MICROWAVE APPLICATIONS OF STNOs

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Analog microwave signal processing systems
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Oscillators for microwave applications

TYPICAL REQUIREMENTS:

power > mW
phase noise < -80 dBc/Hz @ 10 kHz offset
< -140 dBc/Hz > 1 MHz offset
agility > 100%

WHY?:

heterodyne receiver (~ lock-in detection)
[Signals → mixer ← LO] → IF
LO power >> signal power (environment)
reverse mixing => LO noise detection

Agile Microwave Oscillator

Resonator Merit Factor = agility x Q

Tuning element	agility	Q experim/theory	static Ms experim/theory	switching time	dynamic Md experim/theory
MEMs 300K	10%	100 / 100	10 / 10	10 µs	1 / 1 MHz
µ 300K	20%	500 / 500	100 / 100	100 µs	1 / 1 MHz
varactors 300K	50%	500 / 500	250 / 250	10 µs	25 / 25 MHz
ε 300K	10%	500 / 1000	50 / 100	<1 µs	50 / 100 MHz
MEM/YBCO 77k	10%	1000 / 50000	100 / 5000	10 µs	10 / 500 MHz
µ / YBCO 77k	10%	1000 / 50000	100 / 5000	10 µs	10 / 500 MHz
ε / YBCO 77K	10%	1000 / 50000	100 / 5000	<1 µs	>100 /5000 MHz
YIG FMR 300K	**100%**	**2000 / 10000**	**2000 / 10000**	**1000 µs**	**2 / 10 MHz**
STNO	**100%**	**?**	**?**	**µs**	**?**
Objective	**100%**	> 1000	> 1000	<1 µs	> 1000 MHz

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Oscillator = resonator + amplifier

Resonator

center frequency **Fc**

FWHM **ΔF** → **Q** = **Fc/ΔF** 3 dB linewidth (3dB from the top)

+ **Amplifier**

gain G

noise factor NF

1/f flicker noise

+ **Positive Feedback Loop**

= Oscillator

phase noise: Leeson's theory

Fc /2Q =**ΔF/2** → 3 dB linewidth above thermal noise (3dB from the bottom)

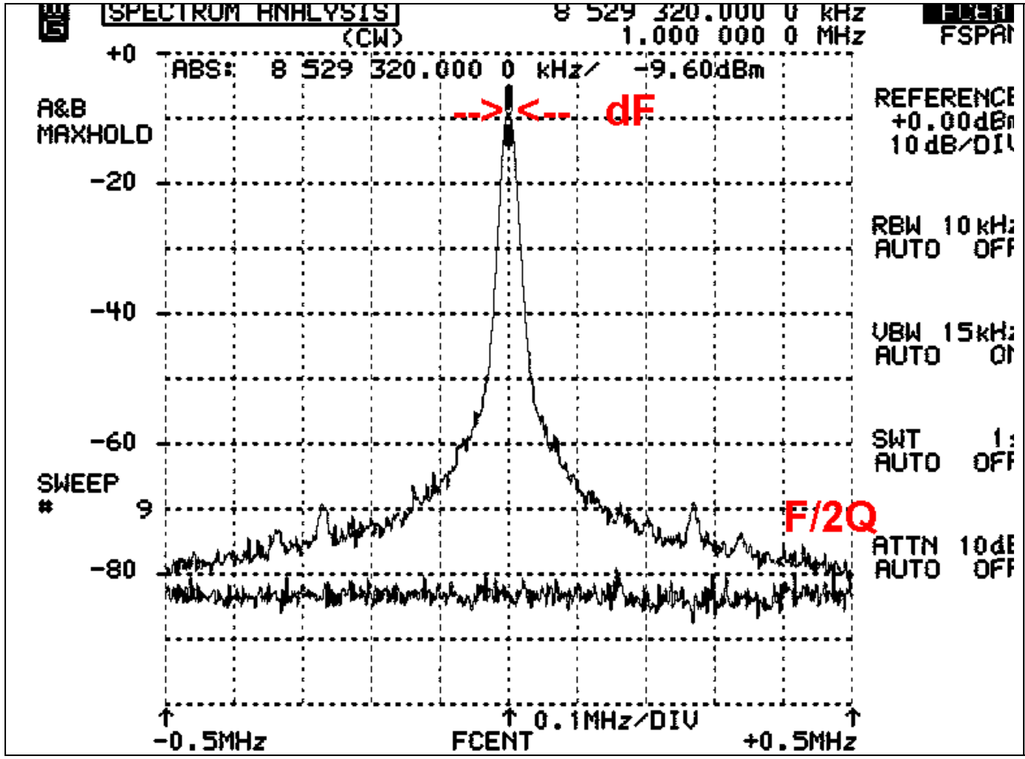
STNO

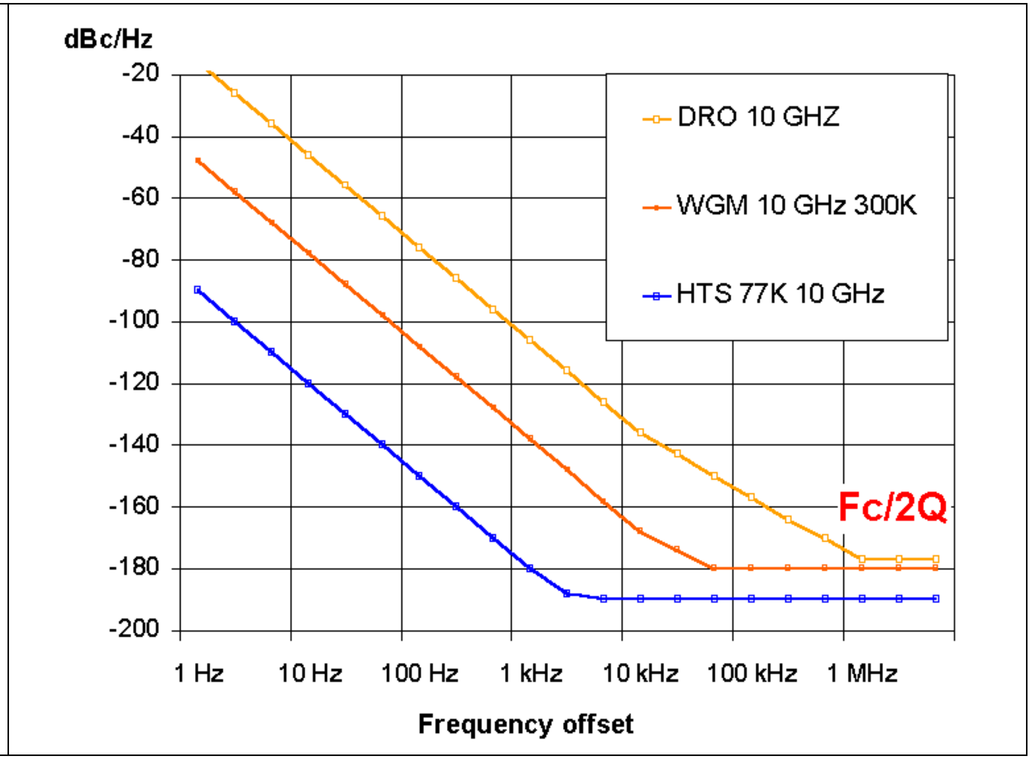
resonator = FMR FWHM = Δ**H** (to be measured MRFM?)

amplifier = spin torque

Can we separate [resonator / amplifier / loop] ?

Phase noise versus Quality factor





DRO Fc = 10 GHz Q = 5000 Fc/2Q = 1 MHz -175 dBc/Hz

dF = 1-10 kHz

STNO dF = 1-10 MHz

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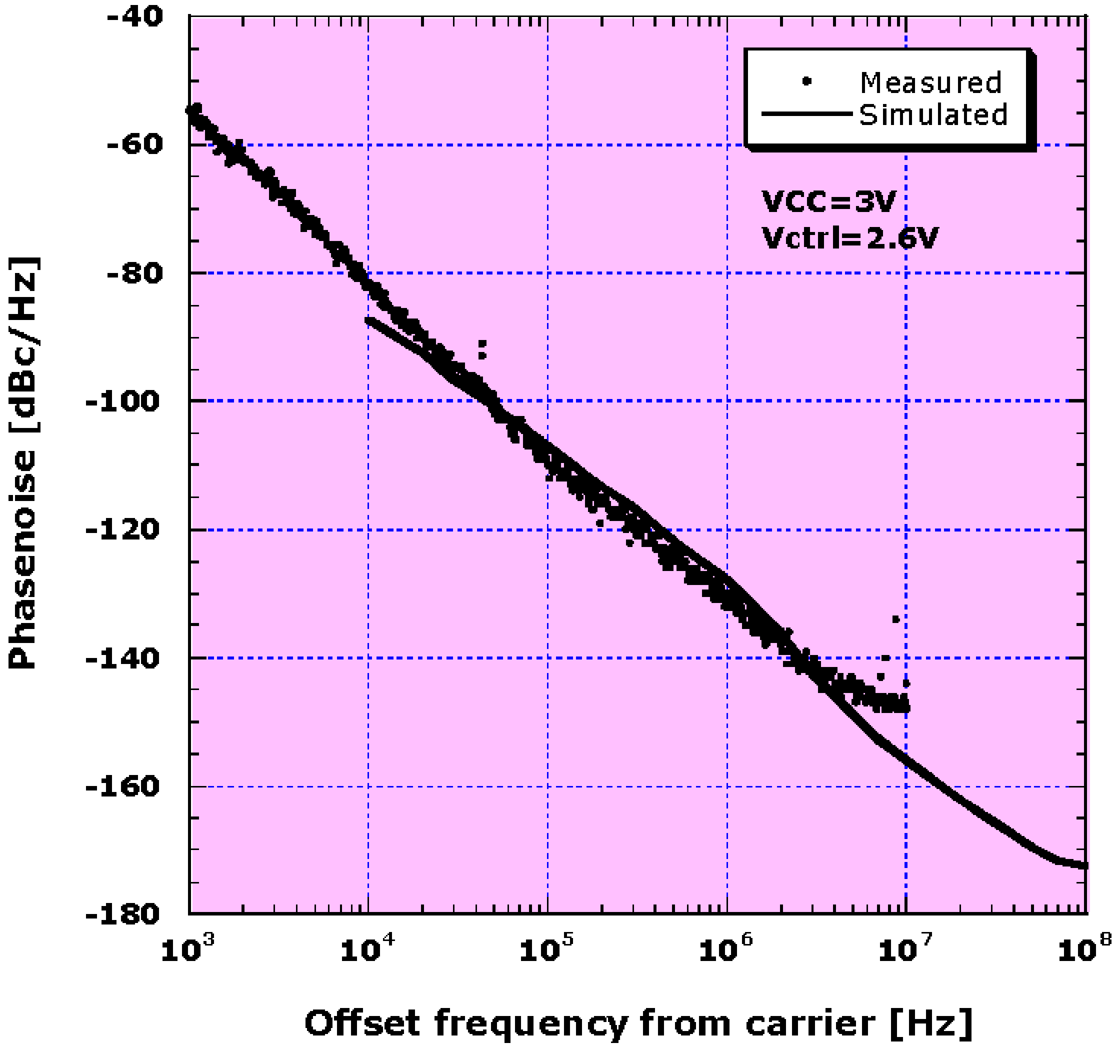
VCO : phase noise Voltage Controlled Oscillator



Fc = 1 - 1.3 GHz

Varactor tuned => Q < 100 **-80 dBc/Hz @ 10 kHz offset**

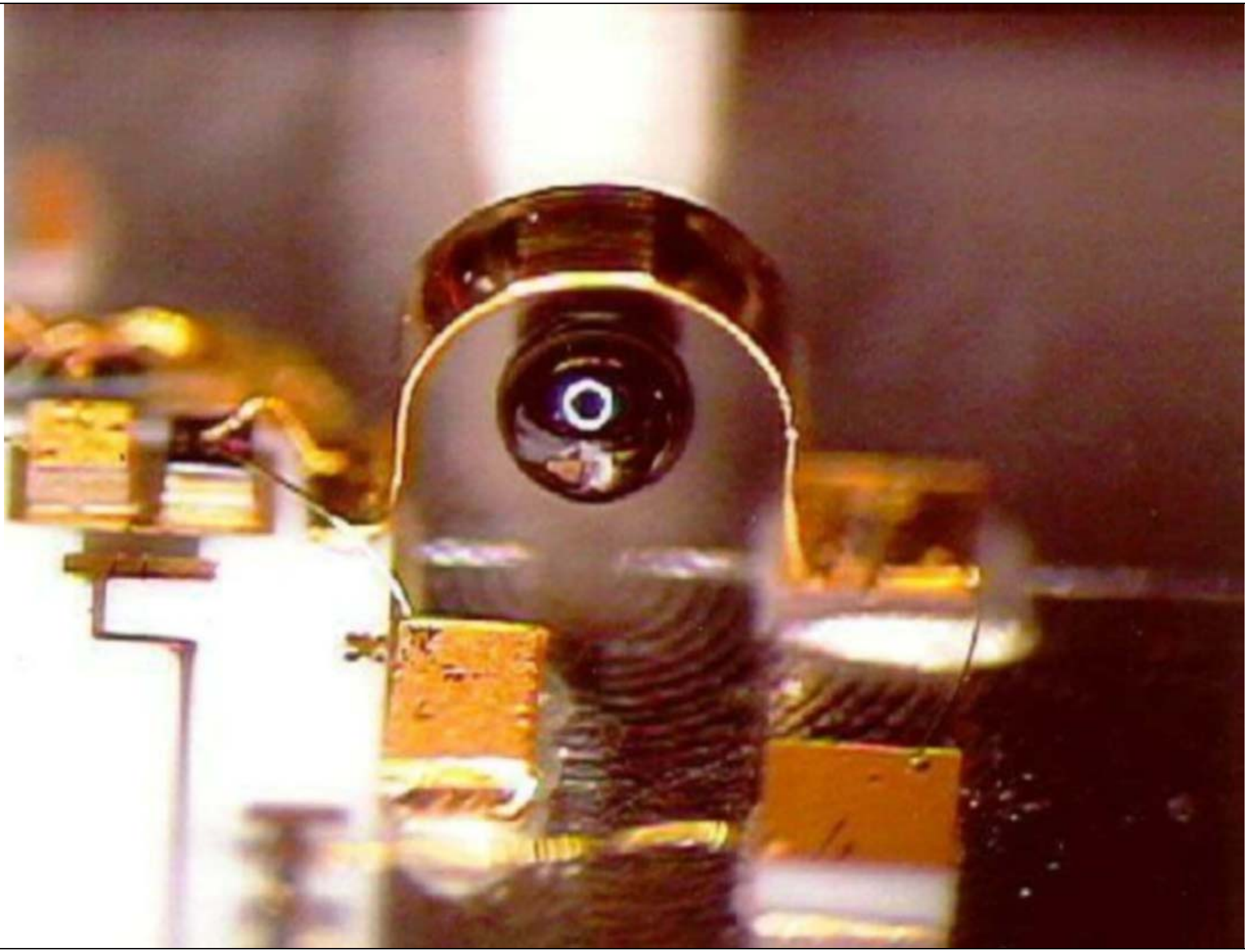
Agile Microwave Oscillator Reference

YTO = YIG Tuned Oscillator

- agility = 1 octave
- spectral purity < -100 dBc/Hz @ 10 kHz offset
- Ferro Magnetic Resonance : spin precession

FMR = the best agile oscillator

YIG oscillator: YIG sphere (+ coupling loop)



Yttrium Iron Garnet
$Y_3Fe_5O_{12}$

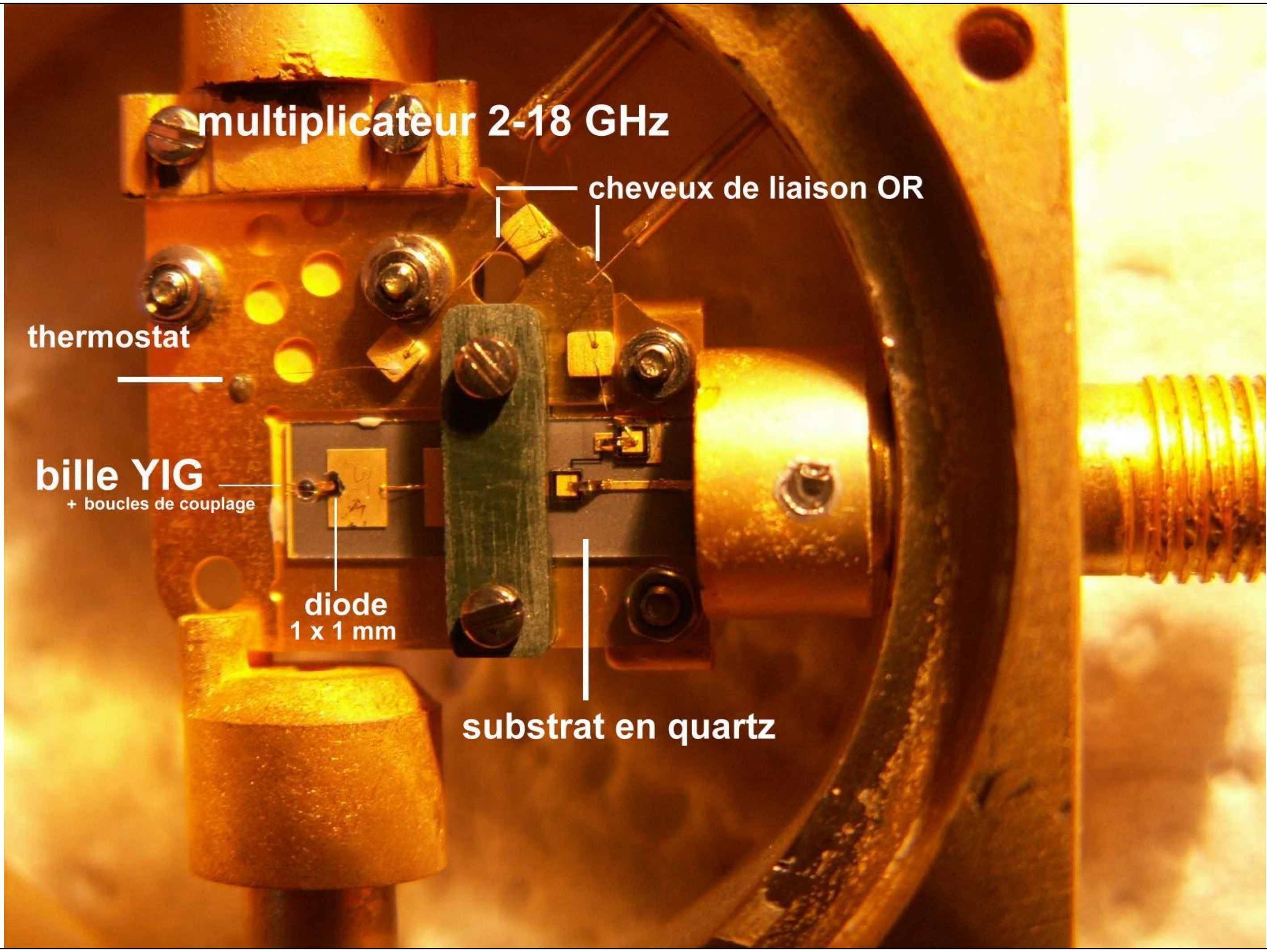
FerroMagnetic Resonance

diameter = 0.5 mm

ΔH = 0.2 Oe
Q = 10 000

zero defect crystal
dicing, grinding
polished sphere
zero scratch

YIG oscillator: microwave circuit



orientation

thermostat (BeO rod)

coupling

amplifier

reaction loop

YIG oscillator: exploded view

Magnetic field bias

28 GHz / Tesla

bias coils: Amp x turns

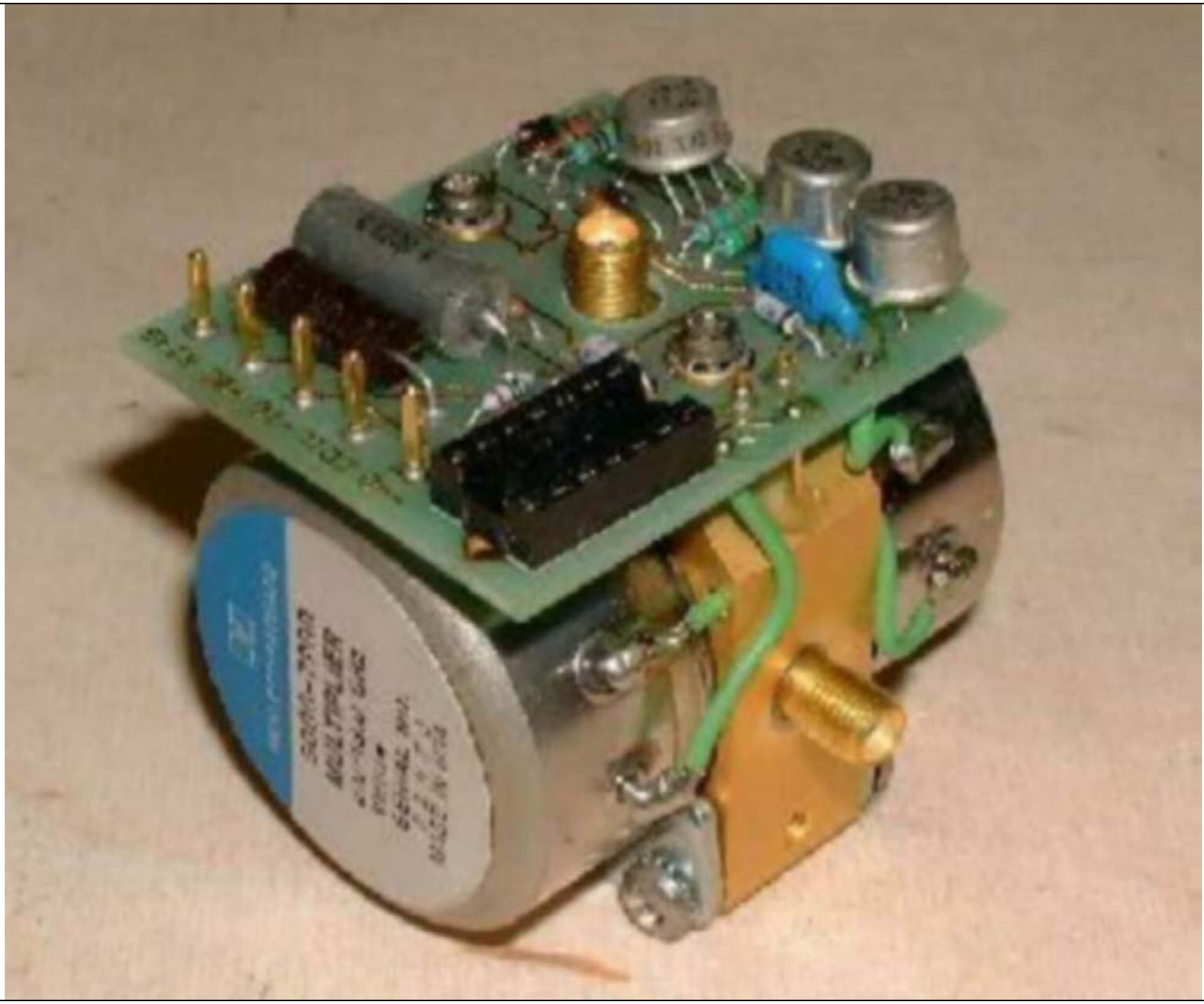
magnetic circuit

high inductance

slow => **ms**

bulky
diameter = 40 mm

YIG oscillator



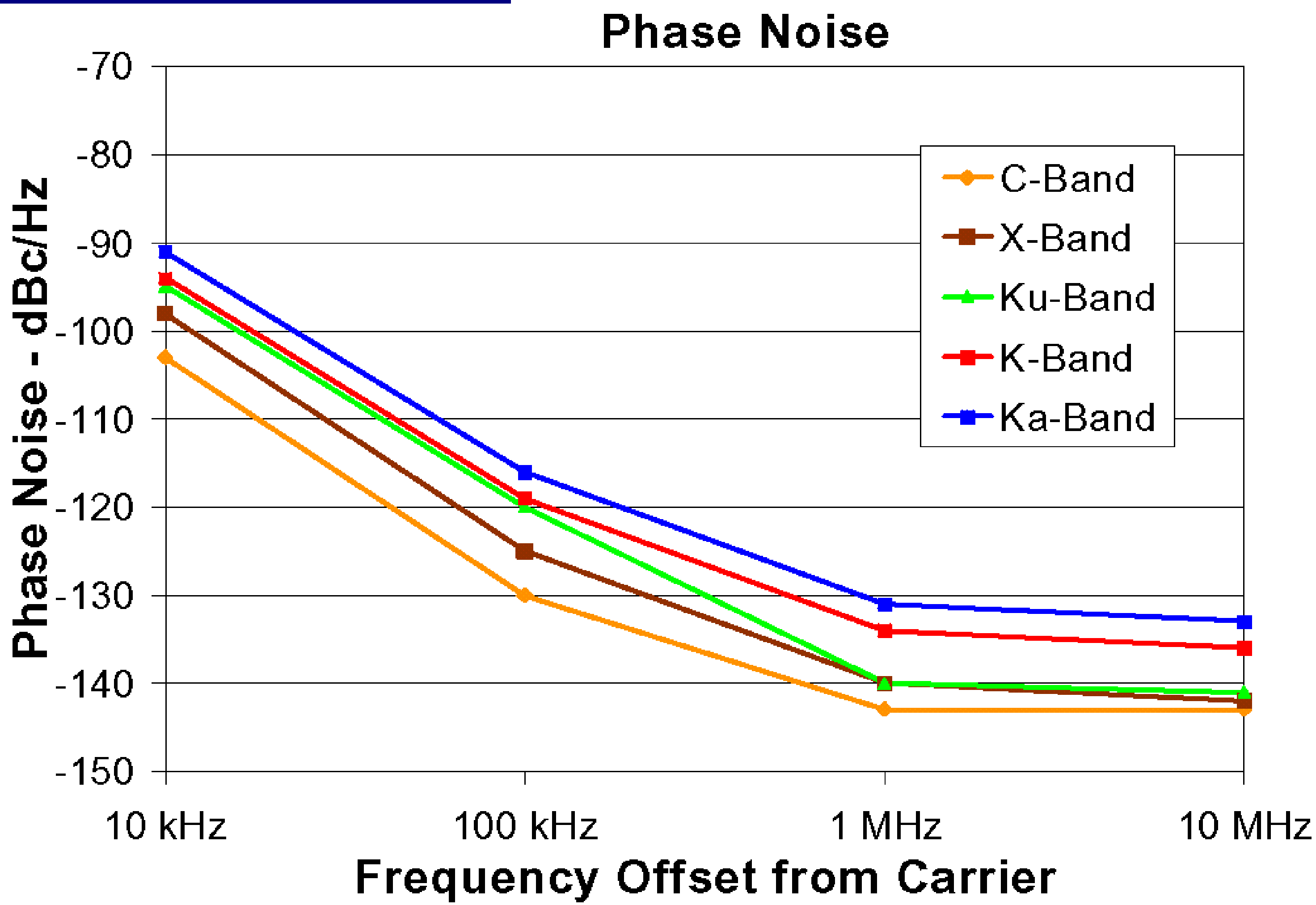
Packaging

masterpiece
inside

power supply
beside
amperes

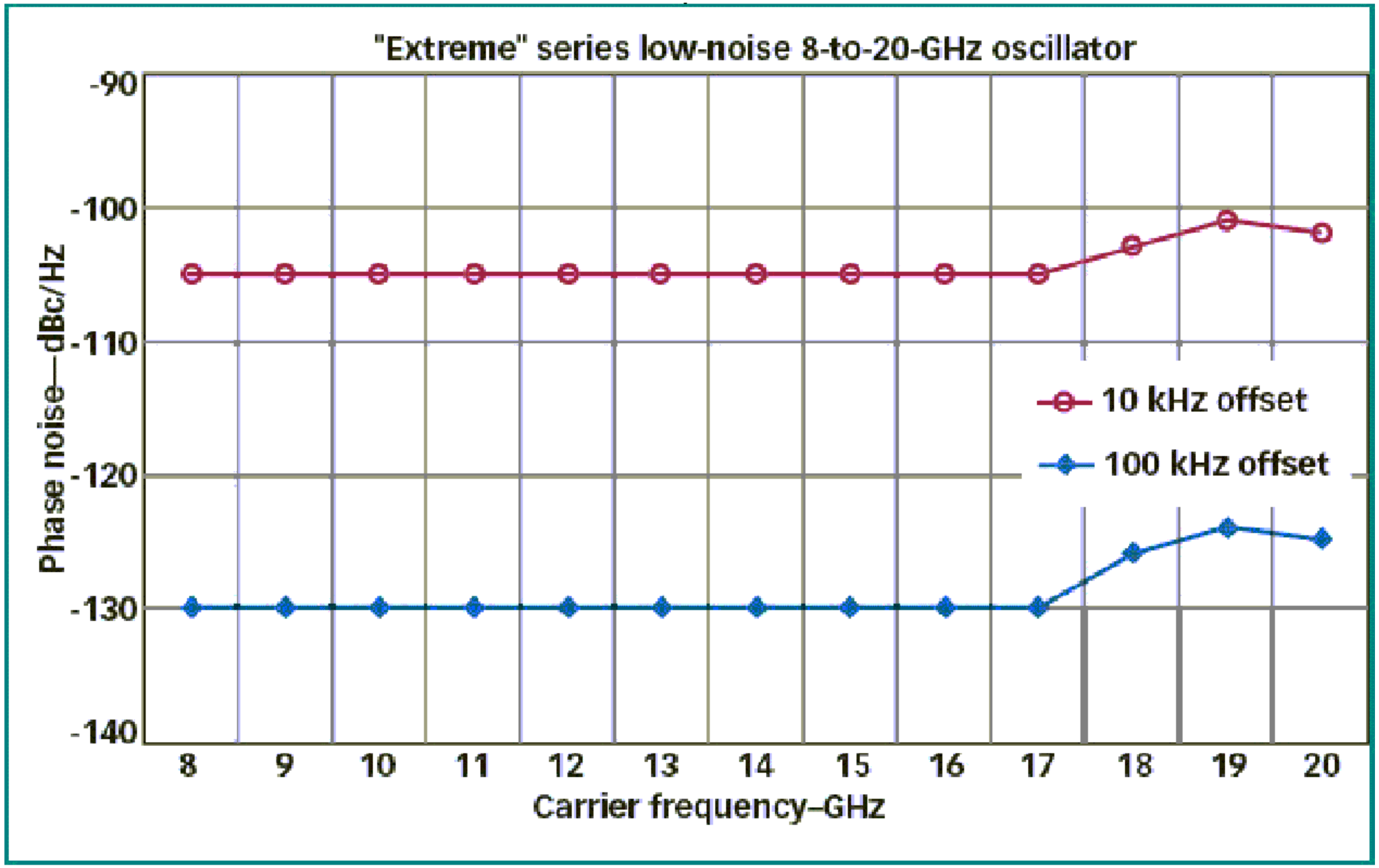
~~**nano**~~

YIG oscillator : phase noise



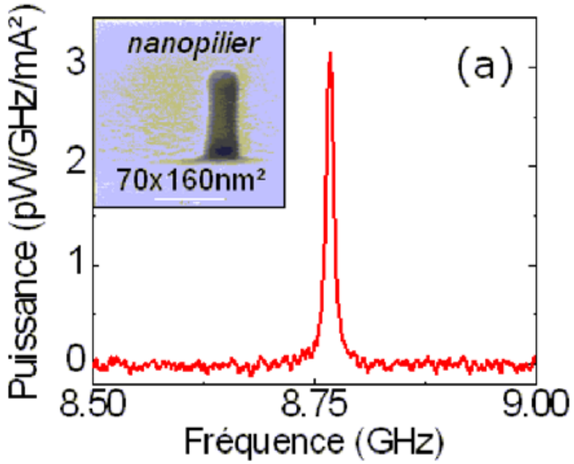
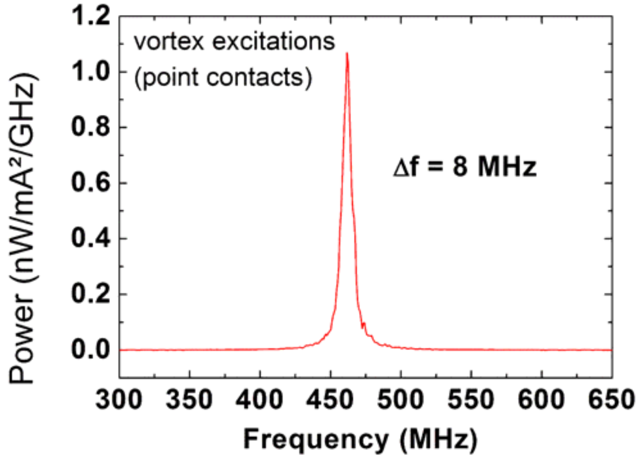
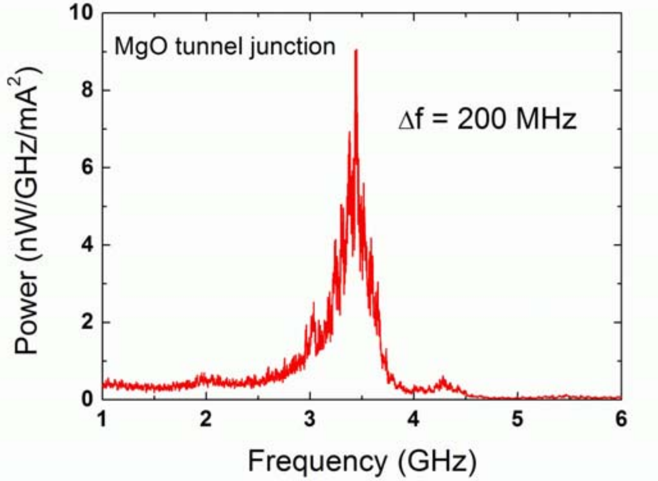
Micro Lambda permanent magnet YIG oscillator **20 dB lower than VCO @ 2 GHz**

YIG oscillator : phase noise versus tuning



Micro Lambda YIG Tuned oscillators

STNO: phase noise

		
nano-pillar pw FWHM = 10 MHz	nano-contact: vortex nw FWHM = 8 MHz	MgO barrier 10 nW FWHM = 200 MHz

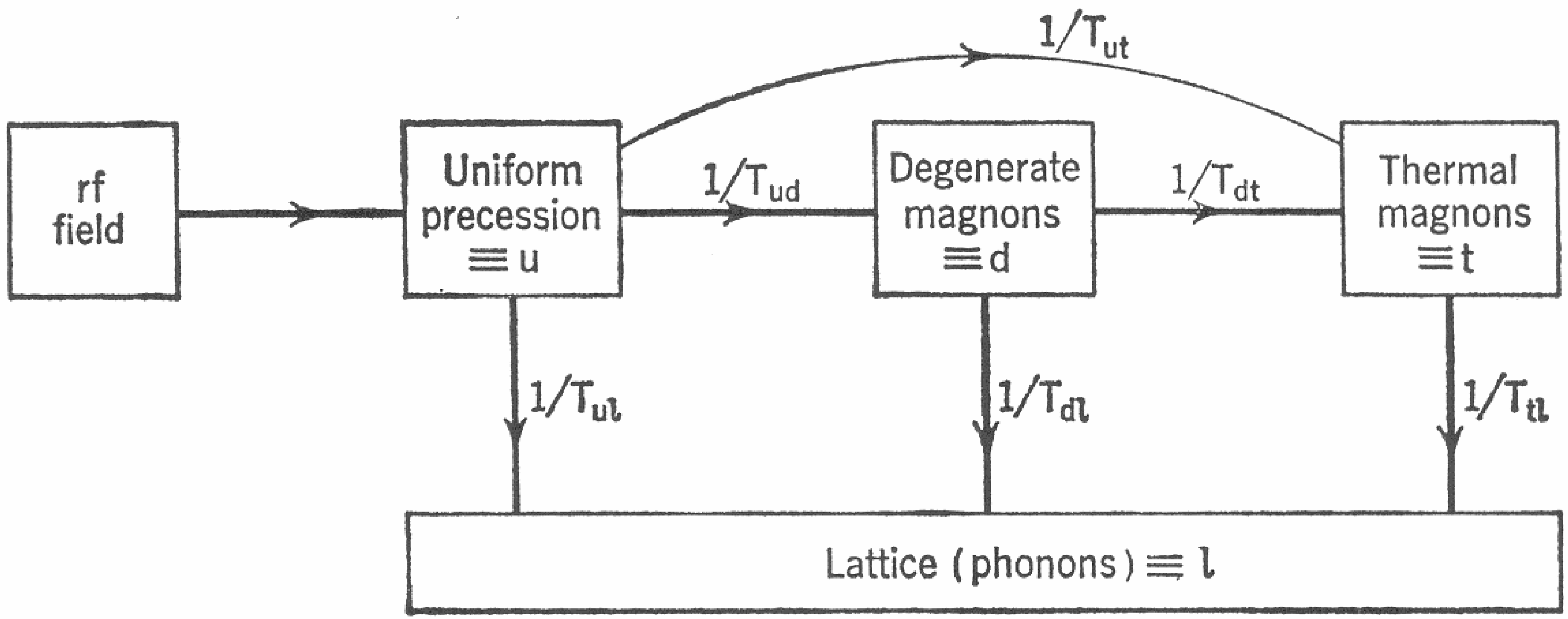
linear scale versus log scale dBc/Hz

Full-Width Half-Maximum **dF ≃ 10 MHz**

higher than YTO **dF ≃ 1 kHz**

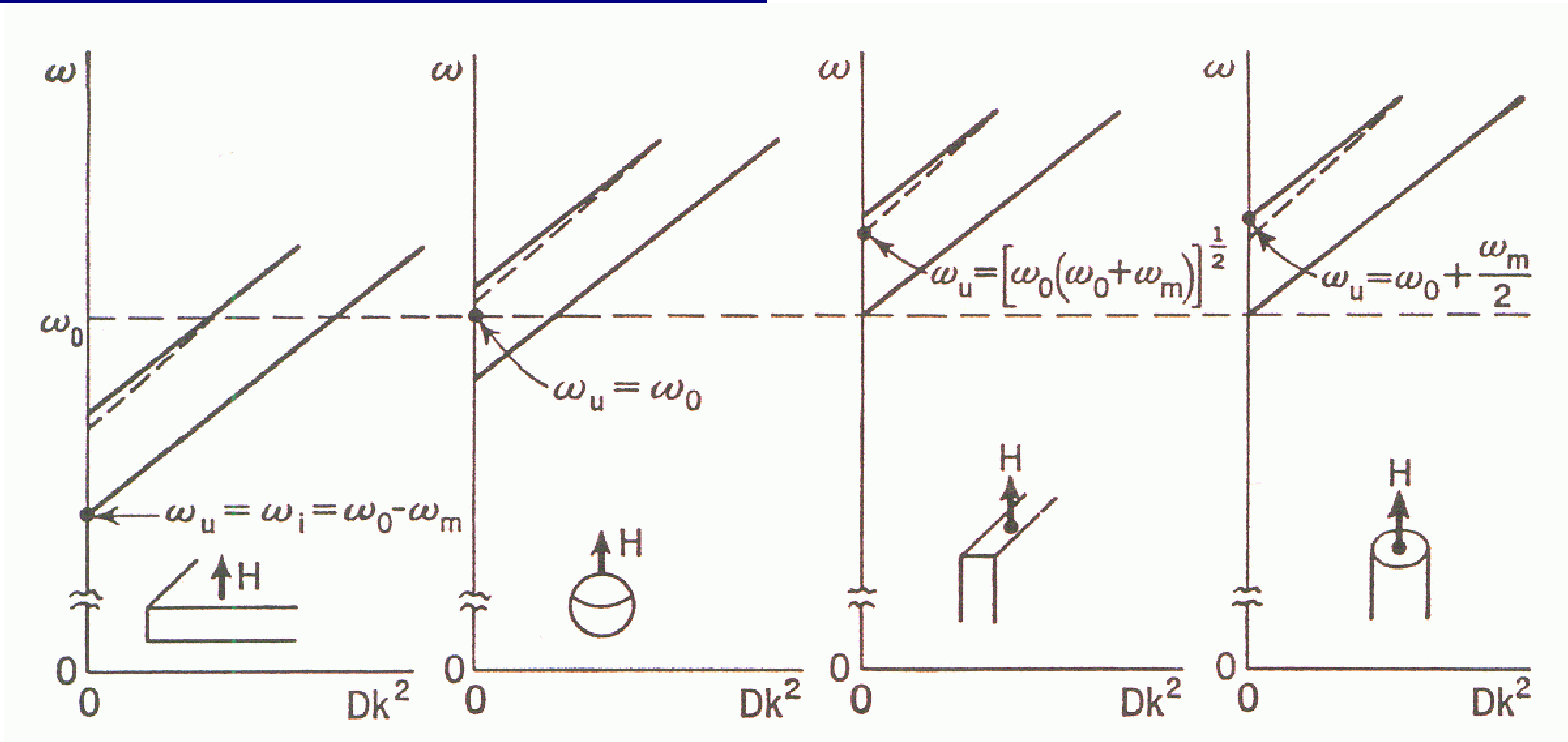
higher than VCO **dF ≃ 10 kHz**

Spin Wave Decay



T_{ut} = Kasuya LeCraw process	intrinsic	low
T_{ul} includes electron magnon interaction	extrinsic intrinsic	 high
T_{ud} = two magnon process through crystal defects	extrinsic	crystal quality + geometry

FMR versus Spin Wave Manifold



STNO YTO nanowire

STNO thin layers => no 2 magnon process
the most favourable geometry
(compared to bulk crystals, ceramics, nanowires)

STNO line broadening

thin layers = no 2 magnon damping
defect tolerant

Causes of damping:

- eddy currents (metal layers)
- **electron magnon interaction (metal layers)**
- **inhomogeneous field (Oersted's field)**
- non uniform modes: magnetostatic modes, short-k spinwaves
- transposed 1/f flicker noise (intrinsic / technology induced, reliability)
- **thermal gradients and instabilities**
- current noise : high df/di ~ 1 GHz/mA (power supply)

Magnetism based oscillators: 3D -> 2D

	YIG sphere	thin film MSW	STNO
Dimensions	3D	2D	2D
Shape	sphere	slab	slab
Uniform precession	2/3 SWM	**bottom SWM**	**bottom SWM**
2 magnons process	**yes**	**no**	**no**
electron magnon	**no**	**no**	**yes**
Linewidth	**ΔH = 0.2 Oe**	**ΔH < 0.2 ? Oe**	**ΔH < 160 ? Oe**
Demagnetising factor	1/3	**1**	**1**
Magnetic bias	high	**higher**	**higher**
Material	pure YIG	substituted YIG	metal
Anisotropy field H_{an}	small	controlled	controlled

Oscillators: YIG versus STNO

	YIG YTO	VCO	STNO
	FerroMagnetic	varactor diode	FerroMagnetic
Command	magnetic field	voltage	electric current
Shape	3D or 2D	LC	multilayer 2D
Impedance bias	high inductance	capacitance	low inductance
Rapidity	slow > ms	fast < µs	fast < µs
Linewidth	Q = 10 000	Q = 100	Q >?
Power	mW	mW	µW MgO barrier
Spectral purity	<-100 dBc/Hz @ 10 kHz	<-80 dBc/Hz @ 10 kHz	?
Size	cm^3	mm^3	nm^3

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STNOs for microwave applications

OBJECTIVE:

YTO on a chip

or better than VCO: resonator Q > 100, agility > 100%

MAIN CHALLENGES:

pW → nW → µW → mW => synchronization

3 dB linewidth top → bottom

MAIN ADVANTAGES:

agility OK

size = nano

consumption

drastically new applications? (cf: JJ for radio astronomy)

SPINSWITCH
Postgraduate Research Position
Vacancy Details

Contract No	MRTN-CT-2006-035327
Project Title	Spin Current Induced Ultrafast Switching
Acronym	SPINSWITCH
Job Title	Postgraduate Research Position
Job Description	Thales TRT invites experienced researchers (ER) for a temporary position in the field of spin electronic and related applications. The applicant must proof at least 4 (but not more than 10 years) of research activity after gaining a degree qualifying them for doctoral studies or must have a doctoral degree (PhD) Applicants should have an academic background in one or more areas: • magnetic thin film characterisation (SQUID, AGFM) • spin electronics (GMR and/or TMR) • transport measurements • dynamic magnetic properties • Spin Torque Oscillators • microwave devices: design and test Starting date is flexible but should not be later than April 1st, 2009.
Contract	temporary (“post-doc”)
Position	Experienced Researcher (ER)
Appl. Deadline	31/09/2008

SpinSwitch month 24 Krakow

Start Date	01/04/2009		
Duration	12 months		
How to apply	e-mail (jean-claude.mage@thalesgroup.com)		
Contact	Jean-Claude MAGE, THALES TRT UMR, Route Departementale 128 F91767 PALAISEAU, FRANCE		
Web Site	http://www.spinswitch.de http://www.trt.thalesgroup.com/ump-cnrs-thales		
Fellowship Type	Research Training Networks FP6		
Last Update	17/12/2007		
Place of Work	**Institution**	**City**	**Country**
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