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VOLTAGE CONTROLLED PUSH-PUSH OSCILLATORS USING MINIATURIZED HAIRPIN RESONATORS

Hiroyuki Yabuki, Morikazu Sagawa, Mitsuo Makimoto

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

ABSTRACT

This paper describes the fundamental characteristics of newly developed compact stepped impedance hairpin resonators having parallel coupled lines and shows their application to voltage controlled push-push oscillators for UHF band operation.The experimental push-push oscillators which were built using these resonators made it clear that they have the advantage of providing compact size, low phase noise and wide tuning operation.

INTRODUCTION

Push-Push oscillators are useful in many system applications[1] because of their good performance in areas such as low phase noise and high output power.

We previously introduced microstrip line split-ring resonators (MSR's)[2],[3] , which are composed of a transmission line and a lumped element capacitor. We also devised new hairpin-shaped split-ring resonators with parallel coupled lines to replace the lumped element capacitor and studied their resonance properties[4].

We have recently developed stepped impedance hairpin resonators with parallel coupled lines to make resonators even smaller. Stepped impedance hairpin resonators have a suitable structure for microwave integrated circuits(MIC's) and can be used at a much higher frequency range than previously described MSR's. And they also have useful features for RF oscillator circuits with low phase noise and wide tuning range.

The push-push oscillators employing this resonator are expected to have compact size, low phase noise and wide oscillation frequency range.

RESONANCE PROPERTIES

A. Resonator Structure

Fig.1 shows a newly developed stepped impedance hairpin resonator with parallel coupled lines. To reduce the size of conventional hairpin-shaped split-ring resonators, we introduce stepped impedance hairpin resonators with parallel coupled lines. In the case of $Z_s > \sqrt{Z_{pe} \cdot Z_{po}}$, the total electrical length of these resonators become shorter than that of conventional resonators.

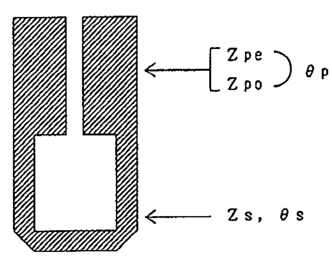
Further miniaturization can be achieved by increasing the coupling between parallel coupled lines and hence decreasing the value of $\sqrt{Z_{pe} \cdot Z_{po}}$.

Some advantages of the new resonators are summarized as follows.

(1) small size, with no Q-value degradation
(2) expansion of the applicable frequency range
(3) easy adjustment of resonance frequency

B. Resonance Behavior

The resonance condition can be calculated from the input admittance using the ABCD matrices[5].



Zs : characteristic impedance of the single line
θ s : electrical length of the single line
Zpe,Zpo : even- and odd-mode impedance of the parallel coupled lines
θ p : electrical length of the parallel coupled lines

Fig.1 Stepped impedance hairpin resonators with parallel coupled lines

Fig.2 shows the frequency responses of the resonator. These results indicate that this resonator has two remarkable characteristics.

One is that it has both a series and a parallel resonance point and the frequency span between them is very close. These characteristics are valuable in a resonator for RF oscillator circuits with low phase noise.

The other is that the frequency range can be varied over one octave by a conventional tuning varactor without changing the resonator structure. Therefore, it is suitable for use in wide band voltage controlled oscillators.

Fig.3 shows the voltage distribution of a hairpin resonator at resonance. It can be seen that the voltages at the open-circuited output port [1] and port [2] are 180° out of phase with each other. This characteristic is an essential property for realization of push-push oscillators.

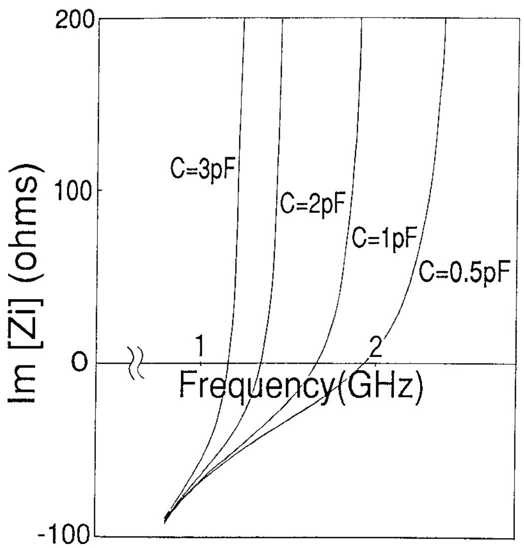


Fig.2 Frequency responses of the resonators

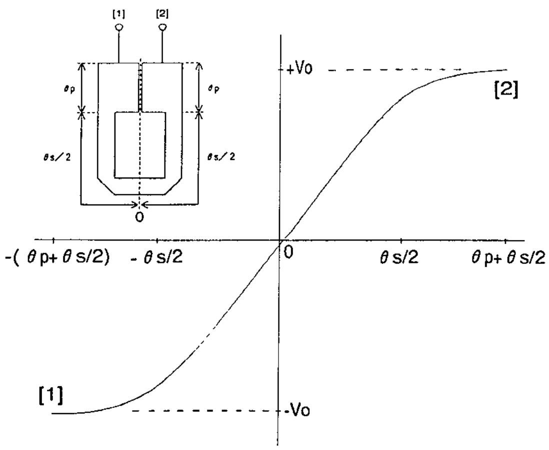


Fig.3 Voltage distribution of hairpin resonator

FUNDAMENTAL PRINCIPLE OF PUSH-PUSH OSCILLATORS

Push-push oscillators have two identical oscillator circuits built from resonators which have the resonant mode 180° out of phase with each other as mentioned before.

A hairpin resonator having parallel coupled lines with an open-circuited end are considered to have either an odd mode or even mode electro-magnetic field distribution in parallel coupled section at resonance. The fundamental resonance occurs in the odd mode. The next higher resonance occurs in the even mode. In this way, higher mode resonance frequencies alternate between odd and even. Push-push oscillators are realized using the lowest odd mode.

Fig.4 shows the circuit diagram of a push-push oscillator. The basic oscillator consists of a Colpitts type circuit with a common base configuration. One part of the circuit oscillates at the fundamental resonance frequency, dependent on the stepped impedance hairpin resonator. The other oscillates at the same frequency, but 180° out of phase.

The combined outputs can be obtained by various circuits, such as differential amplifier, balun and rat-race circuits. In this experimental design a balun consisting of asymmetrical parallel coupled lines has been adopted, as shown in Fig.4. The combined outputs, therefore, have not only twice the delivered power compared with one oscillator, but also an almost pure spectrum, because noise power emerging in phase is cancelled.

On the basis of the above discussion, push-push oscillators employing stepped impedance hairpin resonators have the advantage of inherent low phase noise characteristics. Furthermore, even mode harmonics are suppressed by the combined circuits as mentioned before. Fig.5 shows a simulation result of the combined outputs.

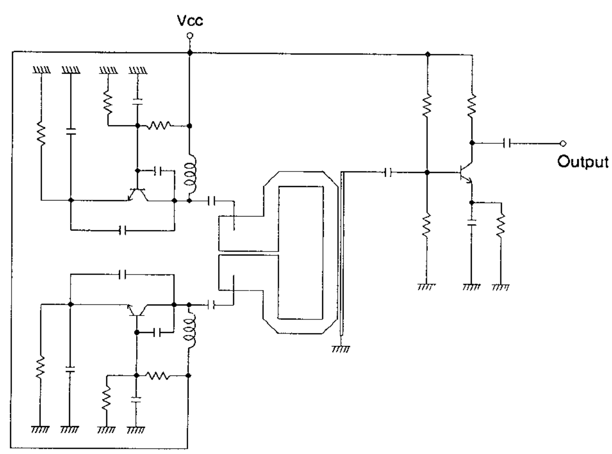


Fig.4 Circuit diagram of the push-push oscillator

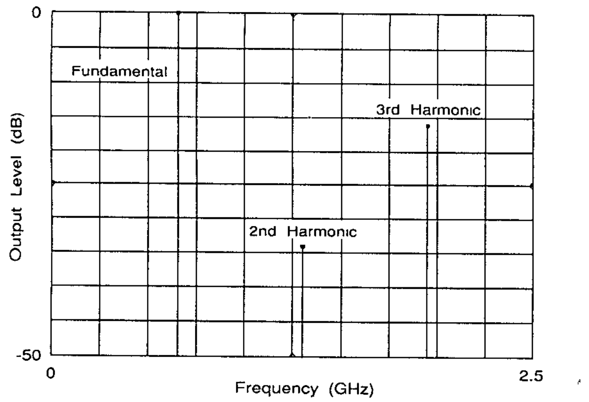


Fig.5 Calculated Spectrum of combined output push-push oscillator

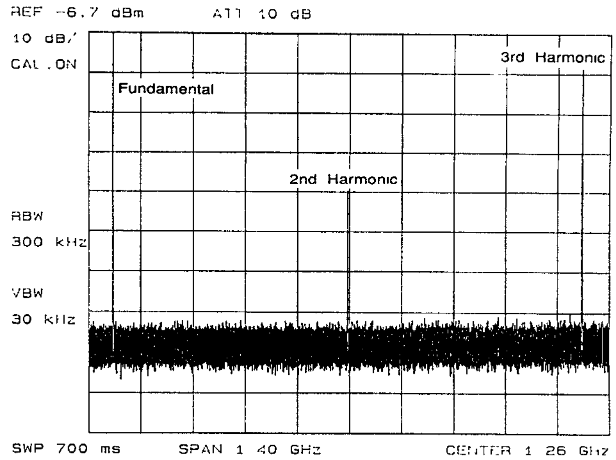


Fig.6 Actual spectrum of combined output push-push oscillator

CHARACTERISTICS OF EXPERIMENTAL PUSH-PUSH OSCILLATORS

Two different types of push-push oscillators using stepped impedance hairpin resonators were experimentally designed and fabricated.

A. Fixed Oscillator with Low Phase Noise

Design parameters of hairpin resonators show below.

Zs = 62.6Ω, θs = 64°

Zpe = 39.4Ω, Zpo = 24.9Ω, θp = 30° (fo=750MHz)

Fig.6 shows the experimental push-push oscillator spectrum. The second harmonic suppression was measured to be about -40dB across the band. The above values are in good agreement with simulation values. It should be noted that the second harmonic is adequately suppressed by the circuit balance.

Fig.7 shows a comparison between the conventional and the push-push oscillator concerning SSB phase noise. The push-push oscillator noise spectrum is superior to the conventional one, with an approximately 9dB improvement over a wide frequency range (offset frequency range from 1KHz to 100KHz).

This is due to the following two factors. First, as discussed in the previous chapter, the combined outputs, having opposite phases, help to cancel noise from external devices. Second, oscillation circuits in the push-push oscillator are in the state of injection locked operation and obtaining narrow band characteristics.

Fig.8 shows the characteristics of the frequency drift and SSB phase noise against temperature. These results indicate that a frequency drift within 600KHz and low phase noise value can be achieved simultaneously from -20°C to 60°C, if the oscillator is compensated.

The experimental oscillator spectrum nearby the oscillation frequency are shown in Fig.9. The output frequency of the push-push oscillator is approximately 650MHz.

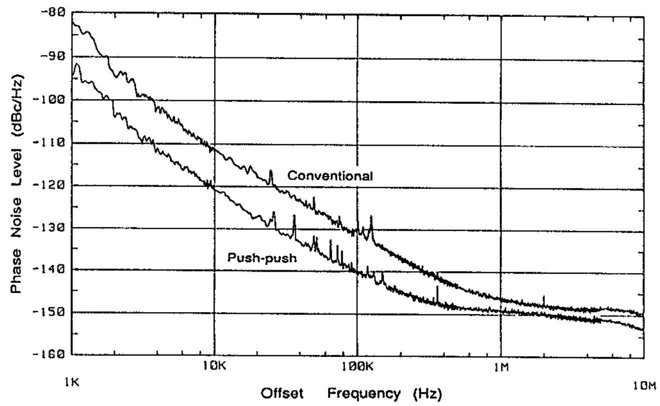


Fig.7 Comparison between SSB phase noise of conventional and push-push oscillators

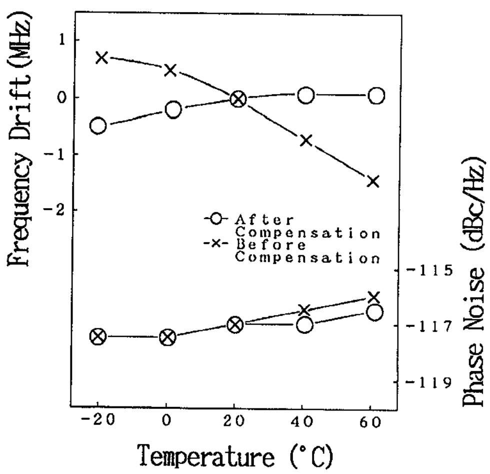


Fig.8 Measured temperature stability of the experimental oscillator

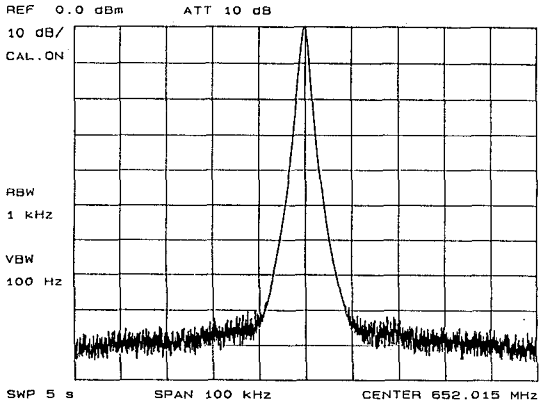


Fig.9 The frequency spectrum of the experimental oscillator

B. Voltage Controlled Oscillator with Wide Frequency Range

A voltage controlled push-push oscillator for L band operation was made.

By connecting a varactor diode between the parallel coupled lines of stepped impedance hairpin resonators, wide band voltage controlled oscillators can easily be constructed.

Design parameters of hairpin resonators show below.

$Zs = 62.6\Omega$, $\theta s = 70°$

$Zpe = 39.4\Omega$, $Zpo = 24.9\Omega$, $\theta p = 30°$ (f_0=1.5GHz)

Fig.10 shows the tuning characteristics versus control voltages. Oscillation frequency varies from 1.0GHz to 1.45GHz with the change of control voltages from 2V to 20V. These results indicate that relative variable frequency range is up by about 35 percent.

Fig.11 shows a photograph of the experimental wide band push-push oscillator. The size of the experimental oscillator is $37 \times 20 \times 2$ mm^3.

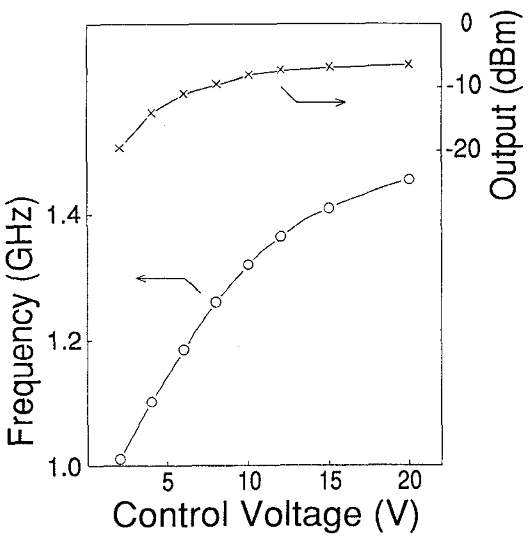


Fig.10 The tuning characteristics versus control voltage

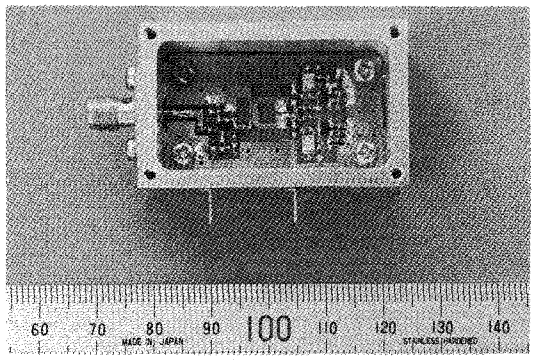


Fig.11 A photograph of the experimental push-push oscillator

CONCLUSION

A stepped impedance hairpin-shaped split-ring resonator with parallel coupled lines was developed and its resonance properties were analytically derived. In addition, we studied the principle of the push-push oscillators employing this resonator.

A fixed push-push oscillator with low phase noise and a voltage controlled push-push oscillator with wide frequency range were fabricated using this resonator. As a result, lower phase noise or wider relative variable frequency range, compared with conventional oscillators is possible.

Push-push oscillators incorporating this resonator are expected to have compact size, low phase noise and wide tuning range.

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