A Novel L-Probe Proximity Fed Patch Antenna With Parasitic Patch and Its Utilization in Antenna Arrays

Libor Sláma¹², Josef Dobeš¹, Tomáš Boštík², and František Vejražka¹

¹Department of Radioelectronics, Faculty of Electrical Engineering, Czech Technical University in Prague
²Tesla, Inc., Prague, Czech Republic
E-mail: poliux@seznam.cz, dobes@fel.cvut.cz, bostik.tomas@tesla.cz, vejrazenka@fel.cvut.cz

Abstract. An analysis of the L-probe fed patch antenna with an extraordinary parasitic patch is described. The element of the antenna is fed by the L-probe partially implemented in PCB. An excellent impedance matching is obtained (< −26 dB in the design frequency band 4.4–5 GHz). The radiation characteristics are also very good (gain > 10 dBi). For the numerical analyses, the Full Wave—CST Microwave Studio software was used in both frequency and time domains, and a very good agreement between the Time Domain Solver (TDS) and Frequency Domain Solver (FDS) was obtained. Real antenna samples have been created and measured as well as eight-element antenna arrays designed by the Dolph-Chebyshev method.

1. Introduction
The microstrip patch antenna [1, 2, 3, 4, 5, 6] is a very popular choice for many wireless communication devices because of its low profile, light weight, and low cost, and it is mostly used in the Wi-Fi technology. The realization of the patch antenna could be very simple, but this simplicity leads to a narrow band (5% for |S₁₁| = −10 dB). This is certainly acceptable for the Wi-Fi technology, but unacceptable for the direct wireless connections. Many techniques with the increase of the frequency band have been published, but only a few of them are useful for the direct wireless connections. The problem with most of them is that the gain of the antenna is decreasing or the direction of the main lobe is deflecting with frequency too much. This paper describes a novel structure which has acceptable properties in these two characteristics.

2. Broadband Patch
There are two fundamental possibilities of how to design the broadband patch antenna. The (natural) first of them is to decrease the Q-factor. The second one is to use a parasitic motive, or an appropriate combination of decreasing the Q-factor and using the parasitic motive. Both are discussed in 2.1 and 2.2.

2.1. Decreasing the Q-Factor
The relation between the Q-factor and impedance bandwidth (BW) is expressed by BW ≈ 1/Q, where the Q-factor can be evaluated as Energy Stored/Energy Dissipated. Combining these formulae, a simple way can be found to get the broadband antenna, which consists in an increase of the losses. Unfortunately, this technique decreases the gain of the broadband patch antenna. Hence, another method is to be found.

A more effective technique of the broadband-patch antenna design is decreasing the stored energy in the patch. If we imagine the patch element like a capacitor, its capacity is dependent on the distance of the conductive planes, and with the distance increasing, the energy decreases. (Fat substrate.) Unfortunately, when the patch is fed by the microstrip transmission line, increasing the described distance can contribute
Figure 1. System with a parasitic patch and L-probe (a.) and cut through the structure with air gaps (b.).

Figure 2. Current densities around the slot (a.) and current density on the L-probe (b.).

to excite the surface wave, and it is the reason why this parameter is a limiting factor. The first mode of the surface wave is the TE1 one with the cutoff frequency $f_{m}^{\text{TE1}} = c/(4h\sqrt{\varepsilon_r - 1})$. Using the fat-substrate method, a construction of the microstrip feeding lines is impossible for a realization of low impedances.

2.2. Parasitic Motives
Inserting the parasitic motives to the patch antenna motive (slot) or inserting another patch near the first one (parasitic patch) can be exciting another resonance. In Fig. 2a, there is a two-dimensional graph of the current density on the patch around the slot. This current excites another antenna mode. However, this resonant need not radiates in a required direction. Therefore, finally, it can lead to a worse directivity.

3. Analysis of the Antenna Element and Array
First experiments have shown that using the microstrip transmission lines on the fat stack substrate leads to exciting the surface wave with the energy decreasing the radiation power.

In our novel proposal, the probe was located under the patch motive. Fortunately, this type of feeding the lines does not excite the surface wave as much as the microstrip line. Using this feeding line, a full separation of the radiating part and the feeding-line structures of the antenna has been achieved.

Finally, the L-probe [6, 2] feeding line has been used. For an easy manufacturability, the probe was particularly implemented in the bottom motive of the patch’s PCB. The whole structure was completed by another PCB with the parasitic patch. The radome board was located in parallel to the PCB, and was

Figure 3. Detail of the L-probe implemented in substrate; $W_{in} = 4.42$ mm, $L_{in} = 11.92$ mm, $R_{in} = 6.7$ mm.
simulated with a precise model. A picture defining the structure is shown in Fig. 1. The feeding line’s impedance is 100 Ω. The thicknesses of the substrates are: FR4 – 1 mm, Taconic TLY-5 – 0.79 mm. The L-probe parameters in Fig. 3 were optimized to the best impedance matching. A metal ring motive connected to the pin was used to decrease the inductance of the probe. For $W_{in} = 4.42$ mm, $L_{in} = 11.92$ mm, $R_{in} = 6.7$ mm, $|S_{11}| < -23$ dB has been achieved. A comparative simulation in FDS for this configuration has also been performed and a very good agreement of both simulations is shown in Fig. 4.

For the measurement of the sample, the structure was completed by the impedance transformer which transforms the antenna impedance to the standard one (50 Ω). Unfortunately, a bit narrower impedance band has been achieved – the results of these simulations are also presented here. However, the gain of the patch in the requested frequency band is still better than 10 dBi as clearly shown in Fig. 6.

For the true capabilities of the antenna, the simulations were also performed without the transformer. Mechanical parameters of both patches were optimized. The impedance dependencies in Smith chart can be seen in Fig. 5, where some dependencies of the impedance matching on $h$ have also been explored.

The radiation patterns were also calculated for $\phi = 0^\circ$ and $\phi = 90^\circ$. In Fig. 7, some shift of the main lobe direction is seen for $90^\circ$. It is due to the current density on the feeding L-probe, which radiates as shown in Fig. 2b. However, the deviation is only 6.5°, which is acceptable. (There is no shift for $\phi = 0^\circ$.)

Finally, an antenna array was created by the Dolph-Chebyshev method [3]. Eight-element arrays were made for the sidelobe levels $-30$, $-25$, and $-20$ dB with the parameters and radiation patterns in Fig. 8.

4. Conclusions
The proposed patch antenna exhibits a good performance in all the important parameters. The impedance matching is excellent and the radiating characteristics are also good. The eight-element antenna arrays yield gains around 20 dBi, 10 dBi more than the element. The antenna/arrays have been made by Tesla.

Figure 4. A TDS, FDS comparison for the structure with the transformer – Smith chart and magnitude.

Figure 5. $S_{11}$ for an $h$ sweep – Smith chart (the circle corresponds to the one in Fig. 4) and its magnitude.
Figure 6. Gain of the patch antenna – frequency dependence and dependence on the height air gap ($h$).

Figure 7. Radiation patterns for the cuts $\phi = 0^\circ$ (left) and $90^\circ$ (right) at $f = 4.4$, 4.7, and 5 GHz.

| Element n. | Cheby -30dB | Cheby -25dB | Cheby -20dB |
|------------|-------------|-------------|-------------|
| 1          | 1.000       | 1.000       | 1.000       |
| 2          | 0.810       | 0.843       | 0.873       |
| 3          | 0.517       | 0.584       | 0.657       |
| 4          | 0.261       | 0.378       | 0.577       |

Figure 8. Antenna array – feeding weights, gains of arrays, and radiation patterns for used sidelobe levels.

Acknowledgment This paper was supported by the Technology Agency of the Czech Republic under the grant No. TE01020186.

References
[1] Balanis C A 2016 Antenna Theory: Analysis and Design 4th ed (New York: John Wiley & Sons, Inc.)
[2] Guo Y X, Mak C L, Luk K M and Lee K F 2001 IEEE Transactions on Antennas and Propagation AP-49 145–149
[3] Dolph L C 1946 Proceedings of the IRE 34 335–348
[4] Zürcher J F and Gardiol F E 1995 Broadband Patch Antennas (Boston: Artech House, Inc.)
[5] Garg R, Bhartia P, Bahl I and Ittipiboon A 2001 Microstrip Antenna Design Handbook (Boston: Artech House, Inc.)
[6] Mak C L, Luk K M, Lee K F and Chow Y L 2000 IEEE Transactions on Antennas and Propagation AP-48 777–783