RF pulse formation dynamics in gyromagnetic nonlinear transmission lines

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Abstract. We present the results of rf oscillations growth dynamics as the high voltage pulse propagates through the gyromagnetic nonlinear transmission line (NLTL). Several equidistant electrical probes were placed inside the NLTL in order to examine the oscillatory wave formation and the role of higher order modes in this process. RF pulses are generated at 2 GHz frequency with nonaveraged peak power of 100 MW. Azimuthal asymmetry of the wave propagating through NLTL is detected.

1. Introduction

Generation of high power microwave (HPM) pulses by gyromagnetic nonlinear transmission lines (NLTLs) as a possible alternative to traditional HPM tubes attends intensified attention of researchers for last ten years [1-6]. Optimal conditions are found for the generation of rf pulses with frequencies from 0.6 GHz [1] to 5 GHz [5], rf power from tens MW [4] to several hundred MW [2], pulse repetition rate from 800 Hz [6] to 65 MHz [7]. Based on these studies, multichannel rf sources with electronically controlled beam steering are designed and investigated [8-9]. In all experiments with gyromagnetic NLTLs, the traditional experimental method includes registration of the high voltage pulse incident on NLTL and the pulse coming out of the NLTL. At that, the intrinsic dynamics of rf pulse formation inside NLTL remains unclear. In this paper we present results of direct measurement of the wave propagating through NLTL by sensors placed inside NLTL.

2. Shock wave formation dynamics

2.1. Experimental set-up

The general scheme of experimental set-up is presented in figure 1. SINUS-150 high voltage pulse generator was used to produce pulses with 5 ns duration and amplitude of 120 kV. Two D-dot sensors were place in transmission lines before and after NLTL. The length of ferrite filling was 700 mm. Three pairs of identical D-dot sensors were placed inside NLTL with 220 mm axial shift and 90° azimuthal shift within the pair. The high voltage pulse was absorbed in an RF resistive load (HVR). The waveforms were recorded by TDS6604 Tektronix Digital Oscilloscope with 6 GHz bandwidth.
The rf cables between oscilloscope and three pairs of sensors inside NLTL were identical and calibrated by Network Analyzer Agilent N5227A.

2.2. Results
At first, the situation without a bias magnetic field was examined. The input and output waveforms as far as waveforms at three cross-sections inside NLTL are presented in figure 2. One can see the shock wave formation with a stationary rise time and velocity. The pulse sharpening is accompanied by pulse shortening because of magnetic losses at the shock front [10].

Figure 1. General scheme of experimental set-up. HVPG – high voltage pulse generator, TL – transmission line, RL – rf resistive load, TDS6604 – Tektronix Digital Oscilloscope.

Figure 2. Input and output waveforms together with waveforms at three equidistant cross-sections inside NLTL. No bias.

Figure 3. Input and output waveforms together with waveforms at three equidistant cross-sections inside NLTL. Bias magnetic field of 32 kA/m.
If the bias magnetic field is applied, rf oscillations with a frequency close to 2 GHz appear, figure 3. One can see similar dynamics with not so distinct pulse shortening because of different sharpening mechanism. The shock wave velocity is changed with the bias magnetic field which is a basis for multichannel NLTL systems with a bias control of phase in each channel [7-8].

3. Azimuthal wave asymmetry
The azimuthal wave symmetry was checked in three cross-sections by D-dots with 90° azimuthal shift. The results are presented in figure 4.

Figure 4. Waveforms at three equidistant (220 mm) cross-sections recorded by two sensors with 90° azimuthal shift. Bias magnetic field of 32 kA/m.
At the first cross-section (at 130 mm from NLTL beginning), the waveforms seem to be very similar to incipient oscillations at the shock front. At the second cross-section while the rise time is the same for both sensors the oscillations are quite different. One sensor shows decaying oscillations while at another the oscillations start is decayed. That could be because of a difference in the group velocities of rf oscillations and a shock front. At the third cross-section there is a significant difference in frequencies of oscillations from both sensors – at the same interval, one sensor shows five oscillations while another - four. These results indicate that the modes of electromagnetic wave inside NLTL are more sophisticated than TEM-mode and additional analysis is needed.

4. Conclusions
The presented results show that traditional view on gyromagnetic NLTLs as systems with single TEM wave should be revised. Different waveforms at the same cross-section of NLTL indicate that azimuthal asymmetry takes place as a result of excitation of at least one higher order mode. That should be checked for other geometries and ferrite materials. Maxwell equations are more preferable for description of wave dynamics in NLTL than traditional for NLTLs Telegraph equations.

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