and

$$\frac{\gamma 4\pi M_s}{\omega} < 0.7 \tag{4}$$

where the gyromagnetic ratio $\gamma \approx 2.8$ MHz/Oe, $\omega$ is the operating frequency in MHz, and the saturation magnetization ($4\pi M_s$) is measured at room temperature.

## IV. Applications and Conclusions

This circulator was designed and built to be used with cooled parametric amplifiers in $L$-band for radioastronomical observations. Until now, cooled $L$-band parametric amplifiers employing very low-loss uncooled circulators could reach a noise temperature of 25°K [4]. This new coolable circulator will contribute less than 2°K to the receiver noise. It will therefore reduce the system noise by about 20 percent to less than 20°K. In addition it results in far better temperature stability and greater bandwidth as compared to a system with an uncooled circulator in $L$-band with sufficient isolation bandwidth by using aluminum-substituted YIG with a low-saturation magnetization ($4\pi M_s \approx 300$ $G$) and a different physical size than necessary at room temperature. In addition a weak external field ($H \approx 65$ Oe) has to be applied.

## Acknowledgment

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## References

[1] G. Smith, "Parametric sum-frequency upconverter," *IEEE Spectrum* (advertisement for AIL), vol. 12, p. 5, December 1969.
[2] D. H. Roth, W. W. Schedelbeck, and G. H. Schollmeier, "Investigation of ferrimagnetic materials at low temperatures and some applications in low-noise receivers," *IEEE Trans. Magn.*, vol. MAG-2, pp. 256–259, September 1966.
[3] R. L. Comstock and C. E. Fay, "Performance and ferrimagnetic material considerations in cryogenic microwave devices," *J. Appl. Phys.*, vol. 36, pt. 2, pp. 1253–1258, March 1965.
[4] J. Edrich and R. G. West, "Very low loss $L$-band circulator with gallium substituted YIG," *IEEE Trans. Magn.*, vol. MAG-5, pp. 481–482, September 1969.
[5] H. Bosma, "A general model for junction circulators; Choice of magnetization and bias field," *IEEE Trans. Magn.* (Digests), vol. MAG-4, pp. 587–596, September 1968.

[1] Operated by Associated Universities, Inc., under contract with the National Science Foundation.

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He was a Teaching Assistant at Columbia University from 1954 to 1957, an Engineer at the ITT Laboratories, Nutley, N. J., from 1957 to 1959, and a Senior Engineer at Republic Aviation Corporation, Farmingdale, N.Y., from 1959 to 1961. From 1961 to 1965 he was a Research Assistant in the Department of Physics, at New York University and an Associate Research Scientist from 1965 to 1967. He is presently an Assistant Professor of Physics at Hofstra University, Hempstead, N. Y. His research interests have been mainly in the field of low-energy atomic scattering theory, and his publications have appeared in the *Physical Review*.

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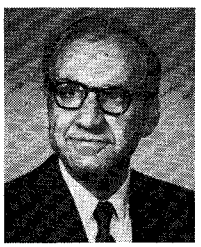

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At Iowa State University he served as a Graduate Assistant in 1957 and as an Instructor from 1958 to 1962, when he became Assistant Professor of Electrical Engineering. He was an Associate Professor at California State College, Los Angeles, from 1963 to 1964. Presently, he is an Associate Professor of Electrical Engineering at the University of Alabama, Huntsville, and is carrying on research in electromagnetic field theory.

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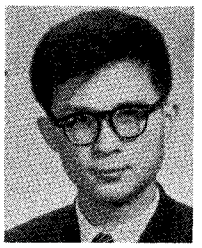

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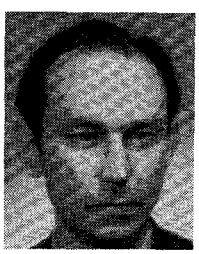

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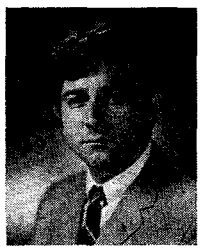

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