# A LOW NOISE SYNTHESIZER FOR AUTOTUNING AND PERFORMANCE TESTING OF HYDROGEN MASERS

by

James M. Cloeren
The Johns Hopkins University Applied Physics Laboratory
Laurel, Maryland

Jeffrey S. Ingold
Allied Bendix Aerospace
Columbia, Maryland

## ABSTRACT

A low noise synthesizer has been developed for use in hydrogen maser autotuning and performance evaluation. This synthesizer replaces the frequency offset maser normally used for this purpose and allows the user to maintain all masers in the ensemble at the same frequency.

The synthesizer design utilizes a quartz oscillator with a B.V.A. resonator. The oscillator has a frequency offset of $5 \times 10^{-8}$. The B.V.A. oscillator is phase-locked to a hydrogen maser by means of a high gain, high stability phase-locked loop, employing low noise multipliers as phase error amplifiers. A functional block diagram of the synthesizer and performance data will be presented.

## INTRODUCTION

The Johns Hopkins University Applied Physics Laboratory has been involved in the research, development and fabrication of Hydrogen Masers since 1975. The NR (NASA Research) Hydrogen Maser, developed at JHU/APL has several innovative features which greatly enhance its performance. One of these features is the ability of the NR maser to tune itself by making frequency difference measurements between itself and a reference signal, offset in frequency by $5 \times 10^{-8}$. The best autotune performance is obtained when the offset reference signal is obtained from another hydrogen maser. Unfortunately this method mandates that the reference maser be offset $5 \times 10^{-8}$ thus removing a valuable maser from the on-frequency clock ensemble. Clearly it would be desirable to operate all masers on frequency and to have a synthesizer phase locked to the maser to provide the offset frequency reference signal. To be an adequate replacement for the reference maser, the synthesizer should not degrade the maser performance in autotuning, and it should be small and rugged enough for maser field repair and alignment operations.

## DESIGN APPROACH

The offset generator is basically a single frequency indirect synthesizer using a multiply-mix - phase locked loop approach. (Please refer to Figure 1). For clarity of presentation, the synthesizer is divided into three parts: the fixed frequency, the phase multipliers and the phase locked loop. The fixed frequency section contains a very stable, spectrally pure VCXO which is operated at 5 MHz + 5 x $10^{-8}$. The VCXO is manufactured by Oscilloquartz using a B.V.A. resonator. The VCXO has excellent short term stability below 1 second. The phase error multiplier section contains two low noise multipliers which multiply the 5 MHz outputs of the offset VCXO and the Maser to 1 GHz. The 1 GHz signals are then mixed to produce a 50 Hz signal which has 200 times the phase information as the original 5 MHz signals. The frequency of the 50 Hz signal is dependent on the fractional frequency difference between the offset VCXO (5 MHz + 5 x $10^{-8}$) and the reference maser. The 50 Hz signal has a frequency sensitivity of 1 x $10^{-9}$ per Hz. The phase locked loop section contains a Motorola MC 4044 phase lock loop I.C., a divide by 100,000 circuit, and a mixer-low pass filter. The 50 Hz signal resulting from the two 1 GHz outputs which contains the Offset VCXO vs maser phase data is compared with a reference 50 Hz signal which is divided down from the maser input. The comparison is made using a Motorola MC 4044 digital phase detector used in the quadrature mode. The resulting error signal is translated and filtered and used to lock the offset VCXO. The 5 x $10^{-8}$ offset signal from the VCXO is the output of the synthesizer.

## PERFORMANCE DATA

The data presented in Figure 2 was taken at JHU/APL and shows the results of comparing two masers together (NRX and NR9) in two configurations. The bottom trace is a sigma tau plot of the NRX maser compared to the NR9 maser with NR9 offset in frequency 5 x $10^{-8}$. The top trace shows a sigma tau plot of the same two masers except in this instance the masers are running at the same frequency. NR9 was placed back on frequency and the offset generator was phase locked to the NRX maser thus producing the 5 x $10^{-8}$ offset. Note there is very little difference between the two traces and that for all practical purposes the offset generator performs as well as the maser which was intentionally offset in frequency.

The offset generator was also performance tested in the field at the Mojave Base Station, Goldstone California, in the following manner. Five NR masers were autotuned using the offset generator. Later one of the masers was offset and used to evaluate the other four masers tuned with the offset generator. The agreement was found to be within 1 x $10^{-13}$ tau.

## CONCLUSION

The design features of a low noise single frequency synthesizer used to provide a 5 x $10^{-8}$ offset signal for tuning NR hydrogen masers has been presented. Test data presented indicate that there is a negligible performance penalty when using the offset generator in place of an offset maser for providing the 5 x $10^{-8}$ offset reference signal used for frequency difference measurements and tuning of NR masers.

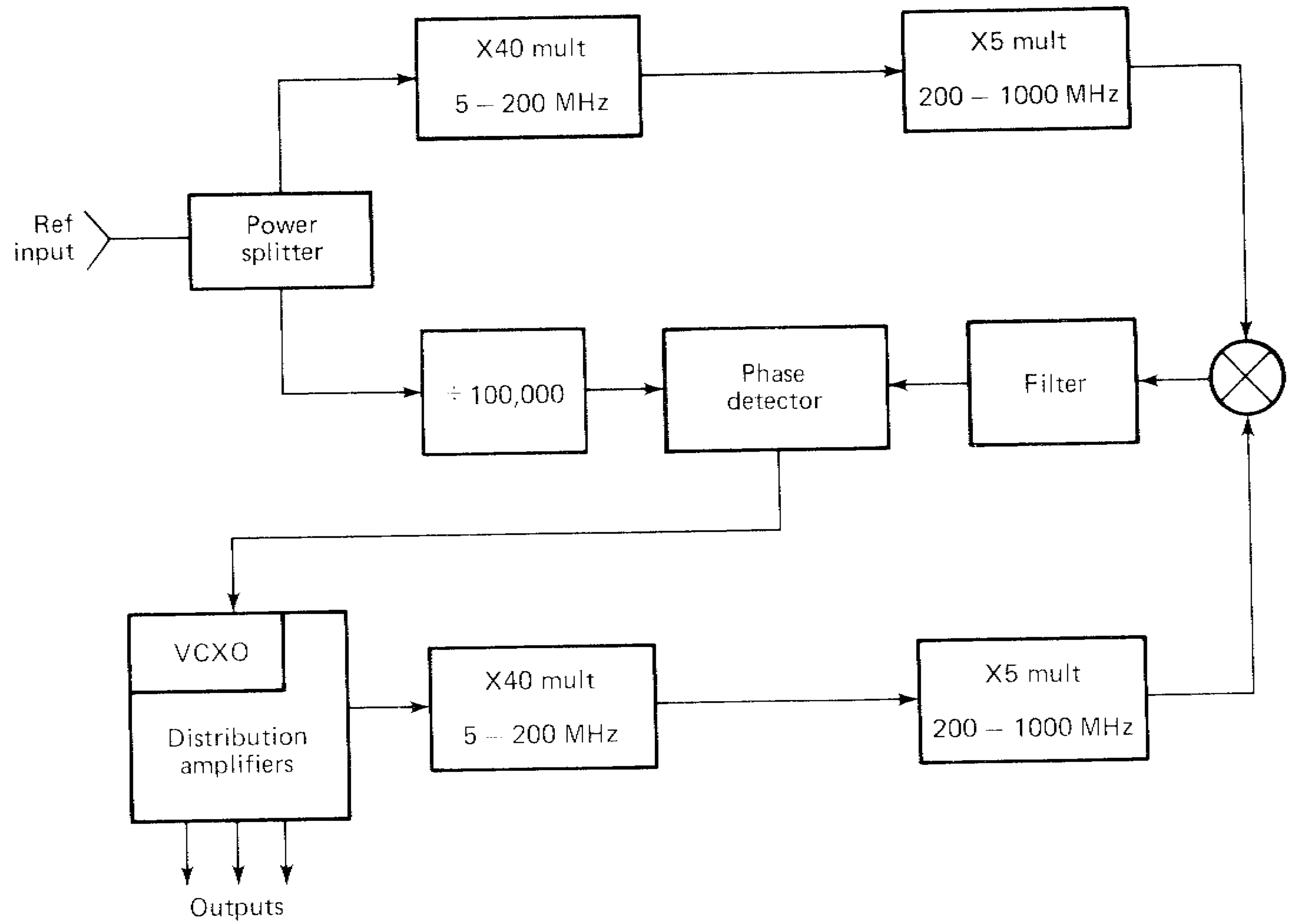


**Fig. 1** Low noise synthesizer for autotuning and performance testing of hydrogen masers.

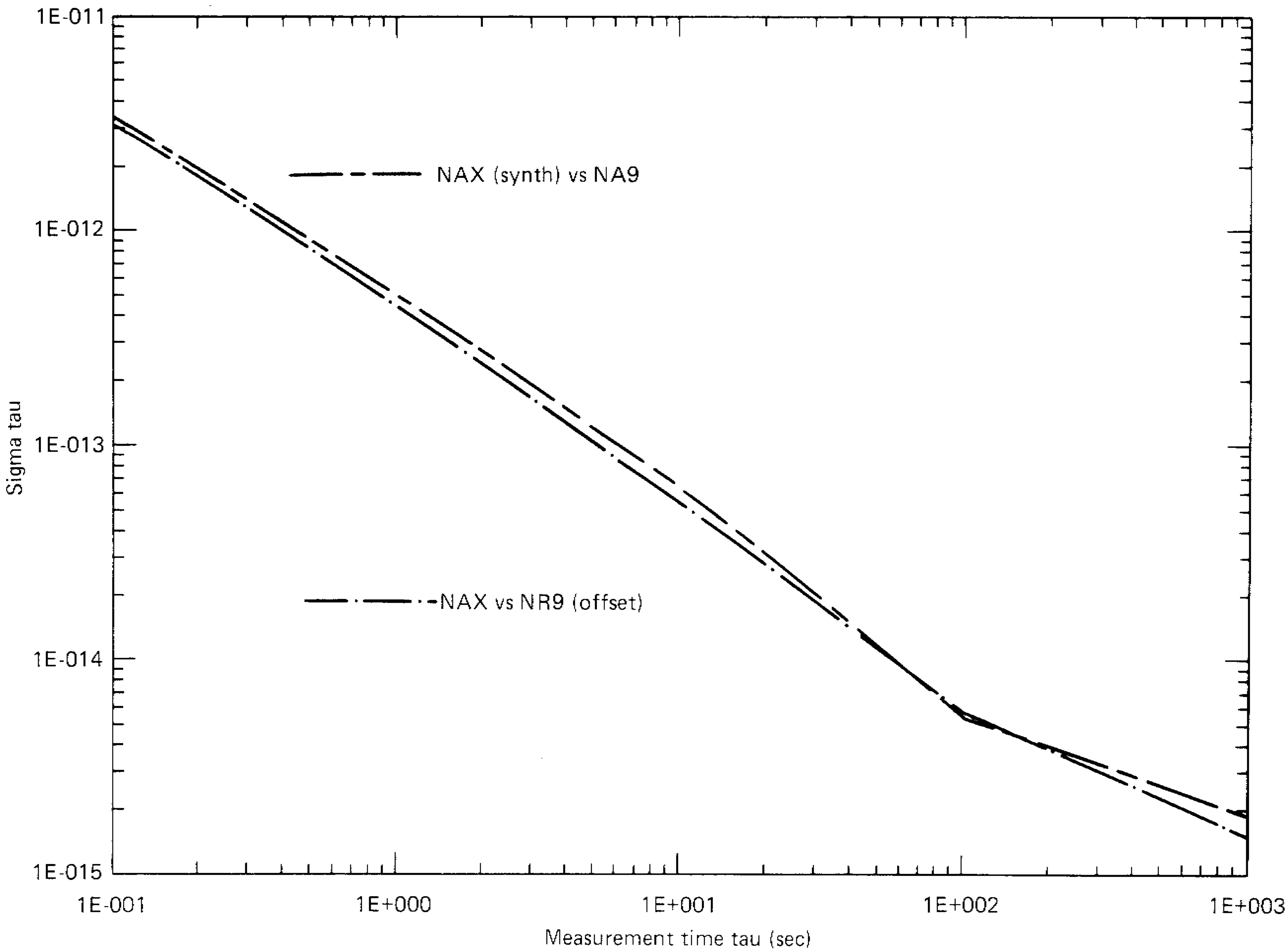


Fig. 2 Stability performance of low noise synthesizer.

## QUESTIONS AND ANSWERS

MR. McCOUBREY: You point out that the use of this synthesizer permits you to operate all the masers in an assembly at the same frequency. I had always understood that when you got a number of identical oscillators close to the same frequency, they tend to pull each other and, therefore, become not all independent, which you like them to be if they are to operate in an ensemble. Is that a problem?

MR. INGOLD: I haven't seen that in the Time and Frequency lab at Johns Hopkins. Maybe Lauren Rueger could answer that.

MR. RUEGER: We have enough isolation in the instrument that we can readily see pulling if it occurred, and we do not. We look at phase plots with resolution of something on the order of one picosecond and see no evidence of pulling. We can move the C fields up and down through the resolution values and see no effect at that point.

MR. McCOUBREY: So you introduce controllable shifts and actually look for this?

MR. RUEGER: Exactly.

MR. McCOUBREY: It's very important to do that. As they get closer and closer, the difference is in the denominator, and you ultimately get them so close that even an extremely small coupling will influence the situation.

MR. RUEGER: We have isolation, in the closed loop system, of about 120 dB, and we have an additional isolation of an initial 120 dB. That's about the leakage through solid coax cables.

MR. McCOUBREY: Ultimately 200 dB.

MR. PETERS: Actually the receivers are mounted in very intimate contact with the top of the cavity, so they have enormous isolation. Besides that, we have synthesizers which have a resolution of 5 times ten to the minus seventeenth. With eleven digits, you can run the maser frequency through another one, through any frequency you wish, and you will never see any pulling phenomenon whatsoever. Unless you take the receiver apart, or put in a high power signal at or near the maser frequency, there is no signal in existence which will effect it.

MR. McCOUBREY: Apparently this has been looked at in depth.

VICTOR REINHARDT, HUGHES AIRCRAFT COMPANY: What you have to realize is that what you are doing in a hydrogen maser when you change the synthesizer is just to move the VCO, but not moving the maser frequency. You can still see effects if you are not careful. They don't effect the maser, but they do effect the VCO, and you can sometimes see interactions and beats between the crystals if you are not careful.

You have to remember that the two masers are always running at 1420 megahertz regardless of what you do with the synthesizers.

MR. RUEGER: They are not really the same frequency.

MR. McCOUBREY: Yes. If the C fields are off, the frequencies will be slightly different.

ALBERT KIRK, JET PROPULSION LABORATORY: Have you actually measured the noise contribution of the offset generator itself?

MR. INGOLD: Yes, we have measured that. It's approximately one part in ten to the thirteenth, tau to the minus one-half. This was for a maser with the external synthesizer compared to another maser.

MR. KIRK: Yes, but have you tried taking one maser and offsetting it and then comparing it against itself?

MR. INGOLD: Yes, it's about one part in ten to the thirteen, tau to the minus one-half.

MR. ALLAN: To the minus one?

MR. REINHARDT: To the minus one-half. Why is it tau to the minus one-half?

MR. INGOLD: I can't explain it.