CONSIGLIO NAZIONALE DELLE RICERCHE
AREA DELLA RICERCA DI ROMA-TOR VERGATA

M$^2$T
Microwave Microsystems Technology

Consiglio Nazionale delle Ricerche
Progetto Sensori e Microsistemi
PSM - Edificio G
Laboratorio Microsistemi a Microonde
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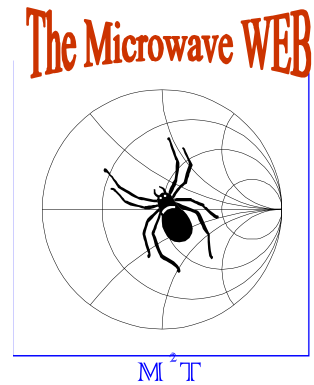
ITALY




# MAGNETICS

# AND

# MICROSYSTEMS TECHNOLOGY

# FOR

# MICROWAVE APPLICATIONS

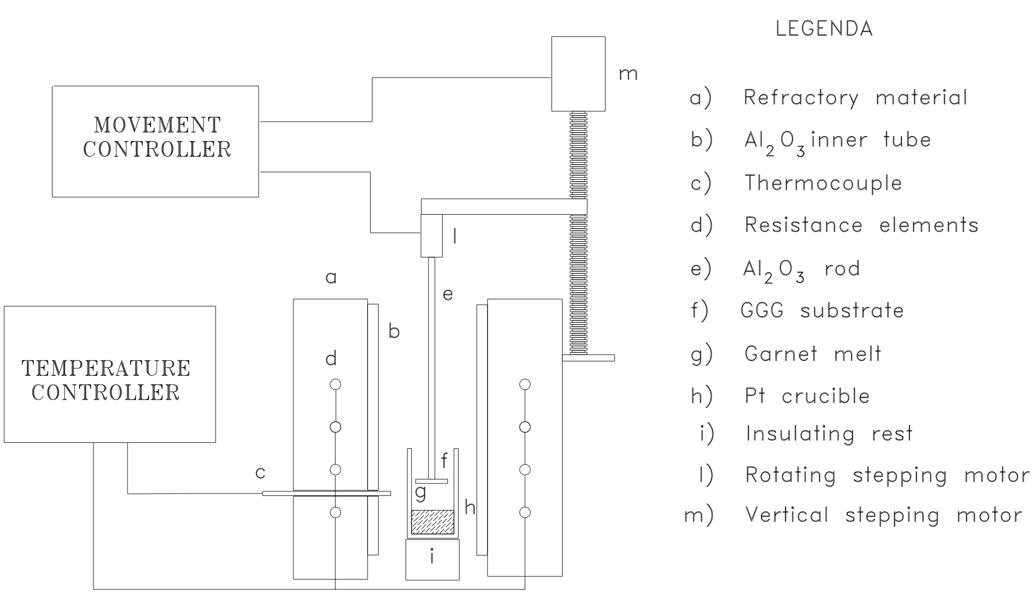
**http://m2t.psm.rm.cnr.it**

National Research Council of Italy
Project Sensors and Microsystems
PSM - Building G
Microwave Microsystems Laboratory
Research Area of Roma-Tor Vergata
Via del Fosso del Cavaliere 100
00133 Roma

**1) Liquid Phase Epitaxy (LPE) growth of single crystal magnetic garnet films from high temperature solutions. Ferromagnetic resonance (FMR) characterization. - Theoretical modeling and software design of the thermodynamic properties of high temperature solutions and of the epitaxial growth of magnetic films.**

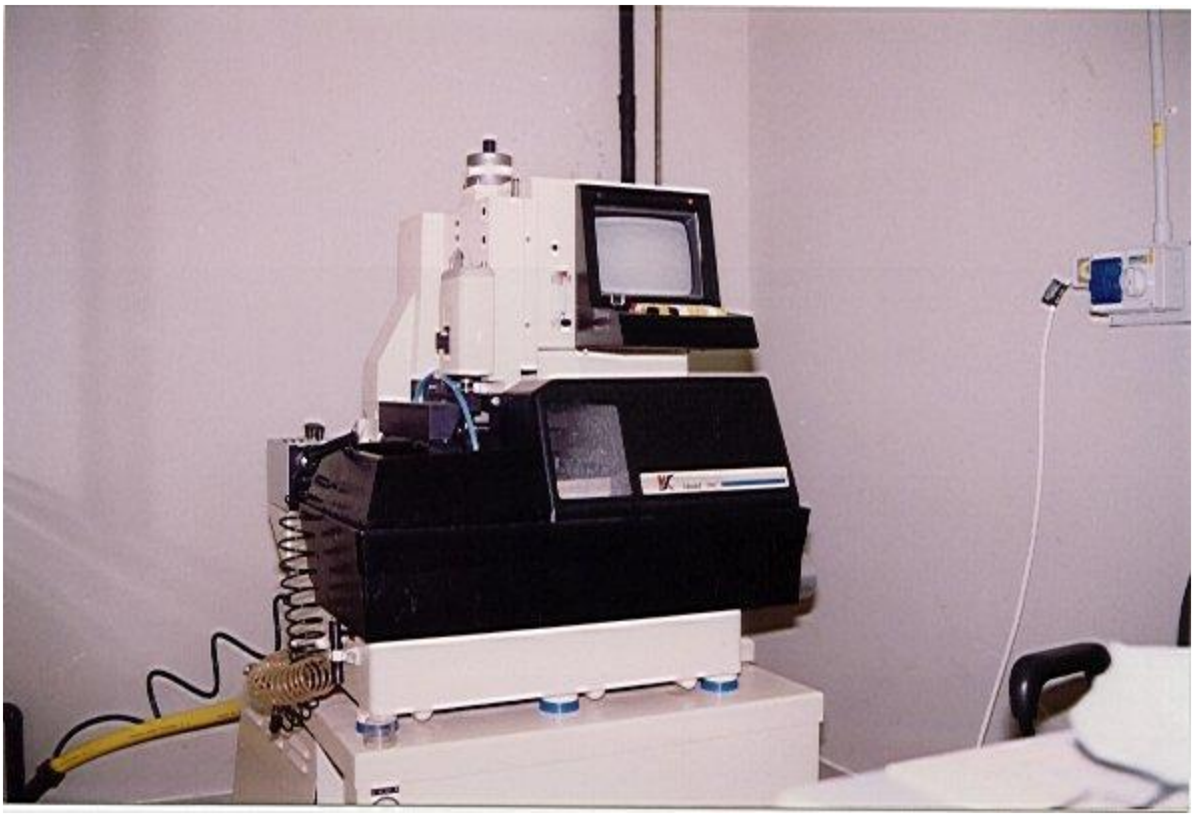
Supported by

- National Task Project "Materials and Devices for Solid State Electronics" (1986-1990);
- National Task Project "Special Materials for Advanced Technologies" (1990-1993);
- ESA/ESTEC Contract No.101886 (1990-1991);
- Alcatel-Bell Telephone Contract, ESA/ESTEC 9965/92/NL/NB/(SC) (1993);
- Italian Space Agency (ASI) Contract for the development of MSW resonating filters (1994-1996).
- Italian Space Agency (ASI) Contract for the development of an MSW oscillator (1997-1999).
- Protocol of Cooperation Italy-P.R. China (1995-1997).
- Protocol of Cooperation Italy-P.R. China (1997-1999).

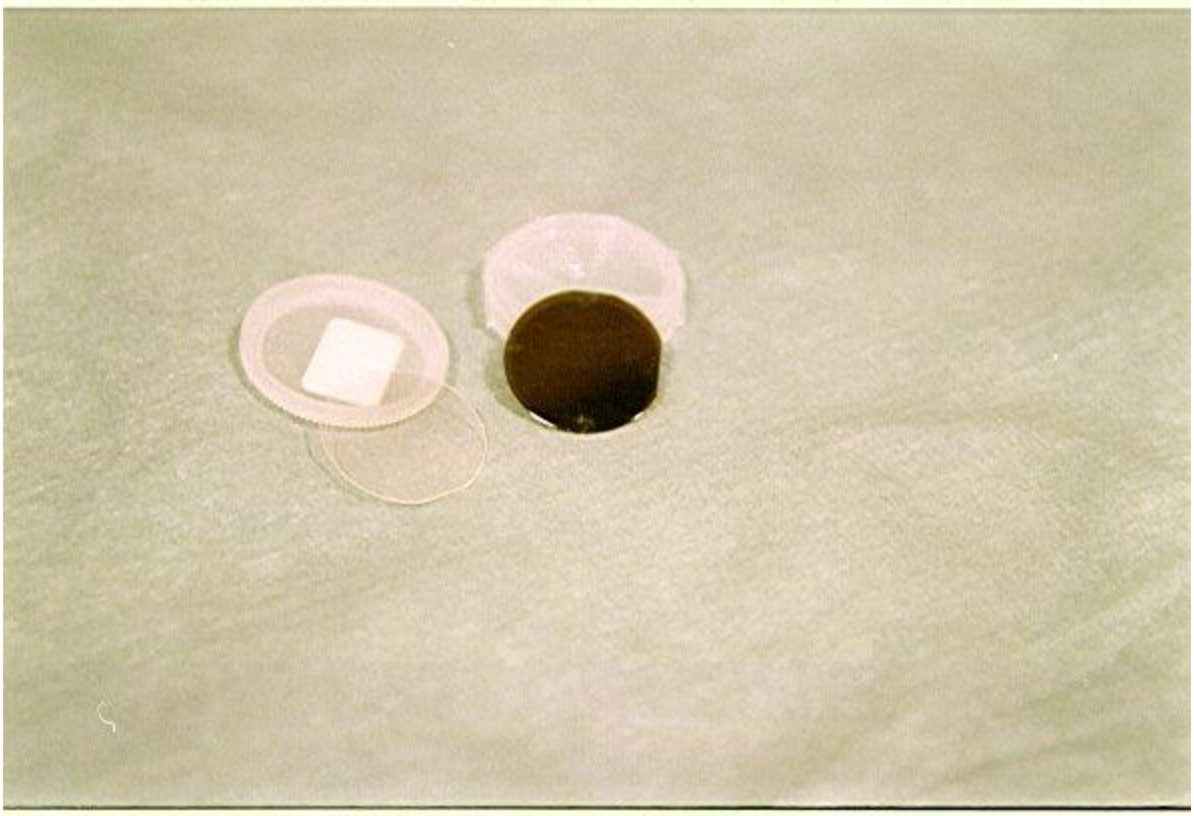



*Typical configuration of a furnace used for liquid phase epitaxy of magnetic garnets.*

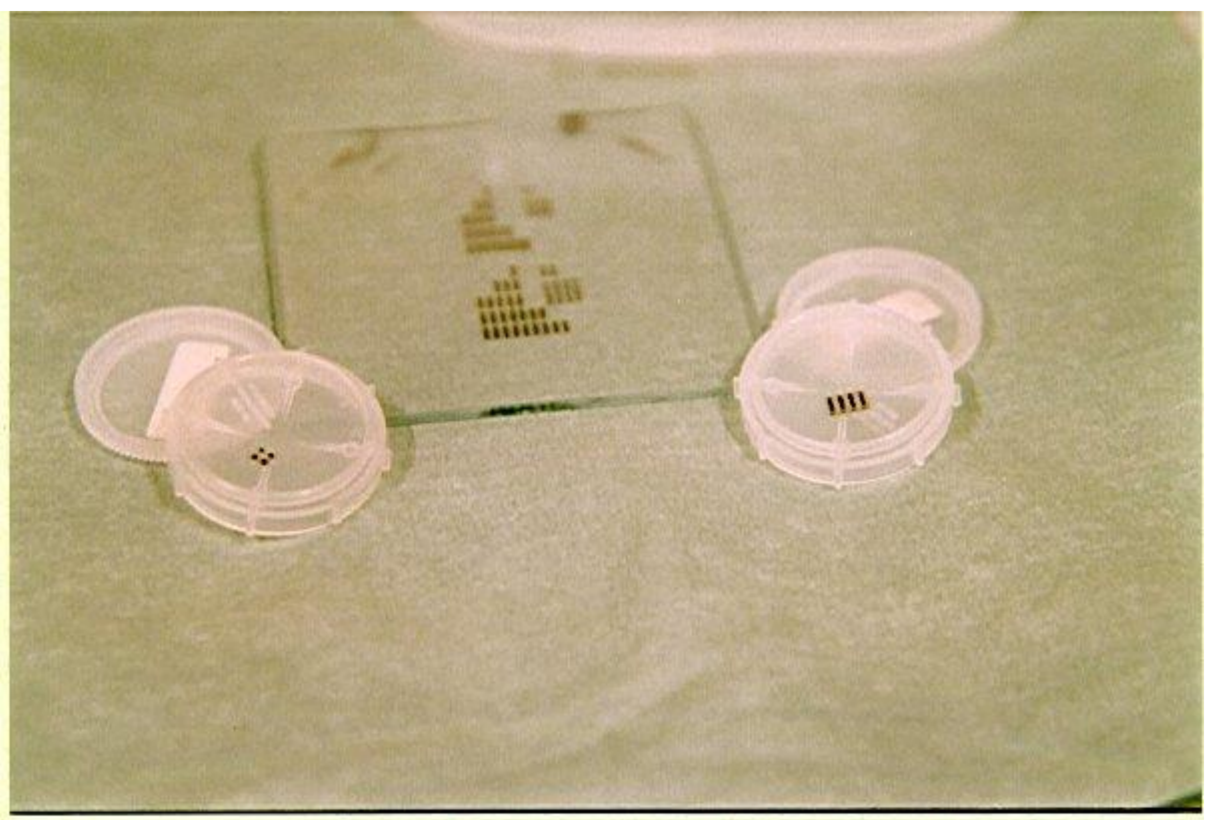
Furnace for epitaxial growth of garnet films



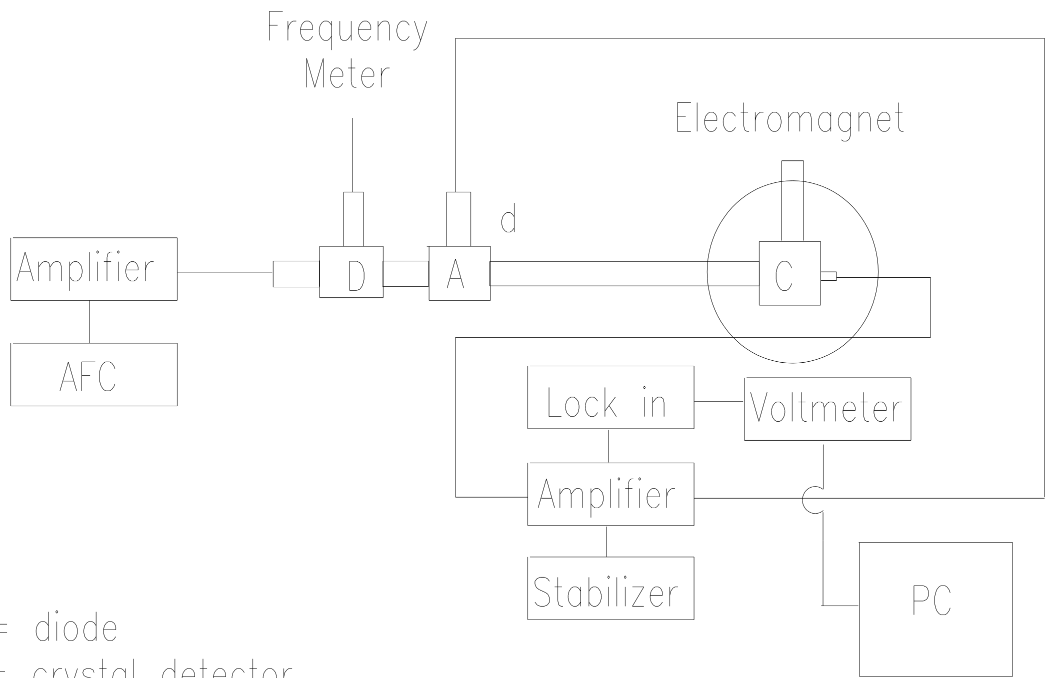
Precision dicing saw for microelectronics wafers



Epitaxially grown LaGa:YIG film and GGG wafer

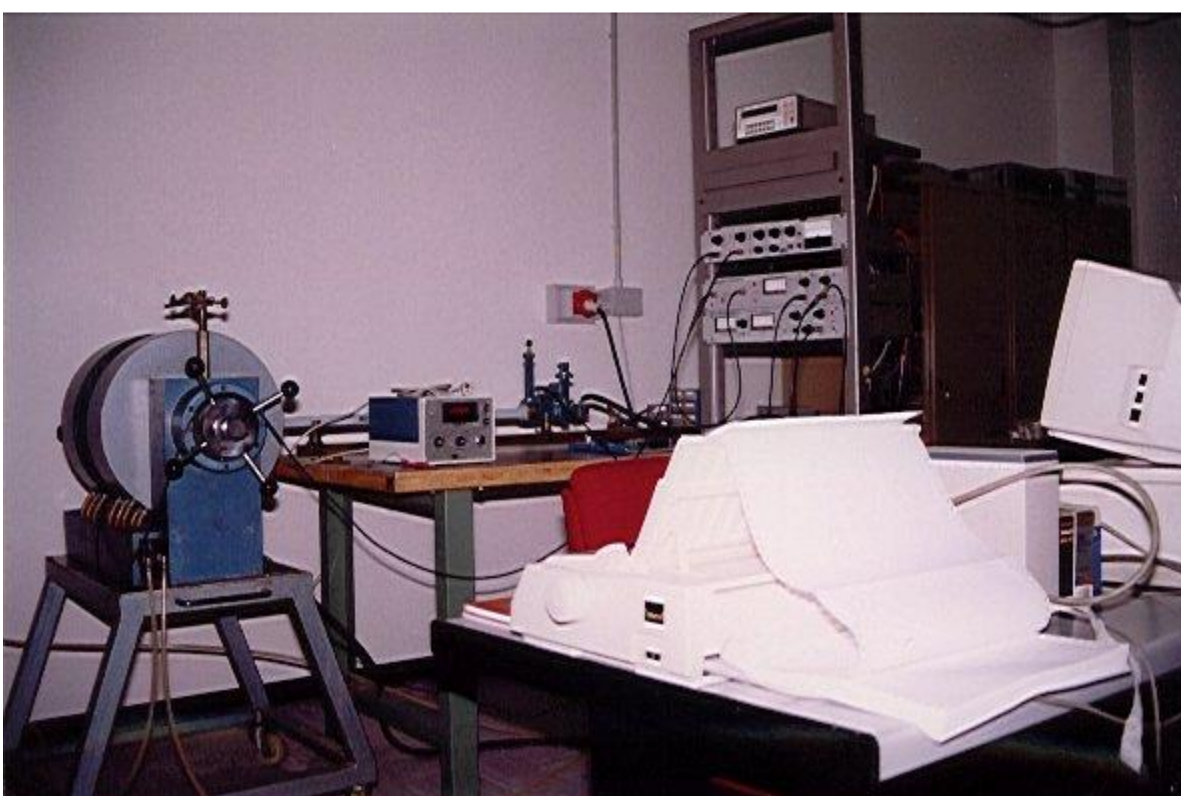


Micromachined series and matrix of resonators




D = diode
d = crystal detector
A = attenuator
C = cavity, where is the sample under test

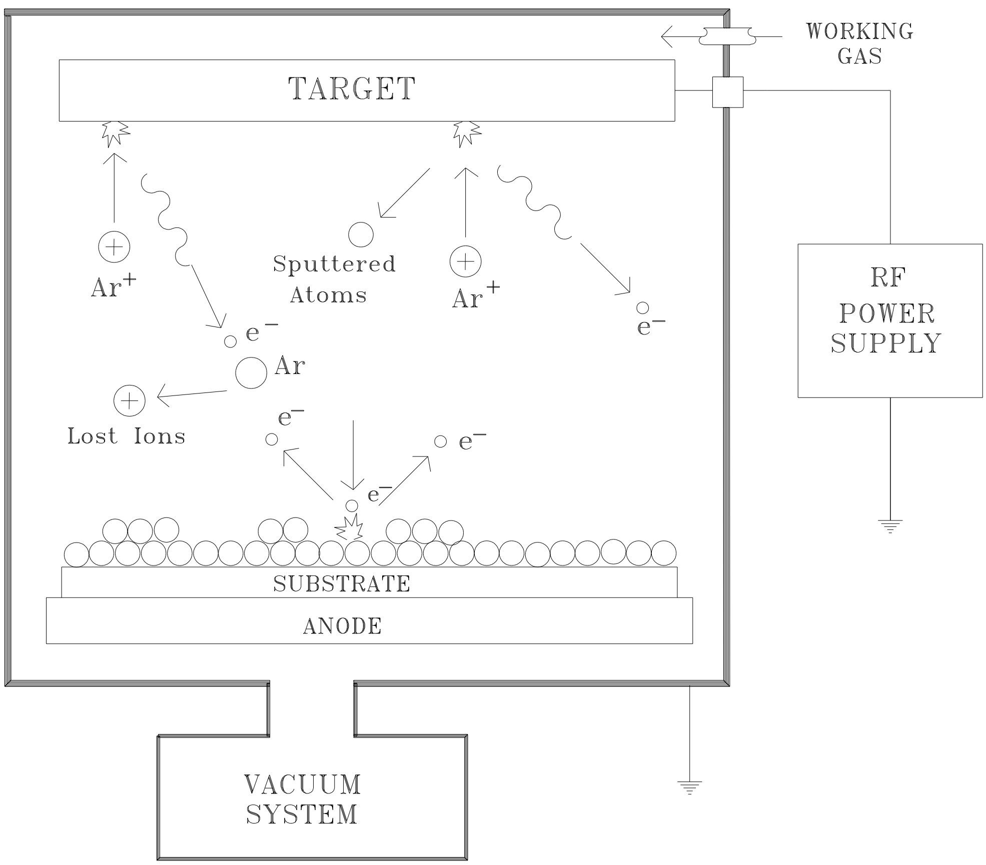
*Remotely controlled setup of a Ferromagnetic Resonance Experiment performed on microwave magnetic samples.*



## 2) Growth by RF sputtering of crystalline and amorphous garnet films and multilayers. Optical absorption characterization and their use as magnetic semiconductors.

Supported by

- National Task Project "Telecommunications" (1989-1990);
- National Task Project "Special Materials for Advanced Technologies" (1990-1993);
- CNR National Project on "Magnetic Films and Multilayers" (1992).

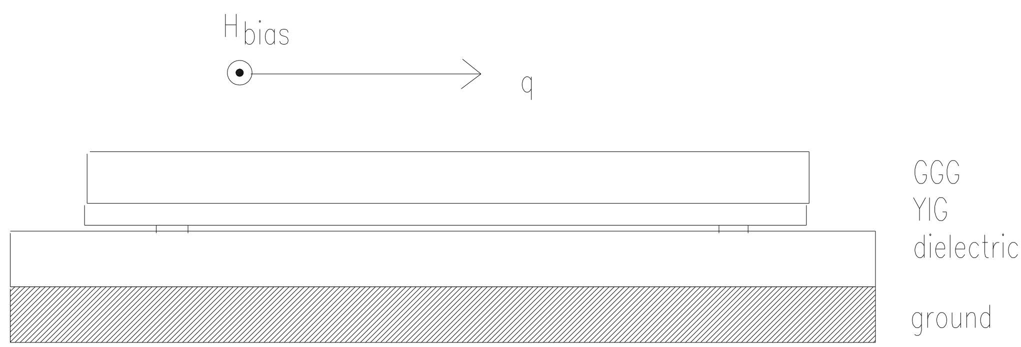



*Schematic of a typical setup for sputtering of thin films. In this case, the substrate can be glass, GGG, silicon or any other dielectric material. The sputtered material is pure or substituted YIG.*

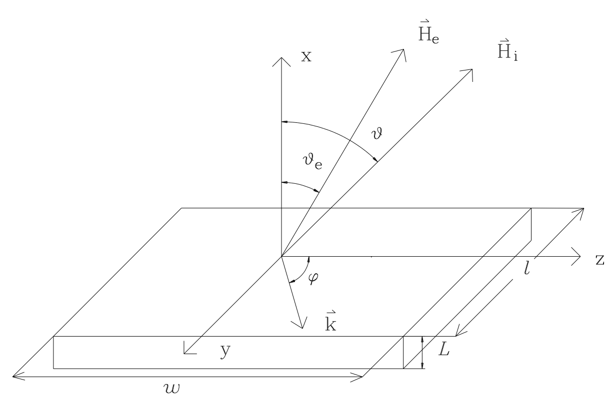
## 3) Computer Aided Engineering, realization and test of magnetostatic wave (MSW) filters for resonators and delay lines (distributed constants).

<u>Supported by</u>

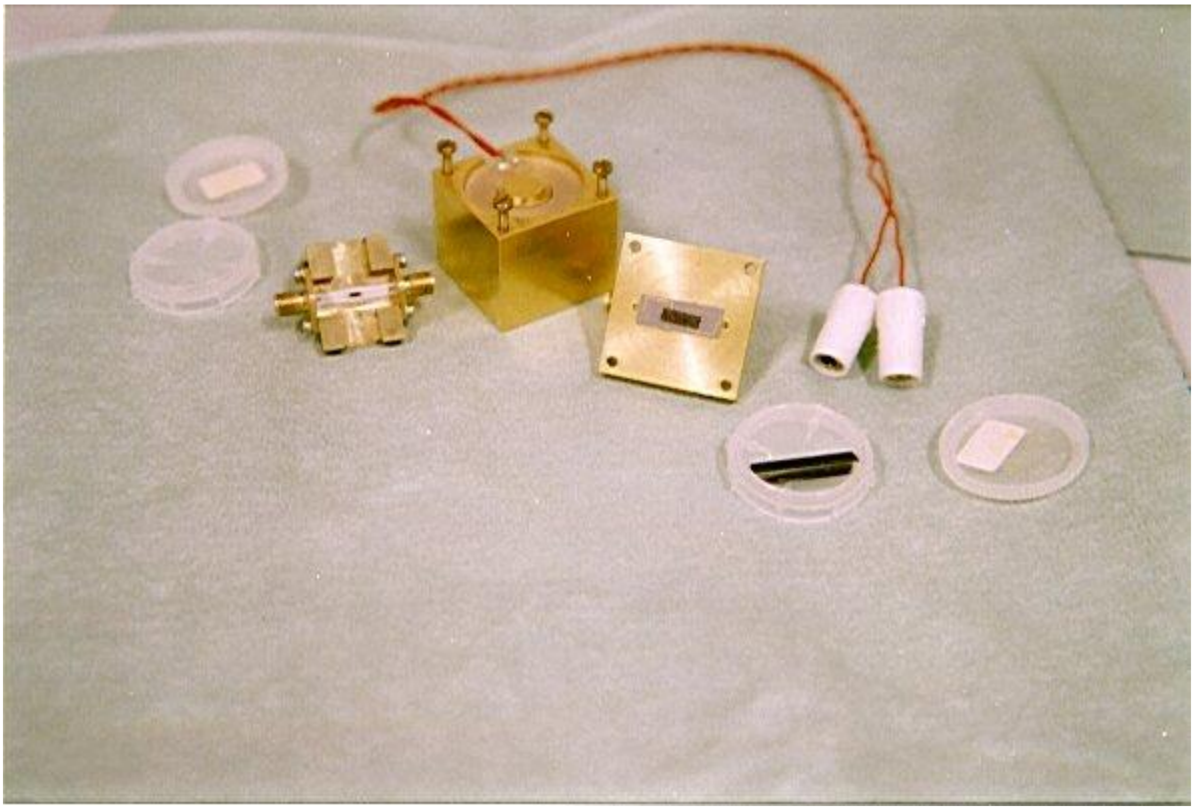
- National Task Project “Materials and Devices for Solid State Electronics” (1986-1990);
- ESA/ESTEC Contract No.101886 (1990-1991);
- Italian Space Agency (ASI) Contract for the development of MSW resonating filters (1994-1996).
- Italian Space Agency (ASI) Contract for the development of an MSW oscillator (1997-1999).




*Magnetostatic wave delay line. A YIG film is top coupled with respect to conventional microstrip transducers evaporated onto a dielectric grounded substrate. A dc magnetic bias is applied to magnetically saturate the sample, while q is the excited wavevector.*




*Geometry of the problem. W is the SER width, ℓ is the length and L is the thickness. $H_i$ and $H_e$ are the internal and external dc magnetic fields,*

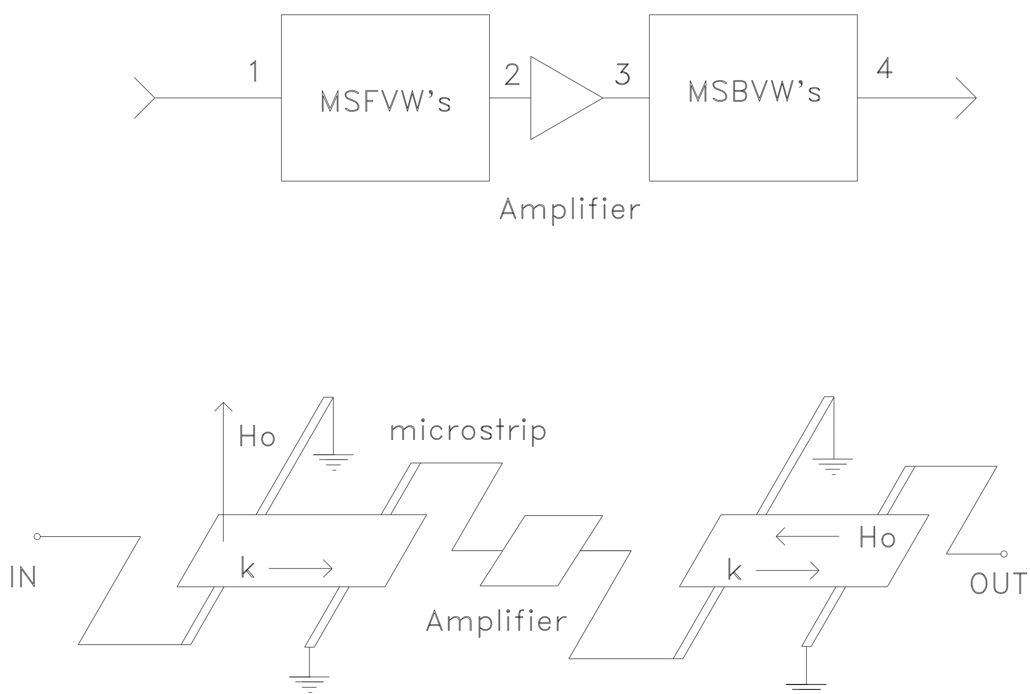


MSW Band-Stop Resonator (left) and delay line (right) loaded by YIG films. A current controlled bias system provides the dc magnetic field for the tuning of the operative frequency

## 4) Experimental techniques for the characterization in *cw* of MSW microwave filters and oscillators by means of Vector Network Analyzer and Spectrum Analyzer. Design, Realization and Test of Nondispersive Filters.

Supported by

- National Task Project “Materials and Devices for Solid State Electronics” (1986-1990);
- ESA/ESTEC Contract No.101886 (1990-1991);
- Contract between CNR and Mediterranean Quantum Systems (Chieti, Italy) (1993);
- Italian Space Agency (ASI) Contract for the development of MSW resonating filters (1994-1996).
- Contract between CNR-IESS and Sincrotron Engineering (Trieste, Italy) (1996).
- Italian Space Agency (ASI) Contract for the development of an MSW oscillator (1997-1999).

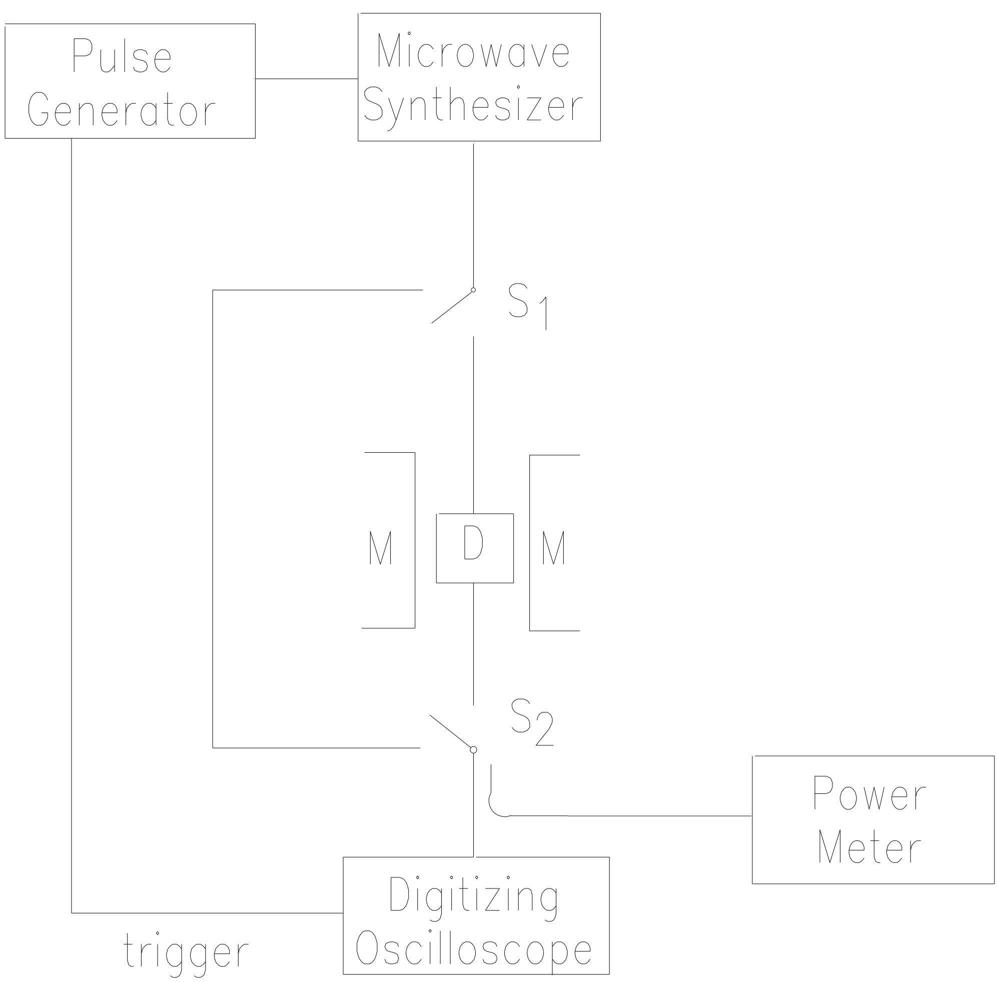



*Experimental setup and schematic diagram of a non-dispersive MSW filter. Two MSW delay line (MSFVW and MSBVW) having opposite chirp frequency response are connected in cascade and separated by an amplifier which provides an isolation between the two stages and an insertion loss decrease.*

## 5) Experimental techniques for pulsed regime measurements of MSW delay lines for soliton detection and modulational instability. Nonlinear effects modeling and software for the interpretation of nonlinear propagation of short pulses in MSW surface delay lines, soliton propagation at microwave frequencies.

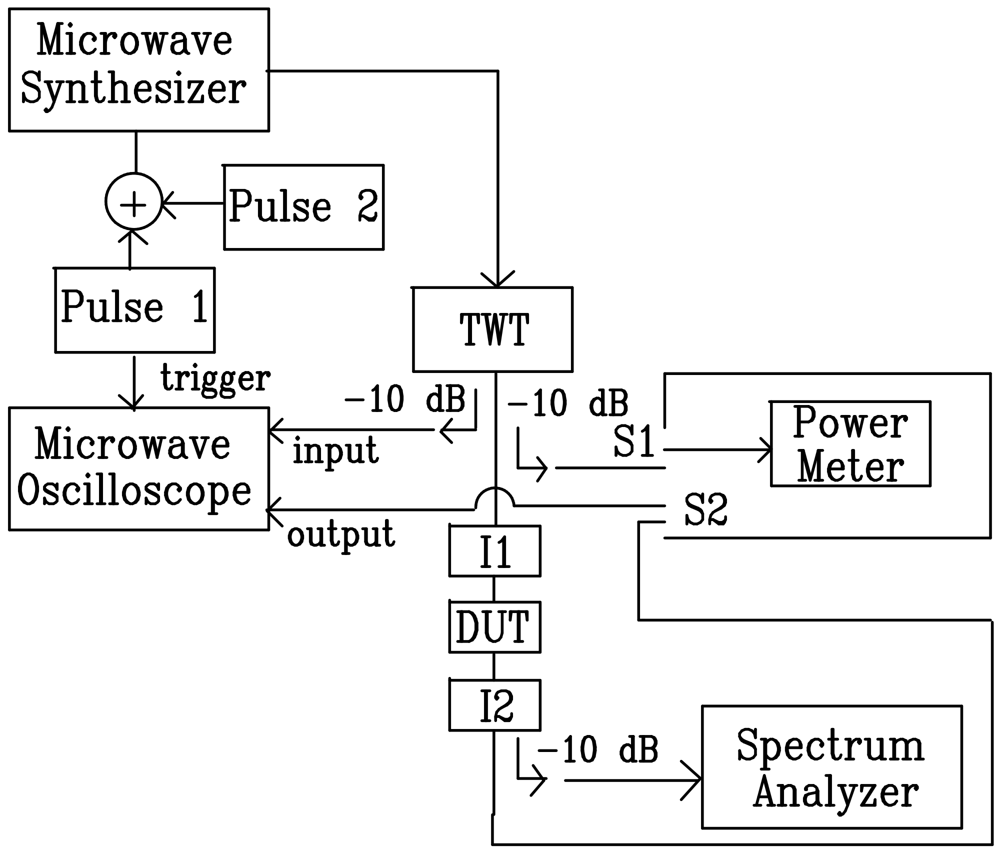
Supported by:

- National Task Project "Materials and Devices for Solid State Electronics" (1986-1990);
- NATO granto No.HTECH.930309 (1993-1995).
- Protocol of Cooperation Italy-Romania (1994-1996).
- Protocol of Cooperation Italy-Romania (1996-1998).
- Protocol of Cooperation Italy-Romania (1998-2000).
- Protocol of Cooperation Ytaly-Russia (2000 – 2002)
- Cooperation with Tamagawa University, Tokyo (2000 - )



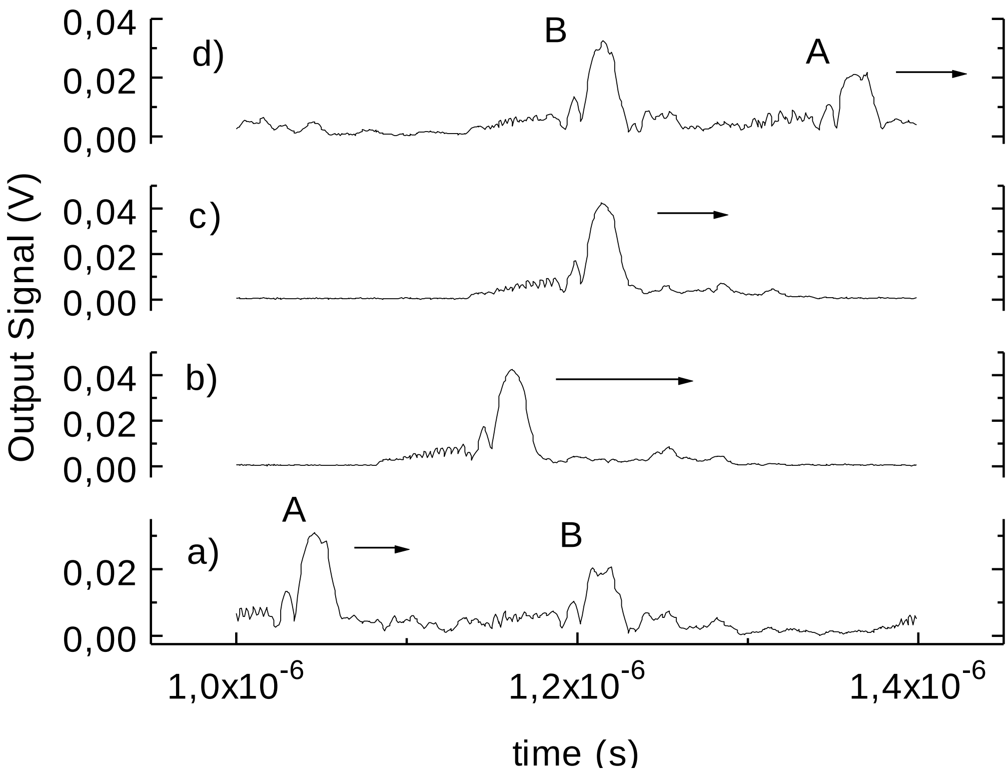



*Time domain and power measurements on a magnetostatic wave device.*




Experimental setup used for the MSSW nonlinear interaction. Two microwave pulses have been obtained from the same synthesizer by splitting the *cw* signal and by using two pulse generators for the amplitude modulation. Pulse 1 is also a trigger for an oscilloscope. S1 and S2 are two switches to allow power and spectrum measurements. I1 and I2 are two isolators used to reduce reflection effects induced by the network. DUT is the device under test.

HP digital oscilloscope for microwave and optical devices characterization up to 20 GHz

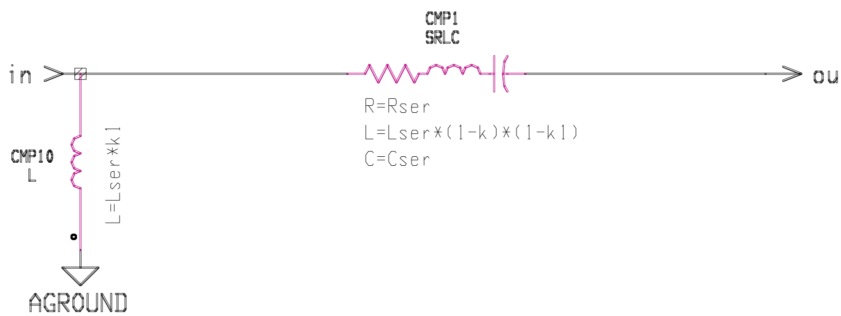



Interacting nonlinear pulses at f=4.230 GHz, for $\tau_{in}$=40 ns and $P_{in}$=0 dBm at the synthesizer output

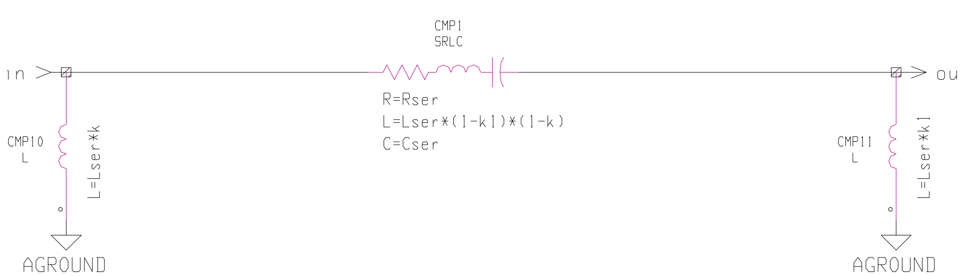
## 6) Lumped element modeling of MSW resonating filters (band-pass and band-stop). Software interface with Vector Network Analyzer. Realization and Characterization.


Supported by:

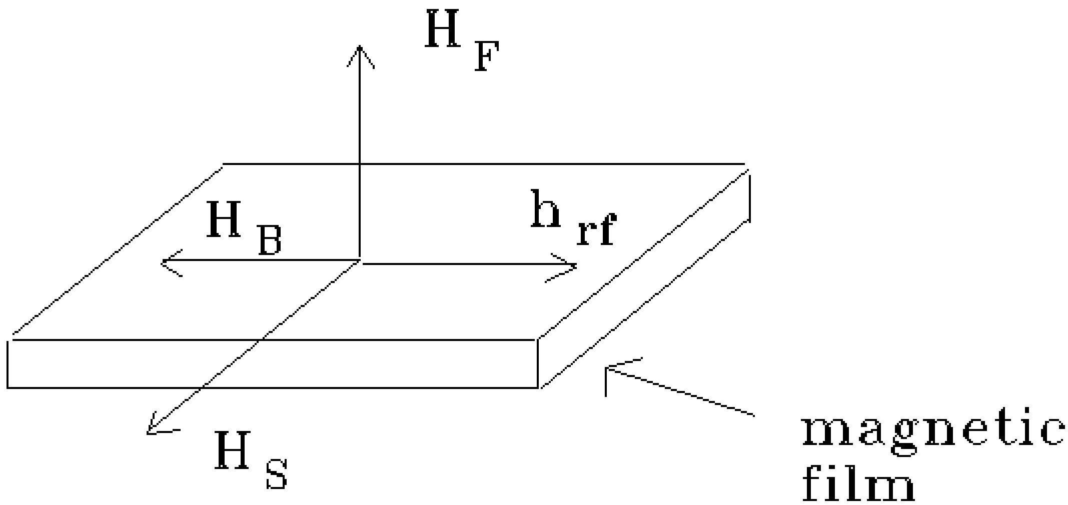
- Contract between CNR and Mediterranean Quantum Systems (Chieti, Italy) (1993);
- Italian Space Agency (ASI) Contract for the development of MSW resonating filters (1994-1996).
- Contract between CNR-IESS and Sincrotron Engineering (Trieste, Italy) (1996).
- Italian Space Agency (ASI) Contract for the development of an MSW oscillator (1997-1999).
- YOTA Project: YIG Oscillator for Telecommunications Applications (2000-2002)

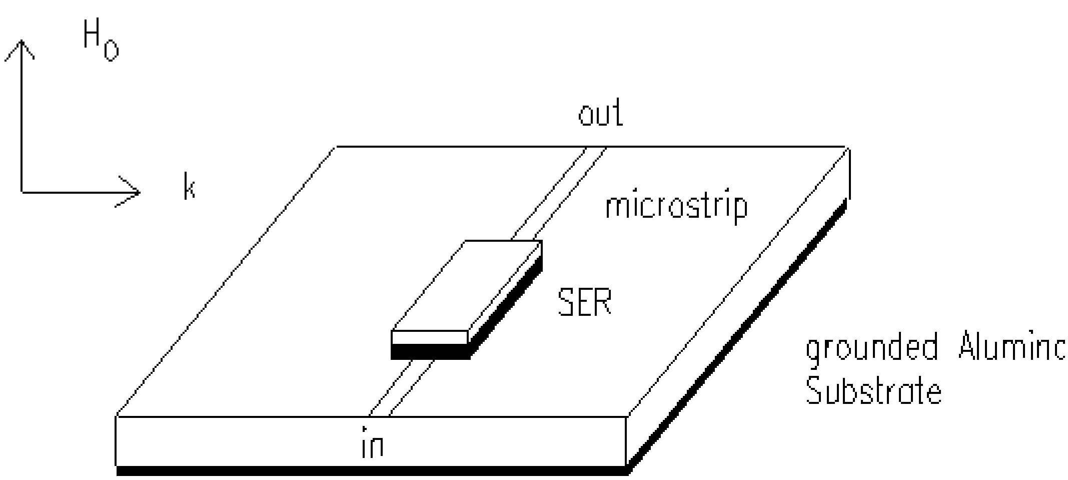

*Input stage of the two coupled SERs simulated band-pass filter. Rser, Lser and Cser are the lumped element values in the case of the FMR measured sample ($\ell_x$=0.94 mm, $\ell_y$=2.9 mm, t=45 $\mu$m, $\Delta H$=1 Oe). k=1/$Q_L$ is the coupling factor between SERs, and k1=2/$Q_{ext}$ the coupling with the input port. Lser×k1 is the input iinductive coupling. Because of the coupling with the input port and the following SER, L×(1-k)×(1-k1) is the new inductance. k1 has been evaluated for d=100 $\mu$m (distance between SER and microstrip).*



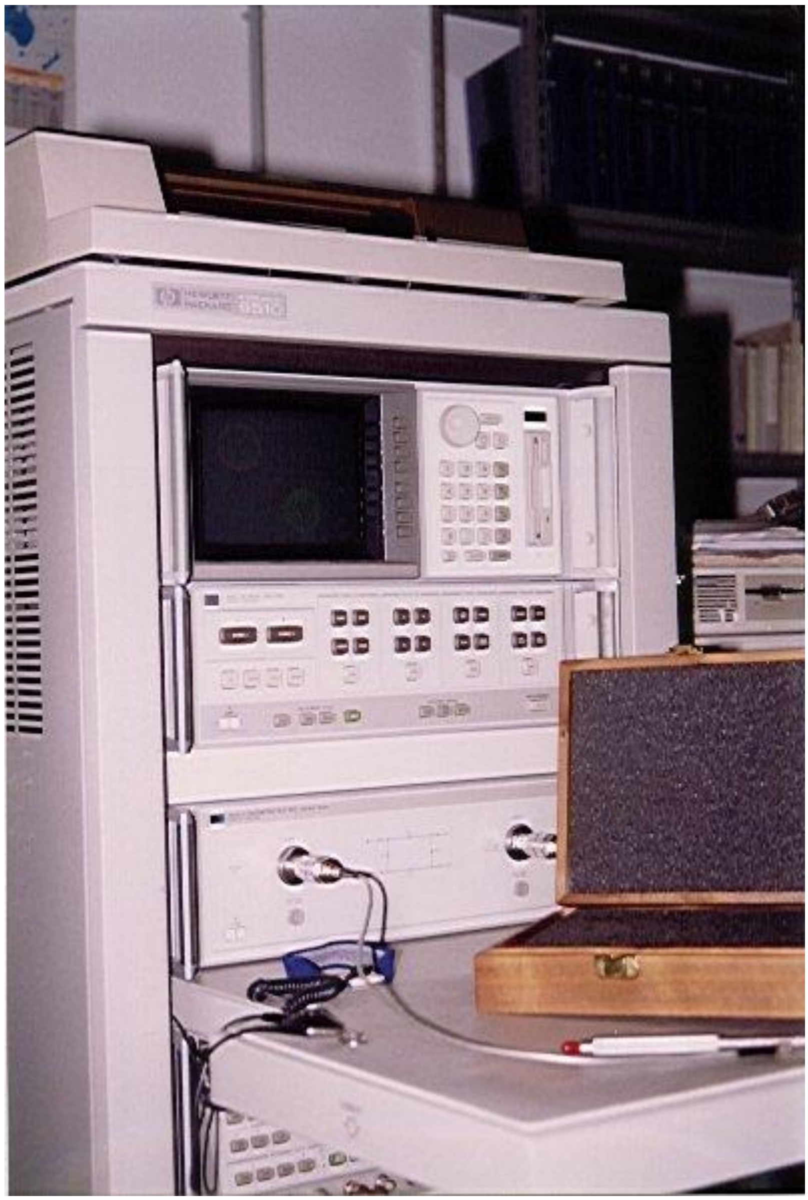

*Output stage of the two coupled SERs. Lser of the second SER is changed again by the factor (1-k1)×(1-k), and this second SER is coupled to the first one by an inductance Lser×k, and to the output port by and inductance Lser×k1 (as for the input).*




Excitation of magnetostatic waves (MSWs) in a yttrium iron garnet (YIG). GGG is the acronym for gadolinium gallium garnet, the diamagnetic substrate for the YIG film growth. H is the dc magnetic bias field and k is the excited wavevector. F=forwward, B=backward, S=surface.

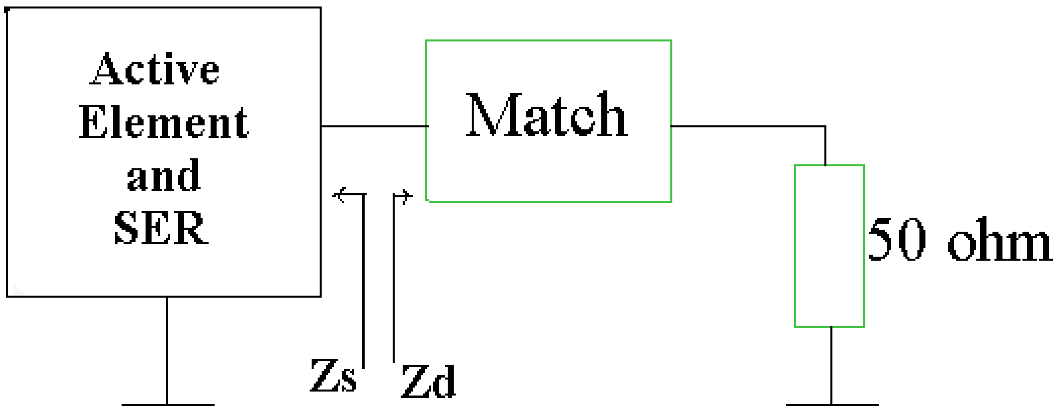


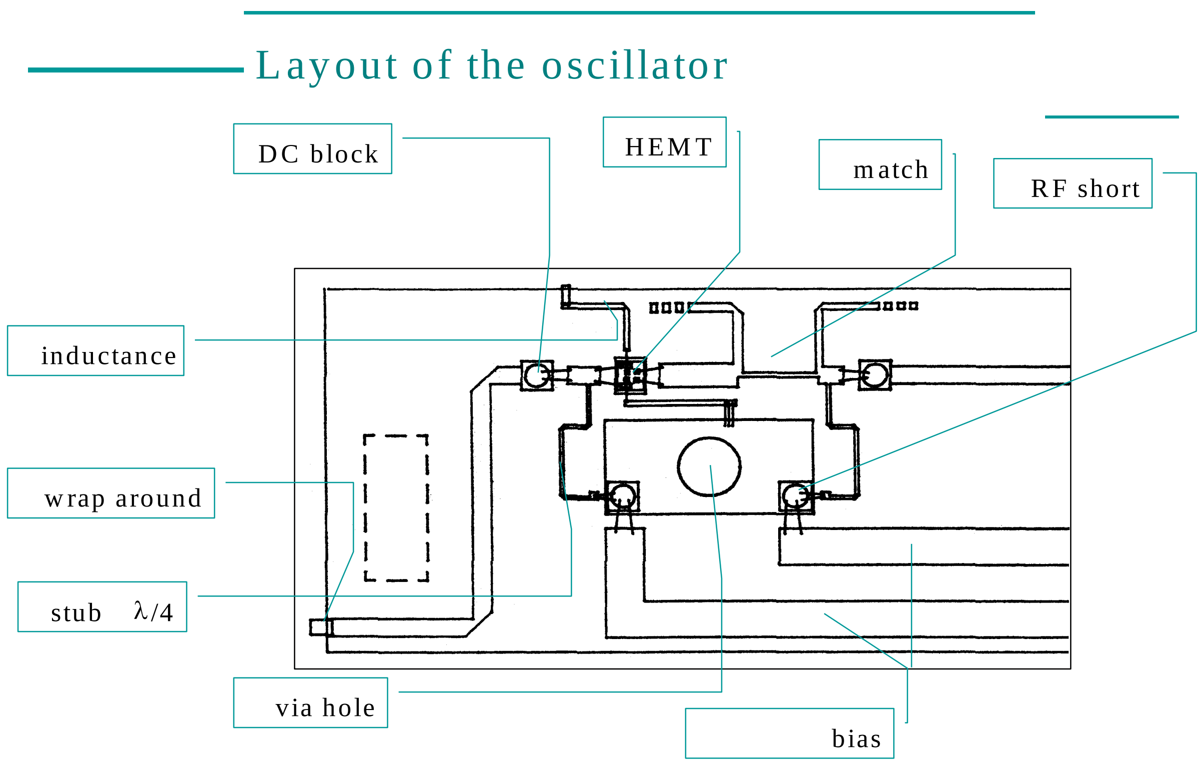

Typical configuration of a two-port band-stop MSW SER. A YIG planar resonator (black in the figure) grown onto a GGG substrate (white in the figure) is properly cut and directly coupled to a microstrip circuit. The bias is that of a forward volume wave, with H normal with respect to the film plane



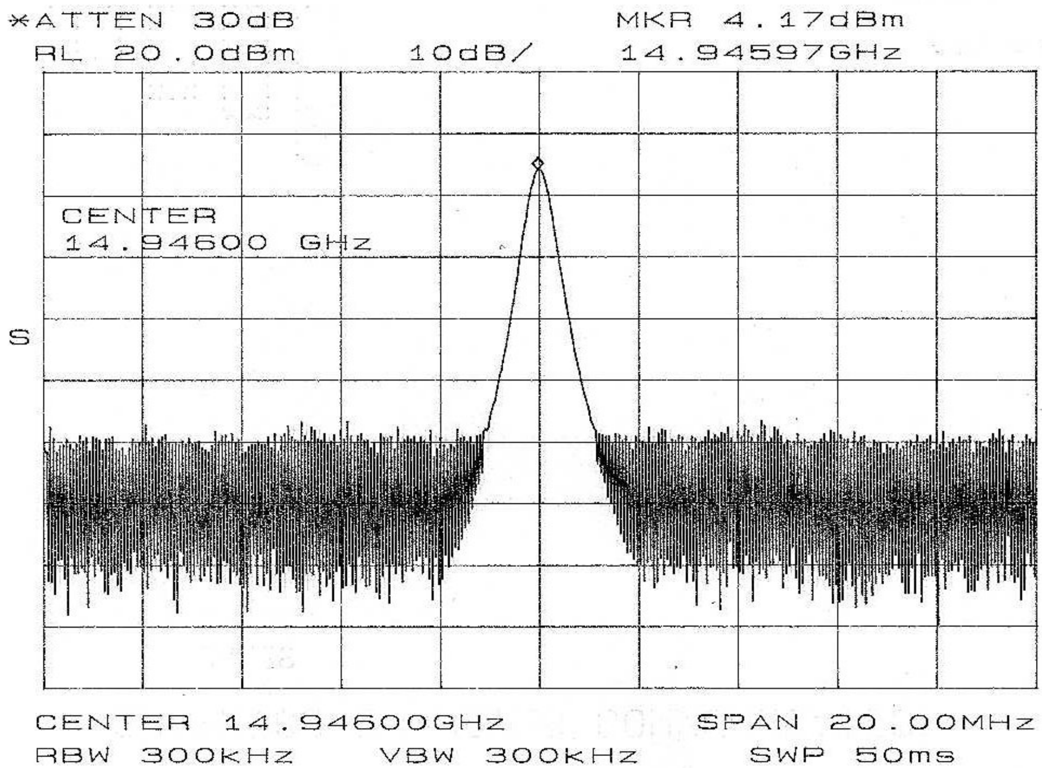
***Two HP8510C Vector Network Analyzer for S-parameter measurements: (i) up to 18 GHz and (ii) up to 50 GHz***

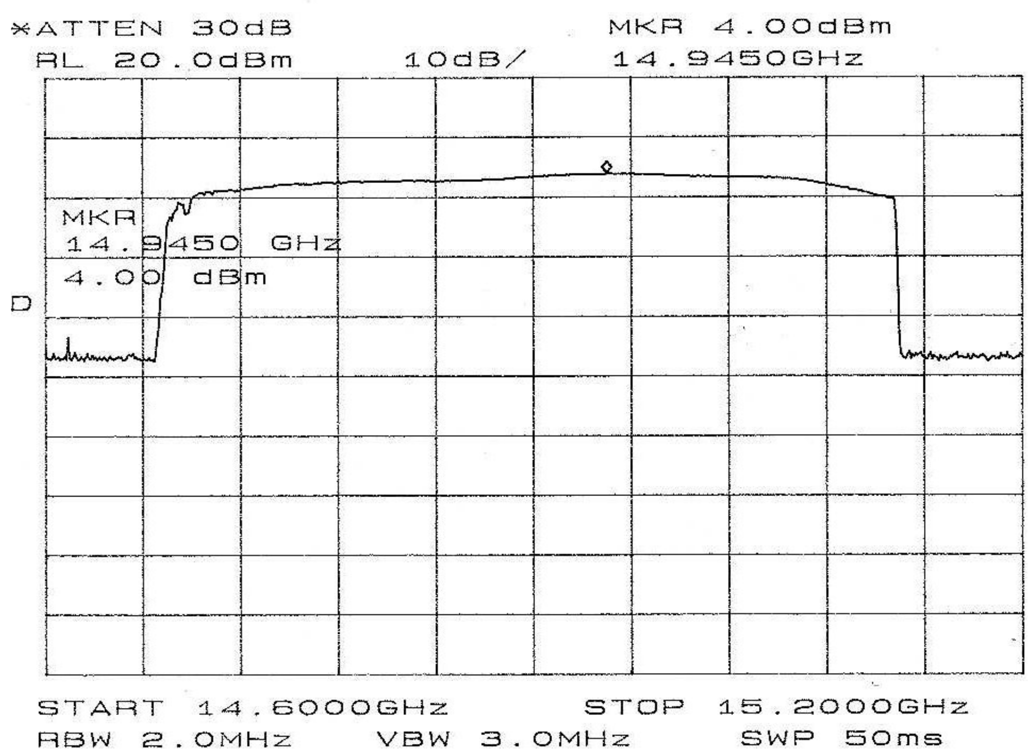
# MSW Oscillator (with Alenia-Marconi Systems)




Model and layout of the planar oscillator realized. The dashed region is the SER with its real dimensions, which, in operating conditions is placed on the top of the microstrip.



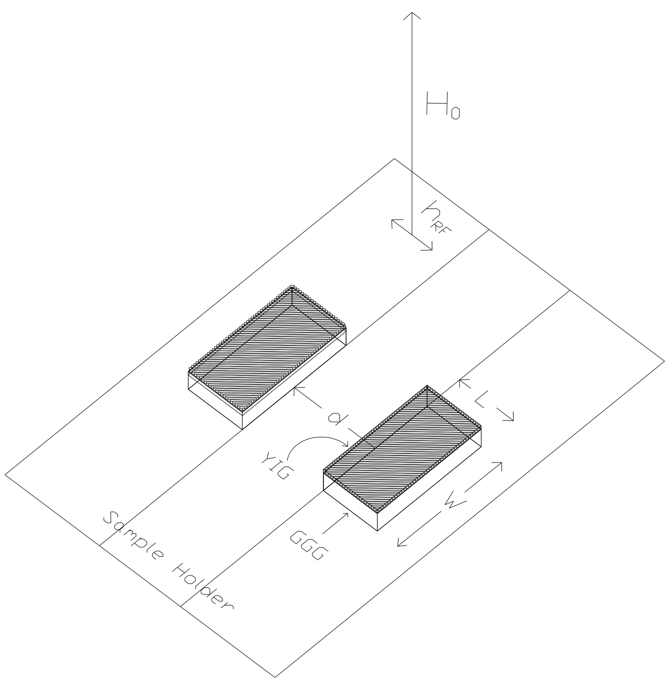

Measured output power of the oscillator as a function of the tuning frequency by changing the dc bias magnetic field

**7) Technologies for the realization by means of chemical etching of:**

- **diffraction gratings for microwave surface magnetostatic waves;**
- **planar geometries suitable of bistability effects in periodic structures;**
- **on-wafer coupled resonators.**

<u>Supported by:</u>

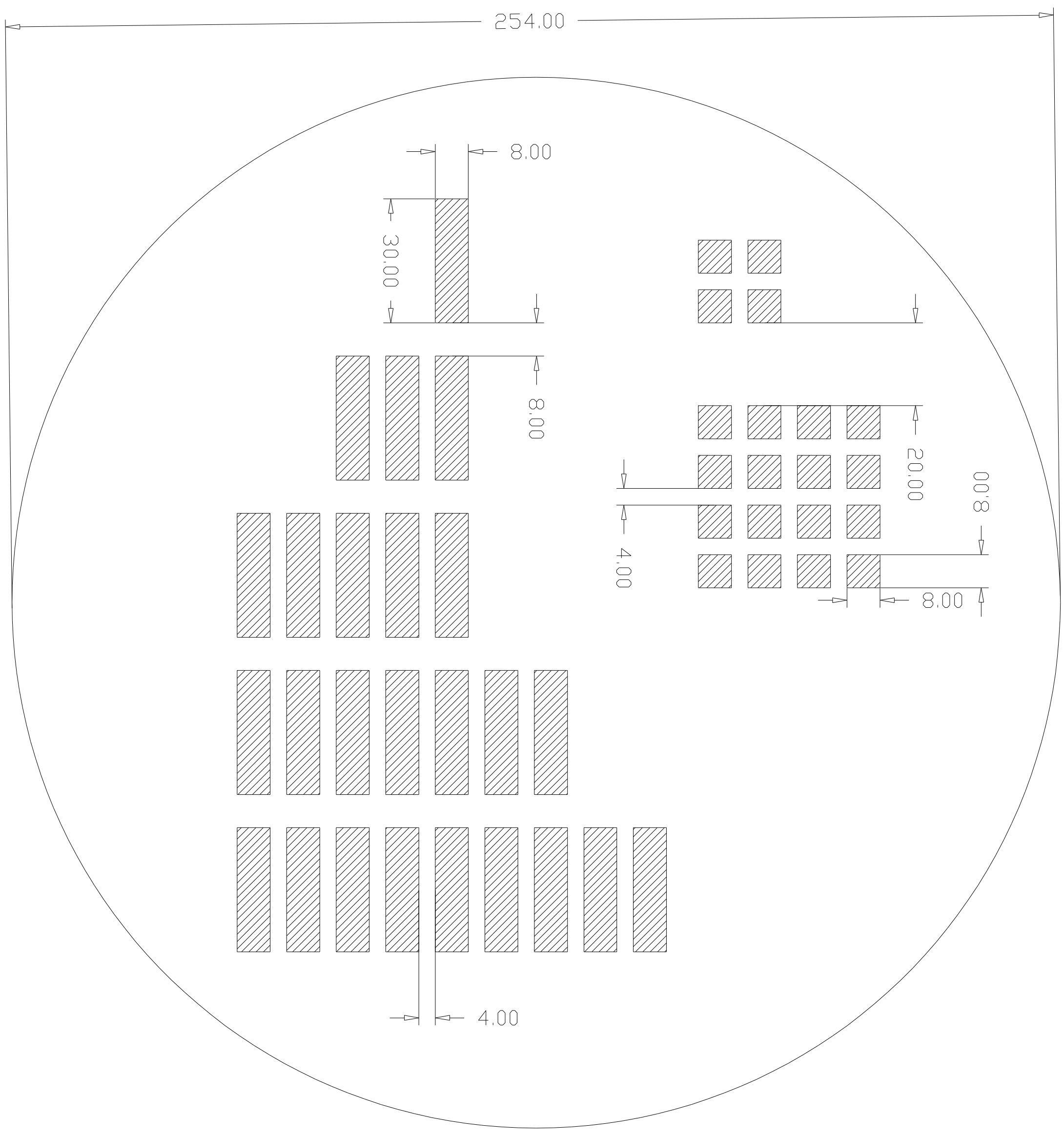
- NATO granto No.HTECH.930309 (1993-1995);
- Italian Space Agency (ASI) Contract for the development of MSW resonating filters (1994-1996).
- Italian Space Agency (ASI) Contract for the development of an MSW oscillator (1995-1997).



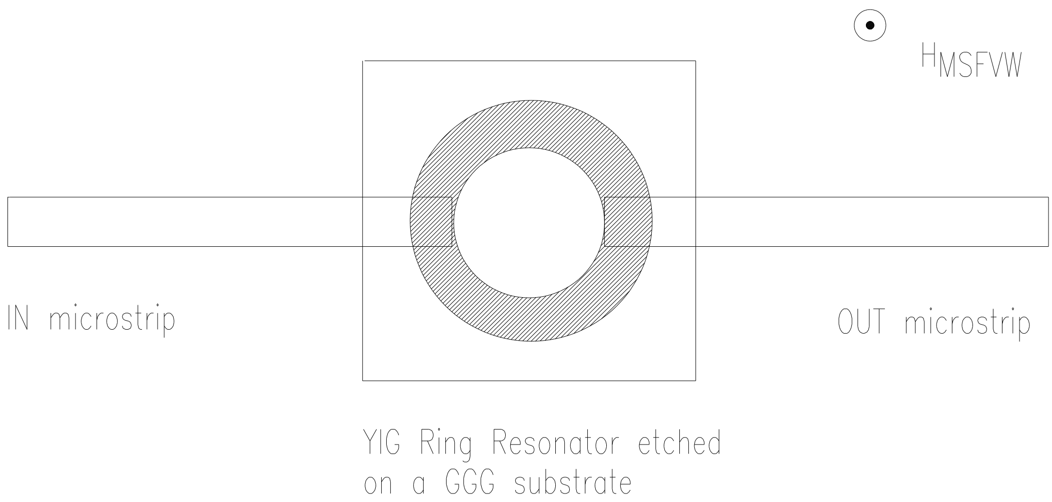

*Layout of the resonating structure.*

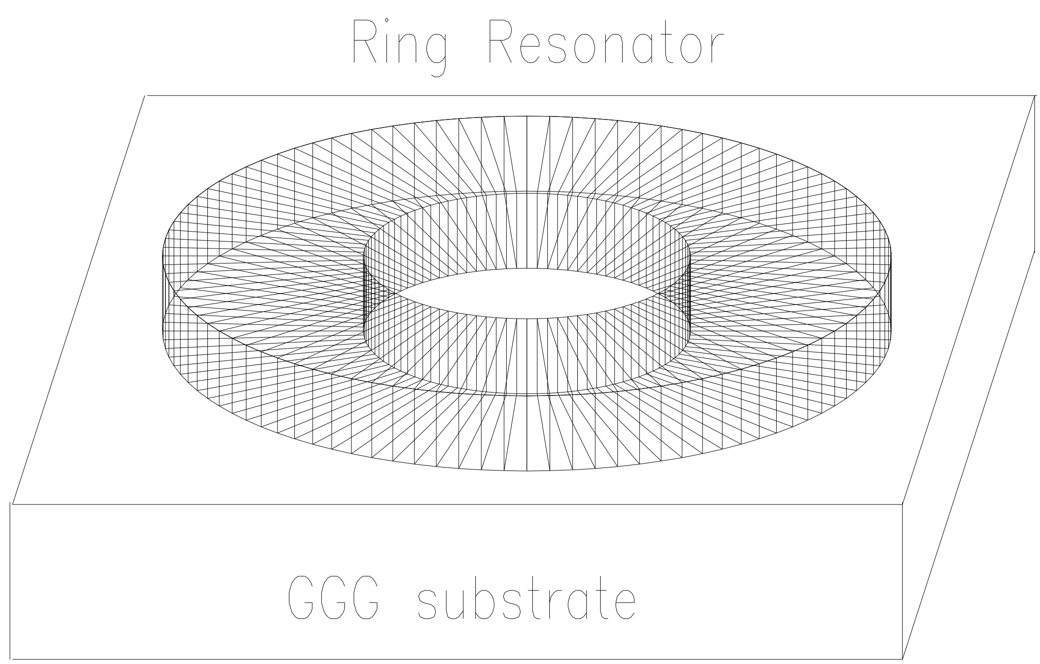
*Two YIG film SERs, epitaxially grown on a GGG substrate are firmly glued onto a dielectric holder. L and W are the length and width for both SERs, while d is the distance between them*

*A dc bias $H_0$ is applied normally with respect to the samples plane. $h_{RF}$ is the microwave field.*




*Mask used for the chemical etching of single and coupled resonators on magnetic wafers.*



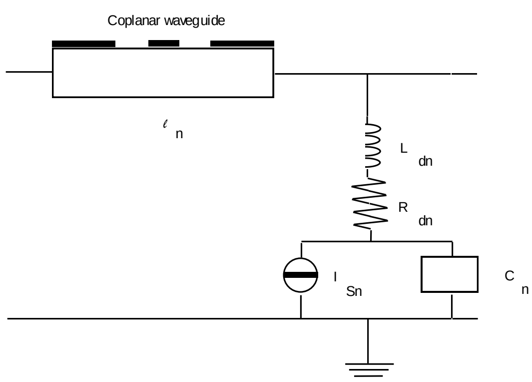




Technology for the realization of an epitaxial YIG ring resonator.

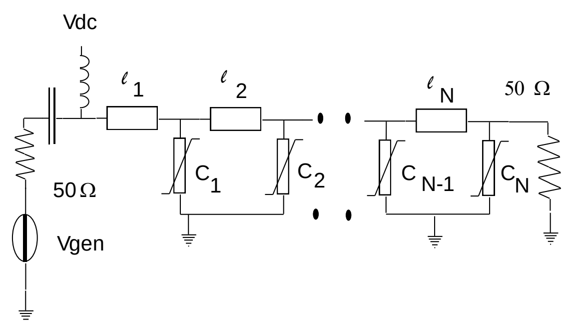
## 8. Design of non-linear transmission lines based on Schottky diodes and resonating tunneling diodes for soliton excitation and harmonic generation in the millimeter wave range by means of GaAs structures.

Supported by:

- Protocol of Cooperation Italy-Romania (1994-1996).
- Protocol of Cooperation Italy-Romania (1996-1998).
- Protocol of Cooperation Italy-Romania (1998-2000).
- University of Roma “Tor Vergata” (1994-1996).




*Elementary cell of the NLTL. A CPW is series connected to the diode, in which the equivalent circuit is composed of a current generator $I_{Sn}$, a non-linear capacitor $C_n$, parasitic inductance $L_d$ and parasitic resistence $R_d$. In a tapered line, all the quantities depend on their n-th position along the NLTL.*

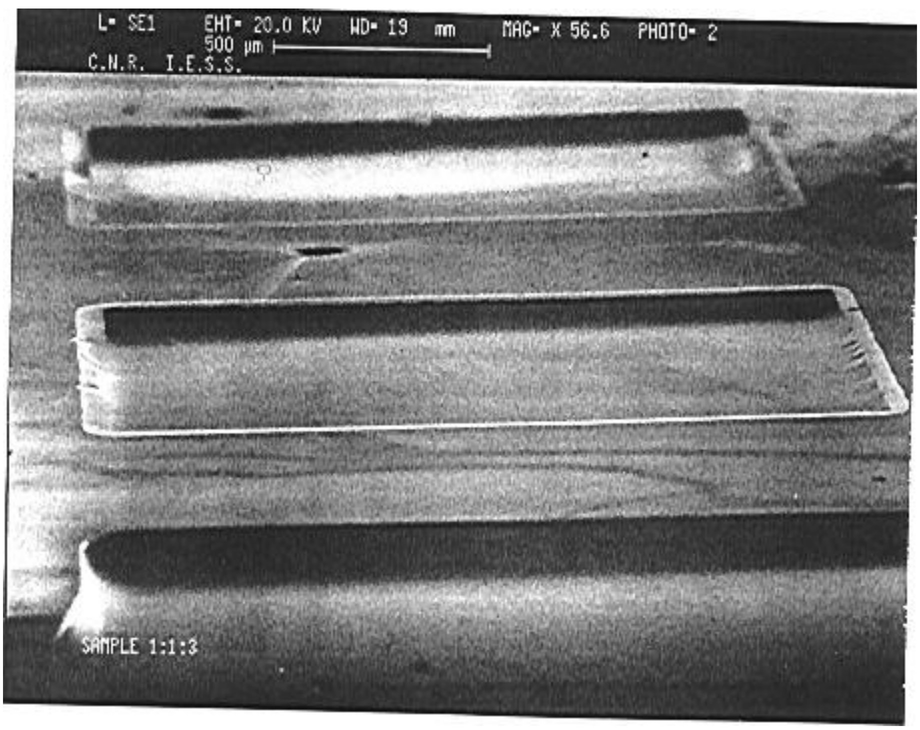



*Configuration of a tapered single NLTL. The tapering is provided by a tapering parameter pa which modulates the lengths l and the capacitances C.*

## 9. Micromachining of GaAs wafers for the realization of microwave nondispersive filters and sensors for hostile environments. Device design, realization and test.

<u>Supported by:</u>

- Protocol of Cooperation Italy-Romania (1996-1998).
- Protocol of Cooperation Italy-Romania (1998-2000).
- INCO-COPERNICUS Project (1998 -2000).

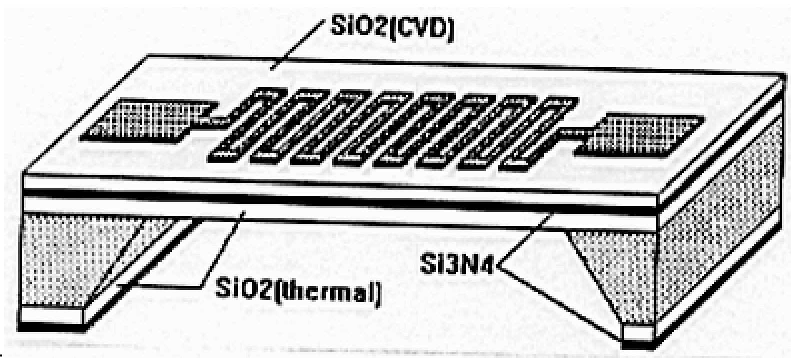



*Micromachined GaAs wafer. The solution used for the chemical etching was* $H_3PO_4:CH_3OH:H_2O_2$ *in the ratio 1:1:3. The obtained membrane is 10 µm thick, as expected by the calibration of the etching rate of the solution vs time at room temperature.*

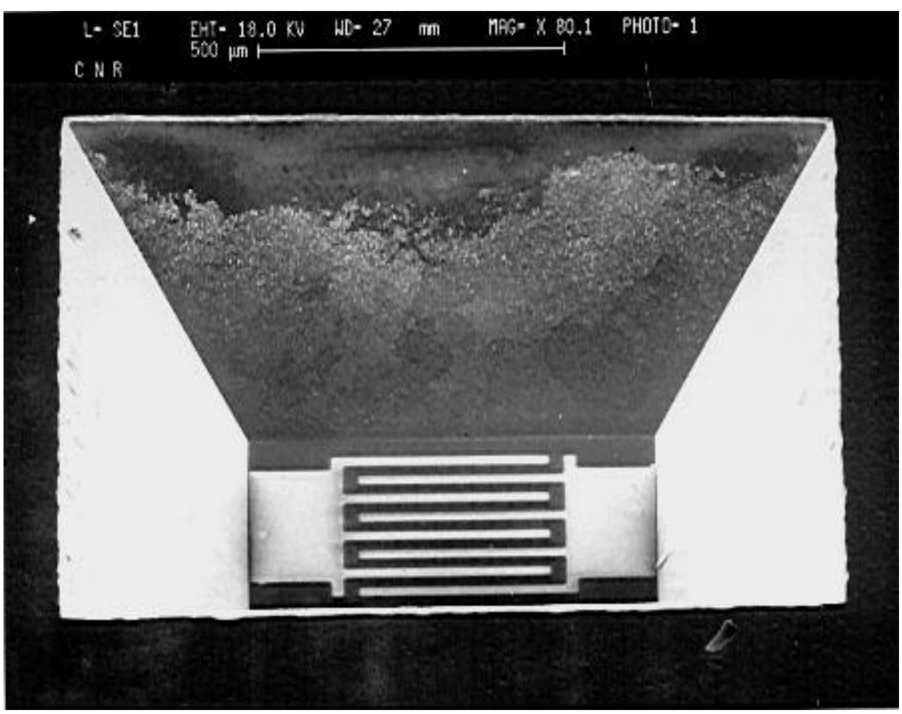
## 10. Micromachining of Si wafers for the realization of micro-waveguides working at frequencies greater than 100 GHz. Device design, realization and test.

Supported by:

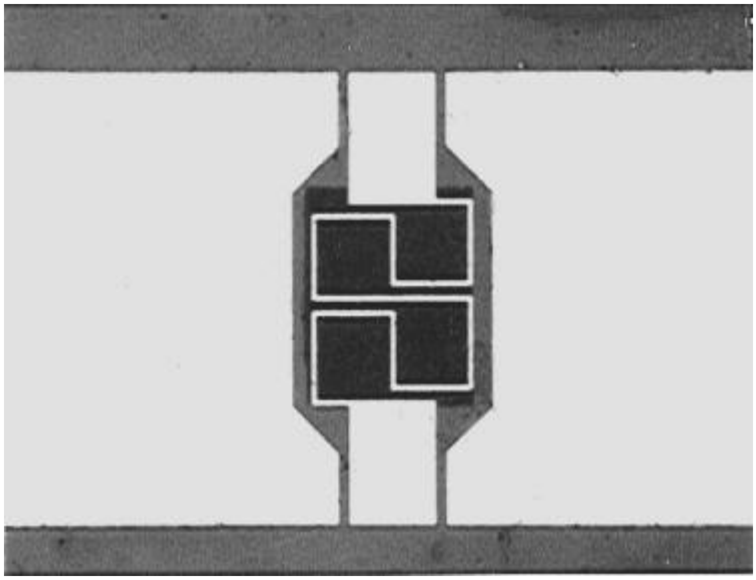
- Protocol of Cooperation Italy-Romania (1996-1998).
- INCO-COPERNICUS Project (1998 - 2000).
- Cooperation CNR-PAT between the National Research Council of Italy and the Institute for Scientific and Technical Research (IRST) of the Istituto Trentino di Cultura (ITC), supported by the Provincia Autonoma di Trento (PAT).



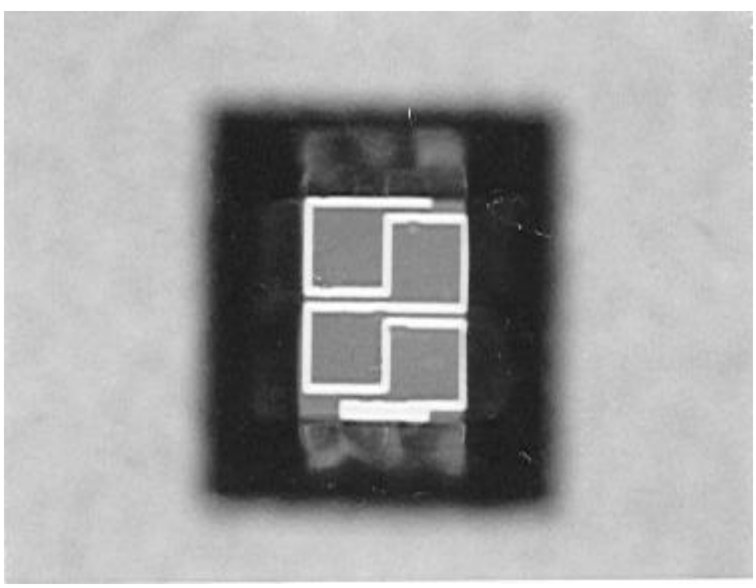

*Schematic view of the three layer membrane supporting a microwave circuit.*




*SEM photo of a micromachined interdigitated capacitor*

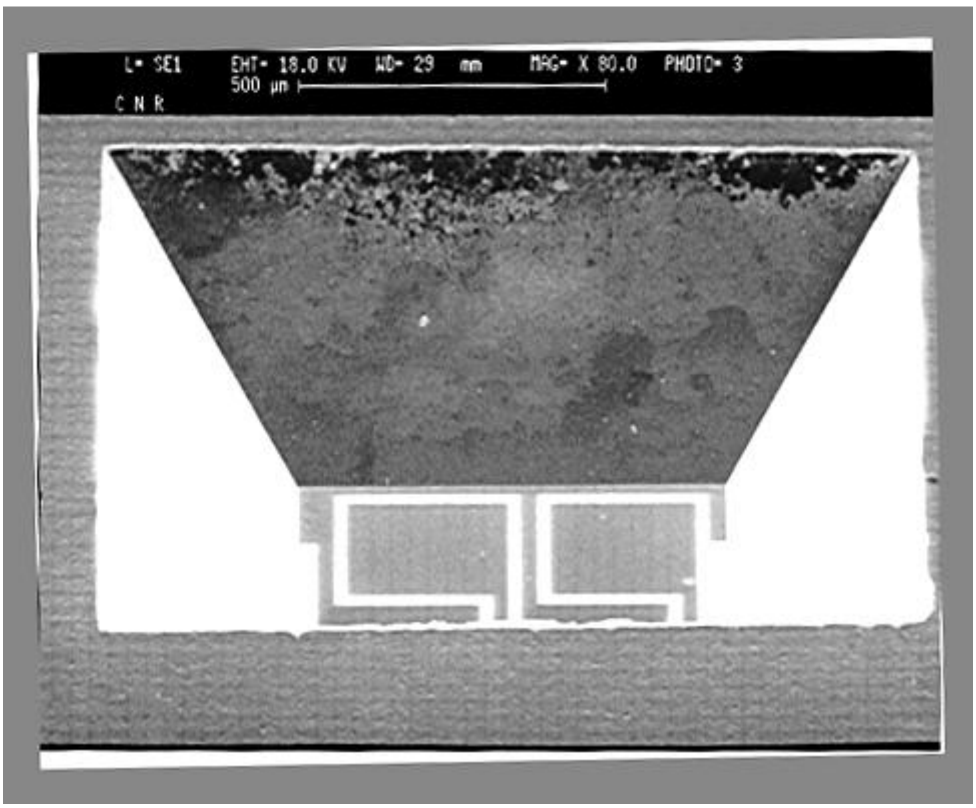


*A*

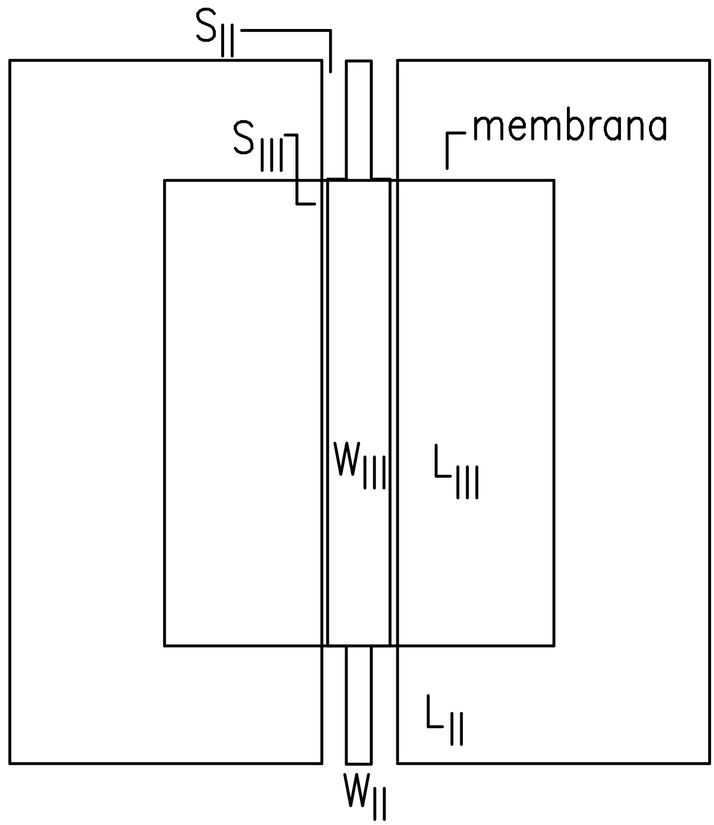


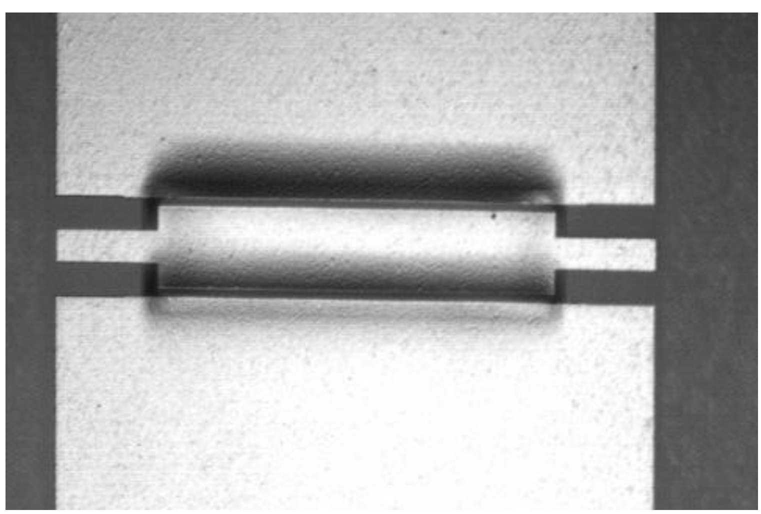
*B*

*Top view A and bottom view B of an S-line micromachined inductor*




*Side walls of the S-line inductor substrate*



Coplanar waveguide (CPW) on membrane. $W_{II}$=80 μm, $L_{II}$=380 μm, $W_{III}$=200 μm, $L_{III}$=1500, 2000, 3000 e 4000 μm, $S_{II}$=80 μm e $S_{III}$=20 μm. $2S_{II}+W_{II}=2S_{III}+W_{III}$=240 μm. The photo is for the 1500 μm one.

# Next future planning

- Higher frequencies (> 50 GHz)
- Micromachined antennas and passive devices in complex architectures, like microswitches and microshielded CPW filters, wafer-bonding
- Integration between passive micromachined elements and active devices on Si and GaAs.
- Space qualification and possible packaging implementation