Miniaturization of Microwave Resonators

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Opinion

Among the devices that were used for microwave range applications, one that proved to be hard to miniaturize was resonator. Earlier wave guide-based cavity resonators were used for frequency selection and for material measurements. They used to give quality factors of a few thousand depending on the material used for making it, geometry, frequency and surface finish. For low power applications, planar microwave integrated circuits came. But the resonators in such planar circuits were giving quality factors mostly in double digits. This difficulty was overcoming with the advent of dielectric resonators (DR). They are ceramic pucks mostly in cylindrical geometry. They are made up of materials that give high dielectric constant (the wavelength of the electromagnetic field inside a material goes inversely as the square root of its dielectric constant) inside a abut with low dielectric loss and low temperature coefficient of resonant frequency (τf). Generally, when dielectric constant goes up the other two also will go up. In some solids, the structure and lattice dynamics are such that they yield a higher value for the dielectric constant but owing to their tight packing or with onset of covalence, the loss factor remains low. In such cases the anharmonicity associated with lattice modes also will be less, leading to lower values of coefficient of thermal expansion. With increasing temperature, the volume will slightly increase while the dielectric constant slightly decreases in these materials. Effects of these two factors are opposite in these materials and when they equalize, that yields a τf that could be close to zero ppm/0C. These DRs can easily be integrated with the planar microwave circuits since the field of the DR can easily get coupled with the field around a planar transmission line. The volume of DRs is about 1cm3 or less depending on the frequency. That is acceptable in a microwave integrated circuit (MIC) but not in a microwave monolithic integrated circuit (MMIC). Therefore, there was a serious effort to identify miniature resonators compatible with MMICs.

The best alternate route for miniaturization of resonators for planar circuits is using electro acoustic resonance. Here one will have to use a piezoelectric material for electro acoustic conversion by piezoelectric effect. The advantage is that, acoustic velocity in material medium is about 5 orders of magnitude lower than that of electromagnetic velocity but the frequency can be in GHz. As a result, wavelength in the material medium at such frequencies is proportionally smaller, facilitating miniaturization. Initially surface acoustic wave (SAW) devices were being used but the resonant frequency of such resonators was in the MHz range. Once the thin films of such piezoelectric were developed, it was possible to make the resonance occur across the thickness of a piezoelectric thin film, making them work at frequencies in the GHz range as the thickness of the film can be in the sub-micron range. They are the film bulk acoustic wave resonators (FBAR) which give Q values of a few thousands in the lower GHz frequency range. There are variants of it which gives multiple resonances with Q values greater than 20,000 by making use of a low loss substrate and acoustic impedance mismatch at the substrate- air boundary. Some of these resonators are slightly tunable if they are made with a ferroelectric thin film.

In the case of RFICs where circuits work in the GHz range with massive integration, resonators are made with tank circuits comprising discreet L and C which offer Q values less than 20. However this deficiency is being overcome now in the 0.5-6GHz wireless communication bands, using new SAW-less radio receiver architectures which realize selectivity by employing N-path filters and mixer-first receivers which offer high-linearity and high-Q RF-filtering around a center frequency defined by a digital clock. It offers the desired programmability also. This is a solution where massive integration is employed in CMOS technology, which works out well for mass production. But for smaller scales, the FBAR or its variants are still important. Another trend towards miniaturization in high frequency resonators is coming up through micro machining. It involves making high Q inductors by one of the approaches that employ micromachining along with MEMS based air bridge capacitors that offer higher Q. Also, there are released mechanical disc resonators. An extension of micromachining is being tried for THz range where the cavity itself is being micromachined as the wavelengths are in submm range. The same approach is easier to be attempted in the mm wave range using surface integrated waveguide (SIW) approach. High Q resonators are becoming more important with emerging 5G scenarios as the number of radios that are required to implement the 5G scheme is

quite high and to accommodate them with minimum component count, such resonators are quite helpful. Therefore, the march towards miniaturized resonators offering narrow band frequency selection with minimum component count is expected to continue by employing novel phenomena, materials, processes and design approaches.

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