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Comments on "Josephson Effect Gain and Noise in SIS Mixers"

Daniel G. Jablonski

In their recent article [1], Wengler *et al.* report their observations and conclusions concerning the effects of Josephson currents on the microwave performance of superconductor-insulator-superconductor tunnel junction devices. I would like to caution that the authors seem poised to rediscover, the hard way, many lessons learned by researchers during the 1970s concerning the use of Josephson devices.

First, Wengler *et al.* do not cite any references published prior to 1982. As a result, they make no mention of a considerable body of published work relevant to their current research. In particular, there is no indication that the authors have reviewed early work in the development of Josephson effect mixers [2] and parametric amplifiers [3] built using point-contact and constriction microbridge devices. Point contacts and microbridges were popular because of the difficulties at the time associated with making reliable tunnel junctions, now known as S-I-S devices. Unlike S-I-S devices, point contacts and microbridges have negligible shunt capacitance and do not generally exhibit the quasiparticle, or photon-assisted tunneling steps exploited by S-I-S devices. Users of point contacts and microbridges instead relied on microwave modulation of the Josephson currents within the devices. These currents give rise to the Shapiro steps discussed by Wengler and his coauthors.

For the most part, it was eventually found that microwave applications of Josephson tunneling in point contacts, microbridges, and tunnel junctions were extremely noisy, at least by cryogenic standards. Furthermore, the application of standard microwave theory led to some surprises, particularly with regard to the problem of defining the noise temperature of a Josephson parametric amplifier [4]. It turns out that the gain of such an amplifier depends on the noise spectrum of the input signal. This makes traditional measurements of noise temperature inappropriate. Even though Wengler *et al.* are not observing this mode of operation, it would be wise for them to review the relevant literature, particularly with regard to a problem known as "noise rise." Related to this is the work of Kautz, his colleagues, and others on chaos in Josephson junctions [5].

With respect to their work on S-I-S devices, the authors make no mention of the work of Henneberger and myself on the effects of Josephson currents on the performance of S-I-S devices [6]. If nothing else, this work will make one aware of the many potential difficulties that arise when Josephson steps and quasiparticle steps interact in high frequency, low capacitance devices.

Finally, it should be emphasized that suppressing the Josephson currents is not the same as eliminating the Josephson currents. Even when external Josephson currents are suppressed with a magnetic field, circulating Josephson currents still flow within the S-I-S device. The results of Wengler *et al.* suggest that these circulating currents may significantly degrade the measured signal to noise performance.

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Reply to Comments on "Josephson Effect Gain and Noise in SIS Mixers"

Michael J. Wengler

In the above paper[1] we should have placed our work in the context of Josephson mixer work done before 1982. This omission leads to Jablonski's caution. I am pleased to reassure that we are in no danger of rediscovering anything. The earlier work all used point contact junctions with low capacitance and with nonhysteretic current-voltage (IV) curves which fit the resistively shunted Josephson junction (RSJ) circuit model [1], [2]. Our work uses planar SIS diodes with higher capacitance and with completely hysteretic IV's which are not even similar to the RSJ model predictions.

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The fact that there are similarities between our SIS Josephson effect mixing results and the results with the very different point contact RSJ mixers is a new discovery which we failed to note in our paper. It might be thought that the SIS and the RSJ point contact junction are not significantly different. Taur's comprehensive theoretical analysis of the RSJ mixer explains the high noise of point contact mixers [3]. However, this theory is based on differential equations for the current response of the RSJ: it does not begin to address the SIS diode we used which has a significance capacitance and no resistive shunt, among other differences.

The first remarkable feature shared by RSJ mixers and our SIS Josephson effect mixer is the presence of excess noise. Taur's theory shows that this is due to the nonlinear interaction of the Josephson current with the Johnson noise from the shunt resistor in the RSJ mixer. It is reasonable to expect a similar result for the SIS Josephson mixer but Taur's theory does not apply.

The second remarkable feature shared by RSJ mixers and our SIS Josephson effect mixer is the ease with which they are each saturated by thermal noise. Jablonski's statement that "traditional measurements of noise temperature are inappropriate" in some microwave devices using Josephson effects is one with which I agree strongly. In Fig. 10 and the text around it, we make the point that the hot/cold load technique can be inaccurate even in an SIS mixer which is operated in its more usual non-Josephson mode. In the Josephson mixing mode, results from hot/cold load measurements were useless because of nonlinear response.

Our paper reports direct measurements of signal, and direct measurements of noise when that signal is present. There is no possibility of error in a measurement of mixer sensitivity made this way. Any saturation, or nonlinear response to signal would be directly seen by our measurement. Even if our mixer noise and conversion gain are affected by broadband noise on the SIS, our methods measure them correctly. I consider this to be a major point of our paper.

I agree that magnetic suppression makes Josephson currents circulate within the SIS, it does not eliminate them. However, the experimental evidence from submillimeter wavelength mixers is clear that these circulating currents do not degrade SIS mixer performance [4], [5]. Neither, in my opinion, do I see evidence for Jablonski's concern in our paper, which reports lower noise when the currents are forced to circulate by magnetic suppression.

To conclude, there is new work to be done in Josephson mixing using SIS's that was not done with the point contact mixer work of the past. The SIS and the point contact junction have very different equations governing their dynamics, so it is reasonable to investigate SIS based Josephson mixers. With planar SIS's, complicated tuning structures can be fabricated integrally with the chip, so much greater freedom in circuit design is available now than was available with point contact junctions. Therefore, it is useful to revisit the topic of Josephson mixing. We are not alone in this opinion: Josephson mixing with resistively shunted SIS's is currently being pursued at Caltech [6]. Their theoretical work suggests much lower noise mixers with the SIS circuits than with the older point contact work.

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Comments on "An Analytic Algorithm for Unbalanced Stripline Impedance"

E. Costamagna and A. Fanni

***Abstract*—Results obtained from numerical inversion of the Schwarz–Christoffel conformal transformation are utilized to discuss data derived from the subject paper and from the subsequent comments in [1].**

In the above paper,[1] algorithms derived from conformal mapping were presented by Robrish to calculate the characteristic impedance of *unbalanced* (or *offset*) stripline in homogeneous dielectric. The allowed accuracy was checked by comparing data computed using the boundary element method. Then, alternative evaluation methods have been discussed by Canright [1], for the Robrish geometry and for structures derived from it to account for undercut.

In principle, all these methods are approximate, and Canright's are applicable to a limited range of dimensions. Therefore, a comparison is useful with impedance data calculated using the numerical inversion of the Schwarz–Christoffel conformal transformation (SCNI), which has already been proved [2], [3] an accurate and reliable general purpose tool.

In Table I, the data computed by Canright [1, Table I] using the Robrish formulas and his own equation (1) in [1] and Wheeler's [4] or Cohn's [5] techniques for balanced striplines are compared with impedances computed by SCNI. In the second column, SCNI was applied to the whole geometry, assuming a magnetic wall along the vertical line of symmetry. In the fourth column, SCNI was utilized to complement formula (1) in [1], computing his impedances Z_{01} and Z_{02} (see Fig. 1 in [1]). As expected, because the ratio $h_1/b = 1/3$ is not very small, the different data are in good agreement, and SCNI values merely confirm the previous evaluations.

Increasing the striplines offset, (1) in [1] leads to larger errors, as shown in Table II for $h_1/b = 1/5$. Errors range from about 4% to 6%, corroborating Robrish's opinion in his reply to [1]. This h_1/b ratio is the limit for which Robrish checked his formulas for maximum errors of 2%. Beyond this limit, errors were expected to increase rapidly: Table III shows the impedance values for $h_1/b = 1/10$ and errors rise to more than 11%.

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