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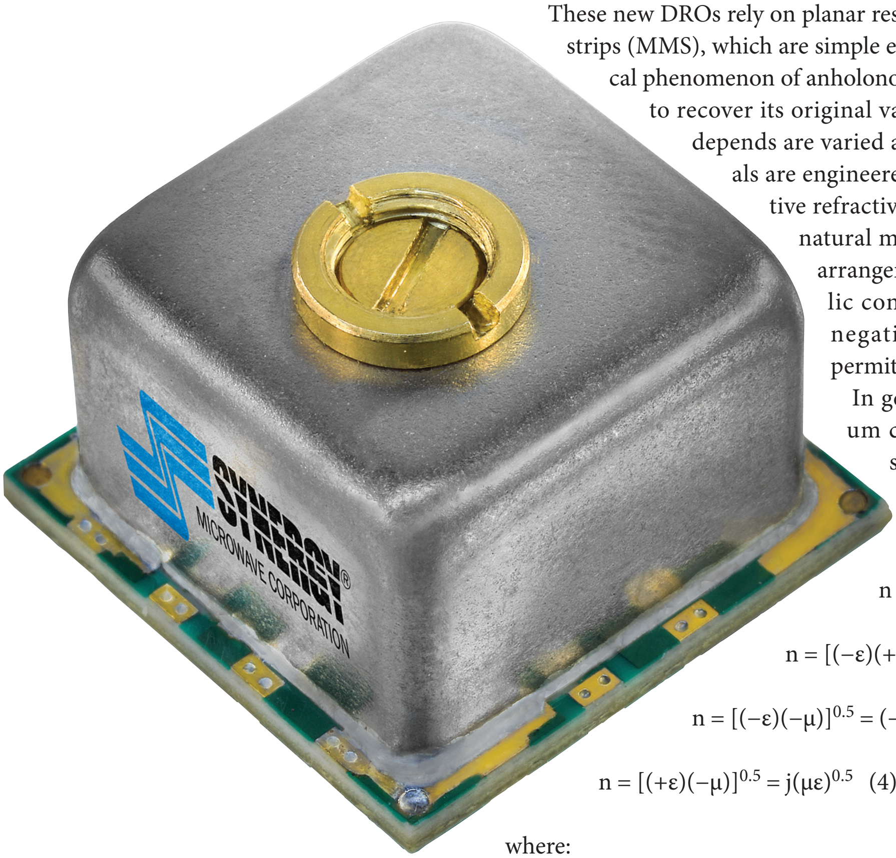
Approach Drops SMD DRO Phase Noise

With the aid of a Möbius coupling mechanism, these fundamental-frequency dielectric-resonator oscillators operate through X-band frequencies with very low phase noise.

Phase noise is an oscillator parameter that grows in importance with the complexity of modern communications modulation formats. Fortunately, work on dielectric resonator oscillators (DROs) at Synergy Microwave Corp. (www.synergymwave.com) has resulted in a line of compact surface-mount-device (SMD) DROs with extremely low phase-noise levels at fundamental-frequency outputs through 6 GHz and higher, suitable for use in commercial, industrial, and military applications.

A Möbius coupling mechanism is employed to help miniaturize the planar dielectric resonators in these oscillators. The design approach helps maintain small size for these oscillators even at lower frequencies, with the low phase noise and low thermal drift required for a wide range of military, industrial, medical, and test-and-measurement applications.

These new DROs rely on planar resonators based on metamaterial Möbius strips (MMS), which are simple examples of anholonomy. The geometrical phenomenon of anholonomy depends on the failure of a quantity to recover its original value, when the parameters on which it depends are varied around a closed circuit.[1-3] Metamaterials are engineered periodic composites that have negative refractive-index characteristics not available in natural materials.[4-7] Such materials, in typically arrangements with split rings (SRs) and metallic conducting wires, can achieve values of negative permeability (−μ) and negative permittivity (−ε).[8]



In general, the refractive index of a medium can be characterized by four possible sign combinations for the permeability-permittivity pair (με) and can be described[9-18] by means of Eqs. 1-4:

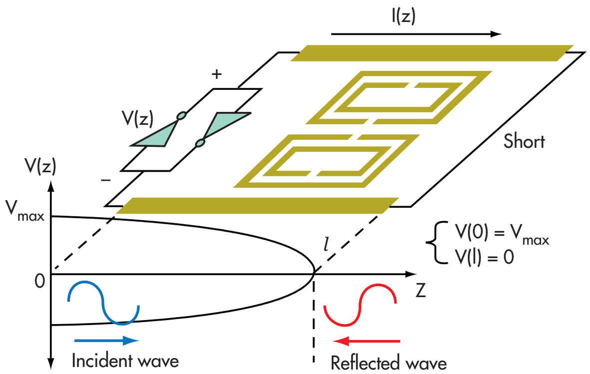
$$n = [(+\varepsilon)(+\mu)]^{0.5} = (+)(\mu\varepsilon)^{0.5} \quad (1)$$

$$n = [(-\varepsilon)(+\mu)]^{0.5} = j(\mu\varepsilon)^{0.5} \quad (2)$$

$$n = [(-\varepsilon)(-\mu)]^{0.5} = (-)(\mu\varepsilon)^{0.5} \quad (3)$$

$$n = [(+\varepsilon)(-\mu)]^{0.5} = j(\mu\varepsilon)^{0.5} \quad (4)$$

where:



1. This is a typical simplified representation of a differential transmission line based SR (ref, 20).

$\varepsilon_0 = 8.85 \times 10^{-12}$ F/m;
$\mu_0 = 4\pi \times 10^{-7}$ H/m; and
n = the refractive index of the medium.

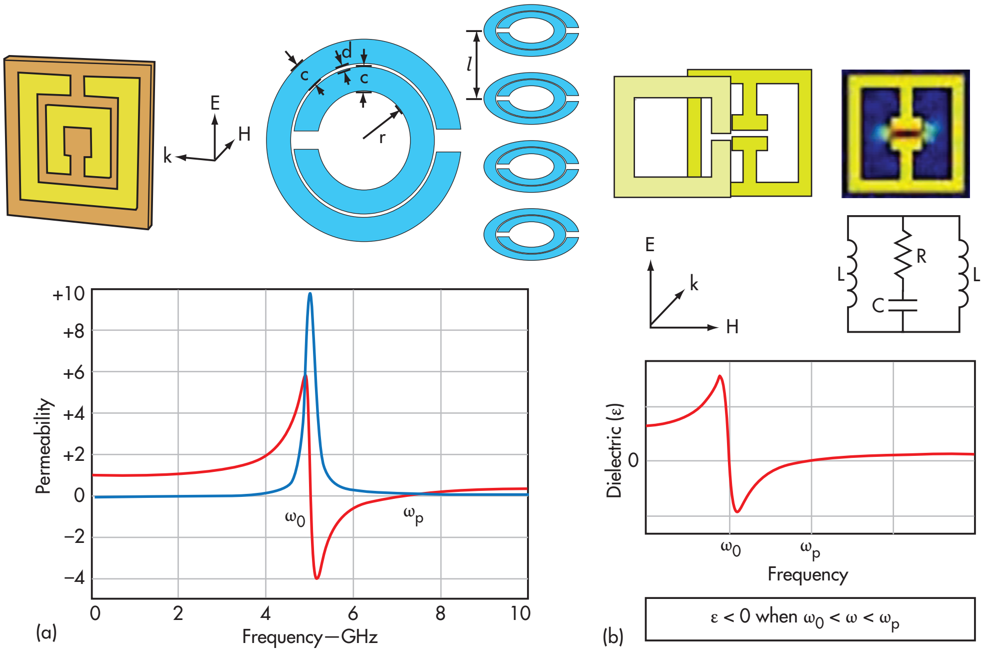
Equation 1 is valid for double positive substrate (DPS) materials, with permittivity and permeability both positive; Eq. 2 is valid for epsilon negative (ENG) substrate materials, with negative permittivity and positive permeability; Eq. 3 is for double negative (DNG) substrate materials, with permittivity and permeability both having negative values; and Eq. 4 is for μ negative (MNG) substrate materials, where the permeability is negative but the permittivity has positive values.

The DNG materials described by Eq. 3 are typically defined as artificial materials and commonly referred to as "metamaterials" in the technical literature. They are alternately known as left-handed materials (LHMs), negative index materials (NIMs), and backward-wave materials (BWMs).[19] The unusual characteristics of metamaterials, such as backward-wave propagation, exhibit group velocity characteristics in a direction opposite to that of its phase velocity, causing strong localization and enhancement of fields. This can result in significant enhancement of a resonator's quality factor (Q), assuming losses can be minimized.[20]

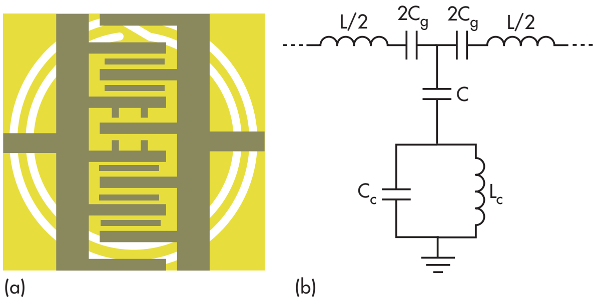
The realization of true DNG material (metamaterial) is questionable. In general, it is difficult to build a material or medium simultaneous with negative permittivity and negative permeability for broad operating frequency ranges from a set of arbitrary passive structure unit cells arranged in predetermined order. This may lead to a violation of energy conservation principle at the intersecting plane between a right-handed material (RHM) and LHM media because of the generation of energy.

An attempt to build the DNG material or medium—based on the fact that for a specific orientation and arrangement of the passive structure, the values of permittivity and permeability diminish as the frequency increases—has been applied to demonstrate virtual negative permittivity and permeability at specific frequencies, but it lacks validity for broadband operation. In reality, it is easier to demonstrate independently negative permeability or negative permittivity, but achieving both negative characteristics in a DNG material can be difficult.

Printed multicoupled slow-wave resonators exhibit improved Q-factor characteristics, and are commonly employed in low-phase-noise oscillator applications.[21] For example, improvement in the Q-factor of a slow-wave resonator (λ/4 coplanar stripline) can be realized by forming an open-



2. A typical SRR structure exhibits tunable characteristics for permeability (a) for μ (μ < 0) near the resonant condition and (b) for permittivity for ε (ε < 0) near the resonant condition (refs. 17 and 18).



3. These diagrams show a typical metamaterial-based Möbius strip resonator: (a) layout and (b) electrical equivalent lumped-element model circuit.

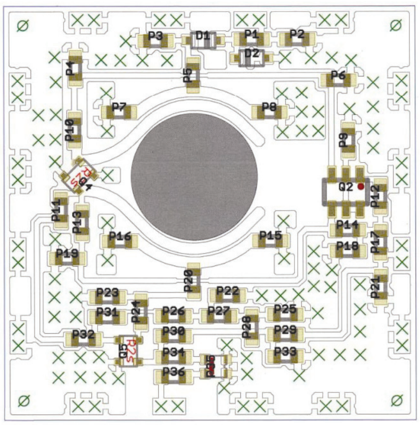
circuit load where the incident and reflected electromagnetic (EM) waves move entirely in-phase with each other. In reality, such open-circuit conditions are difficult to maintain over a desired frequency band.

In addition, the implementation of a $\lambda/4$ coplanar stripline circuit on a substrate can increase the overall size of the circuit. Insertion of additional floating metal shields may help alleviate some of the problems with slow-wave circuit designs.[21-25]

But negative-permeability-based planar split-ring-resonator (SRR) structures and complementary split-ring-resonator (CSRR) structures can enable compact on-chip implementations of these circuits, with promising and cost-effective solutions for metamaterial oscillator and filter applications.[26-29]

In the proper arrangement, planar SRR and CSRR structures can achieve independently negative permeability and negative permittivity at the resonance needed to create optimum coupling for a disc resonator in a high-performance DRO. These structures can be characterized as magnetic and electric dipoles excited by the magnetic (H) and electric (E) fields along the ring axis.[7]

Interestingly, a single-negative property ($-\varepsilon$ or $-\mu$) supported by an SRR or CSRR structure can yield a sharp stopband in the vicinity of the resonant frequency. This enables storage of EM energy into an SRR or CSRR structure through an evanescent-mode coupling mechanism, resulting in high Q. It should be noted that the Q multiplier effect does not violate the law of conservation of energy, since the evanescent mode in an SRR stores energy but does not transport energy.[21]



4. This layout shows the realization of a 10-GHz DRO in a compact 0.75 × 0.75-in. SMD square package.

Figure 1 shows a typical differential transmission-line-loaded, SRR-based metamaterial resonator oscillator. For a differential (push-pull) oscillator, the incident wave energy injected by the cross-coupled inverters propagates in forward waves along the transmission line towards the circuit's short point; the energy is reflected at the SRR load, and the reverse wave has a superposition of the incident wave and leads to a resonance when in phase. Stronger wave reflection means less loss and higher resonator Q.[20]

When working with artificial composite materials, the negative permeability response can be manipulated by including electrically small resonant shapes, such as split rings. *Figure 2* depicts a typical SRR structure for the realization of tunable $\mu(\mu < 0)$ and $\varepsilon(\varepsilon < 0)$ characteristics for applications in tunable oscillator circuits.[17,18]

Möbius strips offer unique characteristics, including self-phase-injection properties along the mutually coupled surface of the strips, enabling enhanced Q for a given size of printed transmission-line resonator. The oscillator's loaded Q, Q_L, is described by Eqs. 5 and 6:

$$Q_L = \frac{\omega_0}{2}\left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} = \frac{\omega_0}{2}\tau_d; \quad \tau_d = \left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} \tag{5}$$

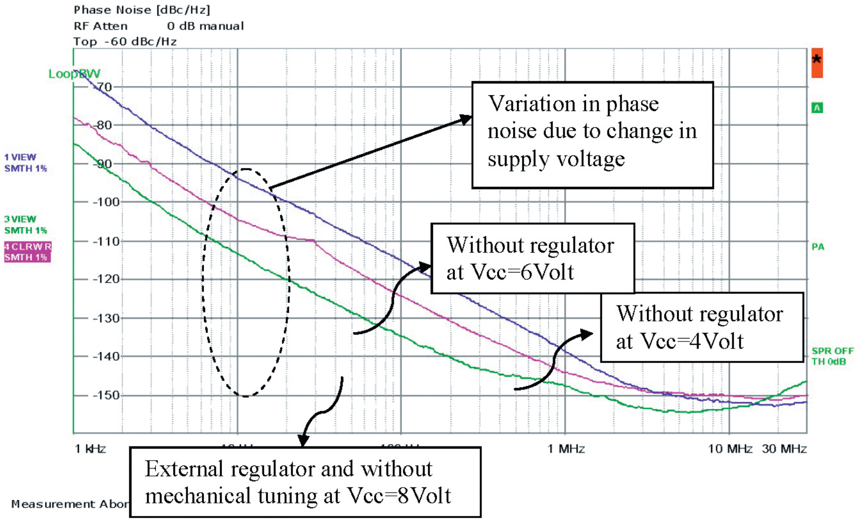
$$\tau_d = \left.\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} = \frac{\varphi(\omega_0 + \Delta\omega) - \varphi(\omega_0 - \Delta\omega)}{2\Delta\omega} \tag{6}$$

where:

$\varphi(\omega)$ = the phase of the oscillator's open-loop transfer function at steady state, and
τ_d = the group delay of the metamaterial Möbius strip resonator.

Figure 3 shows a typical metamaterial-based, Möbius-strip resonator and its equivalent lumped-element model circuits. From Eqs. 5 and 6, by introducing mode injection into metamaterial Möbius strips, phase-dispersion, loss, and group delay can be optimized.

For applications requiring compact size DROs, surface-mount-device (SMD) DROs have been developed in housings measuring just 0.75 × 0.75 in. and also available on printed metamaterial Möbius strips in 0.5 × 0.5 in. and 0.3 × 0.3 in. square packages for low-cost signal-source applications. These oscillators can be extended to any number of fixed frequencies, typically from 3 to 18 GHz, without long lead



5. This phase-noise plot was measured for the 10-GHz model DRO 100-8 oscillator from Synergy Microwave Corp., based on a metamaterial resonator.

times required to produce the sources. *Figure 4* shows a typical layout of a 10-GHz DRO in a 0.75 × 0.75 in. housing (a model DRO 100-8 from Synergy Microwave Corp.) while *Fig. 5* shows measured phase noise, at better than −108 dBc/Hz offset 10 kHz from the carrier.

These oscillators should be powered by a clean DC bias voltage, otherwise an external regulator should be employed to minimize variations in supply voltage. A DRO factory set for an output frequency of 10 GHz, for example, can be mechanically adjusted by about ±50 MHz.

An electrical tuning port provides an adjustment range of ±1 MHz with tuning voltages of +1 to +15 VDC to compensate for frequency drift in phase-locked systems. The supply-current is typically 30 mA and the temperature range is specified from −25 to +70°C. mw

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