assuming the values for γ and f_c given in Table II. The measured and theoretical values for the uncooled case disagree by only 12 percent. The larger discrepancy at 20 K is primarily due to the uncertainty in the exact temperature of the nitrogen cold-load used for the noise measurements, the relatively large second-stage contribution (30 K), and the neglect of other possible noise sources like the pump-heating effect [9].

This measured noise temperature of only 40 K constitutes an improvement of the noise performance by an order of magnitude as compared to previously reported uncooled amplifiers in this frequency range [6]. Based on these results it is felt that amplifiers with such low noise performance which are needed in many radiometry and millimeter-wave radio-astronomy applications can be developed up to frequencies of at least 90 GHz.

ACKNOWLEDGMENT

The author wishes to thank Dr. R. Mattauch of the University of Virginia for his support and for developing the junctions. He also wishes to thank L. Pizziconi, who computed the whisker stray capacitance.

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A Frequently Reinvented Circuit

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***Abstract*—Attention is called to published work describing an impedance-measuring circuit that is frequently reinvented.**

A number of papers have appeared in which the VSWR or impedance is measured by sliding a short circuit in one side arm of a directional coupler and observing the response of a detector located in the other side arm. In addition, this idea has been reinvented on two different occasions of which the author is aware, and the inventors did not publish their independent work when informed of previous work.

Consequently, it appears worthwhile to call attention of microwave engineers to publications which deal with this topic. The following list may not be complete, but should be adequate for the intended purpose:

1) R. Musson-Genon and P. Brissoneau, "Sur un mesureur d'impedances a couplage directif en hyperfrequence," *C. R. Acad. Sci.*, vol. 230, pp. 1258–1259, Mar. 1950.
2) A. I. Zykov, "Impedance measurements by means of directional couplers," *Meas. Tech.*, vol. 3, pp. 211–215, Mar. 1959.
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4) R. K. Jha and V. K. Garg, "Voltage standing-wave ratio measurement by cross coupler," *Int. J. Electron.*, vol. 29, no. 2 pp. 179–183, 1970.

Manuscript received January 11, 1974.
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Generation of Acoustic Signals by Pulsed Microwave Energy

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***Abstract*—A discussion of the production of sound when short microwave pulses are directed at an absorber is presented. Possible mechanisms of the phenomenon are presented. These mechanisms may be important for a better understanding of the so-called microwave "hearing" effect.**

This letter is intended to describe a phenomenon first noticed in our laboratory during some preliminary experiments designed to further elucidate the mechanism(s) responsible for "hearing" pulsed microwave exposure (e.g., [1]–[3]). While attempting to shield portions of the head from RF radiation by using a carbon-impregnated polyurethane microwave absorber (Emerson and Cumming Eccosorb WG4 with a surface area of 3716 cm^2), it was noticed that the apparent locus of the "sound" moved from the observer's head to the absorber. That is, the absorber acted as a transducer from microwave energy to an acoustic signal. This observation, to the best of our knowledge, has not been described in the literature and may serve as an important clue to the mechanism mediating the "hearing" of pulsed microwave signals.

That the signal from the absorber is acoustic is proven by the data presented in Fig. 1 where the ensemble sum of 50 epochs, each 25.6 ms long, is plotted. These data were collected with a General Radio model 1551C sound level meter fitted with a 1560-P5 microphone. The microphone was acoustically coupled to the absorber via one of two cone-shaped guides, 1.42 or 0.73 m long, respectively; these guides were made of construction paper. The recorder output of the sound meter was led through a Krohn-Hite model 3343R bandpass filter (set to pass 150–2500 Hz), to an HP Fourier analyzer model 5451A where the signals were digitized and the 50 epochs were summed at 512 equispaced sample points; the sampling interval was, therefore, 50 μs.

Fig. 1(a) represents one such ensemble sum when the microphone was 1.42 m from the absorber. The sound arrived at, and activated, the microphone approximately 4.68 ms after the trigger pulse was applied to the Applied Microwave Laboratories, Inc., model PG5KB pulse signal source. The output was radiated by a NARDA 646 horn which has a physical aperture of 53.3 × 39.6 cm. When the distance from the absorber to the microphone was 0.73 m, the sound arrived approximately 3.29 ms after the trigger signal [Fig. 1(b)].

Manuscript received October 29, 1973; revised January 11, 1974.
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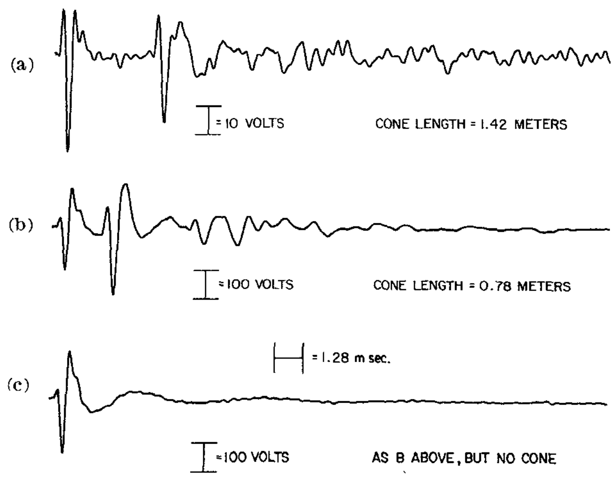

Fig. 1. Ensemble sum of 50 25.6-ms epochs from output of sound meter. (a) Sound meter acoustically coupled to absorber via a 1.42-m paper cone. (b) Same as (a), except transmission distance was reduced to 0.78 m. (c) Same as (b), except the cone was removed which tended to acoustically decouple the sound meter from the absorber.

In each of these two cases, the time delay observed is consistent, within experimental and measurement errors, with the transit time of sound as calculated from the velocity of sound of 332 m/s. If the cone, which served as the acoustic coupler between absorber and microphone, was removed, there was no pickup of a detectable acoustic signal; the artifact caused by the RF coupling with the microphone and associated electronics is clear and unambiguous [Fig. 1(c)].

For the data presented here the microwave pulses were 14 μs long; each pulse was randomly triggered by the random binary output of an HP noise generator model 3722A set to give approximately 3 pulses/s. Equipment was not available to measure the power density directly. However, by using a Pacific Measurements, Inc., peak power meter Model 1018, an HP dual directional coupler model 778D-11, and suitable attenuators, the net transmitted power was determined to be 4500 W/pulse. This yields a calculated power density for a working distance between 0.3 and 0.6 m of approximately 7.5–15 kW/m^2. For the data presented in Fig. 1 the carrier frequency was 1500 MHz. In subsequent tests, using the same setup, little difference was found in the quality or amplitude of the acoustic signal when the carrier frequency was changed from 1200 through 1600 and 2450 MHz. Detectable sounds could be produced in various sizes and shapes of absorber—even to pieces as small as 4 mm^2 by 2 mm thick. Several types of absorber produced audible sounds as did loosely crumpled aluminum foil. The threshold power/pulse for audibility, under less than ideal conditions, was of the order of 275 W peak, for an estimated peak power density in the range from 0.46 to 0.92 kW/m^2. While the observations made with the microphone were done with randomly generated microwave pulses, tests were conducted with regularly repeated pulses with repetition rates up to 500 pulses/s. The sound produced from the absorber seemed to track the repetition rate of the microwave pulses.

One of several likely explanations for this phenomenon is the fact that radiation pressure is exerted on surfaces which cause changes in magnitude and/or orientation of impinging electric and magnetic fields. For a "perfect" absorber, the radiation pressures resulting from impingement of such pulse power (7.5–15 kW/m^2) may be calculated to be 3–6 $\times 10^{-4}$ dyn/cm^2 while the values for a "perfect" reflector would be twice as much [4]. It is interesting to note that, although these pressure levels are extremely small, they are close to the threshold of audible sound pressures [3].

To produce the aluminum foil "sound" it was necessary to crumple the foil in such a manner (presumably) as to reduce the stiffness of the vibrating lip. With the microwave absorber, perhaps because of its resiliency, such special procedures are unnecessary.

Further work is in progress to elucidate the mechanism involved in this phenomenon and to determine whether the same basic mechanism may be applicable to the so-called human "hearing" of pulsed microwave energy. It is possible that there are other transduction mechanisms at work, both in this simplified model and in the real situation. For example, bone is known to have piezoelectric properties and the difference of potential resulting from bone deformation has been measured. If either the radiation pressure or electrostrictive forces are sufficient in the irradiated cranium to engender such a potential difference, then there could be an electrically mediated sensation. Also, there could be direct acoustic excitation of the auditory organ via bone conduction of such a vibration or the basilar membrane may directly couple with the microwave energy. It is entirely possible that more than one of these mechanisms are operating when humans "sense" microwave pulses.

ACKNOWLEDGMENT

The authors wish to thank T. J. Andrews and P. V. K. Brown for their assistance in resolving many of the technical and instrumentation problems encountered while making these observations. They especially wish to thank Dr. J. C. Lin for his help in setting up the microwave apparatus during the initial phase of this research.

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