4. CONCLUSIONS

A novel broadband low-profile cylindrical monopole antenna loaded with a shorted circular patch has been proposed and successfully implemented. The impedance bandwidth of the proposed antenna can be greatly enhanced when the diameter of the cylindrical monopole is increased. An impedance bandwidth of about 14.8% has been obtained for the proposed antenna, which can meet the bandwidth requirements of the existing mobile wireless communication systems operating around 2 GHz.

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PATCH ANTENNA SIZE REDUCTION BY MEANS OF INDUCTIVE SLOTS

S. Reed,[1] L. Desclos,[1] C. Terret,[2] and S. Toutain[1]
[1] IRCCYN Division SETRA
Laboratoire SEI
IRESTE
Ecole Polytechnique de Nantes
BP 60601, 44306 Nantes Cedex, France
[2] LAT
Universite de Rennes I
Rennes, France

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ABSTRACT: *The present letter concerns the reduction of the global size of a patch antenna by the insertion of printed inductive elements. A transmission-line model is established to relate to the TM100 mode and support the different elaborations of the reduced patch. The global reduction can reach 50% of the initial size. Along with the theory, a set of experiments have been made to validate the approach.* © 2001 John Wiley & Sons, Inc. Microwave Opt Technol Lett 29: 79–81, 2001.

Key words: *patch antenna; reduction of size; compact patch antenna*

I. INTRODUCTION

Future wireless communication systems will require the integration of different services in a reduced space. As the size reduces, less space is available to place the antenna; therefore, there is a need to find a technique to reduce low-profile antennas such as patch antennas with a minimum machining cost.

Several authors have already presented some methods [1–11]; however, most of them used a three-dimensional technique to reduce the size. By making some cavities in the substrate or adding some short points and vias, they could reduce more or less by 50% the size of the patch. The authors have already tried another technique [12] to reduce the size of the patch by inserting some slots inside the patch. While keeping a single machining step, it shows a size reduction of 35%. What we propose here is to still keep the approach of single-surface machining for the patch as it will lower the cost of machining, but to load the side of the patch inductively.

The theoretical approach as well as practical measurements show a possible reduction of one-half.

II. THEORY

We will focus on the TM_{100} mode. This is well known, and as shown in Figure 1, the electrical field has constant amplitude along W, and in the L-direction varies with $\cos^2$ with inversion of the direction in the middle. We can then see that the fields at extremities 1 and 3 have the same amplitude and are in phase opposition. Then, the sum of the radiated fields at 2 and 4 is null. However, the sum of fields radiated by 1 and 3 is not null. To have this maximum radiation, the phase must be π between 1 and 3. This condition is respected when the length is $\lambda_g/2$ (λ_g is the guided wavelength).

With this approximation, only parts 1 and 3 contribute to the radiating phenomenon. That is why such an antenna can be modeled by a set of two radiating slots of width W and separated by a π phase shifter. The phase shift is defined by $\varphi = \beta L + 2k\pi$, where β is the phase constant in the substrate.

Hence, if the length of the antenna is reduced, the phase should remain constant, and the loss of the phase shift has to be compensated by additional printed elements.

Moreover, in [13], Hoefer has shown that inserting a slit in a transmission line [Fig. 2(a)] generates an inductive loading effect [Fig. 2(b)].

The related formula defining the equivalent inductance is given by

$$\Delta l = \frac{\mu_0 \cdot \pi \cdot h}{2} \times \left(1 - \frac{Z_0}{Z_0'}\sqrt{\frac{\varepsilon_{r\,\mathrm{eff}}}{\varepsilon'_{\mathrm{eff}}}}\right)^2, \qquad \text{in H}$$

in which Z_0 is the characteristic impedance of the line of width w, Z_0' is the characteristic impedance of the line of width w–a, and h is the substrate thickness.

From the basic theory and the proposition in [13], we propose a structure in Figure 3, in which we see a patch loaded by several inductive slits on each side. An equivalent transmission model is drawn in Figure 4.

In this figure, we see the equivalent slots that are represented by an admittance G standing for the loss by radiation and a capacitance B standing for the line-edge effects. The value of G and B can be found easily in [14]. It is then possible to access the input impedance through a classical line theory using the calculation of each small portion of the loaded lines (representing each portion of the slit) brought back to the input:

$$Y_{\mathrm{in}} = G + jB + Y_c \times \frac{G + j(B + Y_c \tan \beta l)}{Y_c - B \tan \beta l + jG \tan \beta l}.$$

It has to be noticed that the input can easily be set wherever the reference for the calculation plane is. This will allow us to take into account the decay of the feeding point.

III. REALIZATIONS AND COMMENTS

From this theory, several calculations and measurements have been made, and we attempt here to draw a few conclusions and present ideas for designers.

A first approach consists of making an antenna at 1 GHz, and then progressively adding some inductive loading to it and looking at the resonance frequency decay. It permutes us, at the same time, to see the effect of each additional slit,

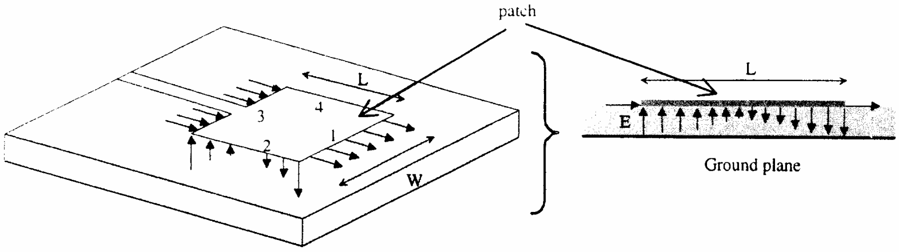

Figure 1 Representation of a patch antenna and associated fields

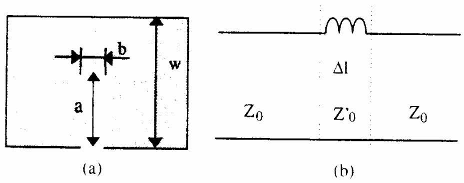

Figure 2 Transmission line loaded by an inductance and its representation

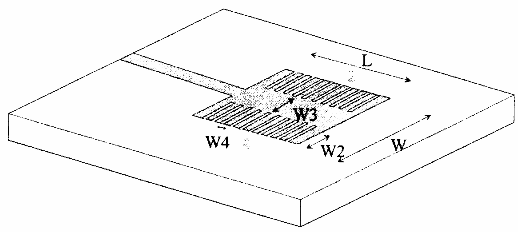

Figure 3 New topology of antenna proposed for size reduction

as well as the possible effect of saturation of the reduction phenomenon. The measured frequency and its theoretical associated size will give the amount of reduction obtained.

The substrate used is an epoxy substrate with a dielectric constant of 4.4 and 62 mils of thickness. The original antenna realized had a size of 7.5 cm (corresponding to the half-wavelength size) × 3.5 cm.

We then progressively realized a set of slits on the side of the patch, and we see in Figure 5 the impact on the resonant frequency, either in theory or practice. We can set, at most, 25 slits of 0.5 mm on each side. The length and period of the slits were 12.5 and 1 mm, respectively. It is seen that, after a certain number of them, the shift in frequency is not achieved anymore.

The maximum shift is then achieved when a frequency of 660 MHz is attained, as shown in the compared measurements and theory in Figure 5. This corresponds to a reduction of 35%.

This validated the concept. However, it is obvious that the reduction is not enough as the inductive value of each slit is not sufficient. To increase this, we have to make the slits penetrate more into the patch itself. Then the reduction could reach 50%, which is the case if we consider a patch 4.5 cm large instead of 3.5 cm.

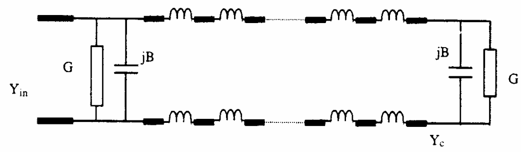

Figure 4 Equivalent circuit of the reduced antenna

Another remark has to be made: the spacing and value of the slits is of critical importance. It is obvious that, if the width and the period of the slit are too small, then there will be a coupling effect arising between the teeth, and the validity of the formulas will no longer be true. We experienced this in the previous example with an offset frequency between experiment and theory.

A good rule of thumb for the sizing is to consider a period 2–2.5 times the width of the slit. We also verified the approach by a moment method that is commercially available [15]. This allows us, after the first calculation, to accurately verify the results, taking into account the coupling effects.

We implemented several examples in the ISM band at 2.4 GHz, and at a lower frequency of 800 MHz. We see in Figures 6 and 7 the matching and gain of an antenna that correspond to a reduced size of 50%, along with the main dimensions. The substrate, in this case, is a Duroid of 21 mm thickness and dielectric constant 3.48.

Matching is better than 12 dB at the center frequency as the gain did not show any degradation compared to the nonreduced antenna.

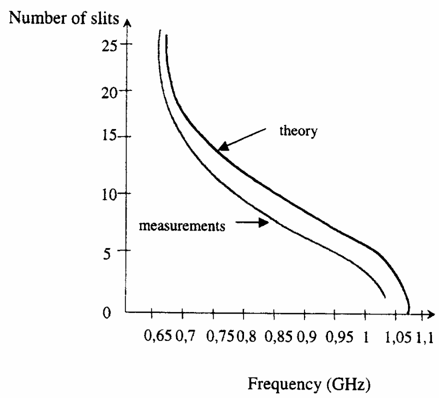

Figure 5 Frequency shift versus number of slits

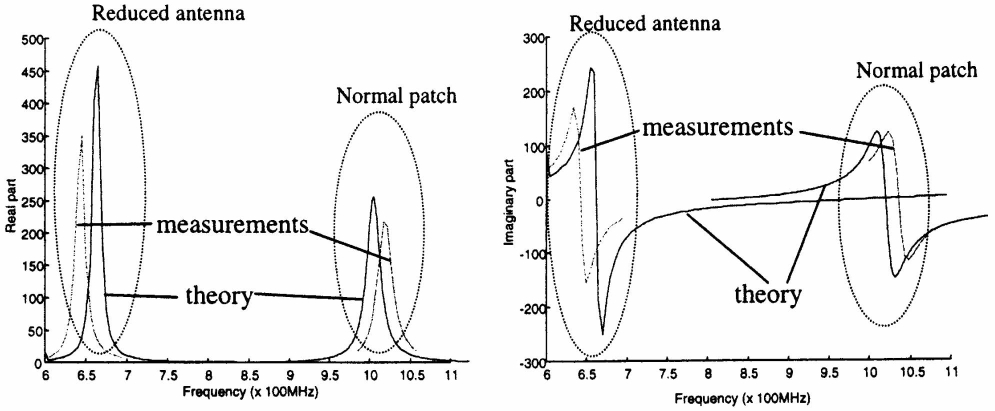

Figure 6 Comparison of measurements and theory for the reference antenna and a reduced one

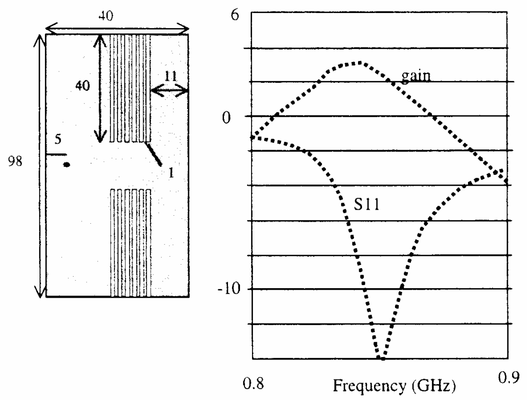

Figure 7 Topology of a reduced 800 MHz antenna

This, in turn, proved that the developed approach is accurate enough to lead to good results without strong limitations.

IV. CONCLUSION

We have demonstrated the possibility of achieving a size reduction of a patch antenna of about 50%, not involving more than one layer or one-step processing in the machining operation. This technique involved a loading effect of the patch by etched inductances. The calculations and measurements are in good agreement, and examples have been shown using different substrate types. Useful ideas on the choice of the sizing have also been given.

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THE SiN_x PASSIVATION THICKNESS EFFECT ON AlGaAs/InGaAs/GaAs pHEMT PERFORMANCE

Li Hongqin,[1] Sun Xiaowei,[1] and Xia Guanqun[1]
[1] Shanghai Institute of Metallurgy
Chinese Academy of Sciences
Shanghai 200050, P.R. China

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ABSTRACT: *The silicon nitride passivation thickness has been investigated extensively for AlGaAs/InGaAs/GaAs pHEMT characteristics in this paper. The experimental results show that the cutoff frequency will drop as the passivation thickness increases for a pHEMT. The electronic*