4. Experimental Content

1) Understand and master the functions and usage methods of various microwave devices.
2) Observe microwave ferromagnetic resonance phenomena of ferromagnetic materials.
3) Determine resonant magnetic field and microwave frequency, calculate gyromagnetic ratio (γ) and Lande's g-factor (g) of microwave ferrite.
4) Measure ferromagnetic resonance line width (ΔH) and estimate relaxation time (τ) of microwave ferrite materials.

5. Experimental Procedure

Note: during experiment, do not remain a large magnetic current for a long period of time (i.e. reducing current after measurements or during idle of the experiment).

1) Assemble components and connect wires according to Figure 1. Do not place the two coupling plates. Set the attenuation amount of the variable attenuator to maximum. Set both magnetic field and sweep field to minimum by turning the adjusting knobs of "MAGNET" and "SWEEP" in counterclockwise direction to end (i.e. no magnetic current to the electromagnet).

2) Turn on power to the microwave signal source and the main unit. Set microwave signal output mode at equal-amplitude (Equal A). Preheat for 20 minutes.

3) Adjust and measure microwave frequency:

   Refer to the "Comparison Table of Frequency-Micrometer Scale" of the microwave signal source shown in Appendix 1, set the micrometer reading of the oscillator to the position of output frequency 9370 MHz, while ensuring the wavelength meter is tuned away from 9370 MHz by reference to Appendix 3.

   Set the "Sweep/Detect" push switch of the main electric unit to "Detect" position. Turn the detection sensitivity "Detect Sen." knob to a middle position. Adjust the attenuation amount of the variable attenuator to make the detector display meter (i.e. the right meter on the panel) to an appropriate reading value (e.g. 2/3 full scale).

   Use the wavelength meter to measure the frequency of the microwave signal following these steps: turn the micrometer of the wavelength meter to the expected reading value (which can be estimated from the output frequency of the signal source with reference to the frequency-scale table of the wavelength meter shown in Appendix 3); slowly and carefully adjust the micrometer until the absorption point of the signal is observed, where signal decreases sharply); look up "Frequency-Scale Table of 3 cm Cavity Wavelength Meter" to determine the oscillation frequency. If the measured frequency is significantly different from that of the sample resonant cavity (i.e. about 9370 MHz), adjust the micrometer of the oscillator of the signal source to achieve this frequency output; finally, turn the micrometer of the wavelength meter away from the resonant point to avoid the influence of meter absorption on experimental results.

4) Insert two coupling plates. Finely tune the oscillation frequency of the signal source (i.e. adjust the micrometer of the oscillator) to achieve a maximum reading on the detector meter. At the same time, adjust the attenuator and the detection sensitivity carefully.

Then, measure the microwave frequency again using the wavelength meter as described in step 3.

5) Observe ferromagnetic resonance signal on oscilloscope:

   a) Insert the mono-crystal sample into the resonant cavity (need to unscrew the small cap on the side of the sample cavity to expose the sample insertion hole). Adjust the "Sweep" field to maximum.

   b) Connect the X- and Y- terminals of the main electric unit to X and Y channels of an oscilloscope, respectively. Set the "SWEEP/DETECT" switch of the main electric unit to "SWEEP" position. Set the oscilloscope at Y-T mode.

   c) Adjust the sensitivity of X-channel and Y-channel of the oscilloscope to achieve an appropriate height of display on the screen.

   d) Adjust the magnetic field current slowly to about 2.0 A. The magnetic resonance signal should be observed on the oscilloscope, as shown in Figure 8.

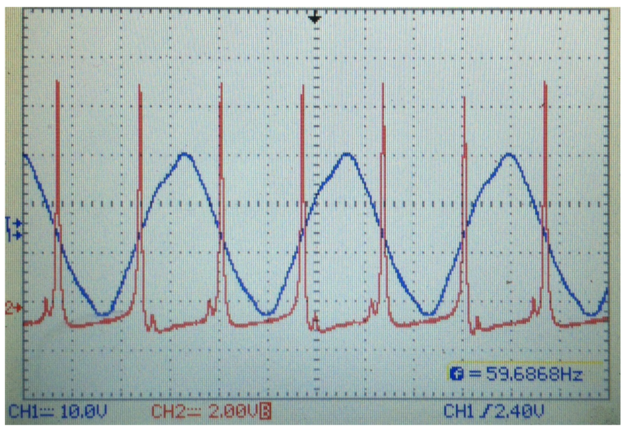

Figure 8 Magnetic resonance signal on oscilloscope in Y-T mode

   e) Change the display mode of the oscilloscope to X-Y mode. Magnetic resonance signal is shown in Figure 9.

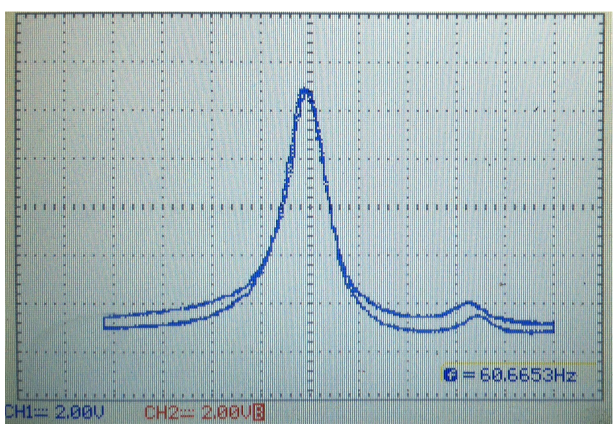

Figure 9 Magnetic resonance signal on oscilloscope in X-Y mode

   f) If the curves of the two resonant signals are not symmetrical to the vertical axis as shown in Figure 10, one may slightly adjust the output frequency of the microwave signal source or move the position of sample resonate cavity in magnetic field to achieve a satisfied graph as shown in Figure 9.

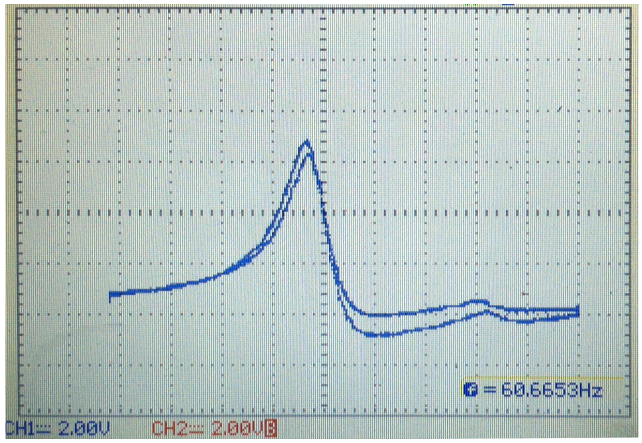

Figure 10 Asymmetrical Magnetic resonance signals

g) If the two peaks do not overlap, adjust the "Phase Adj." knob to bring the two resonance signals to overlap each other.

6) Produce ferromagnetic resonance curve:

a) Insert the mono-crystal sample into the resonant cavity, and place the cavity to the center of the magnetic field. Turn off AC power of the main unit and disconnect the wires of the "SWEEP" field. Set the "Sweep/Detect" switch to "Detect" position. Turn on AC power of the main unit and slowly increase magnetic field current by turning the magnetic field current knob in clockwise direction until the minimum reading is observed from the detector (i.e. the magnetic resonance absorption point is reached).

b) Since the power of microwave signal source is relatively small, the output of the detector satisfies a square law, i.e. the input microwave power is proportional to the detector output current. Therefore, the reading of the detector meter can be used as the ordinate (vertical) of the ferromagnetic resonance curve.

c) The magnetic field strength of the apparatus is varied by changing the magnetic current of the electromagnet. While this current is proportional to the magnetic field strength, it can be used as the abscissa (horizontal) of the ferromagnetic resonance curve to represent the magnetic field strength.

d) Starting from current 1.5 A, record the magnetic current and the corresponding reading of the detector meter to plot a curve similar to Figure 2, find the resonance magnetic field H_r and line width ΔH from the curve.

Alternatively, from P_r which is measured at the resonance absorption point, H_r is obtained, so one can use Equation (1) to calculate $P_{1/2}$; from $P_{1/2}$, one can find two H values corresponding to $P_{1/2}$, so ΔH can be derived without the need to plot the entire curve of Figure 2.

e) If a DC digital voltmeter is available, one can use it to directly measure the output of the detector; as a result, the accuracy of coordinate P_0 of the ferromagnetic resonance curve can be improved.

6. Examples of Data Recording and Processing

Note: following data are for reference only, not the criteria for apparatus performance:

1) Measure gyromagnetic ratio and g-factor

Experimental sample: Mono-crystal ferrite

Measured resonance frequency: $f = 9550$ MHz

Magnetic current at absorption point: 2.005 A, which is corresponding to magnetic field H_r=0.335 T.

Use formula $\varpi_r = 2\pi f = \gamma H_r$ and $\gamma = ge/2m_e$ to derive g-factor, where e is the charge of an electron (e = 1.6022×10^{-19} C), and m_e is the mass of an electron (m_e=9.1094×10^{-31} kg). We get:

$\gamma = 2\pi f/H = 2.250\times10^5\ (A^{-1}*m*s^{-1})$. (Note: $1Gs = 0.1\ mT = 79.6\ A*m^{-1}$).

$g = 2m_e \cdot 2\pi f/(e \cdot H)$ =2.04.

2) Measure resonance line width and estimate relaxation time

Experimental sample: mono-crystal ferrite

Measured current of half height amplitude: left: I_1= 2.010 A, right: I_2= 2.038 A. So we get ΔI=0.018 A.

From Current- Magnetic Field table shown in Appendix 2, we got ΔH=3.1 mT=31 Gs.

Using formula $\tau = \dfrac{2}{\gamma \Delta H}$, we got the relaxation time τ = 3.60×10^{-9} s.