

A 2450-MHz Slab-Loaded Direct Contact Applicator with Choke

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Abstract—A Teflon-slab-loaded direct contact microwave diathermy applicator has been developed. It produces minimal leakage radiation during effective heating of simulated planar tissue models. The use of TEM mode excitation results in heating patterns which are more uniform than the patterns of comparable waveguide applicators without dielectric loading.

I. INTRODUCTION

RECENT STUDIES [1]–[3] of slab-loaded rectangular waveguides with flanges (Fig. 1), used as microwave diathermy applicators at 2450 MHz, have shown that their heating patterns induced in phantoms are highly uniform in the central region. These direct contact applicators were not designed to minimize leakage radiation. To reduce leakage radiation, the waveguide flanges have been replaced with a microwave choke. The purpose of this paper is to report on the design and performance of a slab-loaded rectangular waveguide that produces minimal leakage radiation while delivering a thermally effective absorbed dose to simulated tissue models.

II. DESIGN

The waveguide, shown in Fig. 2, is a WR-430 guide with a standard waveguide to coaxial adapter. Its flanges were removed to surround the remaining aperture with a microwave choke. By loading the waveguide with two Teflon slabs, an inhomogeneously filled applicator with improved performance is obtained. A cross section of this design is shown in Fig. 3.

A. Slab-Loading

The length of the two slabs along the axis of propagation is 7.6 cm. As is indicated in Fig. 3, they have a thickness of 3.2 cm and a height of 5.4 cm. The purpose of the slabs is to provide for a more uniform heating pattern in the central region of the aperture by exciting the TEM mode in the air space between the slabs. The following equation from [4] is used to calculate the thickness t : $t = (\lambda/4) (1/\sqrt{\epsilon - 1})$ where ϵ is the relative dielectric constant and λ the wavelength. Since $\epsilon = 2$ for Teflon and $(\lambda/4) = 3.1$ cm, $t = 3.1$ cm. The resulting width of the air gap is 4.5 cm. Thus, according to inhomogeneous wave-

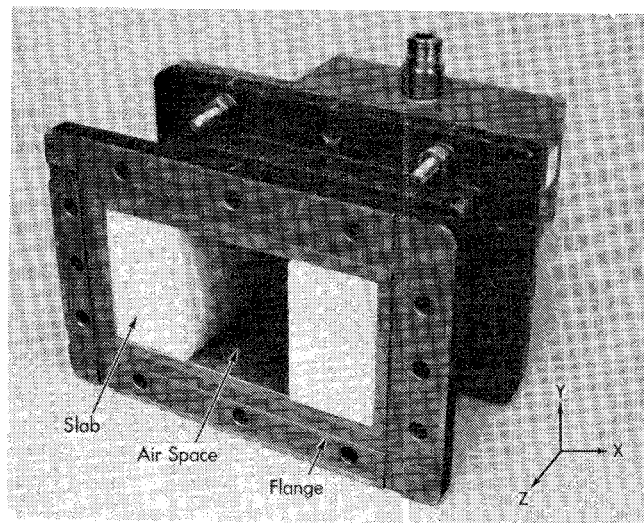


Fig. 1. Slab-loaded applicator with flanges.

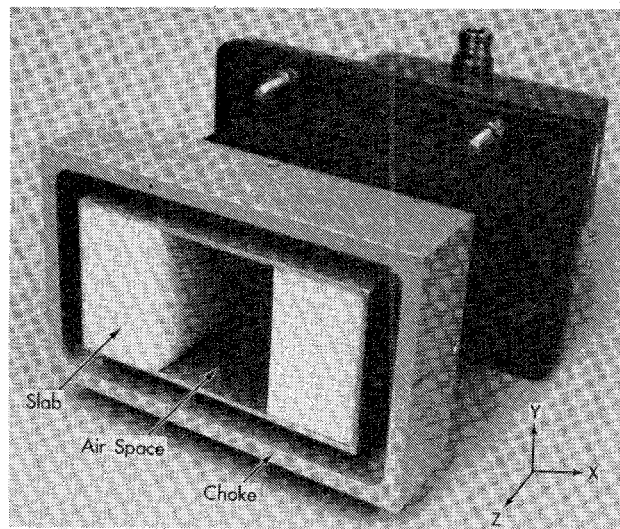


Fig. 2. Slab-loaded applicator with choke.

guide theory [4], higher order modes will not be excited in the waveguide.

B. Choke

In accordance with standard design procedure, the microwave choke is one-quarter-wavelength long at 2450 MHz or 3.1 cm. As indicated in Fig. 3, its outer dimensions are 14.5 cm and 9.1 cm and the air space

Manuscript received May 16, 1980; revised July 24, 1980.

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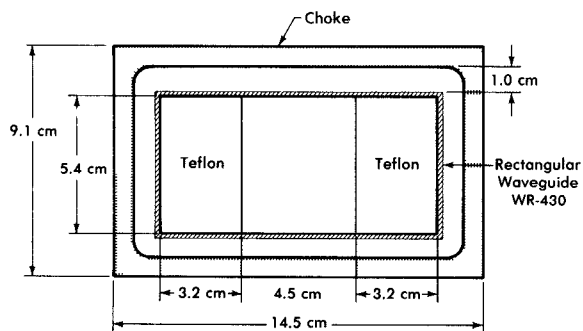


Fig. 3. Cross section of slab-loaded applicator with choke.

between applicator and choke is 1.0 cm. The details of fabrication are available elsewhere.¹

III. PERFORMANCE OF SLAB-LOADED APPLICATOR WITH CHOKE

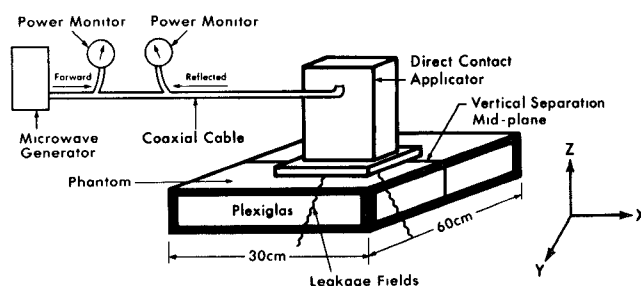
The applicator was evaluated in terms of the heating effectiveness and safety requirements of the Bureau of Radiological Health draft proposed microwave diathermy standard. These requirements consist of a leakage of not more than an equivalent power density of 10 mW/cm^2 , measured at 5 cm from the phantom-applicator boundary, when a Specific Absorption Rate (SAR) of 235 W/kg is delivered to simulated muscle tissue in specified fat-muscle phantoms. (The proposed Bureau of Radiological Health standard specifies three types of fat-muscle phantoms: a planar, an arm, and a thigh phantom.) The performance characteristics of the slab-loaded applicator with choke, which will be discussed below, are summarized in Table I.

A. Heating Patterns

The experimental setup for measuring heating patterns is shown in Fig. 4. It is described in detail in previously published papers [2], [5]. Briefly, for internal heating, the applicator is placed symmetrically on top of a planar phantom with a simulated fat layer (either 1 or 2 cm thick) above simulated muscle tissue. (The configuration of this phantom is shown in Fig. 4.) Before heating the phantom, the ambient temperature profile in the simulated muscle tissue is recorded. After heating the phantom, one-half of the phantom is quickly removed (to minimize thermal diffusion) so that a thermographic camera can view the heating pattern. A typical thermogram with a selected profile is shown in Fig. 5. The upper picture is a thermogram with the heated area shown in white and with a white scan line through the region of maximum heating. The lower picture is a temperature profile along the scan line. To minimize thermal diffusion in the phantoms, the width and depth profiles, such as shown in Figs. 5 and 6, were obtained by heating the phantom separately for each measurement.

Fig. 5 shows the internal patterns of the slab-loaded

Microwave Heating



Heating Pattern Measurement

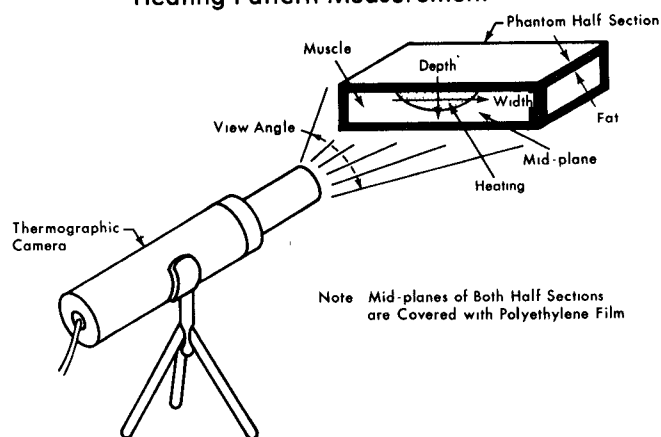


Fig. 4. Experimental setup.

TABLE I
PERFORMANCE OF SLAB-LOADED APPLICATOR WITH CHOKE

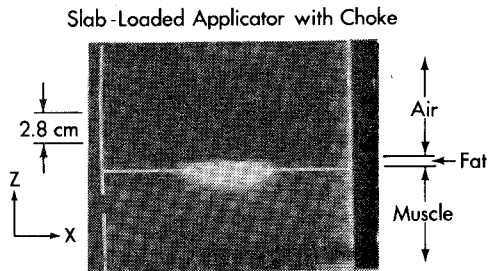
Parameters	Applicator - Phantom Position			
	Direct Contact		1 cm Spacing	
	Fat Thickness (cm)		Fat Thickness (cm)	
	1	2	1	2
w (cm)	6.4	5.7	7.4	5.7
d (cm)	1.3	1.3	1.3	1.3
VSWR	2.5	2.3	1.4	3.2
Net Power* (watts)	22.3	23.3	27.3	23.2
Leakage (mW/cm^2)	0.4	1.2	3.6	2.5

*Required to deliver 235 W/Kg to simulated muscle material

applicator with choke in direct contact with the 1-cm fat layer of a planar phantom. The width w of the temperature profile is 6.4 cm (w is defined [2] as the width of the trace where the temperature rise above ambient level is half the maximum temperature rise). If the slab-loaded applicator with flanges is used [2], the heating pattern is highly uniform; w is 7.3 cm instead of 6.4 cm. This suggests that in the presence of the choke, the uniformity of the electric field distribution between the two slabs is reduced. Yet the heating pattern of a slab-loaded applicator with choke is still significantly broader than of an empty waveguide with choke; its width is 6.4 cm instead of

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INTERNAL HEATING PATTERN



Thermogram-Planar Fat-Muscle Phantom

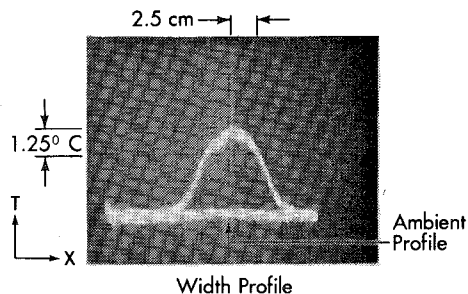
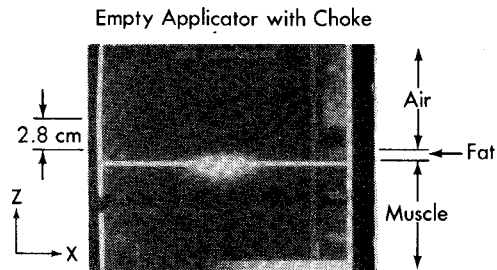


Fig. 5. Internal heating pattern and width profile of slab-loaded applicator with choke in direct contact with 1-cm fat layer of a planar phantom.

INTERNAL HEATING PATTERN



Thermogram-Planar Fat-Muscle Phantom

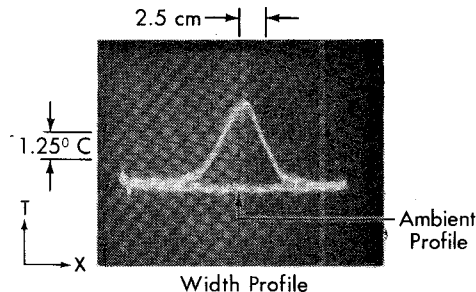
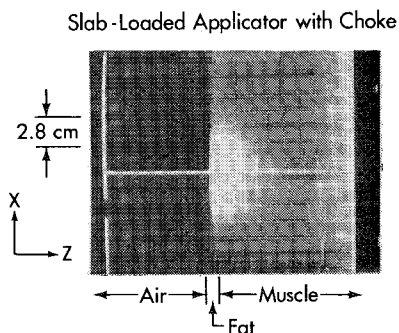


Fig. 7. Internal heating pattern and width profile of empty applicator with choke in direct contact with 1-cm fat layer of a planar phantom.

INTERNAL HEATING PATTERN



Thermogram-Planar Fat-Muscle Phantom

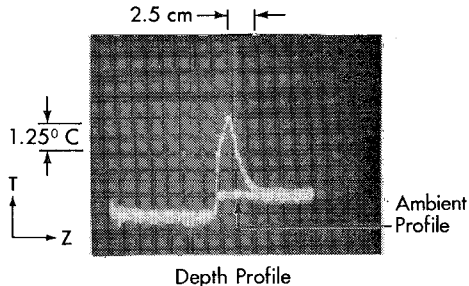


Fig. 6. Internal heating pattern and depth profile of slab-loaded applicator with choke in direct contact with 1-cm fat layer of a planar phantom.

4.6 cm (see Fig. 7). For a 1-cm spacing between the aperture of the slab-loaded applicator with choke and the top of the planar phantom, w is 7.4 cm. (Data for a 1-cm spacing is considered because a small spacing might be preferable for some treatments to prevent overheating of

the skin surface in direct contact with the applicator.) Measurements were also made using a phantom with a 2-cm fat layer. For this phantom, w is 5.7 cm for both the applicator in direct contact and spaced 1 cm from the top of the phantom.

From Fig. 6, for the slab-loaded applicator with choke, the depth of penetration d in simulated muscle tissue is equal to 1.3 cm (d is defined [2] as the distance between the fat-muscle interface and the depth at which there is a 50-percent falloff from the maximum temperature rise). The above value of d remains the same for direct contact and 1-cm spacing for both phantoms (1- and 2-cm fat layers).

To determine the required net power for a thermally effective absorbed dose in the simulated muscle tissue of the planar phantom, the width profiles, such as shown in Fig. 5, were analyzed. The data in Fig. 5 were obtained by heating the phantom with the 1-cm layer for ten seconds with a net power of 125 W delivered to the applicator. A specific absorption rate (SAR) calculation [3] using these data indicated that a net power of 22.3 W is needed to deliver a maximum SAR of 235 W/kg to the simulated muscle tissue of the phantom. For a 1-cm spacing between phantom and applicator, a net power of 27.3 W must be delivered to the applicator to produce 235 W/kg in the phantom. With the 2-cm fat layer planar phantom, the values of the net power for direct contact and 1-cm spacing are essentially the same, namely 23.3 and 23.2 W, respectively.

The VSWR values associated with the above test conditions of phantom and applicator combinations are listed in Table I. A maximum VSWR value of 3.2 is obtained

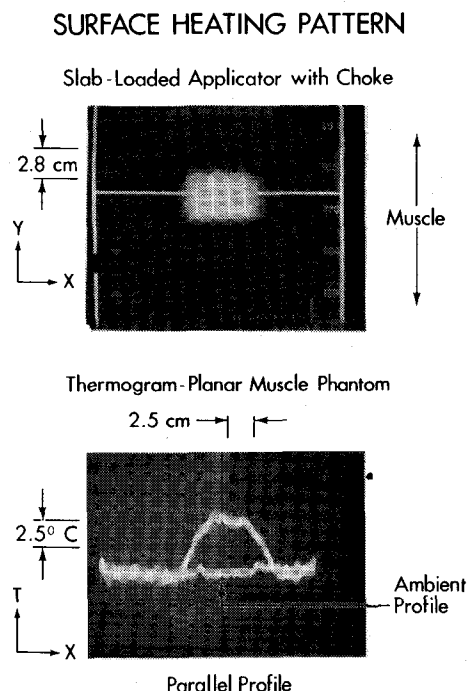


Fig. 8. Surface heating pattern and parallel profile of slab-loaded applicator with choke in direct contact with muscle tissue of a planar phantom.

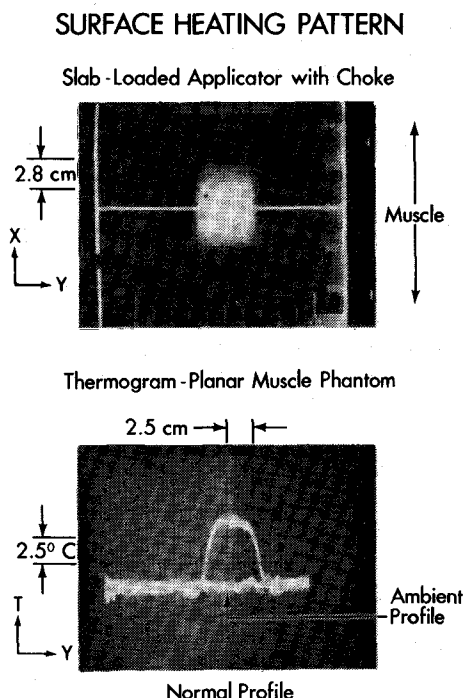


Fig. 9. Surface heating pattern and normal profile of slab-loaded applicator with choke in direct contact with muscle tissue of a planar phantom.

for a 1-cm spacing between the applicator and the top of the 2-cm fat layer of the phantom, while a minimum value of 1.4 is achieved for the same spacing between the applicator and the 1-cm fat layer phantom.

Surface heating patterns were obtained by placing the applicator directly on top of a planar phantom consisting only of simulated muscle tissue. As in Fig. 2, the applica-

tor is positioned on top of the phantom with the aperture length long the x -axis and its width along the y -axis. After the rapid microwave heating is completed, the external surface of the phantom is viewed with a thermographic camera. Fig. 8 shows a surface pattern and a parallel temperature profile. This profile along the x -direction is obtained by setting the white scan line in the region of maximum heating. The parallel profile is quite uniform. The thermogram of Fig. 9 shows the same heating pattern except that the phantom has been rotated 90° so that a normal profile, which is a profile along the y -axis, can be obtained. As in Fig. 8, the temperature profile is also quite uniform.

B. Leakage Measurements

The measurement techniques for leakage were discussed previously [5]. Briefly, a commercially available isotropic probe (Narda 8616) was used with its 5-cm radius foam sphere spacer placed against the planar phantom-applicator boundary. When 235 W/kg is delivered to the simulated muscle layer of a planar phantom, the maximum values of leakage for the 1-cm fat layer phantom was 0.4 mW/cm^2 for direct contact and 3.6 mW/cm^2 for a 1-cm spacing between the aperture of applicator and the top surface of phantom. The corresponding values for the 2-cm fat layer phantom are 1.2 mW/cm^2 and 2.5 mW/cm^2 , respectively. The above leakage data are summarized in Table I. The results of a recent Bureau of Radiological Health study [6] of a circular applicator with a one-quarter-wavelength long choke suggest that the leakage data of Table I would not differ significantly from clinical data provided that tissue areas under treatment would completely fill the aperture of the applicator.

IV. CONCLUSION

The slab-loaded, direct contact applicator with choke enables delivery of a thermally effective absorbed dose to a planar phantom with minimal radiation leakage. Its performance meets with the requirements of the Bureau of Radiological Health draft proposed microwave diathermy standard. The excitation of the TEM mode in the air space between the Teflon slabs results in heating patterns which are more uniform than the patterns of comparable waveguide application without dielectric loading. Although the depth of penetration is smaller at 2450 MHz than at 915 MHz, it is easier to control leakage at 2450 MHz for small spacings (1 cm) between applicators and phantoms [7]. This design is a viable candidate for use in hyperthermia treatments of cancer. It could immediately be applied to animal [8] and clinical hyperthermia studies of cancer [9] that presently use the slab-loaded design without the choke.

ACKNOWLEDGMENT

The mechanical design and the fabrication of the microwave choke were developed at the Bureau of Radiological Health model shop under the able direction of J. E. Duff.

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A Novel Approach to the Design of Multiple-Probe High-Power Microwave Automatic Impedance Measuring Schemes

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Abstract—Starting with a modified look at the phasor diagram of a multiple-probe system on a lossless waveguide, one can attain a geometrical method for designing various direct-reading microwave impedance-measuring schemes using fixed probes. This geometrical method will bypass a significant amount of algebraic complexity as encountered in classical algebraic methods. Hence it allows one to visualize the physical picture more clearly and guides one to modify the design more effectively to meet higher performance demands. This article reports a trend of design developments derived from this new point of view. It starts with the analysis of a two-probe system for measuring an unknown impedance \bar{z} . This is followed by modifications on the design guided by the new geometrical technique. Finally, two practical designs are derived for measuring an unknown microwave impedance automatically. One is to be used under fixed-frequency, swept-power conditions, and the other, under swept-frequency, swept-power conditions. These systems require only inexpensive low-frequency signal processors (either analog or digital) and fixed multiple probes. The output can be either analog with polar display or digital with accurate readouts. To the author's knowledge, these designs

have not been derived in the past using multiple probes. A critical review on all multiple-probe systems reported in the literature is also discussed with their comparison to the present system.

I. INTRODUCTION—BACKGROUND SURVEY

MULTIPLE PROBES mounted on a lossless waveguide terminated by an unknown impedance \bar{z} have been used or proposed by many investigators to obtain data for calculating both phase and magnitude of the unknown complex \bar{z} . Samuel in 1947 [1] used two pairs of equidistant ($\lambda g/4$) probes interlaced by $\lambda g/8$ to measure and to display the impedance on an oscilloscope. He applied V_1-V_3 and V_2-V_4 to the vertical and horizontal inputs of an oscilloscope, respectively, where V_1, V_2, V_3, V_4 are square-law diode outputs from the probes. Although in his measurements the frequency was varied such that the impedance was traced as a curve on the oscilloscope, his scheme was actually derived from fixed-frequency assumptions. That is, he assumed that the angular distance between any adjacent probes is always kept at $\lambda g/8$

Manuscript received March 27, 1980; revised August 26, 1980. Patent application for the new designing method and the new schemes reported in this paper is in progress.

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