Wide-Range Tuner for Generators in THz Bands

Alexander Denisov[1,2], Jinghui Qiu[2], Shengchang Lan[2], Ming He[3], Yang Xiong[3], Fan Zhang[3], Han Zhang[3] and Francesco Soldovieri[4]

[1]*State Research Center "Iceberg", Kiev, Ukraine*

[2]*Department of Microwave Engineering, Harbin Institute of Technology, P.R.China*

[3]*College of Electronic Information and Optical Engineering, Nankai University, Tianjin300071, P.R.China*

[4]*Istituto per il Rilevamento Elettromagnetico dell'AmbienteConsiglio Nazionale delle Recerche ,Napoli, Italy*

alex_denisov2009@ukr.net, qiujh@hit.edu.cn, heming@nankai.edu.cn, soldovieri.f@irea.cnr

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Abstract: Before experiments can be conducted on new generation structures in the THz band when the level of power is small and especially the frequency are practically unknown correctly (or it has place some accidental character) it is necessary to have instruments capable of measuring weak signals in a wide-range frequency band. Receiving instruments for the above-described evaluations must be based better by one measuring block and not only in the limits of the intermediate frequency (IF) amplifier band. Best natural "candidate" for this task is Josephson junction (JJ) – it has super wide voltage electronic regulation on frequency by basic ratio $2eV = h\omega$. JJ can be used as the criterion for a single-block super-wide band frequency-meter and as a sensitive element for the tuning the generation structures. Short description presents the realized innovative idea about simple tuner for generators in THz bands.

1 INTRODUCTION

The idea for this work came after visiting several labs which had interest to realize electromagnetic radiation (EMR) using Josephson media (JM) (H. B. Wang, S. Guénon, etc., 2010) and practical requests for possible good but cheap receivers covering the short part of millimeter band with enough wide bandwidth of the intermediate frequency (IF) amplifier. These labs worked only with liquid nitrogen and oriented on the structures based on high temperature superconductor (HTSC) such as $Bi_2Sr_2CaCu_2O_{8+\delta}$ (A. Koshelev and L. Bulaevskii., 2008, K. Kadowaki, L. Ozyuzer etc, 2008, D. Crankshaw, Enrique Trias., 2001).

Finally, it is worth to mention that purchasing a reliable enough cryocooler based on closed Giffard-McMagon (GM) cycle working till the temperature of a liquid helium is not a big issue today (www.fullsharecryogenics.com).

At least the price of GM machine is not principally more than famous network analyzer "Agilent". If to talk about the perspective using for the above task the Josephson junctions in spite that it is necessary to use cooling from the point of possible alternative to "Agilent" or some the same - from the "the rules of contraries"- there absent other good alternative.

The primary trend in superconductive microwave radio-electronics is the using JJ through the development of the devices employing Josephson oscillation, based on non-stationary Josephson-effect (K. Likharev, B. Ul'rich -1978, I. Kulik, I. Yanson, 1972). This can be used for the development principally new devices which are difficult or impossible to realize by the other methods.

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On the basis of the previous theoretical and experimental investigation **(A.**Denisov, V. Obolonsky, 1990, A.Denisov, V.Gorishnyak, 1981**,** A. Denisov, V.Gaevsky., 1985) there shortly described the innovation decision about wide-range tuner for generators in THz bands.

Why tuner? What is necessary for the tuning of generator? It is need some visual control about frequency and the power of EMR. In reality the calculation of new generation structure can be done according to some current theoretical model and naturally in the simplest approximation. According to this and the real possible mistakes the frequency of EMR has some accident character, so the receiver with standard mixer even with big band of the intermediate frequency is not enough for this task. In the practical case at the beginning of the experiments the generation power is small enough too. Real situation. Besides of this the microwave losses in the transmission line can be very big too according to practically full absence the devices for such control and the matching in THz band.

There raised the question - where is the best suitable decision?

For such task it is need the tuning device with super wide band and with best sensitivity. In this case it will be real guarantee we would not "sleep past cash-box".

This is proved by two devices based on the JJ. First one is the sensitive receiver based on self-pump mode regime of JJ and second one is the using JJ as the criterion according to $2eV = h\omega$ **(**for the frequency measurement by the super wide frequency-meter. Combination of this two devices in one single block was published before**)** (A.Denisov, Qiu Jing Hui, 2014, A. Denisov, A.Gudkov, 2015)

Perhaps, it's interesting to say the fact (A. Denisov , A.Gudkov., 2015) that in 1978 it was the first S&R works to create the practical devices of the generators based on Impatt structures in Scientific Research Institute "Saturn" in Kiev, was oriented on R&D of low and super low noise microwave receivers in former USSR. It was practically lack of measuring devices in frequency bands more than 100 GHz. Spectrum analyzer C4-28 works till~38,5 GHz, and the existing certificated frequency-meter and power-meter worked practically till the same limiting frequency. *It was* realized the first variant of the panoramic sweep generator with monitor for measuring Standing Wave Ratio (VSWR) had been working in 3 mm. It was a real task to construct the generator of 70 GHz. It was came up with the idea to use 'Shapiro steps" (K.Likharev, B.Ul'rich -1978) – their level and position along voltage-frequency scale for the tuning and matching the "room-temperature" Impatt generator to the biggest power. Experiments were successful, but not only for 70 GHz. we elaborated the second harmonic and tuned the Impatt generator on 140 GHz. However, since the certificated measuring equipments were lucking, it was really difficult to confirm the obtained results and to convince the corresponding technical standard control personnel. We observed the harmonics of 140 GHz till more than 1,5 THz with the help of our first analogue variant of the Josephson frequency-meter (A.Denisov, V.Obolonsky, 1990) built on Nb point contact had been working according to the "Shapiro steps" on Current-Voltage Characteristic (IVCh) of the JJ (patented in USSR in 1978).

First of all, this device had extremely super wide momentary wave band. It was not necessary to change the measuring block to modify the measuring frequency band.

2 TECHNICAL EXPLANATION

On fig.1 and fig, 2 presented typical Volt-Amper Characteristic (VACh) of the JJ. Result on fig.1 was made from Tl based HTSC film by one of the author of this work. EMR of the experimental generator falls on JJ which produces microwave radiation according to $2eV= h\omega$ and later visual control of the Shapiro steps on VACh can be used for the tuning and matching of the experimental generator. To obtain a quantitative measure of the microwave power sensed by the Josephson junction, the well known dependence **of** the Shapiro step width on incident microwave power can be employed.

In term of Josephson-effect theory, the reduction of zeroth Shapiro step width is equivalent in quantity to diminish the critical current I_c of JJ which depends on EMR power as zeroth Bessel function. This current which is the result of interference of two signals on JJ has direct influence on the width of the steps. So, the width of the steps or ΔI on Fig 1 is the measure of EMR falling on JJ**.**

And naturally the position of Shapiro steps on the voltage scale of VACh corresponds to the frequency which falls on JJ.

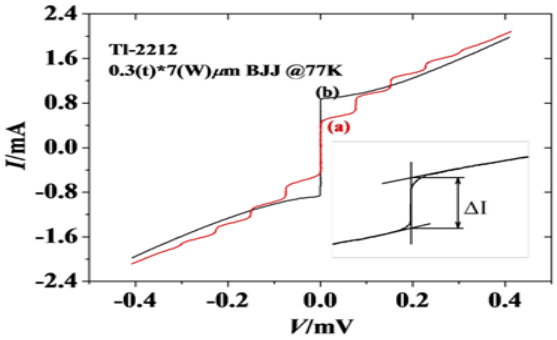

Figure 1: Typical VACh of Josephson junction.

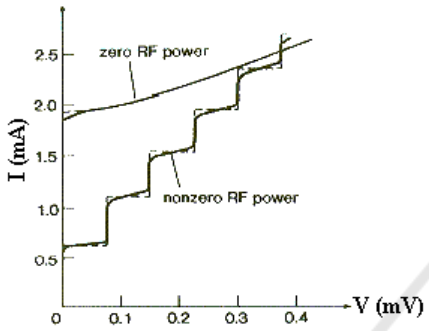

Figure 2: Typical picture of JJ with Shapiro steps

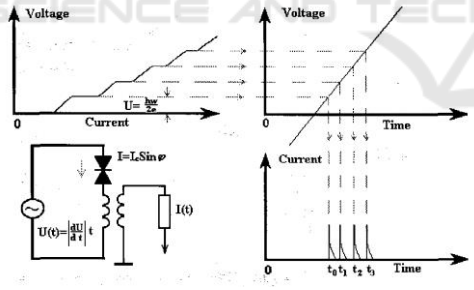

Figure 3: Explanation of how Shapiro steps measurements's JJ frequency meter is operating.

If to transform typical picture of the Shapiro steps on Fig.2 from co-ordinate I-V to co-ordinate V-I and to use transformer in bias network (there is the linear voltage shifting law, where dV/dt ~ fixed constant) it will be situation as on fig.3.

According to Shapiro steps there arise impulses from the second winding. These impulses are given directly by:

$$\omega = (2e|dV/dt| \bullet \Delta t)\, h \qquad (1)$$

The interval between impulses from the second (step-up) winding of the transformer bring needed information about frequency of EMR and after calibration can be re-calculated into the automatic scheme for the frequency measuring.

This time it is reason to remember the result with Tl -based HTSC on fig.1. Based on the Josephson - effect the intrinsic abilities the gap frequency of HTSC is about 30 THz (P. Wang, Zh. Wang, B. Fan, W. Xie, X. J. Zhao, M. He, X. Zhang, L. Ji, and S. L. Yan., 2012), which is higher than that of low temperature superconductor**.**

It denotes that the wide-range THz tuner which is combination of simplest visual power meter and frequency meter based on the Shapiro steps properties in the single block can respond at all the THz band.

3 CONCLUSION

In this paper it was done simplest explanation how to use Shapiro steps which have place in case EMR of JJ for the wide-range tuning of experimental generator in THz band.

It will be especially popular for the tuning of cooled generator.

As the real prognosis - possible later such device will take name *Shapiro-steps tuner of generators in THz band*.

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