Recent Advances on Angular Momentum Magnet-Free Circulators

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The design of magnet-less circulators has recently attracted a lot of attention, for numerous applications in civilian and military communications systems. In particular, circulators are necessary components for the realization of full-duplex communication systems, but so far, they have been typically based on magnetic materials, making their integration in such systems very difficult, if not impossible. Our group has been actively working towards overcoming this problem by introducing a technique for the design of circulators, namely angular-momentum biasing, which does not require magnetic materials and that can be fully implemented through conventional circuit techniques. Our technique is based on introducing an effective spin to a closed circuit, by modulating its parts in time with appropriate electrical signals, which can be shown to lead to the same non-reciprocal effects as the static magnetic field in magnetic circulators. Our initial efforts in this direction were based on loops of three identical resonators strongly and symmetrically coupled to each other, and modulated in time with signals of the same amplitude and a phase difference of 120 deg, and has resulted in circulators with very large isolation and small modulation frequency.

In this talk, we will present our latest progress in this topic towards improving several metrics of the circulators, including reducing the intermodulation products, reducing the insertion loss, increasing the bandwidth and increasing the maximum operation power. In particular, we will present a differential architecture, consisting of two parallel-connected circulators modulated with a phase difference of 180 deg, which can lead to a substantial reduction of the intermodulation products. This approach also leads to an improvement in insertion loss, since intermodulation products are effectively a type of loss, and an increase of the operation power, due to splitting of the power to two parts. We also show how we can further increase the input power by using an anti-series connection of varactors and adding impedance transformers at the ports. Then, we move to the case of extending the bandwidth of the circulator, by replacing the resonators in the original angular-momentum approach with filters of arbitrary order. We present an analytical theory for this case and derive the conditions on the filter characteristics (order, position of poles and zeroes) in order to obtain a specified non-reciprocal response over a given bandwidth. Our results show that by combining these approaches, it is possible to design circulators that meet most of the criteria required in practical systems, yet do not require magnetic bias.