Figure 4 Measured antenna gain against frequency. (a) Antenna with a regular ground plane. (b) Antenna with a slotted ground plane. (c) Antenna with a PBG ground plane

(less than 0.5 dBi) are smaller than those of the antenna with a slotted ground plane.

It is also noted that the backward radiation of the antenna with a slotted ground plane is greatly increased. From the experiments, the backward radiation is increased by about 7 dB compared to the reference antenna. This behavior is partly owing to the embedded slots in the ground plane, and partly because the electrical size of the ground plane is decreased with a decrease of the antenna's resonant frequency. On the other hand, it seems that the PBG ground plane can provide a metallized surface, and an F/B ratio of about 9 dB larger than that of the antenna with a slotted ground plane (12.1 versus 3.2 dB) is obtained. The obtained F/B ratio for the antenna with a PBG ground plane is even larger than that of the antenna with a regular ground plane.

4. CONCLUSIONS

We have presented an experimental study of the characteristics of an air-substrate annular-ring patch antenna with a slotted and a PBG ground plane. From the experimental results, it is observed that the antenna with a slotted ground plane can have advantages of size reduction and bandwidth enhancement. However, a decreased F/B ratio is also obtained. Conversely, although no size reduction is obtained for the antenna with a PBG ground plane, bandwidth enhancement is also observed. In addition, small gain variations within the obtained impedance bandwidth and an improved F/B ratio are seen for the antenna with a PBG ground plane.

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FREQUENCY-SELECTIVE LOADING FOR A TRANSMITTING ACTIVE INTEGRATED ANTENNA

V. B. Ertürk, R. G. Rojas,² and P. Roblin³

¹ Department of Electrical and Electronics Engineering
Bilkent University

TR-06533 Bilkent, Ankara, Turkey

² Department of Electrical Engineering

ElectroScience Laboratory

The Ohio State University

Columbus, Ohio 43212-1191

³ Department of Electrical Engineering

The Ohio State University

Columbus, Ohio 43210

Received 18 April 2001

ABSTRACT: A simple frequency-selective load in the form of a compensating network is attached to an oscillator-type transmitting active integrated antenna (AIA) to suppress undesired low-frequency oscillations and to improve the robustness of the oscillator. Although the input impedance of the active device (transistor) remains unchanged at the upper frequencies, it changes drastically at the lower frequencies. © 2001 John Wiley & Sons, Inc. *Microwave Opt Technol Lett* 31: 3–5, 2001.

Key words: active integrated antennas; low-frequency oscillations

1. INTRODUCTION

Although active devices are represented with sophisticated models in many CAD packages, inaccurately defined device parameters, which can be temperature dependent, produce discrepancies between the simulated and measured results. In particular, in the design of oscillator-type transmitting active integrated antennas (AIAs), the desired operating frequency

is one of the unknowns in the nonlinear equation that determines the stable operation point(s). This may necessitate a compensating network (in the form of a feedback loop or a frequency-selective load network) to obtain the proper frequency of operation, and to ensure that proper operation conditions will continue to be satisfied due to aging, temperature variations, device replacement, etc. However, special case must be taken in the selection of this network since the increased complexity of the circuit may create additional problems such as undesired radiation from or high-power dissipation in the compensating network. Different types of compensating networks in the form of a resistive loading have been proposed to improve the stability of amplifiers below the operating frequency [1], and to suppress the undesired modes in the design of a spatial power-combining array with strongly coupled arrays [2].

In this letter, the effect of a simple frequency-selective load network on the oscillation frequency and design robustness of a transmitting AIA are studied experimentally using a prototype designed for operation at 2 GHz. Measured results of the spectrum of the radiated signal are presented here before and after the load network is implemented. Note that a full-wave/nonlinear analysis of this AIA prototype was presented in [3].

2. CIRCUIT DESCRIPTION AND PERFORMANCE

The prototype of the AIA, shown in Figure 1, consists of a microstrip-fed patch antenna, a silicon bipolar junction transistor (HP-Avantek AT42035), an n - p - n active biasing circuit (only the bias lines are shown in the figure), three microstrip lines attached to the legs of the transistor, and a first-order low-pass Butterworth filter which is composed of a chip resistor ($R = 100 \Omega$) in series with a thin microstrip line ($w = 30$ mils and $l = 0.76$ cm). The dielectric material is Duroid ($\epsilon_r = 2.33$), having a thickness of 62 mils ($= 1.57$ mm). The transistor model used in the design is the integral charge-control model of Gummel and Poon [4], which includes several effects at high bias levels and is present in LIBRA's library (CAD package) and other nonlinear circuit solvers. The transistor is biased with an n - p - n active biasing circuit such that the collector-emitter voltage $V_{CE} \approx 8$ V and the base current $I_B \approx 0.095$ mA.

Figure 1 Top view of the AIA with the low-pass filter included

The design is performed using the one-port negative resistance technique [5], where the well-known oscillation conditions for start up are [6]

$$\text{Re}[Z_{in}(\omega)] + \text{Re}[Z_L(\omega)] < 0 \quad (1)$$

$$\text{Im}[Z_{in}(\omega)] + \text{Im}[Z_L(\omega)] = 0 \quad (2)$$

where $Z_L(\omega)$, being the antenna impedance locus, represents the input impedance of the patch and $Z_{in}(\omega)$, being the device line, represents the impedance of the active unit seen from the collector of the transistor, as shown in Figure 1. It should be kept in mind that the device line depends on the biasing condition of the transistor. The calculated input impedance $Z_{in}(\omega)$ (device line) is shown in Figure 2 before the low-pass filter (the frequency-selective load) is attached to the emitter. As seen in the figure, the active unit shows similar characteristics ($\text{Re}(Z_{in}) < 0$) both around 600 MHz (undesired frequency) and around 2 GHz (desired frequency), and is potentially unstable at these frequencies. Furthermore, the oscillation conditions for start up given by (1) and (2) are satisfied in both regions. It turns out that the first fabricated prototype of the AIA (without the low-pass filter) oscillated around 506 MHz, as seen in Figure 3, where the measured radiated frequency spectrum (from 100 MHz to 2.924 GHz) of this prototype is presented. The reason for this low-frequency oscillation is due to the gain (S_{21}) of the transistor, which is higher at lower frequencies, namely, measured $|S_{21}| \approx 2.9$ at 2 GHz and 4.3 at 500 MHz. In Figure 3, the measured radiated signal around 2.025 GHz, which is the fourth harmonic, appears to be stronger because the patch is designed to radiate at 2 GHz, and acts as a filter.

Attaching this low-pass filter to the emitter (one of the emitter legs of the transistor) changes the shape of the device line $Z_{in}(\omega)$ at lower frequencies, while its shape at the desired frequency remains unchanged, except for a slight frequency shift that increases the operating frequency from 2 to 2.08 GHz, as depicted in Figure 4. The measured radiated frequency spectrum in the presence of the low-pass filter is shown in Figure 5, where a clean oscillation is visible at 2.019 GHz and, as expected, all low-frequency oscillations are suppressed. It is worthwhile to mention at this point that,

Figure 2 Calculated real and imaginary parts of the device impedance without the low-pass filter

Figure 3 Measured frequency spectrum (100 MHz–2.924 GHz) of field radiated by AIA without the low-pass filter. Resolution bandwidth = 3 MHz, vertical divisions = 10 dB

Figure 5 Measured frequency spectrum (1.994–2.044 GHz) of field radiated by AIA after the low-pass filter is added. Resolution bandwidth = 300 kHz, vertical divisions = 10 dB

since the signal at the desired frequency is not affected by the value of R , power loss at the desired frequency is not a concern. Note that harmonics of the fundamental frequency (2.019 GHz) are now present in the oscillator. These harmonics can modify the input impedance $Z_{in}(\omega)$, and slightly shift the frequency of operation as discussed in [3]. Furthermore, experimental studies revealed that the addition of this low-pass filter improves the robustness of the oscillator. For example, it is observed that the frequency of oscillation is less sensitive to small variations of the length of the microstrip lines attached to the emitter when the low-pass filter is added. This implies that some of the inaccurately defined device parameters during the design step or small manufacturing errors during the fabrication process become less of a concern.

Figure 4 Calculated real and imaginary parts of the device impedance after the low-pass filter is added

3. CONCLUSION

A very simple low-pass filter in the form of a compensating network is implemented in an oscillator-type transmitting AIA. Its effect on the device line $Z_{in}(\omega)$, and hence the oscillation frequency, as well as on the robustness of the design are experimentally studied. This filter does not affect the AIA performance at the upper frequencies, yielding a stable operating point at the desired frequency by eliminating undesired low-frequency oscillations. Note that it also helps maintain the oscillation conditions in the presence of small manufacturing errors.

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