Investigating the Origin of Harmonics in a 230 GHz Local Oscillator

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Abstract— **The presence of spurious frequency tones emanating from a harmonically generated local oscillator (LO) signal can significantly degrade the performance of a Superconductor-Insulator-Superconductor (SIS) tunnel junction mixer [1]. The existence of harmonics is often revealed by distorted I-V curves obtained when pumping the SIS device with the LO. We have investigated this effect by using a commercially available source and correlating the photon step induced I-V curve structure with a direct frequency measurement made via a Fourier Transform Spectrometer (FTS) and a spectrum analyser. Our results suggest that intermixing frequency products are generated within the first, low frequency, stage of the LO chain, and these unwanted signals are converted to high frequency tones through subsequent stages of LO amplification and frequency up-conversion. The experimental work has been performed by using measurement facilities available at the University of Oxford and the Rutherford Appleton Laboratory (RAL), UK.**

I. Introduction

Heterodyne frequency down-conversion is a commonly used technique for performing high-resolution spectroscopic observational radio astronomy. The heterodyne frequency conversion process combines the incident radio frequency (RF) astronomical signal with a local reference frequency source, i.e. local oscillator (LO) tone, in a highly non-linear mixing device, such as a Superconductor-Insulator-Superconductor (SIS) tunnel junction. The mixer generates an intermediate frequency (IF) output, which is substantially lower in frequency than the RF and LO input signals; this allows subsequent signal processing and reproduction of the astronomical signal power spectrum. The mixer, LO and IF components combined form a heterodyne receiver.

The LO is a key device within the receiver system. It must, for instance, provide sufficient power to “pump’’ the mixer; be stable in frequency and amplitude; and possess a broad tuning range. Additionally, it is essential that the LO signal is spectrally pure; i.e., spurious harmonic content is of sufficiently low amplitude to avoid spectral contamination and system noise degradation.

The LO spectral purity is difficult to specify for near quantum limited receiver systems, and is often overlooked as a parameter when defining the LO chain. Determining the purity of an LO source is therefore important as the harmonic content can mix with the input signal and result in unwanted parts of the RF spectrum being down converted into the IF band and this degrades the receiver sensitivity and may also introduce confusing spectral artefacts. We have used a commercially available 230 GHz LO source to investigate LO harmonic content and have correlated unusual features identified in an SIS mixer LO pumped I-V curve with direct measurement of frequency tones from the source.

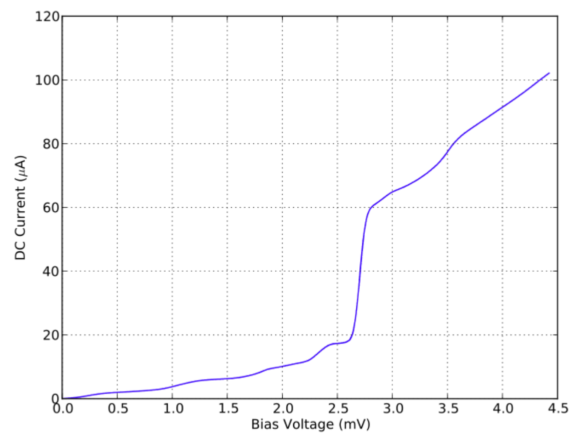

Fig. 1 A 198 GHz pumped I-V curve showing unusual features and a poorly defined photon step structure.

An example distorted I-V is presented in Fig. 1 from which it can be seen that the pumped I-V curve, with the LO set to 198 GHz, shows a poorly defined photon step structure as well as an unusual feature prior to the sharp non-linearity at ~ 2.7 mV. The features seen in Fig. 1 would not be present if the mixer were pumped with a pure LO source tone. For comparison, a normal pumped I-V curve obtained with the same LO is shown in Fig. 2. This curve was captured with the LO set to 252 GHz.

Additional I-V plots with similar structure to Fig. 1 were obtained across a significant fraction of the LO frequency band of operation between ~ 190 – 260 GHz [2], implying a variable nature to the LO harmonic content. We have therefore investigated the frequency output from the LO chain by using a Fourier Transform spectrometer and a spectrum analyser, the latter combined with a solid state millimetre-wave external mixer.

Measurements of the pumped I-V curves were made using a finline SIS mixer at Oxford’s Millimetre Detectors group laboratory.

The paper will describe the experimental set-up and results obtained from measurement of the LO source output. From this, we show that the source generated a complex tonal output at a variety of frequencies. These undesirable signals also produced a substantial degradation in mixer sensitivity.

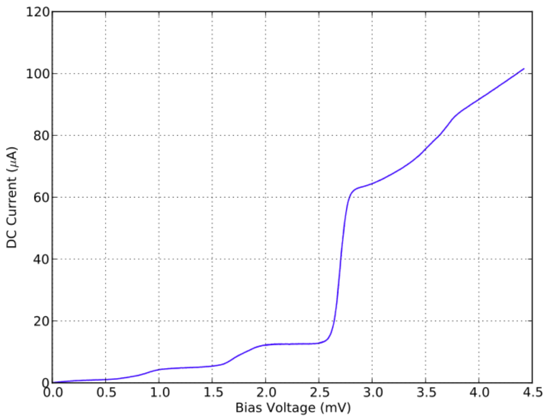

Fig. 2 A 252 GHz pumped I-V curve with a clean photon step structure.

II. Experimental Methods

The LO configuration employed in the experiment consists of a low frequency (~ 10 – 15 GHz) signal generator that provides an input tone into a sextupler that multiplies this tone by a factor of 6 and up-converts it to ~ 60 – 90 GHz. This signal is then amplified and multiplied by 3 using a tripler to bring it to ~ 180 – 270 GHz. This results in an overall multiplication factor of 18 from the original fundamental input frequency. A diagram of the LO chain is given in Fig. 3.

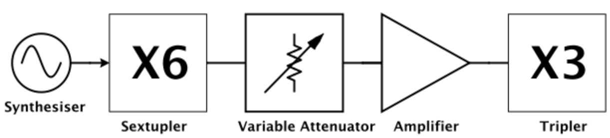

Fig. 3 LO chain block diagram.

The LO investigation was carried out at several frequencies using a polarisation rotation (Martin-Puplett [3]) Fourier Transform Spectrometer (FTS) located at the Rutherford Appleton Laboratory (RAL). This experimental setup can be seen in Fig. 4.

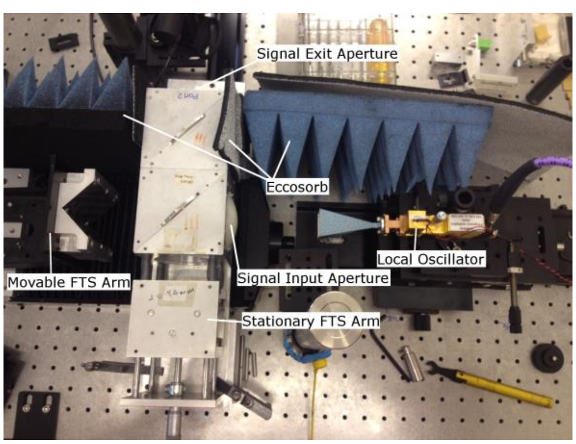

Fig. 4 Experimental setup for the LO using the FTS.

Many variations of the experiment were performed (e.g. varying the LO frequency, using a different LO, adding isolators/attenuators/filters, using a different detector) but it proved non-trivial to pinpoint the cause of the tones and therefore to verify their authenticity directly from the FTS results. For example, the FTS measurements provided an indication of the presence of unwanted tones, but the acquired spectra proved somewhat ambiguous with tone confusion arising from effects such as signal aliasing. Thus, although providing strong evidence of the presence of harmonics, uncertainties in the FTS measurements were sufficient to make the determination of their origin from within the LO chain difficult.

An alternative approach was therefore taken in which external solid state mixers, purchased from Radiometer Physics Gmbh (RPG), and used in conjunction with a Rhode and Schwarz spectrum analyser, were used to directly measure the LO spectral output.

These mixers enabled the direct measurement of frequencies up to 500 GHz. The frequency spectra obtained using two of these mixers with the LO set to 198 GHz (a particularly problematic frequency) are presented in section III.

III. Results

Two example measurements obtained using the FTS are presented in Fig. 5 and 6. It can be seen in Fig. 5 that the frequency spectrum appears to be highly contaminated with harmonics. However, we found that the FTS is potentially prone to the introduction of artefacts and it was therefore not clear whether all these tones originated from the LO itself. For example, Fig. 6 shows an overlay of two sets of data; one set acquired with a W-band filter located at the output of the LO, and the other without the filter. In both cases the frequency tripler was removed in order to test the signal purity prior to the final stage of multiplication. It can be seen from Fig. 6 that the presence of the filter had very little effect on the LO spectrum. This result implied that the tones were not a function of the LO and therefore cast some doubt on the FTS spectral measurements.

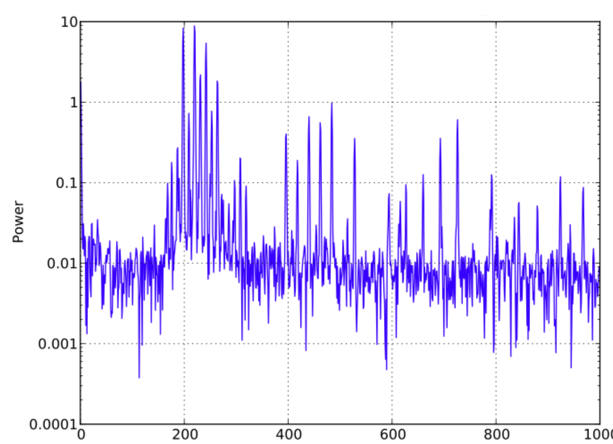

Fig. 5 Frequency spectrum obtained with the FTS. LO set to 198 GHz with the tripler in place. The spectrum appears to be highly contaminated with harmonics.

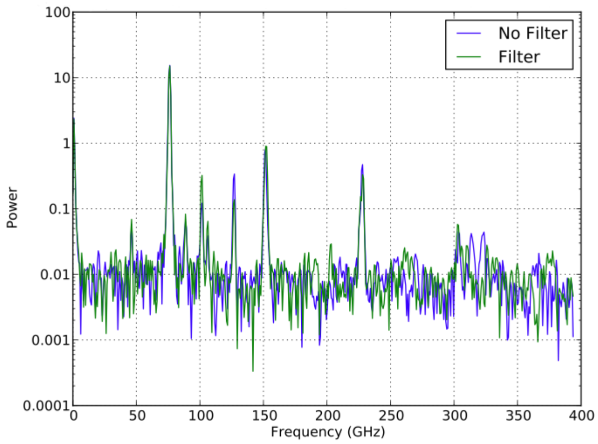

Fig. 6 Frequency spectrum obtained with the FTS with and without a W band filter. LO set to 76.2 GHz and with the tripler removed. Adding the filter has little effect on the spectral features of the LO.

Measurements were made using a spectrum analyser combined with external mixers and with the LO set to 198 GHz. These are shown in Fig. 7 and 8.

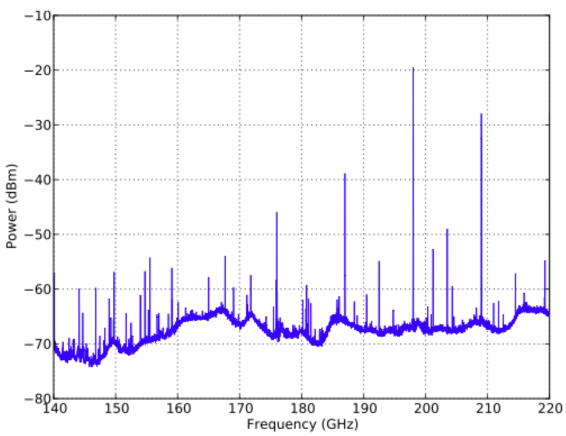

Fig. 7 Frequency spectrum with 140 – 220 GHz mixer. LO set to 198 GHz with the tripler in place. It can be seen that as well as the main tone at 198 GHz, there are other significant harmonics present which are separated by 11 GHz from the main tone.

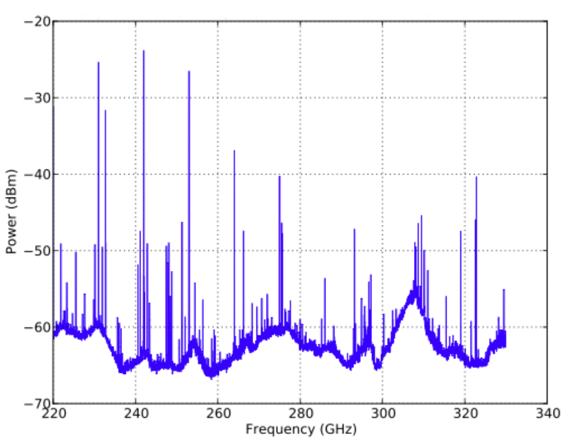

Fig. 8 Frequency spectrum with 220 – 330 GHz mixer. LO set to 198 GHz with the tripler in place. It can be seen that there are other significant harmonics present at frequencies well above 198 GHz.

Examination of these figures shows that the LO source is indeed producing multiple tones of significant amplitude (within 5 – 10 dB of the 198 GHz tone) and which are separated in frequency from the desired 198 GHz harmonic by integer multiples of 11 GHz. It is likely that these tones enter the mixer LO input port and contribute to the distorted pumped I-V curve shown in Fig. 1.

To check whether the tripler was indeed responsible for the production of the harmonics, we performed spectrum analyser measurements with the tripler component removed. This experiment was performed with two, lower frequency, external mixers while keeping the LO set to 198/3 = 66 GHz. The results can be seen in Fig. 9 and 10.

If the tripler was the component solely responsible for the unwanted harmonics, then the plots in Fig. 9 and 10 would show a tone centred at 66 GHz and no other significant tones. However, again there is evidence of harmonics around 66 GHz separated in frequency by integer multiples of 11 GHz which is the fundamental frequency of the sextupler from the signal generator. This would suggest that there is intermixing of the fundamental tone taking place in the sextupler and this leads to the production of undesired harmonics which are separated in frequency by integer multiples of the fundamental as observed in Fig. 9 and 10.

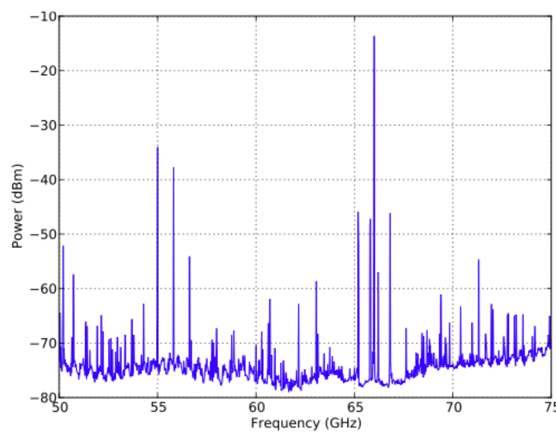

Fig. 9 Frequency spectrum with 50 – 75 GHz mixer. LO set to 66 GHz with the tripler removed. It can be seen that as well as the main tone at 66 GHz, there are other significant harmonics present which are separated by 11 GHz from the main tone.

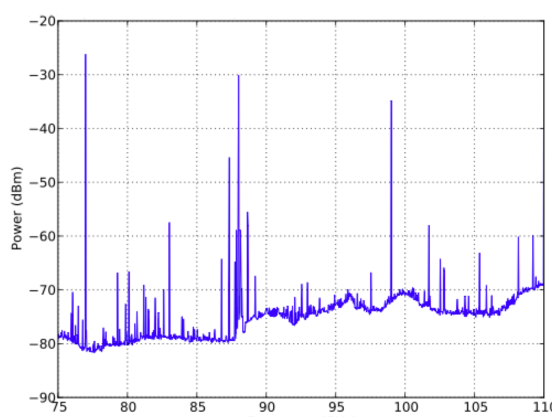

Fig. 10 Frequency spectrum with 75 – 110 GHz mixer. LO set to 66 GHz with the tripler removed. It can be seen that there are other significant harmonics present at frequencies above 66 GHz.

Our conjecture is further supported by the fact that it is possible to pump an SIS mixer with the signal synthesiser set to a particularly low fundamental frequency of 6.9 GHz. This is interesting because $6.9 \times 6 = 41.4$ GHz, which is just above the waveguide cut off (40 GHz) of the amplifier but quite far outside of its range of operation (75 – 110 GHz). Even so, if the 41.4 GHz tone had enough power to pump the mixer, it would be 124.2 GHz by the time it was tripled which is well below the frequency band of operation of the mixer. The fact that it is possible to pump the SIS mixer with the signal synthesiser set to 6.9 GHz suggests that the LO is producing higher order harmonics and it is these harmonics that are consequently pumping the mixer.

To test whether the LO was indeed producing such tones when set to a fundamental frequency of 6.9 GHz, it was tested on the spectrum analyser, using external mixers, over the frequency range of 40 – 110 GHz and with the tripler removed. The results of this measurement can be seen in Fig. 11.

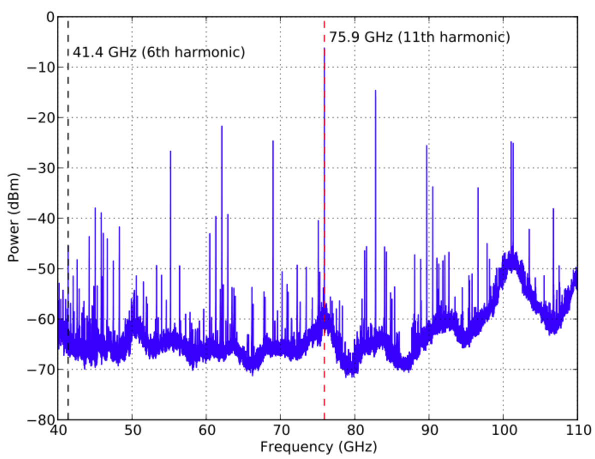

Fig. 11 Frequency spectrum between 40 – 110 GHz. LO set to 41.4 GHz with the tripler removed. It can be seen that the spectrum is contaminated with harmonics and that the desired 6th harmonic of the 6.9 GHz synthesiser input tone is significantly (~ 38 dB) lower in amplitude than the 11th harmonic at 75.9 GHz. It should also be noted that some of the low amplitude harmonics are suspected to originate from the external mixers that were used. However, tones separated by multiples of 6.9 GHz are believed to result from the low frequency multiplication chain of the LO.

It is evident from Fig. 11 that the desired tone of 41.4 GHz (the 6th harmonic of the fundamental) is quite low with an amplitude of ~ - 45 dBm. The 11th harmonic however, at 75.9 GHz, has an amplitude of ~ - 7 dBm and this is the tone which is most likely to be pumping the mixer. Additionally, it is worth noting that the entire spectrum is contaminated with harmonics separated by 6.9 GHz which supports the idea that undesired tones are being generated by the sextupler before being amplified (if within the operating range of the amplifier) and tripled.

IV. Conclusions and Future Extensions

The harmonic content of LOs affects receiver performance in terms of noise and spectral output, and requires careful consideration and evaluation. By way of demonstration, we have investigated the generation of harmonics by a commercially available, coherent millimetre-wave LO source that is used to pump an SIS mixer in the frequency range of 190 – 260 GHz.

We have shown that the generation of unwanted harmonics does not necessarily occur in the final LO frequency multiplication stage, but apparently originates from the spectral impurity of the low frequency multiplier chain.

The correlation between the distorted pumped I-V curves and the LO spectral measurements suggests that close examination of the mixer I-V provides a useful diagnostic tool for detecting spectrally impure LOs. This is particularly important when corresponding receiver systems are used for astronomical observations. For this method to be viable, however, it is necessary to further explore, and improve, the relationship between the pumped I-V curves and the harmonics that are present in the spectrum analyser/FTS measurements.

An important project extension will be to test this particular LO with a Yttrium-Iron-Garnet (YIG) signal synthesiser as it is thought that this may provide a more stable signal than the Voltage-Controlled-Oscillator (VCO) source currently being used. It will therefore be interesting to see what effect using a YIG will have both on the amplitude of the harmonics and the pumped I-V curves. There are plans to carry out this work in the near future and the results will be presented at the ISSTT meeting in March, 2015.

References

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