# Parametric excitation of spin waves under switching of the pump frequency

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We have investigated experimentally the parametric excitation of spin waves in ferrites and established that the eigenfrequency interval in which spin waves are excited is of the same order of magnitude as the relaxation frequency of the spin waves.

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In this letter we report the experimental investigation of the parametric excitation of spin waves in ferrites under the action of two sequentially switched pumps with different frequencies. The experiment was done on single-crystal spheres of yttrium iron garnet 2.5 mm in diameter at a temperature of 4.2 K. Spin waves with wave vector $k \simeq 10^5$ cm$^{-1}$ were parametrically excited by parallel pumping at 9.4 GHz; the samples were placed inside a rectangular resonant cavity with an $H_{011}$ mode and a loaded $Q$ of $\sim 10^3$. The constant magnetic field had a magnitude of $H_0 = 1860$ Oe. Two pulsed pumps with a frequency difference of $\Delta\omega$ were fed into the cavity containing the ferrite (see Fig. 1). The first pump at frequency $\omega_p$, acting for a time $t_1$, "preheated" a packet of spin waves near the frequency $\omega_p/2$. Long before the appearance of the nonlinear mechanisms that limit the amplitude of parametrically excited spin waves (PSWs) the first pump was turned off, and after a time $\delta$ the second pump at frequency $\omega_p + \Delta\omega$ was turned on. After a time $t_2$ a characteristic indent appeared in the pulse of the second pump, indicating that the PSWs had reached a certain level $N$ in their exponential growth in time. This level depends on the sensitivity of the apparatus; in our case $N \sim 10^{17}$ cm$^{-3}$. The time $t_2$ depends on the amplitude and frequency of the spin waves preheated by the first pump. If the pause $\delta$ is large, $\delta \gg \gamma k^{-1}$, where $\gamma_k$ is the relaxation frequency of a spin wave with wave vector **k**, the amplitudes of all the PSWs at the instant the second pump is turned on will be close to the thermal level, and the time required for the indent to appear will be maximum: $t_2 = t_{2\max}$. For small values of $\delta$ there will be a decrease in $t_2$ due to the action of the first pump. If the amplitudes of the PSWs preheated by the first pump are distributed

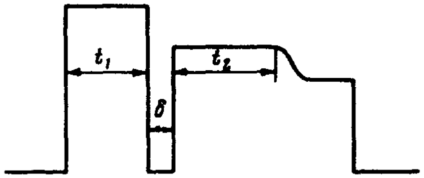

FIG. 1. Shape of microwave signal reflected from cavity containing ferrite .

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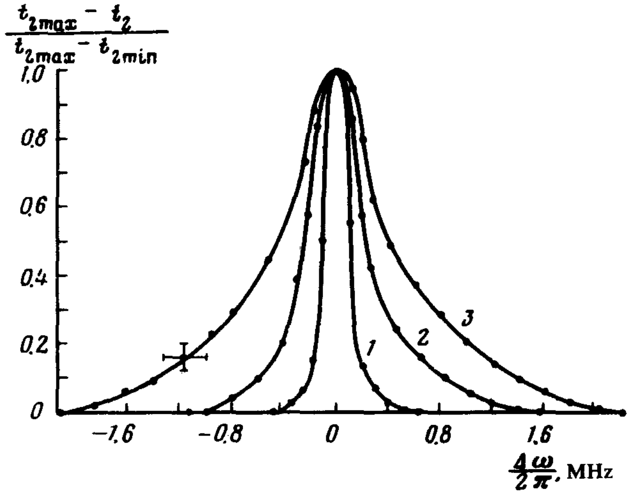

FIG. 2. Normalized time of appearance of indent in second pulse as a function of the difference between the frequencies of the first and second pulse; $\gamma_k/2\pi = 0.033$ MHz, $k \simeq 10^5$ cm$^{-1}$, $\delta = 5$ µsec, $t_1 = 200$ µsec, $\zeta_2 = 1.085$, $t_{2\max} = 200$ µsec, $t^2_{\min} = 30$ µsec. Curve 1 is for $\zeta_1 = 0.945$, curve 2 for $\zeta_1 = 1$, and curve 3 for $\zeta_1 = 1.59$.

over a finite frequency interval $\Delta\omega_k$, then $t_2$ will be a function of the frequency shift $\Delta\omega$: $t_2 = t_2(\Delta\omega)$, where the time required for the indent to appear will be minimum for $\Delta\omega = 0$: $t_2(0) = t_{2\min}$, while for $\Delta\omega \gg \Delta\omega_k$:$t_2(\infty) = t_{2\max}$.

Figure 2 shows the experimental dependence of the normalized quantity $(t_{2\max} - t_2)/(t_{2\max} - t_{2\min})$ as a function of the frequency shift $\Delta\omega$ for various values of the supercritically $\zeta_1 = h_1/h_{\text{th}}$, where $h_{\text{th}}$ is the threshold value of the magnetic field of a microwave pump for the excitation of PSWs. It is seen that in order to have an appreciable change in this normalized time at $\zeta_1 > 1$, it is necessary that the frequency shift between pumps be of the order of the relaxation frequency $\gamma_k$ (several hundred kilohertz). The necessary shift increases as the supercriticality $\zeta_1$ increases. Varying $t_1$ and $\delta$ over wide limits (from 0 to 30 µsec) did not affect the character of the curves in Fig. 2 substantially. For $\delta > 30$ µsec there is no connection between pulses. Figure 2 can be used to estimate the frequency interval $\Delta\omega_k$ in which spin waves are excited by the first pump. For this it must be assumed that the PSW density created by the first pump at the frequency of the second pump at the moment the second pulse is turned on is equal to $N(\omega + \Delta\omega)$. One can then write the simple relations

$$N(\omega + \Delta\omega)\exp[2\gamma_k(\zeta_2 - 1)t_2] = n_0\exp[2\gamma_k(\zeta_2 - 1)t_{2max}] = N,$$

$$N(\omega)\exp[2\gamma_k(\zeta_2 - 1)t_{2min}] = n_0\exp[2\gamma_k(\zeta_2 - 1)t_{2max}] = N,$$

where $n_0$ is the thermal spin-wave density. The excitation interval of the PSWs can be determined from these relations with the aid of the condition $N(\omega + \Delta\omega) = 0.5N(\omega)$, leading to a value of $\Delta\omega_k$ which is of the same order of magnitude as the spin-wave relaxation frequency $\gamma_k$ (here $\Delta\omega_k$ and $\gamma_k$ are angular frequencies).

The results reported here cannot be explained by the theory of Refs. 1 and 2 for the parametric excitation of spin waves, and they even disagree with the results of several experimental papers,[3,4] where the characteristic frequency scale of the PSW system did not exceed tens of kilohertz. In addition, they cannot be explained by the frequency instability of the microwave oscillator, since we made a special study of this with an S4-27 high-frequency spectral analyzer and established that this instability over time $t_2$ ($\leqslant 200$ $\mu$sec) did not exceed 10 kHz. To explain the results it can be assumed that the frequency interval $\Delta\omega_k$ in which PSWs are excited is substantially larger than the theoretical one,[1,2] being of the order of the PSW relaxation frequency. This explanation is also supported by the results of Ref. 5, in which just such as assumption was made to explain the damping rate of the longitudinal shf magnetization.

In conclusion, we point out an interesting fact: The experimental method used here permits the reliable detection of subthreshold excitation of PSWs during parallel pumping in ferrites. As an illustration, Fig. 2 shows an experimental curve measured at $\zeta_1 = 0.945$; it was generally possible to measure the excitation for $\zeta_1 \geqslant 0.91$.

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[1] E. Schlomann and R. Joseph, J. Appl. Phys. **32**, 1006 (1961).

[2] V. E. Zakharov, V. S. L'vov, and S. S. Starobinets, Usp. Fiz. Nauk **114**, 609 (1974) [Sov. Phys. Usp. **17**, 896 (1975)].

[3] L. A. Prozorova and A. I. Smirnov, Zh. Eksp. Teor. Fiz. **67**, 1952 (1974) [Sov. Phys. JETP **40**, 970 (1975)].

[4] I. V. Krutsenko, V. S. L'vov and G. S. Melkov, Zh. Eksp. Teor. Fiz. **75**, 1114 (1978) [Sov. Phys. JETP **48**, 561 (1978)].

[5] V. S. Zhitnyuk and G. A. Melkov, Zh. Eksp. Teor. Fiz. **75**, 1755 (1978) [Sov. Phys. JETP **48**, 884 (1978)].