

III. RADIO ASTRONOMY*

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RESEARCH OBJECTIVES AND SUMMARY OF RESEARCH

The research objectives of the radio astronomy group may be subdivided as follows:

1. Development of techniques for radiometry at millimeter wavelengths.
2. Observation of extraterrestrial radio sources, principally, but not exclusively, at short centimeter and millimeter wavelengths.
3. Microwave studies of the terrestrial atmosphere and surface with application to meteorological satellites.
4. A study of wide base-line interferometry at millimeter wavelengths.

During the past year work has progressed in all of these research areas, to a varying degree. Significant results have included the construction of 4.2-mm radiometer having a bandwidth of 1.8 Gc/sec, and a sensitivity of approximately 1.5°K for an integration time of 1 second. This radiometer incorporates a wide-band crystal mixer, which was also developed under this program within the past year. A digital synchronous detector has been designed and built. Work has progressed on a solid-state local oscillator, the ultimate objective being a 5-mm source of local-oscillator power. At present a high-efficiency quadrupler is in operation from 5 Gc/sec to 20 Gc/sec.

Because the over-all program is concerned with millimeter wavelengths, we must have detailed knowledge of the transmission properties of the terrestrial atmosphere. This has led to a program of atmospheric studies at wavelengths of 13, 5, and 4 mm. Observations of the 13.5-mm water-vapor line have been made over a small region centered on the resonant frequency in an attempt, thus far unsuccessful, to detect stratospheric water vapor. Further observations of the entire line will be made with a multichannel K-band radiometer that is nearing completion. A program for studying the molecular oxygen lines at high altitudes has also been started. A three-channel 5-mm radiometer has been constructed, and one balloon flight has been made. Other flights are planned for the coming year. In conjunction with observations of planetary radiation at 4-mm wavelength, measurements have also been made of atmospheric attenuation at this wavelength.

Three observing programs on extraterrestrial radiation have been initiated during the past year: (i) measurements of Venus, Taurus A, Sun, and Moon at 11.8 mm; (ii) discovery of the interstellar OH line in the absorption spectrum of Cassiopeia A at 18-cm wavelength; and (iii) observations of Jupiter and Taurus A at 4.2-mm wavelength. All of these programs will continue during the coming year, except that the K-band observations will be expanded to cover the wavelength range 16-8 mm.

In the study of wide base-line interferometry we have investigated the degree of phase coherence permitted by the terrestrial atmosphere and ionosphere as a function of frequency, and the advantages to be gained by using "clipped signals" and digital data

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processing to reduce the problem of gain instability of separated amplifiers.

A 10-ft precision parabolic antenna has been put into operation on the laboratory roof and used in the 4-mm observations. The antenna is altazimuth mounted and controlled in celestial coordinates by a PDP-1 digital computer. This whole system is now in operation.

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A. A 22-Gc BALANCED, CANONICALLY TUNED VARACTOR QUADRUPLER WITH 50-mw OUTPUT POWER

To the best of the authors' knowledge the varactor multiplier that is described in this report is the first successful realization of a symmetric, multiple-diode varactor frequency multiplier at centimeter wavelengths. The quadrupler is capable of delivering a power output of more than 50 milliwatts at 22.2 Gc with an efficiency in excess of 13 per cent.

The circuit is unique in several respects. First, separation of even- and odd-harmonic power into different parts of the circuit is inherently accomplished through the use of a two-varactor balanced arrangement which increases the power-handling capability by a factor of two. Second, canonical (noninteracting) tuning is provided in the input, output, and idler circuits. Third, a combination of waveguide and coaxial elements are utilized to achieve the desired separation of harmonic and fundamental power.

The breadboard model of the quadrupler is shown in Fig. III-1. The coaxial

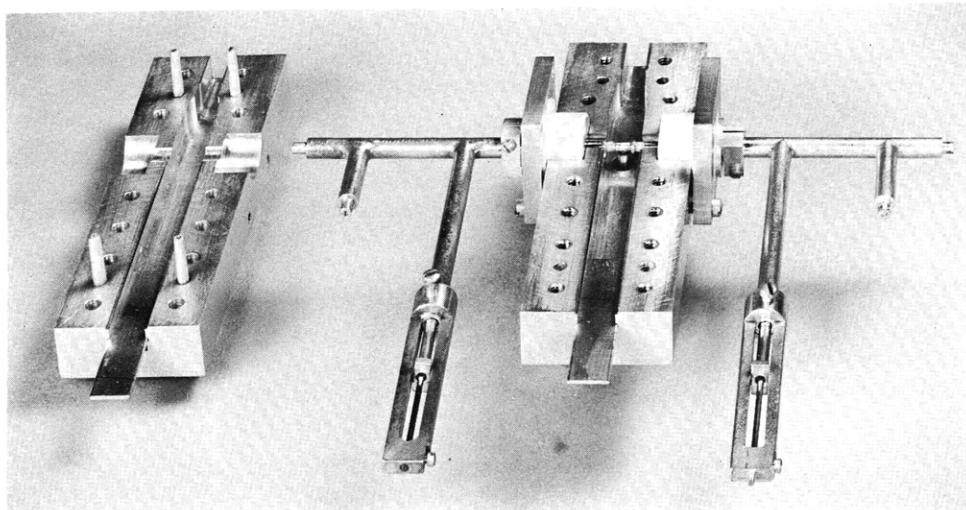


Fig. III-1. Partially exploded view of the 5.55-22.2 Gc balanced quadrupler. The two varactors are mounted across the waveguide and driven coaxially at the center point. The idlers are tuned individually by the two coaxial stubs.

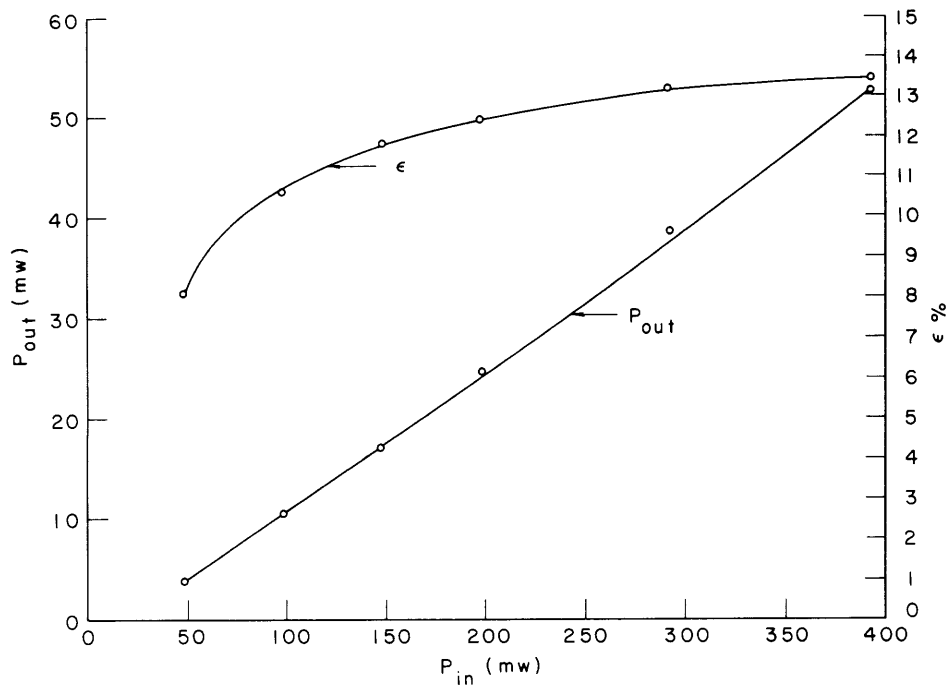


Fig. III-2. Efficiency and power output versus input power for the 5.55-22.2 Gc balanced quadrupler.

structures serve as the idler (11.1 Gc) tuning adjustments while simultaneously providing short-circuits at the guide faces at 5.55 Gc and 22.2 Gc, independently of the position of the idler tuning stubs. The third harmonic (16.65 Gc) is open-circuited at the input port by a quarter-wave series trap. The output is tuned and matched to the load with a sliding backshort and an E-H tuner (not shown), and then filtered with a simple cavity filter (to insure that all of the indicated output power is at 22.2 Gc). Input tuning is provided by coaxial, double-stub tuners. The diodes are individually biased from 1000 Ω ten-turn potentiometers supplied with 12 volts.

The power output and efficiency of the quadrupler is plotted against the input power in Fig. III-2. Note that the efficiency rapidly climbs from 8 per cent to over 10 per cent for a 3-db input-power increase from 50 mw to 100 mw and then levels off to a slow rise to 13.5 per cent at 400-mw input. Calculations have indicated that the diodes begin to overdrive at less than 80-mw input. The canonical tuning makes the adjustment of the multiplier particularly simple. Saddle points and other tuning anomalies are absent; in fact, with a very small sacrifice in efficiency, the quadrupler can be retuned for input powers ranging from 30 mw to 500 mw with bias voltage adjustment alone.

Although the experimental quadrupler employs overdriven graded-junction varactors (two matched, epitaxial GaAs varactors, Type D5047B, supplied by Sylvania Electric Products, Woburn, Mass.), the theoretical results that are available on overdriven doublers^{1,2}

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can be used to extrapolate from the existing abrupt-junction theory.³ If reasonable levels of idler loss and input-output circuit loss are assumed, the measured efficiency is in agreement with the theoretical efficiency. The overdrive ratio is fairly high (greater than 5:1) without appreciable conduction current (less than 1 ma/diode at 50-mw output).

Recent measurements directed toward separation of diode losses and circuit losses indicate that a considerable portion of the circuit loss is associated with the input double-stub tuners. The magnitude of this portion of the loss is approximately 3-4 db. Thus it appears that an improved input tuning structure may increase the efficiency by as much as a factor of two. A new low-loss tuning structure has been designed and construction is now in progress.

The results verify the supposition that careful attention to design, together with symmetric-circuit techniques, can remove a great deal, if not all, of the necessity of having an "agile screwdriver" for successful operation of microwave varactor multipliers. The multiplier presented no surprises other than pleasant ones and proved tractable and free of spurious oscillation.

Further results will be presented at the International Solid State Circuits Conference, to be held in Philadelphia, February 19-21, 1964, and will be published in the Conference Digest.

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References

1. J. A. Davis, A Forward-Driven Varactor Frequency Doubler, S. M. Thesis, Department of Electrical Engineering, M. I. T., May 1963.
2. R. P. Rafuse, Recent Developments in Parametric Multipliers, Proc. National Electronics Conference, October 1963, Vol. XIX, pp. 461-470.
3. P. Penfield, Jr. and R. P. Rafuse, Varactor Multipliers (The M. I. T. Press, Cambridge, Mass., 1962).

B. DISCOVERY OF THE INTERSTELLAR 18-cm LINES OF THE HYDROXYL (OH) RADICAL

Following the detection of the 21-cm line of atomic hydrogen in the interstellar medium, Shklovsky¹ and Townes² both suggested that the Λ -doublet line of the $^2\Pi_{3/2}$, $J = 3/2$ state of the hydroxyl (OH) radical might be detectable. A search, in 1956, by Barrett and Lilley was unsuccessful,³ but this search was made without the benefit of precise laboratory frequencies for the lines. In 1959, Ehrenstein, Townes, and Stevenson⁴ measured the frequencies in the laboratory and obtained 1667.34 ± 0.03 mc/sec for the $F = 2 \rightarrow 2$ hyperfine line, and 1665.46 ± 0.10 mc/sec for the $F = 1 \rightarrow 1$ line.

With accurate values of the frequencies and the improved techniques that are now available, another search was undertaken, in October 1963, as a joint experiment between the Research Laboratory of Electronics and Lincoln Laboratory. M. L. Meeks, S. Weinreb, and J. C. Henry participated from Lincoln Laboratory. The experiment was performed with the 84-ft parabolic antenna at Millstone Hill Observatory, Lincoln Laboratory, M. I. T., and made use of a digital spectral-line autocorrelation radiometer that had been designed and built by Weinreb at the Research Laboratory of Electronics

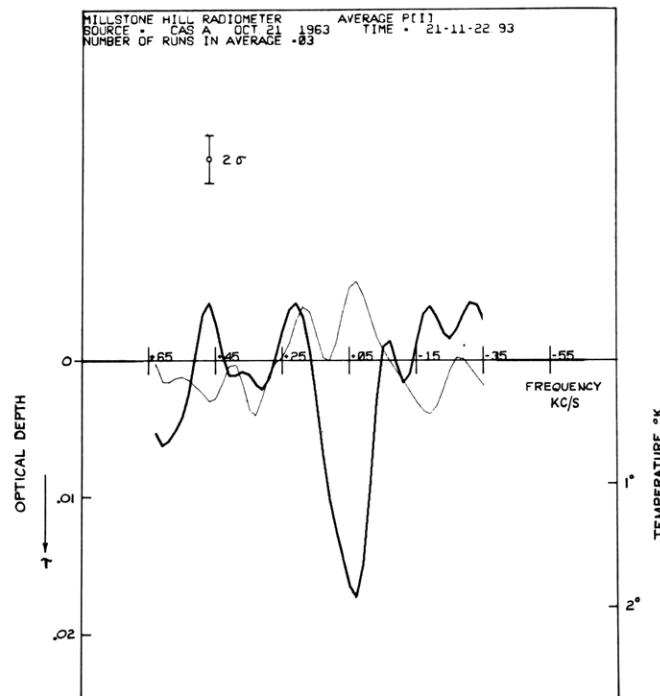


Fig. III-3. A portion of the observed 1667 mc/sec OH absorption spectrum in Cassiopeia A. The heavy line shows 8000 seconds of data taken with the antenna beam directed at Cassiopeia, and the light line shows 6000 seconds of data taken with the beam displaced slightly from Cassiopeia.

as part of his doctoral research program.⁵

Observations were conducted between October 15 and October 29, 1963, in the direction of the strong radio source Cassiopeia A, since this direction would yield the largest observable effect for the least number of OH radicals in the antenna beam. The observation frequency was corrected for the Doppler shift resulting from the motion of the earth and sun. The first night's observation gave strong evidence of a positive detection of OH absorption lines in the spectrum of Cassiopeia A, and subsequent nightly observations furnished verification. Absorption lines corresponding to both OH lines were found at 1665 mc and 1667 mc, with relative intensities in agreement with expected

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values. A 20-kc shift of the lines was observed between October 17 and October 29, 1963, which is in agreement with the orbital velocity of the earth and gives positive evidence that the OH was extraterrestrial. One of the absorption lines is shown in Fig. III-3.

The detection of OH provides radio astronomy with a second radio line, and will lead to many comparison studies with the galactic H distribution as determined from 21-cm research. The OH/H abundance ratio can be computed from our results, and gives values of 10^{-7} . Our preliminary results have been published.⁶ Word of our discovery was communicated to radio astronomers with the result that the Australian group confirmed the detection within three weeks.

Observations of OH in other parts of the galaxy will continue at the Millstone Hill Observatory.

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References

1. I. S. Shklovsky, Doklady Akad. Nauk S. S. S. R. 92, 25 (1953).
2. C. H. Townes, International Astronomical Union Symposium No. 4, edited by H. C. van de Hulst (Cambridge University Press, London, 1957), p. 92.
3. A. H. Barrett and A. E. Lilley, Astron. J. 62, 5 (1957).
4. G. Ehrenstein, C. H. Townes, and M. J. Stevenson, Phys. Rev. Letters 3, 40 (1959).
5. S. Weinreb, A Digital Spectral Analysis Technique and Its Application to Radio Astronomy, Technical Report 412, Research Laboratory of Electronics, M. I. T., August 30, 1963.
6. S. Weinreb, A. H. Barrett, M. L. Meeks, and J. C. Henry, Nature 200, 829 (1963).