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On BRNS-DAE project

"Studies of Spin-Wave Instability in Ferrites for High Power Circulators"

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Dated: October, 2007

INTRODUCTION

High power ferrite circulators have become as indispensable component for CW *rf* systems for ADS applications in RRCAT/DAE. Ferrites are the critical components in circulator. Power handling capability of circulator depends mainly on power threshold of ferrites. As circulator is purely ferrite-oriented design, so power threshold of ferrite is an important issue in design & development of CW ferrite circulators. Spin wave instability is an important measurement required to determine the power handling of ferrite materials for device applications. This information helps in determining its ability to handle high microwave power. The studies of power threshold & spin-wave instability in ferrite & garnet system are being proposed in this project.

OBJECTIVES OF THE PROJECT

1. Studies of Spin Wave Phenomena in Polycrystalline / Nano-crystalline spinel & garnet systems.
2. Development of Parallel Pumping System for Spin-Wave Measurements
3. Measurements of Spin-Wave Width & Instability Threshold for ferrites & garnets
4. Studies of Power Threshold of ferrites with Saturation Magnetization & Bias field
5. Analysis of Non-linearity in ferrites, studies of Spin-Orbit interactions & grain size effect on Spin-Wave instabilities.

SCIENTIFIC AND TECHNICAL PROGRESS

The project is aimed at developing experimental measurement system to determine the power handling capability and hence the spin-wave instability of ferrite materials, which is an essential component for design of high power circulators to be used in ADS in RRCAT, Indore.

The Measurement Technique

When RF power is applied parallel to the static magnetic field, at low power negligible microwave power is absorbed by the ferrimagnetic samples. Beyond a certain critical or threshold value there is an abrupt increase in the absorbed power level-giving rise to non-linear effects.

The measuring setup broadly consists of three parts: a high power source sending pulsed microwave power at X-band, a microwave bench which guides the microwave power and a specifically designed cavity where ferrite sample under test is placed to which the microwave power is pumped. The cavity with the sample is placed under the influence of dc magnetic field such that the microwave magnetic field is parallel to the static field (termed as "parallel pumping"). The butterfly curve data is obtained by sweeping microwave power over a range of static magnetic field. An abrupt increase in absorption of microwave power marks the onset of nonlinearity. Instability is determined by the threshold microwave power level (advent of nonlinearity). The spin wave line width is computed from the minimum instability value, dc magnetic field and cavity parameters.

To facilitate this measurement a prototype of the measurement system has been designed and developed as shown in Fig TP-1.

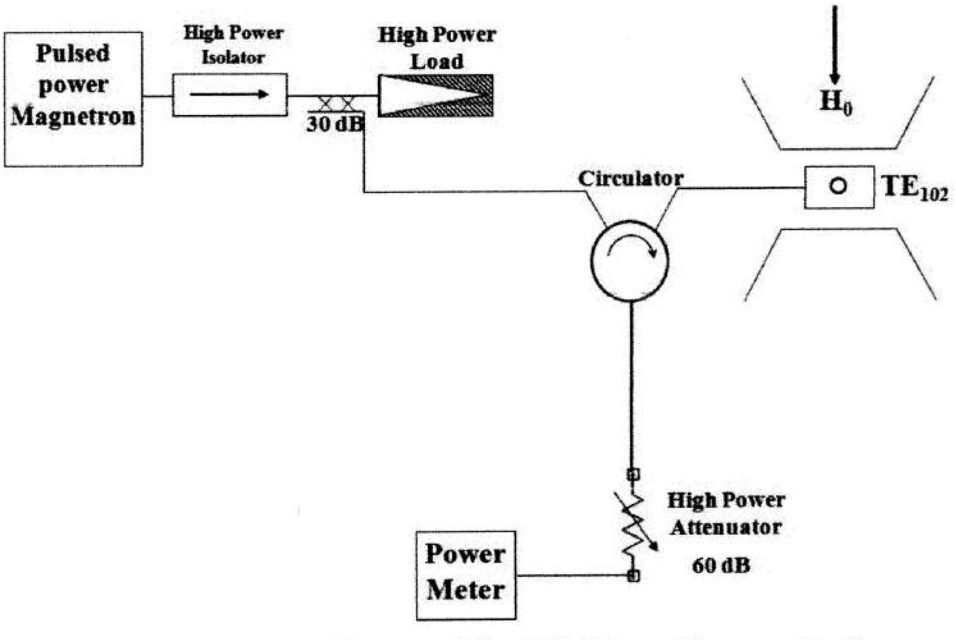


Fig. TP-1: Design and Development of Prototype X-band High Power Microwave Bench

From the schematic of measurement procedure the sub-system equipment required are short listed. The microwave high power source is a Pulsed coaxial Magnetron, (*Model-BEL200MX Peak power - 200KW, Tunable freq. range-8.5-9.6GHz*) acquired from Bharat Electronics Ltd., Bangalore. The electromagnet with rotating arrangement and pulse power supply of magnetron (Model: MPP-23K30A) are procured from M/s Quality Machine Tools Corporation, Indore and M/s Powercon Electro Device and Systems, Pune respectively.

Design Simulation of Electromagnet:

Design simulation of variable gap electromagnet with movable attachment has been carried out using OPERA – 3D FEA Program by PC: Shri. R.S. Shinde, Scientific Officer/H, Head, Ferrite Lab, RRCAT, Indore. Fig TP-2, TP-3, TP-4, TP-5 shows the simulated design of electromagnet. Table-1 highlights the essential features.

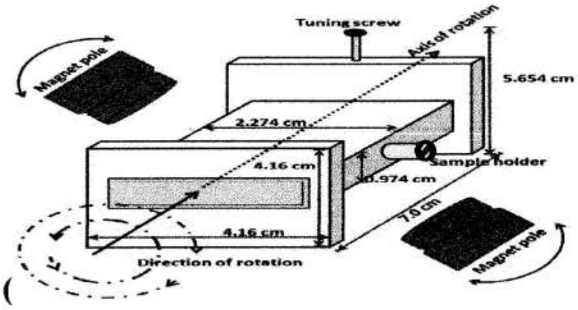


Fig. TP-2 Adjustable Pole gap: Magnetic bias for parallel pump experiment

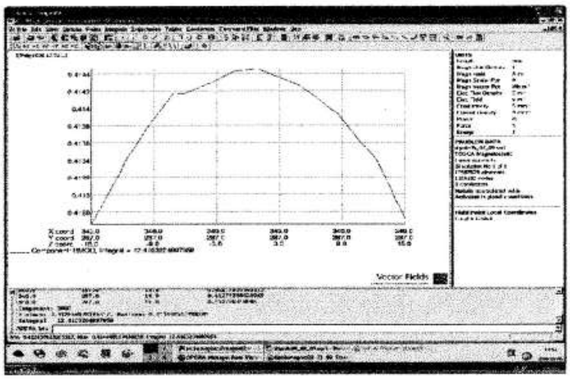


Fig.TP-3 A magnetic field distribution in aperture over pole diameter (30 mm)

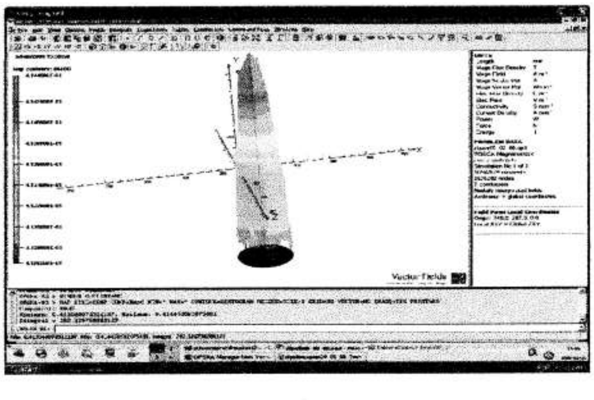
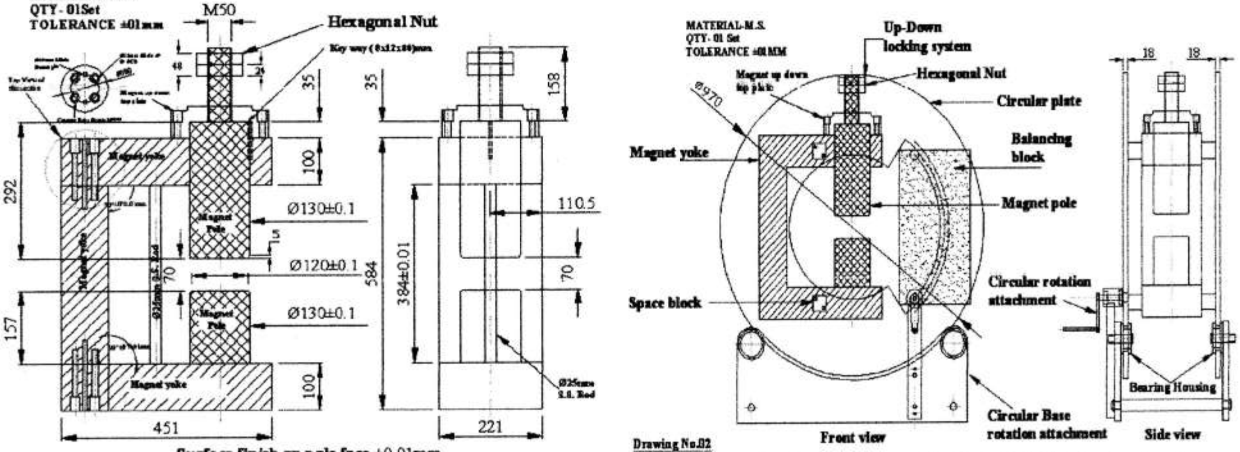


Fig. TP-4 Magnetic field distribution over the pole dia of 30 mm at the mid of pole gap



Surface finish on pole face ±0.01mm

Parallelism between two pole face 70±0.01mm

Drawing No. 01

All Dimension are in mm

Detail of Electro magnet for spin wave measuring setup

Drawing No.02

Detail of Moveable mechanism for Electro magnet

Fig TP-5: Detail of Electromagnet for spin wave measuring setup

Table-1: Important features of Electromagnet for spin wave measuring set up

Features	
1.	Adjustable gap: 0- 70 mm
2.	Maximum Magnetic field in gap of 70 mm: about 4000 Gauss @ 18 A
3.	Cooling: Natural, an air gap duct has been provided insitu coils
4.	Pole width: 120 mm with pole field homogeneity of 0.1 % over 30 mm dia
5.	Locking arrangement provided with movable shaft for fixing of exact gap.
6.	Magnetic field homogeneity ($\Delta B / B_o$) = 0.4362 %, Pole diameter = 30 mm

Design of Magnetron Pulse Power Supply

Design Simulation carried out by the Powercon Electro Device & Systems for prototype development of pulse power supply of magnetron with the help of Shri R. S. Shinde, SO/H, Head Ferrite Laboratory, RRCAT- Indore. Figure TP-6, TP-7, TP-8 shows the schematic and stimulation result. The specifications are highlighted in Table 2.

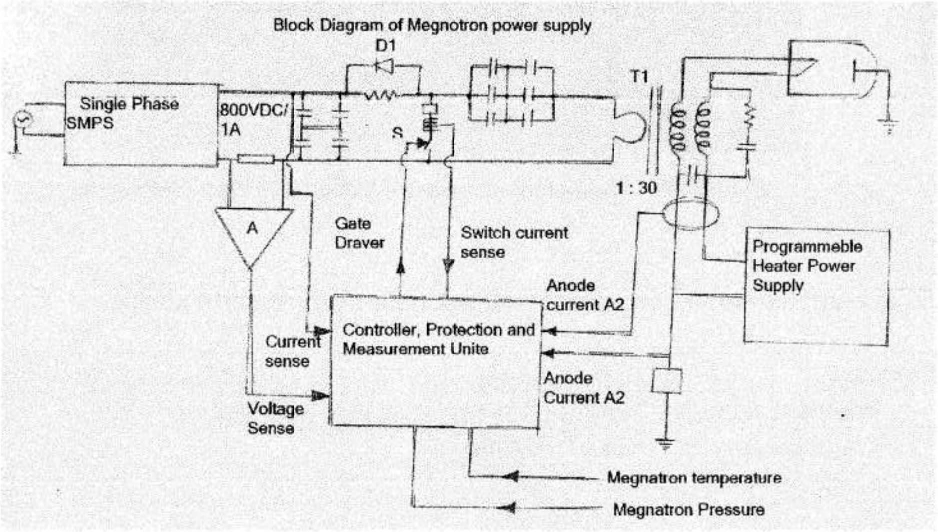


Fig TP-6: Schematic of Magnetron Power Supply

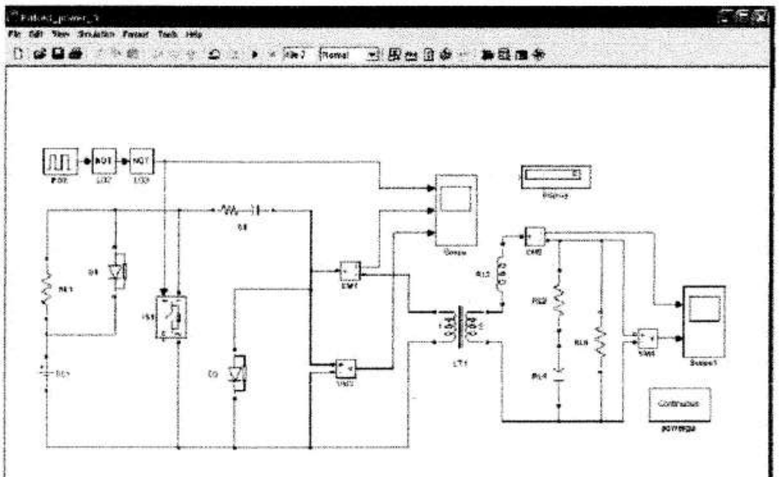


Fig TP-7: Matlab Simulink Pulse Power Supply Modulator

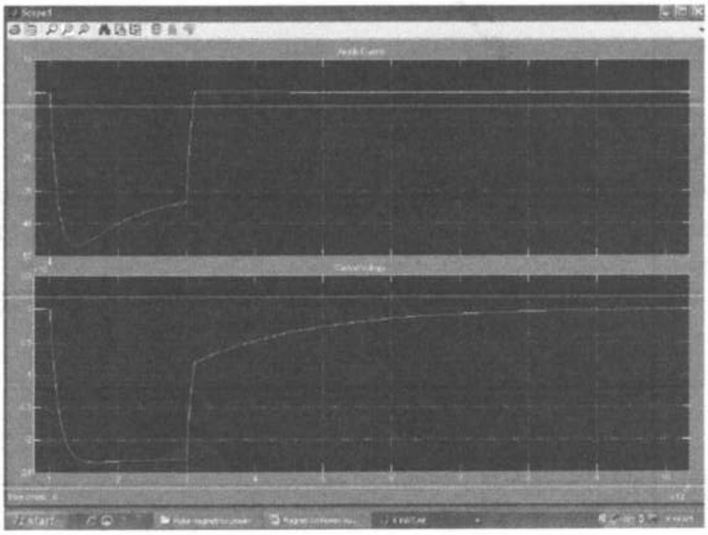


Figure TP-8 The Output Current and Voltage of Pulse Transformer

Table 2.The pulsed power supply for magnetron main specifications:

S.N.	Features
1	Filament voltage : 10-15 volt *programmable with input power*
2	Filament current (Max,) : 10Amp
3	Cathode warm-up time : 5 Min.
4	Anode voltage : 23 kV (Max.)
5	Peak Anode current : 30Amp (Max.): 15Amp (Min.)
6	Pulse duration : 1.5 uSec (*programmable 1-2uS.*)
7	Duty Cycle : 0.0011
8	Pulse repetition rate : 0.5Hz-1 kHz (Preset)
9	Anode Input power (Peak) : 680kW
10	Anode input power (average) : 680W
11	Rate of rise of anode voltage : 220nSec. (Test load resistance 766 OHM) (Assuming Magnetron has 100pF stray cap.)
12	*Interlock with magnetron pressure and temperature*
13	Pulse Flatness : 1.5% on top
14	Cooling : Natural force air cooling
15	Filament Power : regulated DC source at ground.
16	Protection : Pulse to pulse protection against arcing in HV side
17	Input : 220VAC ± 20% 50Hz single phase

Operation of spin wave measurement setup:

Fig TP-9, TP-10 and TP-11 show the complete setup developed for measurement of high power spin wave instability, during its actual operation.

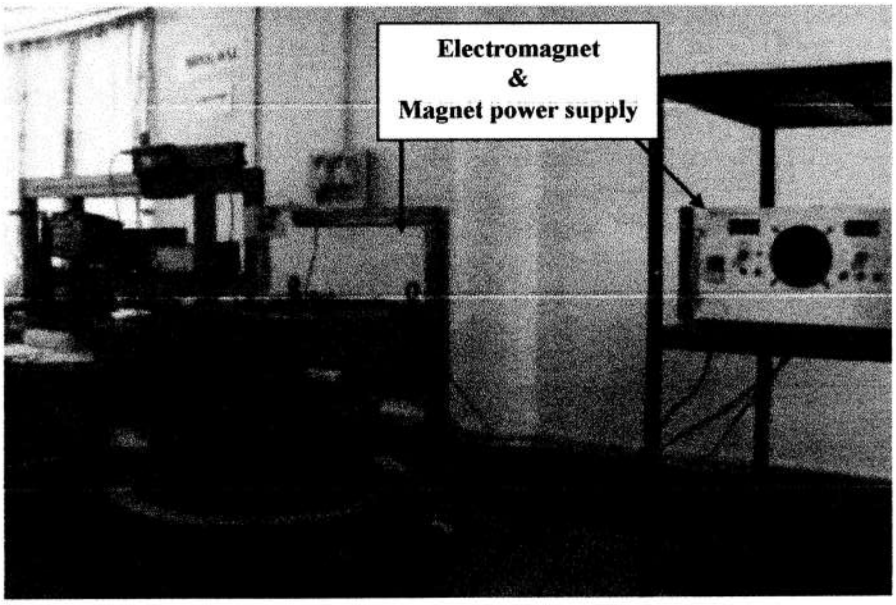


Fig. TP-9: Photograph of the electromagnet with rotational arrangement.

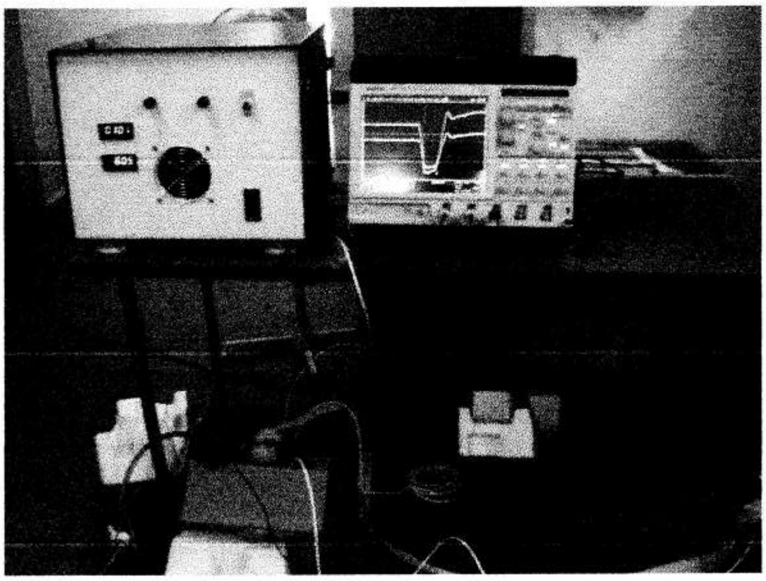


Fig. TP-10: Photograph during online pulse waveform study of the pulse power supply with Magnetron load.

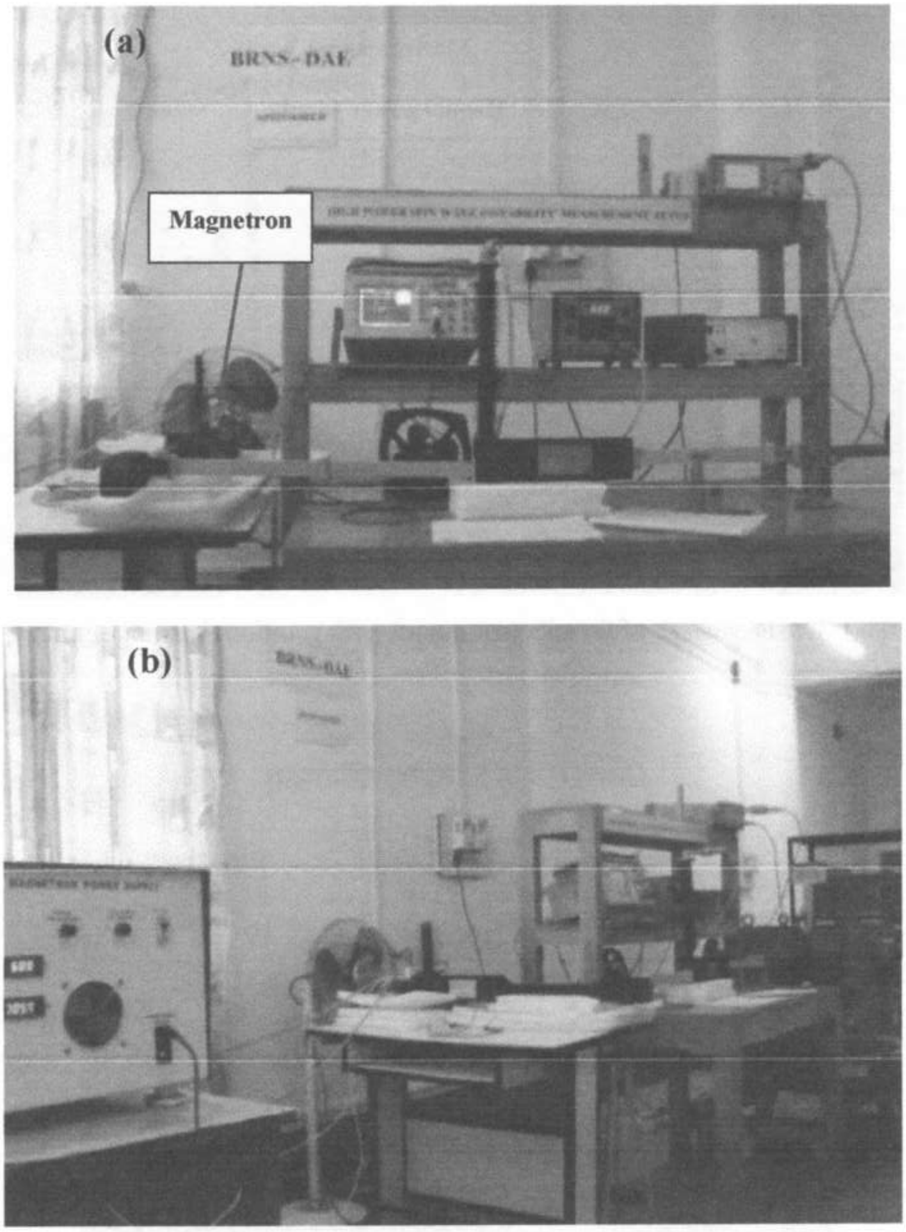


Fig. TP-11 (a) & (b): Photograph of the electromagnet with rotational arrangement.

DESIGN AND FABRICATION OF CAVITY

For our purpose of measurement it was found necessary to have a cavity with high *Q* and exceedingly low losses. To incur this, a reflection type designing was designed as it gives a better coupling which increases the sensitivity. The test samples are spheres of 1-2 mm diameter. For high power measurements the sample has to be placed at the point where the microwave magnetic field is maximum and *r.f.* electric field is minimum. This condition could be realized by using TE_{10n} mode for the cavity design where 'n' can be odd or even. In case where 'n' is odd e.g. in TE_{101} cavity the above condition is fulfilled at the end wall. The leading and trailing edges of the magnetron pulses will have frequency component which will reduce the sensitivity of the cavity. It is strategic to limit the coupling of the cavity. Another way for overcoming this problem was to design cavity with 'n' as even. To avoid higher order mode and considering the economical aspect it was decided to design TE_{102} cavity. In this case the maximum *r.f.* magnetic field occurs at the centre and the sample is placed at this point by using a sample holder made of Teflon which is transparent to microwave power.

Before going into the detail of designing the rectangular reflection type cavity it was necessary to briefly outline the dimensional detail of the cavity and Q-factor which is given below:

Rectangular Cavity resonator

Cavity is metal enclosures which exhibits resonance when excited by electromagnetic radiations. A rectangular resonator is a hollow box of metallic walls of dimensions '*a*', '*b*' and '*l*' in *x*, *y* and *z* directions respectively as shown in Figure 5.8. Generally a rectangular waveguide which is sorted at both ends can be easily employed for designing this cavity. The cross-sectional dimension of waveguide is taken to be '*a*', '*b*' and '*l*' is the distance between the two shorting ends. The cavity is coupled to electromagnetic radiations through irises.

Any resonant phenomenon is generally assessed by a quality factor which is defined as ratio of stored energy and energy loss at the resonant frequency. Thus

$$Q = 2\pi v \frac{\text{Energy Stored}}{\text{Energy Loss per cycle}} |\omega_r = \omega_r \frac{\text{Energy Stored}}{\text{Average Power Loss}} \tag{1}$$

Q-factor is precisely of three types: Unloaded Q, External Q and Loaded Q and is formulated as follows

Unloaded Q : $Q_U = \omega_r \frac{\text{Energy Stored in the Resonant Circuit}}{\text{Power Loss in the Resonant Circuit}} |at\ \omega_r$ (2)

External Q : $Q_E = \omega_r \frac{\text{Energy Stored in the Resonant Circuit}}{\text{Power Loss in the External Circuit}} |at\ \omega_r$ (3)

Loaded Q : $Q_L = \omega_r \frac{\text{Energy Stored in the Resonant Circuit}}{\text{Total Power Loss}} |at\ \omega_r$ (4)

The unloaded Q is a measure of the quality of the resonant circuit itself, while external Q measures the degree to which resonant circuit is coupled to the external circuitry. Loaded Q is a function of degree of coupling between external circuitry and resonant circuit. The three Q factors viz. Q_U, Q_E, Q_L are related together as follows:

$$\frac{1}{Q_L} = \frac{1}{Q_E} + \frac{1}{Q_U} \tag{5}$$

Moreover, the frequency response of the resonant circuit is characterized by the loaded Q (Q_L) as follows:

$$Q_L = \frac{\textit{Resonant Frequency}}{\textit{3 dB bandwidth}} = \frac{f_r}{(f_2 - f_1)} \tag{6}$$

Where f_1 and f_2 are the frequencies at which the current or the voltage is 0.707 of its value at resonance. For rectangular cavity driven into resonance by electromagnetic excitations a similar formulation can be used to find its quality factor.

For an air filled cavity the dielectric loss is negligible. Hence the unloaded Q of the cavity can be formulated as the ratio of volume to surface ratio of the cavity. Moreover, the energy stored depends on the shape and hence the volume of the cavity and the power loss is a surface phenomenon due to currents in the wall of the cavity and is proportional to the skin depth. Thus, at resonance, Q of a cavity can also be approximately given as

$$Q_U - \frac{V}{A\delta} \tag{7}$$

Where V is the volume of the cavity. A is the total surface area of the cavity and δ is the skin depth.

Design Considerations of the Rectangular Reflection Cavity at 9.1 GHz

As mentioned in the preceding section waveguides when shorted at both ends can be used as the cavity resonator. As there is a cut off effect, i.e. beyond a particular frequency called the cut off frequency the wave is evanescent wave and the propagation factor 'β' becomes imaginary, the guide wavelength is given by

$$\lambda_g = \frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}} \tag{8}$$

Where λ_c is the cut off wavelength of the guide and λ is the operating wavelength. If λ_r is the resonant wavelength, thus the above equation is

$$\lambda_r = \frac{1}{\sqrt{\left(\frac{1}{\lambda_c}\right)^2-\left(\frac{p}{2l}\right)^2}} \tag{9}$$

But, $f_r \times \lambda_r - c/\sqrt{(\mu\varepsilon)}$, where μ and ε are the permeability and permittivity of the dielectric filling the cavity, c is the velocity of the light in free space. Hence, the resonant frequencies for the various cavity modes are given by

$$f_r = \frac{f}{\sqrt{\mu\varepsilon}} \frac{1}{\sqrt{\left(\frac{1}{\lambda_c}\right)^2 + \left(\frac{p}{2l}\right)^2}} \tag{10}$$

For a TE_{mn} mode the cut off wavelength for rectangular waveguide is given as follows:

$$\lambda_c = \frac{1}{\sqrt{\left(\frac{m}{2a}\right)^2+\left(\frac{n}{2b}\right)^2}} \tag{11}$$

So,

$$\lambda_r = \frac{1}{\sqrt{\left(\frac{m}{2a}\right)^2+\left(\frac{n}{2b}\right)^2+\left(\frac{p}{2l}\right)^2}} \tag{12}$$

The magnetron generates the microwave power at 9.1 GHz, this power is guided through a X-band microwave bench, to a cavity which is designed at the same resonant frequency. As the resonant frequency of the rectangular cavity is 9.1 GHz, a rectangular waveguide whose cross section (a and b) is such that it can support propagation of microwaves at x-band is used to fabricate the resonator. The typical values of 'a' and 'b' are 2.286 cm and 1.016 cm respectively. The frequency range recommended for TE$_{101}$ mode (m = 1 and n=0) for this dimensioned waveguide is 8.2 - 12.4 GHz. The cut off wavelength λ_c (=c/2a) is 6.557 GHz. For designing a TE$_{102}$ cavity to resonate at 9.1 GHz, the number of half cycles variation in the z-direction should be two i.e. $p = 2$, and the length 'l' of the cavity can be determined by substituting these values in the equation 12. The length of the TE$_{102}$ cavity to resonate at the magnetron frequency is computed to be, $l = 4.465$ cm. Figure TP-12 (a) & (b) show the photograph of the cavity designed and fabricated in the laboratory.

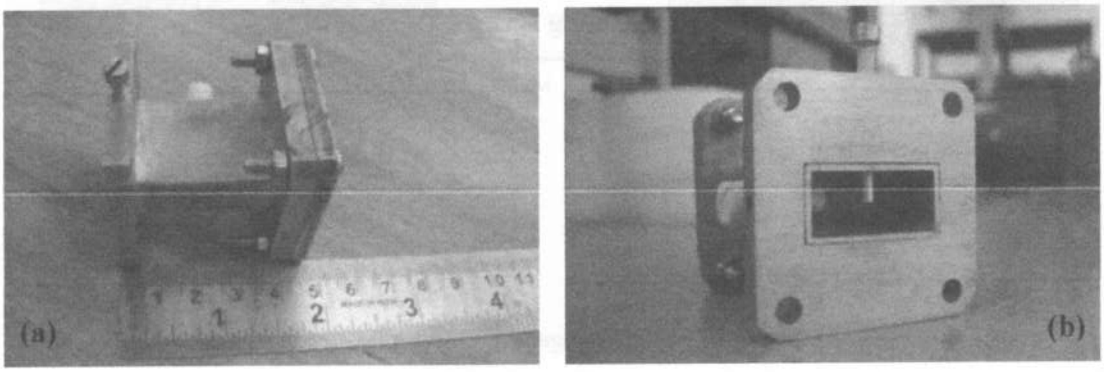


Fig. TP-12 (a) & (b): Photographs of the TE$_{102}$ resonant cavity designed and fabricated in the laboratory.

Coupling of the Cavity

Oscillations excited within the cavity have to be coupled outside microwave circuit. In present investigation a reflection type rectangular cavity has been designed with aperture coupling by using an iris as shown in figure TP-13 (a) & (b). The diameter 'd' of the iris hole is found by trial and error method for this different detachable plate with varying hole diameter at the centre is used and coupling is observed on the Agilent E8362C Vector Network Analyzer. The critically coupled iris shows the maximum reflected peak. The iris hole diameter for critical coupling in the cavity was found to be 8.42 mm.

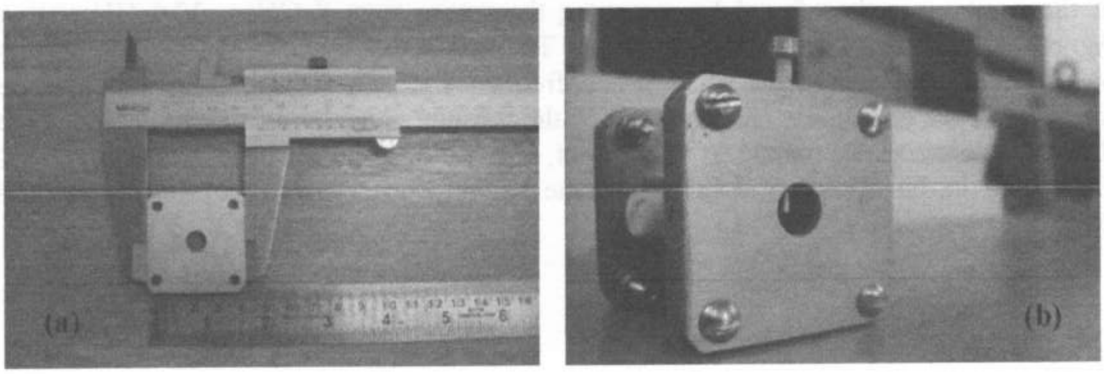


Fig. TP-13 (a) & (b): Rectangular cavity designed with aperture coupling by using an iris of hole diameter =8.42 mm.

Tuning Screw

The cavity is designed to resonate at 9.1 GHz, coinciding with the frequency generated by the magnetron. A frequency shift (both +ve and -ve) is observed when the cavity is excited with the magnetron due to mismatch, further a similar frequency shift is observed when the sample is placed in the sample holder. As such a shift of resonant frequency in reflection type cavity may lead to error in the power measurements related to the sample. To overcome this, tuning screw was incorporated into the cavity as shown in the figure TP-14 (a) & (b). The tuning screw has the ability to adjust the frequency shift by ± 5%, which is what generally observed during the investigation. Such tuning lead to a perfect match of the frequency at the resonance.

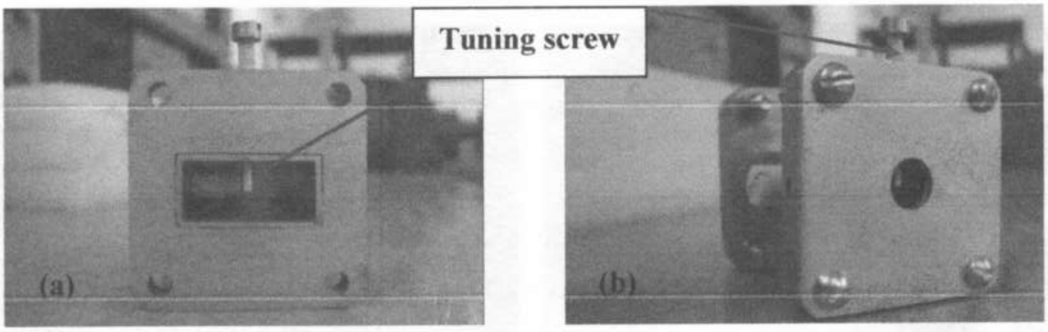


Fig. TP-14 (a) & (b): The tuning screw arrangement to adjust the frequency shift by ± 5%.

The tuning screw has a unique property that when first inserted it presents a capacitive discontinuity and can be represented by equivalent capacitance in parallel and when it is all the way inside it is like an inductive post, thus a transition point is always there. The tuning screw is placed subsequent to the iris coupling so as to adjust the Q of the incoming electromagnetic wave.

Results of the Cavity

The test cavity was coated inside with silver keeping the thickness slightly more than the skin depth (2.642366e-08 mils) to decrease the conductor losses. The inside surface is well polished to avoid dissipation of the electromagnetic energy. Before exciting the cavity a reference level was traced using a shorting plate before the cavity. The loaded Q of the cavity was then found by sweeping the cavity from 8 GHz - 12.4 GHz using Agilent E8362C Vector Network Analyzer. The cavity was tuned to resonant frequency by adjusting the tuning screw. The resonant frequency and the 3dB point were found. The loaded Q of the cavity was calculated using the formula given by equation 6. f_2 and f_1 are the frequencies corresponding to 3 dB point, where $f_2 > f_1$. The resonant frequency = 9.1 GHz, and the bandwidth = 3.483 MHz. the loaded Q of the TE_{102} resonant cavity = 2612.69.

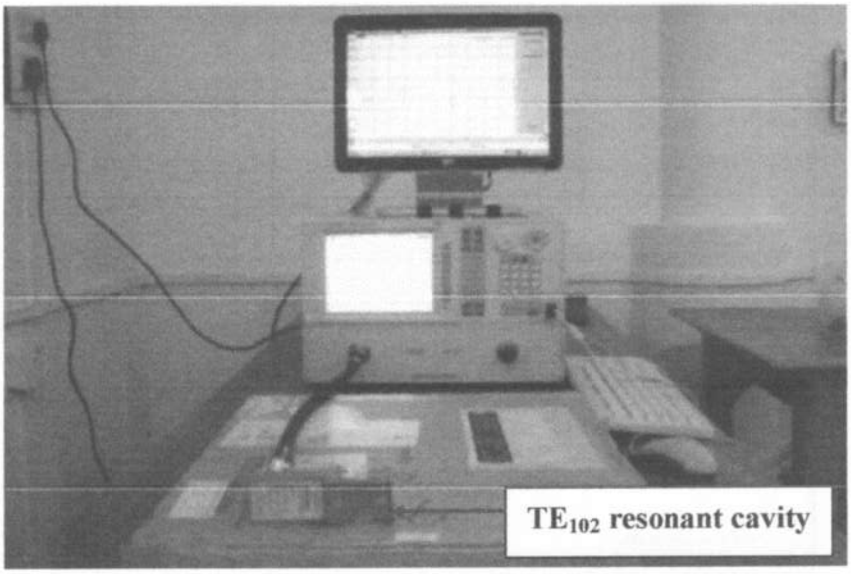
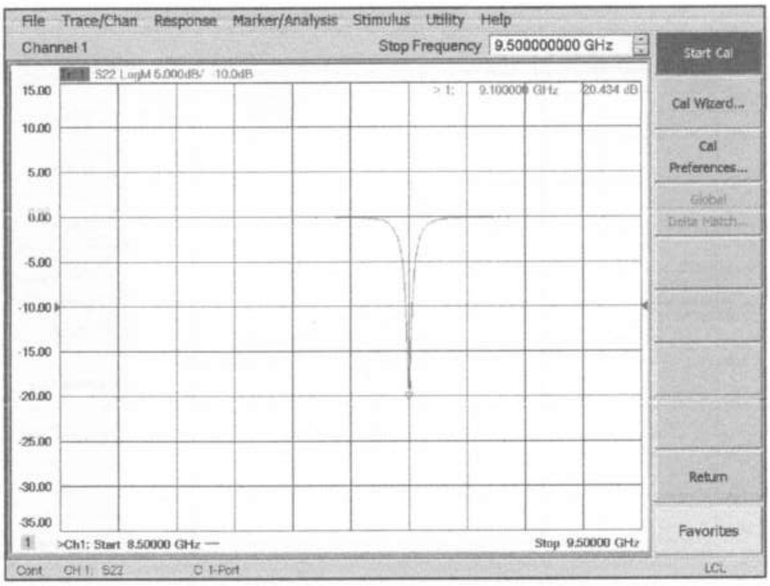


Fig. TP-15: Set up for loaded and unloaded resonant cavity tuning



Stop Frequency 9.500000000 GHz

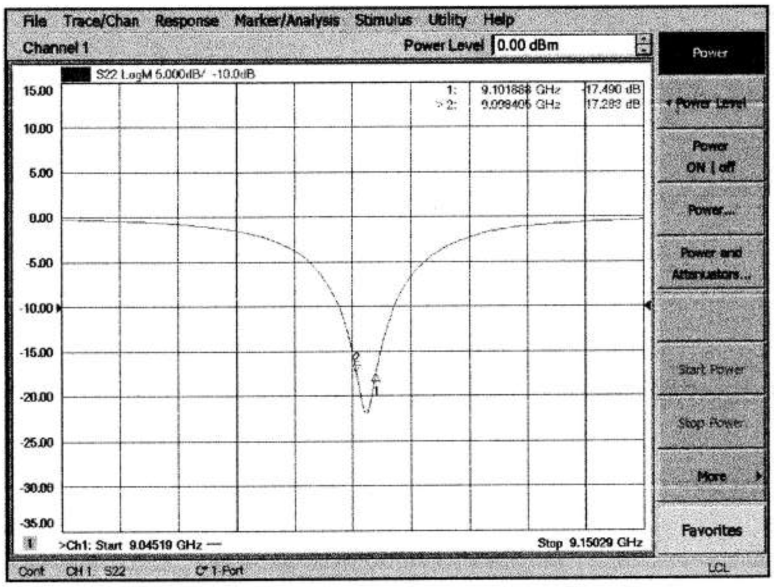
Tr 1 S22 LogM 5.000dB/ -10.0dB

> 1: 9.100000 GHz 20.434 dB

1 >Ch1: Start 8.50000 GHz — Stop 9.50000 GHz

CH 1: S22 C 1-Port

Fig. TP-16: Resonant frequency for the empty cavity at 9.1 GHz with -20.434 dB return loss.

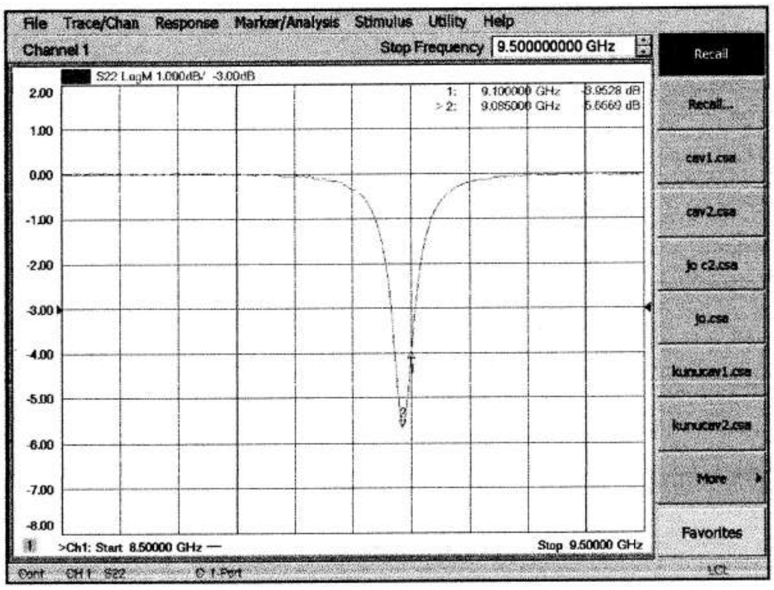

Power Level 0.00 dBm

S22 LogM 5.000dB/ -10.0dB

1: 9.101888 GHz -17.490 dB
> 2: 9.098405 GHz -17.283 dB

>Ch1: Start 9.04519 GHz — Stop 9.15029 GHz

Fig. TP-17: Loaded $Q = 2612.69$ with -3 dB bandwidth of 3.483 MHz.


Stop Frequency 9.500000000 GHz

S22 LogM 1.000dB/ -3.00dB

1: 9.100000 GHz -3.9528 dB
> 2: 9.085000 GHz -5.5569 dB

>Ch1: Start 8.50000 GHz — Stop 9.50000 GHz

Fig. TP-18: Shifting of the resonant frequency by 15 MHz on insertion of $Gd_{1.50}Y_{1.50}Fe_5O_{12}$ nanophase sample.

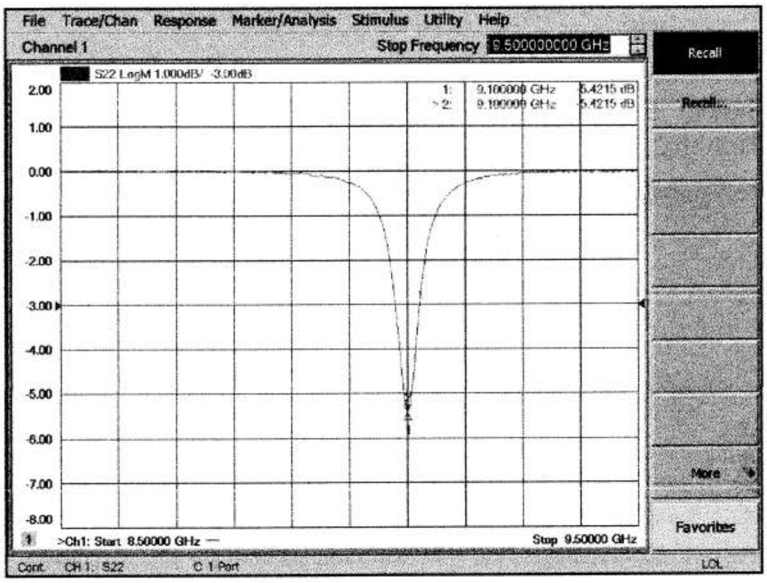


Fig. TP-19: Tuning of resonant frequency of the cavity with the sample to 9.1 GHz (empty cavity) with the help of tuning screw.

Samples for Spin Wave measurement

The ferrite and garnet spheres for spin wave instability studies are provided by PC- Shri R. S. Shinde, SO/H, Head Ferrite Laboratory, RRCAT- Indore. The bulk as well as nanophase ferrite and garnet spherical samples are synthesized at PC's lab in RRCAT-Indore. The spherical samples with size and preparation technique are tabulated in Table 3

Table 3: Details of ferrite and garnet spheres

Sl. No.	**Sample code**	**Sphere details**	**Sphere diameter (mm)**	**4πMs (G)**
01	$Gd_{0.25}Y_{1.75}Fe_5O_{12}$	Nanophase Gd-YIG- Prepared by Microwave Hydrothermal Method & sintered @ 1300 ^{0}C for 6 hrs	∅ 1.77	1000
02	$Gd_{1.50}Y_{1.50}Fe_5O_{12}$	Nanophase Gd-YIG- Prepared by Microwave Hydrothermal Method & sintered @ 1300 ^{0}C for 6 hrs	∅ 2.03	900
03	$Gd_{1.50}Y_{1.50}Fe_5O_{12}$	Nanophase Gd-YIG- Prepared by Microwave Hydrothermal Method & sintered @ 1250 ^{0}C for 6 hrs	∅ 1.92	850
04	$Gd_{1.30}Y_{1.70}Fe_5O_{12}$	Nanophase Gd-YIG- Prepared by Microwave Hydrothermal Method & sintered @ 1300 ^{0}C for 6 hrs	∅ 0.98	500
05	$Ni_{0.8}Al_{0.2}Fe_2O_4$	Nanophase Ni-Al ferrite- Prepared by Microwave Hydrothermal Method & sintered @ 1000 ^{0}C for 6 hrs	∅ 2.03	500
06	CAT-3/2C	$Ni_{0.4}Zn_{0.6}Fe_2O_4$ – Ni-Zn ferrite – Prepared by Ceramic Method & sintered @ 1300 ^{0}C for 6 hrs	∅ 1.95	4209

Measurement Procedure

The measurement procedure is to sweep the *r.f.* field over ferrite or garnet samples placed in the sample holder at different dc-magnetic field and determine first the onset of instability and from that point spin wave instability.

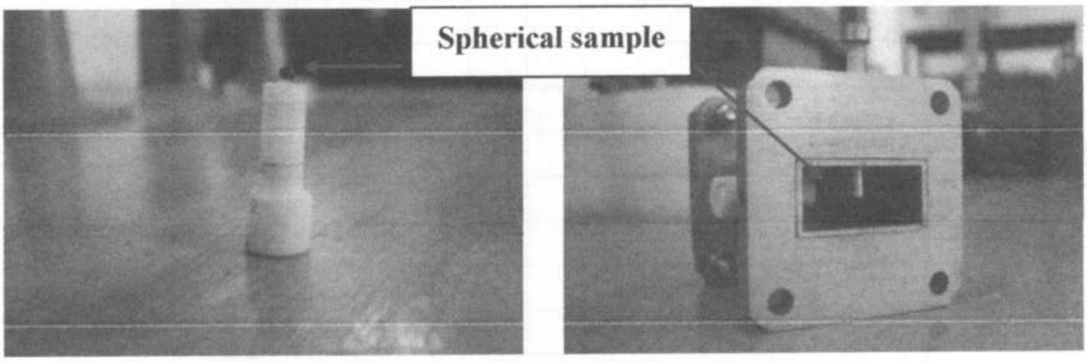


Fig. TP-20: Insertion of the spherical samples in to the resonant cavity

Formulations for Spin-wave instability

The power handling capability of ferrites and hence the circulators are determined by following calculations:

The threshold microwave field is given by

$$h_{crit} = \frac{\omega}{\omega_m}.\frac{\Delta H_k}{\sin^2 \theta_k} \qquad (13)$$

Where $\omega = 2\pi$ the operating microwave frequency, $\omega_m = \gamma.4\pi M_s$ and θ_k is the angle between the wave vector and internal magnetic field.

At the threshold level $\theta_k = \pi/2$, so the threshold changes to

$$h_{crit}\big|_{\min} = \frac{\omega}{\omega_m}.\Delta H_k \qquad (14)$$

The threshold h_{crit} is evaluated measuring return loss at various microwave power levels with changing static magnetic field and determining the onset of nonlinearity (which can be observed by abrupt change in power level and can be determined by following expression:

$$h_{crit}^2 = \frac{4Q_U}{\mu_0 \omega V_c}\left(\frac{\lambda_0}{\lambda_g}\right)^2 \times P_{crit} \qquad (15)$$

Where

P_{crit} = the critical incident peak power in watts

ω = frequency in $rad/\sec = 2\pi f$

f = the magnetron frequency in Hz

Q_U = unloaded Q of the cavity = $\dfrac{2Q_L}{1 - P_0 - P_{\min}}$

Q_L = loaded Q of the cavity

P_0 = maximum power at the input of the cavity

$P_{\min}$ = minimum power absorbed by the cavity

V_c = volume of the cavity in $cm^3 = a \times b \times l$

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda c}\right)^2}}$$ is the guided wavelength

λ_0 = free space wavelength

λ_c = cut-off wavelength

l, *a* and *b* are the length, width and height of the resonant cavity respectively (in centimeters).

The threshold h_{crit} as a function of static field for parallel pumping configuration gives the "butterfly curve" (h_{crit} vs. H_0) from which minimum value is determined.

Measurements on standard YIG samples

Spin wave line width is measured using the fabricated TE_{102} rectangular cavity. Measurement is carried out on spherical YIG samples, 1-2 mm. in diameter, placed at a point of minimum microwave electric and maximum microwave magnetic field. The sample holder is made of Teflon whose dielectric constant is less than 2, which is comparable to that of air and does not absorb any microwave power, thus the losses associated with holder are negligible as compared to cavity losses. The Butterfly curve data is obtained by sweeping microwave power over a range of static magnetic field. The pulsed microwave power is generated by a magnetron (BEL 200MX) at 9.1 GHz. and is applied to the standard YIG sample placed in cavity in parallel configuration, i.e., the microwave magnetic field is parallel to static magnetic field.

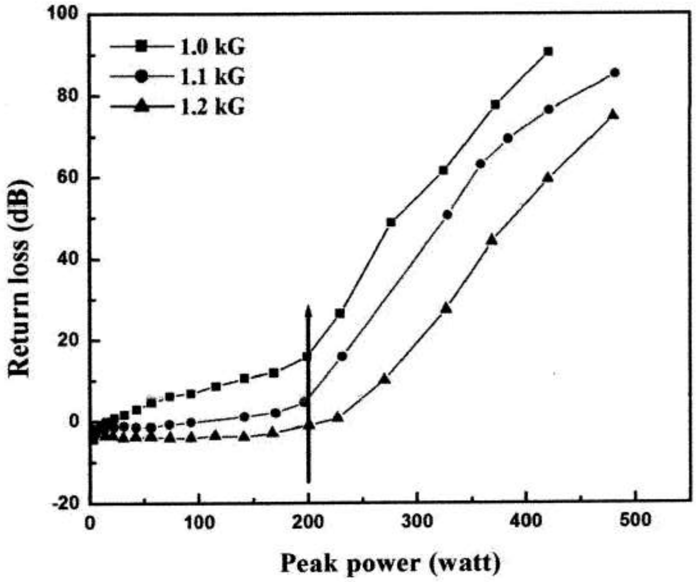


Fig. TP-21: Return loss with increasing peak power for YIG at three different magnetic field

The microwave power for which there is an abrupt in increase in absorption by the sample is noted. This is the threshold power P_{crit}. Fig. TP-14 shows the plots of power variation for standard YIG sample. The threshold power is where there is abrupt rise in the peak power (marked by arrows). The value of h_{crit} is calculated using equation (3). Fig. TP-22 shows two h_{crit} plots of YIG samples measured at two different times. The value of hcrit $|_{min}$ is taken from the minimum point of the butterfly curve plot. Using equation (1) the spin wave instability ΔH_k is calculated. For YIG samples ΔH_k (Oe) is found to be $18.5/M_s$ (Gauss).

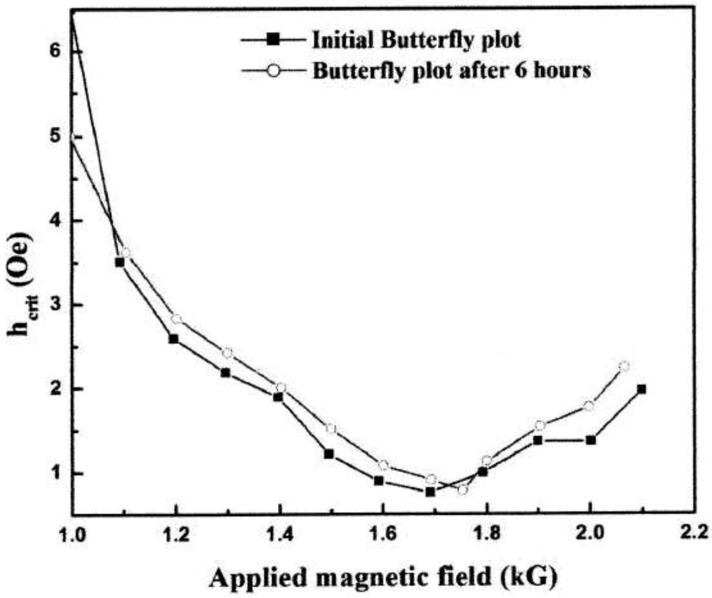


Fig.TP-22: Showing butterfly curve and repeatability of the data for standard YIG sample at different times.

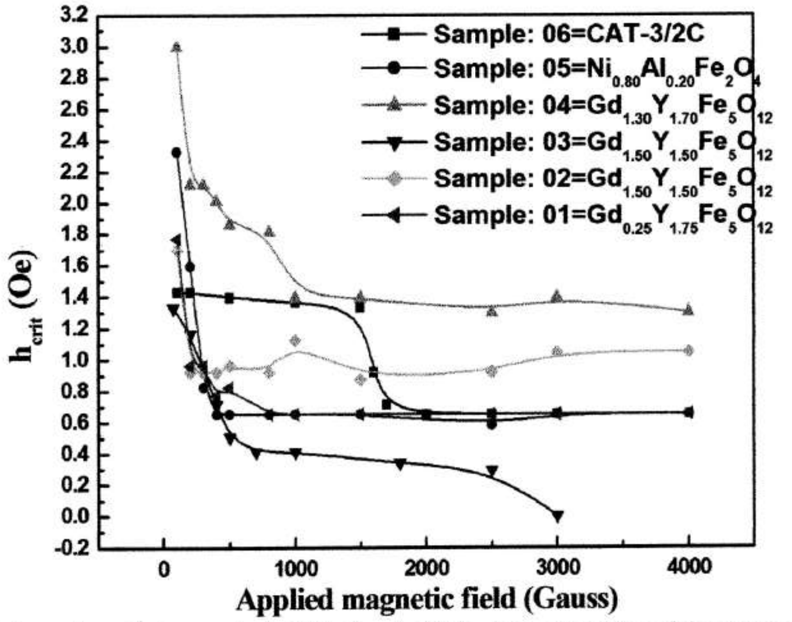


Fig. TP-23 Variation of parallel pump instability threshold (h_{crit}) as a function of dc magnetic field (H_0) for sample 01, 02, 03, 04 and 05.

The above Fig. TP-23 shows variation of parallel pump instability threshold (h_{crit}) as a function of dc magnetic field (H_0) for sample 01 – 06. The plots depicts that instability threshold decreases with increasing H_0. It reaches minimum at 3 kG for sample: 06 and about 4 kG for sample: 01, 02, 03, 04 and 05. Values beyond the said minimum are not plotted as the higher pulse power leads to air breakdown. Breakdown results in conducting discharge, which dissipates and reflects significant fractions of incident wave power, thus preventing normal operations. After the first breakdown, the air in the cavity becomes more susceptible for the subsequent pulse. Beyond 30 W power level the erroneous readings are observed. To overcome this it is planned to work in complete nitrogen or dry air atmosphere inside the cavity. Incorporating the mechanism is in development. Moreover measurements on other samples are being carried out and will be presented during the meeting. Spin-wave line width will be calculated after the minimum threshold values are determined. From the threshold value plots, power handling capability of the said samples can be predicted to be larger than that reported in literature for similar configurations as upto 3 kG no non-linearity is observed. This could be because of nano-phase of the ferrites samples. Smaller grain sizes generally increases the power handling capability which is called as transit – time theory. Effect of grain size on h_{crit} for Mg ferrites was studied by Vrehn et.al. [1, 2]. Patton [3 – 5] reported a similar study for YIG. They fond that losses increase with increase in grain size and more power will be required to overcome the losses and produce instability, thus increasing the peak power handling capability in the material. Thus, there is an inverse relation between spin wave linewidth and grain size ($\Delta H_k \infty a^{-1}$).

References:

[1] Vrehen, Q.H.F, Brose van Groenou, A. and de Lau, J.G.M., Phys. Rev., vol. 1, pp. 2332,1970.
[2] Vrehen, Q.H.F., J. Appl. Phys., vol.40, pp.1849, 1969.
[3] Paton C.E., Proc. Int. Conf. Ferrites, Kyoto, pp. 524, 1970.
[4] Patton C. E., J. Appl. Phys., vol. 41 pp. 1637, 1970a.
[5] Patton C. E., J. Appl. Phys., vol. 41 pp. 431, 1970b.

TASK ACCOMPLISHED TILL JUNE 2011

1. Equipments Acquired:

- Microwave High Power Source : Pulsed coaxial Magnetron
  Specifications : Model-BEL200MX
  Peak power - 200KW,
  Tunable freq. range-8.5-9.6GHz
  Status :: *Procured, tested and installed*
- Power meter : Microwave power measurement system
  Specifications : Model-Agilent E4418B
  Status :: *Procured, tested and installed*
  Power sensor : Compatible with Power meter
  Specifications : Model: Agilent 8481B
  Status :: *Procured, tested and installed*
- Data compiling and computation system : Model HP Pavilion Desktop, Model:A6340IN
  Status :: *Procured, tested and installed*
- Accessories : Imported
  Status :: *Procured, tested and installed.*
- Electromagnet with Rotational Arrangement : Designed by
  Shri R.S. Shinde, SO-G
  Head,Ferrite Lab,RRCAT- Indore
  Status :: *Procured, tested and installed*
- Power supply of Magnetron : Designed simulation carried out by
  Powercon Electro Device & Systems, Indore
  with the help of Shri R.S. Shinde, SO-G
  Head,Ferrite Lab,RRCAT- Indore
  Specification : MODEL NO: MPP-23K30A
  Programable power supply for Cathode heating
  Status :: *Procured, tested and installed*
- Sample holder: Designed at PI's Lab
  Specification : TE_{102} at 9.1 GHz with tunable range ±0.5 GHz
  Status :: *Fabricated and tested*

2. Functioning of high power set-up :: Established and functionalized at PI's Lab

3. Ferrite & garnet sample preparation :: Spherical ferrite & garnet sample of both bulk and nanophase are synthesized and fabricated at PC's Lab- RRCAT, Indore.

4. Spin-wave measurement :: High power spin-wave measurements are carried out at PI's Lab.

PLAN AND DELIVERABLES TARGETED

Target Year: Ist Year (October 2007- March 2008)

S.No.	Targeted	Target Accomplished
1.	Procurement of equipments, Materials & related fabrications	Procurement: Tender Enquiry sent
2.	Design studies of spin-wave pump Experimentation	Prototype design studies for parallel & perpendicular pumping have been carried out
3	Prototype studies of Spin-Wave instabilities in spinel ferrite & garnets	Prototype studies of spin wave instabilities in ferrite & garnets were initiated.

Target Year: IInd Year (April 2008- March 2009)

S.No.	Targeted	Target Accomplished
1.	Experimental Set up fabrications	Scheme of experimental set up for spin wave measurement have been finalized, Microwave cavity fabrication completed, Design of Electromagnet system & Power supply completed
2.	Magnetic & Microwave Characterization of ferrite & garnets	Prototype studies of Microwave magnetic measurements for ferrite & garnets have been taken up.
3.	Development of Parallel Pumping System for Spin-Wave Studies	Prototype Microwave bench – X – band setup scheme finalized, prototype fabrication initiated.
4.	Measurements of Power Threshold of ferrite & garnet samples	Studies of Power Threshold of ferrite samples with varying magnetic bias have been done.
5.	Evaluation of Spin-Wave instability at RF Bias field	Prototype studies for spin wave instability at RF bias have been done.

Target Year: IIIrd Year (April 2009- June 2010)

S.No.	Targeted	Target Accomplished
1.	Development of Parallel Pumping system for Spin-Wave Studies	In accordance with the schematic of experimental set up developed in last year equipments rotating electromagnet system, magnetron, power meter with sensor & power supply for magnetron has been procured, tested and system being set in accordance with figure TP-6 through TP-17, Microwave cavity testing is over (Fig Tp18 &19). A prototype X-band low power bench was made using essential accessories from that already existing in PI's Lab.
2.	Low power calibration with standard samples	Basic calibration and testing of spin wave measurement setup at low power has been carried out on standard YIG ferrite sample.
3.	Low power Magnetic and Microwave Characterization of Ferrite and Garnet Sample for spin-wave studies	Using the prototype Microwave X – band bench, study on YIG sample with low power has been done and the non-linearity determined Fig TP-20.
4.	Low power measurements of power threshold evaluation of butterfly curves ferrite & garnet samples at RF Bias field	Using the data in the no.3, studies of power threshold of standard YIG ferrite samples with varying magnetic bias have been done and plotted as butterfly curve Fig TP-21.
5.	Evaluation of Spin-Wave instability at RF Bias field	From butterfly curves the spin wave instability for standard YIG samples have been found to be 18.5/M_s carried out at low power.

Target Year: IIIrd Year (June 2010- June 2011)

S.No.	Targeted	Target Accomplished
1.	Establishment and functioning of high power Parallel Pumping system for Spin-Wave Studies, at PI's lab.	The magnetron is excited to generate 9.1 GHz frequency with 200 kW peak pulse power.
2.	Ferrite & garnet sample preparation and saturation magnetization studies.	Synthesis and fabrication of spherical ferrite & garnet samples of both bulk and nanophase and measurement of saturation magnetization are carried out at PC's Lab- RRCAT, Indore.
3.	Spin-wave measurement	Prototype studies up to 30 W CW have been completed and high power studies have been started during June 2011. High power spin-wave measurements of the spherical ferrite & garnet samples, provided by PC, are being carried out at PI's Lab and the results are to be analyzed.

Over All Projected Schedule: October 2007-June 2011

Activities	**Projected schedule**
Design studies of Spin-Wave Pump Experimentation	October 2008
Prototype studies of Spin-Wave instabilities in spinel ferrite & garnets	October 2009
Experimental Set up fabrications	October 2009 to June 2010
Procurement of high power accessories and functioning of the high power experimental set up	March 2011- March 2012
Measurement and analysis of spin wave instabilities of ferrite and garnet samples (to be provided by PC)	March 2012

Procurement Schedule:

Activities	**Procurement/ Job completion schedule**
Microwave High Power Source	September 2008
Power meter & Power sensor	August 2008
Data compiling and computation system	June 2010
Electromagnet with rotating arrangement	June 2010
Pulsed power supply for Magnetron	June 2010
Sample holder	October-November 2008
Accessories	June 2010
Complete low power measuring System	June 2010
Prototype low power measurement of Spin-wave threshold on standard YIG sample.	June 2010
Complete high power spin-wave measurement setup	March 2012
Measurement and analysis of spin wave instabilities of ferrite and garnet samples (provided by PC)	June 2012

FORM-III

UTILISATION CERTIFICATE

Out of the total amount of **Rs. 42,56,775/- (Rupees forty two lakhs fifty six thousand seven hundred seventy five only)** sanctioned and received for the four Grant-in-aids during **2007-2013**, total amount of **Rs. 38,87,436/- (Rupees thirty eight lakhs eighty seven thousand four hundred thirty six only)** has been spent during the **2007-2013** financial year periods and there is a total unutilised balance of **Rs. 3,69,339/- (Rupees three lakhs sixty nine thousand three hundred thirty nine only)** and an amount of **Rs 2,07,242/-(Rupees two lakhs seven thousand two hundred forty two only) as interest** on the said grants as on as on **30/06/2013** in respect of the Research project viz **Studies of Spin-Wave Instability in Ferrites for High Power Circulators.**

Principal Investigator
Principal Investigator
BRNS-DAE Project
Title "Studies of.. Circulators"
Department of Physics
Tezpur University
R&D Reg No. DoRD/Phy/NSB/2052

Statutory Auditor (Govt.)/
Chartered Accountant 18/07/14
Finance Officer
Tezpur University

Head of the Institution
Registrar
Tezpur University

FORM-IV

Board of Research in Nuclear Sciences (BRNS)

STATEMENT OF ACCOUNTS (SA) as on JUNE 30, 2013 (date)

Sanction No: 2007/34/15-BRNS/1259 Dated: September 07, 2007

Sl. No.	1st Year (Sept. 2007-March 2008)	Sanctioned	Opening Balance (Brought Forward)	Received	Total (4+5)	Spent	Unspent (carried Forward)
1	2	3	4	5	6	7	8
1.	Equipment	21,95,000	NIL	21,95,000	21,95,000	NIL	21,95,000
2.	Staff Salaries	1,20,000	NIL	1,20,000	1,20,000	5,806	1,14,194
3.	Technical Assistance	NIL	NIL	NIL	NIL	NIL	NIL
4.	Consumables	60,000	NIL	60,000	60,000	NIL	60,000
5.	Travel	80,000	NIL	80,000	80,000	24,009	55,991
6.	Contingencies	1,00,000	NIL	1,00,000	1,00,000	6,773	93,227
7.	Overheads	1,84,125	NIL	1,84,125	1,84,125	1,84,125	NIL
8.	*Interest Earned*		NIL				
	TOTAL:	27,39,125	NIL	27,39,125	27,39,125	2,20,713	25,18,412
	2nd Year (April 2008-March 2009)						
1.	Equipment	NIL	21,95,000	NIL	21,95,000	4,19,010	17,75,990
2.	Staff Salaries	1,20,000	1,14,194	NIL	1,14,194	1,20,000	-5,806
3.	Technical Assistance	NIL	NIL	NIL	NIL	NIL	NIL
4.	Consumables	50,000	60,000	NIL	60,000	NIL	60,000
5.	Travel	80,000	55,991	NIL	55,991	26,753	29,238
6.	Contingencies	25,000	93,227	NIL	93,227	NIL	93,227
7.	Overheads	18,750	NIL	NIL	NIL	18,750	-18,750
8.	*Interest Earned*						
	TOTAL:	2,93,750	25,18,412	NIL	25,18,412	5,84,513	19,33,899
	3rd Year (April 2009-March 2010)						
1.	Equipment	NIL	17,75,990	NIL	17,75,990	5,62,500	12,13,490
2.	Staff Salaries	NIL	-5,806	1,20,000	1,14,194	1,20,000	-5,806
3.	Technical Assistance	NIL	NIL	NIL	NIL	NIL	NIL
4.	Consumables	NIL	60,000	50,000	1,10,000	49,756	60,244
5.	Travel	NIL	29,238	80,000	1,09,238	9,028	1,00,210
6.	Contingencies	NIL	93,227	25,000	1,18,227	37,479	80,748
7.	Overheads	NIL	-18,750	18,750	NIL	18,000	-18,000
8.	*Interest Earned*						
	TOTAL:	NIL	19,33,889	2,93,750	22,27,649	7,96,763	14,30,886

Principal Investigator

Principal Investigator
BRNS-DAE Project
Title "Studies of.. Circulators"
Department of Physics
Tezpur University

18/02/14

Auditor/ Chartered Accountant/
Accountant General
Finance Officer
Tezpur University

18/2/14

Head of the Institution
Registrar
Tezpur University

FORM-IV

Board of Research in Nuclear Sciences (BRNS)

STATEMENT OF ACCOUNTS (SA) as on JUNE 30, 2013 (date)

Sanction No: **2007/34/15-BRNS/1259** Dated: **September 07, 2007**

	4th Year (April 2010-March 2011)	**Sanctioned**	**Opening Balance (Brought Forward)**	**Received**	**Total (4+5)**	**Spent**	**Unspent (carried Forward)**
1.	Equipment	5,00,000	12,13,490	5,00,000	17,13,490	11,94,536	5,18,954
2.	Staff Salaries	2,64,000	-5,806	2,64,000	2,58,194	2,71,677	-13,483
3.	Technical Assistance	NIL	NIL	NIL	NIL	NIL	NIL
4.	Consumables	40,000	60,244	40,000	1,00,244	40,076	60,168
5.	Travel	80,000	1,00,210	80,000	1,80,210	80,521	99,689
6.	Contingencies	25,000	80,748	25,000	1,05,748	18,893	86,855
7.	Overheads	62,700	-18,000	62,700	44,700	44,700	NIL
8.	**Interest Earned*						
	TOTAL:	9,71,700	14,30,886	9,71,700	24,02,586	16,50,403	7,52,183

	5th Year (April 2011-March 2012)	**Sanctioned**	**Opening Balance (Brought Forward)**	**Received**	**Total (4+5)**	**Spent**	**Unspent (carried Forward)**
1.	Equipment	NIL	5,18,954	NIL	5,18,954	2,27,410	2,91,544
2.	Staff Salaries	2,16,000	-13,483	2,16,000	2,02,517	2,02,517	NIL
3.	Technical Assistance	NIL	NIL	NIL	NIL	NIL	NIL
4.	Consumables	NIL	60,168	NIL	60,168	52,482	7,686
5.	Travel	NIL	99,689	NIL	99,689	26,881	72,808
6.	Contingencies	20,000	86,855	20,000	1,06,855	1,04,711	2,144
7.	Overheads	16,200	NIL	16,200	16,200	16,200	NIL
8.	**Interest Earned*						
	TOTAL:	2,52,200	7,52,183	2,52,200	10,04,383	6,30,201	3,74,182

	6th Year (April 2012-March 2013)	**Sanctioned**	**Opening Balance (Brought Forward)**	**Received**	**Total (4+5)**	**Spent**	**Unspent (carried Forward)**
1.	Equipment	NIL	2,91,544	NIL	2,91,544	NIL	2,91,544
2.	Staff Salaries	NIL	NIL	NIL	NIL	NIL	NIL
3.	Technical Assistance	NIL	NIL	NIL	NIL	NIL	NIL
4.	Consumables	NIL	7,686	NIL	7,686	4,843	2,843
5.	Travel	NIL	72,808	NIL	72,808	NIL	72,808
6.	Contingencies	NIL	2,144	NIL	2,144	NIL	2,144
7.	Overheads	NIL	NIL	NIL	NIL	NIL	NIL
8.	**Interest Earned*						
	TOTAL:	NIL	3,74,182	NIL	3,74,182	4,843	3,69,339

18/02/14

Principal Investigator

Principal Investigator
BRNS-DAE Project
Title "Studies of.. Circulators"
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Auditor/ Chartered Accountant/ Accountant General

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Tezpur University

18/2/14

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FORM-IV

Board of Research in Nuclear Sciences (BRNS)

STATEMENT OF ACCOUNTS (SA) as on JUNE 30, 2013 (date)

Sanction No: **2007/34/15-BRNS/1259** Dated: **September 07, 2007**

	7th Year (April 2013-June 2013)	**Sanctioned**	**Opening Balance (Brought Forward)**	**Interest Earned**	**Total (4+5)**	**Spent**	**Unspent (carried Forward)**
1.	Equipment	NIL	2,91,544	NIL	2,91,544	NIL	2,91,544
2.	Staff Salaries	NIL	NIL	NIL	NIL	NIL	NIL
3.	Technical Assistance	NIL	NIL	NIL	NIL	NIL	NIL
4.	Consumables	NIL	2,843	NIL	2,843	NIL	2,843
5.	Travel	NIL	72,808	NIL	72,808	NIL	72,808
6.	Contingencies	NIL	2,144	NIL	2,144	NIL	2,144
7.	Overheads	NIL	NIL	NIL	NIL	NIL	NIL
8.	*Interest Earned*			2,07,242	2,07,242	NIL	2,07,242
	TOTAL:	NIL	3,69,339		5,76,581	NIL	5,76,581

GRAND TOTAL:	**Sanctioned**	**Received**	**Interest earned**	**Total (3+4)**	**Spent**	**Unspent (carried Forward)**
	42,56,775	42,56,775	2,07,242	44, 64,017	38,87,436	5,76,581

Principal Investigator

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FORM- V

Inventory of equipment

Inventory of equipment purchased for the project entitled: **Studies of Spin-Wave Instability in Ferrites for High Power Circulators**.

1) DAE Sanction Number and Date :**2007/34/15-BRNS/1259**,dated **07/09/2007**

2) Amount sanctioned for equipment : **Rs. 26,95,000.00**

3) List of equipment sanctioned for the project :
   (1) 200 MHz DSO
   (2) UPS System for High Power source
   (3) High power RF system
   (Magnetron Source+Power supply for source)
   (4) Average RF power sensor
   (5) Electromagnet and Gauss meter
   (6) High power accessories
   (7) PC with printer

4) Details of the equipment procured :

Name of the equipment	Date of purchase	Amount (Rs.)
200 MHz DSO (Make: Agilent)	16/01/2012	1,70,660
UPS System for High Power microwave source	10/01/2012	56,750
High Power Directional Phase Shift Circulator, High Power Directional Phase Shift Isolator, Waveguide High Power Attenuator, Broadwall Directional Coupler, Wavegide High Power Termination	29/09/2010	4,13,662.00
Power supply of Magnetron (Model No. MPP-23K30A)	20/07/2010	6,80,925.00
Electromagnet system with movable attachment and digital gauss meter	05/07/2010	99,949.00
Pulsed Coaxial Magnetron Model: 200MX	30/09/2008	5,62,500.00
Power Meter Model: Agilent E4418B	27/09/2008	1,87,954.96
Average Power Sensor Model: Agilent 8481B	27/09/2008	1,76,349.02
HP Colour Laserjet printer Model: 2600N	05/03/2008	17,056.00
Computer + U.P.S. Model: HP Pavilion A6340IN		37,650.00
	Total amount utilized	24,03,455.98

Investigator-in-charge

Date:

Registrar/Head of the Institution

Date: *Registrar*
Tezpur University

Principal Investigator
BRNS-DAE Project
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(Seal)