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14. ABSTRACT

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Electromagnetic Modeling and Simulation of a Directly-Modulated L-band Microstrip Patch Antenna

Steven D. Keller*(1), W. Devereux Palmer (2), and William T. Joines (1)
(1) Duke University Electrical and Computer Engineering, Durham, NC, 27708
(2) U.S. Army Research Office, Research Triangle Park, NC, 27709

Introduction

The direct pulse modulation of a carrier wave by incorporating fast-switching semiconductor devices into an antenna structure and biasing them with a baseband information signal has recently emerged as a promising technique for improving communication system bandwidth [1], [2]. In order to refine and expand upon this technique, known as direct antenna modulation, the specific physical mechanisms behind the direct carrier wave pulse modulation must be fully understood. An electromagnetic simulation model of an L-band microstrip patch antenna with integrated PIN diodes [3] is constructed using *Ansoft* High Frequency Structure Simulator (HFSS) [4] and is analyzed to explore how the antenna's input impedance, center frequency and carrier wave radiation pattern are impacted by biasing the PIN diodes with a baseband modulation signal. By exploring the radiation characteristics of this specific example of direct antenna modulation, as applied to a patch antenna structure, the first steps are taken towards a general model of the direct antenna modulation technique.

Simulation and Analysis

The first step in the development of a simulated model for a directly-modulated microstrip patch antenna was to determine the dynamic impedance of the *Skyworks Solutions* SMP1340-011 PIN diode, the semiconductor switching device used in the L-band DAM prototype detailed in [3], as a function of the applied bias signal. The dynamic impedance of the SMP1340 was measured by engineers at *Skyworks Solutions* using the HP4291A RF Impedance Analyzer at a frequency of 1.5GHz, corresponding to the center frequency of the DAM prototype patch antenna. Since the SMP1340 is a current-controlled device, diode impedance measurements were made at bias current values within a range corresponding to -0.750V to 0.8V applied bias voltage. This range fully encompassed the 0V to 0.8V peak-to-peak baseband information signal that was successfully used in [3] to switch the SMP1340 between high impedance and low impedance to achieve direct antenna modulation. Diode impedance data for bias voltage levels between 0.000V and 0.536V was extrapolated from the measured impedance data obtained for bias voltage levels between -0.750V to 0V and 0.536V to 0.8V in order to obtain data for a full sweep of the SMP1340 PIN diode from high impedance to low impedance.

Next, discrete resistance, capacitance and inductance values were calculated based on the information in [5], [6] and from the measured impedance data for the SMP1340 PIN diode. Specifically, the lumped inductance was set as a fixed value of 1.48nH, and the lumped resistance and capacitance values were calculated from the measured diode impedance magnitude and phase data. As expected, the resistance steadily decreased from a ~5.7kΩ at 0V bias to ~2.0Ω at 0.8V, with a very sharp transition occurring between 0V and 0.6V.

With impedance data for the SMP1340 accurately measured over an applied bias voltage range representative of the 0V to 0.8V baseband information signal used for direct antenna modulation in [3], a simulation of a directly-modulated patch antenna was then carried out using *Ansoft HFSS*. First, a model for the microstrip patch antenna design was constructed, similar to the model detailed in [3]. The dimensions of the symmetric patch antenna model were set to 4.75 x 4.75 cm, with a feedpoint ~2.43 cm (36.1% of the patch length) along the patch diagonal. A spherical radiation boundary was created approximately 10λ from the center of the patch (with λ = 20cm in vacuum at f = 1.5GHz), to ensure a far-field radiation pattern. Next, to represent the diode switching devices responsible for direct modulation in the DAM prototype, lumped R/L/C components were placed at the corners of the patch antenna between the patch and the ground plane with discrete values corresponding to those calculated from the measured SMP1340 impedance magnitude and phase. As detailed in [6], the circuit model for the biased SMP1340 PIN diode was assembled as a parallel RC circuit in series with an inductance L for the zero/reverse bias regions and a series R-L circuit for the forward biased region. The HFSS model for the directly-modulated patch antenna is shown in Figure 1.

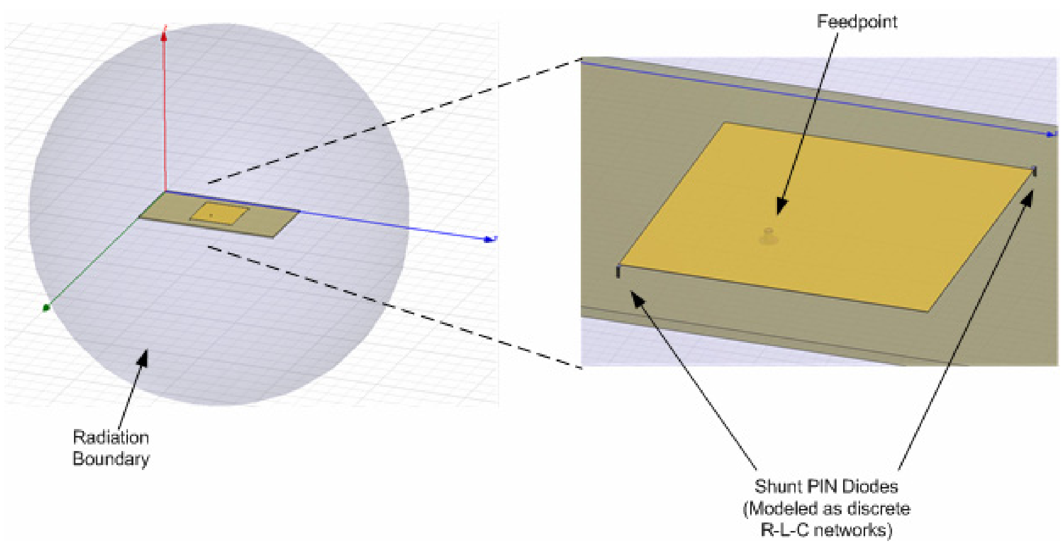

Figure 1. *Ansoft* HFSS model of directly-modulated L-band patch antenna

A discrete-sweep HFSS simulation was run from 1.4GHz to 1.6GHz and from 1.45GHz to 1.8GHz for 52 discrete impedance values of the SMP1340 PIN diode. For each simulation, the shunt lumped R and C component values were updated to correspond with the measured diode impedance data for a distinct bias voltage between 0.0V to 0.8V. The resulting patch antenna return loss, feedpoint impedance, VSWR, and radiation pattern data was recorded for each simulation in order to examine the effects of the shunt PIN diodes on the antenna as the diode bias voltage is swept from 0.0V to 0.8V.

The return loss at 1.5GHz as the SMP1340 is biased from 0V to 0.8V is shown in Figure 2. Each data point represents the simulated patch antenna return loss for a discrete diode bias level, with the diode structure modeled from the measured impedance data as a lumped R/L/C connection between the patch antenna and ground plane. As expected, the sharp drop in the diode resistance between 0V and 0.6V (from ~5.7kΩ to ~30Ω) significantly impacts the patch antenna return loss at the 1.5GHz carrier wave frequency, steadily increasing it to above -3dB at 0.42V bias and to above -0.3dB at 0.80V bias.

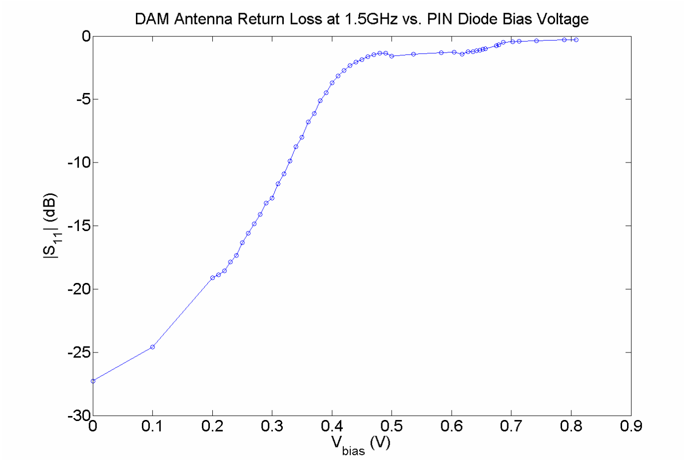

Figure 2. Return loss vs. bias voltage (f = 1.5GHz) for DAM patch antenna

As shown in Figure 3, the center frequency of the patch antenna was also significantly affected as the SMP1340 was biased from 0V to 0.8V. As the diode is increasingly forward-biased, the patch antenna center frequency drifts from its original value of 1.5GHz to ~1.7 to 1.8GHz, similar to a varactor-tuned antenna system. Since the carrier wave of the antenna remains at 1.5GHz in the DAM antenna system, the antenna radiation becomes increasingly reduced as the antenna center frequency begins to drift away from 1.5GHz, starting at a bias voltage of ~0.38V.

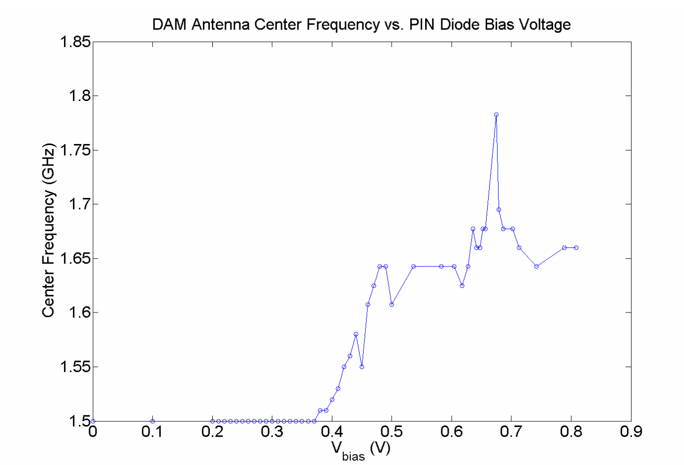

Figure 3. Center Frequency vs. bias voltage for DAM patch antenna

From these plots, two significant mechanisms behind the direct antenna modulation technique demonstrated in [1], [2], and [3] are seen. When a baseband pulse-width modulated signal, with peak-to-peak voltage from 0V to 0.8V, is applied to a DAM antenna structure with incorporated SMP1340 PIN diodes, the antenna radiation is significantly diminished during the active (0.8V) sections of the applied signal due to both a large increase in the antenna return loss as well as a significant shifting of the antenna's center frequency. By effectively switching the antenna radiation on and off (or at least significantly reduced), such a baseband signal may be directly-modulated onto the antenna's carrier wave. Since the diode bias signal must be larger than ~0.4V to significantly increase the antenna return loss and shift the antenna's center frequency, a baseband signal with a sharp rise and fall time is essential for a clean directly-modulated carrier wave. With additional analyses of these simulation results and with further HFSS simulations, a complete model of the direct antenna modulation technique may be constructed.

Conclusion

A directly-modulated L-band patch antenna has been successfully modeled and simulated in HFSS. From the limited results shown above, the direct modulation effect can be partially, but significantly be attributed to both an increase in the antenna return loss and a shifting of the antenna center frequency as a result of the biased high-speed SMP1340 PIN diode. The entirety of these simulation results will be presented at the IEEE AP-S International Symposium in June 2007. Additionally, future simulations will be conducted to compare whether additional diodes or alternative diode locations on the patch will significantly affect antenna performance. With the results of these future simulations and the data presented in this paper, the groundwork will be laid for the development of an accurate general model of direct antenna modulation and further improvements to this technique may be developed.

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