

## PROGRESS AT CENAM TOWARD THE CONSTRUCTION OF A SHORT CESIUM BEAM OPTICALLY PUMPED FREQUENCY STANDARD

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### ABSTRACT

We report the progress at the Centro Nacional de Metrología, CENAM, toward the construction of a short Cesium beam optically pumped frequency standard. We describe the geometry of our Ramsey cavity, magnetic shield, and light collection. To pump and probe the atoms we use two 5mW DBR diode lasers with linewidth about 1MHz, the lock of this lasers to the 852nm Cesium transition line is described. The spectral purity and short time stability of the microwave synthesizer are reported.

### RAMSEY CAVITY, MAGNETIC SHIELD AND LIGHT COLLECTION

The cesium tube we are using was previously used by NIST in early experiments to demonstrate the potential performance achievable in cesium beam frequency standards in which laser driven optical pumping is used for the atomic state selection and state detection in place of the magnetic state selection (1).

The cesium tube that we are using to built a short cesium beam frequency standard is schematically shown in figure 1, it is a modification on an commercial beam tube manufactured by Frequency Electronics Inc. The magnets "A" and "B", hot wire ionizer, electron multiplier and vac-ion pump were omitted in construction. The magnetic shields, C-field and Ramsey cavity remained unchanged from the standard commercial tube. In figure 1, the darker line shows the magnetic shield. The cesium oven is separated from the beam tube by a gate valve which could be closed when the beam tube system is opened. In "A" and "B" field regions are the optical pumping and detection optics, the fluorescence collection optics is a combination of a spherical mirror and an aspheric lens followed by lens which refocused the fluorescence onto a photodetector

mounted outside the vacuum envelope. The Ramsey cavity is 13cm long, the pumping and detection laser beams are 3,5cm apart from the ends of the cavity.

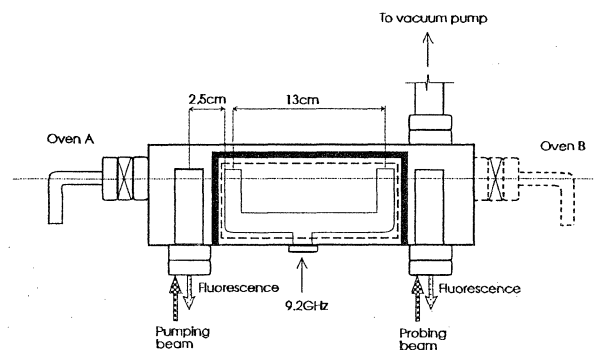


Fig. 1. Schematic of the Cesium tube.

### DIODE LASERS

We use Distributed Bragg Reflection (DBR) type laser diodes to pump and detect the hyperfine Cesium transitions. The DBR laser used has an output power of about 5mW, a linewidth  $\approx$  1MHz and operating wavelength 852nm. The lock of the laser wavelength to the  $D_2$  line is achieved with FM sideband locking. A block diagram of the locking system is shown in figure 3. We use a 20 MHz current to be injected directly into the gain section of the laser diode giving rise to FM sidebands which are about 20 dB down from the single frequency carrier. A small part (about 5%) of the laser beam is passed through the Cesium cell and returned nearly on itself giving rise to the saturated absorption signals from the Cesium  $D_2$  transition line at 852nm. The 20MHz signal (the beat between the FM sidebands and the carrier) is amplified and quadrature phase detected in the phase-loop-filter section. The quadrature detection discriminates against the Doppler broadened background signal and the saturated signals appear as a type of dispersion. The signal obtained with the

quadrature detection is used as a discriminant to lock the emission wavelength of the diode laser to any of the  $D_2$  hyperfine transitions. Because the response time of the DBR control section is larger than  $10^{-5}$ s the gain of the control loop is rolled off at 100kHz. The DBR set-up has no gratings, PZT transducers, or laser cavities to keep aligned. In reference (2) a DBR diode laser similar to this one was found equivalent to an extended cavity diode laser when it was used as the optical source for the fluorescence detection in the USA primary frequency standard, NIST-7.

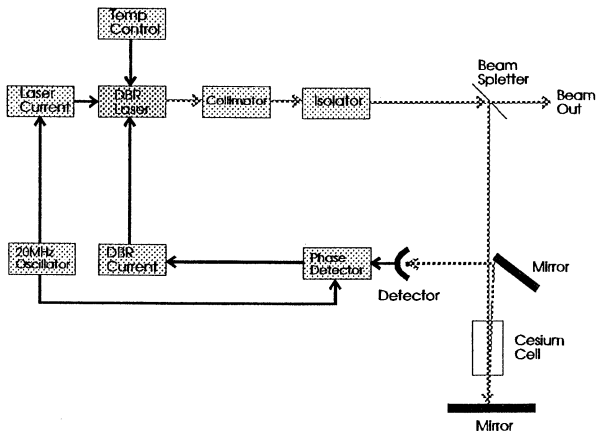


Fig. 2. Block schematic of the DBR laser stabilized to the Cs saturated absorption.

### MICROWAVE SYNTHESIZER

Our synthesizer was developed at NIST (National Institute of Standards and Technology) under a collaborative program between CENAM and NIST. The synthesizer is of the HR (high resolution) type described in reference (3), and it can be stepped  $\pm 180$ kHz at 9,192GHz to interrogate Zeeman resonance, it has a frequency resolution of  $2 \times 10^{-15}$ . The frequency stability of 100MHz to 9,192GHz is approximately  $1 \times 10^{-16}$  at 15 minutes and approaches  $1 \times 10^{-17}$  in one day in a laboratory with thermal variations of about 1K as is shown in figure 4. The temperature coefficient of this synthesizer is less than 1ps/K for synthesis from 100MHz to 9,192GHz and 10ps/K for synthesis from 5MHz to 9,192GHz. The power spectrum of the 9,192GHz output is shown in figure 5. As is shown, it has a very clean spectrum. Except for the residuals left from filtering the 10,7MHz and 510,7MHz comb product of the synthesis chain, there are no spurs higher than -73dBc (dB below de carrier). Figure 6 shows the PM noise from 1Hz to 100kHz for a pair of synthesizers and figure 7 shows the upper limit to the AM noise for Fourier offset frequencies from 1Hz to 100kHz.

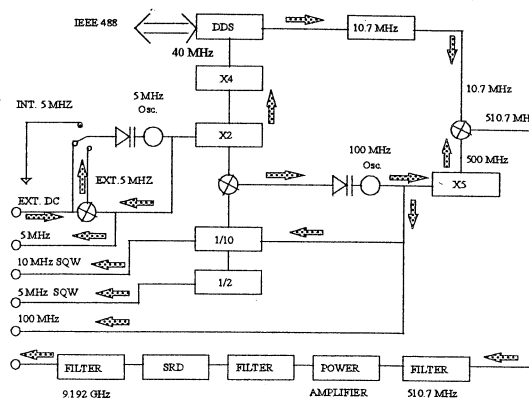


Fig. 3. Block diagram of the CENAM's HR1 type high stability synthesizers developed at NIST to interrogate passive Rb or Cs (depicted) atomic frequency standards.

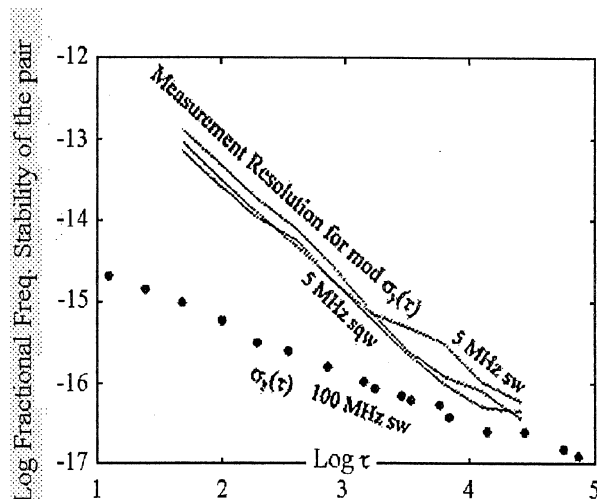


Fig. 4. Fractional Frequency stability of 100MHz output for the pair of HR1 Cs Synthesizers. The other curves show the fractional frequency stability for the 5MHz square-wave and 5MHz sine-wave outputs of the pair.

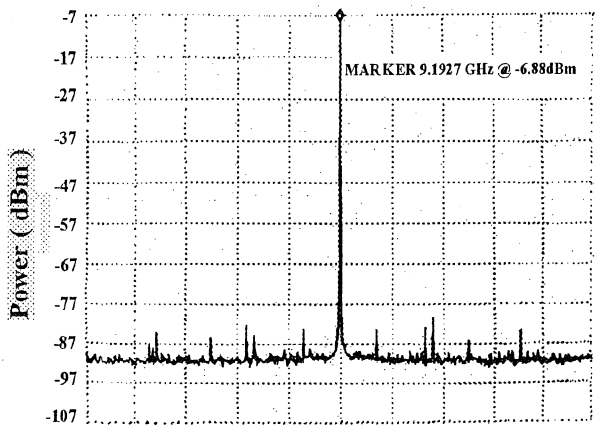
## CONCLUSIONS

We report the progress at the Centro Nacional de Metrología, CENAM, toward the construction of a short Cesium beam optically pumped frequency standard. The beam tube we are using has been derived from a commercial Cesium tube with a minimum modifications. We use DBR type diode lasers to pump and probe the Cesium atoms. The microwave synthesizer has been constructed in collaboration with the Time and Frequency Division of NIST, it has been designed to work in both Cesium thermal beam and Cesium fountain experiments.

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## REFERENCES

- (1) Amy Derbyshire *et al*, 1985, "Optically Pumped Small Cesium Frequency Standard; A Status Report", Proc. of the 39th Symposium on Frequency Control, Philadelphia, 1985, pp. 18-21.
- (2) R.E. Drullinger *et al*, 1996, "DBR Laser Diodes for Optically Pumped Cs Frequency Standards", Proc. 1996 Conference on Precision Electromagnetic Measurements, pp. 260-270.
- (3) J.F. García-Nava *et al*, 1996, "Environmental Effects in Frequency Synthesizers for Passive Frequency Standards", Proc. of the 1996 IEEE International Frequency Control Symposium, pp. 973-979.



CENTER FREQUENCY 9.192 76 GHz      SPAN 20 MHz  
RESOLUTION BANDWIDTH 300 Hz      VIDEO BANDWIDTH 300 Hz

Fig. 5. Power spectrum of 9,192GHz output of the HR1 Synthesizer.

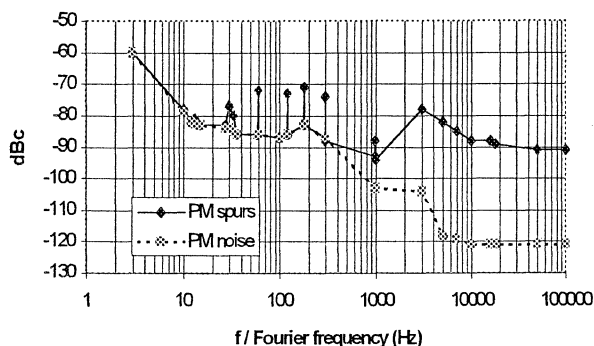


Fig. 6. Typical PM noise and upper limit to the PM spurs @ 9,192GHz for Cesium version of the HR1 synthesizers.

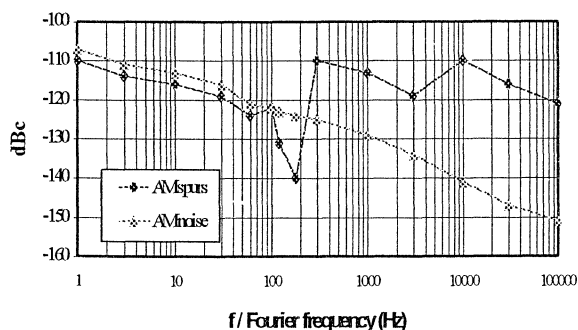


Fig. 7. Typical AM noise and upper limit to the AM spurs @ 9,192GHz for the Cesium version of the HR1 Synthesizers.