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DESIGN, REALIZATION, AND TEST OF A 900 MHZ CERAMIC OSCILLATOR

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ABSTRACT: *The design of a 900 MHz ceramic oscillator, delivering a power of 10 dBm, has been carried out by using the negative-resistance condition. A new procedure based on the Nyquist criterion, implemented within microwave CADs has been used to test the onset of oscillations at the desired frequency and the presence of spurious oscillation. An excellent agreement between nonlinear simulations and measurements performed on a prototype has been observed.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 1713–1717, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22528

Key words: *oscillators; ceramic resonators; Nyquist criterion, hybrid RF circuits*

1. INTRODUCTION

High-performance and low-cost oscillators are largely required due to the growth in the application of microwave and millimetre-wave systems. Each system requires oscillators with specific characteristics: e.g., when the oscillator operates as local reference for a receiver chain, a low phase noise is usually required; when the oscillator operates within a test circuit, the specifications on the output power and harmonics rejection are more stringent. Different configurations and design procedures have been developed in the last years to design oscillators at microwave frequencies [1–4]. A typical configuration consists of an active device in positive feedback coupled to resonators of different kinds (e.g., dielectric, coaxial, planar, etc.) to compose a hybrid low-cost oscillator. The hybrid configuration is still a challenging solution, if the production cost is a stringent demand and device size is not a constraint. For small-size applications, instead, an integrated solution is unavoidable. The design methodology of such hybrid devices is also a critical issue; as the oscillator operates in nonlinear regime, a nonlinear analysis is required to accurately simulate the oscillator performance. However, a straightforward design technique, based only on linear analysis and feasible to be implemented in linear simulators of commercially available CAD tools, would be helpful.

In this article, a design technique based on the linear analysis in frequency domain is presented and applied to the synthesis of a low-cost hybrid oscillator composed of a FET device and a coaxial resonator. The design criteria are presented in Section 2, and in Section 3 they are applied to the design of a 10 dBm oscillator at 0.9 GHz on RO4003 substrate. Finally, experimental test and comparison to simulated results are presented in Section 4.

2. METHODS

Microwave oscillators are generally realized by interfacing an active element with a resonator as shown in the block model of Figure 1.

The active element is generally realized by using a transistor with a series-series feedback applied to its source, thus obtaining a negative resistance behavior at the other two terminals. The

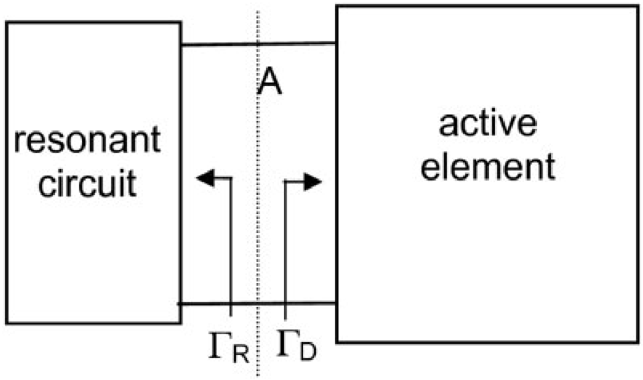


Figure 1 Block model of a microwave oscillator

resonant circuit is usually realized with dielectric or coaxial resonators or with YIG spheres, all of which can be modeled, around their first resonance frequency, as parallel RLC circuits. Indicating by Y_D the admittance of the active element (with negative real part) and with Y_R the admittance of the resonator, the condition to obtain permanent oscillation is, as is known:

$$Y_D + Y_R = 0 \tag{1}$$

Separating between real and imaginary parts it derives:

$$G_D + G_R = 0 \tag{2}$$

$$B_D + B_R = 0 \tag{3}$$

In terms of reflection coefficients this condition becomes:

$$\Gamma_D \Gamma_R = 1 \tag{4}$$

that can be written in terms of magnitudes and phases as:

$$|\Gamma_D \Gamma_R| = 1 \tag{5}$$

$$\angle\Gamma_D + \angle\Gamma_R = 2n\pi \tag{6}$$

For the oscillations to begin, Eq. (3) must be verified together with the condition:

$$G_T = G_D + G_R < 0 \tag{7}$$

If Eqs. (3) and (7) are satisfied, oscillations grow with time until nonlinearities stop their growth. It is worth to be noted that from the condition $G_T < 0$ it derives $\Gamma_D \Gamma_R > 1$ (if $Y_0 > G_D > G_R$) or $\Gamma_D \Gamma_R < 1$ (if $G_D > G_R > Y_0$). This means that the start-up condition, reported in terms of reflection coefficients, can create ambiguity. Moreover, it is often very important to verify the frequency behavior of the system in order to check for other possible resonant frequencies.

A rigorous method for the study of the stability of a microwave circuit is based on the Nyquist criterion. This criterion has been used for the analysis of microwave amplifier stability [5, 6] but it can also be used for the instability analysis of oscillators [7, 8].

The Nyquist criterion is a graphical method that allows for studying the stability of a closed loop system from the analysis of open loop transfer function. In particular, if P_{cl} is the number (greater or equal to zero)of right half-plane poles (RHP) of the closed loop transfer function, P_{op} is the number (greater or equal

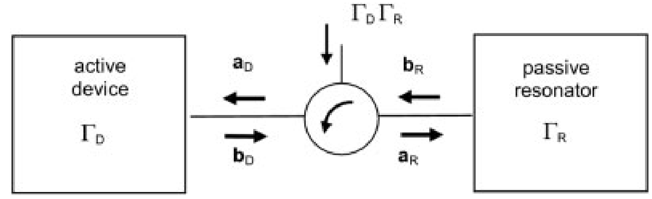


Figure 2 CAD schematic for the evaluation of $\Gamma_D(f)\cdot\Gamma_R(f)$

to zero) of right half-plane poles of the open loop transfer function, and N_t is the number of clockwise encirclements around the critical point (1, j0) of the open loop transfer function (negative if counterclockwise), the closed loop system is unstable (i.e. it oscillates) if and only if [9]:

$$P_{cl} = P_{op} + N_t > 0 \tag{8}$$

As described in [6] this criterion can be applied to microwave circuits by considering as open loop transfer function the product $\Gamma_D(f)\cdot\Gamma_R(f)$. This product is easily evaluated in microwave CADs by using an ideal circulator inserted as in Figure 2.

To verify the applicability of the Nyquist criterion to the design of microwave oscillators we have considered the two circuits reported in Figure 3. In the first one [Figure 3(a)] we have $G_D = -12.5$ mS and $G_R = 10$ mS ($Y_0 = 20$ mS $> G_D > G_R$). In the second one [Figure 3(b)], instead, we have $G_D = -50$ mS and $G_R = 25$ mS ($G_D > G_R > Y_0$). On the basis of the oscillation starting condition ($G_T < 0$), both circuits can oscillate. However, as discussed before, in the first case we have $\Gamma_D \Gamma_R > 1$, while in the second $\Gamma_D \Gamma_R$ lt] 1. In these conditions the open chain transfer function ($\Gamma_D\cdot\Gamma_R$) does not present poles in the right half plane. The corresponding Nyquist plots are reported in Figure 4.

In both cases, the Nyquist plots turn around the critical point (1 + j0) and hence the circuit instability is correctly predicted. On the Nyquist plot it is also possible to evaluate the oscillation frequency of the circuits [[$f = 1/(2\pi\sqrt{LC}) = 1.26$ GHzin this case]: in fact, it corresponds to the frequency where the plot crosses the positive real axis.

It is interesting to note that, if the circulator was placed as in Figure 5(a), the Nyquist plot would be the one reported in Figure

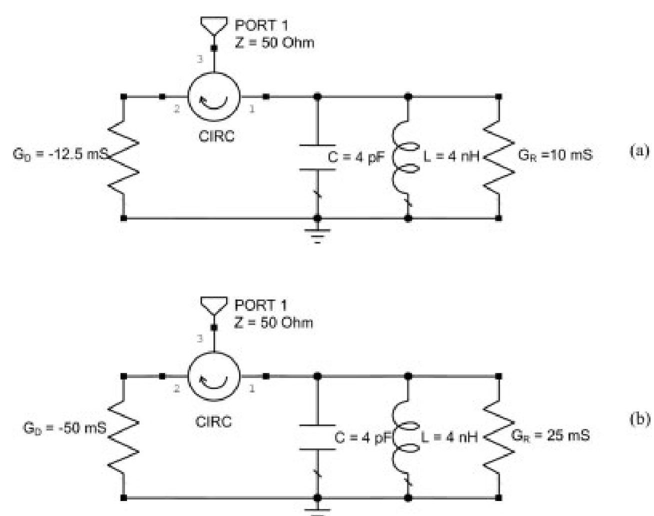
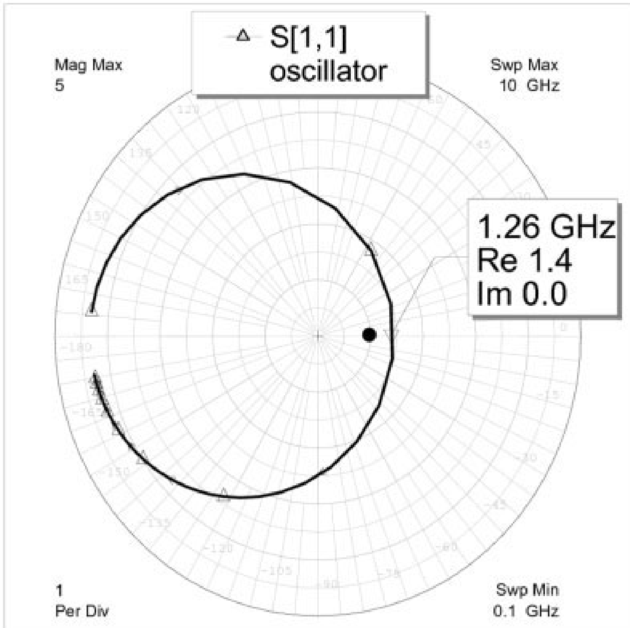
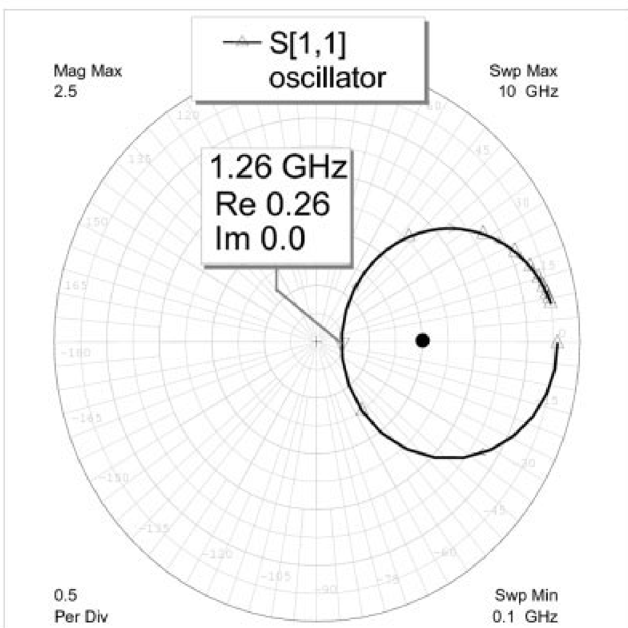


Figure 3 Oscillating circuits with $Y_0 > G_D > G_R$ (a); and $G_D > G_R > Y_0$ (b)



(a)



(b)

Figure 4 Nyquist plots of the two circuits reported in Figures 3(a) and 3(b), respectively

5(b). In this case the plot does not turn around the critical point (1 + j0); however, the circuit oscillates (oscillations are independent of the observation point). In this case, in fact, the transfer function $\Gamma_D(f)$ presents poles with positive real part (due to the condition $G_D + Y_0 < 0$) and hence, the circuit is unstable also with $N_t = 0$. As shown in Figure 5(b), also in this case, the point in which the Nyquist plot crosses the positive real axis gives the oscillation frequency of the circuit.

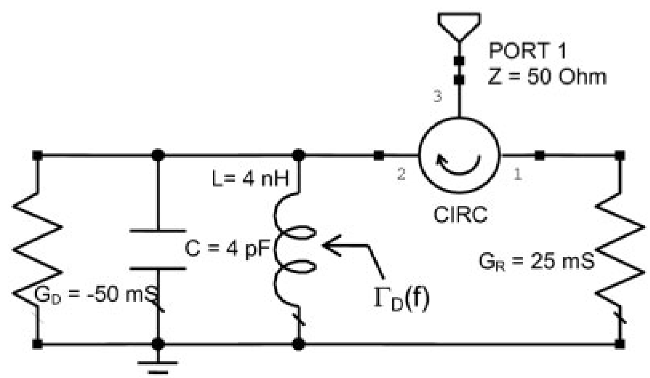
In conclusion, if the circulator is placed between the active element and the resonator, the Nyquist plot gives the frequency behavior of the open chain transfer function, and the resonance frequencies are given by the values at which the plot crosses the positive real axis.

3. DESIGN OF THE CERAMIC OSCILLATOR

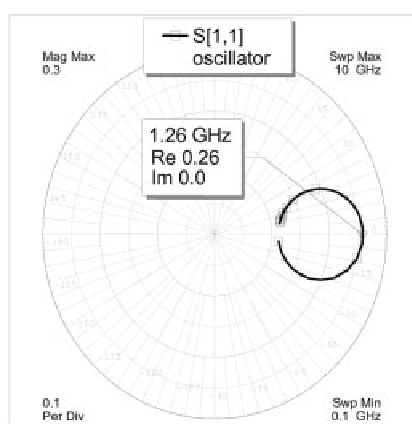
A 0.9 GHz ceramic oscillator has been designed by using AWR Microwave Office™ CAD tool and realized to prove the feasibility of the proposed design approach. The schematic of the oscillator is presented in Figure 6.

First the NE34018 FET, with an output power of 12 dBm at P_{1dB}, has been chosen to guarantee the specified output power. The active device has been connected in common source configuration and self-biased in saturation region (V_{DD} = 2V, R_S = 22 mA). The FET nonlinear model provided by NEC has been implemented in Microwave Office. However, only linear simulations have been performed during the design phase, as required by the methodology presented in Section 2.

Then, a feedback capacitance C_S has been added in order to maximize, at 0.9 GHz, the reflection-coefficient module at the transistor gate (Γ_D). By means of a parametric analysis, it has been found that a 18 pF capacitance allows for a maximum value of 1.15 for Γ_D .

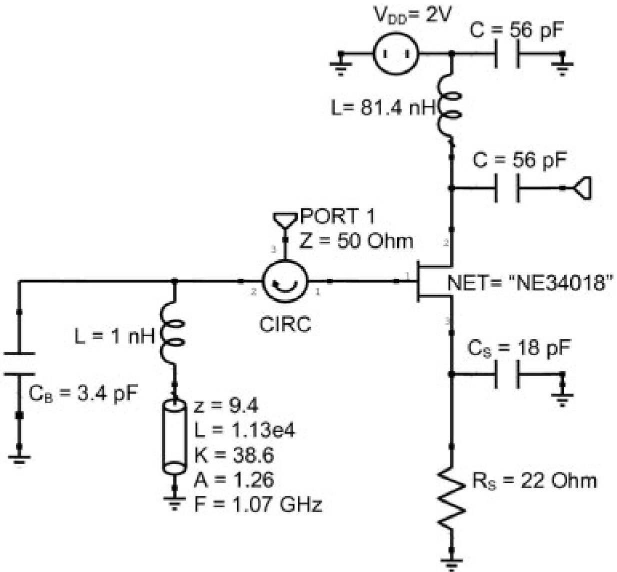


(a)

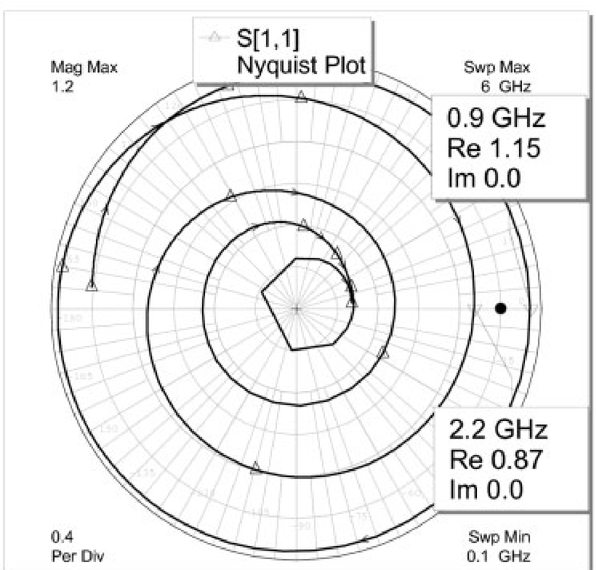


(b)

Figure 5 Oscillating circuits and Nyquist plot



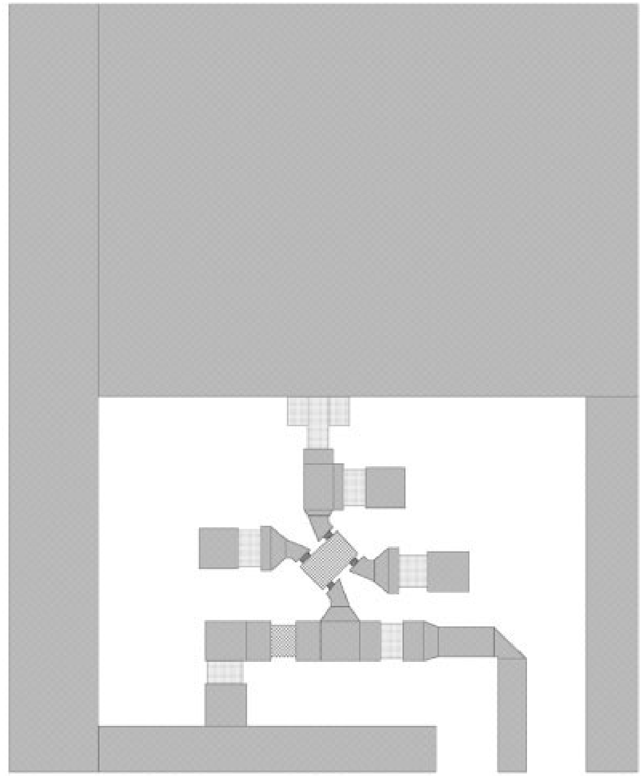
(a)



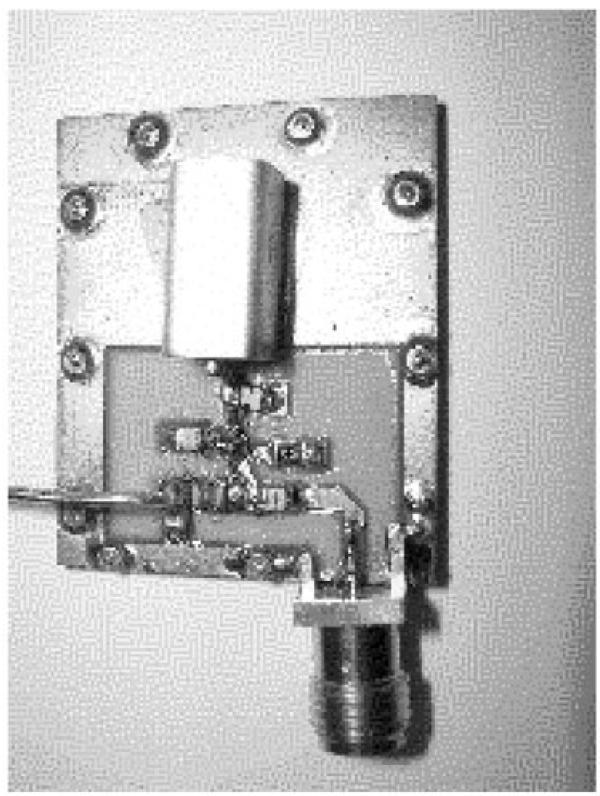
(b)

Figure 6 Designed circuit and resulting Nyquist plot

As the obtained reactance at the transistor gate is capacitive, a coaxial resonator operating in its inductive region has been chosen in order to satisfy (3). The SR8800SPQ1070BY quarter-wave coaxial resonator from Trans-Tech has been selected whose resonance frequency (1070 MHz) is about 20% greater than the specified oscillation frequency.



(a)



(b)

Figure 7 Final layout (a) and photograph (b) of the oscillator. Board dimensions are 30 $\times$ 25 mm^2

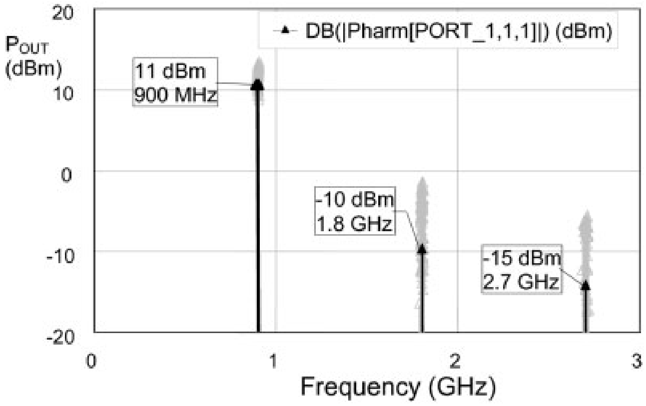


Figure 8 Measured output power of the designed oscillator as a function of frequency (black arrows). Simulated output power as a function of circuit parameter variations (gray arrows)

Finally, a balancing capacitance (C_B) of 3.4 pF has been added in parallel to the resonator to satisfy the oscillation condition (3) at 0.9 GHz

Tocheck for correct and undesired oscillation frequencies, an ideal circulator has been added to the simulation test bench as shown in Figure 6(a). The resulting Nyquist plot is shown in Figure 6(b). Since the conductance at the transistor gate G_D at 900 MHz is about −0.001 S, the designed oscillator can be modeled following the scheme shown in Figure 3(a); therefore the Nyquist plot follows that of Figure 4(a). The only frequency that satisfies the oscillation condition in Figure 6(b) is that at which the Nyquist plot intersects the positive real axis at the right side of the point (1 +j0), equal to the specified frequency of 900 MHz.

During the design of the layout, care has been paid to avoid that reactive parasitics (both the capacitance to ground and the parasitic of microstrip patches and via holes) could produce a further frequency of oscillation. In particular, on each branch of the circuit, the effects on loop gain of adding via holes and lines have been evaluated by means of Nyquist plots. Problems have been detected during the layout design of the FET source biasing network. An RF blocking inductor was placed in series to the source resistance in an early design version. In these conditions Nyquist plot revealed the presence of high-frequency RHP poles. To solve this problem the inductor has been eliminated and the design has been repeated by considering the presence of the negative feedback produced by the source resistor. As a result of the attenuation introduced in the loop gain, only one pole has been found in the RHP.

4. REALIZATION AND MEASUREMENTS ON THE OSCILLATOR

The oscillator has been realized on RO4003 substrate with 35 μm copper metallization in the laboratories of "La Sapienza" University of Rome, by using a microforge (Quick Circuit 5000™). In Figure 7, the final layout (a) and a photograph (b) of the circuit are shown.

Measurements have been performed by means of a HP 8594E Spectrum Analyzer and are reported in Figure 8 (black arrows): an 11 dBm maximum output power has been measured at the frequency of 897.39 ± 0.05 MHz.

A Monte Carlo analysis of the designed oscillator performed with a Harmonic Balance simulator has been performed considering tolerances of passive devices and statistical parameter variations of the active device. The statistical variations of both frequency and power of oscillations falls well inside measured values (see the gray arrows in Fig. 8).

5. CONCLUSIONS

In this article, a 900 MHz ceramic oscillator delivering a power of 10 dBm has been designed, realized, and tested. The circuit synthesis has been performed by using a linear analysis based on the parallel resonance condition. The onset and frequency of oscillation have been tested by using a version of the Nyquist criterion suitable to be used within microwave CADs. A prototype of the oscillator has been built on R04003 material and a very good agreement between nonlinear simulations and measurements has been observed.

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ANALYSIS OF PATCH ANTENNAS ON A MULTILAYER SUBSTRATE WITH A EMBEDDED PERIODIC STRUCTURE

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ABSTRACT: *The goal of this work is to further investigate on the use of a truncated planar metallic periodic structure (grounded FSS-based) to create new resonance frequencies in a patch antenna. The periodic structure is placed inside the microstrip patch antenna (between the metallic ground plane and the patch) in the middle of a multilayer dielectric. The frequency behavior of the antenna as a function of the parameters of this periodic structure has been studied. Also the extension to a stacked patches configuration, which provides another resonance frequency, has been validated. Final antenna design presents flexible multiband operation.* © 2007 Wiley Periodicals, Inc. Microwave Opt Technol Lett 49: 1717–1722, 2007; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.22527

Key words: *patch antenna; multilayer substrate; periodic structure*