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AN EXPERIMENTAL ARRANGEMENT FOR INJECTION LOCKING Ka-BAND OSCILLATORS

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Abstract-**Two Ka-band oscillators, which have a free-running frequency difference of 20-50 MHz, can be combined as an injection-locked assembly by inserting a waveguide magic-T, an attenuator and a suitably dimensioned ferrite circulator between their respective multiplier outputs. A waveguide mixer is used to detect the phase difference between the two oscillators. In locked state, the mutual frequency can be fine tuned through the adjustment of one of the supply voltages. Because no synthesizers or frequency dividers are involved, the spectrum is practically free of close-in sidebands. Low-noise coarse frequency adjustment up to 10 ppm can be accomplished through water cooling. The proposed arrangement has been tried in selected test instruments and for short-range radar.**

***Keywords* - oscillators, phase locking, injection locking, microwave measurements**

I. INTRODUCTION

Most current RF, microwave and lower millimeter wave sources utilize some kind of frequency synthesis from a suitable crystal unit in order to meet their frequency stability specifications [1] that have been derived from respective system-level requirements. However, as the amount of information to be transferred in networks is continuously increasing, higher carrier frequencies have to be taken into use and this puts a severe cost burden on the oscillator electronics [2]. Particularly devices used in the communication mass market and in selected industrial sensors require oscillators, which are low-cost, small and consume very little supply energy but can track the frequency and perhaps also the phase of a second, almost similar unit. Related wishes appear also in some high-end measurement systems [3], in navigation, radar and e.g. in radio astronomy [4].

Injection locking has been known both as an adverse effect and occasionally as a useful process between two electronic oscillators. The idea is simple indeed and relies on the application of sufficient signal power close to the initial frequency of the target oscillator whereby its frequency will be captured and pulled to equal that of the injected signal. Various forms are in use and there is often a possibility to utilize harmonics of either unit as well. Quite often the injected signal is taken from a high stability source, but this is not mandatory for the locking action itself. One of the key issues that define the chances of this approach is the level of complexity in the necessary circuitry [5]. As an example, an industrial test instrument developed by the authors and documented e.g. in [6] required a stable IF to be produced from two millimeter wave sources. Because hardware cost was of major importance (due to foreseen future volume production) there was a desire to try most straight-forward means of performing this frequency conversion. For this purpose we have developed a simple and reliable arrangement for mutually frequency-locking two DRO-type Ka-band (34-40 GHz) oscillators without any synthesizer action.

II. PROPOSED LOCKING SYSTEM

The test system comprises of two separate oscillators, which are each actually a combination of a simple X-band GaAs field-effect transistor unit and a diode frequency tripler, two magic-T power dividers, three ferrite circulators, a balanced Ka-band mixer and a 20 dB attenuator. The configuration, illustrated in detail in Fig. 1, is as follows. First, the signal from the master Ka-unit is fed through a ferrite circulator to a magic-T, from which one half goes out to the desired application and the other half through the 20 dB attenuator to the mixer RF port. Then, the output of the slave Ka-unit goes to the second magic-T, from where it is divided through separate circulators to the LO port of the mixer and also to the desired application, which is assumed to be outside the circuit considered here. A DC block is needed at the mixer IF port just because of the particular diode configuration. An optional low pass filter can be used to reject unwanted mixing products.

The commercial oscillators are manufactured as microstrip boards and the adjacent multiplier fits into a microstrip-to-waveguide transition as is shown in Fig. 2. Unfortunately, that particular oscillator housing is far from hermetic [7], in fact it is not even closed in RF sense at the particular operating frequency. Leaking causes severe stability problems as unwanted coupling may exists between adjacent electrical units. The circulators, magic-T's and the attenuator are all WR-28 waveguide hardware. Matched terminations were inserted to the unused ports of the magic-T's in order to reduce the effects of manufacturing inaccuracies [8]. The mixer, which is used as a phase detector and indicates the locked status, is also a waveguide design and employs a 3.5 mm IF connector. If no lock information is necessary, the mixer can be omitted but at the same time we must increase the attenuation to 40 dB in order to compensate for the missing LO-RF isolation. The entire system assembled as a ”waveguide-breadboard” setup for trials is highlighted in Fig. 3.

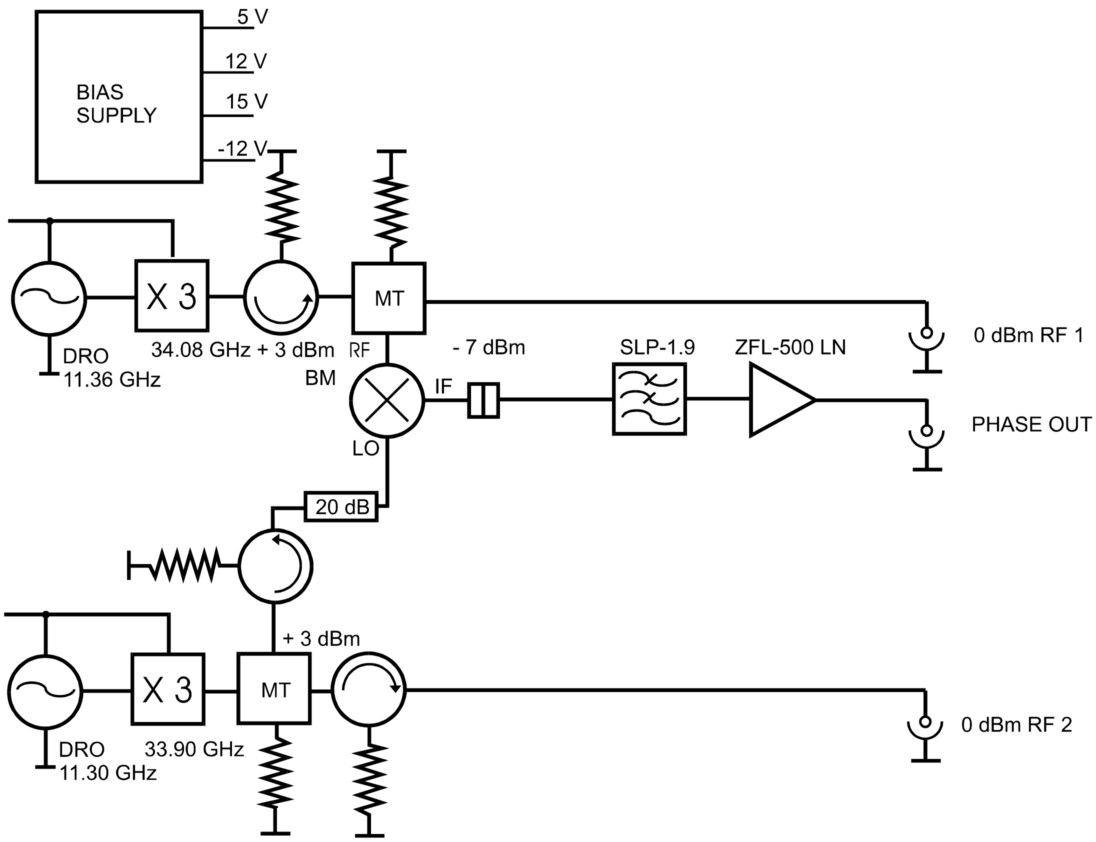

Fig. 1. The schematic construction of the proposed injection locking waveguide circuit. If lock information is not needed, the mixer can be replaced by a 20 dB attenuator.

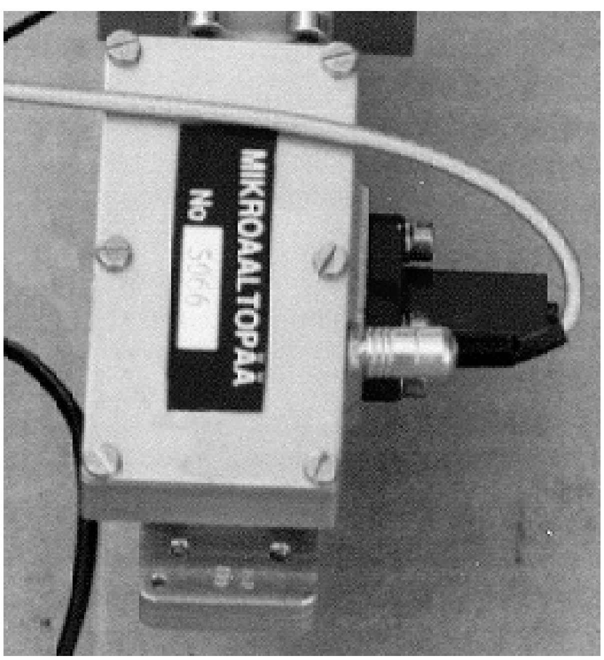

Fig. 2. DRO-type oscillators with integrated waveguide diode multipliers (below the main cover) were utilized in our tests. The waveguide termination for the ferrite circulator is seen to the right. The design of the housing is far from hermetic - not even RF tight, and caused frequent problems in the form of unwanted couplings.

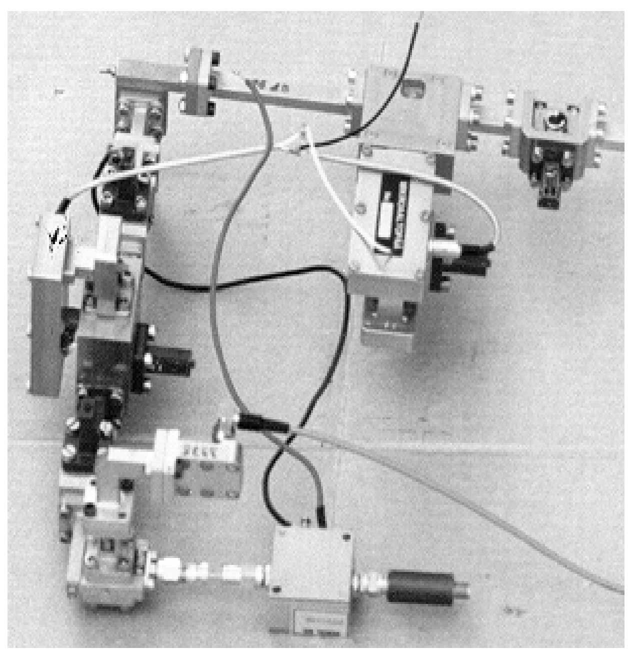

Fig. 3. Experimental waveguide setup that proved the suggested injection locking scheme. Only DC power supplies are missing.

III. RESULTS FROM FIRST EXPERIMENTS

In our experiments, the initial or free-running frequency offset between the two oscillators has been 3-70 MHz, depending on sample. Most measurements were performed with otherwise identical units having a frequency difference of 20 MHz. Their output power is about +11 dBm (without the ferrite circulator). The isolation performance of the circulators was measured to be better than 22 dB and their insertion loss is 1.2 dB between any two forward arms. Once power is turned on, both units start to warm up and interact and finally the slave oscillator has been locked to the master. The process can be monitored at the mixer IF port where the rapidly decreasing difference frequency - and in the end the steady-state DC-voltage representing the phase state if the block is removed - is seen. It takes about 2 minutes from a complete cold start at room temperature to reach the locked state but this time can be further reduced by applying a slight voltage control to the slave oscillator, the frequency of which in our case was a linear function of operating frequency and showed a tuning sensitivity of 7 MHz/V. Once mutually locked, no external actions (e.g. reasonable temperature, load or voltage fluctuations) can alter the situation, if power is not cycled. No synthesizer noise appears in the output spectra because no PLL circuits are used.

Already the first trials brought some interesting and even astonishing results. The operation of the circuit ceased completely - both oscillators had their independent frequencies - when accidentally the two units were physically interchanged during mounting. This suggests that in order to have the injection locking phenomenon in action, we must provide the slightly higher frequency to the upper arm of the magic-T in Fig. 1. One - both obviously not the only - reason to this was observed to be in the tuning characteristics of the two DROs as illustrated in Fig. 4. A succesful attempt of indirect coarse frequency control through forced cooling was also tried. Fig. 5. shows the experimental arrangement, which utilized cold tap water to bring both DROs to about +7 degrees centigrade. The cooling circuit utilizes common automotive brake tubing due to its good corrosion resistance. Because both oscillators consume about 0.5 W of DC power and run at around + 50 degrees centigrade without external cooling, their die temperature can be effectively lowered by adjusting the amount of flow. Although this is certainly a non-precision approach, its clear benefit is in avoiding any electrical interaction with the output spectrum. Besides, by using more precise temperature sensing, an accuracy comparable e.g. to that shown in [9] for sapphire resonators at 9 GHz (0.1 MHz for 10 degrees centigrade when our oscillators exhibit about 2 MHz for 50 degrees) is achievable.

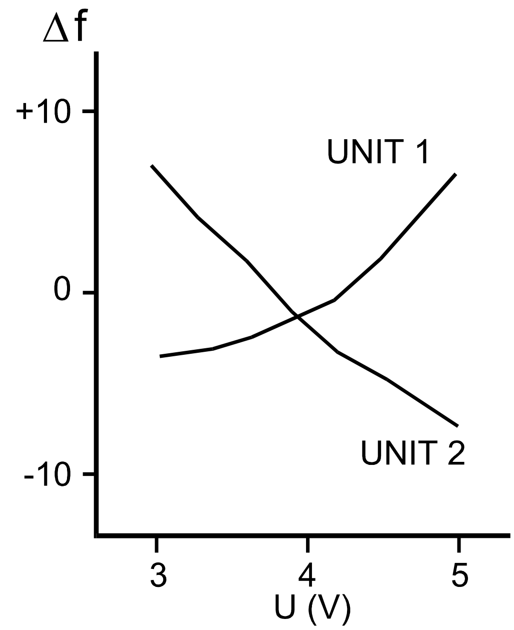

Fig. 4. The frequency control slope of the two test oscillators as a function of control voltage. Because the sign of the derivative is different, the units can not be exchanged in the proposed layout.

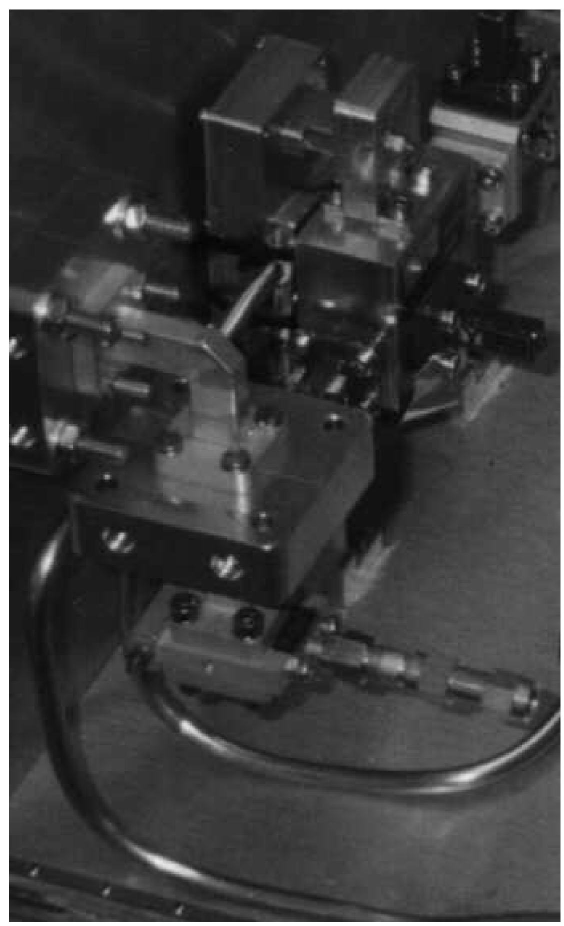

Fig. 5. Water cooling (copper tubes in the front) is an efficient and low-cost way of providing coarse frequency adjustment of millimeter wave oscillators without sacrificing their spectral purity close to the carrier.

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