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SOLID-STATE MILLIMETER-WAVE POWER GENERATION AND AMPLIFICATION

FINAL REPORT

National Aeronautics and Space Administration
Grant NGL-22-009-163

covering the period
March 1, 1966 - February 28, 1970

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March 31, 1970

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SUMMARY OF RESEARCH

1. Millimeter-Wave Circuits

A low-noise mixer has been built to operate at 60 GHz. The pertinent results are as follows.

Noise Figure (Double Sideband):	<4.78 ± 0.5 dB (8.78 ± 0.5 dB over-all receiver noise figure with 4.0 ± 0.5 IF amplifier at 3.1 GHz and 0.5 dB insertion loss of mixer-to-IF stage circuit.
Bandwidth:	Cursory examination reveals a noise figure at 4-6 dB over a bandwidth >1 GHz.

This represents an approximate 3-dB improvement over the best reported noise figure of a mixer in this frequency range: ≈7 dB with a 70 MHz IF (L_c = 5-6 dB, Nr = 1.3-1.35) and a substantial improvement in bandwidth.[1]

Furthermore, no attempt was made to properly terminate the image frequency. A new mixer is being built that will do so, and an improvement in performance is expected.

The diodes used in the mixer described here were Gold-Gallium Arsenide Schottky-barrier diodes of the "honeycomb" configuration. Their characteristics were the following.

I_{co} (intercept)	=	4×10^{-15} A
R_s	=	12 Ω at 10 mA
V_B at -10 μA	=	3.7 V
$C\|_{ov.\ bias}$	=	≈0.02 pf
Diode diameter	=	5 μm.

Improved diodes are being made with 2-μm diameter junctions. The

zero bias capacitance is too small to measure, being estimated at <0.001 pf. The R_s = 10-15 Ω at 10 mA. The total change in capacitance over a 2-V reverse bias range is 10^{-15} pf. More definitive measurements are being made before these diodes will be incorporated in a new mixer.

2. Power Generation and Amplification

Avalanche diodes have been characterized over a substantial frequency range (4-12 GHz) on a small-signal basis. An equivalent circuit has been derived and is now the basis for low-level negative resistance reflection amplifier design using the avalanche diode as the active element. Initial circuits have provided a 10-dB gain over a 3.2% fractional bandwidth, but theoretical calculations indicate that the performance can be substantially improved by a better choice of the imbedding network.

Investigation continues in the area of large-signal modeling of avalanche diodes using frequency-independent nonlinear circuit elements.

A model for the imbedding network of a varactor frequency multiplier has been proposed that enables calculation of the expected over-all efficiency from small-signal measurements. The small-signal impedance vs bias measurements determine parallel and series loss terms that can then be plugged into the equations derived for over-all efficiency. A complete description will be available in a thesis to be submitted to the Department of Electrical Engineering, M.I.T., by A. Y. Chen entitled, "Microwave Frequency Doubler."

3. High Dynamic Range Circuits

Many common circuit elements are being investigated to determine their dynamic range. The special test set built by R. D. Mohlere is in use and helps to set fundamental limits on dynamic range of such components as ferrite cores and ceramic capacitors. Data taken on crystal filters have clearly shown that they are probably the weakest part of a high dynamic range receiver.

Further details on all of these projects may be found in the publications listed below.

4. Theses and Publications

D. H. Steinbrecher and D. F. Peterson, "Small-Signal Avalanche Diode Equivalent Circuit Model," Quarterly Progress Report No. 96, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1970, pp. 51-53.

J. E. Rudzki, "60-GHz Mixer," Quarterly Progress Report No. 95, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., October 15, 1969, p. 17.

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R. D. Mohlere, "Intermodulation Distortion Analysis," S.M. Thesis, Department of Electrical Engineering, M.I.T., September 1969.

P. W. Rosenkranz, "Smith Chart Plotting Circuit," Quarterly Progress Report No. 94, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1969, pp. 55-57.

J. G. Webb, "Nonlinear Circuit Elements," Quarterly Progress Report No. 94, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1969, pp. 57-58.

R. D. Mohlere, "Intermodulation Distortion," Quarterly Progress Report No. 94, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1969, pp. 58-59.

D. F. Peterson, "Avalanche Diode Analysis," Quarterly Progress Report No. 94, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1969, p. 59.

J. G. Webb, "Realizability of Nonlinear Circuit Elements," S.M. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., June 1969.

J. E. Rudzki, "60-GHz Mixer," Quarterly Progress Report No. 93, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., April 15, 1969, p. 33.

D. F. Peterson, "Avalanche Diode Analysis," Quarterly Progress Report No. 93, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., April 15, 1969, pp. 33-41.

K. H. Gerrath, "Frequency Doubler 15.2-30.4 GHz," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1969, pp. 69-74.

D. F. Peterson, "Avalanche Transit Time Oscillator Analysis," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1969, pp. 74-76.

J. E. Rudzki, "60-GHz Mixer," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1969, p. 76.

A. A. M. Saleh, "Mixer Analysis," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1969, p. 76.

R. D. Mohlere, "Intermodulation Distortion in Mixers," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1969, p. 77.

A. Y. Chen, "High-Power 60-GHz Solid-State Source," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1969, pp. 77-78.

J. G. Webb, "Nonlinear Circuit Theory," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., January 15, 1969, pp. 78-79.

D. F. Peterson, "Characterization of an Avalanche Diode Oscillator," S.M. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., January 20, 1969.

R. E. Crochiere, "Investigation of Subtransit-Time Oscillations in the Avalanche Region of a P-N Junction," S.M. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., September 1968.

J. E. Rudzki, "60-GHz Mixer," Quarterly Progress Report No. 91, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., October 15, 1968, p. 12.

D. F. Peterson, "Avalanche Diode Oscillator," Quarterly Progress Report No. 91, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., October 15, 1968, pp. 11-12.

K. H. Gerrath, "The Design and Realization of Varactor Multipliers for the VHF-UHF Range," S.M. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., September 1968.

R. E. Crochiere, "An Investigation of Subtransit-Time Oscillations in the Avalanche Region of a P-N Junction," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 19.

J. E. Rudzki, "60-MHz Mixer," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 20.

J. W. Majer, "S-band Mixer," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 20.

J. W. Majer, "Frequency Doubler," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 21.

K. H. Gerrath, "L-band Quadrupler," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 21.

D. F. Peterson, "Avalanche Diode Oscillator," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, pp. 21-22.

R. E. Snyder, "High Dynamic Range Mixer for the 200-400 MHz Band," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 22.

A. A. M. Saleh, "Mixer Theory," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 22.

R. D. Mohlere, "D-C Amplifier," Quarterly Progress Report No. 90, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., July 15, 1968, p. 22.

A. A. M. Saleh, "Theory of Resistive Mixers," Ph.D. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., January 1970.

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William J. Cadogan, "A Low-Power X-band to UHF Radar Transponder," S.B. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., June 1969.

V. C. Howey, "LOG (I) vs V Diode Display Unit," S.B. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., June 1969.

Michael Ching, "Observations of Modern Technology to the Observation of Wildlife," S.B. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., September 1968.

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M. J. Ward, "A Wide Dynamic Range Single-Sideband Receiver," S.M. Thesis, Department of Electrical Engineering, M.I.T., Cambridge, Mass., January 1968.

5. Forthcoming Publications

A. Y. Chen, "Microwave Frequency Doubler," Quarterly Progress Report No. 97, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., April 15, 1970, p. 13.

A. A. M. Saleh, "Theory of Resistive Mixers," Quarterly Progress Report No. 97, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., April 15, 1970, pp. 13-14.

D. F. Peterson, "Avalanche Diode Mixers," Quarterly Progress Report No. 97, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., April 15, 1970, p. 14.

V. C. Howey, "Status of Research: Electronics Instrumentation," Quarterly Progress Report No. 97, Research Laboratory of Electronics, M.I.T., Cambridge, Mass., April 15, 1970, p. 15.

D. H. Steinbrecher and D. F. Peterson, "Small-Signal Model with Frequency-Independent Elements for the Avalanche Region of a Microwave Negative-Resistance Diode" (submitted to IEEE Trans. on Electron Devices).