A Slotline DC Block for Microwave, Millimetre and Sub-Millimetre Circuits

Boon-Kok Tan and Ghassan Yassin

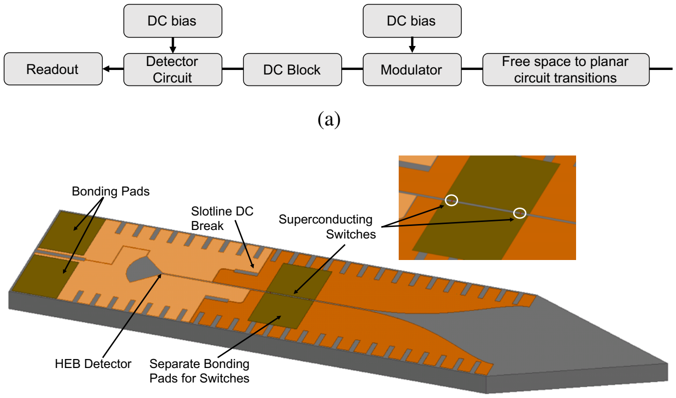
***Abstract*—DC blocks are used frequently in planar circuits to enable separate DC voltage/current biasing of active components inserted along the transmission lines. In this Letter, we present a slotline DC block design where the conductors of the transmission line can be physically broken, while allowing the propagation of the RF signal across the discontinuity with negligible insertion loss. The DC block comprises two break-lines with narrow gaps, patterned on the two ground planes of a slotline with each break-line connected to an RF choke. The RF chokes present open circuit nodes that prevent the RF power from leaking into the break-lines gaps. We have fabricated and tested the DC block, and demonstrated that the measured performance agrees very well with simulated results. The insertion loss was close to –0.5 dB in the designated range of 12–16 GHz, demonstrating that the RF leakage through the DC block is indeed negligible.**

***Index Terms*—DC block, Microwave propagation, Microwave circuits, Millimeter wave integrated circuits, Printed circuits.**

I. INTRODUCTION

DC blocks are commonly used in many circuits when different components in the circuit require separate voltage or current biasing without interference. For example, in a multi-stage varactor oscillator or a radiometric system such as the modulating power detector circuit shown in Fig. 1 (a). Since all the components in these setups are connected by a conducting transmission line, a DC break in the transmission line is needed in order to obtain independent biasing of separate components. DC blocks are also used to isolate the ground loop problem that afflict many uniplanar circuit systems, and to reduce low-frequency noise that can leak into the system.

A high performance DC block requires careful design in order to minimise the loss of the RF signal as it crosses the break. At low frequencies, DC blocks are realised using series-connected lumped-element capacitors. At microwave to sub-millimetre (sub-mm) frequencies however, high quality lumped element capacitors are not readily available. Hence we need to use either planar circuit capacitors or end/edge coupled bandpass filters to block the flow of DC current along the transmission line. These solutions however are only applicable to unbalanced transmission lines, such as microstrips or coplanar waveguides (CPWs) where DC blocking is achieved by breaking the top wiring layer of the microstrip or the central conductor of the CPW with an end/edge coupler or a capacitor [1], [2], [3], [4], [5], [6], [7]. To apply this technique to balanced transmission line such as slotlines, the slotline needs first to be transformed into an unbalanced transmission line [8], [9] which complicates the fabrication, increases the losses and the size of the circuit, and inevitably limits the bandwidth of operation. Therefore, for balanced uniplanar transmission lines such as slotlines or finlines, which are used extensively in microwave to sub-mm applications, a direct slotline DC block is a very attractive solution.



(a)

(b)

Fig. 1. (a) An example of a detector circuit integrated with a modulator which requires a DC block to enable separate DC biasing for the detector circuit and the modulator. (b) A planar HEB detector chip integrated with superconducting switches, operating at millimetre frequency range.

Our motivation for developing the DC block described here is to use it as a component in a high-speed low-loss modulator circuit at millimetre wavelength, where the electromagnetic waves propagate along a superconducting finline chip, as shown in Fig. 1 (b). The modulator in this example comprises two superconducting bridges shunting the finline slot. The detail of operation of the superconducting switch can be found in [10]. Switching between the *on* state (wave transmitted) and the *off* state (wave reflected) is achieved by using an external current bias, which alternates above and below the superconducting critical current value. In this example, detection of the transmitted waves is performed using a hot electron bolometer (HEB) detector [11]. As both the detector and the switch require separate biasing arrangement, a slotline DC block therefore is necessary without the complexity of multi-layer fabrication. Such circuits are common in astronomical receivers that use superconducting devices as detectors. Hence, these types of application would benefit greatly from a direct slotline DC block design.

II. DESIGN

We shall now describe a new concept for designing a slotline DC block that does not require the complexity of transition to

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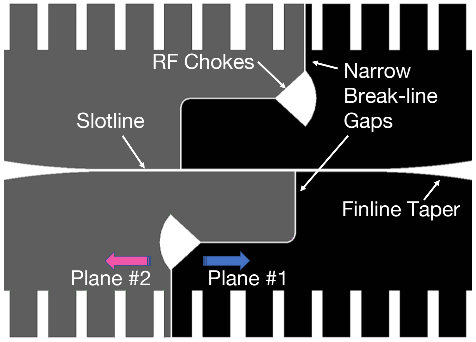


Fig. 2. Illustration of a slotline DC block utilising two RF chokes and the accompanying narrow break-lines to physically break the transmission line.

microstrip or CPW, nor the need for multi-layer capacitors that require complex lithographic techniques at the millimetre and sub-mm regime. This is achieved by fabricating break-lines connected to quarter-wavelength RF chokes in the ground planes on either side of the slotline, as shown in Fig. 2. The RF chokes present open-circuit nodes to the signal propagating along the break-line gap, hence preventing the power leakage into the DC break, and enabling the RF wave to propagate along the slotline almost uninterrupted by the break. The two break lines and RF chokes are antisymmetric to each other, to prevent the RF signal leaking into both narrow break gaps from the same slotline location simultaneously.

Based on this method, we have designed two slotline DC blocks operating near 220 GHz range, one with radial chokes and another with rectangular chokes, using the 3-D electromagnetic simulator Ansys High Frequency Structure Simulator (HFSS). The slotline and the DC blocks are formed using 50 nm thick niobium nitride superconductor (operating at 4 K cryogenic temperature), deposited on a 100 μm thick quartz substrate. The radial choke design has a slightly broader bandwidth performance, but wide angle radial chokes could potentially intercept the slotline, if it is placed too close to the slotline, hence limits the flexibility in designing the DC block. The rectangular choke on the other hand is more compact, but has a slightly narrower operational bandwidth. These DC block designs can be modified as required by specifications, for example to further widen the bandwidth, one could cascade a series of chokes at slightly different lengths. The narrow break-line gaps in the ground plane are 3 μm wide, with the two RF chokes placed at a distance approximately $n\lambda/4$ from the slotline where n is an integer and λ is the guided wavelength. As shown in Fig 3, we can achieve 40% operational bandwidth with return loss close to –20 dB from ~180–265 GHz, and the insertion loss around –0.5 dB.

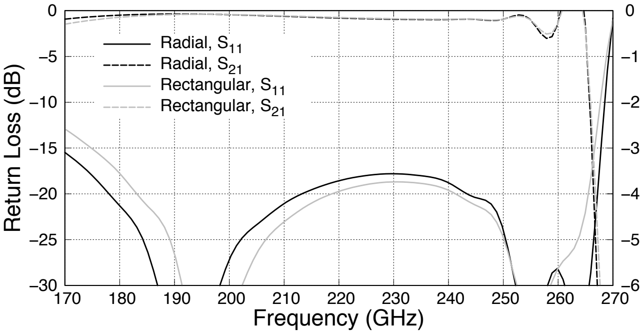


Fig. 3. HFSS simulated performances of the slotline DC blocks operating at millimetre wavelength.

III. Scale Model & Experimental Results

To measure the performance of the DC blocks without the complication of cryogenic environment, we scaled the design presented above to the microwave (Ku-band) regime, so that measurements can be done using a 2-port vector network analyser (VNA). This is justifiable since the DC-block is a passive device, and because we wanted to demonstrate that the same design could operate well in the microwave range.

For these scale models, we fabricated the DC block across the slotline between two back-to back unilateral finline tapers [12]. The narrow break-line gaps in the ground plane of these scale models are 50 μm wide. The finline tapers acted as slotline-to-waveguide transitions, as shown in Fig. 2 and 4, such that we can perform the measurement with the VNA equipped with rectangular waveguide ports. The DC block and the finline transmission lines were fabricated on one side of a 31 mil (0.787 mm) thick Duroid Roger 5880 printed circuit board ($\epsilon_r = 2.2$), and the chip was mounted in the E-plane of a Ku-band rectangular waveguide block. The entire structure (DC block integrated in the finline taper transitions) was optimised using HFSS to accurately model the DC block and the 3-D surrounding structure.

To assess the measured performance of the DC block, we also fabricated and tested two additional chips. One of them comprised a back-to-back waveguide-to-slotline transition without the DC block structure. It allowed us to calibrate out the insertion and return losses caused by the waveguide-to-slotline transitions and hence to determine the S-parameters corresponding to the DC block alone. The second chip comprised an identical back-to-back transition with the 50 μm break-lines on both ground planes but without RF chokes. This allowed us to demonstrate the sensitivity of the DC block design to the existence of the RF chokes.

In Figure 5 (a) and (b), we show the measured return and insertion loss of the DC block, calibrated with the S-parameters of the back-to-back finline transition (see Figure 5 (c)) as explained above. The measured results agree very well with simulated results for both the rectangular and the radial choke designs. The return loss of the DC block with rectangular

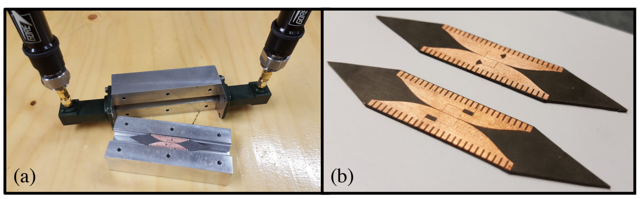
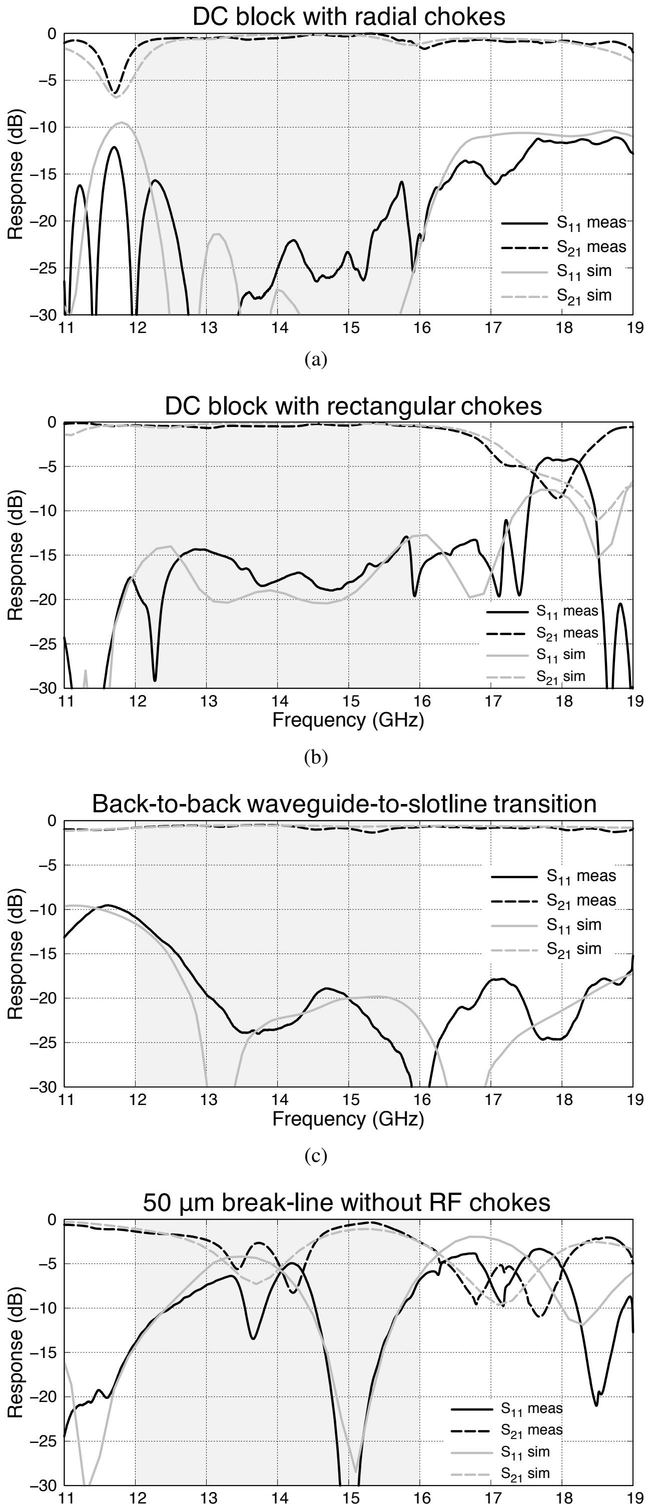


Fig. 4. (a) A slotline DC block fabricated between two back-to-back finline tapers mounted in a rectangular waveguide block for measuring the performance of the DC block. (b) A photo of the fabricated prototypes.

choke is below –15 dB in the frequency range 11–16 GHz, but the performance of the DC block with radial chokes is significantly better with return loss close to –20 dB in the frequency range 12.5–15.5 GHz [1]. This demonstrates that the loss in the RF signal propagating along the transmission line and crossing the DC block is negligible. Finally we show in Figure 5 (d) the S-parameters of the same chip in Figure 5 (c) but with 50 μm break-lines without the RF chokes. Both the measured and the simulated results show substantial loss in the propagating signal as a result the power leakage, demonstrating that the performance of the DC block is substantially improved by the presence of the RF chokes.



(d)

Fig. 5. Measured performance of the (a) radial chokes DC block and (b) rectangular chokes DC block; corrected for the (c) measured insertion and return loss of a back-to-back waveguide-to-slotline transitions. (d) Measured performance of the back-to-back transition with 50 μm break-lines on both sides of the ground plane but without RF chokes.

IV. CONCLUSION

We have presented a new design of a DC block for balanced uniplanar transmission lines that can operate from microwave to sub-mm wavelength. The DC block is easy to fabricate and avoids the need for complex 3-D lithography used in fabrication of parallel-plate capacitors or end/edge coupled filters. We have shown by both simulations and experimental tests that a DC block employing two narrow break-lines with RF chokes can have a return loss less than –20 dB and insertion loss better than –0.5 dB across the designated bandwidth. This design will be vitally important for fully planar miniaturised circuits at millimetre and sub-mm wavelength such as in astronomical receivers.

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[1] The power transmission is zero at DC and well below –30 dB below 1 GHz (simulated using HFSS with only the slotline and the DC blocks).