Study of Conformal Integration Positions for Multiband and Frequency Reconfigurable Antennas

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Abstract

The development of multiband and frequency reconfigurable antennas makes integrated antenna placement a frequency-dependent design factor. In this work, a multiband electromagnetic visibility study on a small laptop chassis is presented. The electromagnetic visibility of several locations was modeled at three frequencies (2.4, 3.5, and 5.2 GHz) to determine a maximally visible location for all frequencies from all incident angles with vertical polarization in the azimuthal plane. The performance of several candidate positions is presented and discussed, illustrating the design tradeoffs in packaging that are necessary with new levels of antenna capability.

1. Introduction

Laptop computers are becoming more and more important as wireless communication devices. Multiple communication standards for these connections now operate at a number of different frequencies. In the past, a separate antenna was required for each band of operation. Reconfigurable antennas (e.g., [1]-[3]) and multiband antennas (e.g., [4, 5]) support multiple frequencies from a single set of internal connections, greatly reducing manufacturing and packaging costs. These types of antennas open the possibility of having all communication protocols on the laptop transmitting and receiving with the same antenna. However, the introduction of a reconfigurable or multiband antenna increases the complexity of integration, as both the performance of the antenna and its placement on the laptop chassis have to be evaluated at each frequency of operation.

In the past, electromagnetic visibility studies have been performed to evaluate possible integration positions for antennas on conducting chassis at single frequencies [6, 7]. However, when additional operating frequencies are considered, well-performing antenna locations become frequency dependent. In the present work, we consider as an example the integration of a frequency reconfigurable or multiband antenna with three different operating bands (WiFi and WiMax) using electromagnetic visibility studies, described in the next section.

2. Electromagnetic Visibility Studies

An electromagnetic visibility study provides information about the relative performance of potential antenna integration positions in a known chassis [6, 7]. The study begins with the simulation of incoming plane waves incident on the conducting parts of the candidate chassis, with no antennas present. The induced currents on the chassis are then considered in terms of both their time-averaged magnitude as well as the standard deviation of this magnitude over an area equivalent to that of a potential integrated antenna. Previous studies [e.g., 6, 7] indicate that areas with larger average magnitudes and smaller standard deviations over desired incoming angles provide favorable integration locations, resulting in greater spatial coverage and/or more ideal (pre-integration) antenna characteristics.

This study introduces the case of multiple design frequencies present with either multiband or frequency reconfigurable antennas. In addition to calculating average and standard deviation with respect to incident angle, these quantities are also calculated with respect to frequency.

3. Laptop Model

The laptop chassis modeled was a prototype mini-laptop design, measuring 21 x 15 x 1.5 cm when closed. The laptop shielding was modeled as copper with a glass screen measuring 15 x 9 x 0.25 cm. The angle between the screen and the base of the laptop was 90^o. Initially, the laptop was simulated in XFDTD© [8] with vertically polarized incident waves at 2.4 GHz to gauge the general current density pattern on the laptop chassis. In general, integrated laptop antennas are placed on the laptop lid, as it is the most visible area of the laptop. The average current density was calculated at several test points spread over the back and edge of the laptop screen, as shown in Fig. 1.

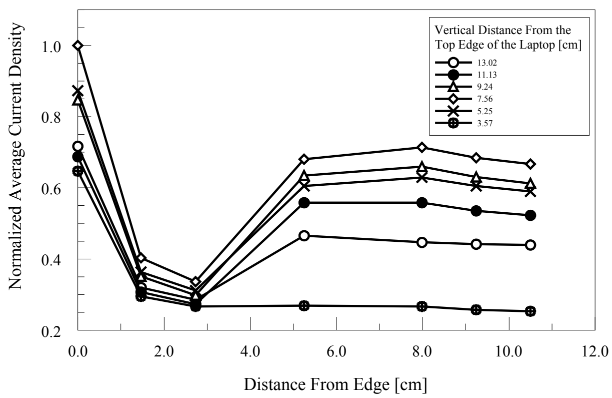

Fig. 1. Normalized average current density as a function of position on the chassis at 2.4 GHz at discrete points. (Data at 0 cm from the edge is taken on the thin edge perpendicular to the plane of the laptop screen. Data at 10.5 cm from the edge is taken at the lateral center of the laptop screen.).

4. Test Setup

The points where the induced current had the highest magnitude in the initial test were more closely examined in XFDTD© [8]. A square area measuring 1.47 x 1.47 cm was examined at several of the high visibility points from the initial test. Simulations were conducted with vertically-polarized incident plane waves spaced 30 degrees apart in the azimuthal plane for each of the frequencies of interest.

The average current density (J_M) for each area was calculated with respect to incident angle by averaging all currents over the simulated FDTD cells in that area, as well as the standard deviation (σ_M) with respect to incident angle. In addition, the average (J_{FM}) and standard deviation (σ_F) of the average current density on each area were calculated with respect to frequency as calculated in Equations 1-4,

$$\overline{J}_M(f) = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\left|J_{mn}(f)\right| \tag{1}$$

$$\sigma_M(f) = \sqrt{\frac{1}{M}\sum_{m=1}^{M}\left|J_m(f) - \overline{J}_M(f)\right|} \tag{2}$$

$$\overline{J}_{FM} = \frac{1}{F}\sum_{f=1}^{F}\left|\overline{J}_M(f)\right| \tag{3}$$

$$\sigma_F = \sqrt{\frac{1}{F}\sum_{f=1}^{F}\left|\overline{J}_M(f) - \overline{J}_{FM}\right|} \tag{4}$$

where N is the total number of cells in an candidate integration area, M is the total number of incident angles, F is the total number of frequencies, and $J_{mn}(f)$ is the current density at a given cell, incident angle, and frequency.

The standard deviation needs to be analyzed independently with respect to incident angle and with respect to frequency because the interest of this study is to investigate integration positions that perform well for a variety of incident angles and over the three frequencies. The standard deviation provides a figure of merit of the spread of the current density with respect to the incident angles and frequencies. Hence, an integration location with a high average current density, but also a high standard deviation with respect to one of these variables may not be a good candidate because a high standard deviation indicates that for several of the incident angles or frequencies, the current distribution was significantly lower than the average.

Fig. 2 is a visualization of the laptop model used and the patch locations. In addition to an integration position on the edge of the screen, three high current density areas on the back of the laptop were chosen from the initial test set and analyzed in detail, located in the horizontal center of the back of the laptop screen, at displacements of 3.78 cm, 7.35 cm, and 9.03 cm from the top edge of the laptop, as shown in Fig. 2.

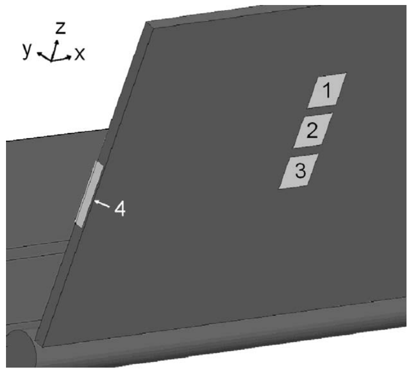

Fig. 2. Candidate integration positions on laptop screen. Shading indicates electromagnetic visibility results for preliminary 2.4 GHz simulations, with light being high and dark being low visibility.

5. Results and Analysis

The electromagnetic visibility studies conducted at multiple frequencies provided induced currents in each of the integration areas of interest. The results of all of the studies, assuming complete azimuthal coverage with vertical polarization is desired for all antennas, are presented in Table 1. Note that Δz_t is the vertical offset in cm from the top edge of the laptop screen.

Table 1. Summary of normalized current density and standard deviation results over incident angles for laterally central areas on the back of the laptop screen and the vertical laptop screen edge .

		Top (1)	**Middle (2)**	**Bottom (3)**	**Edge (4)**
	Δz_t (cm)	3.78	7.35	9.03	7.35
2.4 GHz	**J_M**	0.368	0.428	0.459	1.000
	σ_M	0.181	0.164	0.165	0.127
3.5 GHz	**J_M**	0.522	0.361	0.299	0.461
	σ_M	0.317	0.106	0.056	0.150
5.2 GHz	**J_M**	0.475	0.516	0.598	0.514
	σ_M	0.238	0.313	0.412	0.251
accumulation	**J_{FM}**	0.455	0.435	0.452	0.658
	σ_F	0.079	0.078	0.149	0.297

The best aggregate visibility over the three operating frequencies is realized by the area on the vertical edge of the laptop. The areas in the lateral center of the laptop also perform very well, especially if visibility at frequencies other than 2.4 GHz is prioritized. At 3.5 GHz, the top, center area (position 1) in the back of the screen has the highest current density, and at 5.2 GHz, the bottom, center area (positon 3) has the highest current density. The average current density at either of these positions is only marginally higher than the vertical screen edge (position 4). In both of these cases, σ_M is much higher than that of the vertical screen edge.

Past studies [6, 7] have shown that at 2.4 GHz the location of highest visibility for an antenna on a laptop chassis is on the vertical screen edge. At frequencies besides 2.4 GHz, other places on the back of the laptop screen have somewhat higher average current density than the vertical screen edge, as shown in Fig. 3. However, the edge does perform well for all frequencies, and consistently has the lowest standard deviation, σ_M, with respect to incident angle.

The standard deviation with respect to angle, σ_M, tends to go up as average current density increases for areas on the back of the screen. As a result, when areas on the back of the screen have higher current densities than the edge area, their standard deviations tend to be significantly higher than the edge area.

6. Conclusions

This paper presented a multi-frequency electromagnetic visibility study on a small prototype laptop chassis at three frequencies. There was found to be no "optimal" antenna location for all frequencies. This work shows that when multiple frequencies are considered in laptop antenna integration, each has to be studied individually to find the best overall position. This result is paramount in the packaging of reconfigurable antennas, as it shows that for each integration design, consideration needs to be taken into antenna performance in each operating mode individually.

Acknowledgment

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