues. The period between the first and the second world wars spanned the early days of radio and electronics. Vacuum tubes were the radio frequency oscillation generators, the spectrum ranged between few kHz and 15 MHz. Measurements on biological materials were based on resistivity or impedance and instruments such as the Wheatstone bridge. After the second world conflict, investigations on biological materials were extended into the microwave bands. 1

Among the pioneers in this field were H. Fricke 2 and S. Morse 3. In their 1926 paper entitled ”The electric capacity of tumors of the breast”, they reported that “malignant tumors have a greater polarizability than normal breast tissues or benign tumors”. They carried out their experiments at low frequencies around 20 kHz. Tissues were cut into small blocks and placed in
a conductivity cell for measurement. They claimed that measurements performed on tissues from locations other than the breast convinced them that the method was of general applicability and that in some cases the “measurements may be made directly on the patient”. Following the publication of these results,

Fricke published a paper in which he declared that “It seems probable that the measurement of the capacity may provide a very practical method for diagnosing the malignancy of a tumor.”

In 1934, H. Dänzer extended the frequency range of the dielectric properties of biological materials up to 600 MHz, by exploring the propagation of the electromagnetic waves on Lecher wires of variable length and which were terminated by a wire surrounding the biological material.

The technological advances in electronic engineering following the second world war made possible the first work on complex permittivity measurements on biological materials up to 30 GHz. In 1957, Rajewsky and Schwan published their results on blood cells and other biological tissues.

Burdette, Cain and Seals presented a method which eliminated the need for sample preparation and thus allowed dielectric measurements to be made on living tissue (‘in vivo’ measurements). The real time determination of complex permittivity is possible over a large frequency band (100 MHz – 10 GHz) by a rapid and continuous frequency scan. One such method is based on an antenna modeling theorem and on the application of microprocessor-controlled microwave measurement instrumentation. A short monopole antenna is used as the in vivo probe. A network analyzer combined with error-correction routines and a semi-automated data acquisition/processing system (microcomputer) is used to determine the real part \( \alpha \) of the permittivity and the conductivity \( \sigma \) of the biological tissue being analyzed.
A non-destructive method for measuring the dielectric properties of materials by means of an open transmission line resonator was developed by Tanabe and Joines. The perturbation of the electromagnetic field at the open end of a transmission line due to the dielectric material of unknown properties is analyzed. This method is fast and accurate up to 4 GHz. The open end of the coaxial line must be in direct contact with the surface of the dielectric material being investigated which has to be smooth and flat. To avoid any air gap effect, and it is necessary to apply a pressure to the material under test. Measurements on the human skin were given as an example because of the low penetration depth but, the aim was primarily therapeutic.

Joines et al. used an open-ended coaxial probe to measure and compare the fractional power absorption for malignant tumors relative to normal adjacent tissue in rats between 30 MHz and 2 GHz. They found that ‘tumors have a greater absorption, with a broad peak, centered in the 300 – 400 MHz region’.

The majority of the studies cited here in refer to measurements and assessments of passive biophysical parameters of the tissues investigated. Measurements were of capacitance, resistance, complex dielectric constant. The present study carried out by the author, confirmed that it was possible to observe a stimulated response in altered agglomerates of cells (cancer tissues). Furthermore, it offered the possibility of detecting responses from biological tissues. When stimulated by the particular pattern of electromagnetic oscillations these tissues responded in a very selective way and quite distinct from the previously investigated Debye and Maxwell-Wagner resonances which extend over decades of frequency.

In the practical application of this effect, the author first constructed some prototype pieces of apparatus then, proceeded to the international patent application n. WO 01/07909A1 and the licensing of this technology to Galileo Avionica, a Finmeccanica Company. The final stage is an apparatus devoted to medical diagnostic analysis which is CE certified with the commercial name of Trimprob.
The applicative possibilities on the human body

The research program that led to these results was carried out by C. Vedruccio at the end of the 1980’s, while he was collaborating with the “Battaglione San Marco” the Italian Navy Infantry. Vedruccio’s aim was to investigate the possibility of designing an electronic equipment for the analysis of electromagnetic interactions with various geological terrains exposed to a multiple-frequency UHF free-running coherent beam of radiation. This was to be a piece of portable equipment to measure the dielectric properties of the soil as distinct from other materials present, to facilitate the detection of buried explosives such as non-metallic anti-personnel land mines. During laboratory experiments, an astonishing aspect emerged: if the experimenter was not in perfect health and, if the wave beam emitted by the generator search-head was directed towards the diseased areas of the body, there was an impressive absorption of one or more spectral lines evidenced by means of a spectrum analyzer situated outside the near field of the generator head. The observation of this unusual effect, lead the author to realise that this would form the basis of an innovative diagnostic apparatus.

The physical principles of the equipment

In the brief description of the equipment which follows, it is necessary to appreciate the method used. The main feature of this apparatus is a cylindrical probe within which a resonant cavity incorporates a transmission line tuned to the frequency of oscillation which is in the 65 cm wavelength band (460 MHz) (fig.1).
At the open end of this line is a semiconductor with non-linear characteristics which is activated by a nanosecond electromagnetic pulse. This transient provides an injection of electromagnetic energy into the tuned line which performs a damped oscillation. This particular tuneable amplifier-oscillator represents the core of the Trimprob diagnostic device. It possesses lock-in or synchronisation characteristics and because of its particular construction, it produces an harmonically related group of coherent electromagnetic waves. These oscillations are radiated as a beam through the “beam window” of the oscillator dome at the end of the probe where it has been geometrically focused and is used to irradiate the diseased tissues. The working principle can be explained by considering the equivalent circuit diagram of figure 2.

Figure 2: 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 $\alpha$ 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 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. 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, 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, initially introduced to account for the possible actions of a triode. Even when the amplification coefficient $\alpha$ 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 $\alpha$, 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 of the non-linear resonance interaction.¹⁰

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 \( \alpha \) is small, but a higher value will allow for a simultaneous search of resonance phenomena at the fundamental frequency \( f \) and its harmonics \( 2f, 3f, \ldots \)

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 TRIMPROB e.m. field before resonance (healthy tissues)

The TRIMPROB e.m. field at resonance on a pathologic tissue: Note the field deformation.

The subject under test must be further from the probe than the “near field” as must the spectrum analyser which is a part of the system. Using this arrangement, it is possible to observe an effect that appears as an absorption of one or more of the spectral lines radiated by
the HSM. This is observed on the spectrum analyzer display that transforms the received signal into a Fast Fourier Transform (FFT). These lines are specifically tuned to the types of tissues to be investigated. At the moment, three spectral lines are used, the first in order of wavelength, responds specifically to highly anisotropic states like micro-agglomerates of cancer cells; the second line responds to parenchyma (soft tissues) diseases; the third line responds to anomalies of the lymph and vascular system.

One of the first prototype of the Bioscanner /Trimprob (Vedruccio’s laboratory 1999)

After many years of biophysical experiments with the collaboration of many volunteers, aimed to improving this technology, we finally arrived at a program of medical trials sponsored by Galileo Avionica and approved by the Italian Health Ministry. This started in some of the principal Italian hospitals and the Medical Research Institute. The first body organ to be investigated for cancer detection was the prostate\textsuperscript{11,12}, followed by the breast\textsuperscript{13}. Further human body organs currently being studied with this equipment include the stomach and duodenum\textsuperscript{18},
as well as liver and lungs\textsuperscript{34}, bladder\textsuperscript{15}, thyroid\textsuperscript{16,17}, and in the coming months, others will be investigated. We hope that this user-friendly and relatively inexpensive system can contribute to mass screening and sufficiently early detection of malignant tumors, to allow for efficient treatment before metastasis formation.
Trimprob: spectrum analysis and database plotting.
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