VII. MICROWAVE AND MILLIMETER WAVE TECHNIQUES

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A. LOW-TEMPERATURE MILLIMETER WAVE RECEIVERS

Joint Services Electronics Program (Contract DAAB07-71-C-0300)

1. SUMMARY OF RESEARCH

Richard B. Adler, Madhu S. Gupta, Robert L. Kyhl,

Paul L. Penfield, Jr., David H. Staelin

Experimental projects in progress include a 20-GHz single-diode mixer instrumented for detailed microwave measurements, a 20-GHz double-diode balanced mixer assembly to test performance in a cooled mixer mode, and a 118-GHz single-diode mixer for radio astronomy use. All units use the GaAs Schottky-barrier diodes on Lincoln Laboratory chips.

Room temperature measurements and preliminary cooled measurements with the 20-GHz research mixer are reported in Section VII-A. 2. The design work on the balanced mixer, which uses packaged Lincoln Laboratory chips, has been completed and fabrication has begun. The 118-GHz mixer is in the assembly stage. Fabrication problems that have been solved include forming a .001" silica dielectric sheath on a .005" tungsten post and soldering a .0007" gold-plated tungsten whisker to the post.

Parallel analytic studies of mixer behavior continue. One example is the improved method of local-oscillator current and voltage waveform calculation which is described in Section VII-A. 3. Such waveform calculations are basic to low-level signal analysis.

2. K-BAND GaAs SCHOTTKY-BARRIER DIODE MIXER

Robert W. Freund, Robert L. Kyhl

One of the major goals of this project is to increase the understanding of millimeter-wave single-diode mixers. Toward this end, an experimentally measurable K-band mixer has been fabricated using GaAs Schottky-barrier diodes. The type of diodes, mounting configuration, and a portion of the waveguide mount were described in Quarterly Progress Report No. 113 (page 35).
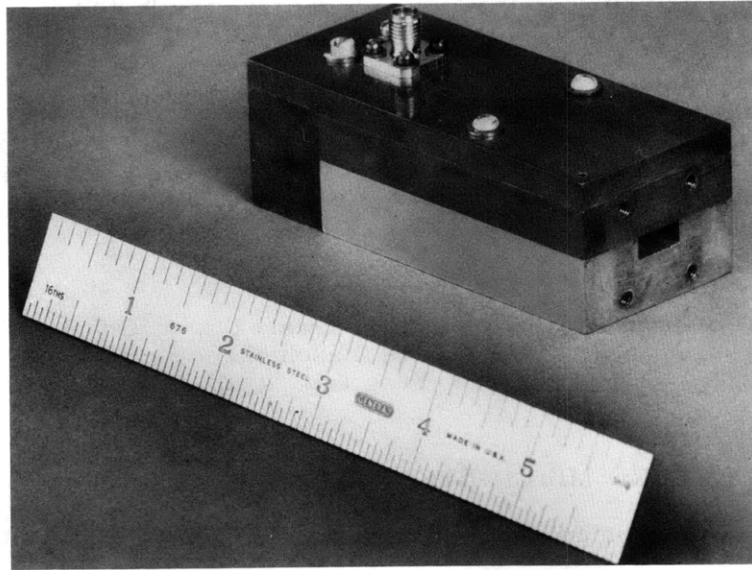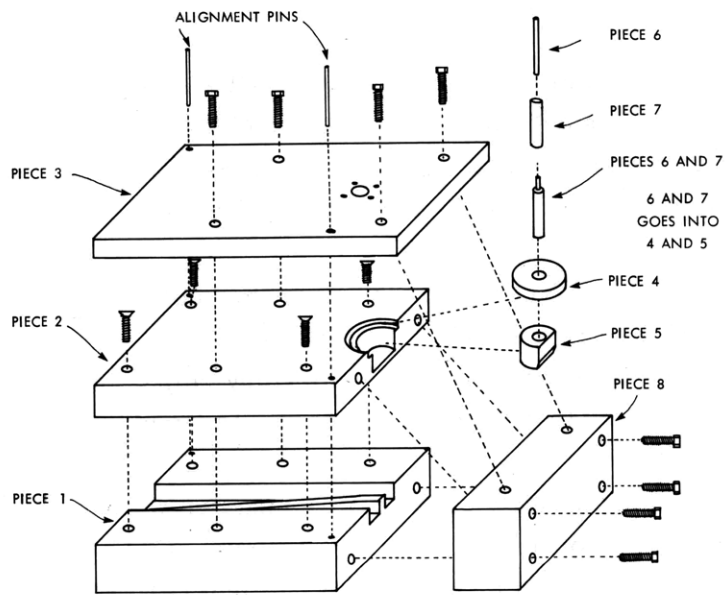
Fig. VII-1. Complete K-band mixer mount.

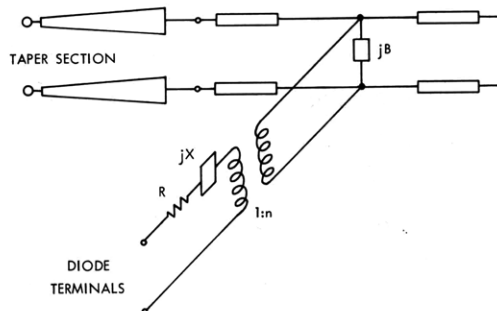Fig. VII-2. Perspective assembly drawing for a single K-band mixer mount.

Fig. VII-3.

Equivalent circuit for waveguide embedding network.

Several different diode "dots" on a single chip were successfully incorporated into a working mixer. Various overall mixer system measurements were performed, including noise temperature and conversion loss. A typical value of double-sideband system noise temperature was 900°K. This value is based upon the following conditions: (a) an IF amplifier with a noise temperature of 240°K, (b) IF matching adjusted for optimum noise performance, and (c) no microwave matching. This value of system noise temperature implies a double-sideband mixer noise temperature of 360°K. Because of the unknown effect of the microwave mismatch, this is a pessimistic value for this mixer and it should decrease with source optimization.

The complete K-band mixer assembly is shown in Fig. VII-1, and a perspective drawing of the assembly in Fig. VII-2. The mount is composed of a tapered section of ridged waveguide, a uniform length of ridged waveguide, a back-short, and an elaborate IF filter section. Ridged waveguide was used to facilitate impedance matching of the diode to the transmission line. The taper section acts as a broadband matching transformer to standard waveguide with a VSWR of less than 1.15 across the entire frequency range of 18 GHz to 26.5 GHz.

An equivalent circuit representation for the waveguide portion of the mixer mount is shown in Fig. VII-3. We now have a complete description of the taper section, which, together with small-signal microwave impedance measurements, permits evaluation of the elements. Comparison of the measured diode quality factors as defined by Kurokawa and Schlosser[1] and by theory, indicates that the model is valid. By using the equivalent circuit and a circuit for the IF filter section, two-port mixer parameters can be deduced for the diode mixer.

To increase our understanding, mixer operation will be studied at cryogenic temperatures. Preliminary results indicate improvements in mixer noise temperature, but these data are incomplete and further work is anticipated.

References

1. K. Kurokawa and W. O. Schlosser, "Quality Factor of Switching Diodes for Digital Modulation," Proc. IEEE **58**, 180-181 (1970).

3. NONLINEAR COMPUTER-AIDED ANALYSIS OF A
   MICROWAVE MIXER

Wojciech Gwarek, Robert L. Kyhl

Nonlinear large-signal analysis of local-oscillator current and voltage wave shapes was made for mixers with Schottky-barrier diodes. The diode can be treated as a parallel connection of the diode conductance characterized by the function $I_D = I_S(\exp(\beta V) - 1)$ and the nonlinear capacitance $C_D = C_o / \left(1 - \frac{V}{\phi}\right)^{1/2}$, where ϕ is the diode contact potential.
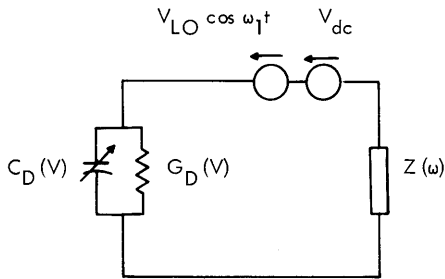
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Fig. VII-4.

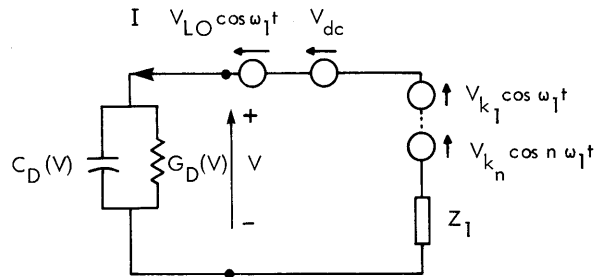Model of the diode circuit.

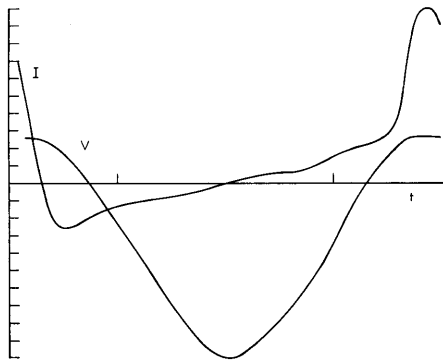Fig. VII-5.

Model used in the algorithm.

Fig. VII-6.

Example of the diode voltage and
current waveforms.

The microwave circuit seen from the diode point of view can be characterized by a frequency-dependent impedance $Z(\omega)$ and a source voltage V_o. This situation is shown in Fig. VII-4. $Z(\omega)$ can be calculated by the method described by Eisenhart and Khan.[1] This impedance characterizes the waveguide structure, and it is usually impossible to make a reasonable approximation of it by a simple RLC network.

The large-signal problem was solved by developing the following algorithm in FORTRAN for the model shown in Fig. VII-5.

1. It solves the nonlinear circuit problem by the Runge-Kutta method of integration, under the assumption that $Z(\omega)$ is the impedance of a simple RLC network.

2. Within an iteration loop it introduces the voltage sources $V_{k_1} \ldots V_{k_n}$ to bring the impedances at the frequencies $\omega_1 \ldots n \cdot \omega_1$ to the values expressed by $Z(\omega)$.

For most practical calculations the method converged within 20 or 30 cycles of oscillation. The results of calculations by this method were compared with results accomplished by a frequency domain analysis using a method similar to that of Egami.[2] The comparison shows that the new method is faster and more convenient. One of the reasons is that in the frequency domain analysis we must guess the set of the solutions. The wrong guess can significantly slow down the program or even cause divergence of the algorithm.

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Figure VII-6 shows an example of the results of calculations using the new technique for a Schottky diode in a K-band waveguide structure.

References

1. R. L. Eisenhart and P. J. Khan, "Theoretical and Experimental Analysis of a Waveguide Mounting Structure," IEEE Trans., Vol. MTT-19, No. 8, pp. 706-719, August 1971.
2. S. Egami, "Nonlinear, Linear Analysis, and Computer-Aided Design of Resistive Mixers," IEEE Trans., Vol. MTT-22, No. 3, pp. 270-275, March 1974.

B. MICROWAVE MEASUREMENTS AND INSTRUMENTATION: MICROWAVE APERTURE-SYNTHESIS INTERFEROMETER

1. SUMMARY OF RESEARCH

Bernard F. Burke

Among our objectives with the three-antenna aperture-synthesis system now under construction at the Haystack Observatory has been the measurement of atmospheric refraction at millimeter and submillimeter wavelengths. The current work in the field indicates that atmospheric refraction limitations for stable image construction at radio wavelengths are roughly the same as at optical wavelengths; that is, the atmospheric "seeing" is of the order of magnitude of 1 arc-second. There are questions about the completion of the analysis, however, on two gounds: First, the differential phase shift, even at millimeter wavelengths, is seldom as great as 2π. Second, the "phase closure" properties of an interferometric system allow more complete control over the image reduction process than in the optical analog.

The antennas are ready for operation, the antenna wiring and preparation of the railroad track are nearly complete, and when the Spring rains stop, the entire system should be under test within a month. During the winter, work was concentrated on the electronic systems and software. In particular, phase stability measurements of the 1-3 cm local oscillators were made, which have resulted in the development of phase-locked systems of high absolute stability.

2. STABILITY OF 1.3 cm OSCILLATORS

David H. Blake, Aubrey D. Haschick

Two Gunn-diode oscillators were phase-locked to a harmonic of a Rubidium atomic frequency standard, and their phase stability was compared. The limiting factor in the phase stability of the systems was the harmonic mixers, which had a temperature

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coefficient of 10 electrical degrees per degree C. The accuracy of the measurements was 0.1 electrical degrees at K-band, which corresponds to a difference in path length of 3 μm to the two oscillators.

3. HARD-WIRED TAPE CONTROLLER

Brian J. Rossin

The Nova 800 minicomputer that will control the interferometer system and reduce the data must spend an inordinate time at present in magnetic tape read and write sub-routines. The efficiency of the system has been greatly enhanced by development of a tape control unit that performs all of the tape read and write subroutines with hard-wired logic. The unit is relatively simple and inexpensive, and should be of use to anyone who wishes to make more efficient use of a minicomputer system.

C. VERY LONG BASELINE INTERFEROMETRY

Kwok-Yung Lo, Robert C. Walker, Bernard F. Burke

The program to establish the long-term stability of microwave maser sources continues. We have established that the 18-cm OH maser sources associated with H II regions such as W49 and W3 appear to be stable in position and intensity over a period of years. The H_2O sources (at 1.35 cm wavelength) are variable in intensity, but a paper has recently been completed, in conjunction with the Naval Research Laboratory, which demonstrates that the positions remain stable, to at least .01 arc-second.

A new type of maser source at 18 cm has been discovered by K-Y. Lo and K. Bechis of this laboratory. The star V1057 Cygni is an example of a young star that has recently appeared, either as a result of brightening as nuclear burning sets in, or by having its dust cocoon blown away. A maser source, of unique type, has been discovered, which exhibits maser action only at 1720 MHz. When the source was discovered, it was the brightest known maser source in the sky. As time has progressed, however, the source has steadily weakened, and it is probably not a suitable class of object to use in a long-term program such as in geodesy or an operating system. Our observations have shown, however, first by using the California Institute of Technology Owens Valley interferometer and then by an NRL-NRAO VLBI experiment, that the line has polarization and angular properties that are completely consistent with a Zeeman effect in the maser. The magnetic field would be approximately 1.5×10^{-3} G.

Some work has been completed on a conceptual VLBI working system that could be

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used either for navigation or as a means of remote synchronization of time signals.