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TITLE

Development of a Non-Invasive Intracranial Three Dimensional Thermography System

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DEVELOPMENTOF A NON-INVASIVE INTRACRANIAL THREE DIMENSIONAL THERMOGRAPHY SYSTEM

by

N. Uzunoglu, E. Ventouras, and I. Karanasiou

Microwave and Fiber Optics Laboratory Institute of Communication and Computer Systems
Athens, Greece

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Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West
Toronto, Ontario, Canada
M3M 3B9

DCIEM Scientific Authority:
Dr. Stergios Stergiopoulos
(416) 635-2049

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DEVELOPMENT OF A NON-INVASIVE INTRACRANIAL THREE DIMENSIONAL THERMOGRAPHY SYSTEM

FINAL CONTRACTUAL REPORT

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Prof. Nikolaos Uzunoglu
Assist. Prof. Eric Ventouras
Dipl. Eng. Irini Karanasiou

MICROWAVE AND FIBER OPTICS LABORATORY
INSTITUTE OF COMMUNICATION AND COMPUTER SYSTEMS

ATHENS – GREECE

May 2000

Abstract

During the past 30 years, many researchers have proposed and used to some extend the microwave radiometry technology to measure non-invasively the temperature distribution within the human body. The reasoning in this suggestion is the fact that microwaves at the frequency region 1-5 GHz have sufficient penetration into human tissues, while they can also provide satisfactory directivity. Another reason in putting forward this idea is the failure of infrared (IR) thermography techniques to provide useful information for the temperature distribution within the human body. Indeed, despite the fact that the human body emits maximum radiation at the IR wavelengths, the very high attenuation of this radiation passing through tissues makes the IR thermography techniques only of a limited value.

Although the amount of energy emitted by human tissues at microwave wavelengths is relatively small, temperature distribution inside the human body can be measured at least up to 5-7 cm depths. Furthermore the technology defined in this report can lead into measurement ability up to 10 cm. However, there is a practical problem in sensing the radiated intracranial thermal energy in the microwave frequency regime. This is because, there is a requirement of an array of microwave antennas to coherently integrate the scattered thermal energy and localize the source area inside the human brain that radiates thermal energy. Thus, There is no current method and or apparatus that provides non-invasively a three- dimensional temperature distribution deep within the human head.

The present report details the development of a microwave non-invasive thermography system being able to provide three - dimensional temperature distribution deep within the human head. The potential usefulness of mapping of temperature inside the human brain -especially in the cortex - is considered to be of very high value in prevention of heat stroke of brain, psychiatry, and neurology. In this report, the development of a prototype system for clinical testing is described. Furthermore, this document includes a design of a follow-up field-deployable system integrated as a soldier's helmet for fully automated scanning operations of interest to the Canadian Forces.

I. Introduction

A fundamental law of modern physics is related to the chaotic radiation emerging from material objects because of the thermodynamic equilibrium of matter with radiation. Indeed one of foundations of the modern physics, the Quantum Theory was born by Planck [4] in the effort to explain experimental observations of this chaotic radiation theoretically, examining an ideal black body. Another aspect of this phenomenon is to imagine the random fluctuations of matter microscopic particles and their coupling to electromagnetic field in the vicinity of the material objects. The random oscillations of microscopic particles generates within the matter a current distribution [5] having the following law order statistics:

$$< \underline{J}(\underline{r},t) >= 0 \qquad (1)$$

$$< \underline{J}(\underline{r},t)\underline{J}(\underline{r}',t) >= \bar{\underline{1}}\delta(\underline{r} - \underline{r}')\ \delta(t - t')\frac{kT(\underline{r}')\sigma(\underline{r})}{\pi} \qquad (2)$$

where $\underline{J}(\underline{r},t)$ is the current density vector measured in A/m^2, $\bar{\underline{1}}$ is the unit dyadic (or matrix), while $T(\underline{r})$ and $\sigma(\underline{r})$ are the matter temperature and conductivity at the point $\underline{r}$. Notice that Eq.(2) has a matrix (dyadic) form and white noise type spatial and temporal statistical behavior is observed. Furthermore, it is observed that if one has a lossless media then no chaotic radiation exists ($\sigma = 0$), while in case of perfect conductor ($\sigma \to \infty$) as will be shown later also no radiation is observed.

Consider now the structure shown in Figure 1 where a lossy media is placed within a perfect conductor wall room to provide an absolute isolation from the rest of the world. The chaotic current streams inside the lossy media being radiation sources generate a field distribution inside the conductor wall cavity. In order to calculate the electric field, it is suitable to use Green's function theory. To this end consider the structure shown in Figure 1-b, where an elementary current source as

$$\underline{J}(\underline{r},t) = \bar{\underline{1}}\delta(\underline{r} - \underline{r}')\delta(t - t') \qquad (3)$$

is placed within the lossy medium.
Then by applying electromagnetic theory techniques the electric field at an arbitrary point $\underline{r}$ can be computed taking into account as a primary source the current given in Eq.(3) and by satisfying the boundary conditions on the perfect conductor walls.
The corresponding electric field distribution at an arbitrary point is represented in a dyadic format and is shown as [6],

$$\frac{\partial}{\partial t}\underline{\bar{G}}(\underline{r},\underline{r}',t - t') \qquad (4)$$

which is equivalent to the spatial and temporal response function of the medium bounded by the conductive walls in the presence of the lossy medium. Returning to the structure of Fig.1(a) and assuming an arbitrary current distribution $J(\underline{r},t)$ within the lossy media m the electric field at an arbitrary point $\underline{r}$ is computed to be [6],

$$\underline{E}(\underline{r},t) = -\mu_o \frac{\partial}{\partial t} \iiint_{\substack{V-lossy \\ medium}} \int_{-\infty}^{t} \bar{\underline{G}}(\underline{r},\underline{r}',t-t') \cdot \underline{J}(r',t')dVdt \qquad (5)$$

$$V_r^{\omega} = \iint_A \underline{\Phi}(\underline{r}) \cdot \underline{E}_{\omega}(\underline{r})ds$$

where A is the antenna surface and $\underline{\Phi}$ is the antenna aperture field function measured in m^{-1}.

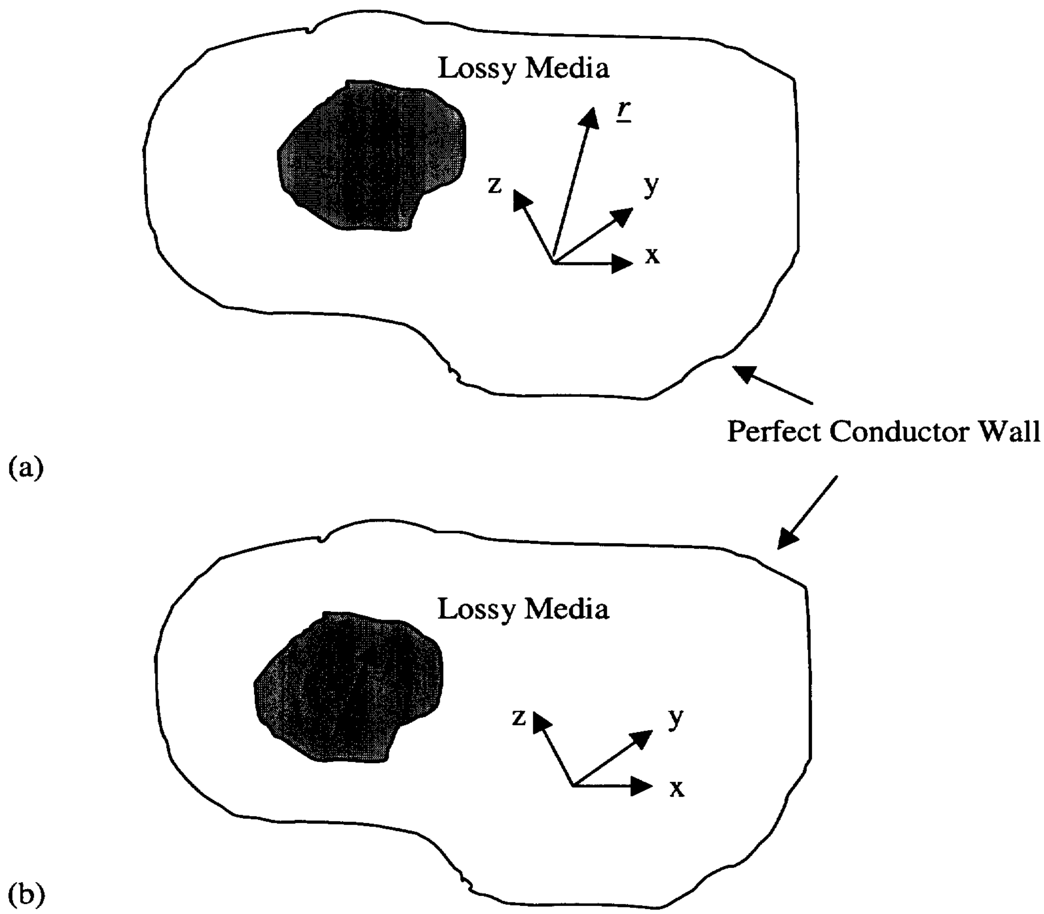


Fig.1. Lossy Media placed with a perfect Conductor Cavity

Then computing the received power intensity

$$V_r^{\omega} V_r^{*\omega} = \iint_A \underline{\Phi}(\underline{r}_1) \cdot \underline{E}_{\omega}(\underline{r}_1)ds_1 \iint_A \underline{\Phi}^*(\underline{r}_2) \cdot \underline{E}^*_{\omega}(\underline{r}_2)ds_2 \qquad (6)$$

Substituting Eq.(4) into (6) ,

$$V_r^{\omega}V_r^{*\omega} = \iint_A ds_1 \underline{\Phi}(\underline{r}_1)\cdot(-j\omega\mu_o)\iiint_A \underline{\overline{G}}\bullet\ (\underline{r}_1,\underline{r}')\cdot \underline{J}_\omega(\underline{r}')d\underline{r}'$$

$$\iint_A ds_2 \underline{\Phi}(\underline{r}_2)\cdot(\sigma\omega\mu_o)\iiint_V \underline{\overline{G}}\bullet\ (\underline{r}_2,\underline{r}'')\cdot \underline{J}_\omega(\underline{r}'')d\underline{r}''$$

where μ_0 is the free space magnetic permeability. Since, usually, frequency domain measurement are carried out in electromagnetics, by computing the Fourier transform of eq.(3), the following results are obtained:

$$\underline{E}_\omega(\underline{r}) = -j\omega\mu_o \iiint_{\substack{V-lossy\\ medium}} \underline{\overline{G}}\bullet\ (\underline{r},\underline{r}')\cdot \underline{J}_\omega(\underline{r}')d\underline{r}' \qquad (7)$$

where $\underline{E}_\omega, \underline{\overline{G}}\rceil$ and $\underline{J}_\omega$ are the Fourier transform quantities.

It is evident that the measurement of the electric field at an arbitrary point $\underline{r}$ will result into $\langle \underline{E}_\omega(\underline{r})\rangle = 0$. Consider now the case of measuring the voltage at the output of a receiving antenna. Following the application of antenna theory the receiving voltage is determined to be:

$$V = \iint_A d\underline{s}'\underline{\Phi}(\underline{r}')\cdot \underline{\mathrm{E}}(\underline{r}')$$

and computing the ensemble average, we obtain:

$$\langle V_r^{\omega}V_r^{*\omega}\rangle = \omega^2\mu_o^2 \iint_A ds_1 \iint_A ds_2 \underline{\Phi}(\underline{r}_1)\iiint_V dr' \iiint_V dr'' \underline{\overline{G}}\rceil\cdot\langle \underline{J}_\omega(\underline{r}')\underline{J}_\omega^*(\underline{r}'')\rangle\cdot$$

$$\underline{\overline{G}}\rceil^*(\underline{r}'',r_2)\cdot\underline{\Phi}(\underline{r}_2) \qquad (8)$$

and making use of eq.(2),

$$\langle V_r^{\omega}V_r^{*\omega}\rangle = \omega^2\mu_o \iint_A ds_1 \iint_A ds_2 \iiint_V d\underline{r}' \iiint_V d\underline{r}''$$

$$\underline{\Phi}(\underline{r}')\cdot\underline{\overline{G}}\bullet\ (\underline{r}_1,\underline{r}')\frac{kT(\underline{r}')\sigma(\underline{r}')}{\pi}\cdot$$

$$\delta(\underline{r}'-\underline{r}'')\underline{\overline{G}}\bullet^*(\underline{r}'',\underline{r}_2)\cdot\underline{\Phi}(\underline{r}_2) \qquad (9)$$

and finally,

$$\langle V_r^{\omega}V_r^{*\omega}\rangle = \frac{\omega^2\mu_o k}{\pi}\iint_A ds_1 \iint_A ds_2 \iiint_V d\underline{r}'T(\underline{r}')\sigma(\underline{r}')$$

$$\underline{\Phi}(\underline{r}_1)\cdot\underline{\overline{G}}_\omega(\underline{r}_1,\underline{r}')\cdot\underline{\overline{G}}_\omega(\underline{r}',\underline{r}_2)\cdot\underline{\Phi}(\underline{r}_2) \qquad (10)$$

Let us define the Kernel function related to the specific antenna and conductive wall geometry as,

$$\Gamma_A^\omega(\underline{r}') = \iint_A ds_1 \iint_A ds_2 \underline{\Phi}(\underline{r}_1) \cdot \overline{\underline{G}} \cdot (\underline{r}_1, \underline{r}') \cdot \overline{\underline{G}} \cdot (\underline{r}', \underline{r}_2) \cdot \underline{\Phi}(\underline{r}_2) \qquad (11)$$

Then

$$\langle V_r^\omega V_r^{*\omega} \rangle = \frac{\omega^2 \mu_o k}{\pi} \iiint_V d\underline{r}' \Gamma_A^\omega(\underline{r}') T(\underline{r}') \sigma(\underline{r}') \qquad (12)$$

Considering the fat that the measurement devices-radiometers-measure a finite bandwidth, the measured quantity is related to

$$\mathrm{I} = \int_{\omega_o - \Delta\omega/2}^{\omega_o + \Delta\omega/2} d\omega \langle V_r^\omega V_r^{*\omega} \rangle \cong \frac{\omega_o^2 \mu_o k}{\pi} \int_{\omega_o - \Delta\omega/2}^{\omega_o + \Delta\omega/2} d\omega \iiint_V d\underline{r}' \Gamma_A^\omega(\underline{r}') T(\underline{r}') \sigma(\underline{r}') \qquad (13)$$

And defining

$$\Delta\omega \Gamma_A(\underline{r}') = \int_{\omega_o - \Delta\omega/2}^{\omega_o + \Delta\omega/2} d\omega \Gamma_A^\omega(\underline{r}') \qquad (14)$$

We obtain

$$\mathrm{I} = \frac{\omega_o^2 \mu_o k}{\pi} \Delta\omega \iiint_V \Gamma_A(\underline{r}') T(\underline{r}') \sigma(\underline{r}') d\underline{r}' \qquad (15)$$

Examination of eq.(15) shows that in order to have a satisfactory spatial resolution of the microwave thermography device, to be able to measure three dimensional temperature distributions inside the lossy medium, it is required that:

$$\Gamma_A(\underline{r}') \sim c_t \delta(\underline{r}_A - \underline{r}') \qquad (16)$$

where $\underline{\mathrm{r}}_{\mathrm{A}}$ is the antenna center coordinates and c_t is a constant. Then, if eq.(16) is valid,

$$\mathrm{I} = \frac{\omega_o^2 \mu_o k}{\pi} \Delta\omega \cdot c_t \mathrm{T}(\underline{r}_A) \sigma(\underline{r}_A) \qquad (17)$$

II. System Concept for a 3D Intracranial Thermography System

The mathematical analysis in the previous section has shown that the intensity of the radiated filed, defined by Eq.(15), details the requirement associated with the measurement of 3-D temperature distribution inside the lossy medium. Thus, in order to have a satisfactory spatial resolution of the microwave thermography device:

$$\Gamma_A(\underline{r}') \sim c_t \delta(\underline{r}_A - \underline{r}') \qquad (18)$$

where $\Gamma_A(\underline{r}')$, is the transfer function for the medium, $\underline{r}_A$ is the antenna center coordinates and c_t = 3x10^{8}m/sec is a constant. Then, if Eq.(18) is valid,

$$I = \frac{\omega_o^2 \mu_o k}{\pi} \Delta\omega \cdot c_t T(\underline{r}_A)\sigma(\underline{r}_A) \qquad (19)$$

is the solution of Equation (15), in terms of measurable quantities that form the core of the present innovation. In particular, the definition of the parameters of Eq. (19) are:

ω_o is the center frequency (in radians/sec) of the observed microwave spectrum bandwidth.
μ_o is the magnetic permeability constant.
k Boltzaman's constant.
$\Delta\omega$ Bandwidth of observed microwave spectrum.
$T(\underline{r}_A)$ is the temperature spatial distribution within the medium of interest
$\sigma(\underline{r}_A)$ is the spatial distribution within the medium of interest for the electric conductivity.

The present invention will provide estimates of the product of $T(\underline{r}_A)\sigma(\underline{r}_A)$. Since the electric conductivity spatial distribution is approximately constant within the brain tissue structure, estimates of the product term $T(\underline{r}_A)\sigma(\underline{r}_A)$ by the apparatus of the present invention, will provide estimates of the Temperature distribution within the medium of interest (intracranial cavity).

II.1 Ellipsoidal Cavity as a Sensor Concept for 3D Intracranial Thermography System

The novelty of the method considers the above arguments. Thus, we invented the deployment of an ellipsoidal cavity to achieve maximum peak of radiation pattern, as expressed by Eqs.(18) & (19), in order to measure the intensity of the radiated microwave energy by using a microwave antenna.

Indeed it is well known property of ellipsoidal cavities that every ray originating from the one focus will merge on the other focus with the same path length. Therefore a sharp focus is expected to arise in case the lossy medium is placed in one center while receiving antenna is at the other focus. In Figure (2) this concept is presented. Notice that all the rays starting from F_1 pass from the F_2 keeping the total path lengths following a single reflection from the cavity walls. The use of ellipsoidal (spheroidal) conductive wall cavity essentially is operating as a three dimensional BEAMFORMER. An exact assessment of the Γ_A(r') function in Eq.(15) would require an extensive and rigorous analysis of the corresponding electromagnetic problem. The present invention uses a geometrical optics approach to estimate the resolution properties of the structure shown in Figure 2. On taking the path on each ray emerging from the focal point F_1 and neglecting the reflection phenomena it is shown that the spherical volume around the focus F_1 with radius of $\lambda_g/4$ (λ_g being the wavelength inside the tissue) will be coherently contributed to the field at the point F_2 Considering the fact that for the human brain tissue the relative dielectric constant approximately is equal to $\varepsilon_r \cong 60$ (real part) then $\lambda_g = \lambda / \sqrt{\varepsilon_r}$ where $\lambda = \frac{2\pi}{\omega_o} c$ is the free space wavelength ($c=3\times10^8$m/s).

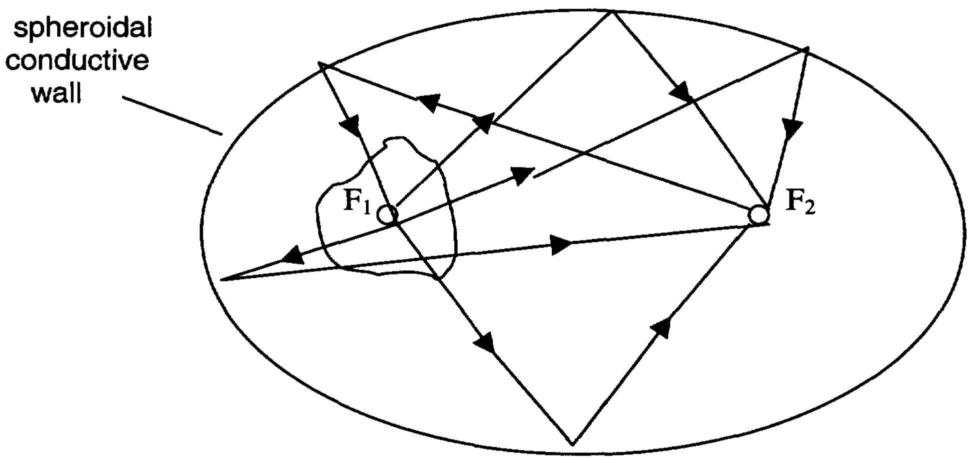


Figure 2. Focusing properties of an ellipsoidal cavity

The selection of operation frequency f_o should be based on the penetration property of radiation to human head. In the framework of the present project the frequency of 1.5GHz was considered to be suitable since a sufficient spatial resolution equal to $20cm / \sqrt{60} \cong 3cm$ is obtained while the penetration depth is of the order of 6-10 cm.

Based on the above considerations an ellipsoidal cavity was designed. Considering the requirement of housing human head and to keep the size of the cavity of reasonable the following initial selection was done:

Major Axis Total Length (2a) = 150cm
Minor Axis Total Length (2b) = 120cm

And the interfocal distance is:

$2c=2\sqrt{a^2-b^2}=90$cm

II.2 Construction of Ellipsoidal Cavity

Following a review of possible construction techniques (bonding of metallic patches, use of wire meshes, etc), it was found that the most suitable construction technique is to use fiberglass method usually employed in small ship industry to construct boats. The ellipsoidal structure was split into to upper and lower pieces to ease the construction process. In Figure 3 the ellipsoidal cavity in opened and closed form is shown.

The inner surface of the two half-ellipsoidal shells was painted with a conductive paint to achieve a good reflection of incident electromagnetic waves. To achieve good reflection properties, various paints were tested by using a network analyzer-antenna (open waveguide) measurement process. Following a thorough and lengthy process it was found that the paint ELCTRODAG 440AS Highly Conductive Nickel Coating (Acheson Company) is suitable to be used. It is interesting that despite the expected good conductivity of many paints (i.e. aluminum paint), they failed to provide a satisfactory solution.

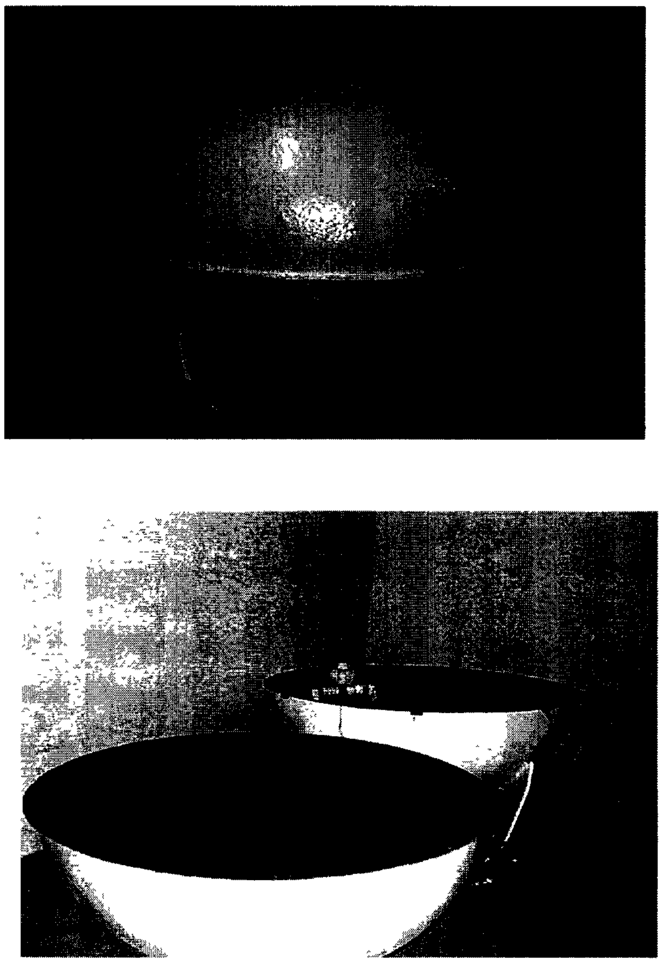


Figure 3. Constructed Elliptical Cavity

II.3 Construction of Radiometer System

A total power radiometer was designed and constructed with a center frequency of 1.5GHz and a bandwidth of 400MHz. The block diagram of the radiometer system is shown in Figure 4.

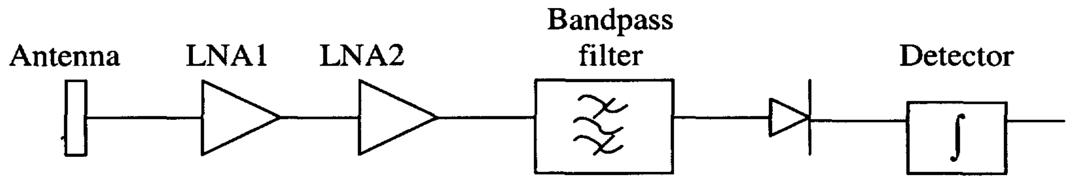


Figure 4. Radiometer Block diagram

The signal incident from the antenna is amplified and filtered sequentially. The two identical low noise amplifiers (LNA) are used to raise the signal amplitude to compete with the detector shot noise which has an equivalent power of -40dBm. The detected signal is fed to an integrator-low pass filter which incorporates a dc amplifier. The band-pass filter is constructed using inter-digital line architecture to achieve a 400MHz bandwidth. The total radiometer microwave frequency gain is computed by requiring the measured power at the output of the radiometer to be -30dBm when the observed object by the antenna has a T=300K equivalent temperature. The incident to radiometer being:

$$P_{in} = kTBN_f \qquad (20)$$

where
$k = 1.38 \times 10^{-23}$ J/K
T=300K
$B = \Delta\omega/2\pi = 10^8$ Hz, is the bandwith
N_f (LNA noise figure) = 0.85dB

and then in dBm units:

P = -173.8+80+0,85 = -92,95dBm

Therefore the required total gain is:

G = 92,95-30 = 62,95dB

Figure 5 presents the experimental radiometer that was prepared for the prototype. The dc signal at the output of the integrator is measured using a sensitive voltmeter HP 3478A MULTIMETER.

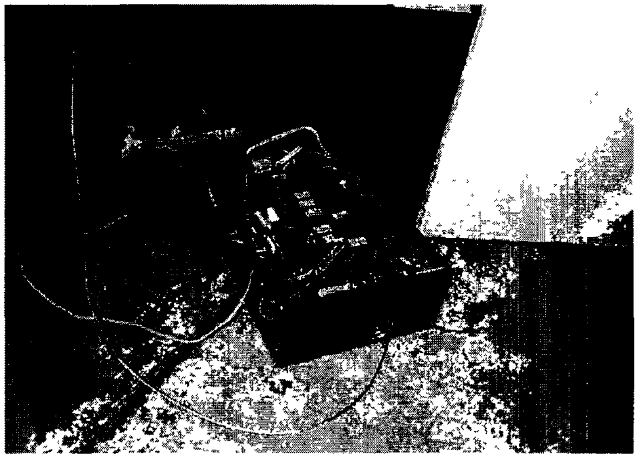


Figure 5 Radiometer operating at λ = 20cm

II.4 Antenna Design

A standard sleeve dipole constructed using a semi-rigid coaxial line as shown in Figure 6 and was tuned with a network analyzer to achieve good match at the antenna input. A satisfactory 1.5:1 VSWR at the full 400MHz was achieved. Notice that the sleeve dipole prevents the induction of surface currents on the coaxial feeding line which is important not to disturb the radiation pattern of the antenna.

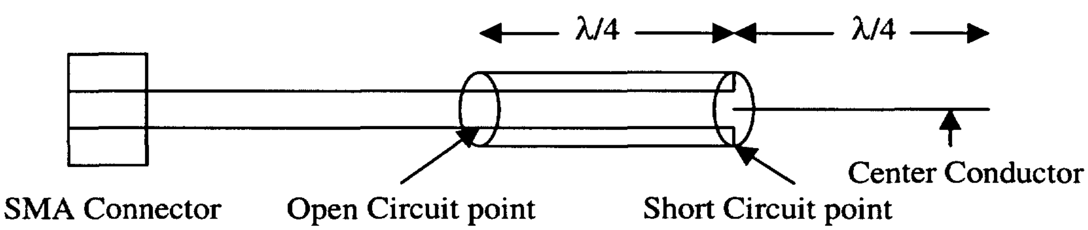


Figure 6: Sleeved Coaxial Line

III. Results

The setup shown in Figure 7 was deployed to test the prototype microwave thermography system. A spherical water tank with glass wall (thickness 1mm) was used to test the performance of the system. The spherical tank was filled with hot water while the temperature was measured by an LM35 sensor. The spherical tank was moved mechanically to observe the focusing properties of the system. The sleeved dipole was placed as shown in Figure 7 at the focus of the ellipsoid while the other focus was occupied by the spherical water tank.

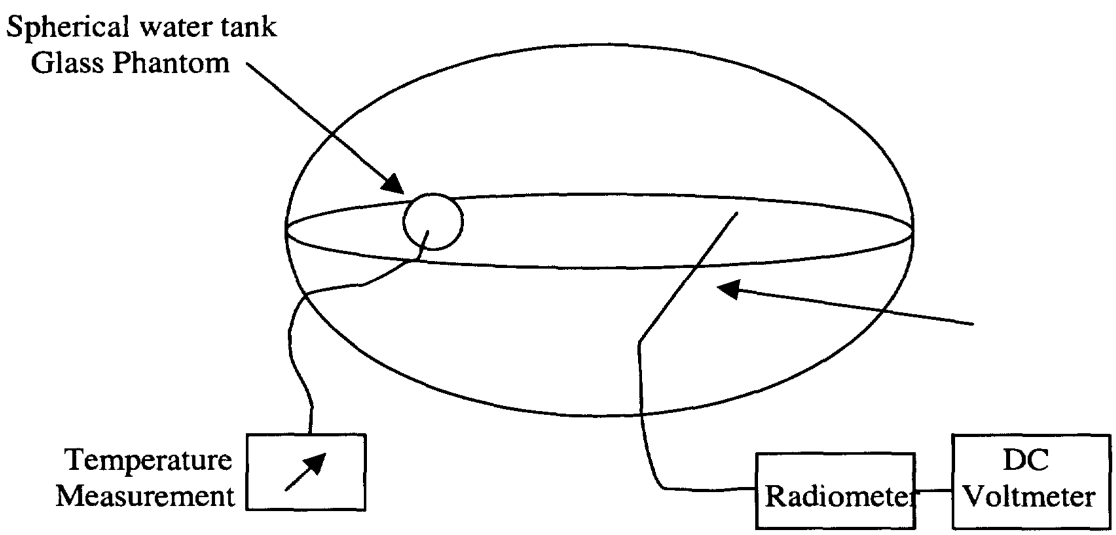


Figure 7: Measurement setup

The experimental set-up of Figure 7 was placed in a basement room to lower the possible external interference.

III.1 Results with Spherical Phantom of 6cm radius

The glass phantom was filled with 1.25lt water starting at 55°C and the radiometer output was recorded versus the water temperature which dropped to environmental temperature. The recording range was down to 33.3°C.
In Figure 8 the variation of radiometer voltage with the temperature is shown where an average slope of 0.0226mV/°C is observed.

III.2 Orthogonal phantom of 8cm x 12cm

The same measurement was carried out using a 0.5lt water phantom also placed at the ellipsoid cavity phantom focus. The average slope of the measurement now is 0.0268mV/°C. During carrying out the above measurements the noise at the output of the radiometer was 0.005mV which corresponds to $\delta T = 0.25$ °C. Without the phantom the measurement was 9.2mV. The results are shown in Figure 9.

III.3 Measurement of Spatial Resolution

In order to assess the spatial resolution of the system the experiment (4.1) was repeated by replacing the orthogonal phantom towards the ellipsoidal cavity center by 15cm. A significant reduction of detected signal is observed as shown in Fig. 10.

Fig. 8

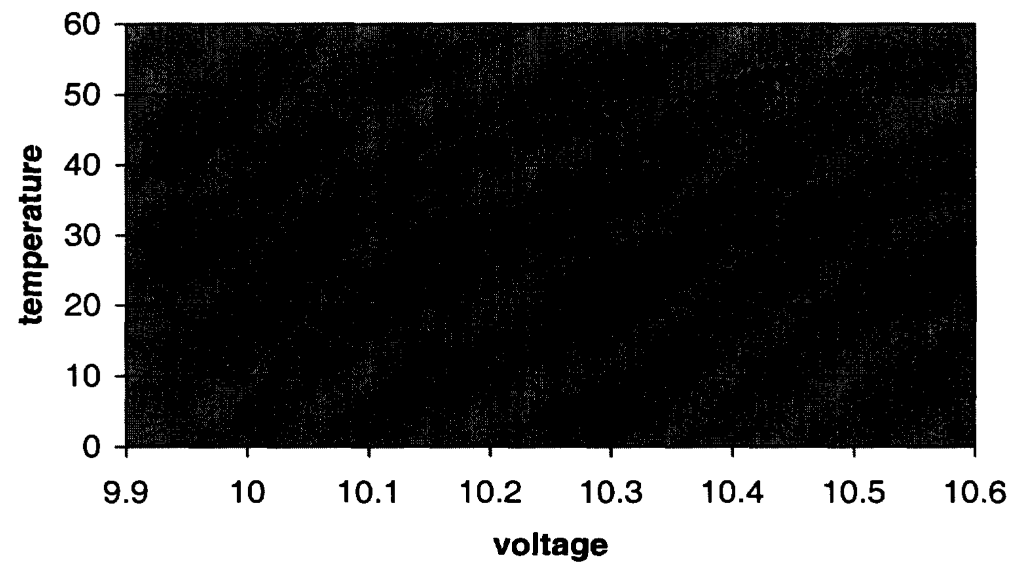


Fig. 9

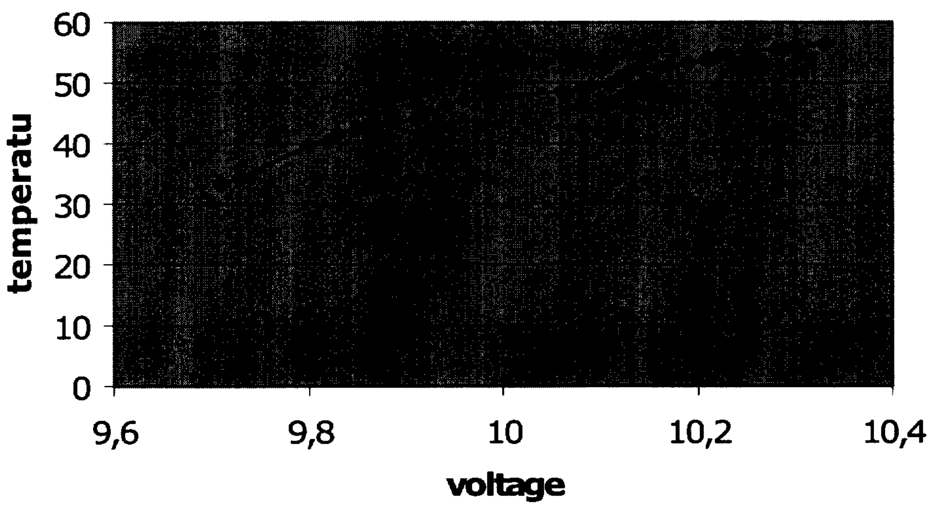
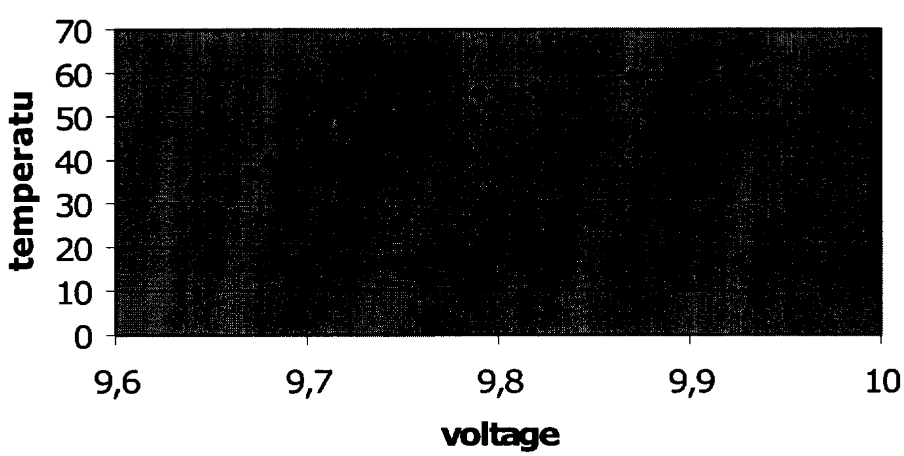


Fig. 10



III.4 Assessment of Experimental Results

The prototype microwave thermography system developed in the frame work of the present project proved to be able to measure accurately and on-line temperature inside human head phantoms. The principle of using the focusing properties of an elliptic reflector proved to be a feasible and right solution. Based on the measurements carried out the system operating at the 1.5GHz receiving frequency is able to achieve the following specifications:

Spatial resolution: ± 1.5 **cm**

Temperature measurement Accuracy: $\pm 0.25^o C$

It is important to emphasize the fact that the system potentially is able to measure the three dimensional temperature distribution inside the human body and in general within an opaque dielectric object in almost real time since only 1-2 sec integration times are required.

IV. Conclusion

In the present report the design development and evaluation of a prototype non-invasive three dimensional intracranial thermography system has been demonstrated. The work has been cocused to prove the practical feasibility of the fundamental idea based on the use of an elliptical cavity to achieve high spatial resolution in conjunction with a wide band radiometer system. Certainly, the developed system is open to many improvements to become a clinical diagnostic device. The developments and improvements to be carried out in the immediate future are:

- Development of a moving table which will allow the movement of human body and this measurement of spatial distribution of temperature field inside the human head
- Improvement of receiving antenna of the radiometer to achieve increase of the received signal. The use of multi-polarization wide band dipoles as well as conical dipoles are expected to improve the temperature measurement accuracy
- The development of a fully automatic system incorporating a three axis measurement of human body and recording automatically the three dimensional temperature should also be addressed and will be done in the near future

IV.1 Practical Exploitation and Prospects of Utilization of the Innovation as an Intracranial Thermography System

Considering the fact that temperature distribution inside the human body is a fundamental physiologic parameter the clinical use of the developed system as a diagnostic tool is very important. To mention a few examples one can list the following possible applications:

- Measurement of temperature within the human brain such is in the thalamus in association with the measurement of event related brain potentials in physiology studies
- Detection of breast cancer by exploiting the very high spatial focusing properties of elliptic cavity
- Measurement of temperature variations within abdomen and pelvic region can be highly useful

Furthermore, the system of the present invention can provide the answer to the highly important issue of mobile phone effects on the human brain. Indeed the increasing public concern which is highly justifiable for the possible negative health effects of mobile phones can be assessed with the developed system. This will be carried out immediately by our research group.
Moreover, if one is interested to measure only the average temperature of the human brain, rather than the three dimensional temperature distribution, it is possible to use more compact elliptic or other type cavities to carry out temperature measurement of human brain.

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14. ABSTRACT

(U) During the past 30 years, many researchers have proposed and used to some extend the microwave radiometry technology to measure non-invasively the temperature distribution within the human body. The reasoning in this suggestion is the fact that microwaves at the frequency region 1-5 GHz have sufficient penetration into human tissues, while they can also provide satisfactory directivity. Another reason in putting forward this idea is the failure of infrared (IR) thermography techniques to provide useful information for the temperature distribution within the human body. Indeed, despite the fact that the human body emits maximum radiation at the IR wavelengths, the very high attenuation of this radiation passing through tissues makes the IR thermography techniques only of a limited value.
Although the amount of energy emitted by human tissues at microwave wavelengths is relatively small, temperature distribution inside the human body can be measured at least up to 5-7 cm depths. Furthermore the technology defined in this report can lead into measurement ability up to 10 cm. However, there is a practical problem in sensing the radiated intracranial thermal energy in the microwave frequency regime. This is because, there is a requirement of an array of microwave antennas to coherently integrate the scattered thermal energy and localize the source area inside the human brain that radiates thermal energy. Thus, There is no current method and or apparatus that provides non-invasively a three- dimensional temperature distribution deep within the human head. The present report details the development of a microwave non-invasive thermography system being able to provide three - dimensional temperature distribution deep within the human head. The potential usefulness of mapping of temperature inside the human brain -especially in the cortex - is considered to be of very high value in prevention of heat stroke of brain, psychiatry, and neurology. In this report, the development of a prototype system for clinical testing is described. Furthermore, this document includes a design of a follow-up field-deployable system integrated as a soldier's helmet for fully automated scanning operations of interest to the Canadian Forces.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) intracranial thermography system; heat stroke; brain core temperature; microwave antenna; ellipsoidal cavity