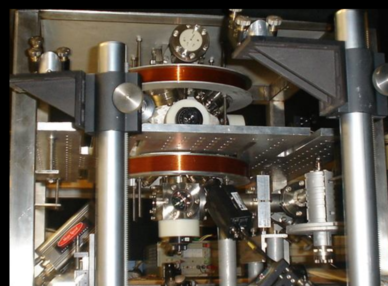
Time and Frequency Activities at CENAM

Mauricio López R.

Centro Nacional de Metrología, CENAM



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Primary Frequency Standards development at CENAM

Mauricio López R.

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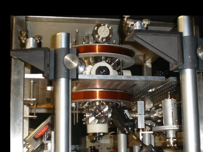

CENAM

Outline

1. Introduction
2. Optically pumped thermal Cesium frequency standard
3. Cs fountain
4. Sapphire Oscillators
5. Time dissemination services

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Primary Frequency Standards development at CENAM

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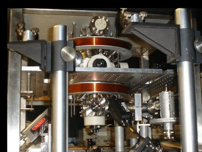

Outline

1. Introduction

2. Optically pumped thermal Cesium frequency standard

3. Cs fountain

4. Sapphire Oscillators

5. Time dissemination services

N 20º 32´ 13”
W 100º 15´ 17”

N 20º 32´ 13"
W 100º 15´ 17"
H 1917 m

CENAM facilities

CENAM´s Time and Frequency Group

Dr Sergio Lopez
Thermal cesium beam clock and systematics effects on primary standards

CENAM´s Time and Frequency Group

Dr Nikolay Shtin
Microwaves and Sapphire oscillators

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Dr Eduardo de Carlos
Lasers and optics for primary frequency standards

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Francisco Jiménez
Time Services

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Nélida Diaz
Time scales

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Maria Espinosa (post graduate student)
Proyect: Cs fountain clock

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Luis Lizama (post graduate student)
Proyect: cryptographic quantum key generation and secure communications

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Alex Castilla (post graduate student)
Proyect: blue photon production through inverse compont scattering

CENAM´s Time and Frequency Group

Sofia Morales
Administration suport

CENAM´s Time and Frequency Group

Dr Mauricio López
Division Chief

CENAM´s Time and Frequency Group

... And the Newton apple trhee

CENAM´s Time and Frequency Group

Primary Frequency Standards development at CENAM

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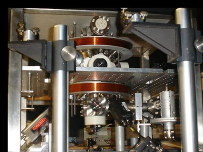

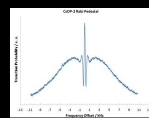

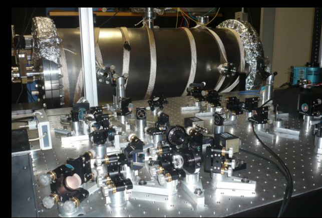

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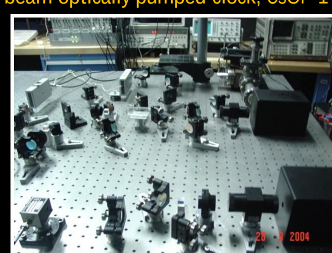
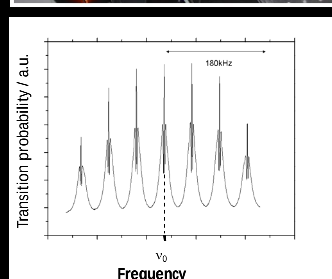
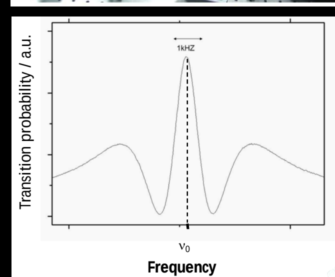
First prototype 1998

Short Ramsey cavity thermal Cesium beam optically pumped clock, CsOP-1







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Systematic effect	Fractional frequency shift $\times 10^{-13}$	Fractional frequency Uncertainty $\times 10^{-14}$
2th order Zeeman	2410	20
2th orden Doppler	-4.2	0.2
Gravitational	2.09	<0.1
Black body radiation	-15.1	0.1
end to end pahase shift	-6.1	5
cavity pulling	32.4	8

CsOP-1 Main operational parameters

Cs oven temperature	100º C
Transit region length	110 mm
Interaction region length	12 mm
Mean atom speed	215m/s
Clock transition linewidth	950 Hz
C-Field	7.6 Tμ

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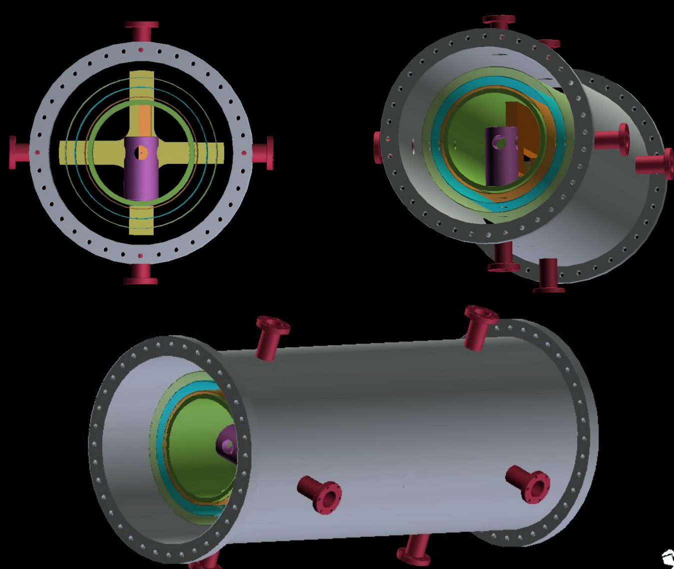
2006: The new CsOP-2 clock



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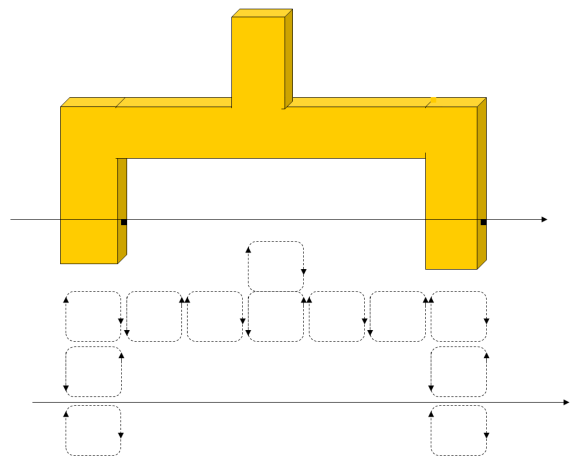
Type H Ramsey Cavity



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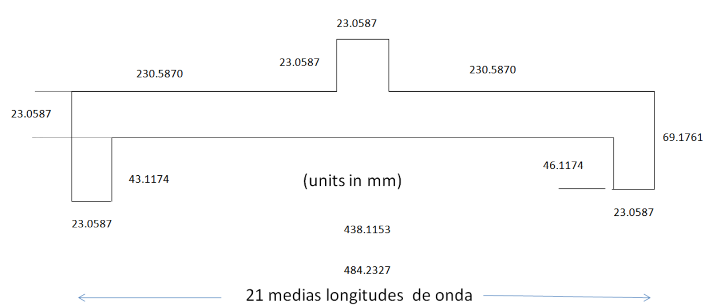
CsOP-2 Ramsey Cavity design



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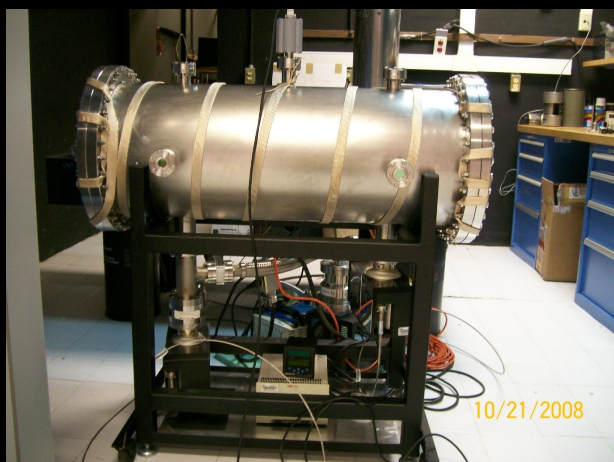
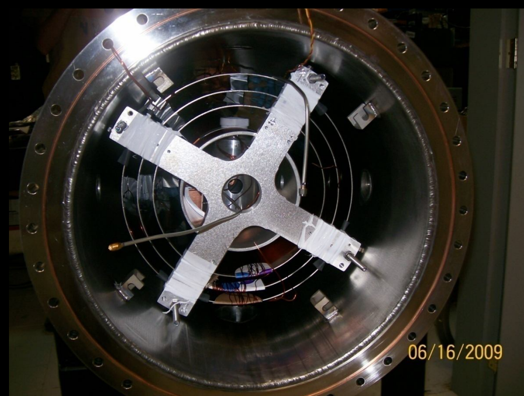
CsOP-2 Ramsey Cavity

aaa

CsOP-2 physics package

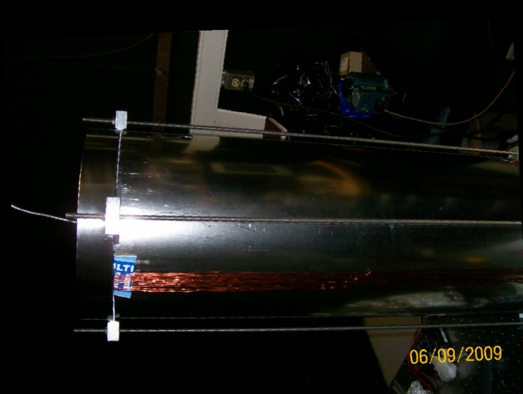


CsOP-2 physics package



CsOP-2 physics package

Demagnetization process of the magnetic shields

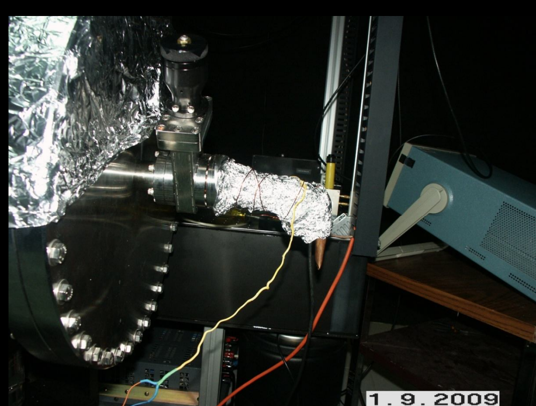


CsOP-2 physics package

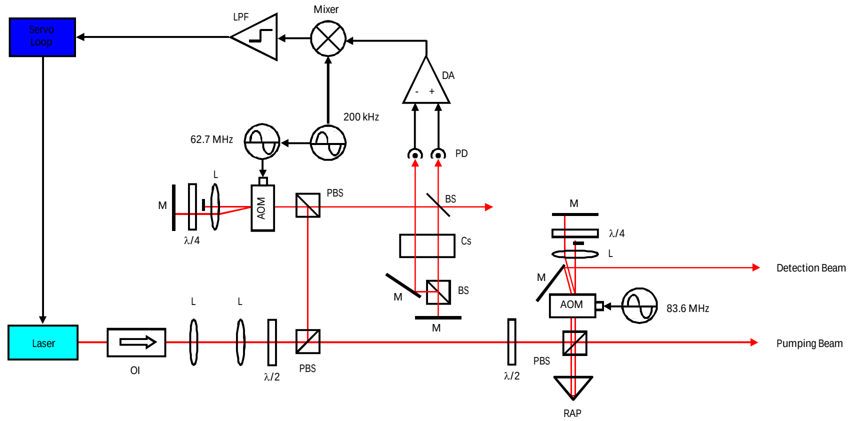
C-field coil adjusments

CsOP-2 physics package

Cs ovens

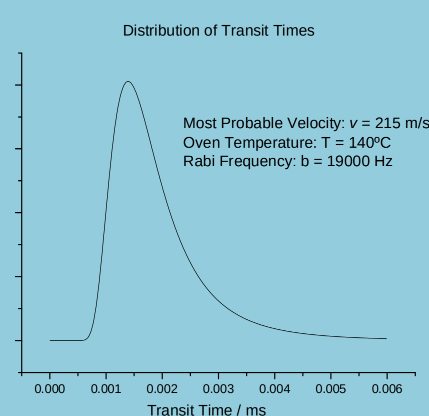


CsOP-2 optical system



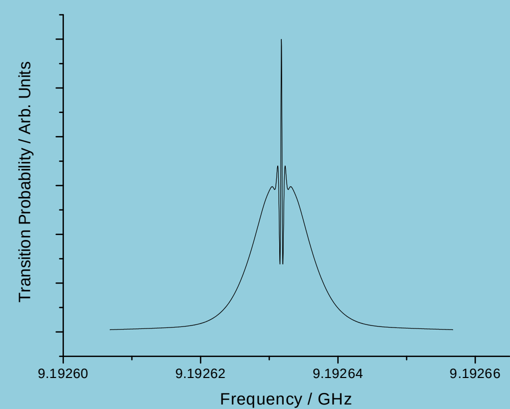
CsOP-2 m=0→m=0 transition

Theoretical Rabi pedestal



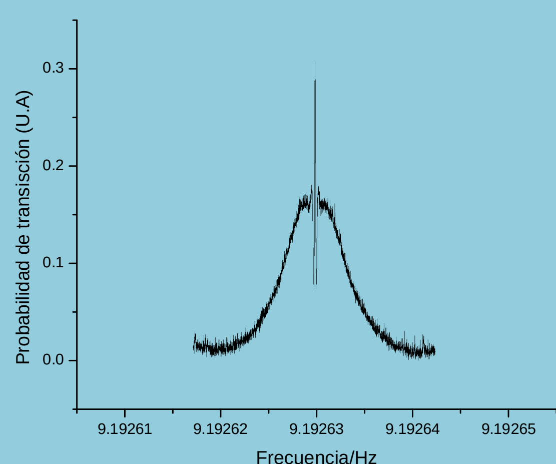
CsOP-2 m=0→m=0 transition

Theoretical Rabi pedestal



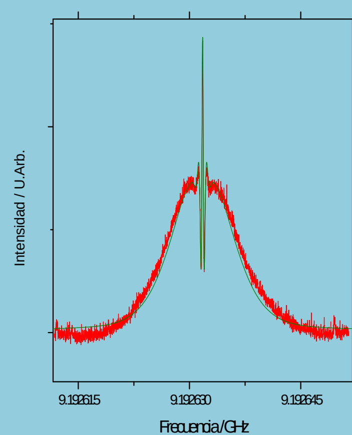
CsOP-2 m=0→m=0 transition

Experimental Rabi pedestal



CsOP-2 m=0→m=0 transition

Rabi pedestal



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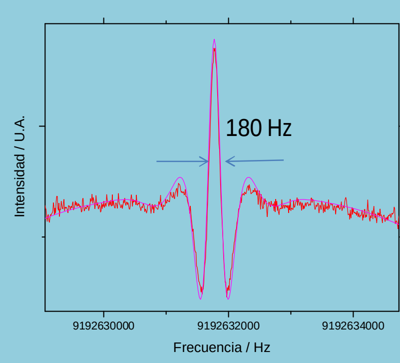
CsOP-2 m=0→m=0 transition

Ramsey fringe



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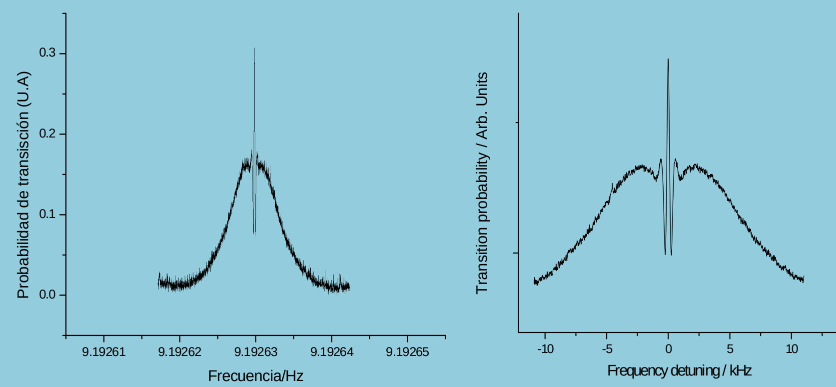
CsOP-2 m=0→m=0 transition

Ramsey fringe



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CENAM´s Optically pumped thermal Cesium frequency standard

Some expected values for systematics

	CsOP-1		CsOP-2	
Systematic effect	Fractional frequency shift $\times 10^{-13}$	Fractional frequency Uncertainty $\times 10^{-14}$	Fractional frequency shift $\times 10^{-13}$	Fractional frequency Uncertainty $\times 10^{-14}$
2th order Zeeman	2410	20	2410	3
2th orden Doppler	-4.2	0.2	-4.2	0.2
Gravitational	2.09	<0.1	2.09	<0.1
Black body radiation	-15.1	0.1	-15.1	0.1
end to end pahase shift	-6.1	5	2	2
cavity pulling	32.4	8	5	2
Uncertainty		22		4

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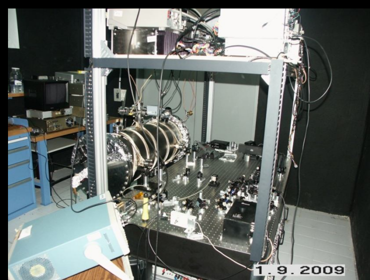
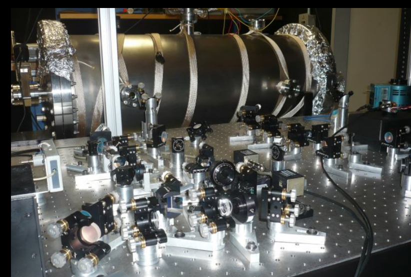
CENAM´s Optically pumped thermal Cesium frequency standard

Work in progress





1. Improvement of signal to noise ratio
2. Long term comparison against UTC(CNM) to evaluate frequency stability
3. Full evaluation of systematics

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Primary Frequency Standards development at CENAM

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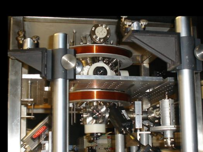

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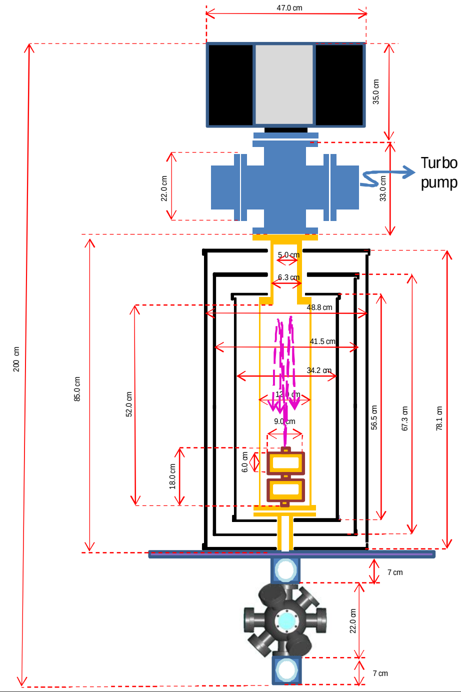
CsOP-2 physics package



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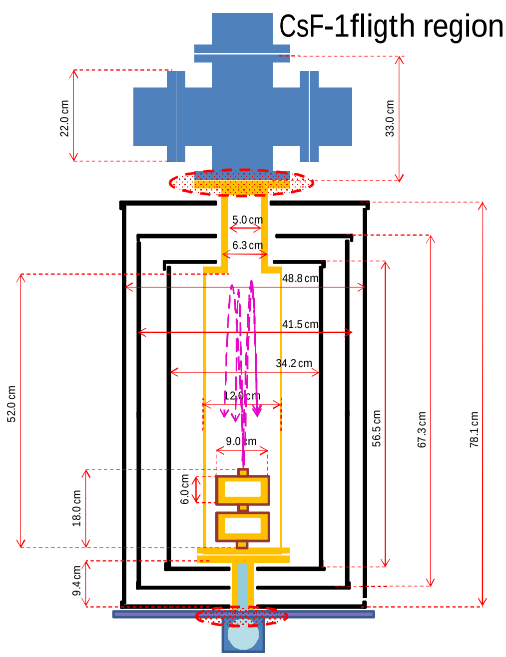
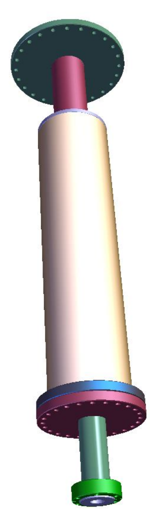
CsF-1fligth region





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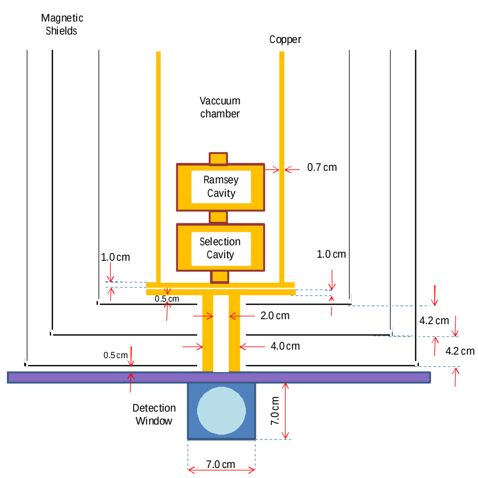
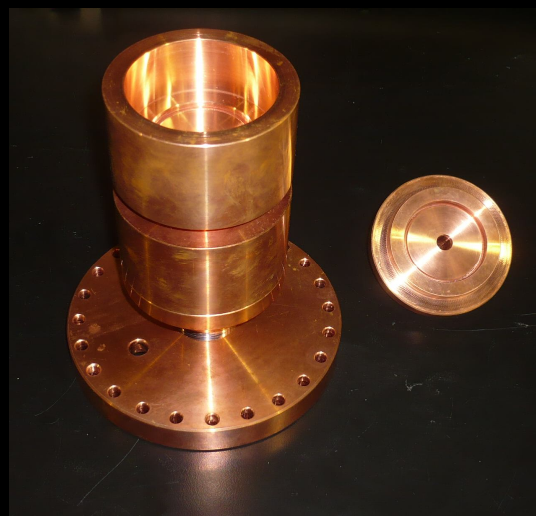
CsF-1fligth tube

CsF-1 microwave cavities



CsF-1 microwave cavities



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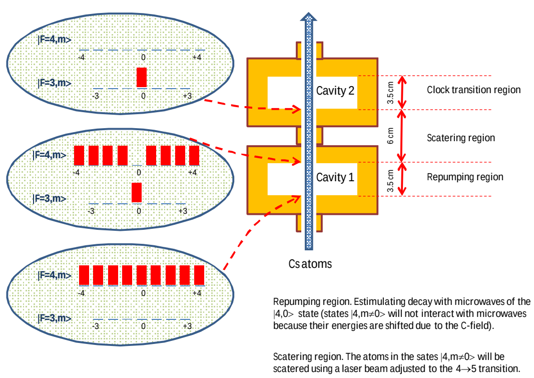
CsF-1 state selection



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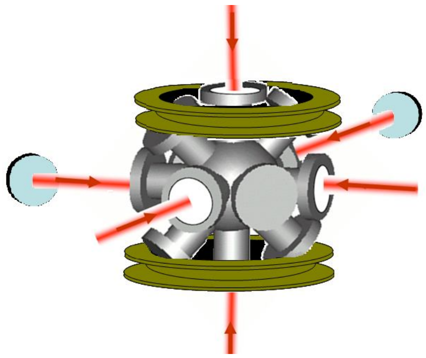
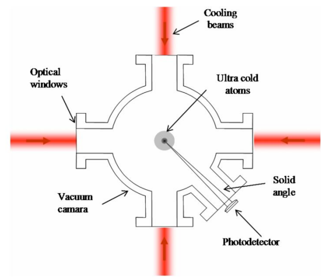
CsF-1 MOT design





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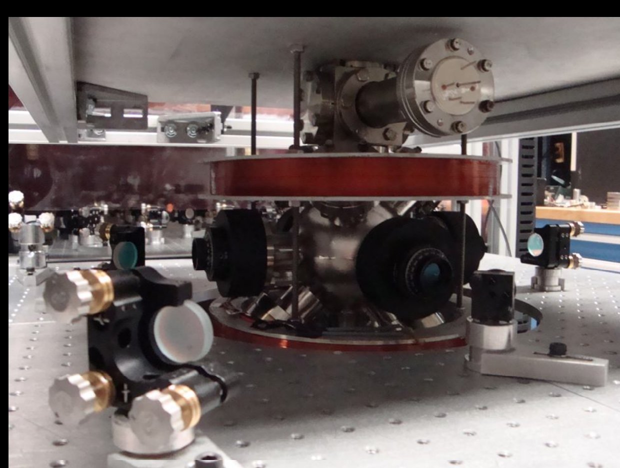
CsF-1 MOT



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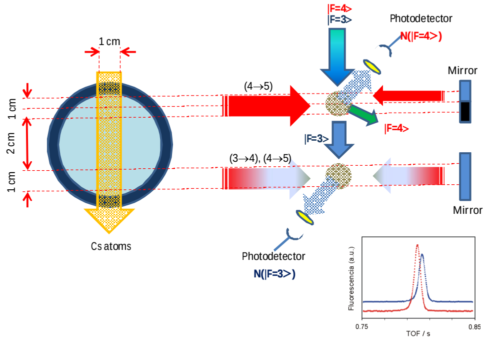
CsF-1 detection system



$$N = \frac{N(|F=3\rangle)}{N(|F=3\rangle) + N(|F=4\rangle)}$$

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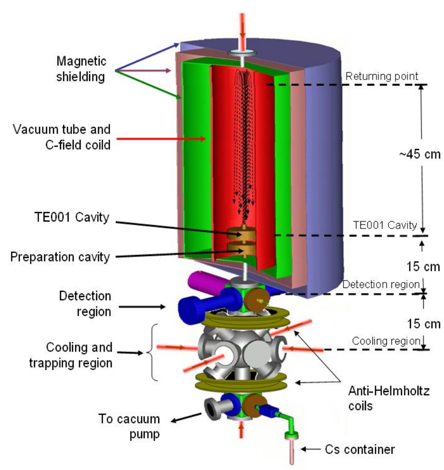
CsF-1 physics package design



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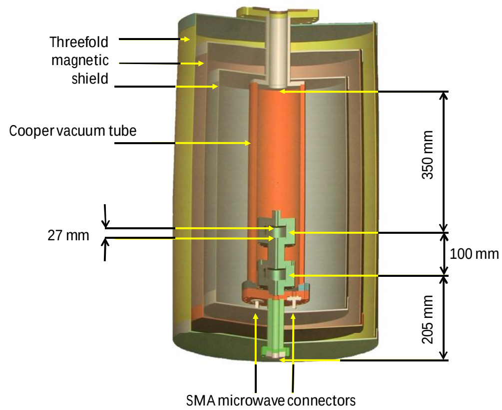
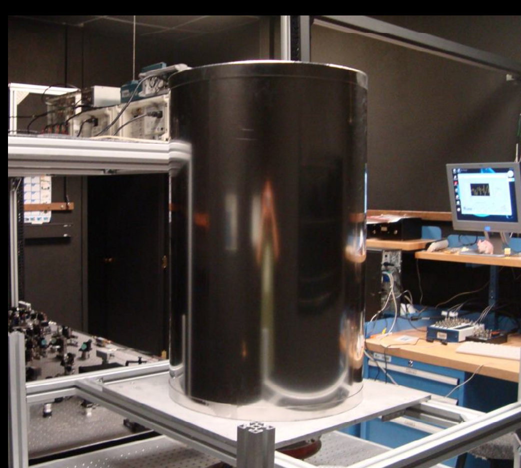
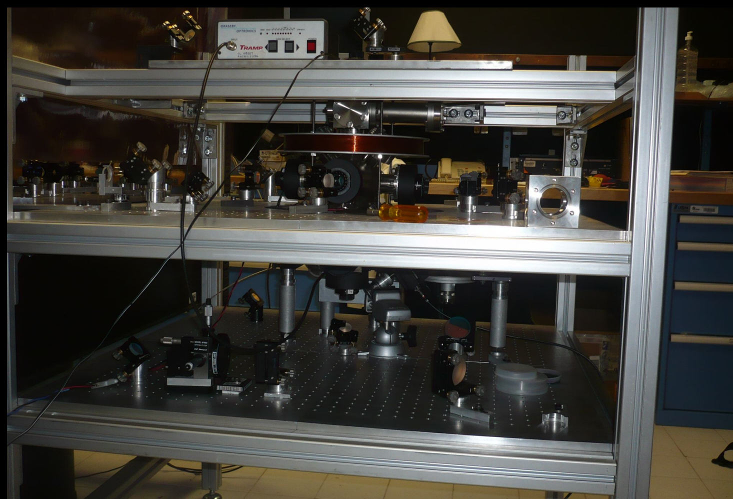
CsF-1fligth region



CsF-1 Magnetic shields



CsF-1 MOT



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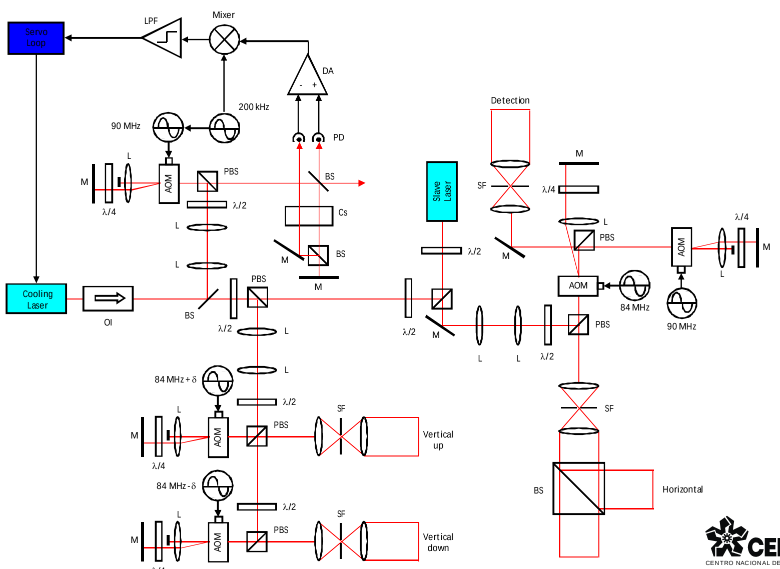
CsF-1 Optical System



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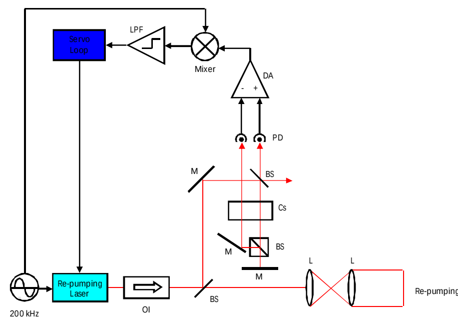
CsF-1 Optical System

Repumping laser



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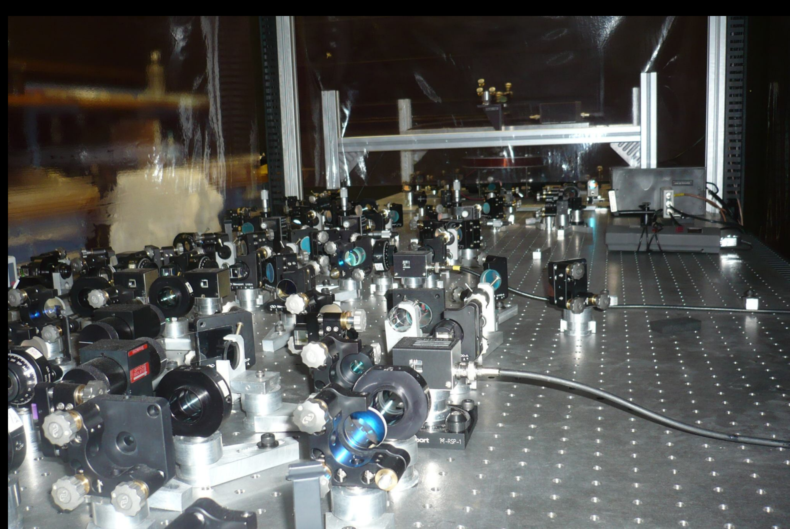
CsF-1 Optical System



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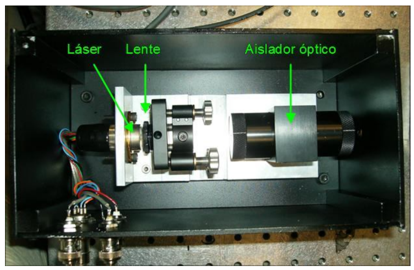
CsF-1 light sources

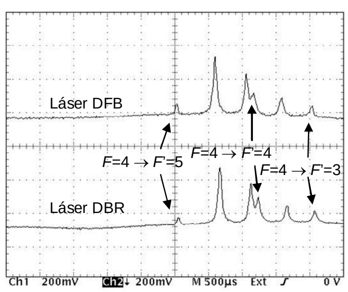
Láser DFB Eagleyard
EYP-DFB-0852-00150-1500-TOC03-0000

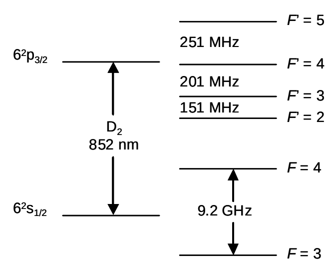


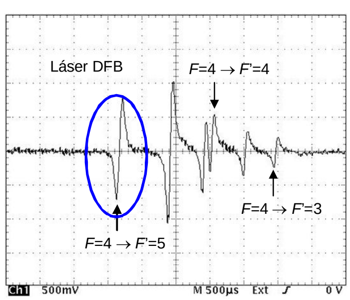
Longitud de onda 852 nm

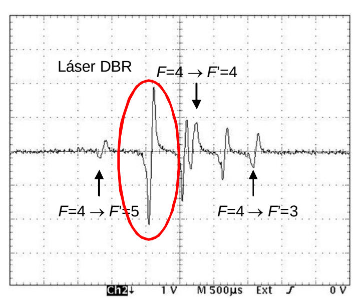
150 mW de potencia

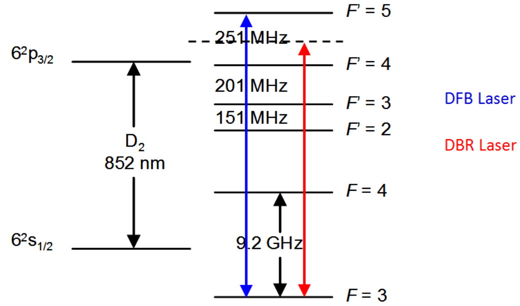
Termistor y TEC incluido



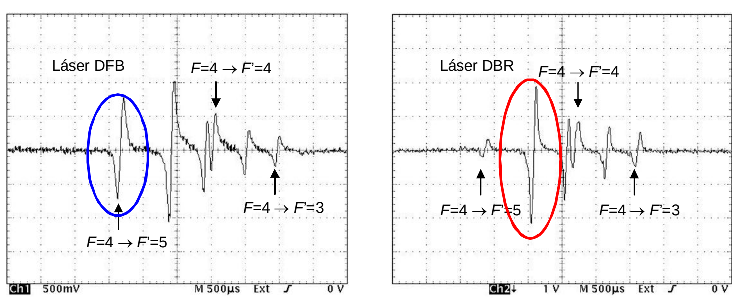




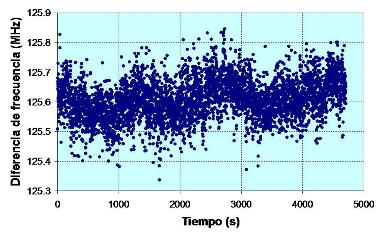


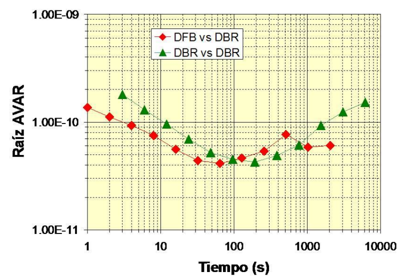


F' = 5
251 MHz
$6^2p_{3/2}$
F' = 4
201 MHz
F' = 3
151 MHz
F' = 2
DFB Laser
DBR Laser
D_2
852 nm
F = 4
$6^2s_{1/2}$
9.2 GHz
F = 3



Láser DFB
F=4 → F'=4
F=4 → F'=3
F=4 → F'=5
Láser DBR
F=4 → F'=4
F=4 → F'=5
F=4 → F'=3





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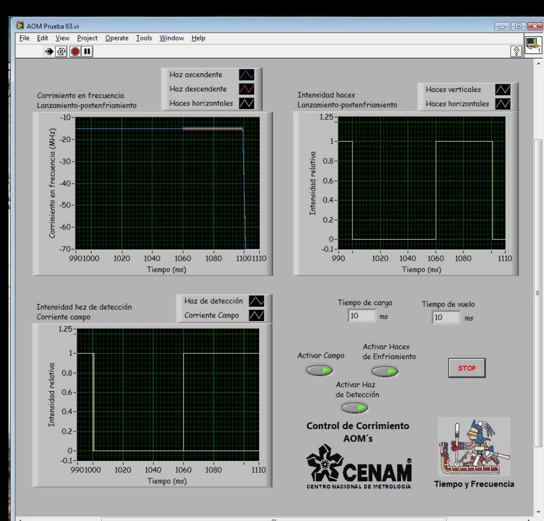
Laser system control



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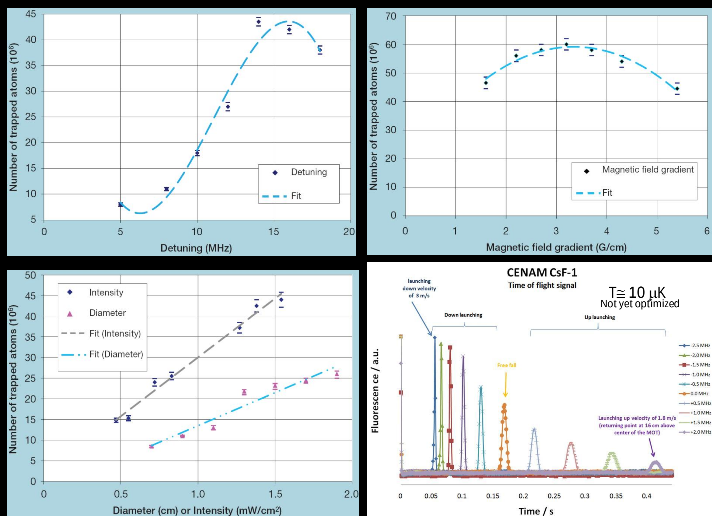
CsF-1 MOT Characterization



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CENAM´s Cs Fountain frequency standard

Work in progress

1. Integration of the fligth region
2. Instalation of Sapphire oscilator as microwave source
3. Lot of work to be done!

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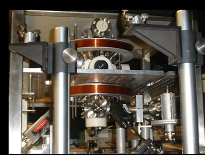
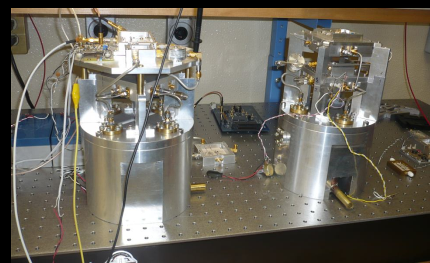
Primary Frequency Standards development at CENAM

Mauricio López R.

Centro Nacional de Metrología, CENAM





Outline

1. Introduction
2. Optically pumped thermal Cesium frequency standard
3. Cs fountain
4. Sapphire Oscillators
5. Time dissemination services

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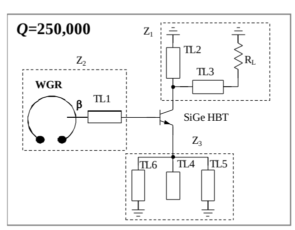
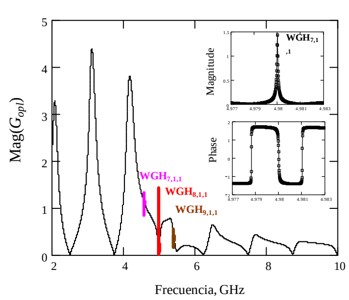
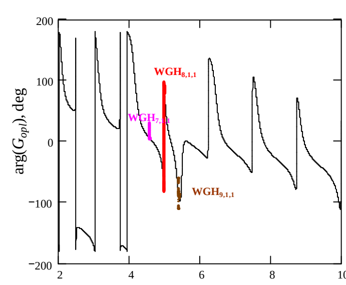
Reflection WGR Oscillator

First prototype



N. A. Shtin, J. M. Lopez Romero and E. Prokhorov, "Design and Performance of Ultra Low Phase Noise Reflection Whispering Gallery Resonator Oscillator," Microwave and Optical Technology Letters, Vol. 49, No 8, pp. 2026-2030, 2007.





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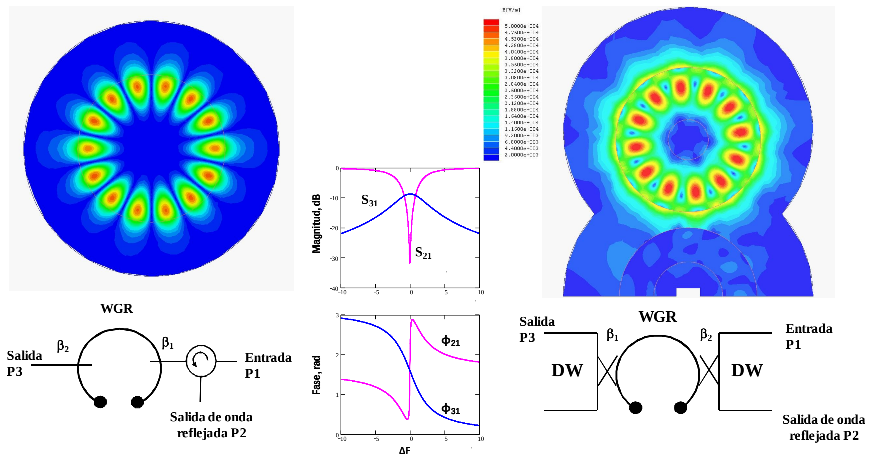
TW WGR Oscillator

Traveling wave whispering gallery resonators



D. P. Tsarapkin, N. A. Shtin, "Whispering gallery traveling wave interferometer for low phase noise applications," Proc. 2004 IEEE IFCS pp. 762-765.

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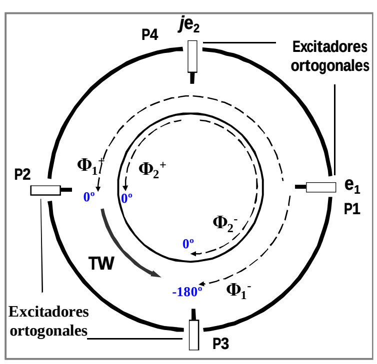
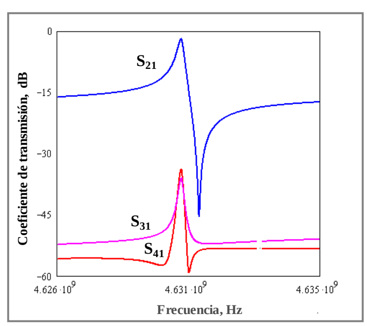
TW WGR Oscillator

Traveling wave excitation

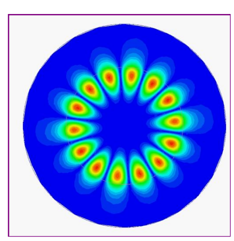




$$\Phi(t,\varphi) = \mathrm{Re}\left(\Phi_{01}^{+} e^{j(\nu\varphi-\omega t)} + j\Phi_{02}^{+} e^{j(\nu(\varphi-\pi/2)-\omega t)}\right)$$
$$+\mathrm{Re}\left(\Phi_{01}^{-} e^{j(-\nu\varphi-\omega t)} + j\Phi_{02}^{-} e^{j(-\nu(\varphi-\pi/2)-\omega t)}\right)$$

$$\Phi_{01} = \Phi_{02} = \Phi_0 \qquad \Phi(t,\varphi) = \mathrm{Re}\left(2\Phi_0^{+} e^{j(\nu\varphi-\omega t)}\right)$$

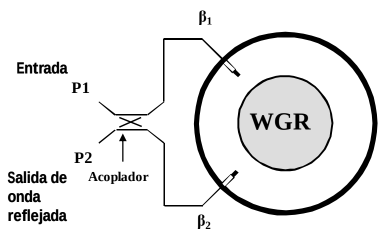
N. Shtin, J. M. Lopez Romero and E. Prokhorov, "Novel Sapphire Directional Filters for Application to Ultra Low Phase Noise Oscillators," in proc. ICEEE-CIE 2006, pp. 403-407.



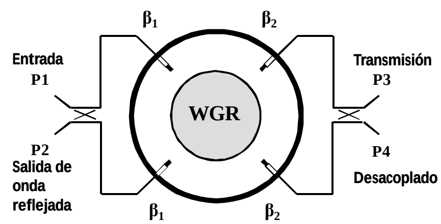
TW WGR Oscillator

Traveling wave interferometers

Filtro direccional de 2 puertas

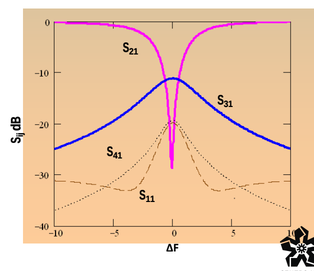


Filtro direccional de 4 puertas



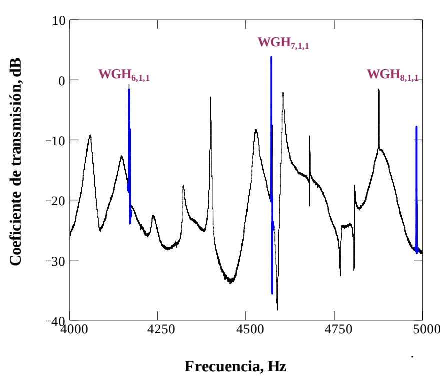
$$S_{11}^{DF} = \delta e^{j\pi/2}$$

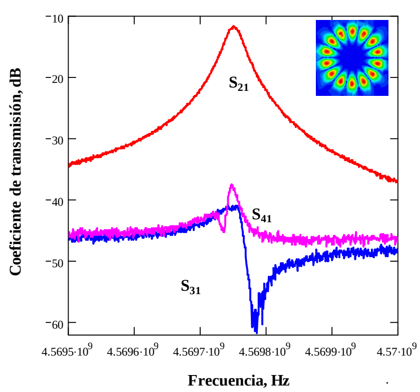
$$S_{21}^{DF} = S_{11}^{WGR} e^{j\pi/2}$$



TW WGR Oscillator

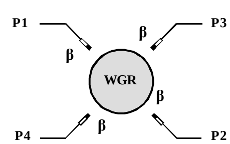
Characterization of TW WGR in aluminium cavity with D = 130 mm (D/d_{res} = 1.86)



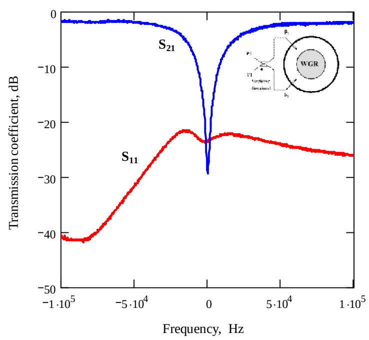


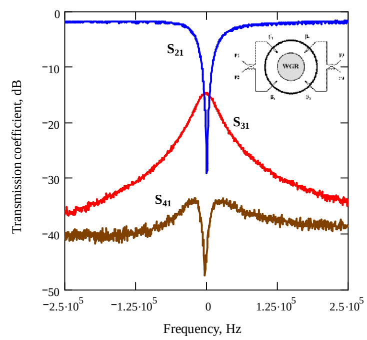
$WGH_{7,1,1}$ F_{res} = 4.5697 GHz

Q_0 = 350,000

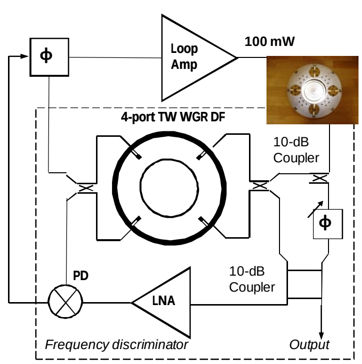


TW WGR Oscillator

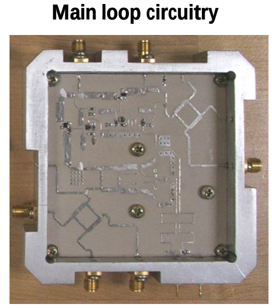




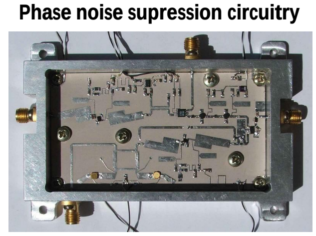
TW WGR Oscillator



Main loop circuitry



Phase noise supression circuitry



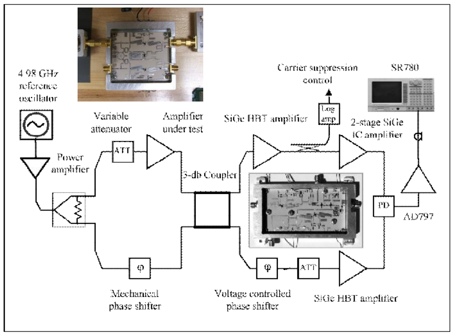
Nicolas Shtin, J. M. Lopez Romero and Eugen Prokhorov

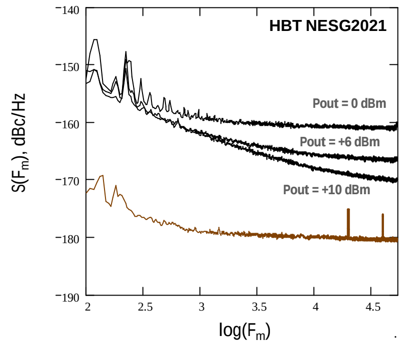
"Novel Sapphire Directional Filters for Application to Ultra Low Phase Noise Oscillators"

2006 3rd International Conference on Electrical and Electronics Engineering and XII Conference on Electrical Engineering

TW WGR Oscillator

Phase noise suppression system





$S_{\varphi}^{amp}(1kHz) \propto -162 dBc/Hz$ $S_{system}(1kHz) \propto -180 dBc/Hz$

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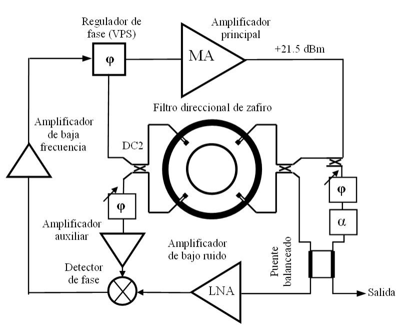
TW WGR Oscillator

100 mW



f = 4,5712 GHz Q_0 = 220,000 P_{res}= 100 mW

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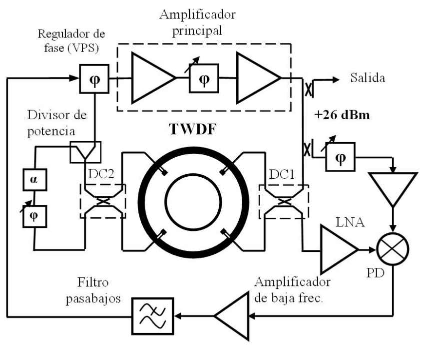
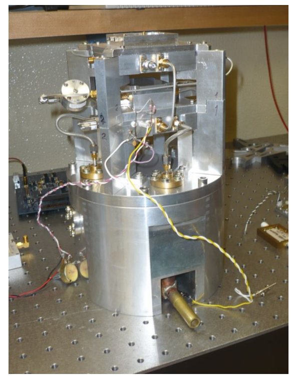
TW WGR Oscillator

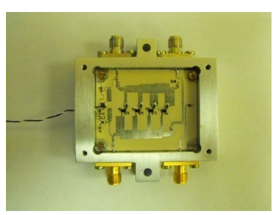
300 mW

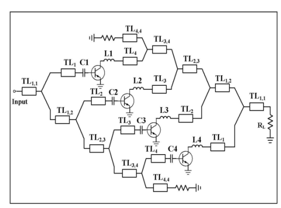


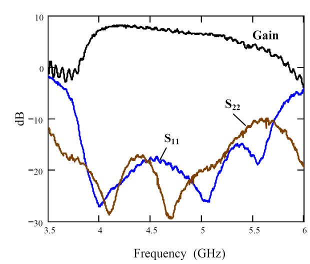


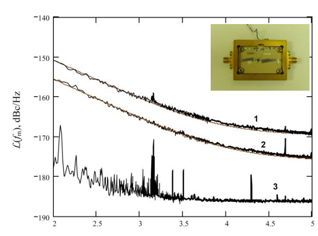
f = 4,5721 GHz Q_0 = 350,000 P_{res}= 300 mW

Ultra Low Residual Phase Noise Amplifier









N. A. Shtin, and J. M. Lopez Romero, "Medium Power C-Band Array Amplifier Featured Ultra Low Residual Phase Noise" Microwave and Optical Technology Letters, Vol. 52, No 2, 2010. (to be published)

Phase Noise

$$L_{\varphi}^{osc}(f_m) = L_{\varphi}^{loop}(f_m)\left(K_{br}K_{pd}K_{la}K_{vps}\frac{q_{eff}}{1+\beta_1+\beta_2}\right)^{-2} + +L_{\varphi}^{pd}(f_m)\frac{B_0^{\ 2}}{K_{br}^2 q_{eff}^2} \qquad \textbf{(1)}$$

donde $B_0 = f_0/2Q_0$; β_1 y β_2 son los coeficientes de acoplamiento del resonador; K_{pd}, K_{lfa}, K_{br} y K_{vps} son respectivamente los coeficientes de transmisión del detector de fase, del amplificador del baja frecuencia, del puente de cancelación de la portadora y del regulador de fase controlado por voltaje; y

$$q_{eff} = \frac{1}{1-\beta_1+\beta_2} - \frac{1}{1+\beta_1+\beta_2} \qquad \textbf{(2)} \qquad L_{\varphi}^{pd}(f_m) = \frac{kT_k NF}{P_{inc}L_{br}\Gamma_0} + \frac{a_{-1}}{f_m} \qquad \textbf{(3)}$$

donde k es la constante de Boltzmann; T_K es temperatura en Kelvins; P_{inc} es la potencia en la entrada del FD; NF es la figura de ruido del amplificador de bajo ruido incorporado en el DF; L_{br} es el cociente de supresión de portadora del puente; y Γ_0

$$\Gamma_0 = (1-\beta_1+\beta_2)/(1+\beta_1+\beta_2) \qquad \textbf{(4)}$$

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Phase Noise

100 mW Oscillator
P_{inc} = 100 mW, f_0= 4.57 GHz, Q_0 = 220,000, β_1 = 1.09, β_2 = 0.15, NF = 1 dB, L_{br} = 30 dB, G_{LNA} = 32 dB, then

L_{φ}^{OSC1}(1 kHz) = -165 dBc/Hz.

300 mW Oscillator
P_{inc} = 300 mW, f_0= 4.57 GHz, Q_0 = 350,000, β_1 = 1.09, β_2 = 0.15, NF = 1 dB, L_{br} = 30 dB, G_{LNA} = 32 dB then

L_{φ}^{OSC2}(1 kHz) = -174 dBc/Hz.

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Sapphire Oscillators

Work in progress

1. Cross correlation technique to measure the phase noise
2. Development of 10 GHz and 40 GHz Ultra stable oscillators

Primary Frequency Standards development at CENAM

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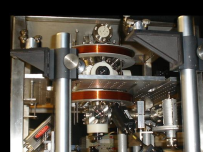
Centro Nacional de Metrología, CENAM



Outline

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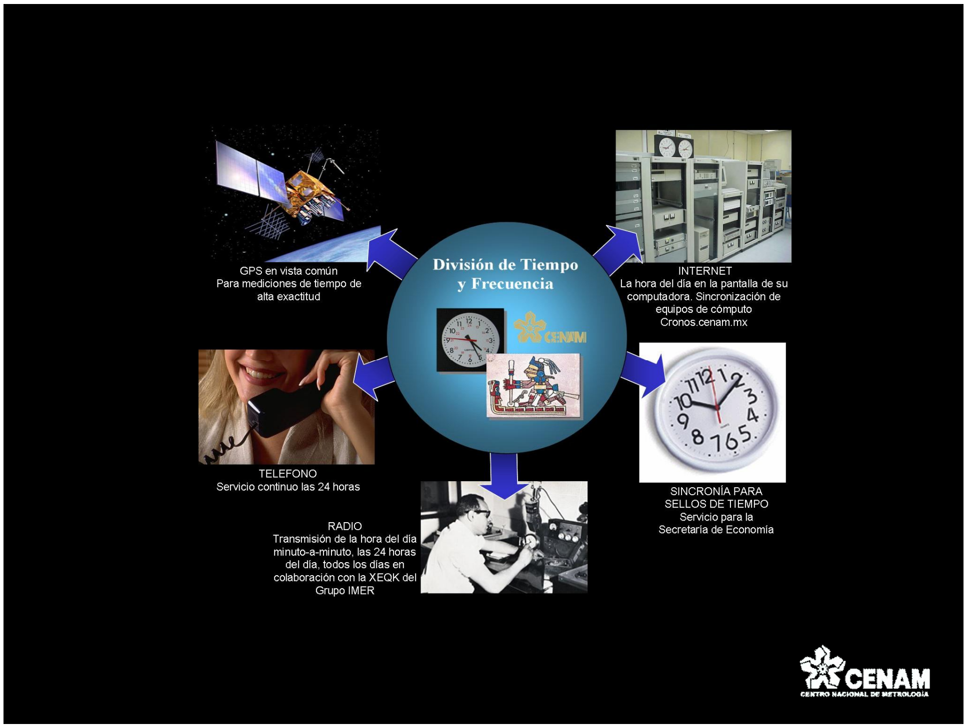
2. Optically pumped thermal Cesium frequency standard
3. Cs fountain
4. Sapphire Oscillators
5. Time dissemination services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