U. S. flange ". . . there is little to compete with the Philips flange as an International Standard." Earlier he had stated: "The British also developed flanges for millimeter-wave work using the Union-type principle, but these found little favor in the U. S." Although nowhere specifically stated, it is strongly implied that this British flange is not being put forward as an international standard. In fact, the situation is that the British Union-type flange, or C-type, has been accepted as an international standard and is listed in document IEC publication 154. It is widely used in Great Britain both for millimeter wave sizes and, in large quantity, at X-band (WG16).

It is used extensively in airborne equipment, is an approved NATO design, and is fully specified in STANAG 4058 (3rd preliminary draft) document AC/67-D/65 of 6.9.63. for rectangular waveguide sizes WG15 to 26 inclusive.

The status of this flange in relation to Anderson's communication was discussed at a recent meeting of the United Kingdom Radio Component Research and Development Sub-Committee 16 (waveguide components), and members felt that it would be useful to put these points on record lest failure to do so might imply lack of use or interest in the Union-type flange.

It is, perhaps, unfortunate that some early samples of this flange were not made accurately to specification, or were heavily plated, with the result that some potential users were put off their design. As currently made, they have for a long time given adequate service and, as reported above, are in large scale use and are an internationally standardized item.

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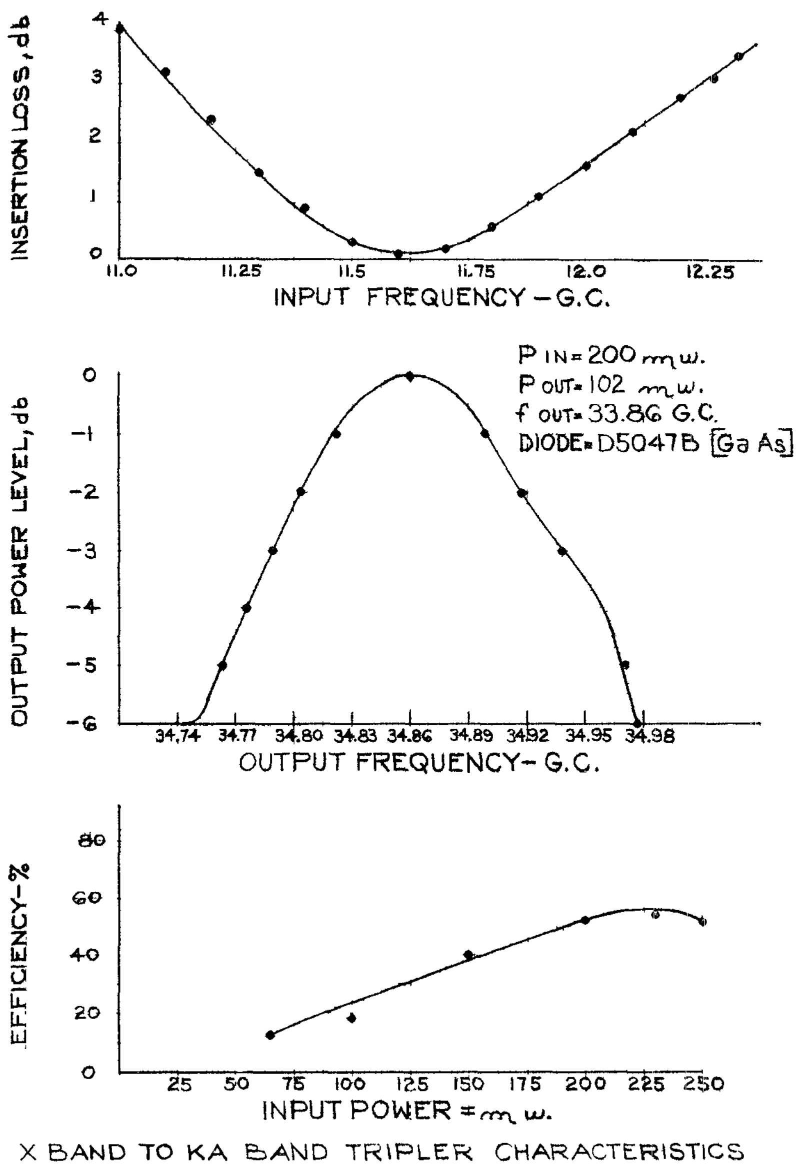


Fig. 1—x band to $K_A$ band tripler characteristics.

## $K_A$ Band Klystron Replacement

We have successfully fabricated a harmonic tripler from 11,620 Mc to 34,860 Mc using a diffused junction gallium arsenide varactor (Sylvania D5047C) with an efficiency of approximately 50 per cent at an input power of 200 mw (Fig. 1).

This work was begun as a potential cost savings measure to eliminate the use of expensive short life $K_A$ klystrons in test equipment. The present unit is being used in conjunction with an X-13 X-band klystron with a life expectancy far exceeding the original $K_A$ band-tube source. The tripler itself is running unbiased with no dc return and should have near infinite life. To date, it has run for over 1900 hours with no indicated change in output.

The design is based on a half wave rectangular cavity with the diode mounted at the voltage maximum point. This arrangement tends to suppress the second harmonic and generate the odd harmonics. The cavity is essentially $\frac{3}{2}\lambda$ long at the desired third harmonic.

With an output power of +20 dbm, the second harmonic could not be detected and the total unwanted harmonic power above the third was approximately −30 dbm.

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## Microwave Transmission Through a Plasma Sheath

Propagation of an electromagnetic wave of a given frequency in a plasma will occur only if the plasma density is less than a critical value.[1] When the density is expressed in terms of the plasma frequency $\omega_p^2 = ne^2/\epsilon_0 m$, propagation occurs if the plasma frequency is less than the frequency of the electromagnetic wave. When the plasma density is such that the plasma frequency is in excess of the signal frequency, the plasma acts like a conductor reflecting and severely attenuating the signal so that it cannot penetrate to any great depth into the plasma.

The interaction which takes place between the electromagnetic wave and the plasma at microwave frequencies is primarily that occurring between the electrons in the plasma and the electromagnetic field since at these frequencies the motion of the heavy positive ions is negligible compared with that of the electrons. If it is desired to pro-

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[1] M. P. Bachynski, "Plasmas and the Electromagnetic Field" McGraw-Hill Book Co., Inc., New York, N. Y.; 1962.

duce a transmission path through the plasma, it is sufficient that the electron density be reduced to a value below the plasma frequency corresponding to the signal frequency in the region where transmission is desired.

A method of achieving this reduction in electron density is to insert a grid of metal wires in the plasma oriented in a direction perpendicular to the electric vector of the microwave signal so that the grid will interfere as little as possible with the propagation of the microwave signal. If such a grid is now charged to a large negative potential with respect to the plasma, the electrons in the vicinity of the grid will be repelled, and there will exist in the immediate vicinity of the grid a region containing only ions and neutral particles.

A positive ion current will flow to the grid, and, if the supply of ions in the plasma is unlimited, space-charge limitations will determine the amount of this current. The plasma at the edge of the sheath is a virtual source of ions for the sheath, and the probe is an ion collector. The situation in the ion sheath thus resembles that in the high vacuum diode in which the electron current is space-charge limited, while, in the ion sheath, the ion current is space-charge limited.

The Child-Langmuir law[2] for space-charge limited flow for the ion sheath is

$$J_i = \frac{4\epsilon_0}{9}\sqrt{\frac{2e}{m_i}}\,\frac{V^{3/2}}{t^2} \tag{1}$$

where $V=(V_p-V_0)$ is the potential difference across the ion sheath, and $t$ is the sheath thickness. Eq. (1) gives the space charge limited current density $J_i$ for a probe voltage $V_0$ and a sheath thickness $t$. From energy considerations and the assumption that the ions behave like particles in a gas, further relation can be obtained between the current density and the temperature of the ions,

$$J_i = en_i\sqrt{\frac{kT_i}{2\pi m_i}}\,. \tag{2}$$

This allows a relationship to be established between the voltage and the thickness of the sheath,

$$V^{3/2} = \frac{9n_i}{8\epsilon_0}\sqrt{\frac{ekT_i}{\pi}}\,t^2. \tag{3}$$

It should be noted that this relationship is not a function of the ion mass. Thus the sheath thickness produced by a voltage applied to the grid is a function of the average ion energy and density but is independent of the type of ion.

For an ion density of $10^{18}$ $m^{-3}$ and assuming an equivalent ion temperature of 20,000°K, the above relationship requires a voltage of 600 volts for a sheath thickness of 1 mm. For an argon plasma at this same ion density and temperature, (2) gives an ion current density $J_i=220$ amp/m$^2$.

If the region through which transmission is desired is filled with a grid with a spacing

[2] L. B. Loeb, "Basic Processes of Gaseous Electronics," University of California Press, Berkeley and Los Angeles; 1960.

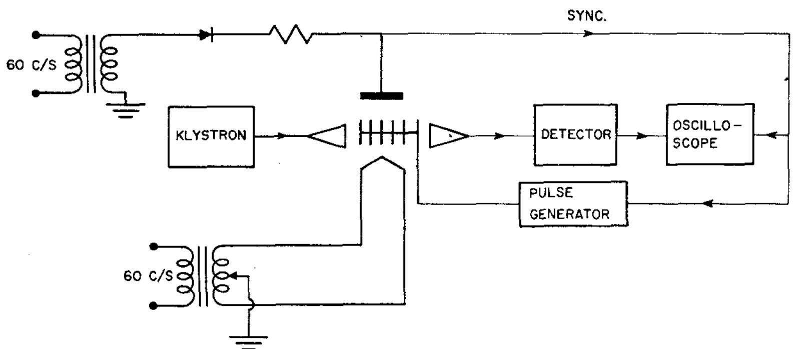


Fig. 1—Experimental setup.

of 2 mm, then a pulse of the order of 600 volts applied to the grid will deplete the region of electrons in the volume occupied by the grid and allow transmission through the region.

Fig. 1 shows a schematic diagram of an experimental arrangement set up to demonstrate the foregoing. An $X$-band waveguide assembly inside a bell jar has a 1 inch section removed. A plasma was generated in this section between a thoriated tungsten filament and an anode placed on either side of a grid structure which filled the entire volume between the open ends of the waveguides. The wires of the grid structure were spaced 2 mm apart and allowed a uniform reduction of the plasma density over the entire cross section and length of this part of the microwave path.

The anode was connected to a half-wave rectified 60 cps supply producing an electron density in the plasma such that for several msec every half cycle the microwave transmission was interrupted. A negative pulse of ½ msec duration synchronized with the anode pulse was applied to the grid, and, by means of a variable delay, the time of occurrence of the cut-off pulse relative to the grid pulse could be varied.

An argon atmosphere was maintained in the bell jar at a pressure of 50 $\mu$ of mercury.

Figs. 2, 3 and 4 show the microwave transmission cut-off and recovery characteristics for various grid pulse delay times. The transmission recovery during the grid pulse ranged from 90 to 100 per cent of full transmission. The recovery is clearly visible in each of the figures. The rise time of the recovery pulse ranged from about 50 $\mu$sec to 100 $\mu$sec in all cases.

Fig. 5 shows the effect on the plasma current of pulsing the grid. The upper trace shows the applied grid voltage and the lower trace the plasma arc current. The figure shows that pulsing the grid has an observable but negligible effect on the plasma current. This clearly shows that the recovery of the signal transmission is due to reduction of electron density in the region of the grid wires and not by interruption of the arc.

The amplitude of the pulse required to restore full transmission was of the order 600 volts which agrees with the value predicted by (3) for the 2 mm grid spacing. The amplitude of the current pulse to the grid was 0.5 ampere. Since the area enclosing the volume of the grid (1 inch×1 inch×½ inch) was $2.5\times10^{-3}$ m$^2$, the current density was 200 amp/m$^2$ which agrees with the value predicted from (2). In the experiment,

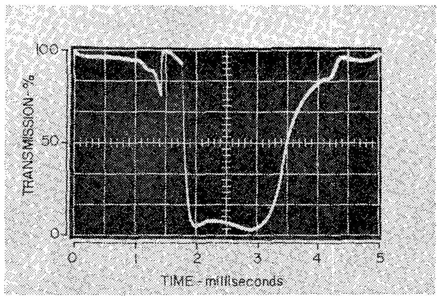


Fig. 2—Microwave transmission.

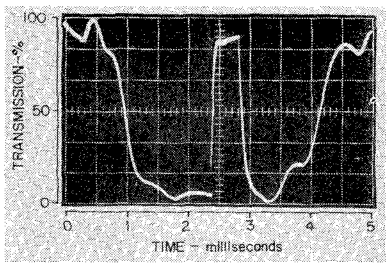


Fig. 3—Microwave transmission.

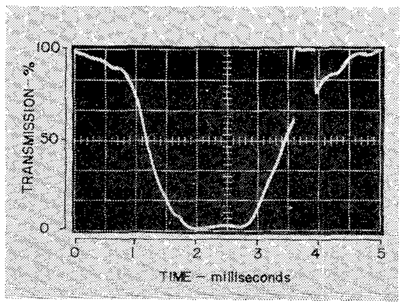


Fig. 4—Microwave transmission.

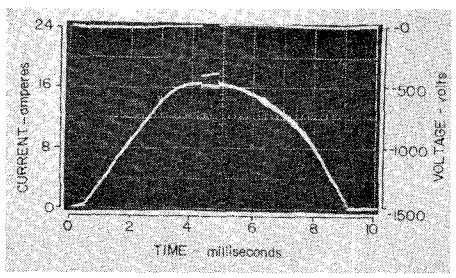


Fig. 5—Grid voltage and anode current.

the plasma density corresponded at its maximum value to about twice the signal frequency, while at a pressure of 50 $\mu$, the loss frequency would be of the order of 1/10 of the signal frequency.

Within the limitations of the experiment, the results show that an electron-free tunnel can be created in a plasma slab and that such a tunnel would provide an attenuation-free path for a microwave signal. Limitations are imposed on the geometry of the grid since it must not appreciably affect the transmission of the signal, and yet its electrodes must be spaced sufficiently close so that excessive power need not be used to create the electron free region. The possibility of using such a device to enable a signal to penetrate a plasma sheath will depend on whether or not a grid can be designed with the restrictions discussed above and at the same time be able to withstand the environmental conditions in which it is to function.

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## A Low-Loss Launcher for the Beam Waveguide

The beam waveguide[1] shows great potential for providing an extremely low-loss method of guiding millimeter and submillimeter waves. However, the low-loss mode in the beam waveguide differs considerably in form from the fundamental modes of metal waveguides. This leads to the problem of finding an efficient way to couple from the metal waveguide to the beam waveguide or between the metal waveguide and devices such as resonators utilizing beam waveguide modes.

The usual method used to solve this problem is to use a rectangular horn with a phase correcting plate to launch the low-loss beam mode. However, this technique usually results in launching some of the energy into higher modes which have high losses. The best efficiency reported for launching into the fundamental mode, using this technique, is 85 per cent.

An attempt was made to find a launcher which would excite only the lowest mode and couple almost all of its energy into that mode. This type of device should prove to be a highly efficient launcher and could take full advantage of the low-loss potential of the beam waveguide. Several possibilities for launchers were investigated, optimized rectangular horns, circular horns, and dual-mode horns. The most promising launcher found was the dual-mode conical horn.[2]

The far-field criteria used for determining an efficient launcher were as follows:

1) Amplitude distribution—$\phi$ independent gaussian
2) Sidelobes—at least 20 db down
3) Polarization—linear
4) Phase front—plane.

Extending the work of Potter[2] it was found that the aperture distributions of the dual-mode conical horn are to a first approximation gaussian nearly $\phi$ independent and contain very little cross-polarized energy. For circular apertures with $\phi$-independent aperture distributions, the far-field radiation pattern can be found by taking the finite Hankel transform of the aperture distribution. However, for this case, the Hankel transform of the $\phi$-independent gaussian distribution is another $\phi$-independent gaussian distribution.[3] It was also noted that since the aperture distribution has amplitude taper in all directions, the sidelobe level should be very low. Therefore, it was concluded that the far-field pattern of the dual-mode conical horn should essentially satisfy requirements 1), 2), and 3) for an efficient launching device.

To check these predictions, a 34-kMc dual-mode conical horn was constructed by use of the electroforming technique. Comparison of measurements made on the horn with the requirements stated above are summarized in the next few paragraphs.

As an example, a beam waveguide of diameter 20$\lambda$ is assumed. The required gaussian amplitude distribution for an "$a$"[4] value of 2.25 (corresponding to a loss of 0.02 db per iteration) is plotted in Fig. 1. Superimposed on this plot are the $E$ plane, $H$ plane, and 45° plane measured data points for the electric field distribution measured at a distance of 24.5 cm from the horn.

It is seen that, at least to the region of very small fields, the dual mode conical horn's amplitude distribution is very nearly gaussian and essentially $\phi$ independent, satisfying requirement 1).

The measured sidelobe levels of horn were found to be at least 30 db down. This more than amply satisfies requirement 2).

The cross-polarized component of the field was measured and found to be at least 26 db down from the main polarization. This essentially satisfies condition 3) in the above requirements.

The measured deviation from a plane phase front is shown in Fig. 2. This deviation is essentially symmetric in the region from the axis out to about 7 cm radius where it loses its symmetry. The loss of symmetry is not of large importance because it occurs in the region where the fields have fairly small magnitudes (see Fig. 1). In the region of interest, the phase deviation is of a form which easily lends itself to correction to a planar distribution by the use of a physically realizable phase-correcting plate. If this were done, the combined horn and phase-correcting plate would satisfy requirement 4) for an efficient launcher. In practice, this phase plate may be combined with the first lens of a beam waveguide system as shown in Fig. 3.

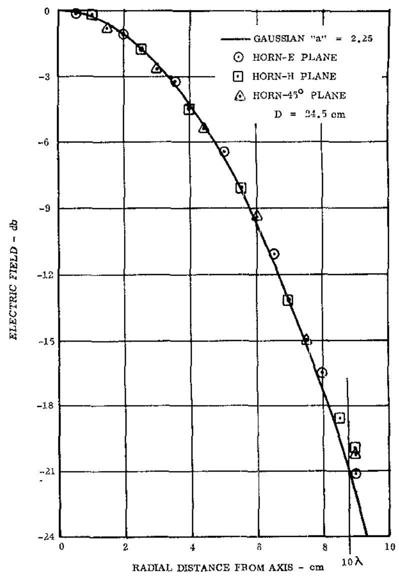


Fig. 1—Amplitude distributions.

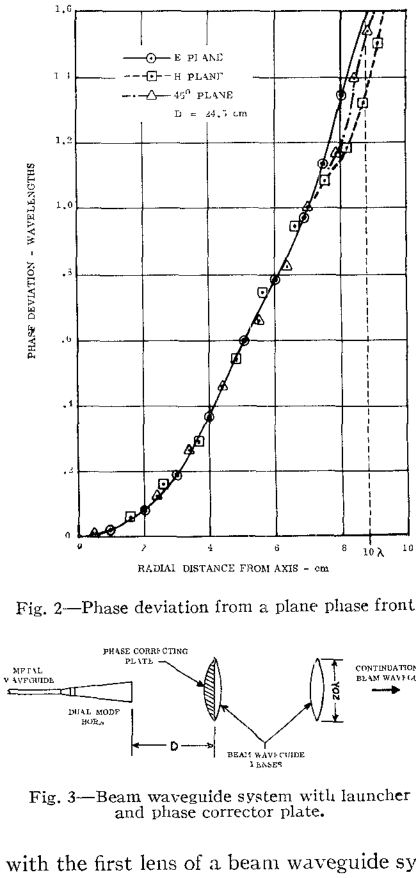


Fig. 2—Phase deviation from a plane phase front.

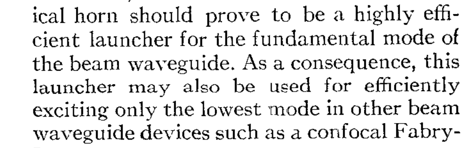


Fig. 3—Beam waveguide system with launcher and phase corrector plate.

Hence, it is seen that the dual-mode conical horn should prove to be a highly efficient launcher for the fundamental mode of the beam waveguide. As a consequence, this launcher may also be used for efficiently exciting only the lowest mode in other beam waveguide devices such as a confocal Fabry-Perot resonator.

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[1] G. Goubau and F. Schwering, "On the guided propagation of electromagnetic wave beams," IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-9, 248–256; May, 1961.

[2] P. D. Potter, "A new horn antenna with suppressed sidelobes and equal beamwidths," *Microwave J.*, vol. VI, pp. 71–78; June, 1963.

[3] J. B. Beyer and E. H. Scheibe, "Higher modes in guided electromagnetic-wave beams," IRE TRANS. ON ANTENNAS AND PROPAGATION (*Correspondence*), vol. AP-10, pp. 349–350, May, 1962.

[4] J. B. Beyer amd E. H. Scheibe, "Loss measurements of the beam waveguide," IEEE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-11, pp. 18–22; January, 1963.