A Simple Method to Widen the IF Bandwidth of a High Frequency SIS Mixer

Boon-Kok Tan, Ghassan Yassin, *Member, IEEE,* and Paul Grimes

***Abstract*—In this paper, we describe a simple method for widening the instantaneous frequency (IF) bandwidth of a high frequency superconductor-insulator-superconductor (SIS) mixer. This method requires only a standard PCB technology, without incurring any difficulties or complication in altering the tunnel junction fabrication. It involves the use of a simple multi-stage IF transformer to match the dynamic output impedance of the SIS mixer to a 50 Ω load over a wide IF bandwidth. We use an existing 650 GHz SIS mixer chip as an example to illustrate the methodology of the IF transformer design. In this example, we show how we widen the IF bandwidth of the mixer to operate over 4–12 GHz bandwidth using this simple impedance matching method.**

***Index Terms*—Superconducting integrated circuits, system-on-a-chip, submillimeter wave devices, silicon on insulator technology, mixers.**

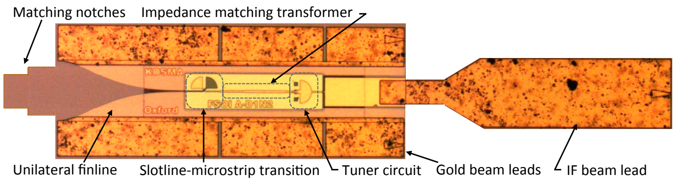
I. INTRODUCTION

AN SIS mixer that is capable of capturing a broad IF bandwidth has always been one of the main aim in SIS mixer design. For example, Atacama Large Millimetre/Submillimetre Array (ALMA) requires at least 8 GHz of IF bandwidth to enable observation of several astronomical emission lines in a single observation run. It is also important for mixers designed to detect the SunyaevZel'dovich effect such as the GUBBINS (220 GHz Ultra-BroadBand INterferometer for S-Z) telescope [1], which requires an IF bandwidth of 20 GHz wide. In recent years therefore, there has been extensive efforts to produce wideband IF bandwidth SIS mixers through fabrication of ultra-low capacitance junctions, or by employing distributed junctions [2]. However, most of these methods involve alteration to the junction fabrication process, which proved to be difficult and complicated.

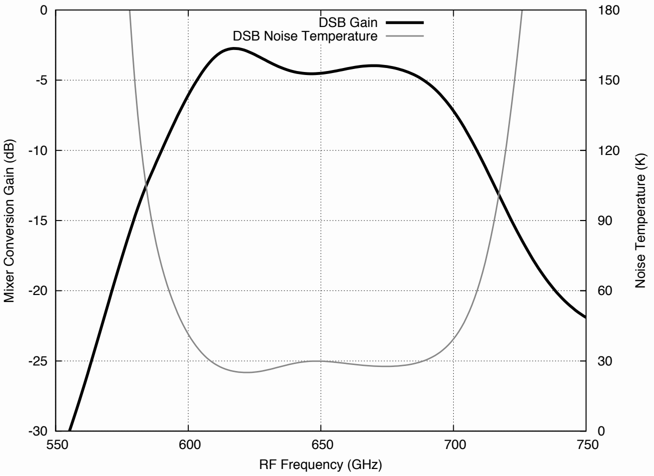
In this paper, we present a simple method of broadening the SIS mixer's IF bandwidth by impedance matching the dynamic capacitance of an SIS mixer chip to the 50 Ω IF amplification chain, using a multi-stage transformer. This method is simple and elegant, and requires only a PCB board at IF frequency which can be easily fabricated using standard PCB technology. It also do not alter the RF performance of the mixer, hence this method can also be applied to an existing SIS mixer chip design.

II. RF CHARACTERISTIC OF THE 650 GHZ UNILATERAL FINLINE SIS MIXER

To assist the illustration of the methodology, we use an existing 650 GHz unilateral finline SIS mixer as example, and widen its IF operating frequency to 4–12 GHz, in lieu with the bandwidth of our low noise amplifier (LNA). For completion, we shall briefly summarise the RF characteristic of the SIS mixer here. The detail of the design and the measured performance of the mixer chip can be found in [3].



(a)



(b)

Fig. 1. RF gain and DSB Noise Temperature

Unlike conventional mixers, our finline mixer was fabricated on a 15 μm thick SOI substrate [4]. It comprises a unilateral finline taper and a slotline-to-microstrip transition for coupling the RF signal from the waveguide to the tunnel junction. The unilateral finline gently tapers down the slot width from the waveguide width to about 3 μm, with impedance matching notches formed before the finline to minimise the return loss (see Fig. 1 (a)). The output of the finline (i.e., the slotline) is then transformed into microstrip line via two 90° radial stubs. The mixer's tuning circuit comprises an inductive strip with a half-moon stub, an inductive strip before the junction, and a broadband multi-stage transformer. The two inductive strips

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Manuscript received XXXX XX, 2013; revised XXXX XX, 2013.

are employed to tune out the junction capacitance [5], while the 3-step quarter-wavelength transformer is placed before this tuning circuit to bridge the impedance from the slotline-to-microstrip transition. As shown in Fig. 1 (b), the finline mixer has a wide RF bandwidth from 600–720 GHz, covering the entire atmospheric window of ALMA Band 9 receiver.

III. Design of the IF transformer

The key component to this new method of widening the IF bandwidth of an SIS mixer is the design of the IF transformer board. The design procedure is fairly simple, and can be optimised using conventional circuit design packages. We used Ansys High Frequency Structure Simulator (HFSS) to provide the flexibility of including structures such as the beam leads and bond pads, to make certain that the effective impedances induced by these structures are included in the design of the matching transformer. In the following, we lay down the steps for designing a multi-stage IF transformer PCB board for the above-described 650 GHz unilateral finline SIS mixer, for its best IF performance from 4–12 GHz.

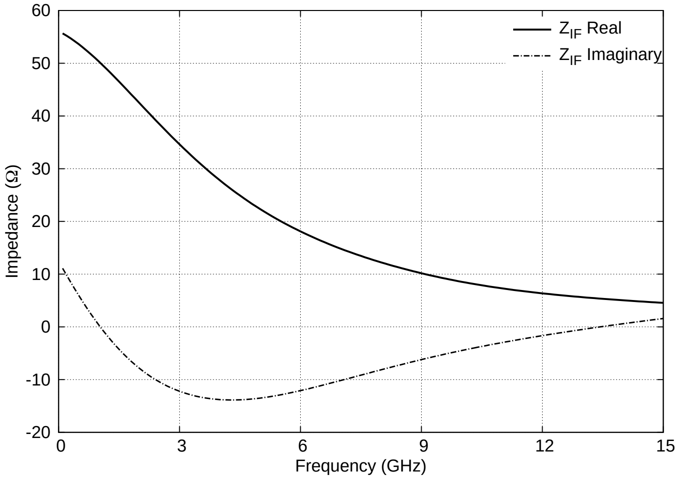

Fig. 2. The complex output impedance of the mixer chip seen from the IF port.

1) First, we constructed an equivalent circuit to obtain the IF termination output impedance of the mixer chip. This can be done using commercially available lumped circuit package such as Ansys Designer. We imported the scattering matrices of the passive components of the mixer chip from HFSS to form a sub-model in Designer to represent the RF mixer chip, once the RF design of the mixer chip was completed within HFSS model. The tunnel junction, represented by a lumped element resistor and a capacitor in parallel, was connected to the sub-model to form the complete RF circuit. By setting input port of the circuit to the incoming waveguide impedance, and the output port as 50 Ω, one can immediately plot the complex IF output impedance seen from the output port towards the mixer circuit, as shown in Fig. 2.
2) Once the RF equivalent circuit of the mixer chip is setup, several microstrip components from the Ansys Designer's library is cascaded together to form the IF transformer.

   In this example, we use a 6-stage IF transformer, where the first two section of the IF transformer form two inductive strips to tune out the majority of the mixer chip's capacitance, and the subsequent four sections serve to transform the remaining resistance to 50 Ω. This IF transformer design is then optimised to obtain the best performance over the desired 4–12 GHz bandwidth.

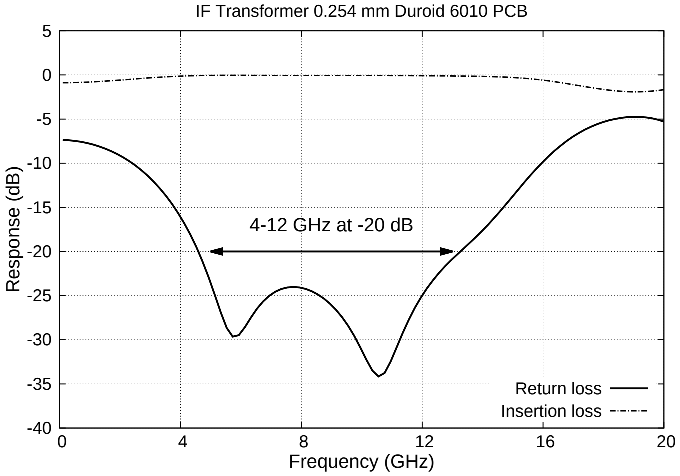

Fig. 3. Figure shows the HFSS predicted performance of the IF transformer.

3) Next, we use the HFSS package to refine the this lumped circuit model IF transformer, to include the effects of the IF gold beam leads, the bonding pads, and a more rigorous electromagnetism description of the IF transformer. Due to the large difference in size of the mixer chip and the IF transformer, we replace the actual model of the mixer chip with an RLC equivalent circuit, which is justifiable at the IF frequency. As shown in Fig. 3, we now have a close-to-realistic transformer design that has return loss less than –20 dB over 4–12 GHz.
4) Finally, the scattering matrix of the IF transformer is exported from HFSS to SuperMix for verification of the final full mixer IF performance. This step is important to make sure that the additional IF transformer does not deteriorate the RF performance of the mixer chip.

TABLE I

Dimensions of the optimised IF transformer on a 7.0 mm × 11.15 mm, 254 μm thick Duroid 6010 printed circuit board. All dimensions are in mm.

	Sect. 1	Sect. 2	Sect. 3	Sect. 4	Sect. 5	Sect. 6	Sect. 7
Width	0.40	1.31	0.60	0.36	0.14	0.35	0.20
Length	0.50	0.70	3.34	3.64	0.79	0.78	1.50

Figure 4 shows the performance of the SIS mixer working in conjunction with the IF transformer, simulated using the SuperMix model. As can be seen, the mixer gain is flat and remain stable from 0–15 GHz. Comparing to the case where the IF transformer is replace by a 50 Ω line (see Figure 4), the IF transformer has now broaden the IF bandwidth of the mixer by about a factor of three. Fig. 5 shows the finalised design of the IF transformer and the optimised dimensions of the IF transformer are given in Table I.

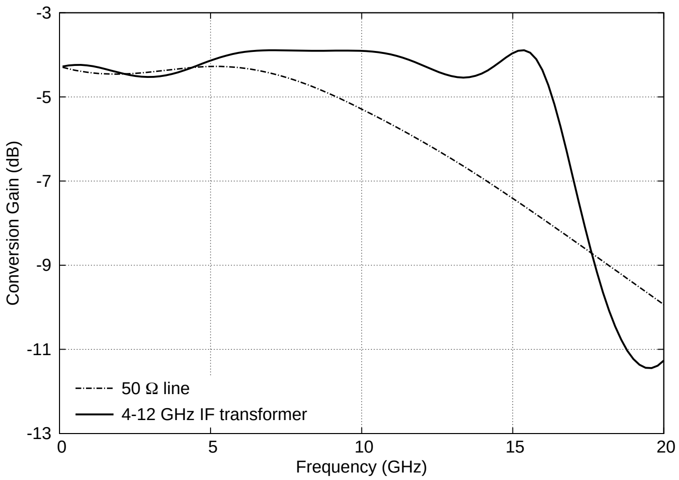

Fig. 4. SuperMix predicted mixer gain, with and without the IF transformer. With the matching IF transformer, the DSB gain remains flat up to ∼15 GHz, compared to the 50 Ω line case, where the gain starts to deteriorate around 5 GHz.

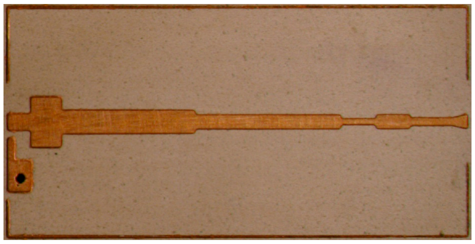

Fig. 5. The numbers in the diagram is corresponding to the numbers assigned to the transformer section tabulated in Table I. An additional section of a 50 Ω microstrip was added and flared wider (approximately 30°) towards the end to provide extra area for soldering contact with the pin of the SMA (SubMiniature version A) connector.

IV. CONCLUSION

We have presented a simple method for designing a wide IF bandwidth SIS mixer, by impedance matching the mixer's output impedance to a 50 Ω load using an IF transformer. The design of the transformer can be easily done using combination of commercial and free packages such as Ansys Designers, Ansys HFSS and Caltechs SuperMix package. The fabrication of the transformer board is straightforward using standard PCB technology. We use this method to broaden the IF bandwidth of an existing 650 GHz unilateral finline SIS mixer to 4–12 GHz. With the optimised IF transformer installed between the mixer chip and the LNA, SuperMix predicts a good IF performance from 0–15 GHz.

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