DUAL MODE MICROWAVE SYSTEM TO ENHANCE EARLY DETECTION OF CANCER

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ABSTRACT

A dual mode microwave system has been developed that will permit early detection of cancer. The system combines the use of the passive microwave radiometer[1,2,3] with an active transmitter. The active transmitter will provide localized heating to enhance early detection by taking advantage of the differential heating (i.e., tumor temperature with respect to surrounding tissue) associated with thermal characteristics of tumors.

SUMMARY

It is well known that a carcinoma, or malignant tumor, is normally hotter than the surrounding tissue and that, from "black body" theory, any perfectly absorbing body emits radiation at all frequencies in accordance with Planck's radiation law. It is further known[4] that the tumor tissue will die at temperatures above 42°C, and it has been reported[5] that tumor temperatures of greater than 45°C can be held with adjacent normal tissue remaining at or near normal temperature.

This paper describes the design approach taken in the development of a microwave system, shown in Figure 1, to diagnose and treat cancer using non-invasive techniques. A sensitive passive microwave radiometer specifically designed to sense subsurface temperatures is coupled with a solid state transmitter to provide localized heating of subsurface tissue, thereby taking advantage of the differential heating due to vascular insufficiency associated with the thermal characteristics of tumors to highlight and enhance early detection of cancer.

The selection of both the radiometer and the transmitter frequencies was based upon several factors:

1) Emissivity, which increases with increasing frequency;
2) Spatial resolution; and
3) The microwave transmission characteristics.

The frequency chosen for the radiometer was 4.7 GHz which is far removed from the microwave heating frequency of 1.6 GHz.

The microwave radiometer is of the common load comparison, or Dicke, configuration. The radiometer

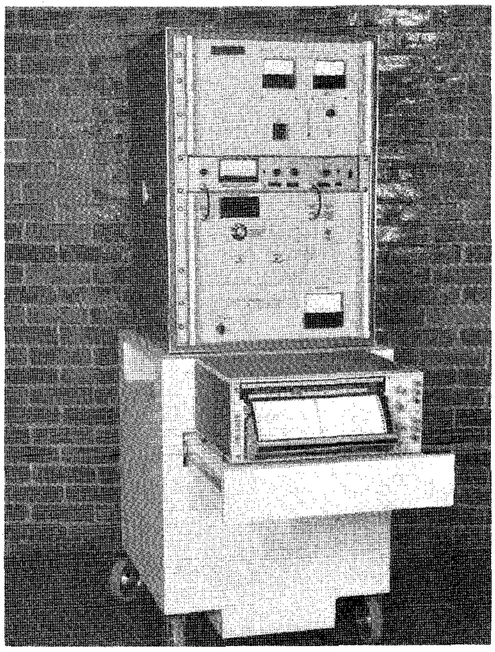

Figure 1
Microwave System - Drawer Extended

design employs a low noise RF amplifier in conjunction with a single-ended square law detector rather than the common superheterodyne configuration involving a local oscillator and IF amplifier, thereby minimizing the potential drift and noise associated with this approach. The Dicke, or comparator, switch is a ferrite latching switch. The individual components that make up the radiometer shown schematically in Figure 2, together with the solid state transmitter shown schematically in Figure 3, will be discussed in greater detail.

The minimum detectable temperature sensitivity, ΔT, was well within the desired 0.1°C. The minimum detectable temperature sensitivity, ΔT, is expressed as follows:

$$\Delta T = \frac{k\left[(FL - 1)\ T_1 + T_2\right]}{\sqrt{B\tau}}\ , \ ^{o}K \qquad (1)$$

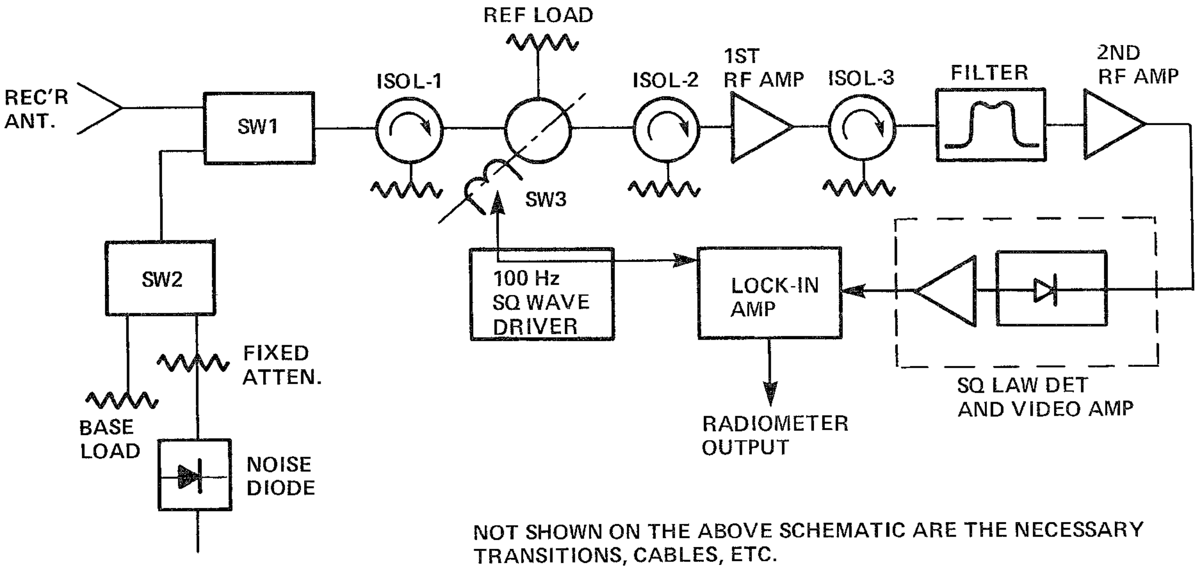

Figure 2
Microwave Radiometer Schematic

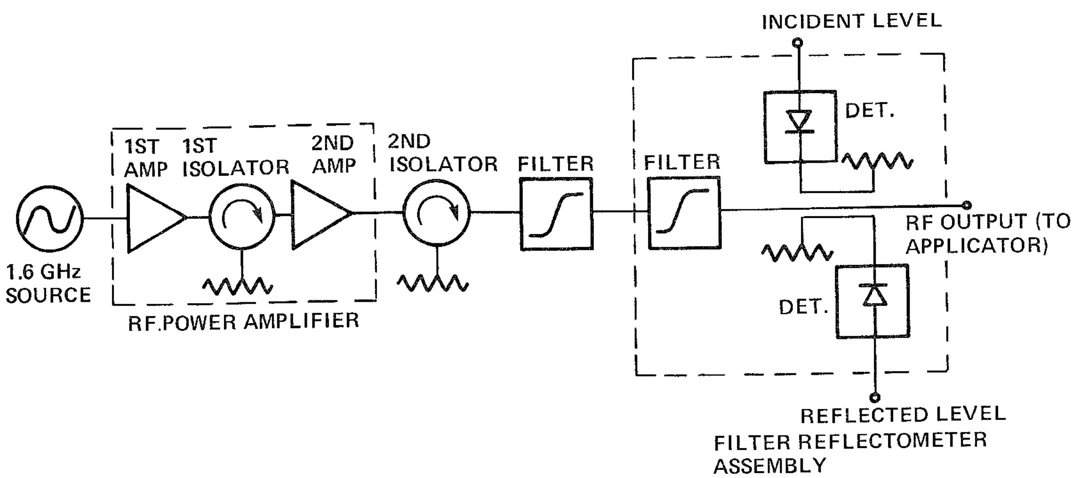

Figure 3
L-Band Transmitter Schematic

In the case of the Dicke switch employing square wave modulation, the value of k is 2.0.

F = noise figure (first amplifier stage), which in our case is 2.2 dB (1.66 ratio).

L = input losses, expressed as a power ratio. The total loss is 2.0 dB (1.58 ratio).

The effective noise figure, FL, is therefore 2.2+2, or 4.2, which represents a power ratio of 2.63.

T_1, is the ambient radiometer temperature (microwave portion); namely, 290^{o}K.

T_2, the source temperature (i.e., temperature seen by antenna), namely 310^{o}K.

B, the receiver bandwidth (i.e., the 3 dB bandwidth of the bandpass filter following the first RF amplifier); namely, 500 MHz.

τ, the radiometer output time constant in seconds.

Utilizing a three-second time constant, we obtain a minimum detectable temperature sensitivity of

$$\Delta T = \frac{2\left[(2.63 - 1)\,290 + 310\right]}{\sqrt{500\text{x}10^6\text{x}3}} \text{, or } .04^{\circ}\text{K rms} \qquad (2)$$

Increasing the time constant, T, to 10 seconds results in a ΔT of $.02^{\circ}K$. Similarly, reducing the time constant to one second will result in a ΔT of $.07^{\circ}K$. The calculated temperature sensitivities are well within our design goals.

The totally battery-operated system eliminates possible problems associated with line transients, pickup, etc. A simple TE_{10} mode aperture is placed in direct contact with the radiating or emitting surface. A normal waveguide transition at L-band corresponding to WR-510 would be 5.10" (12.95cm) x 2.55" (6.48cm). To reduce the physical size of this aperture, single-ridged waveguide was employed since the use of ridged waveguide lowers the frequency at which cutoff will occur. To further reduce the overall size of the aperture, dielectric loading was employed.

The dimensions of the ridged portion of the L-band ridged waveguide were selected to allow propagation of the higher frequency associated with the C-band radiometer. The plated surface of the dielectric-loaded C-band waveguide, therefore, formed the single ridge of the L-band waveguide as shown in Figure 4. The dielectric material used is aluminum oxide having a dielectric constant, ε_r, of 9.8.

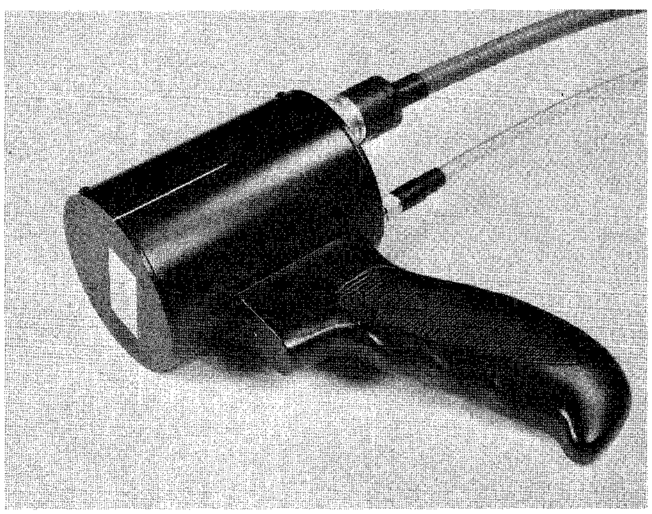

Figure 4
Dual Mode Applicator

It can be seen in the aforementioned figure that by having the radiometer input contained within the single-ridged waveguide L-band transition, we have placed the point of maximum field of the source of heat in close proximity with that point of thermal detection. The cutoff characteristics of the C-band waveguide have been utilized in addition to other filtering provided, the waveguide forming a high pass filter to isolate the high power L-band source from the sensitive radiometer. A heater and proportional thermostat are provided in the dual mode transition, or antenna, to maintain a constant temperature at or very near to that of the temperature of the human body.

It should also be noted that we have taken advantage of the large mismatch (approximately 12:1) associated with the low impedance ridged waveguide when left open-circuited; i.e., in the atmosphere removed from contact with the human body with its high dielectric constant to which the waveguide is matched. The measured power level, in free space, of 1" from the waveguide opening with the L-band power source fully on was less than 0.4 mW/sq.cm. The safety standard established by the Federal Government is 10 mW/sq.cm. for electromagnetic radiation regardless of the frequency.

Microwave thermograms were taken on patients suspected of having breast carcinoma, as well as patients known to have cancer. The temperature differentials measured in patients known to have breast carcinoma ranged between 1.0 and $3.3^{\circ}C$. In one patient suspected of having breast cancer the microwave thermogram was negative, although the 3cm. infiltrating ductal carcinoma was positive by X-ray mammography. On another patient, however, the microwave thermogram demonstrated not only a $1.2^{\circ}C$ hot spot (ΔT) on the patient's right breast, but also a $2.5^{\circ}C$ (ΔT) on the unsuspected left breast. X-ray mammographic results on the left breast were inconclusive although the hot spot as determined by microwave thermogram was ultimately biopsy-proven as carcinoma.

A ΔT consistent with areas of known tumor was seen in patients with Hodgkin's disease and patients with anterior chest wall recurrence of breast carcinoma following mastectomy. In these patients, the magnitude of ΔT correlated well with the clinical course of the disease during the following X-ray treatments. Microwave thermograms were negative in one patient with mid-third esophageal carcinoma, and in one patient with lytic metastases from the breast in her right femur and left humerus.

The available data to date has been obtained by passive radiometric measurements without the use of microwave heating. Additional data will be available at the time of presentation.

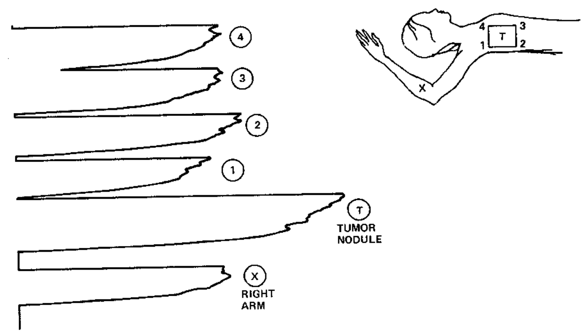

Figure 5
Microwave Thermogram

Figure 5 is a typical scan taken of a woman with an axillary tumor nodule following mastectomy for breast cancer. The temperature of her right arm and four areas bordering the tumor are about $37^{\circ}C$; the tumor nodule itself measures $38^{\circ}C$, a significant temperature differential (ΔT). Subsequent X-ray therapy resulted in a decreasing temperature differential corresponding well with roentgenographic evidence of tumor shrinkage.

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