THE JOSEPHSON JUNCTION AS APPLIED TO THE MEASUREMENT OF THE FREQUENCIES OF SEVERAL LASER LINES*

Allan S. Risley

Atomic Frequency and Time Standards Section
National Bureau of Standards
Boulder, Colorado 80302 USA

Abstract: The Josephson junction has been applied to the measurement of laser frequencies as high as 3.8 THz by direct multiplication from an X-band source. An attempt is being made to extend this technique to frequencies as high as 10.7 THz.

The Josephson junction (JJ) has demonstrated its ability to generate a high harmonic of an X-band signal and to mix this harmonic with laser radiation. The results obtained so far suggest that the JJ may have a part in the accurate measurement of the frequency of the methane-stabilized He-Ne laser ($\approx$ 88 THz).†

The application of the JJ to measure the frequencies of various laser lines began about one year ago. The people involved are Donald G. McDonald and John D. Cupp of the Cryoelectronics Section of the Cryogenics Division; myself, of the Atomic Frequency and Time Standards Section of the Time and Frequency Division; and Kenneth M. Evenson of the Quantum Electronics Section of the Quantum Electronics Division. All of us are with the National Bureau of Standards, Boulder, Colorado.

† Since the time of the Quebec Seminar, a group at the National Bureau of Standards, Boulder, Colorado, has succeeded in measuring the frequency of the 3.39-μm transition of methane. Using a room temperature metal-on-metal diode, K. M. Evenson, G. W. Day, J. S. Wells, and L. O. Mullen have measured the ratio of frequencies of the 3.39-μm line of methane and the R30 line of the CO_2 laser.[3]

It is apparent from the paper by Joseph Wells that the 28-μm emission from the H_2O laser is very important in the measurement of the frequency of the 3.39-μm line of methane. It has therefore been a major objective of the JJ work to reliably measure the 28-μm line (≈ 10.7 THz).

One of the major advantages of the JJ in this work is that it offers an excellent indication of its capability of doing the necessary multiplication and mixing before the experiment is performed. If an external signal of frequency ν_s is applied to the junction and if the voltage across the junction is swept, then there is a discontinuity--a constant voltage step--in the I-V curve when the voltage reaches a value V_o such that $2eV_o/h = \nu_s$. [The quantity e is the electronic charge and h is Planck's constant.] The experiment we perform is described by the equation

$$\left|\nu_{laser} - n\nu_{X\text{-band}}\right| = \nu_{IF} ,$$

where n is an integer. If there is a step in the I-V curve (when the laser signal is applied) corresponding to the frequency ν_{laser}, then one is assured of observing the beat frequency, ν_{IF}. That is to say, so far the beat has always been observable under these conditions. On the other hand, there is no equally reliable diagnostic for the room temperature metal-on-metal junctions that David Knight and Joe Wells have described.

Very early in our work we succeeded in beating harmonics of the order of 100 with the fundamental of the 337-μm (0.891 THz) emission of the HCN laser.[1] From extensions of this work we discovered that one requirement for significantly increasing the order of harmonic generation was an improved X-band source.

It has become clear from our experiments to date that if we are to go directly from X-band to the 28-μm line of H_2O (a multiplication factor of about 1100) we need second-to-second stability of about 1 part in 10^8 or better. We have achieved this by locking our X-band source to a quartz crystal oscillator, and it appears that a quartz crystal oscillator will continue to be a necessary part of the system. Using a quartz oscillator without a bandpass filter does, however, tend to introduce an intolerably large amount of high frequency (5 kHz and higher) noise into the X-band output.

With the consultation of Professor J. Robert Ashley of the University of Colorado Electrical Engineering Department, we have assembled a multi-stage system that exhibits both good stability for averaging times of the order of one second and low FM and AM noise as measured in the frequency domain. This system uses a cavity-stabilized klystron which is injection-locked to a klystron which is in turn locked to a quartz crystal oscillator. The first X-band source has a very low noise level for frequencies further than a few hundred hertz from the carrier. The second system is quite good from about 0.1 Hz to 1 kHz from the carrier but poor in the tens of kilohertz range.

Our latest complete measurement system incorporates two other essential changes. They are (1) an X-band IF system (instead of the 30- or 60-MHz IF that we initially used) to give us a much larger signal, and (2) a ruby maser (operating at 9.0 GHz) which gives us preamplification at a much lower noise level than did our original system. The improvement in signal level obtained by raising the IF frequency is based on an idea by Zimmerman and Frederick.[2] Another feature of our X-band IF system is that we know we are operating under a condition of good impedance match.

Using the system described above we have succeeded in observing the beat between the 4th harmonic of the 311-μm line of the HCN laser and the 78-μm line of the H_2O laser. (The 5th harmonic of an X-band signal was also used here to reduce the beat frequency to 9.0 GHz.) Our latest success was the observation of the beat between the 401st harmonic of the X-band source and the 78-μm line of the H_2O laser.

The question still remains as to whether the JJ will be useful in the measurement of the frequency of the 28-μm line of the H_2O laser. We have made three attempts to use the JJ to detect the beat between this line and a lower frequency source. We did not succeed. We are currently modifying our system to produce a bigger signal, to further reduce the noise level of our detection system, and to further improve the stability of our X-band source. When these modifications are completed we will try again.

References:

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2. "Miniature Ultrasensitive Superconducting Magnetic Gradiometer and Its Use in Cardiography and Other Application," J. E. Zimmerman and N. V. Frederick, Applied Phys. Letters 19, 16 (1971).

3. "Extension of Absolute Frequency Measurements to the cw He-Ne Laser at 88 THz (3.39 μ)," K. M. Evenson, G. W. Day, J. S. Wells, and L. O. Mullen, Applied Physics Letters 20, No. 3, 134 (1972).