Use of Subharmonically Pumped SIS Mixer with High Harmonics Number for Phase and Amplitude Antenna Measurements

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ABSTRACT

For the ALMA Interferometer and FIRST Mission a means of measuring accurately the phase and amplitude of horns and other antenna structure in the submillimeter bands is required to ensure good alignment and high coupling efficiencies to the telescopes.
This paper gives a means for making these measurements by using a SIS junction as a sub-harmonically pumped mixer. The measurements that are shown were made at 640 GHz, which is in the ALMA band 9, but they can be taken up to higher frequencies. A High harmonic number (>30) was used in these measurements and dynamic range of about 40 dB was achieved.
Any type of antenna structure connected to a SIS mixer could be measured. For these measurements a diagonal feed horn antenna was chosen. The mixer was mounted into a wet cryostat with a 1.2 GHz to 1.7 GHz IF. The cryostat was aligned against far field antenna measurement range. The transmitter moves in an X-Y raster scan in front of the cryostat window. The transmitter horn was a fundamental mode open-ended waveguide. The local oscillator in the range of 10-20 GHz was injected into the mixer by means of cold -20 dB directional coupler mounted into its IF chain. The phase locked Gunn multiplier chain was used as the transmitter. High harmonic of LO and Gunn chain output are combined to give an IF of 1.2 GHz. A homodyne phase and amplitude receiver was used for this measurement.
It is to be noted that no LO insertion was used at high frequencies. This has a great advantage for investigation of systems with wide beam because it does not limit the field of view taken up with optical local oscillator injection.
We will show the polar diagram, measured with this technique. The linearity of sub-harmonically pumped mixer was ensured by repetitive measurements of the same pattern with different signal levels. The IF output dependence from the SIS junction bias voltage will be presented. Optimal pumping power, signal level, operating bias point and conversion coefficient will be reported.

SUBHARMONICALLY PUMPED SIS MIXER

SIS junctions are widely used as detector element for quantum-limited mixers[1-6]. The high nonlinearity of SIS junction I-V curve allows making these mixers very efficient. The same high nonlinearity allows it to be used as a subharmonically pumped mixer. For instance, an SIS junction can be pumped with a local oscillator (LO) at microwave frequency F_{LO} to detect an input signal (RF) of a much higher frequency, F_{RF}, at an intermediate frequency (IF) $F_{IF} = F_{RF} \pm n \times F_{LO}$ where n is the harmonic number.

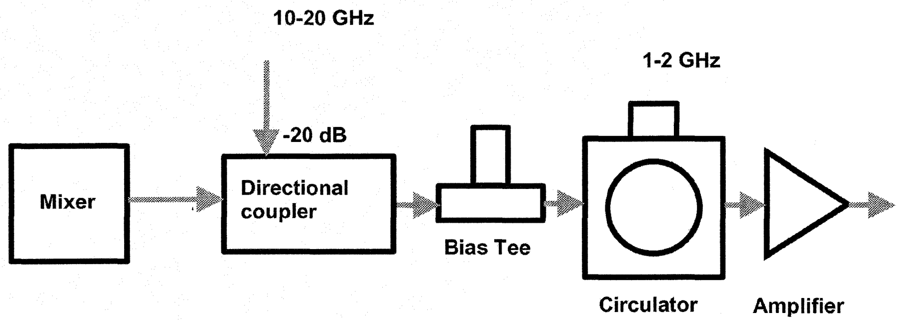

Figure 1: Scheme of mixer LO connection.

Subharmonically pumped SIS mixers for low harmonics number $\boldsymbol{n} = 2\text{-}5$ were used by various groups [7]. Higher ($\boldsymbol{n} > 30$) harmonic numbers were used in on-chip harmonic SIS mixers to study the linewidth and phase-locking of the Flux-Flow oscillator [8]. In this paper we present details of the operation of a subharmonically pumped SIS mixer for high harmonic numbers, and phase-and-amplitude antenna beam measurements using such a mixer.

The experimental mixer layout that was used to inject the LO is shown in fig. 1. The mixer was mounted on the cold plate in the vacuum space of a liquid helium dewar. The LO was injected through the –20 dB port of a directional coupler, providing at least 20 dB attenuation. The IF frequency, ranging between 1 and 2 GHz, was picked up through the main path of the directional coupler via a bias-tee and isolator, and amplified by a low noise Berkshire Technologies amplifier. The isolator provides good rejection of the LO signal to avoid damaging of the amplifier by the relatively high level of LO power. A waveguide mixer in the range of 450-520 GHz was used for studying the subharmonically pumped mixer operation. A Thomson carcinotron was used as RF source. To calibrate the conversion efficiency, the RF signal was injected through a 12 μm thick Mylar beamsplitter. A rotating grid was used to regulate the RF signal power. It was possible to pump the SIS mixer to alpha level $\alpha = 1.2$ during the experiment.

The IF output power was amplified by room temperature amplifiers with a total gain of 60 dB, and then connected through a tunable band-pass filter (30 MHz bandwidth) to a power detector. An automated measurement system [9] was used to record data.

The I-V curves of the measured SIS mixer are shown in fig. 2. The R_n value of the SIS junction is about 20 Ω. The junction's quality factor is about 30. The I-V curve with only LO power applied is shown by dotted line. Note that the LO power applied in this case is significantly smaller than the optimum LO power. No photon steps corresponding to 9.09 GHz are resolved in the picture. The dashed line represents the SIS junction pumped by the RF signal only. In this case the height of the photon-assisted tunneling step can be used as a measure of incident RF power. The junction's I-V curve corresponding to the optimum operation is shown as a continuous line. It looks like a "straight line", meaning that the mixer is "overpumped". The appropriate level of magnetic field was applied during the experiment to suppress the noise and conversion due to the Josephson effect.

The IF output power vs. mixer bias for these I-V curves is shown in fig. 4 for odd, and in fig 5 for even harmonic numbers. The output power has a periodical behavior with a period that is much larger than the width of the photon-assistant tunneling step

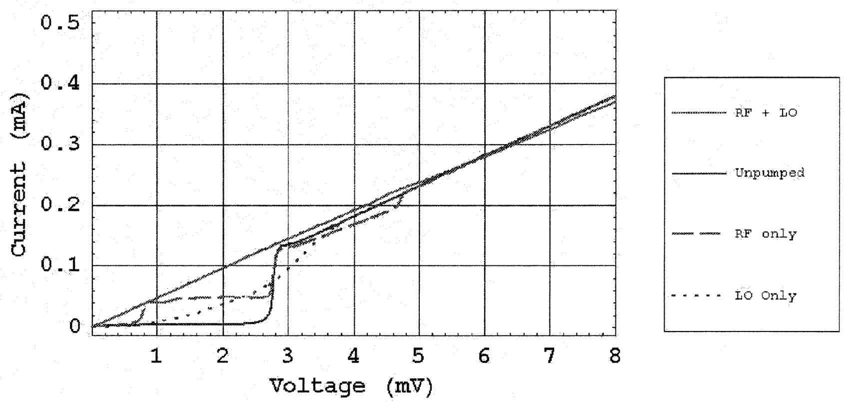

Figure 2: I-V curves of the SIS mixer 1) with neither RF or LO, 2) with RF only, 3) with LO only, 4) with RF and LO. Note that cases 3) and 4) have different LO power. F_{RF} *= 484 GHz,* F_{LO} *= 9.907 GHz*

corresponding to F_{LO}. The IF output has comparable amplitude for adjacent odd and even harmonic numbers. One should note that, due to the symmetry of the SIS junction's I-V curve, the odd harmonics have a zero in the output power at zero bias voltage while the even harmonics have a maximum at that point. The relative amplitude of the peaks in figs. 3 and 4 is changing nonlinearly as function LO input power. The estimated optimum LO input power was about –10 dBm, measured at the mixer-directional coupler interface. The loss due to mismatch between mixer and LO is not taken into account. It can also be seen that significant IF output power is produced, even for bias voltages far above the SIS junction's gap voltage of about 2.8 mV.

An additional measurement was made to check the linearity of a subharmonically pumped mixer with respect to the input RF signal. For this, the output power of the mixer was recorded while changing the mixer bias for different RF power levels. The RF power level was then calibrated by switching the LO off and measuring the height of the pumping step at a bias of 2 mV.

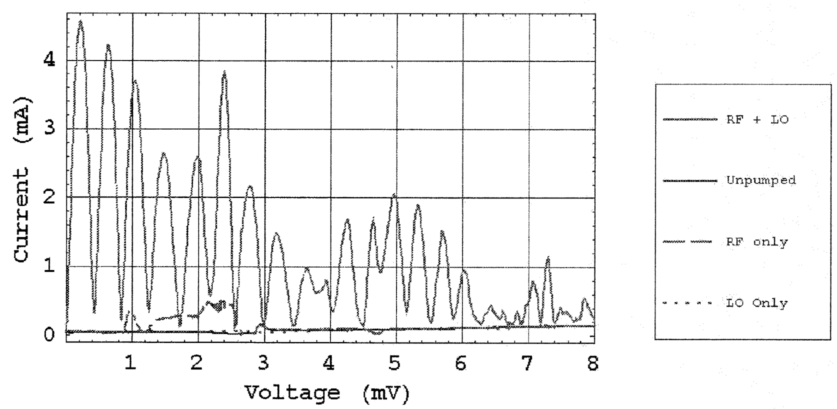

Figure 3: IF output power vs. SIS mixer bias for different operations regimes. F_{RF} *= 484 GHz,* F_{LO} *= 9.907 GHz,* ***49th*** *harmonic of synthesizer is used.*

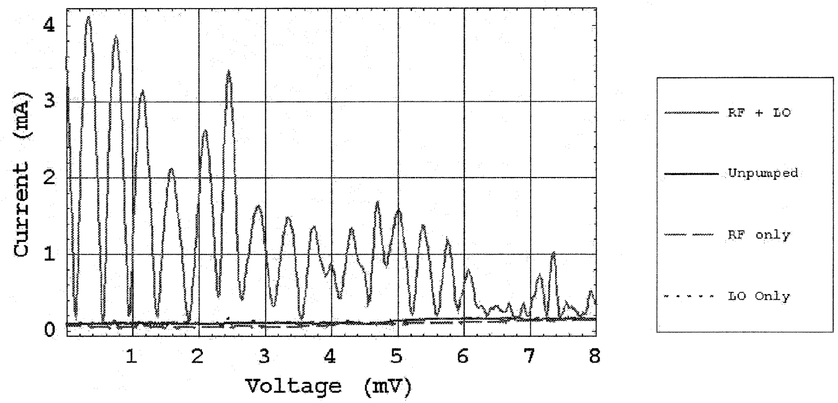

Figure 4: IF output power vs. SIS mixer bias for different operations regimes. ***F_{RF}*** *= 484 GHz,* ***50th*** *harmonic of synthesizer is used.*

For low pumping levels (α<1) this current is proportional to the RF power coupled to the junction. We assume that, if the mixer is linear for such a high input power, that there will be no problem to use it for the much lower input powers that are typical for antenna beam pattern measurements.

The results of such a measurement procedure is presented in figs. 5 and 6. The mixer current of about 50 μA corresponds to the mixer pumping level α=1. One can conclude that this mixer should only be used in the bias region close to zero, since the 1 dB compression point is highest there.

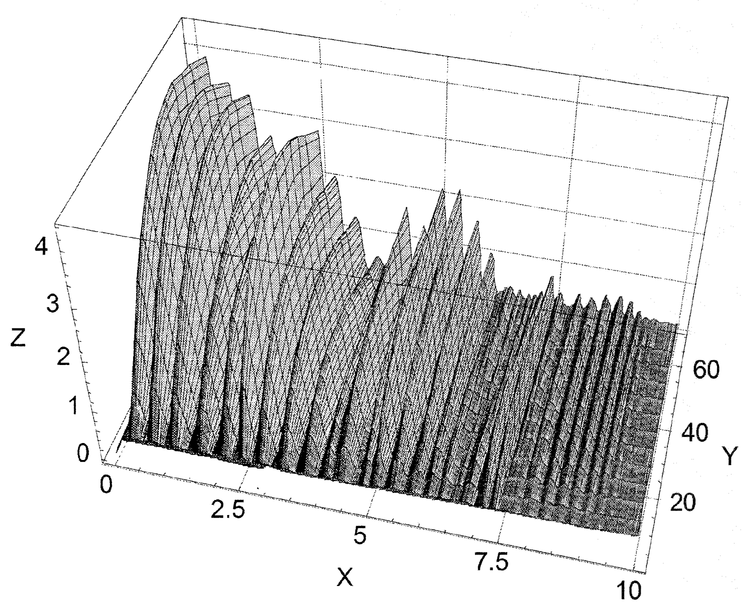

Figure 5: IF output power vs. SIS mixer bias for different RF signal power levels. ***F_{RF}*** *= 484 GHz,* ***49th*** *harmonics of synthesizer is used. X axis: SIS mixer bias voltage in mV, Y axis: SIS mixer bias current at 2 mV with LO switched off (proportional to input RF power) in μA, Z axis: IF output power (a.u.)*

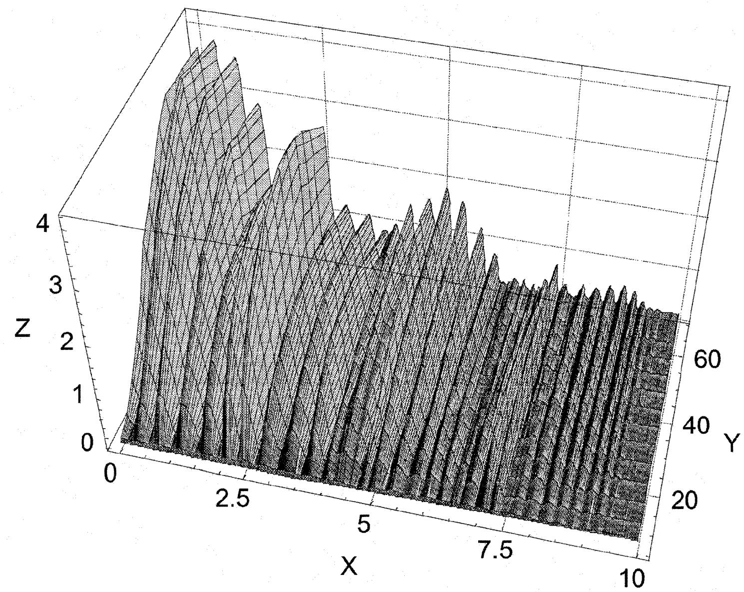

*Figure 6: IF output power vs. SIS mixer bias for different RF signal power levels. F_{RF} = 484 GHz, **50th** harmonics of synthesizer is used. X axis: SIS mixer bias voltage in mV, Y axis: SIS mixer bias current at 2 mV with LO switched off (proportional to input RF power) in μA, Z axis: IF output power (a.u.)*

ANTENNA BEAM PATTERN MEASUREMENTS

We used the waveguide SIS mixer, with diagonal feedhorn, described in [10] as subharmonically pumped mixer in our experiment. The mixer was mounted directly in front of the infrared radiation filter and the dewar window in such a way that its beam could be measured by a probe outside the dewar. The X-Y translation stage described in [11] was used for scanning. A tapered open-ended waveguide probe mounted on the multiplier chain was used as test feed.

The electrical connection scheme used in the experiment is shown in fig. 7. A phase-locked Gunn oscillator followed by a Shottky diode doubler and tripler was used as signal source. The signal (17 GHz) from a microwave synthesizer (G2) was used to pump both the SIS mixer and a harmonic mixer mounted between the Gunn source and the doubler. The IF output of the latter is filtered, amplified and multiplied by 6 to create a reference signal, coherent with the source signal, which is used to lock a vector voltmeter. The IF signal (1.2 GHz) from the SIS mixer was connected to the signal port of the vector voltmeter.

Since the RF frequency is in the range of 600-720 GHz, high multiplication numbers of the LO have to be used. That made the phase noise in the reference signal too high for the vector voltmeter to lock on it. However, since the same phase noise is also present in the SIS mixer IF signal, it can be subtracted by using the two-mixer chain shown in the bottom part of fig. 7. This scheme allows us to extend the measurement frequency even higher because it eliminates

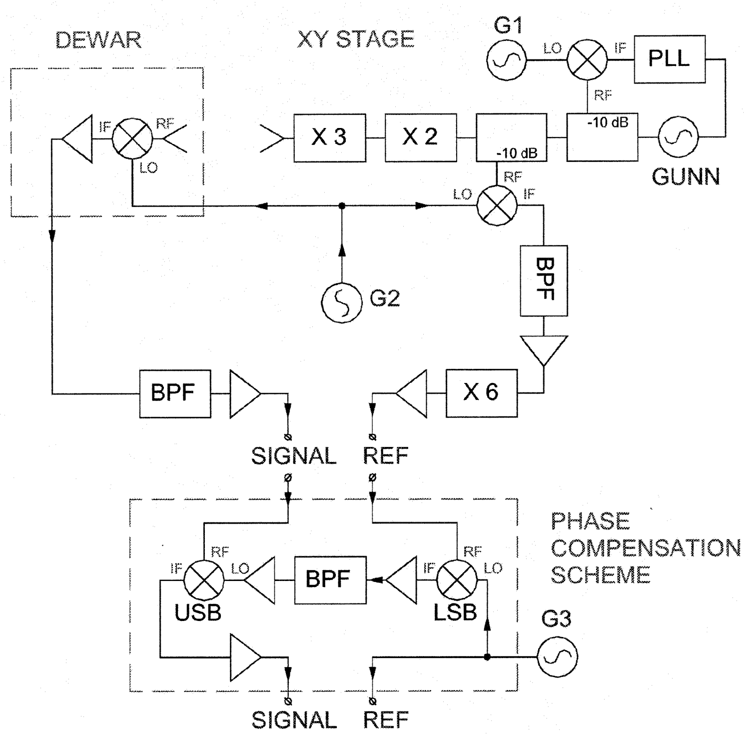

Figure 7: Scheme of the measurements and phase compensation scheme

the phase noise present in the source signal. A very narrow-band filter can be placed after the chain to further increase the signal to noise ratio of the system.
The antenna beam pattern for different signal source powers is presented in fig. 8. Some saturation at the 0 dB source level can be observed, but none is visible for source levels of –3, –6 and –9 dB. The small variations between the traces are due to slight changes in the effective signal path between the source and receiver due to different attenuator settings. A residual standing wave exists between source and detector, caused by imperfect matching of the source and detector elements. The measurements were done at 634 GHz RF using the 42nd harmonic of the LO signal source.

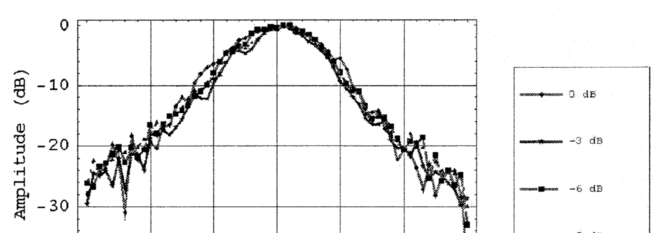

Figure 8: IF output power vs. source position for different source powers.

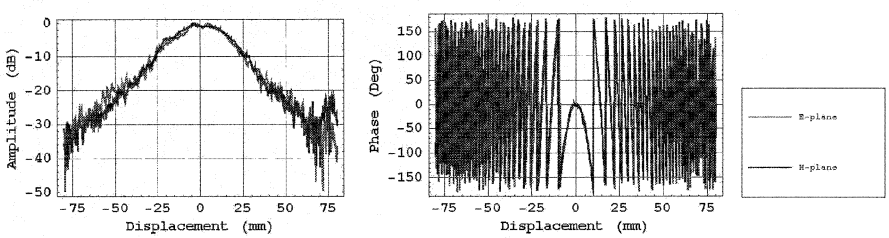

Figure 9: IF output power (left) and detected phase (right) vs. source position measured in the E and H planes.

The measured phase-and-amplitude antenna pattern of the diagonal horn, in both E and H direction, are presented in fig. 9. The signal to noise ratio of the system was about 45 dB. The phase is clearly detected even when the amplitude of the signal is close to -40 dB, due to the phase compensation technique described above. For all antenna beam patterns presented here, the subharmonically pumped SIS mixer was used at zero bias.
A comparison was made between the classical way of measuring the beam pattern by means of two RF sources (as described in [11]), and the subharmonically pumped SIS mixer. During the experiments, the system was switched over from one type of measurement to the other, while keeping all positions (including that of the beamsplitter) the same. The far field antenna beam pattern, calculated from the near field measurements is shown in fig. 10.

CONCLUSION

The operation of an SIS junction as a subharmonically pumped mixer with large harmonic numbers was studied experimentally. It was demonstrated that the conversion efficiency and linearity of such a mixer is good enough for using it in phase-and-amplitude antenna beam pattern measurements. A comparison was made between the conventional external-LO scheme and the one with the subharmonically pumped mixer, by performing antenna beam pattern measurements using both of them. The patterns were found to correspond to a high degree. The phase-noise compensating technique made it possible to use the system at very high frequencies.

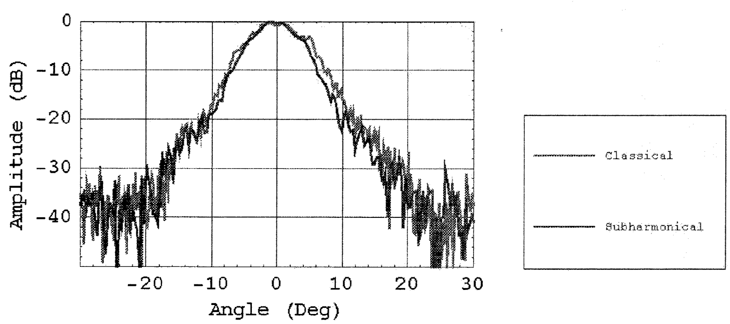

Figure 10: IF output power in the far field vs. angle for classical and subharmonically pumped measurements.

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