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## REGIONAL HEATING OF TISSUE WITH CONTROL OF APPLICATED POWER AND WITH MINIMIZED LEAKAGE RADIATION

Joachim W. Brose and Gerhard Flachenecker

Institute of High Frequency Technique

University of the Bundeswehr, Munich

### ABSTRACT

Distance-sensitive applicators for UHF diathermia are described. A novel power and frequency controlled diathermia system using this applicators shows a leakage radiation of more than 20dB below that of conventional systems when unloaded. Furtheron, the new system keeps the actually applicated power constant as long as the patient is in a correct position.

### INTRODUCTION

High frequency power is often used for heating biological tissue for example to increase the blood flow. This stimulation is caused by the very sensitive temperature control system of the body which tries to keep the temperature constant at 37°C. Because of the increased blood flow high frequency diathermia can have beneficial properties for medical applications.

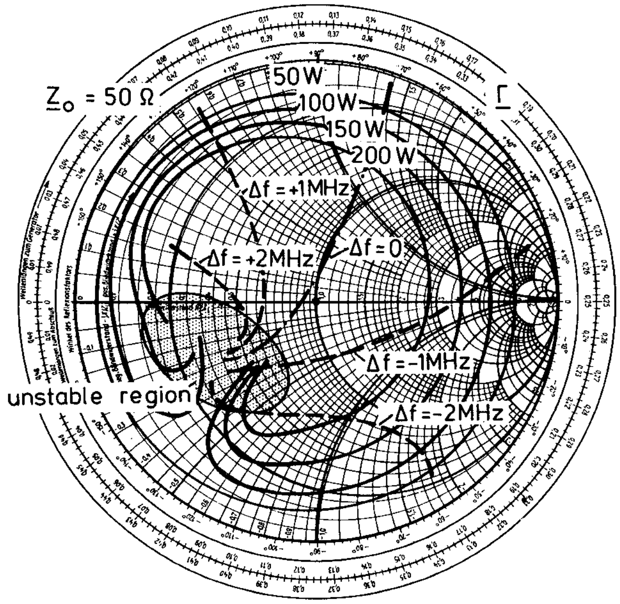


Fig.1 Measured Rieke plot of a typical 0.434GHz tube generator

However, for some reasons the therapeutic use of diathermia also involves risks for the patient and for persons in vicinity of the EM applicator.

Depending on the frequency and the size and type of the applicator most diathermia systems radiate EM power into the whole sphere and cannot recognize how much of the radiated power really heats the patients tissue.

Because of the high EM power requirements diathermia generators are usually tube oscillators with coaxial resonators (for VHF and UHF) or with resonant circuits respectively (for HF). This self oscillating generators are sensitive in frequency and output power to the load impedance as shown in the Rieke plot of Fig.1. As the usable ISM frequencies have quite narrow bandwidth limitations, typical applicators are designed not to change their impedance whether there is biological tissue or not just to fulfil the bandwidth regulations.

### CONVENTIONAL SYSTEMS

Several different UHF applicators have been investigated to find the influence of tissue and the amount of leakage radiation. With 180 W available generator power, $2mW/cm^2$ of power density could be measured at a distance of more than 1 meter even at the rear side of one of the applicators (see Fig.2). No applicator could be found with less than $2mW/cm^2$ of power density at a distance of 0.4 meter. Biological tissue at the aperture of the applicator causes changes of the reflection coefficient of typically 10% with the investigated antennas. On this account, there will be nearly no difference of radiated EM power whether there is a patient or not. Especially without a patient nearly the total available power is radiated into the environs. So, people using heart pacers are in danger in the surrounding of the antenna and other electronic equipment may fail, too.

### A NEW DIATHERMIA SYSTEM

In order to avoid the disadvantages of diathermia a different system has been developed which radiates only a very small part of the available generator power if no patient is in front of the applicator.





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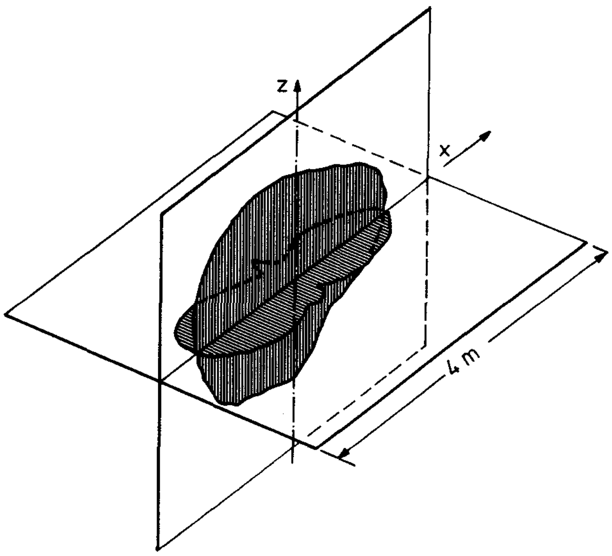


Fig.2 Three dimensional contour plot of 2mW/cm power density measured with 180W available RF power and with a conventional applicator in the center

Furtheron, the applicated power is kept constant as long as the patient is in a correct position.

The main problem is to find applicators with reflection coefficients strongly depending on the distance to the tissue. The reflection coefficient has to be very close to 1 when there is no tissue and it has to be close to 0 if the tissue is in a distance of 0 to about 6cm. Furtheron, the applicator's behaviour must not be changed by rough treatment.

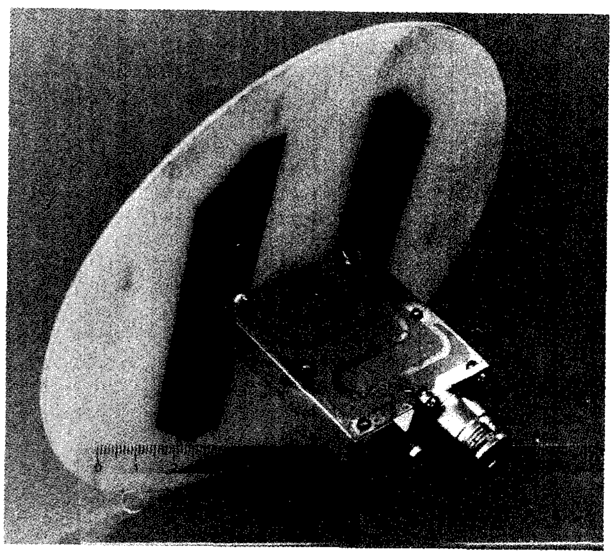

Fig.3 New distance-sensitive 'disk' applicator

So, the diathermia antenna has to have a very simple mechanical construction and the far field in lossless media has to be very small. Several antennas have been developed most of them with the basic scheme shown in Fig.3 and Fig.4, respectively. The small disk applicator (see Fig.3) consists of two radiating stripline elements on an epoxy substrate and a stripline feeding network on RT-Duroid substrate.Its distinctive features are similar to that of the applicator sketched in Fig.4.

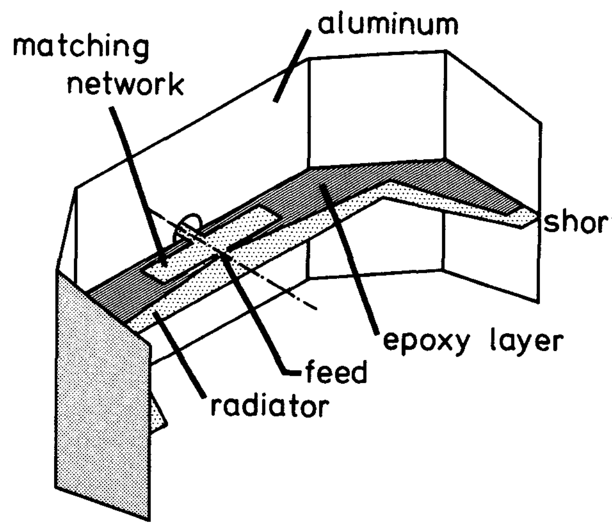


Fig.4 Schematical sketch of the new distance-sensitive 'long-field' applicators

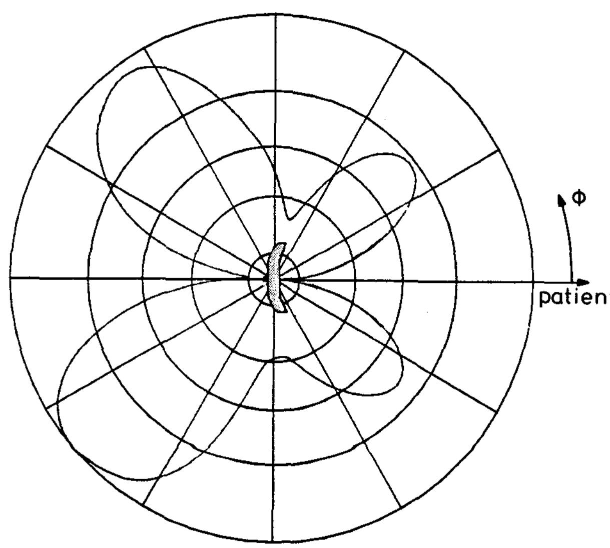


Fig.5 Radiation pattern of the new applicator when unloaded. The main lobes are more than 10dB below the main lobes of conventional applicators with identical available RF power.

The radiating elements of this antenna type are etched on an epoxy layer. This layer is mounted on an aluminum "reflector". The feeder point is in the center of the radiating elements at the front side of the applicator. The currents in both halfs of the radiator are equal in magnitude but contrary in phase.

Because of the 180° phase difference, the far field of both currents is cancelled in the x-z-plane and very small (more than 10dB below the fieldstrength of conventional applicators) in all other directions (see Fig.5).

With lossy tissue close to the applicator the imaginary part of the antenna's admittance is altered by the permittivity of this tissue. The length of the antenna elements is optimized to show a resonance when the applicator is loaded with typical tissue at distances of a few centimeters. The strong near fields of the resonance currents produce thermal losses in the tissue which cause the intended temperature rise and a lower real part of the antenna's admittance. With a symmetrical stripline network located between the radiator's feeding point and the reflector the antenna is matched to the generator's source impedance.

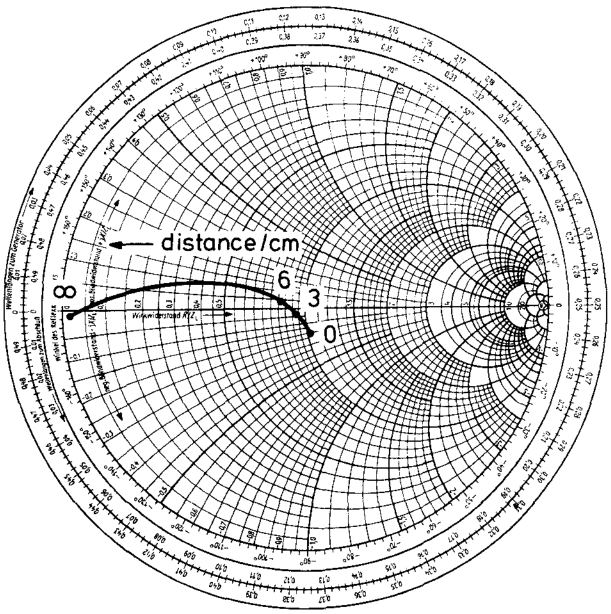


Fig.6 Reflection coefficient of the new 'long-field' applicator depending on the distance d between applicator and tissue

Because of the overall symmetry of the applicator the far fields of the loaded and, as well of the unloaded antenna are very small.

The reflection coefficient achieved with this antenna type is about 0.95 in the free space and less then 0.1 with tissue at a distance of 0 up to 6cm (see Fig.6).

To get the percentage of power delivered to the tissue a phantom model made of a thickly liquid saline solution has been heated up with the help of the applicators presented here. The temperature distribution was measured threedimensional with a plane array of 20 thermocouples (Fig.7). The theromocouples were plunged in 12 steps into the phantom from a motor unit.

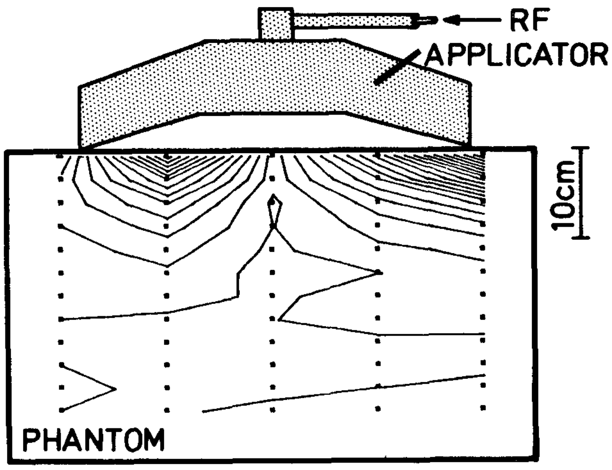


Fig.7 Lines of constant temperature in a phantom made of saline solution

The ratio of thermal energy which is necessary to achieve the measured temperature differences and EM energy was found to be better than 0.72. The temperature rise was 50% of the surface-temperature rise at a depth of 3cm.

This type of near field applicator should not be used with a conventional self oscillating UHF generator as changes in frequency will be caused whenever the patient is moving. Therefore, a new generator, equipped with a motor driven tuning assembly has been developed (see Fig.8).

The control circuit (see Fig.9) consists of a quartz controlled reference oscillator (VCXO) that is tuned itself by a fast PLL circuit (PD and LPF 1) to achieve a hysteresis identical to the tolerances permitted by legal regulations. Because of this fast control loop minor frequency differences are neglected and the motor unit is only activated from the slow PLL circuit (PD and LPF 2) if the frequency limits are touched.

As the applicator's impedance strongly depends on the distance to the tissue and as more than 70% of the radiated power are applicated only to the tissue it is possible to measure and to control the applicated EM power. The forward power and the reflected power are measured with a directional coupler and square law detectors. A Schmitt trigger circuit compares the reflected power with a fixed percentage of the forward power.

Fig. 8 Coaxial plate resonator with tube and tuning element

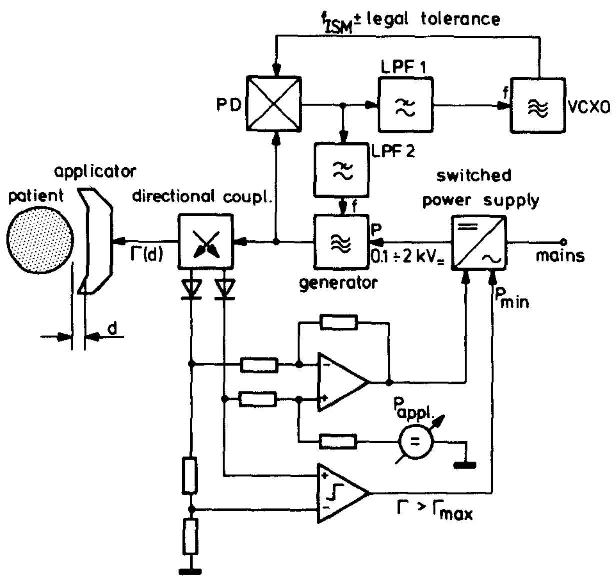


Fig.9 Circuit diagram of the new diathermia system

As long as the reflection coefficient is greater than the maximum acceptable reflection coefficient $\Gamma_{max}$ the generator power is kept down at a low level $P_{min}$ (approximately 10dB below the maximum power) which is sufficient for the measurement.

If the patient is close to the optimum position the generator power is increased to that level where the difference of forward and reflected power is equal to the desired applicated power $P_{appl}$.
This is achieved with the help of a power control loop consisting of a differential amplifier and a switched power supply for the generator's plate voltage.

## CONCLUSION

A new diathermia system has been developed that will make the clinical use of diathermia safer for the patients and for the clinical personell. The applicated power is controlled within a tolerance of a few ten percent and the leakage radiation of the loaded applicator and, even more, of the unloaded applicator is decreased remarkable.