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ENHANCING THE FREQUENCY STABILITY OF A MILLIMETER WAVE NETWORK ANALYZER WITH AN ADD-ON UNIT

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Abstract - **A proper arrangement frequency generation greatly enhances the stability of commercial millimeter wave instrumentation, particularly in network analyzers operating above 110 GHz. When distributed crystal clocks of varying uncertainty classes are replaced by a centralized rubidium master oscillator, the phase and frequency errors of the entire measuring system are reduced by a factor of ten. Galvanic ground loops and load pulling effects can be entirely avoided in these physically large installations by using optical fibers as a synchronization path. Millimeter wave spectrum characteristics remain unaffected because no additional phase locked loops or frequency multipliers are needed. The suggested modification is of great help in prolonged near-field scanning measurements, where a constant phase and carrier frequency have to be maintained even for a couple of days. Repeatability is extended up to several months through GPS-based frequency steering, which however must be disabled during millimeter wave activity in order to avoid phase jumps.**
Keywords - Frequency stability, network analyzers, millimeter wave measurements, antenna measurements

I. Introduction

Above about 110 GHz, most commercial millimeter wave network analyzers, such as [1], use a principle of constant frequency offset or frequency tracking between their receiver and transmitter. This ingenious idea helps in reducing equipment cost compared to the case where fully synthesized signals might be tried. However, this scheme as illustrated in Fig. 1 naturally does not create a truly constant test port frequency. Because for example antenna measurements [2] also at and above 300 GHz require a distinct and stable output frequency and phase [3], an external frequency counter has to steer the first sweeper or source. This reduces cost compared e.g. to fully synthesized solutions shown in [4] or [5]. Unfortunately, the long time constants involved don't allow easy phase locking between receiver and transmitter.

Despite the selected scheme of [1], the internal crystal oscillators of the particular network analyzer in use were found in authors' measurements to cause excessive short-term phase and frequency uncertainties at millimeter wave frequencies [6]. Phase drifting of 0.5^{o}/h at 100 GHz was observed [7]. As continuous antenna measurements extending over a couple of days were expected, remedies had to be found. It also turned out, that the two crystal oscillators (marked $XTAL_1$ and $XTAL_2$ in Fig. 1.) suffered from severe load pulling and temperature effects - which is apparently not due to the special microwave generation arrangement itself but to less successful circuit and system layout - whereby any reconfigurations or changes of cabling could hamper the accuracy of continuous millimeter wave recordings. Fig. 2 shows an example of measured performance of $XTAL_2$ 50 MHz signal when an oscilloscope channel was connected to its parallel output just for monitoring purposes. Because of such rather discouraging findings, we decided to follow the systems engineering approach.

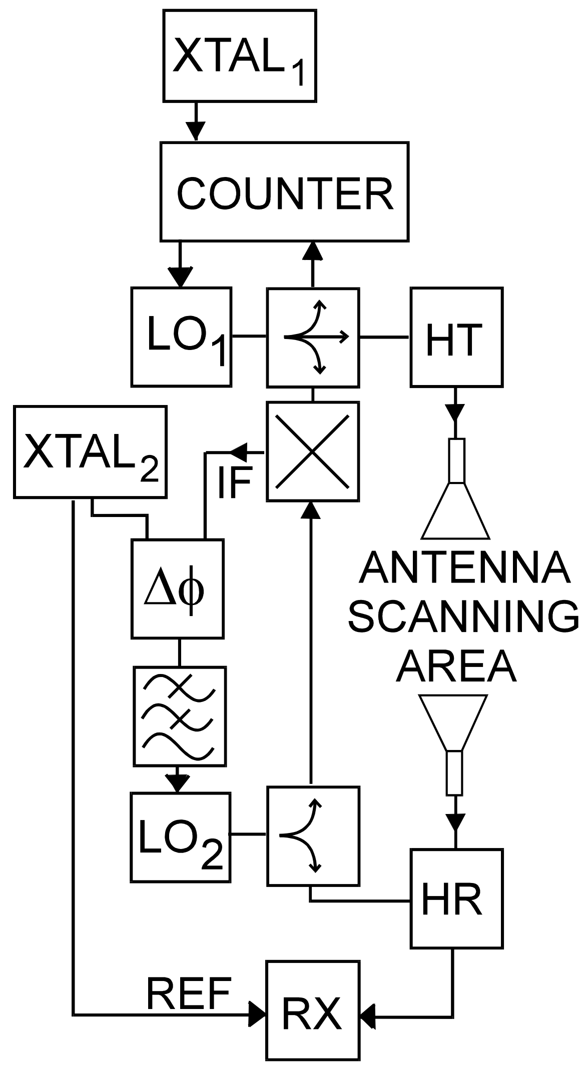

Fig. 1. This is how certain commercial millimeter wave measuring instruments create their test port signals. Only the frequency difference between transmitter (HT) and receiver (HR) is maintained constant.

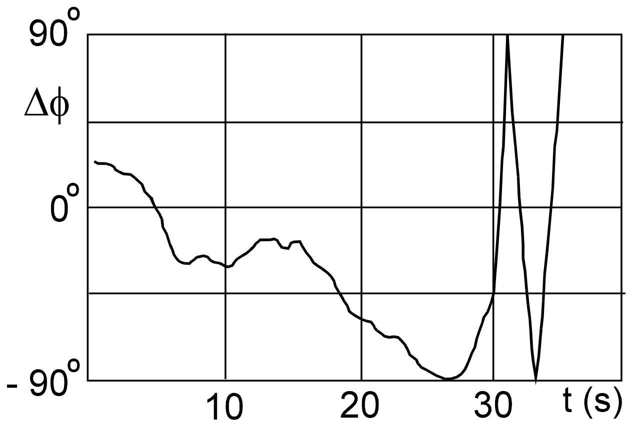

Fig. 2. Regardless of application philosophy, this is obviously not the way an oscillator's output phase should rush when a 10 Mohm oscilloscope channel is connected to it (at t = 30 s) for monitoring purposes.

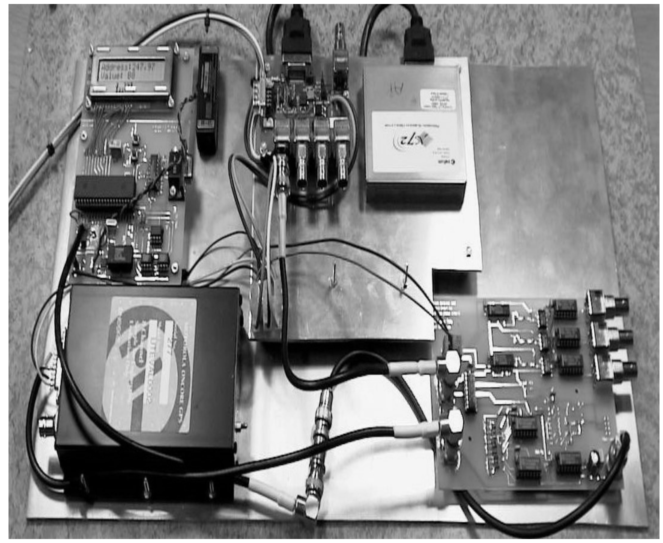

Fig. 3. All necessary items of the add-on unit mounted on an aluminum sheet. The main rubidium oscillator, PIC processor and Motorola GPS receiver share common mechanics but the second GPS device is kept separate due to its larger physical size. An uninterrupted power supply unit sits on floor level due to its weight.

II. Proposed frequency generation arrangement

We have carried out a relatively straightforward improvement of the analyzer's frequency stability by replacing the individual, spatially distributed crystal oscillators with a centralized rubidium standard, supplemented by optically isolated outputs and dividers. Actually the practice followed is very similar to that of modern telecommunication network upgrading where autonomous switches and base stations are being replaced by fully synchronous units - only the geographical scale is here different. Two GPS clocks of different make form the long-term stability reference system for the rubidium unit. This was considered mandatory, as very little data has been released about the built-in time keeping and holdover algorithms in popular commercial receivers.

An on-board PIC processor performs data logging, GPS source selection and calculates the long-term control output for the rubidium unit. Initial tests suggested problems in serial communication with this oscillator and at the time of writing the device is still under repair at the dealer's premises. Much of the GPS-based time constants were adopted from similar measurements made by the authors and described in [8]. Therefore, averaging over 10 000 seconds was considered as beneficial although we did not have to make preparations for Selective Availability. Helpful ideas regarding short-term phase fluctuations were obtained from [9]. The prototype master oscillator assembly is illustrated in Fig. 3. Because all essential individual elements were already adequately protected in terms of electromagnetic compatibility, we could start with an "open" construction giving best possibilities for measurements and evaluations. Our intention is, however, to incorporate the add-on electronics as an integral part of the millimeter wave analyzers. A COTS-type (Commercial Off The Self) uninterrupted power supply with feeding capacity in excess of three hours is currently in use. Its main mission is to guarantee continuous long-term phase recordings. Currently the whole setup is totally open indeed whereby normal airflow in the room easily stabilizes thermal gradients. The PIC unit allows an expansion of the temperature sensor system and thus we are able to monitor and even control the situation also after the entire oscillator assembly has been put into an enclosure for enhanced electromagnetic protection.

Special arrangements were necessary due to the physically dispersed nature and layout of the original millimeter wave electronics [10], which we did not want to modify. In fact, millimeter wave losses simply dictate for example the location of the receiver front-end and associated downconverter. Optical fiber must be used for distributing the reference signal because the distance between receiver and transmitter local oscillators is several meters and their power supplies and transmission lines already create closed galvanic paths. A further challenge is the fact that the receiver must move physically during an antenna measuring scan within a square of about 1.5 m^2, which introduces phase fluctuations up to 10^o in the microwave cables.

The PIC processor has a manually operated hold-function, which prevents GPS-based rubidium frequency adjustments during near-field patterns scans, because their integrity would be otherwise lost. Our system uses an integration time of 10 000 seconds to average out GPS and phase detector noise, as was found suitable in [8] but under less favorable conditions - i.e. with Selective Availability and other intentional GPS signal degradations activated. Therefore, much better performance can be anticipated nowadays.

III. Preliminary results

An example of measured frequency correction from the GPS to the add-on rubidium as a function of elapsed time is shown in Fig. 4. The quite unsteady upper plot presents the outdoor (and GPS antenna) temperature, which fluctuated between + 5 and -15 degrees centigrade during the observation period. As can be seen from the recording, the temperature measurement resolution is arbitrarily set at one degree. The second plot of Fig. 4 presents actually the phase detector output voltage from which the linear effect of constant frequency offset has been removed. In order to preserve reasonable scaling we have not converted the voltage to the respective momentary phase differences. However, the scaling constant is 5 volts for 360 degrees of phase angle.

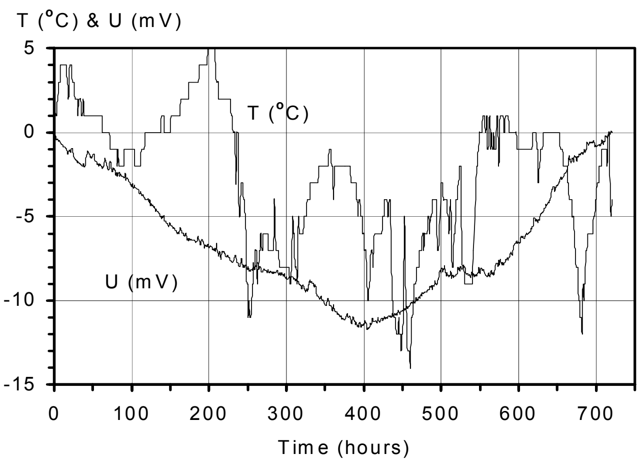

Fig. 4. Frequency steering of the main rubidium is based on averaging over 10 000 seconds from comparisons with the associated GPS receiver output. This plot shows frequency control and GPS antenna temperature as a function of time for a 30-day recording. For visual clarity, the conversion from 1 V to 72 degrees of phase angle has been omitted.

Some correlation can be seen between temperature and phase, but the time constant is around 120 hours. Therefore we expect to be able to perform antenna tests over one full working week with enhanced accuracy. The millimeter wave phase disturbances at 300 GHz are currently reduced by a factor of 10 and the respective frequency stability is improved to the order of 10^{-10} as is expected based on the respective oscillator performance figures. Phase noise close to carrier remains practically unaffected because no additional PLL is included.

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