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MICROWAVE WIENER PROCESSORS

- J. G. DUNN, A. L. VANKOUGHNETT, AND W. WYSLOUZIL -

OTTAWA

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ABSTRACT

In response to a request of the Food Research Institute of the Department of Agriculture a program was initiated to examine techniques for in-line microwave cooking of wieners. This report describes two types of equipment developed for this purpose. The first unit described operates at a frequency of 2450 MHz and is powered by a 2.5-kW magnetron and the second unit operates at 915 MHz and is powered by a 1-kW magnetron.

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Introduction

The Food Research Institute, Research Branch, Canada Department of Agriculture has for several years been investigating possible uses of microwave energy in the manufacture of food [1, 2, 3]. One microwave energy application examined by the Food Research Institute was continuous process cooking of wieners during their manufacture.

Wieners are traditionally made by stuffing a meat emulsion into a cellulose casing which is linked to form wieners of the desired length by twisting or tying the casing at appropriate intervals. The strings of wieners are then transferred to racks and cooked to an internal temperature of approximately 155°F in a steam-heated smokehouse. The cooking time required is approximately 90 minutes. "Liquid smoke" is often used since this allows the cooking time to be reduced to approximately 60 minutes. The wieners are then cooled, the cellulose casing stripped away, and the wieners are packaged.

A process whereby the cooking could be rapidly done by a continuous process would clearly be advantageous. The Food Research Institute thus investigated continuous cooking of wieners in a conventional microwave oven which was suitably modified for continuous processing [1]. The results of this investigation were encouraging in that excellent quality wieners were produced in so far as emulsion stability, colour, skin, peelability, and microorganisms were concerned. However, the modified microwave oven proved to have a rather non-uniform heating pattern which resulted in bursting of the cased emulsion when one attempted to dissipate sufficient energy in the wiener to raise the temperature to 155°F on one pass through the oven. The bursting was due to the temperature of portions of the wiener being raised above the boiling point of water with the consequent release of steam.

In view of the above results, NRC undertook the development of a microwave applicator better suited to cooking wieners. Since the only microwave heating equipment initially available operated at 2450 MHz, this frequency was used in the development of the first unit. Interest in larger foodstuffs led to the acquisition of 915-MHz microwave heating equipment and the subsequent construction of a second wiener processor operating at this frequency.

Unlike many applications of microwave power, no difficulty is encountered in devising a system with high microwave efficiency wherein nearly all of the available microwave power is dissipated in the wieners. Measurements indicate that the loss factor for wieners is considerably greater than that of water at microwave frequencies. As indicated above, the major applicator requirement in this instance is that the wieners be heated with sufficient uniformity that the average temperature of the wiener can be raised to 155°F without the temperature of any portion of the wiener exceeding 212°F. Failure to achieve this requirement results in steam generation and consequent bursting of the air-tight casing.

Two techniques are used in the units described herein to meet this requirement. Firstly, an effort is made to design the applicator such that the wieners are heated as uniformly as possible throughout their cross section. Secondly, methods are used to control the degree of coupling to the wieners so the rate of power transfer can be kept sufficiently low that some thermal redistribution takes place during exposure of the wieners to microwave power. Use of this second technique clearly reduces the uniformity requirement in that heat generated in the higher temperature areas of the wiener has a longer time to diffuse to lower temperature areas while microwave power is being absorbed.

Many applicator types can be used to heat a lossy product such as wieners but the extended interaction time requirement suggests an applicator in form of a waveguide through which the wieners are transported longitudinally. When this configuration is adopted, the design problem remaining is that of devising a waveguide geometry which displays the appropriate coupling and heats the wieners with the desired uniformity.

The following sections describe two units of this form. The first unit operates in the 2450-MHz ISM band and the second in the 915-MHz band.

2450-MHz Applicator

The most elementary applicator for a product such as wieners consists of a conventional rectangular waveguide with suitable means for introducing and extracting the string of wieners. One applicator of this nature considered by others consisted of a short-circuited section of rectangular waveguide with means provided to pass the string of wieners through the waveguide such that the wieners travelled perpendicular to the axis of the waveguide and parallel to the E vector of the dominant waveguide mode. By adjusting the position of the short circuit relative to the wiener string a reasonable input match and efficiency were achieved. However, the wieners were severely overheated at the ends unless special provisions, such as inclusion of metallic rings at the twist or tie points in the string, were included. In a second approach proposed, wieners were introduced and extracted from the waveguide by passage through a tube which was in the plane of the electric field in a standard rectangular waveguide and inclined at an angle of 15° to 20° to the waveguide axis. This form of applicator closely resembles a conventional water load.

Other forms of applicator for heating products such as wieners have been suggested [4, 5], using waveguides operating in higher order modes such as the TM_{01} mode. Such modes have a field distribution which would seem particularly well suited for this purpose, but some limited experimentation suggests that this advantage is not readily realized owing to the gross field redistribution and mode conversion which occurs when wieners are introduced in the waveguide.

In the rectangular waveguides described above, very strong coupling to the product is inherent, and thus the uniformity with which the product is heated must be excellent and steam generation and consequent bursting of the casing is avoided. Figure 1 illustrates a waveguide geometry [6] which allows some control of the coupling to the

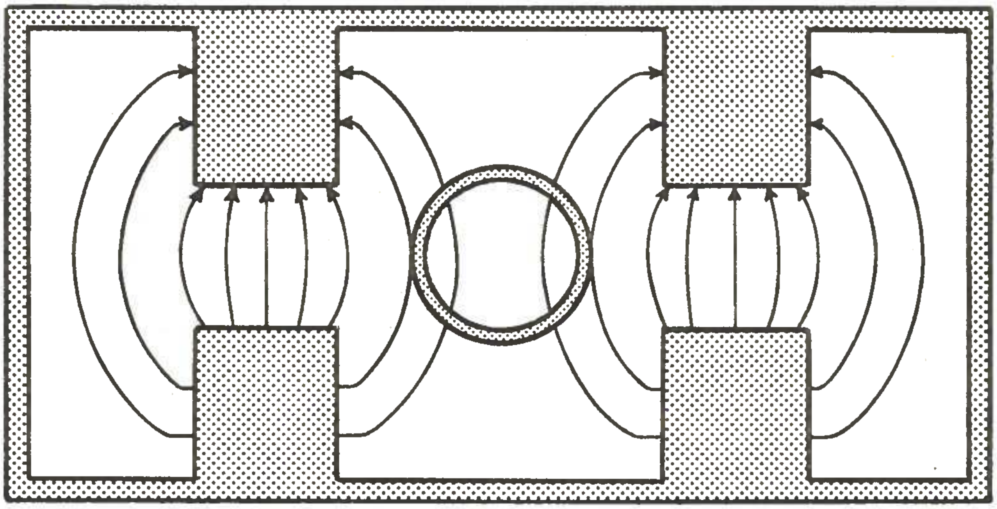

Fig. 1 Electric field distribution in multiple-ridge waveguide

wieners and thus the rate of energy transfer. The waveguide has a rectangular cross section in which four metallic ridges are introduced to alter the electric field distribution. A circular cylindrical tube of Teflon is centrally located in the waveguide and the string of wieners passed therethrough. Field distributions and other properties of such a waveguide were previously reported [7, 8]. Qualitatively, the electric field tends to be concentrated in the region between opposing ridges and be depleted in the central region as depicted in Fig. 1. The degree of field concentration or depletion depends upon the size of the gap between opposing ridges and the distance between ridge pairs. In the present case, the ridge pairs must be separated sufficiently to allow introduction of the Teflon tube and wieners without exposure to the intense fringeing fields that exist near the ridge corners. For ease of development and fabrication, the rectangular waveguide containing the ridges and workpiece was made with the same dimensions as conventional WR 340 waveguide. The parameters to be determined were thus the width of the ridge, the size of the gap between opposing ridges, and the separation of ridge pairs.

The final geometry was determined experimentally with some guidance from previous analysis [7, 8]. The best compromise between heating uniformity and the degree of coupling to the wieners was obtained when the gap between opposing ridges was reduced to $\frac{1}{16}$ inch with ridges $\frac{3}{8}$ inch thick and a center-to-center ridge spacing of 1.90 inches. For this geometry, the coupling to the wieners is reduced by a factor of approximately 10 compared with that realized in rectangular WR 340 waveguide without ridges. Plate 1 is a photograph of a section of this waveguide. A $1\frac{3}{8}$ inch O.D. $\times$ $\frac{1}{8}$ inch wall Teflon tube was located centrally in the waveguide and the wieners were passed through it.

Plate 2 shows a completed model of the 2450-MHz unit. The active section of the waveguide is approximately 40 inches long and is terminated on both ends by 15° E-plane bends which are formed by welded butt joints of the ridged waveguide. The ridged waveguide is continued in the terminations for approximately $2\frac{3}{4}$ inches so that unduly strong coupling to the wieners at the entry and exit ports does not exist. Linear tapers, $7\frac{1}{2}$ inches long, of the ridge spacing from $\frac{1}{16}$ inch to 1.7 inches provide transitions at each end to WR 340 waveguide. This waveguide assembly is mounted on a wooden frame as shown in Plate 2 and the output of a 2.5-kW magnetron delivered to the left-hand end of the waveguide section while the right-hand end is terminated by a water load. To transport the string of wieners through the Teflon tube a continuous belt constructed from fiberglass fly screen material is provided. Near the left-hand entry port is included means for introducing hot or cold air into the Teflon tube heating chamber.

With the arrangement of Plate 2, approximately 10% of the incident microwave power reaches the water load when a string of wieners is being processed, or the efficiency of utilization of the microwave power generated is 90%. Cooking at a rate of about 12 wieners per minute is possible with this unit. The characteristics of wieners so heated (colour, skin, peelability, and microorganisms) were similar to those processed in the conveyor oven. Some evidence of non-uniform heating was found. If the wieners are split as soon as they exit from the waveguide, some portions of the wieners are noticeably lighter in colour than others indicating underheating in the light areas. If the wieners are examined after a few minutes in room temperatures, good colour uniformity is found. The heating uniformity is clearly not perfect but is sufficiently good to raise the average temperature of the wiener to the desired value without steam generation at the maximum available 2.5-kW microwave power input.

Non-uniformities in the heating pattern were of three types. Firstly, the bottom of the wieners tended to be heated more than the top. This was found to be due to lack of alignment of the waveguide axis and the axis of the string of wieners such that the bottom of the string was closer to the strong fringeing fields near the lower ridge gap than was the top of the string to the fields near the upper gap. This problem was resolved in a later model by mounting the waveguide at 90° to the waveguide in Plate 2 so that the ridges lie in the vertical plane as in Fig. 1. In addition, the Teflon tube was displaced from the axis of the waveguide so the wieners traveled on the waveguide axis.

The second type of non-uniformity noted was an underheated area near each end of the wiener. This non-uniformity is associated with the discontinuity and hence reflection of energy from the tie points in the strings of wieners and cannot readily be avoided in this type of applicator. Fortunately, this non-uniformity does not appear to be particularly serious. The third type of non-uniformity found was general underheating of the central portion of the wiener and was found to be associated with the limited penetration depth of 2450-MHz microwave energy.

In summary, the 2450-MHz model is capable of cooking wieners at a rate of approximately 12 per minute with adequate uniformity of heating so that steam generation is avoided. Colour uniformity is not impressive if the wieners are slit soon after exiting from the waveguide but is good if sufficient time for thermal redistribution is allowed as would be the case in an industrial situation.

915-MHz Applicator

This section describes a second approach to the problem of designing an applicator suitable for microwave cooking of wieners. In the previous section it was noted that depth of penetration of wieners by 2450-MHz energy was not as great as desired and that a special waveguide geometry is required to reduce the coupling to the wieners. Both of these factors suggest that use of the lower available ISM frequency, 915 MHz, would be desirable.

The applicator requirements are of course the same as those described previously, so the same basic geometry in which the string of wieners is passed longitudinally through a waveguide is chosen. In the case of a 915-MHz waveguide, however, the coupling to the string of wieners is quite weak and some means must be used to improve the coupling if a respectable microwave efficiency is to be realized without an excessively long waveguide applicator. The waveguide geometry chosen in the present case is shown in Fig. 2. Again

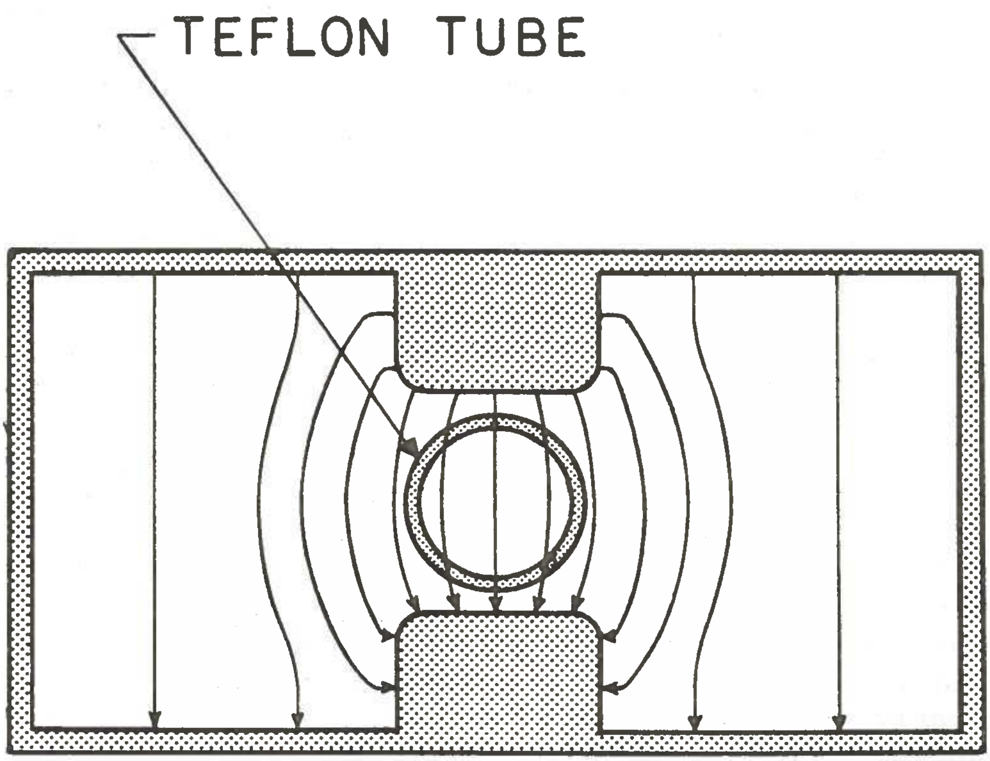

Fig. 2 Electric field distribution in double-ridge waveguide

a Teflon tube is provided for transport of the wieners. Ridges are introduced in this case to concentrate the microwave energy in the vicinity of the string of wieners whereas in the previous case the ridges served to deplete the vicinity of energy. As depicted in Fig. 2, electric field lines tend to concentrate in the gap between the ridges and thus increased coupling to the wieners is realized.

Plate 3 shows the waveguide configuration used for the 915-MHz unit. The waveguide is rectangular WR 975 with inside dimensions 4.875 inches X 9.75 inches. The ridges are 1 inch thick and the separation of opposing ridge faces is $1\frac{3}{8}$ inches and the Teflon tube is $1\frac{3}{8}$ inch O.D. X $\frac{1}{8}$ inch wall thickness. A quarter-wave transformer provides a simple transition from open to ridged waveguide as shown. Plate 4 shows the remaining details of the 915-MHz unit. The left-hand end of the unit contains a General Electric JC-300 magnetron which is driven by a laboratory built power supply (not shown) to produce approximately 900 watts of microwave power. The magnetron is coupled to WR 975 waveguide through a coax-waveguide transition and a matched 90° E-plane miter bend delivers the microwave power to the ridged waveguide section. Power emerging from the 4 foot ridged waveguide section is delivered to a water load via another 90° E-plane bend.

The microwave efficiency of this unit is in excess of 90% and hence wieners can be cooked at a rate of approximately 4 per minute. This cooking rate is slower by a factor of 3 than the 2450-MHz unit as expected on the basis of available microwave power. The slower heating rate allows more time for thermal redistribution and thus obscures heating non-uniformities but it seems clear that very good uniformity of heating was achieved with only slight evidence of underheating near the ends of the wieners. The heating uniformity of the 915-MHz unit is clearly better than that of the 2450-MHz unit.

Conclusions

Two versions of a microwave system suitable for in-line cooking of wieners have been described. Both units are capable of cooking wieners at the maximum rate dictated by the quantities of microwave power available in our laboratory without steam generation inside the casings.

A production model of a microwave wiener processor will require 100 to 150-kW of microwave power to achieve required processing rates of 3000 lb of wieners per hour. For either of the available frequencies, 915 and 2450 MHz, the largest microwave source readily available for industrial applications delivers 30-kW of microwave power. Clearly four or five such units would be required. The question posed then is whether the units described herein could be operated at 30-kW power levels to form the basic modules for an industrial system. So far as the 2450-MHz system is concerned, the answer to this question is certainly 'no', owing to the limited power handling capability of the ridged waveguide shown in Plate 1. With the power level as low as 5-kW occasional problems with arcing in this waveguide are encountered. No problems of this nature are anticipated with the 915-MHz waveguide. Since the uniformity with which the wieners are heated in the 915-MHz system appears to be very good, one might expect that the unit could be operated at 30-kW power levels without steam generation in the wieners.

Acknowledgment

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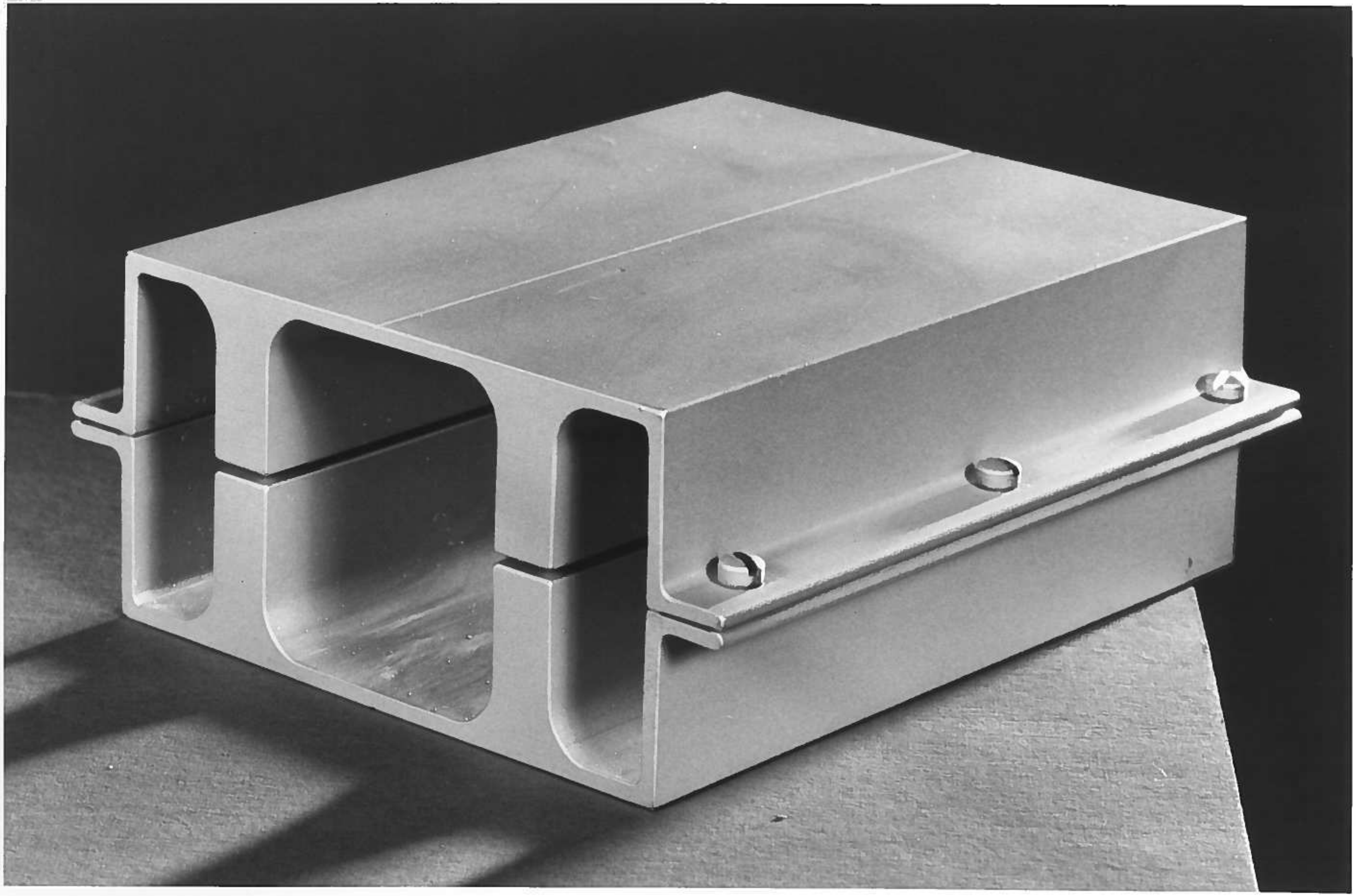

PLATE 1
A section of the 2450-MHz wiener processor waveguide.

PLATE 2
The 2450-MHz wiener processor.

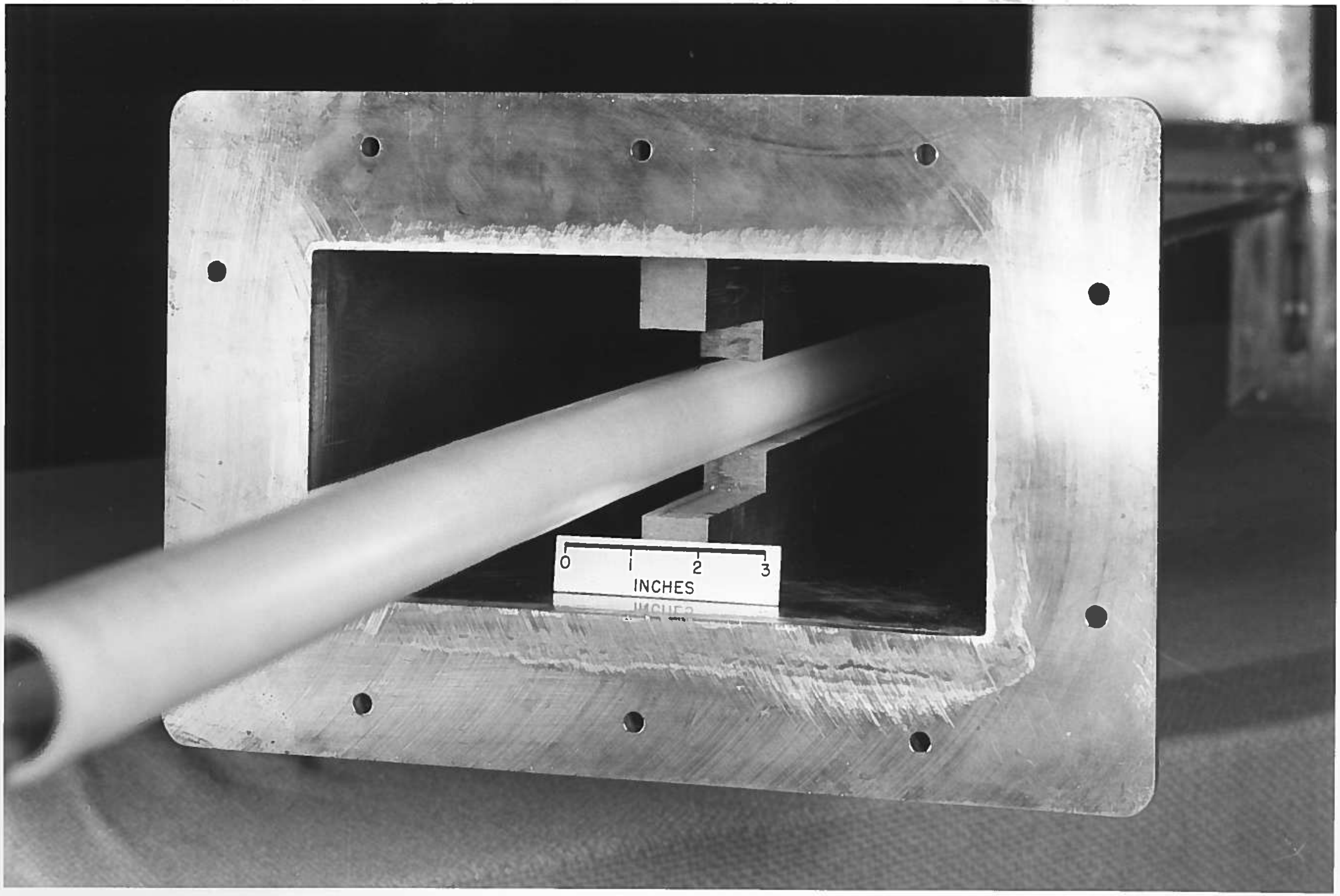

PLATE 3
The 915-MHz wiener processor waveguide.

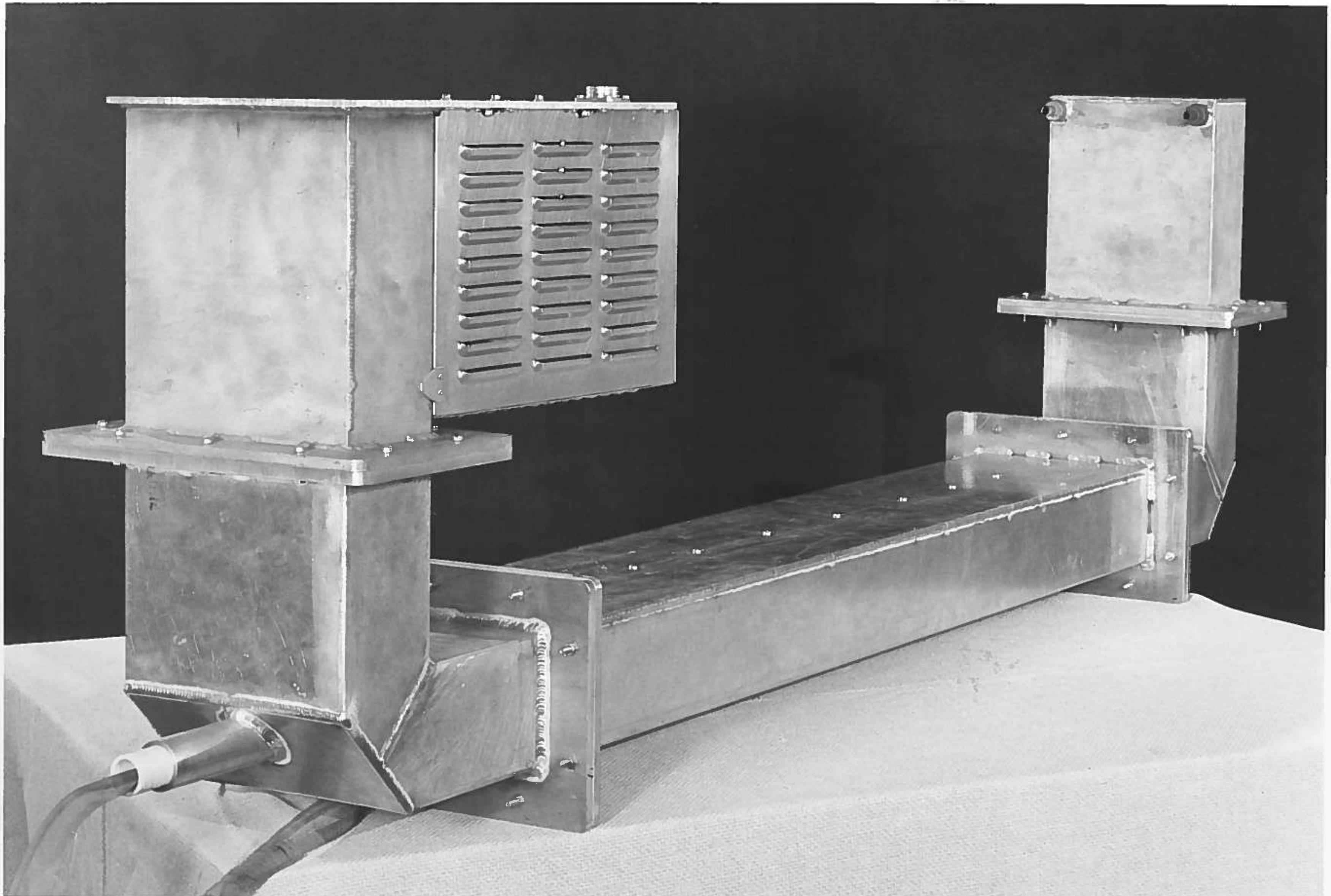

PLATE 4

The 915-MHz wiener processor.