Miniaturized Stripline Dual-mode Ring Resonators and Their Application to Oscillating Devices

Hiroyuki Yabuki, Michiaki Matsuo, Morikazu Sagawa and Mitsuo Makimoto

Information and Communications Technology Laboratory
Matsushita Electric Industrial Co., Ltd., Kawasaki, Japan

Abstract

Novel structures of miniaturized stripline dual-mode resonators (DMRs) have been proposed, and their fundamental properties related to orthogonal modes are analytically derived. DMRs have attractive features which will provide many distinctive oscillating circuits.

Experimental oscillating devices such as osciplier and low phase noise voltage controlled oscillators using miniaturized DMRs are expected to have a practical use for various kinds of radio equipment in the RF and microwave regions. Moreover, this design concept is applicable for millimeter wave oscillators or smaller.

Introduction

It is well known that ring resonators have low radiation loss, high Q value and two orthogonal resonant modes (dual-mode)[1]. Filters and duplexers using dual-mode dielectric resonators or waveguide ring cavities have been used for satellite communications[2]. However, there are few applications which make use of the dual-mode in a stripline configuration[3]. The authors have previously reported fundamental properties of one wavelength dual-mode resonators, such as exciting methods and a means of coupling control between two modes[4]. We also have proposed their application for filtering devices[5].

This paper describes practical methods for miniaturization of the stripline dual-mode ring resonators (DMRs) and their fundamental properties. Moreover, we investigate their application to novel oscillating devices in the RF and microwave regions. The experimental oscillating circuits using miniaturized DMRs have the advantage of a low-profile structure, a low power consumption and low phase noise characteristics. Therefore, they are expected to be applicable for various kinds of radio equipment.

Resonance Properties

Fig.1 shows some structures of stripline DMRs. Fig.1(a) is a basic structure of the one wavelength DMRs. By arranging four ports whose interval is one quarter of the resonator length, two orthogonal modes can be excited in the ring resonators. One mode propagates from port1 to port3 and the other independently from port2 to port4 at the same frequency. One wavelength DMRs are miniaturized by adding a lumped element capacitor to the resonators at the high electric field points. There are two methods which can be used to attain this property. One method is to connect a capacitor between opposite ports, as shown in Fig.1(b). The other is to ground every port via capacitors, as shown in Fig.1(c).

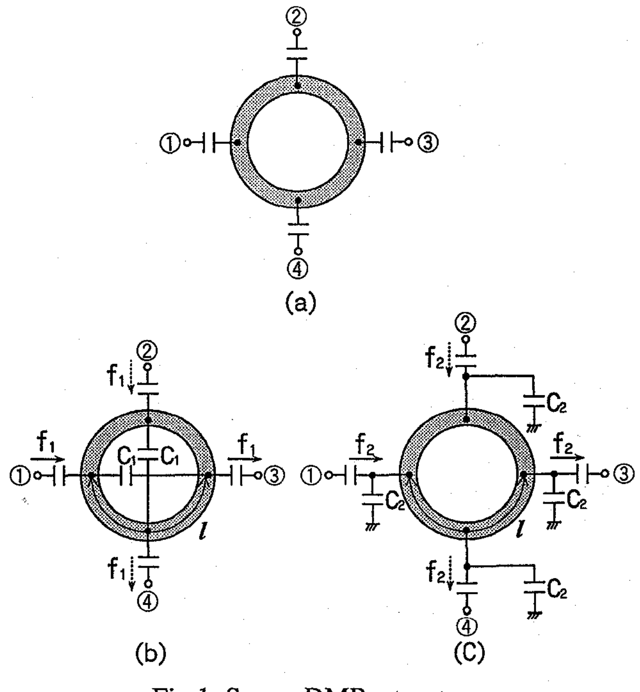

Fig.1 Some DMR structures

The resonance condition of the miniaturized DMRs indicated in Fig.1(b) and (c) can be obtained by theoretical analysis. The results are as follows :

(b) type : $Y_0 \sin\theta_{01} + \omega C_1(\cos\theta_{01} - 1) = 0$

(c) type : $(4Y_0^2 - \omega^2 C_2^2)\sin\theta_{02} + 4Y_0\omega C_2\cos\theta_{02} = 0$

where

$$\theta_{01} = 2\pi l\, f_1/v_p\ ,\quad \theta_{02} = 2\pi l\, f_2/v_p\ .$$

Y_0 is the characteristic admittance of the transmission line consisting of DMRs, v_p is the phase velocity on the substrates, and f_1 and f_2 show the resonant frequency of Fig.1(b) and (c), respectively.

Isolation Characteristics

The voltage distribution exhibits a sinusoidal property along the transmission line when port1 is excited at the resonance frequency. Then, port2 and port4 become minimum voltage points and port3 is maximum voltage point. The same behavior occurs if port2 is excited at the resonance frequency. Therefore, two ports whose physical distance is one quarter of the ring resonator's length are spatially orthogonal at resonance frequency. Hence, they are electrically isolated from each other.

Isolation characteristics are important factors to consider in oscillating devices using DMRs. For high isolation characteristics between fundamental and even order harmonics, it is possible to suppress a fundamental frequency signal and to take out even order harmonics. This feature is available for oscipliers (oscillator with multiplier function). In addition, two circuits are able to oscillate without interaction between them. This feature can be applied to widen a frequency range of voltage controlled oscillators (VCOs). A detailed explanation is given in the next section.

Fig.2 shows isolation characteristics due to the miniaturization of DMRs. Here, we define isolation level (S21/S31) as the selective ratio between isolation ports and transmission ports. θ_T is the total electrical length of a DMR at resonance frequency. In the case of the Fig.1(b) type, isolation characteristics degrade in accordance with miniaturization. However, the Fig.1(c) type maintains excellent isolation characteristics. This means that those of the Fig.1(c) type are adequate for making oscillating devices. Therefore, the Fig.1(c) type is used in the following examinations. For MIC applications, it is preferable to replace the capacitor C_2 with an open stub element, as shown in Fig.3.

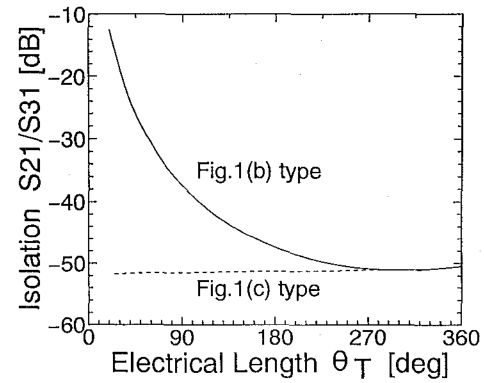

Fig.2 Isolation characteristics

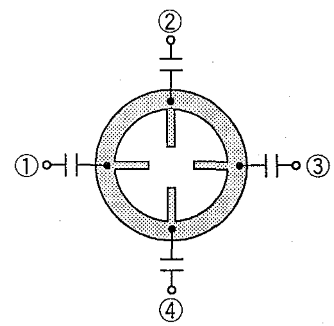

Fig.3 A DMR with an open stub structure

Oscillators

A ring resonator is often used for reactive elements of low phase noise oscillators because of its high Q and steep susceptance gradient.

On the basis of the above discussion, the following two types of oscillating circuits can be designed and fabricated :

1) Osciplier
2) Low Phase Noise VCOs

(1) Osciplier

DMRs have special structures for obtaining two outputs of the fundamental oscillating frequency f_0 and its second harmonic frequency $2f_0$, separately, with high isolation between them.

Fig.4 shows the circuit configuration of an osciplier using a miniaturized DMR. Points A and B, whose distance from point C is one quarter of the DMR's length, become minimum voltage points at a resonance frequency of f_0. However, the maximum voltage can't be obtained at $2f_0$. To make points A and B maximum voltage points at $2f_0$, it is necessary to connect capacitors from the output ports to the ground. Even in this situation, the f_0 signal isn't affected because these points are short-circuited points at f_0.

The phase difference between A and B becomes 180° out of phase at the f_0 signal and is in phase at the $2f_0$ signal. The osciplier can be produced by in phase combining the two outputs of A and B, whose fundamental frequency is suppressed and whose second harmonic frequency is emphasized.

Next, we study voltage controlled osciplier. Maximum isolation points, whose output level is a minimum at f_0 and a maximum at $2f_0$, vary in proportion to oscillation frequency when a varactor diode is connected to one side of the ports. However, the maximum isolation points are fixed when varactor diodes are connected to both sides of the ports, as shown in Fig.4.

Fig.5 shows a photograph of an experimental voltage controlled osciplier. This circuit is manufactured from a four-layered printed circuit board. Fig.6 and Fig.7 show the experimental results of the osciplier for the f_0 and $2f_0$ output spectrum. The output frequency of f_0 is about 800MHz. Both output levels are constant and the fundamental suppression level is about 18dB in a control voltage range from 0.5V to 3.0V. The osciplier which use DMRs are expected to operate at a high frequency with low power consumption due to their having no multipliers.

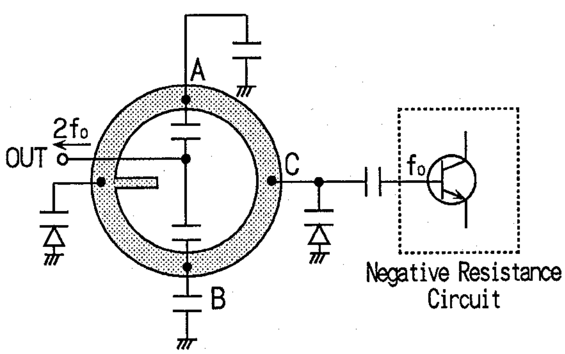

Fig.4 The circuit configuration of the osciplier

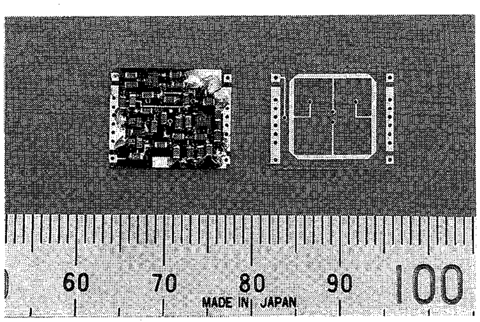

Fig.5 A photograph of an experimental osciplier

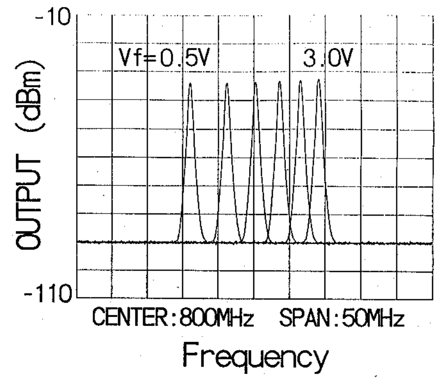

Fig.6 Experimental results of the osciplier (f_0 output)

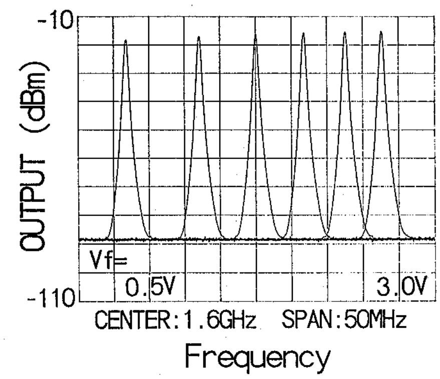

Fig.7 Experimental results of the osciplier ($2f_0$ output)

(2) Low Phase Noise VCOs

It is known that the phase noise characteristics of VCOs degrade remarkably in accordance with a wider frequency range. This problem can also be solved by using DMRs as a resonator. Two VCOs using DMRs can operate independently at the frequency range at which isolation performances are superior to the injection locked gain.

Fig.8 shows the circuit configuration of the trial VCOs. Circuit 1 covers the lower, and circuit 2 covers the higher frequency band ranges. Both oscillators are composed of a common DMR and two identical negative resistance circuits. The introduction of this method reduces the variable frequency range to about one half of the conventional one. As a result, the phase noise characteristics of the oscillators are significantly improved.

Fig.9 shows the injection locked characteristics. The oscillator circuit is connected to the point A and the oscillation frequency f_0 is 880MHz, while the signal generator is connected to the point B. This means that the two oscillators are independent of each other when the oscillation frequency difference between them is more than 5MHz.

Fig.10 shows a photograph of an experimental low phase noise VCO. This circuit is constructed from a four-layered printed circuit board. Fig.11 shows a comparison between the conventional and the proposed VCOs concerning oscillation frequency and SSB phase noise versus control voltages. The noise spectrum of proposed VCOs is superior to the conventional one with an approximately 5dB improvement within the tuning range. The experimental VCOs using DMRs are able to realize low phase noise characteristics due to their low sensitivity against control voltages.

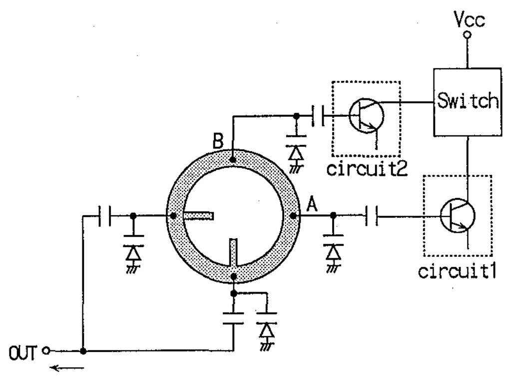

Fig.8 The circuit configuration of a low phase noise VCO

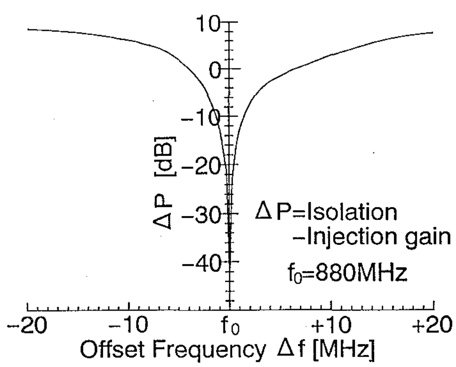

Fig.9 Experimental results of injection locked characteristics

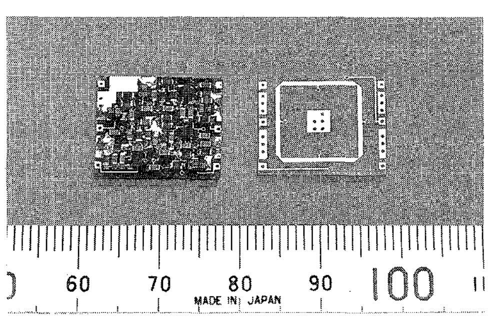

Fig.10 A photograph of an experimental VCO

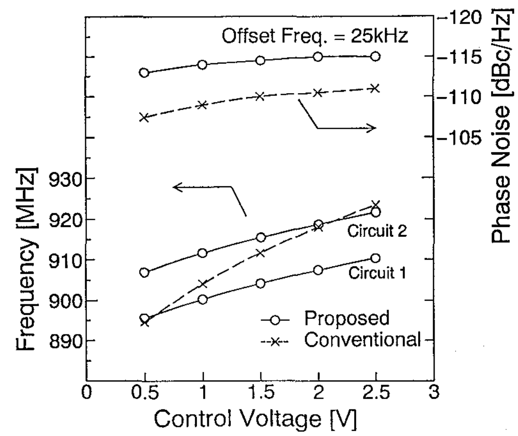

Fig.11 Comparison between the tuning characteristics of the conventional and the proposed VCOs

Conclusion

Two circuits, the osciplier and the low phase noise voltage controlled oscillator, have been developed using miniaturized DMRs and have demonstrated excellent experimental results. These circuits are extremely useful and practical for making low-profile, low power consumption and low phase noise circuits for various kinds of radio equipment in the RF and microwave regions. Moreover, this design concept is applicable for millimeter wave oscillators or smaller.

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