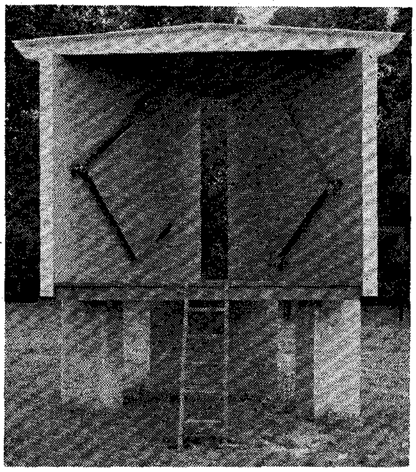

Fig. 1. One of the two refocusers used in the experiment showing the two cylindrical mirrors attached on wood panels. The generatrices of these mirrors make a 50.5° angle with the vertical direction. A 135° beam axis deflection is provided by the system.

type [4] and make use of 30-in (0.75-m) parabolic dishes and dual-mode feeds. The field radiated by these antennas was found to have an almost Gaussian amplitude distribution with a radius ($1/e$ point) equal to 0.2 m. The convergence of the launched beam can be varied by displacing the feed along the paraboloid axis.

Each refocuser incorporates two 4-ft by 4-ft (1.2-m by 1.2-m) cylindrical mirrors whose angular orientation is chosen such that the same focusing effect is produced in every meridional plane, as discussed in [5]. These mirrors are commercial 0.25-in (6-mm) thick glass mirrors bent to the required radius of curvature by exerting bending moments at the edges. They are used as front-surface mirrors, the coating protecting the copper plating being transparent to millimeter waves. Fine-thread screws allow the mirrors to be tilted in two directions for purposes of alignment.

Fig. 2 shows the measured 52-GHz round-trip loss as a function of the deformation at the center of the mirrors (the same for all four mirrors). For these data, the transmitted power is referred to the power measured when the launcher and collector feeds are directly coupled to one another. The measured attenuation, therefore, includes the losses of the launching and collecting antennas (resulting from blocking, spillover, ohmic losses, and wavefront distortion). The round-trip attenuation, which is as high as 7 dB when the mirrors of the refocusers are flat, drops to 1.5 dB when they are curved with optimum radii. This 1.5-dB attenuation is to be compared with the 1.3-dB loss observed when the launcher and collector face each other with a separation of about 2 m. These results indicate that the loss per refocuser is as low as 0.1 ± 0.05 dB. It should be noted, however, that this evaluation is based on the assumption that the losses add in decibels, an assumption that may not be completely justified if part of the loss results from wavefront distortion or spillover.

The curve in Fig. 2 gives the theoretical [6] minimum loss resulting from mismatch between the launched beam and the beam accepted by the collector under the assumption that the beams are Gaussian in shape and that spillover at the refocusers can be neglected. The measured launcher and collector losses (1.3 dB) and the absorption by the oxygen line of the atmosphere (0.085 dB) have been added to the calculated loss. There is rather close agreement between this curve and the experimental points.

When the experimental results are extrapolated to higher frequencies, such as 100 GHz, one finds that the total loss in the system during clear atmospheric conditions would not exceed 10 dB for a 1-mi long link. Note that, at 100 GHz, with the same mirror size, the separation between adjacent refocusers can be extended to 100 m. A 1-mi link would therefore incorporate 15 refocusers. Recent measurements [7], [8] indicate that the attenuation by rainstorms in New Jersey exceeds 40 dB/mi only 0.01 percent of the time at 100 GHz. A total loss of $40+10=50$ dB appears quite tolerable, even for large capacity systems, if 50-mW IMPATT oscillators are used as

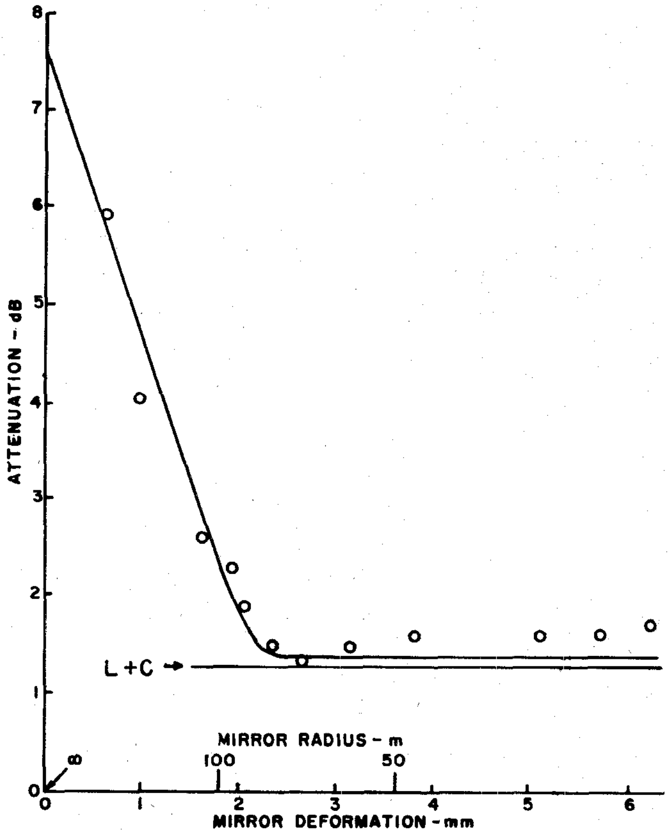

Fig. 2. The circles in this figure are the measured round-trip attenuations around the path as a function of the radius and maximum deformation of the four mirrors. The straight line ($L+C$) is the loss observed when the launcher and collector antennas face each other. The theoretical attenuation is represented by the curve.

sources. An extension of the reported experiment to higher frequencies and longer path lengths is planned for the near future.

ACKNOWLEDGMENT

The authors wish to thank R. Kompfner and L. C. Tillotson for useful suggestions, and R. A. Semplak for construction of the launcher and collector.

REFERENCES

[1] J. R. Christian and G. Goubau, "Experimental studies on a beam waveguide for millimeter waves," *IRE Trans. Antennas Propagat.*, vol. AP-9, pp. 256–263, May 1961.
[2] R. Kompfner, unpublished, Apr. 1969.
[3] L. C. Tillotson, *Science*, vol. 170, pp. 31–170, Oct. 1970.
[4] A. B. Crawford and R. H. Turrin, *Bell Syst. Tech. J.*, vol. 48, pp. 1605–1622, July–Aug. 1969.
[5] J. A. Arnaud and J. T. Ruscio, *Appl. Opt.*, vol. 9, pp. 2377–2380, Oct. 1970.
[6] J. A. Arnaud, *J. Opt. Soc. Amer.*, vol. 61, pp. 751–758, June 1971.
[7] D. C. Hogg, *Bell Syst. Tech. J.*, vol. 48, pp. 2949–2962, Nov. 1969.
[8] D. A. Gray, to be published.

Correction to "A 10-GHz Single Sideband Modulator with 1-kHz Frequency Shift"

J. D. E. BEYNON

In the above correspondence[1] the fourth sentence of the fourth paragraph should read as follows: "For an error of less then 2 percent (not 1 percent) in the measurement of attenuation and 1° in that of phase shift, the unwanted sideband must be suppressed by at least 40 dB (assuming an infinite carrier suppression)." We apologize for this mistake.

Manuscript received November 11, 1971.
The author is with the Department of Electronics, the University of Southampton, Southampton S09 5NH, England.
[1] P. G. Brooker and J. D. E. Beynon, *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-19, pp. 829–834, Oct. 1971.