# SOLID-STATE MILLIMETER-WAVE POWER GENERATION AND AMPLIFICATION

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# SOLID-STATE MILLIMETER WAVE POWER GENERATION AND AMPLIFICATION

## SUMMARY OF RESEARCH

### 1. High Dynamic Range Circuits

We have continued our studies of high dynamic range mixers. An HF mixer covering the frequency range 0.5-29.5 MHz, with no input tuning, has been constructed using four MOSFET's in a symmetric bridge circuit. Measurements of the dynamic range show that a +4 dBm two-tone signal at the input gives third- and fifth-order intermodulation terms greater than 120 dB down. This, in effect, gives a so-called third-order intermodulation "intercept point" (where signal and intermodulation would be equal in amplitude if the small-signal rules still held) of +64 dBm. The single-sideband conversion loss of the mixer was approximately 7 dB. The mixer has been described in a Master's thesis by M. J. Ward[1] and in a paper by R. P. Rafuse, which was presented at the 1968 International Solid State Circuits Conference.[2]

The theoretical stage of the measurement of intermodulation distortion on a varactor-tuned 200-MHz cavity is just being completed. Two helpful papers on theory of biased diode capacitance have been found. The theoretical analysis of intermodulation is close to completion, and capacitance and intermodulation measurements will follow. A comparison of theoretical results with actual results, and possible explanations for discrepancies, will be included in the final report on the subject.

The amplitude-to-phase conversion in a field-effect transistor bridge is being studied. For various input drive signals the DC output will be plotted against phase differences. We expect that the output will remain constant for a wide range of drive-signal amplitudes for a constant phase difference. The variable phase-shift network and amplifier have been set up to drive the phase splitter and gate circuit. There has been some difficulty encountered in obtaining ultra wideband four-terminal balance in the FET bridge but the problems are being resolved.

One principal area of activity has been the implementation and testing of a circuit designed by D. H. Steinbrecher. The circuit in question is a high input impedance (of the order of $10^{15}$ Ω), low output impedance (of the order of 5 Ω) small-signal DC amplifier with unity voltage gain. The circuit employs two FET bridges as chopper and decorrelator, with a random chopping waveform derived from avalanche noise in a silicon junction. The bridges, the noise generator, and bridge driver have been built, and the components mentioned above have been individually tested. The system is in the stage of being assembled.

Testing and development of wideband hybrids using ferrite beads and coaxial transmission line is progressing. Tests on a simple 50-Ω inverting transformer indicate that approximately 0.5-dB insertion loss is attainable when using 4 beads strung on 20-mil coaxial cable. This loss will be lower for balanced to unbalanced transformers with 4 beads per line. Bandwidth tests are not complete at the high-frequency limit, but the transformers should be useful beyond 1 GHz. The low-frequency limit is much higher than that computed when using a simple R-L model for the beads. The measured half-power cutoff frequency is approximately 3 MHz, while the computed frequency is 0.3 MHz. The discrepancy is still unresolved. Measurements of input impedance vs frequency for a 50-Ω balanced to 50-Ω unbalanced transformer with matched balanced output are now being made.

## 2. Device Characterization

Measurements of IMPATT oscillators at X-band and Ku-band have been completed. A detailed analysis of these microwave measurements is now under way. The most interesting feature of the latest data, (on Varian, Bomac Division, devices), is the very large reactance variations that take place under oscillating conditions. Complete characterization of the dynamic impedance of an avalanching junction may predict that imbedding networks that include harmonic terminations will improve the efficiency of IMPATT sources.

The design and construction of the microwave circuit required to hold the diode for measurements have been completed. A search for equipment that is needed for the project is now under way, and a list is being made of necessary pieces.

Certain aspects of the theory associated with the device and measurement techniques that will be used have been studied.

Measurements will begin as soon as most of the equipment is available.

Transition-time measurements on punch-through varactors have indicated the possible presence of a dynamic capacitance-voltage relationship that is a function of drive level. In fact, certain diodes appear to exhibit hysteresis in their capacitance-charge characteristic. Isolation of the hysteresis-producing mechanism and its characterization will permit improved design of high-power varactors.

## 3. High-Power and High-Efficiency Varactor Multipliers

We have continued the device characterization and computer-aided design portions of this effort. Most of the results have been published or reported in individual technical exchange sessions with industry.

Most of the research done during the last quarter was concerned with measurements on varactor punch-through diodes for the purpose of getting information upon a more extended equivalent circuit of the diode. Measurements have been made to determine the inductance of the diode in a certain configuration. Other measurements have been made to determine the first series resonant frequency of the diode in a configuration similar to that in a multiplier which will be built later. First attempts have been made to compute the idler network of an L-Band quadrupler.

## 4. Computer-Aided Design

Composite programs developed during the reporting period deal with IMPATT-diode data reduction and analysis, transition-time calculations for punch-through varactors, microwave measurement processing, and many other areas of current research. Many subprograms have been compiled into a function library that permits simple analysis and design programming in the microwave field. Examples of library functions are routines that transform impedance through generalized coupling networks, do least-mean-square fits of data to commonly occurring functionals such as circles and lines, and rotate, transform, and plot Smith-Chart data.

5. Mixer Theory

Some of the major results have been reported by Professor Rafuse in a paper, entitled "Low Noise and Dynamic Range in Symmetric Mixer Circuits," which was presented at the Cornell University Conference on High-Frequency Power Generation and Amplification, August 30, 1967. Some of the results of a theoretical examination of balanced-mixer performance are highly promising. They indicate that high-quality Schottky-barrier mixers are capable of giving noise-figure performances not very different from those obtainable at the same frequency with the same diode cutoff frequency in an optimized parametric amplifier. As an interesting verification of the theory, a mixer constructed for the megahertz frequency range exhibited a conversion loss less than 0.1 dB. It is clear that fundamental advances in mixer performance are now possible if the proper design parameters are utilized.

It has been found that shorting the harmonics at one end while opening them at the other end of a balanced mixer (or vice versa) gives a lower conversion loss than the classical method of shorting (or opening) the harmonics at both ends of the mixer for a square, near square, sinusoidal or near sinusoidal local-oscillator driving voltage. The effect of incomplete harmonic termination on the conversion loss of a square-driven balanced mixer has also been studied.

6. Millimeter-Wave Technology

A study of loss in microwave circuits has culminated in the construction of a 23.5-GHz degenerate parametric amplifier, (pumped at 47 GHz). Preliminary tests on the completed circuit, which has no tuning adjustments except for the diode bias, indicate that the measurable input-circuit loss is below 0.08 dB. The bias-tunable bandwidth appears to be over 1 GHz. The total effective input noise temperature is 150°K at room temperature and the amplifier has an instantaneous bandwidth of 70 MHz at a gain of 20 dB.

Two frequency multipliers have been designed from 15.2 GHz to 30.4 GHz, and from 30.4 GHz to 60.8 GHz. Four such units (two of each) are under construction in the machine shop. These multipliers will be used initially for diode measurements, and then modified to provide a 57-GHz local oscillator for the 60-GHz mixer.

We are engaged in developing a low-noise solid-state 60-GHz receiver. Theoretical predictions have been made which indicate an expected single-sideband receiver noise figure less than 6-dB for the system described by the block diagram shown in Fig. 1.

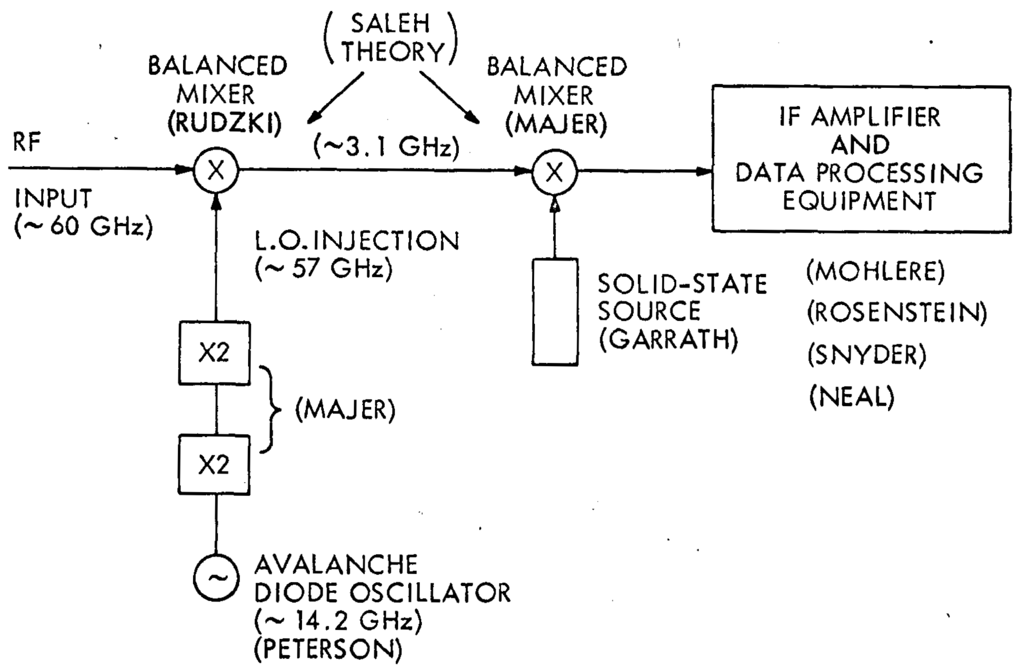


Fig. 1. Diagram of 60-GHz receiver. (Names of those responsible for development are indicated.)

The 60-GHz mixer program is approximately 15% complete. Theoretical studies have been made on the design parameters of the diode package and diode mount. The mounting studs and IF filters have been completed. Quartz diode sleeves have been obtained, and the assembly of the diode packages has begun. The machining of balanced mixer waveguide hardware with a reduced height is 75% complete. A 60-GHz test bench is 50% assembled. No tests have been made.

Two coaxial diode holders for a 3-GHz balanced mixer have been designed and fabricated in the machine shop. A special rack-bench has been mounted with devices for measurement of impedance and noise figure at S-band. The input impedance of the holder vs diode bias has been measured at 3.1 GHz. In order to find two similar diodes, the impedance measurements are under way.

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Preliminary results just obtained on the mixer diodes for 60 GHz indicate that they are among the best ever obtained, and might well give surprisingly low conversion losses at 60 GHz. The 60-GHz, all solid-state receiver now looks very promising.

## References


1. M. J. Ward, "A Wide Dynamic Range Single-Sideband Receiver," S.M. Thesis, Massachusetts Institute of Technology, January 1968.
2. R. P. Rafuse, "Symmetric MOSFET Mixers of High Dynamic Range," Digest of Technical Papers, International Solid State Circuits Conference, February 14-16, 1968.