Substrate-Integrated-Waveguide Diplexer Filter for SATCOM-on-the-Move

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***Abstract*—Satellite communication (SATCOM) on-the-move applications require low-cost compact antenna arrays to enable mobile users to track the satellites. Full-duplex operation requires efficient diplexers that satisfy stringent requirements in a compact footprint to enable tight integration within the antenna system. In this contribution, substrate-integrated-waveguide technology is leveraged to design a single-layer third-order diplexer filter based on a dual-mode cavity. Simulations and measurements demonstrate that the diplexer enables full-duplex operation for Ku-band SATCOM on-the-move systems, effectively separating the [11.7–12.75] GHz downlink (Rx) band from the [13.75–14.50] GHz uplink (Tx) band, yielding an isolation larger than 20 dB and an insertion loss below 3.7 dB over a fractional bandwidth (FBW) of 8.6% in Rx and 5.3% in Tx.**

***Index Terms*—Dual-mode cavity filter, Ku-band Diplexer, SATCOM-on-the-move, Substrate integrated waveguide.**

I. Introduction

Satellite communication (SATCOM)-on-the-move (SOTM) enables 5G wireless communication in the most remote locations on the planet as in the air. To exploit the full capacity of the data link with the satellites, full-duplex operation, with simultaneous uplink and downlink communication, is preferred. For easy deployment in mobile user equipment, a digitally controllable [1] shared-aperture phased antenna array that covers both uplink and downlink bands should be compact, lightweight and integrable. Within a footprint that is limited by the maximally allowed antenna element spacing, highly specialized components must be fitted, such as dual-band antennas, integrated circuits, feed lines, transitions and diplexers [2]–[7]. The latter are of utmost importance to implement full-duplex communication in a shared aperture system with minimal interference between transmit and receive chains. To further limit undesired interaction with the environment or other system components, the diplexer should also be self-packaged, while being tightly and compactly integrated with the antenna and the active beamforming electronics.

Most existing diplexer designs, which combine two filters by a T-junction [8]–[14], exhibit excellent performance, but are bulky and non scalable. Other diplexer types rely on mode perturbation [10]–[12], negative coupling and modal cross-coupling [9], [13]. The latter also plays a role in common dual-mode cavity-based designs, which is the topology exploited in this contribution. Other solutions take advantage of special transitions with diplexer functionality [6] or implement a self-diplexing antenna [15]. However, these designs yield limited bandwidths and their geometry does not allow scalability. Also more specialized and complex designs exist [16]–[21]. However, they lack scalability and introduce too much complexity for the application of interest. The scalable diplexers in [22] make use of technologies that are too expensive. An interesting approach to reduce the diplexer's size in a more flexible way consists in exploiting a common cavity that replaces the T-junction [23]–[28].

This contribution presents a novel very compact and cost-effective Substrate-Integrated-Waveguide (SIW) diplexer architecture, targeting SOTM applications in the Ku-band. Therefore, the designed single-layer diplexer separates the [11.7–12.75] GHz downlink (Rx) band from the [13.75–14.50] GHz (Tx) uplink band, with an isolation larger than 20 dB and an insertion loss lower than 3.7 dB. The fractional bandwidths (FBWs) in which this performance is obtained correspond to 8.6% for Rx and 5.3% for Tx, respectively. In particular, the FBW along the Rx path is large in comparison to existing diplexer designs. This response is achieved by first dimensioning three substrate integrated rectangular cavities (SIRC) as to achieve a third-order Chebyshev filter characteristic, for both separate Tx and Rx filters. Next, a common dual-mode cavity is exploited to integrate both circuits into a single-layer diplexer.

II. Ku-band SIW diplexer design

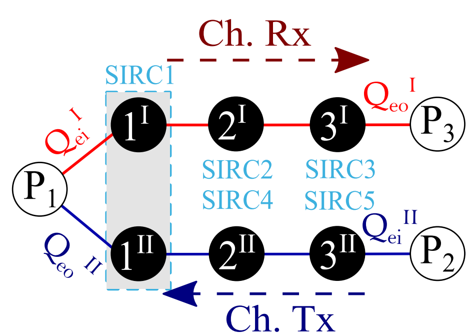

Fig. 1. Topology of single-layer third-order direct-coupled SIW diplexer.

The topology of the diplexer is schematically shown in Fig. 1. The Rx and Tx channel, annotated by I and II superscripts, respectively, both consist of three SIRC resonators, implemented in a 0.508 mm-thick Rogers RO4350B ($\epsilon_r = 3.66$, $\tan\delta = 0.0037$) high-frequency laminate. Two cavities operate with their TE_{101} resonance at the center frequency (CF) of the corresponding channel, being f^I or f^{II}. The third cavity is shared between both channels and is designed such that its TE_{101} resonance corresponds to f^I

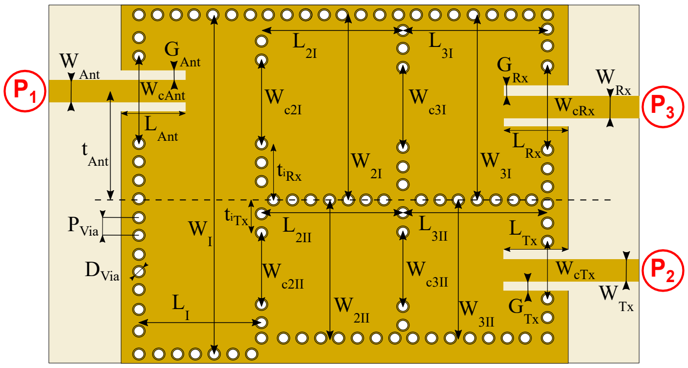

Fig. 2. Geometric configuration of single-layer third-order direct-coupled SIW diplexer. Optimized dimensions in millimeters: $D_{Via} = 0.5$, $G_{Ant} = 0.6$, $G_{Rx} = 0.51$, $G_{Tx} = 0.53$, $L_{2I} = 7.49$, $L_{2II} = 7.77$, $L_{3I} = 7.54$, $L_{3II} = 6.92$, $L_{Ant} = 3.45$, $L_I = 6.5$, $L_{Rx} = 1.93$, $L_{Tx} = 2.75$, $P_{Via} = 1$, $t_{Ant} = 5.77$, $t_{i_{Rx}} = 3$, $t_{i_{Tx}} = 1.93$, $W_{2I} = 10.47$, $W_{2II} = 7.76$, $W_{3I} = 10.47$, $W_{3II} = 8.78$, $W_{Ant} = 1.4$, $W_{c2I} = 4.74$, $W_{c2II} = 3.9$, $W_{c3I} = 4.48$, $W_{c3II} = 4.05$, $W_{cAnt} = 5.74$, $W_{cRx} = 4.6$, $W_{cTx} = 3.46$, $W_I = 18.97$, $W_{Rx} = 1.4$, $W_{Tx} = 1.4$, $h_{dielectric} = 0.508$. Single-layer dielectric implemented in Rogers 4350B (ϵ_r= 3.66, tanδ= 0.0037).

and the TE_{201} resonance to f^{II}, thus operating as a dual-mode cavity. The coupling to adjacent resonators and the feed of the common cavity is optimized through modal cross (bypass) coupling [29] to generate an additional transmission zero between the Tx and Rx channel, allowing to achieve the requirements with a third-order Chebyshev-like diplexer design.

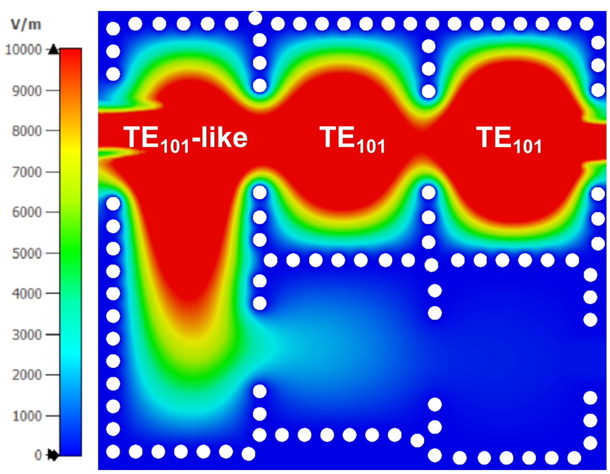

Fig. 3. Electric field magnitude distributions at 12.2 GHz when port 1 (antenna) is excited. Signal propagating to port 3 (Rx, receiver).

Fig. 2 shows the final diplexer design, featuring a footprint of 22.1 mm by 19.7 mm. All relevant dimensions, obtained by computer-aided optimization in CST Microwave Studio, are listed in the figure's caption. The operating principle of the realized diplexer is illustrated in Fig. 3, showing the signal at 12.2 GHz, propagating from the antenna to the receiver port and being blocked by the dual-mode cavity to suppress potential reception at the transmitter port, and in Fig. 4, visualizing the signal at 14.4 GHz, propagating from

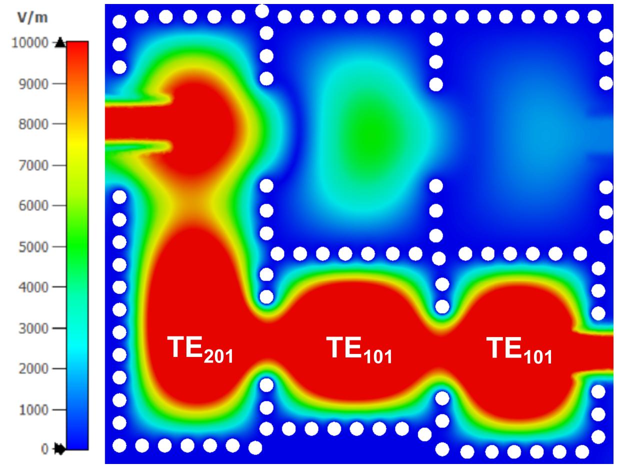

Fig. 4. Electric field magnitude distributions at 14.1 GHz when port 2 (Tx, transmitter) is excited. Signal propagating to port 1 (antenna).

the transmitter port to the antenna and suppressing potential reception at the receiver port by the dual-mode cavity and the transmission zero implemented by modal cross-coupling.

III. Prototype and Measurements

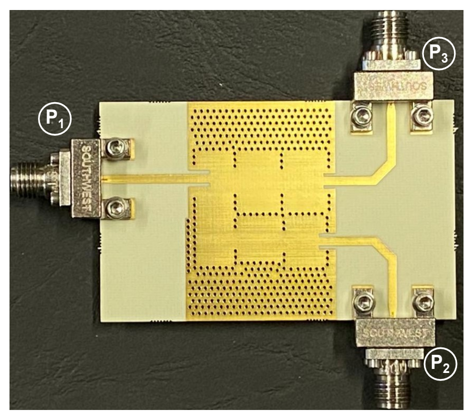

Fig. 5. Fabricated prototype of the single-layer third-order direct-coupled diplexer.

To validate its operation, a prototype of the diplexer, shown in Fig. 5, was manufactured and characterized. Fig. 6 shows the transmission and reflection coefficients (S_{31} and S_{33}) along the Rx path, demonstrating that the [11.7–12.75] GHz band is covered with a maximum insertion loss of 3.69 dB, and with more than 20.47 dB suppression in the Tx band. Fig. 7 confirms that the transmission coefficient S_{12} along the Tx path exhibits an insertion loss lower than 3.59 dB over the complete [13.75–14.5] GHz band, with more than 25.18 dB suppression in the Rx band. Moreover, the isolation between Rx and Tx channel was measured to be better than 20.57 dB.

IV. Conclusion

A single-layer third-order direct-coupled SIW diplexer is proposed, with a minimum isolation of 20 dB and an insertion

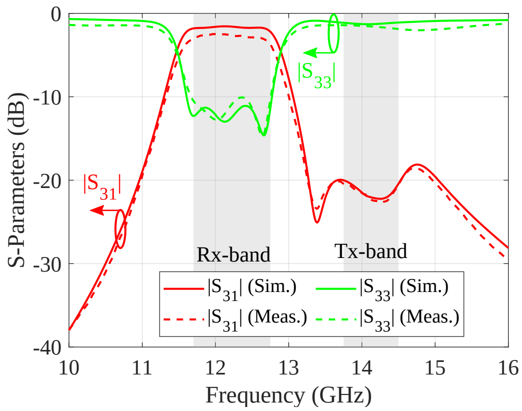

Fig. 6. Simulated (full line) versus measured (dashed line) transmission (S_{31}) and reflection (S_{33}) coefficients along the Rx path.

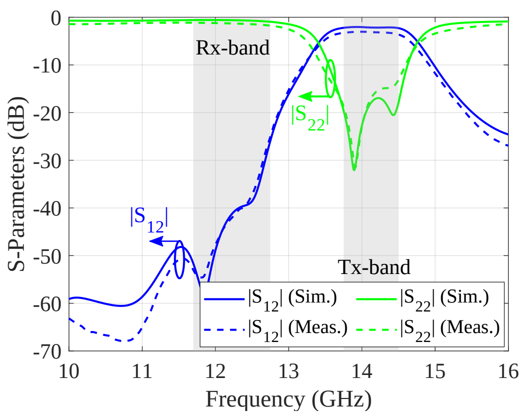

Fig. 7. Simulated (full line) versus measured (dashed line) transmission (S_{12}) and reflection (S_{22}) coefficients along the Tx path.

loss below 3.7 dB, paving the way for low-cost shared-aperture full-duplex antenna arrays for next-generation Ku-band SATCOM-on-the-move applications.

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