Analysis of Intermodulation Distortion in Ferrite Circulators

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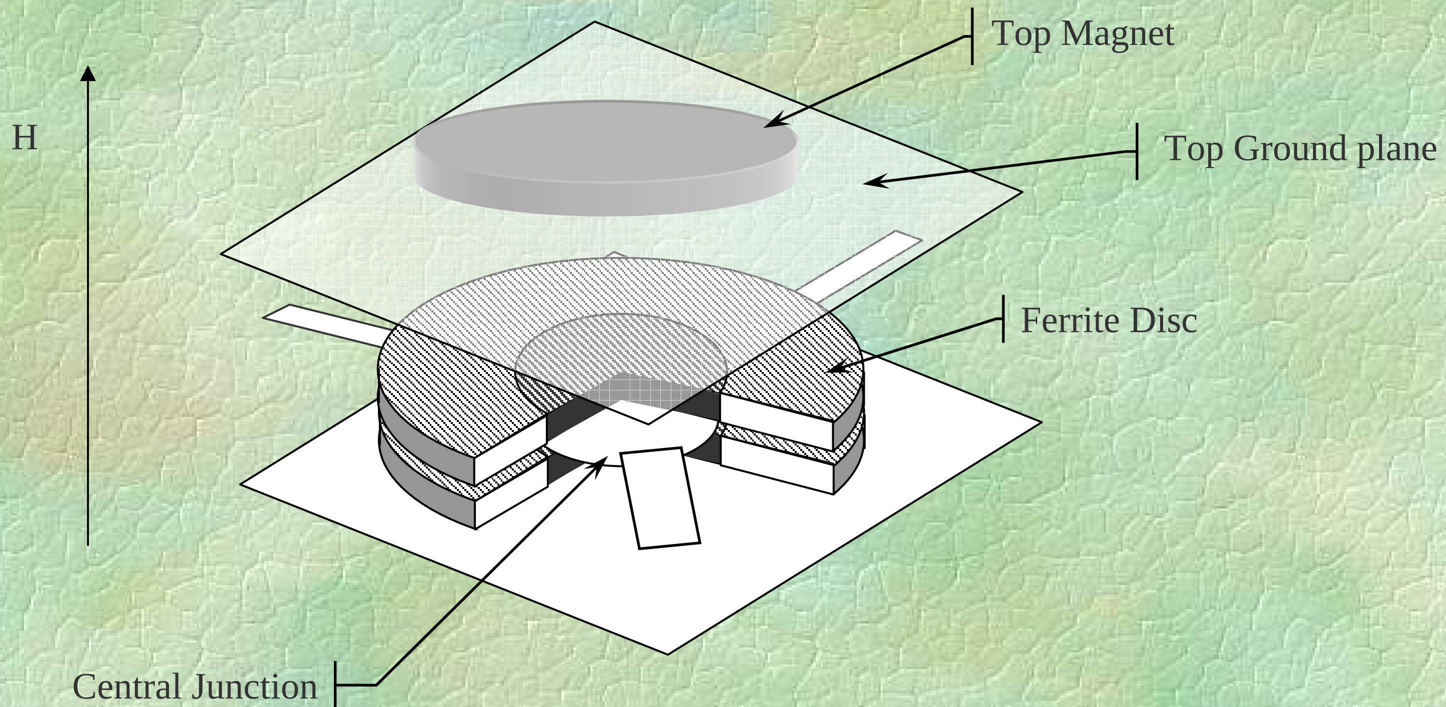
OVERVIEW

- Introduction
- Linearized Equation of Motion for Magnetization
- Nonlinear Oscillations of Magnetization
- Nonlinear Model
- IMD Data on a PCS Circulator
- Summary

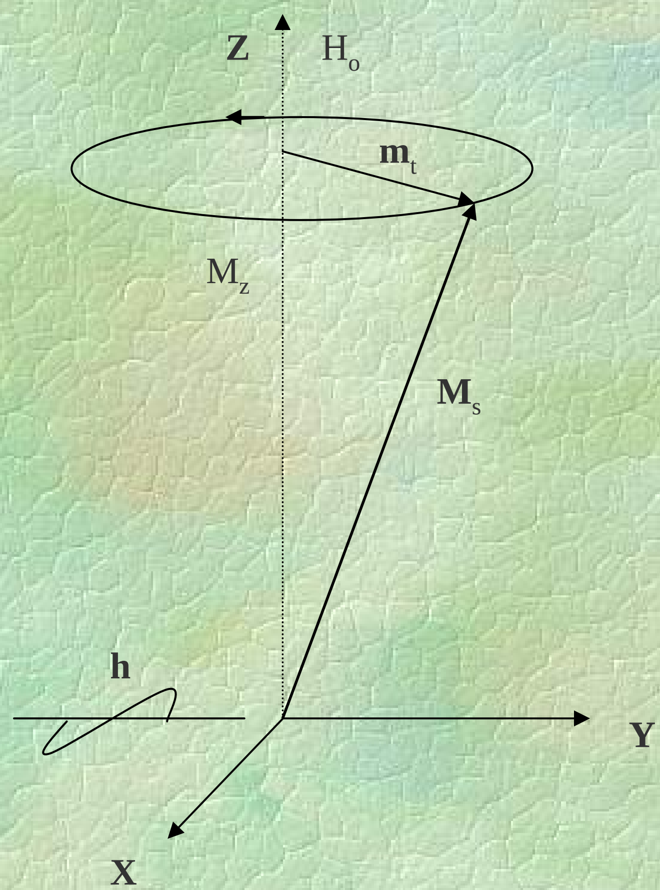
Basic Construction of a Stripline Ferrite Junction Circulator



OBSERVATION: As H was increased, 3rd order IMD reduced considerably.

Equation of Motion of Magnetization Vector

Linear Theory



$$\boxed{\frac{dM_s}{dt} = -\gamma\left(M_s \times H\right)}$$

$$M_s = M_z + m_t \qquad H = H_o + h$$

$$h << H_o \qquad m_t << M_z$$

Assuming rf products (hm_t) ~ 0

$$\boxed{\frac{dm_t}{dt} + \gamma\left(m_t \times H_o\right) = -\gamma\left(M_z \times h\right)}$$

Solution of Linearized Equation of Motion

Assuming harmonic (exp(iωt)) time dependence of **h** and $\mathbf{m}_t$:

$$i\omega m_x + \gamma H_o m_y = \gamma M_z h_y$$

$$i\omega m_y - \gamma H_o m_x = -\gamma M_z h_x$$

$$i\omega m_z = 0$$

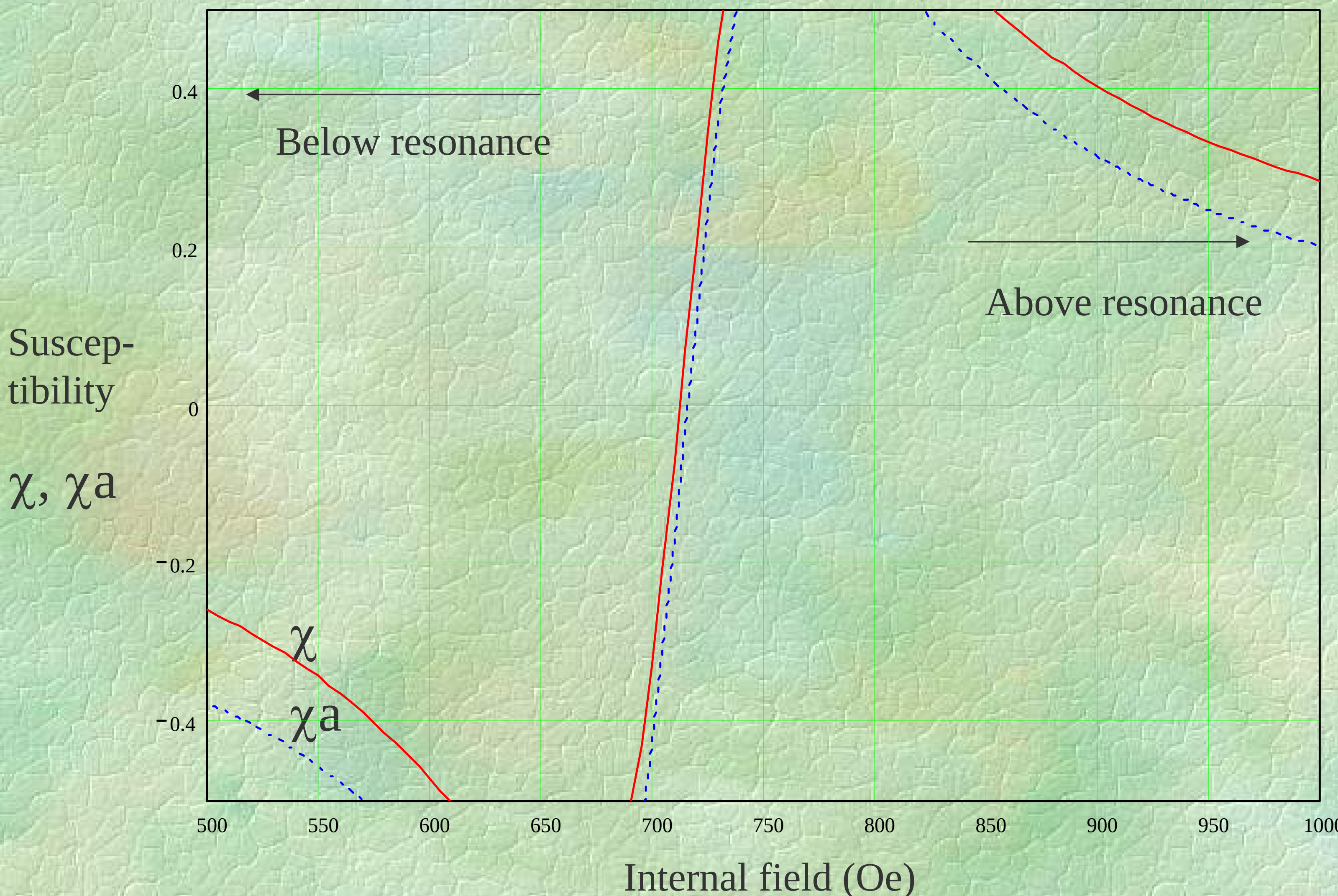
Solution:

$$m_x = \chi h_x + i\chi_a h_y \qquad m_y = \chi h_y - i\chi_a h_x \qquad m_z = 0$$

$$\boxed{\chi = \frac{\gamma M_z \omega_o}{\omega_o^2 - \omega^2}} \qquad \boxed{\chi_a = \frac{\gamma M_z \omega}{\omega_o^2 - \omega^2}}$$

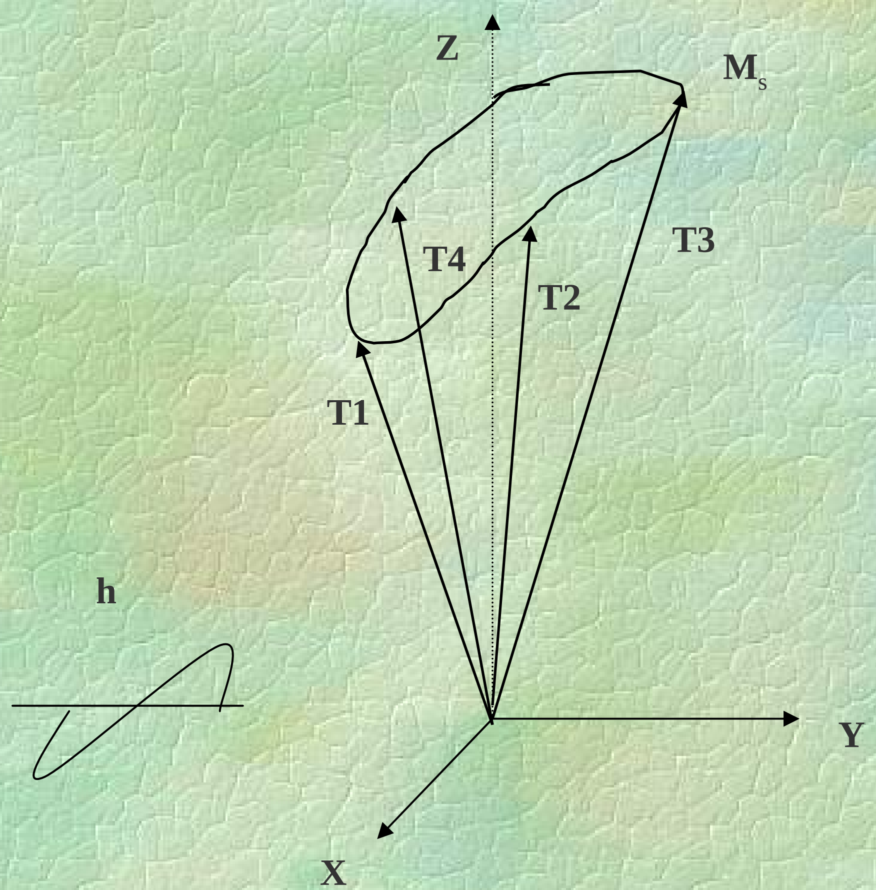
Ferromagnetic resonance: $\omega_o = \gamma H_o$

Tensor Susceptibility vs. Internal Field



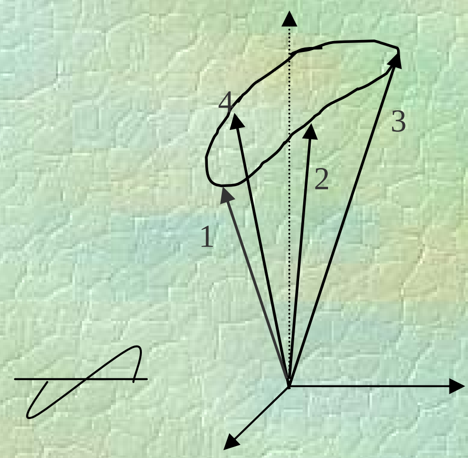
Difference between χ and χa is more in the below resonance than above resonance region

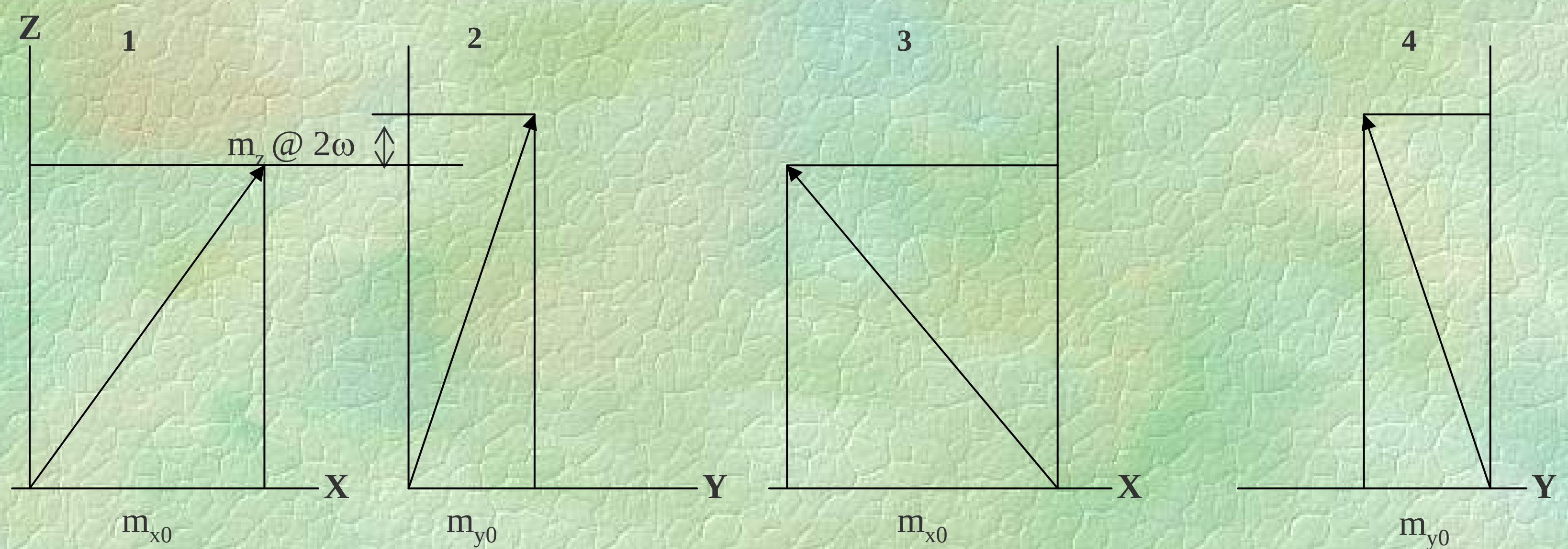
Nonlinear Oscillations of Magnetization



- Magnetization vector does not precess in a circular path.
- As the rf power is increased, higher order terms become significant and can no longer be neglected. Time derivative of m_z is not zero.
- Instability in the non-linear motion at high power levels depends on the anisotropy (shape, magneto-crystalline) present in the sample.

Harmonic Generation





Note: Magnetization M_s is held constant

Nonlinear Model

•Small signal approximation:

$$m_x = \chi h_x + i\chi_a h_y \qquad m_y = \chi h_y - i\chi_a h_x \qquad m_z = 0$$

•High signal levels (for linearly polarized rf fields):

$$m_x = \chi h_x \qquad m_y = -i\chi_a h_x$$

$$m_t^2 = m_x^2 + m_y^2 = h_x^2\left[\left(\chi^2 - \chi_a^2\right)\left(\frac{1-\cos(2\omega t)}{2}\right) + \chi_a^2\right]$$

$$M_s^2 = \left(M_z + m_z\right)^2 + m_t^2$$

$$\frac{d}{dt} m_z \neq 0$$

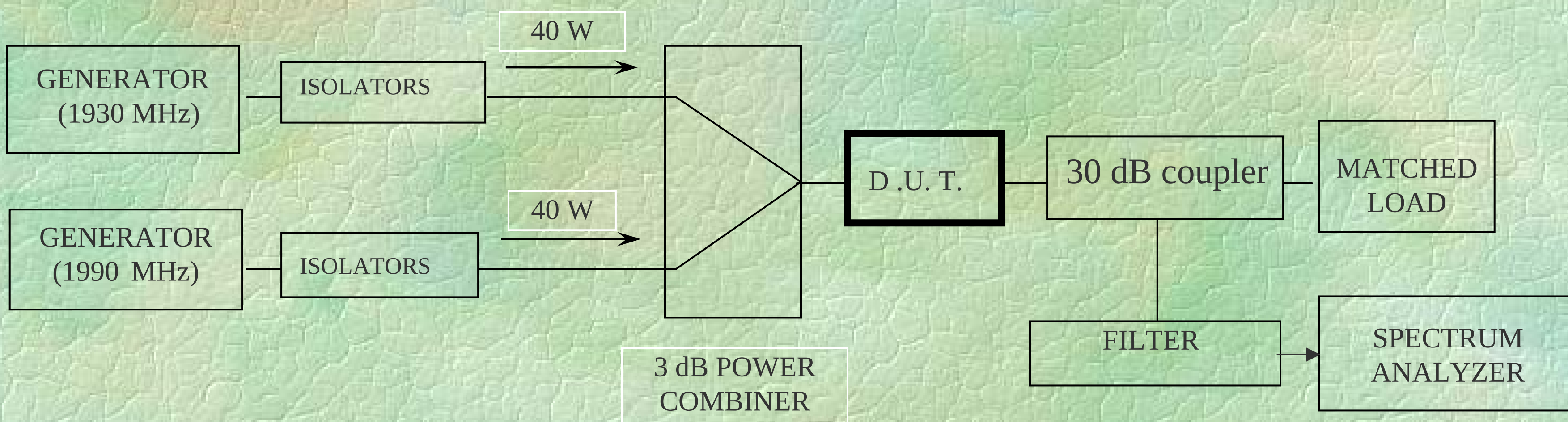
Final Expression

$$m_z = M_s \sqrt{1 - \left(\frac{m_t^2}{M_s} \right)} - M_z \sim \exp(2i\omega t)$$

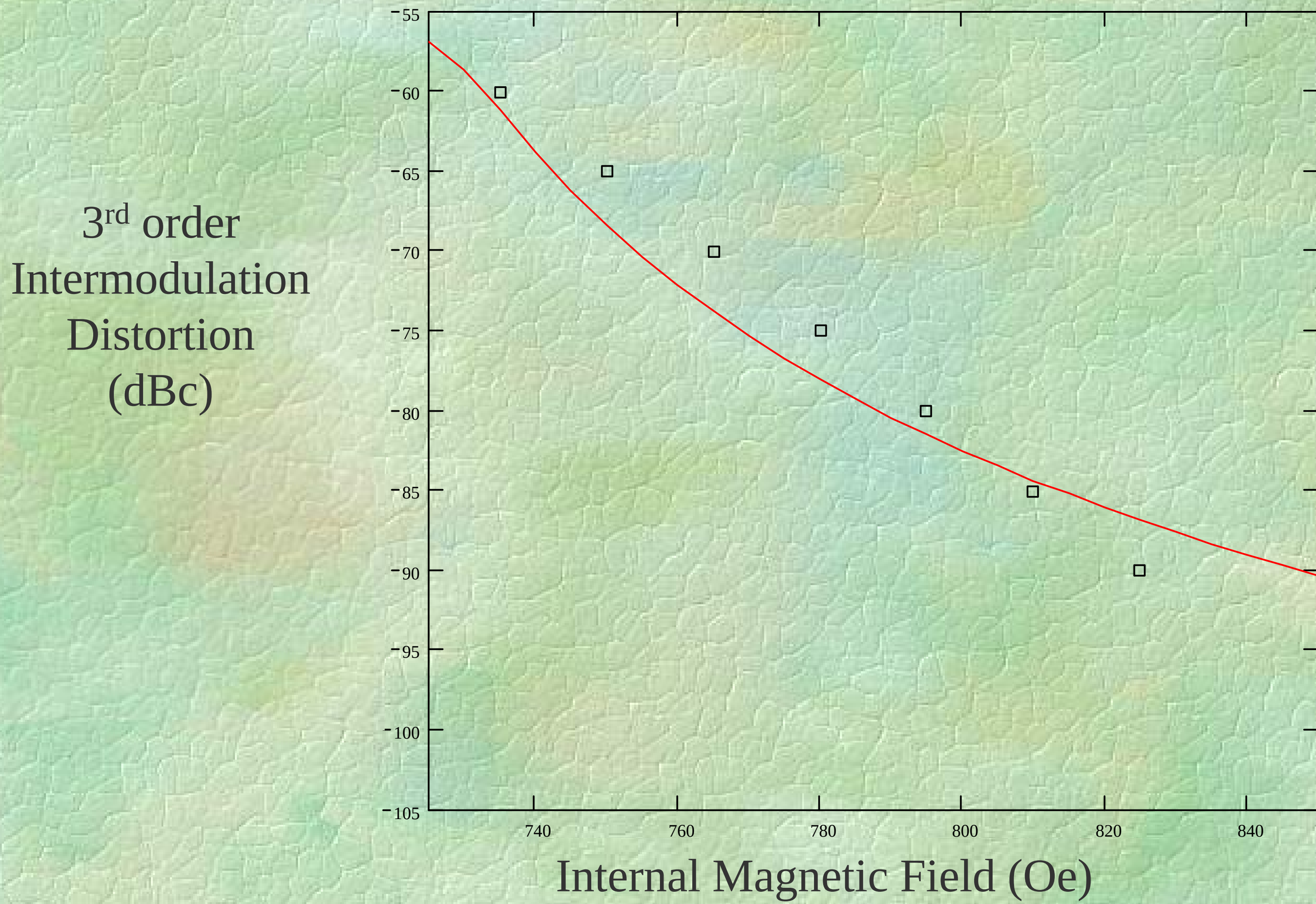
•**Harmonics due to m_t's 2ω dependence.**

•**When two frequencies co-exists, combined frequencies, $2\omega_{1,2} \pm \omega_{2,1}$, develop.**

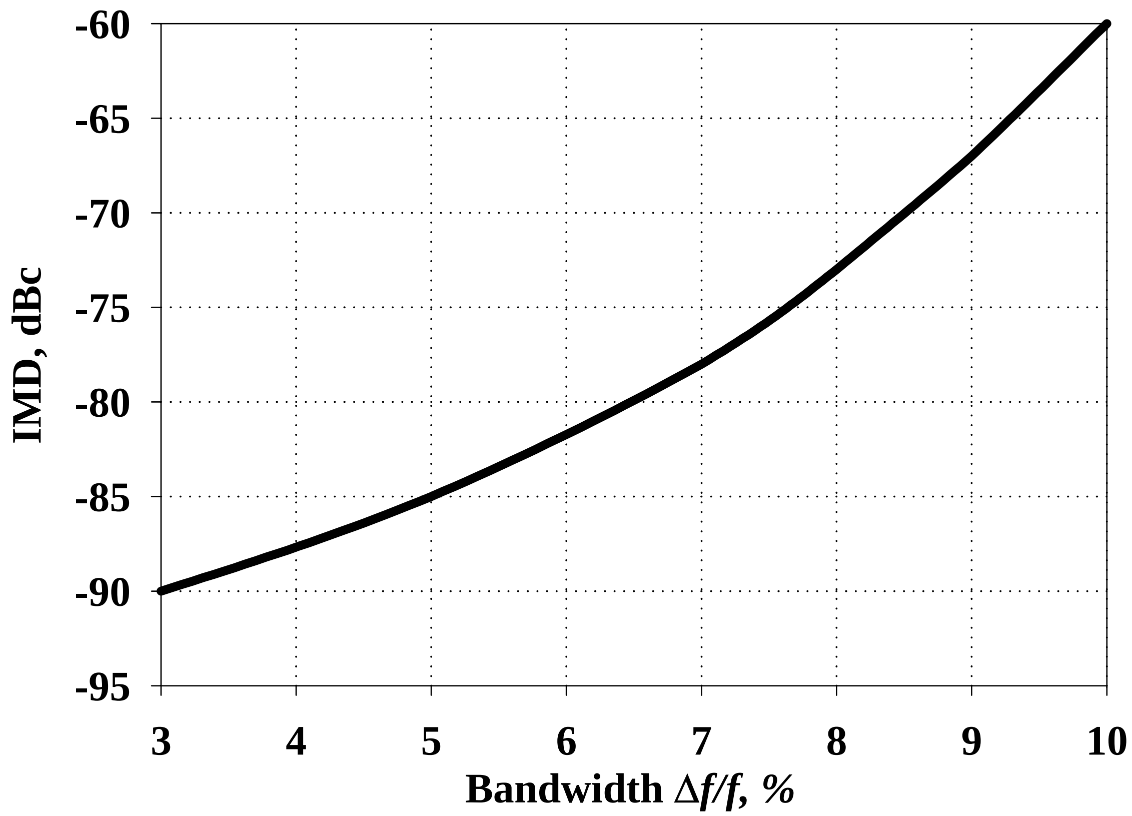
Experimental Setup



IMD as a function of field offset



IMD vs. Bandwidth



Bandwidth is Inversely Proportional to the Internal Magnetic Field

Summary

- Intermodulation distortion decreases rapidly as operating field is moved away from resonance - valid for both above resonance and below resonance devices.
- Above resonance devices should have better IMD performance than below resonance.
- Planar anisotropy shall result in higher intermod values with respect to Isotropic conditions.