A Broadband Tunable Distributed Feedback Resonator

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Abstract

A tunable Bragg type distributed feedback microwave resonator is presented. The resonator is formed by a transmission line periodically loaded with varactor diodes. A tunable periodic superstructure is superimposed on the transmission line by periodically dc biasing the varactor diodes. Two resonators of this type were fabricated, one on an alumina substrate in coplanar hybrid integrated technology and the second in microstrip on RT-Duroid substrate. With this resonator configuration we achieved a tuning bandwidth from 400 MHz to 4 GHz and 200 MHz to 2 GHz, respectively.

Introduction

The principle of Bragg-reflection and distributed feedback structures has found application in semiconductor laser diodes and as resonators for Gunn oscillators in the mm-wave range [1]. This tunable Bragg resonator allows the control of the period length of the variation of the capacitive load formed by discrete varactor diodes. The resonator has a wide frequency tuning range that is not limited by the maximum capacitance ratio C_{max}/C_{min} of the varactor diodes used for tuning. The resonator consists of a transmission line which is periodically loaded with varactor diodes. A characteristic property of periodic structures is the periodic appearance of pass bands and stop bands [2]. In the following, the spacing between the varactor diodes connected to the transmission line will be called the fundamental periodicity.

The varactor diodes are dc-biased periodically along the length of the transmission line. In this way a periodic superstructure is superimposed on the fundamental periodicity. The spatial period Λ of the superstructure is controlled by the bias voltages of the varactor diodes. The minimum biasing periodicity must be greater than twice the spacing between the varactor diodes. This periodic biasing of the varactor diodes also provides pass bands and stop bands, which are in the frequency range of the first pass band of the fundamental periodicity. In contrast to the fundamental periodicity, the second superposed periodicity can be tuned, making the double periodic structure a tunable resonator. The tuning bandwidth is only limited by the first stop band of the fundamental periodicity and the length of the structure.

Analysis of a periodically loaded transmission line

We consider the structure as depicted in Fig. 1 which is a periodically loaded lossless line terminated by its characteristic impedance. This structure can be divided into symmetric elementary cells consisting of a line, which has half the length of the distance between two capacitors a load capacitance, and another line.

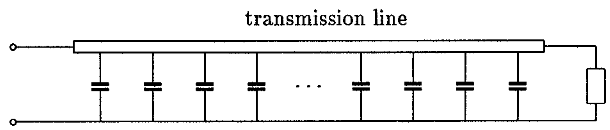

Figure 1: A periodically capacitive loaded transmissionline

The voltage $\bar{V}_n$ and the current $\bar{I}_n$ at the input port of this basic unit depends on the voltage $\bar{V}_{n+1}$ and the current $\bar{I}_{n+1}$ at the output port via

$$\begin{pmatrix} \bar{V}_n \\ \bar{I}_n \end{pmatrix} = \mathbf{A} \begin{pmatrix} \bar{V}_{n+1} \\ \bar{I}_{n+1} \end{pmatrix} \quad (1)$$

$$\mathbf{A} = \begin{pmatrix} \cos\theta_l - \frac{\bar{B}}{2}\sin\theta_l & j(\frac{\bar{B}}{2}\cos\theta_l + \sin\theta_l - \frac{\bar{B}}{2}) \\ j(\frac{\bar{B}}{2}\cos\theta_l + \sin\theta_l + \frac{\bar{B}}{2}) & \cos\theta_l - \frac{\bar{B}}{2}\sin\theta_l \end{pmatrix}$$

where B is the loading susceptance and θ_l is the electrical phas shift of the line between two shunt capacitors. The bar indicates normalization to the transmission line impedance Z_l.

Following Floquet's theorem [2,3,4], voltage and current in consecutive cells in a periodic structure can only differ by a complex constant. Thus we can write

$$\bar{V}_{n+1} = e^{-\gamma d}\bar{V}_n \quad (2)$$

$$\bar{I}_{n+1} = e^{-\gamma d}\bar{I}_n \quad (3)$$

From Eqs. (1,2,3) we obtain the eigenvalue equation of wave propagation of the periodically loaded transmission line.

$$\cos(\beta d) = \cos\theta_l - \frac{\bar{B}}{2}\sin\theta_l \tag{4}$$

Fig. 2 shows the k_0-β-diagram for $\bar{B} = 2k_0d$. Real solutions for βd which correspond to a propagating wave are possible for $0 \leq k_0d \leq 0.416\ \pi$ which is related to the first pass band. The maximum tuning bandwidth of the second periodicity will be restricted to this frequency range.

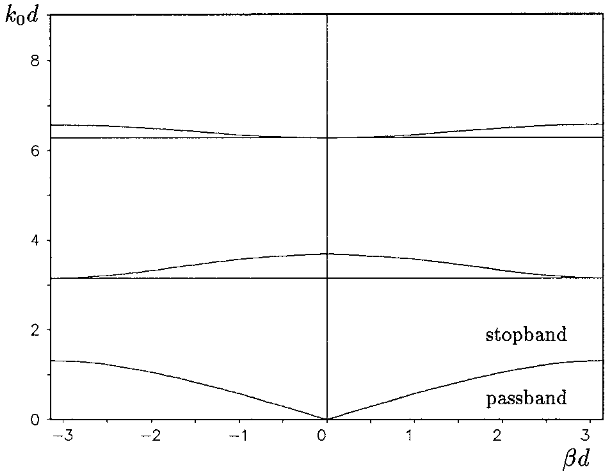

Figure 2: Brillouin diagram of the periodically loaded transmission line ($\bar{B} = 2k_0d$)

The periodic structure has to be terminated with its characteristic impedance given by

$$\bar{Z}_c = \frac{\bar{V}_{n+1}}{\bar{I}_{n+1}} = \sqrt{\frac{2\sin\theta_l + \bar{B}\cos\theta_l - \bar{B}}{2\sin\theta_l + \bar{B}\cos\theta_l + \bar{B}}} \tag{5}$$

to provide a nonreflective termination in the first passband when the same bias voltage is applied to all varactors along the line. For sufficiently low frequencies where the spacing between the varactor diodes is small compared with the wavelength on the structure, the characteristic impedance can be approximated by a nondispersive impedance

$$Z_c = \bar{Z}_c Z_l = \sqrt{\frac{L_l'}{C_l' + C_{mid}/d}} \tag{6}$$

where C_{mid} is the average varactor capacitance, d is the spacing between the varactors, and L_l', C_l' are the inductivity and capacitivity per unit length of the line. The Bragg-resonator was terminated by this impedance.

The Periodic Superstructure

Until now only single periodic structures have found application in single frequency systems [1,5]. With this structure the capacitances of the varactor diodes are modulated according to the following tuning specification

$$C_i = C_{mid} + \Delta C \cdot \sin[(i-1)\frac{d}{\Lambda} + \varphi] \tag{7}$$

where Λ is the Bragg-period of the superstructure. ΔC is given by

$$\Delta C = \frac{C_{max} - C_{min}}{2}.$$

The properties of this structure were calculated numerically from the product of the chain matrices of the elementary cells. The losses of the microstrip or coplanar transmission lines were taken into account, as well as the losses of the varactor diodes and their parasitic series inductance. The parasitic series inductances of the varactor, the bias-capacitor and the via hole reduce the the cut-off frequency of the first passband of the basic periodicity and should be kept as small as possible.

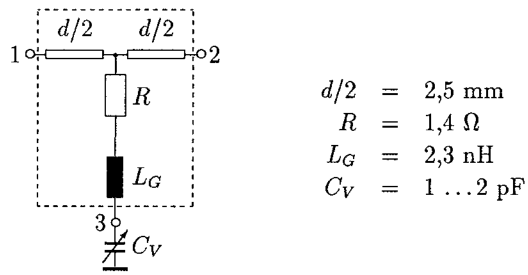

Figure 3: Equivalent circuit of one unit cell of the periodic structure. R = loss resistance, L_G = total parasitic inductance, C_V = varactor capacity

Fig. 4 is a 3D-plot of the reflection coefficient of a periodic structure with 64 varactors and a second superposed periodicity over frequency and over the superposed periodicity. The reflection coefficient exhibits a maximum depending from the superposed period. At frequencies above 2.2 GHz the first stop band of the basic periodicity occurs and the reflection coefficient increases to a value of 1, since no wave propagation is possible. The reflection coefficient was normalized to 50 Ohms and not to the characteristic impedance of about 20 Ohms.

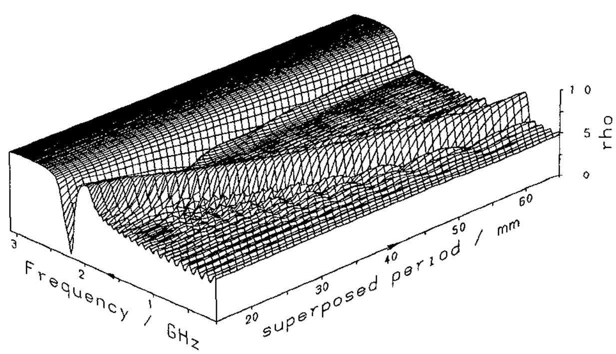

Figure 4: A 3D-plot of the reflection coefficient over frequency and the superposed periodicity

A resonator was fabricated with 64 Siemens BB801 packaged varactor diodes on a RT-Duroid substrate with $\epsilon_r = 10$. The distance between the diodes was 5 mm, total parasitic series inductance of one unit cell was 2.3 nH and the equivalent loss resistor was 1.4 Ω. Fig. 3 shows the equivalent circuit of one elementary unit.

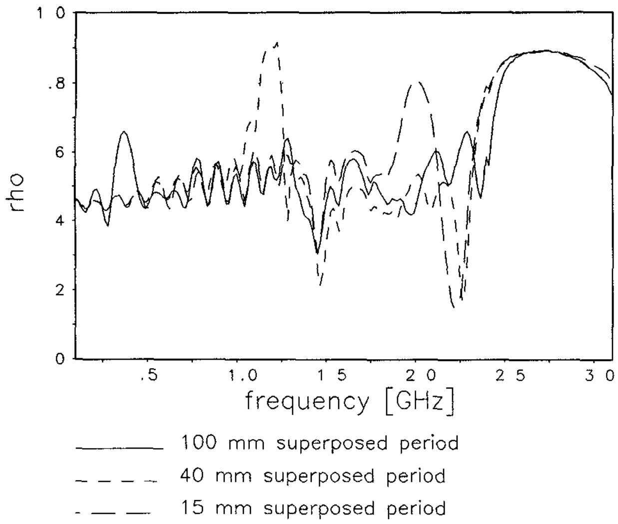

Figure 5: Measured reflection coefficient over frequency of the microstrip resonator for several superposed periods (N = 64 varactors, d = 5 mm)

The impedance of the microstrip line was choosen to 25 Ω to achieve a high linearitiy of the solutions of Eq. 4 in the first passband of the Brillouin-diagram. The varactor diodes were driven from 1 pF to 2 pF. With this arrangement we achieved a tuning bandwidth from 200 MHz to 2.1 GHz. The quality factor of the Bragg-resonator was calculated by comparing the structure with an equivalent circuit as shown in Fig. 6. The Q-factor calculates to

$$Q = \frac{\omega_0 L_s}{R_s \left(1 + \frac{R_s}{R_p}\right)} = \frac{1}{\omega_0 C_s R_s \left(1 + \frac{R_s}{R_p}\right)} \qquad (8)$$

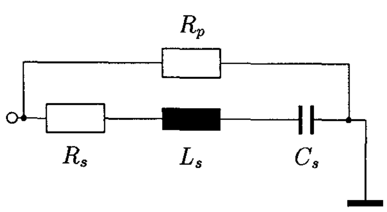

Figure 6: Equivalent circuit of the resonator in series resonance

A second resonator of this type was fabricated as a coplanar transmission line on a 2" × 2" alumina substrate in hybrid integrated technology. The line was loaded with 64 unpackaged chip varactors of the same type, separated by 1.5 mm and driven again from 1 pF to 2 pF. The coplanar design provides very low parasitic inductances which are responsible for the limit frequency of the first pass band. With this configuration we achieved a tunable resonance frequency from 400 MHz to up to 4 GHz. The resonator could be either adjusted in parallel resonance or in series resonance depending on the choice of a phase offset $\varphi = 180^o$ or $\varphi = 0^o$. However, the phase of the reflected wave can be adjusted to any arbitrary value when varying φ. Fig. 8 and Fig. 9 show the reflection coefficient of the coplanar resonator at a frequency of 2 GHz for series and parallel resonance in the Smith chart, measured with an HP8510B network analyser.

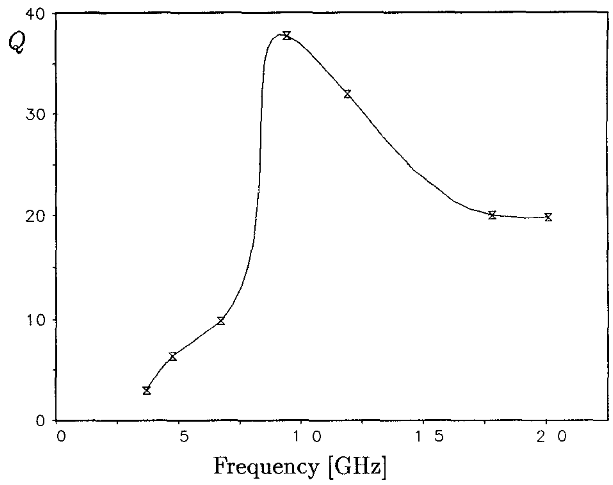

Figure 7: Quality factor Q of the Bragg-resonator versus frequency. The resonator is in series resonance.

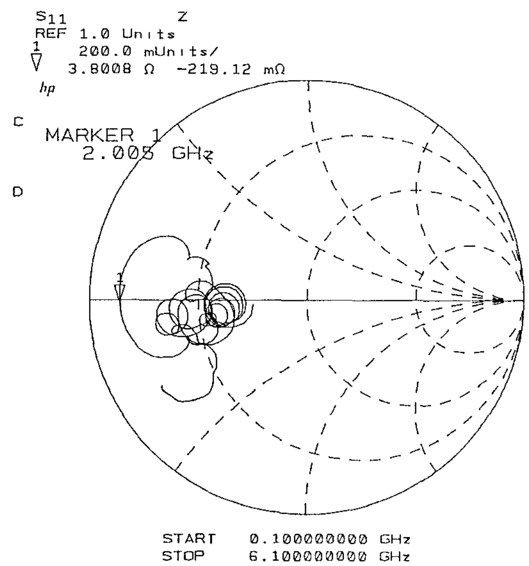

Figure 8: Measured reflection coefficient for series resonance $\varphi = 0^0$ (N = 64 varactors, d = 5 mm)

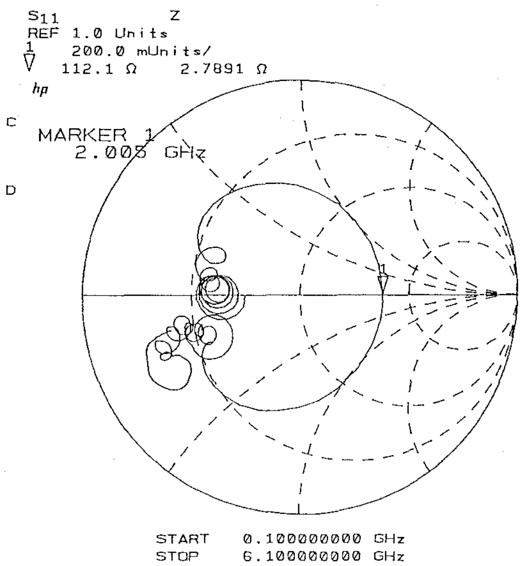

Figure 9: Measured reflection coefficient for parallel resonance $\varphi = 180^0$ ($N = 64$ varactors, $d = 5$ mm)

Application

We used the microstrip structure as the frequency determining element of a microwave varactor-tuned oscillator. The varactor diodes of our periodic structure are driven by a voltage pattern generator providing a sinusoidal modulation of the capacity along the loaded line. In the case of a resonator structure operated as a tunable distributed feedback resonator with a periodically varying capacitance per unit length, the tuning bandwidth is no longer restricted by the capacitance ratio but only by the length of the periodic structure and the space between the varactors that adjust the additional periodic capacitance per unit length.

In this way we have designed and fabricated a tunable Bragg type resonator oscillator. For the active part, two packaged Mitsubishi GaAs-FET's MGF 1502 were employed in a parallel feedback configuration. The parallel feedback network of the active part was realized with high Q and high precision ATC microwave capacitors. Range of operation of the oscillator was from 180 MHz to 1300 MHz. The oscillator could be tuned continously without any jumps in frequency within this range. Thus we have fabricated an extremely broadband varactor-tuned oscillator. Extending this principle to a higher frequency range, a broadband tunable mm-wave oscillator should be possible in monolithic integrated technology. Fig. 10 is a photograph of the oscillator with the Bragg-resonator. On the left hand side, the resonator is visible with varactors and biasing circuit. The resonator was folded five times forming a rectangular spiral to reduce packaging size.

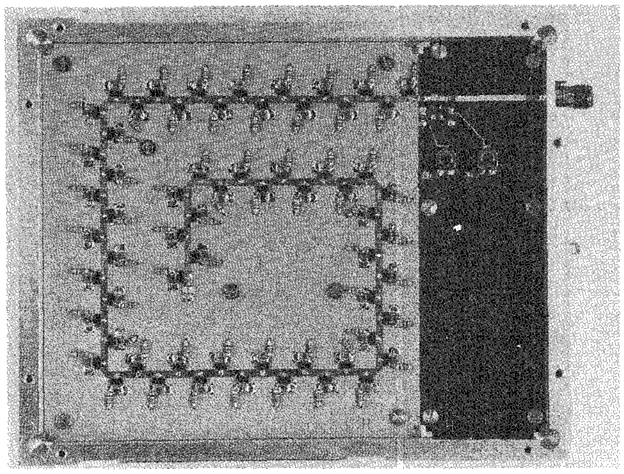

Figure 10: Photograph of the oscillator with the distributed feedback resonator

Conclusion

Within the first passband of the basic periodic structure, the variable periodic superstructure generates an additional stop band at a frequency where the double period of the superstructure equals the line wavelength. In this manner varactor tuned-resonators can be realized with a frequency tuning range not limited by the varactor capacitance ratio. These tunable Bragg type resonators will facilitate the construction of tunable oscillators with a high tuning range. Monolithic integration could make this type of resonator very useful for broadband planar oscillators in higher frequency regions e. g. in millimeter wave applications since the size could be reduced significantly without a reduction in bandwidth.

References

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