OBSERVATIONS OF CHAOS IN MICROWAVE CIRCUITS

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ABSTRACT

This paper summarizes observations of chaotic behavior in some microwave circuits that have been reported over the last 10 years. Also, it extends results previously reported for a PIN diode limiter in order to identify the nonlinearities in the diode that allow for chaotic behavior. Further knowledge of chaotic microwave parameters will allow system designers to make use of these properties in future applications.

INTRODUCTION

Chaotic techniques have potential for application in microwave communication and radar systems. In communication systems, discrete data can be sent without the need for digital circuitry by direct control of the oscillator (completely analog). In phased-array radar systems, the beam can be scanned without the use of phase shifters. These chaotic techniques would surely affect system designs such as local area networks and small phased-array radars.

Experimenters have observed chaotic behavior in microwave components. In most cases, they have worked to avoid this mode of operation, because it appeared to be uncontrolled. However, for short periods of time, the performance of chaotic components is predictable and controllable with minimal external stimuli. The goal now is to use this characteristic in the design of electronic components for system applications.

This short paper summarizes some observations of chaos in both microwave components and larger systems; it also presents specific observations in a PIN diode limiting filter. The following four papers in this Digest present an overview of the current understanding of how chaotic techniques could be applied to microwave applications.

SOME OBSERVATIONS OF CHAOS

Microwave Components

Diodes connected to linear tuned circuits have demonstrated chaotic behavior usually preceded by a bifurcation mode [1]. At the University of Kent, experimenters reported this behavior in IMPATT oscillators [2] in 1990 and in Gunn oscillators [3] more recently. Varactor diodes in linear circuits have been analyzed [4] and chaotic behavior observed [5,6]. PIN diodes have also been observed to show period doubling and chaos when used in a limiting filter configuration [7]. Nonlinear transmission-line resonators also show period-doubling bifurcations, periodic spiking, and periodic self-pulsing [8].

Josephson junctions have been analyzed, yielding synchronized oscillations and almost periodic oscillations depending on dc and rf levels [9] and mixing [10].

Some of the earliest observations of chaotic behavior were of thermionic devices. Backward-wave amplifiers and oscillator components demonstrated in 1983 and earlier that high-power chaotic sources are available [11,12]. An analysis of a gyrotron has yielded self-modulated oscillation and period doubling [13].

Microwave Systems

Chaotic behavior arises because of the interaction of a nonlinear device(s) with linear circuits under certain excitation conditions. The quasi-optical array using low-dimensional chaos controlled by the coupling strength [14] is an example of chaotic behavior being used, not avoided. Controlled chaos has been used for digital signaling [15], and secure baseband communication has been demonstrated [16]. Synchronized signals and baseband systems have been demonstrated [17].

CHAOTIC BEHAVIOR IN A PIN DIODE LIMITING FILTER

In 1992, Robert Tan at the Army Research Laboratory first observed the chaotic response of a limiting filter (a bandpass filter with a PIN diode at either the input or

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output port); some results have been reported in the literature [7]. This section extends the results with the emphasis on understanding the characteristic(s) of the diode required to create chaotic behavior. Chaotic behavior herein is defined as either bifurcation (period doubling, etc) or chaos (broadband noise-like) signals. The experiments were performed with a combline filter whose response without a PIN diode at the output was centered near 1.185 GHz, as shown in figure 1. This figure also shows the filter response with the diode connected from the output resonator's high-impedance end to ground. With the diode at the output, signals generated at the diode could be observed over a broad frequency band on a spectrum analyzer.

The experiments consisted of measuring the onset of bifurcations and chaotic behavior as a function of temperature. The diode's low-frequency, current-voltage characteristic was also measured at room, dry ice, and liquid nitrogen temperatures (21, –78, and –196 °C). The onset of bifurcations (figure 2) and chaotic behavior (figure 3) was measured across the passband as a function of temperature. Figure 4 give an example of the bifurcation spectrum, and figure 5 shows the chaotic spectrum. In general, the threshold for the bifurcations and chaotic oscillations decreased as the temperature decreased.

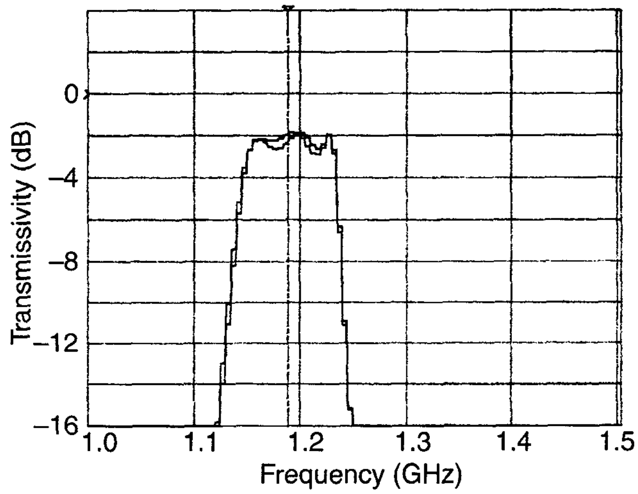

Figure 1. Response of combline filter with (upper curve) and without (lower curve) PIN limiting diode. Cursor at 1.185 GHz.

The dependence of the threshold shift on temperature was an unexpected result, since the forward current-voltage nonlinearity increases with decreasing temperature, as shown in figure 6. I estimated the magnitude of the voltage at the diode by noting the input power level where third-harmonic signals were first observed; this

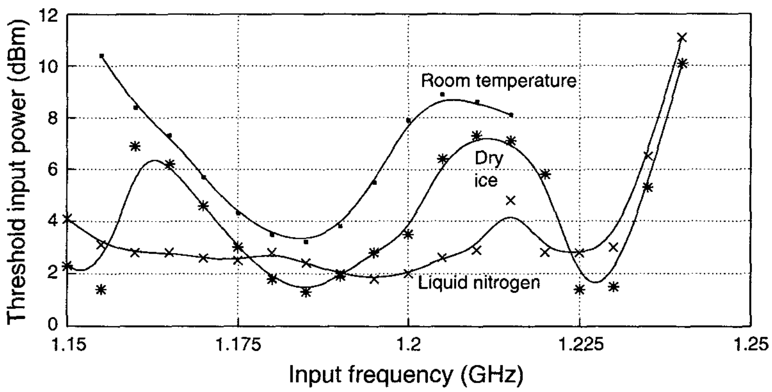

Figure 2. Threshold of bifurcations across passband of filter at three temperatures.

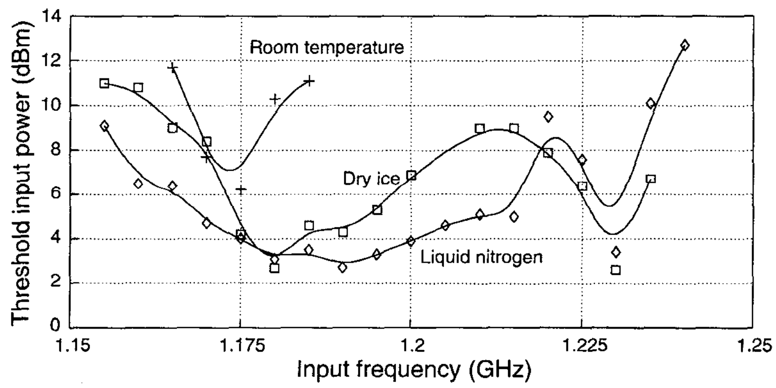

Figure 3. Threshold of chaos across passband of filter at three temperatures.

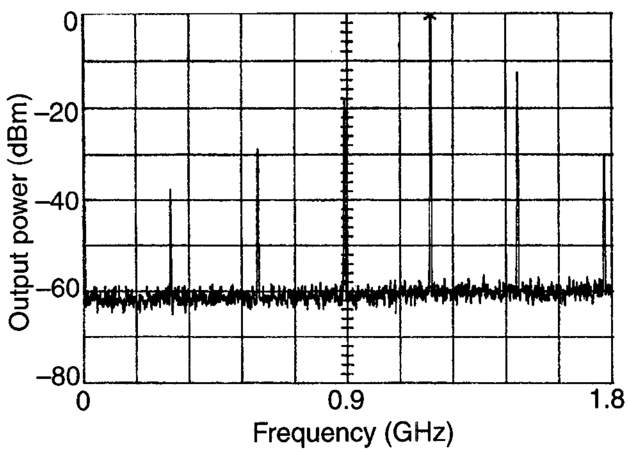

Figure 4. Example of bifurcation spectrum with an input signal at 1.185 GHz. Resolution bandwidth is 3 MHz.

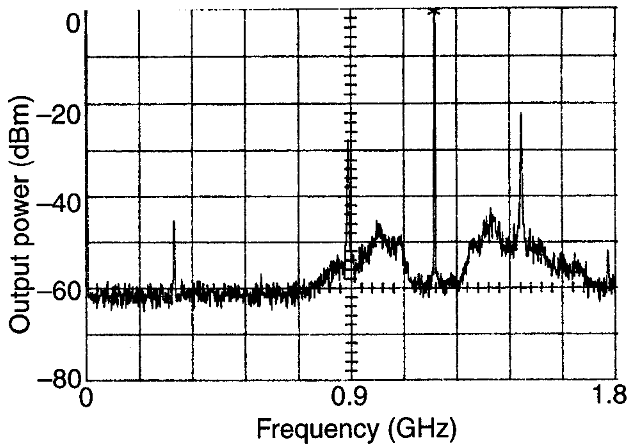

Figure 5. Example of a chaotic spectrum with an input signal at 1.185 GHz. Resolution bandwidth is 3 MHz.

level is associated with the onset of the forward conduction curvature of the diode. I then scaled the onset voltage as the half-power of the input power and the voltage standing wave ratio (VSWR). The onset voltage was estimated to be larger than the voltage associated with the curvature of the diode characteristic, but much less than the breakdown voltage. Therefore the source of the observed behavior appears to be the physics associated with the negative-differential resistance when the diode is reverse biased [18,19]. Similar chaotic behavior in a varactor diode has been attributed to recombination [20]. Further experiments with PIN diodes are ongoing to reveal the roles of nonlinearity, recombination, and diode structure in such observations.

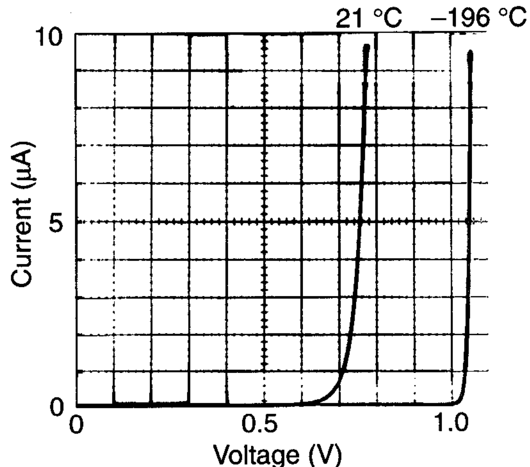

Figure 6. Forward current-voltage characteristics of PIN diode at 21 and –196 °C.

CONCLUSION

Chaotic behavior has been observed in many microwave devices and systems, but additional details need to be understood before the intentional use of chaos can be incorporated into microwave systems.

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Note: Many more references are available. Only a few key publications are noted here. Where several references to similar work are available, the IEEE references have been favored because of their ready availability.

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