Tunable microwave generator based on ferrite-ferroelectric film structure

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Abstract

Investigation of the microwave generator based on ferrite-ferroelectric metamaterial structure is reported. Possibility of auto-generation of complicated chaotic signals is experimentally observed. It is shown that a change of the direction and magnitude of the bias magnetic field leads to a change of chaos parameters in a wide range. Application of the electric bias field leads to a small increase of the fractal dimension.

1. Introduction

In recent years, devices operating in the microwave frequency range have found increasing use in information and telecommunication technologies. These applications stimulate the seek and investigation of new means for data recording and transmission. A promising direction in this field is related to the use of dynamic chaos as a carrying signal in communication systems. Dynamic chaos offers several advantages in this respect, including large information capacity and security of communication [1].

Ferrite-film-based microwave feedback rings have recently been used to self-generate stationary periodic short microwave pulse sequences in the form of bright, gray, or black spin-wave(SW) envelope soliton trains. In addition to the stationary waveforms, chaotic microwave signals can also be self-generated in ferrite film feedback rings. Initially, a narrow-band dynamic chaos generators have been studied in [2], where the linear waveguiding medium was based on the yttrium iron garnet (YIG) films. More recently, a relatively broadband ferrite-film generator of chaotic pulses has been studied [3], which generated dynamical chaos with a bandwidth of about 1 GHz. A ferrite-film auto-generator can be tuned by varying the bias magnetic film applied to the film. One should note that such method of tuning is rather slow. In our experiments, the dual-tunable microwave generators based on ferrite and ferrite-ferroelectric film structures were studied. In other words, in order to create auto-generators we utilised not only pure magnetic but also artificial media, also known as “metamaterials”, composed of ferromagnetic and ferroelectric components. Utilization of the ferrite-ferroelectric or multiferroic media allow relatively fast tuning of the auto-generators through varying the bias electric field.

2. Experimental set-up

Our experiments were performed using the YIG-film-based as well as the multiferroic-based feedback ring as shown in Fig. 1. This figure gives the schematic diagram of an active resonance ring comprising serially connected delay line (DL) based on multiferroic structure (1), a semiconductor microwave amplifier (2), a tunable attenuator (3), and a directional coupler (4). The DL played the role of a nonlinear frequency-controlling element of the active ring. The amplifier compensated for microwave losses in the DL and attenuator. Using the attenuator, it was possible to control the gain for microwave signal circulating in the ring. The signal circulated in the ring was sampled through a directional coupler for spectrum analysis in the frequency domain and wave-form analysis in the time domain.

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A multiferroic waveguide used in the delay line was manufactured from a YIG film (12) grown on a gadolinium gallium garnet substrate (11) and a ferroelectric layer (15), which was pressed from below to the surface of the YIG film. The layer was fabricated from barium strontium titanate ceramics and was covered from the bottom side by a 5-μm-thick copper film. The upper surface of the ferroelectric layer, which was in contact with the ferrite film, was covered by a very thin (50 nm) film of chromium. The metallic electrodes were used to apply voltage creating a bias electric field. To excite and receive waves in the multiferroic waveguide two microstrip antennae were used.

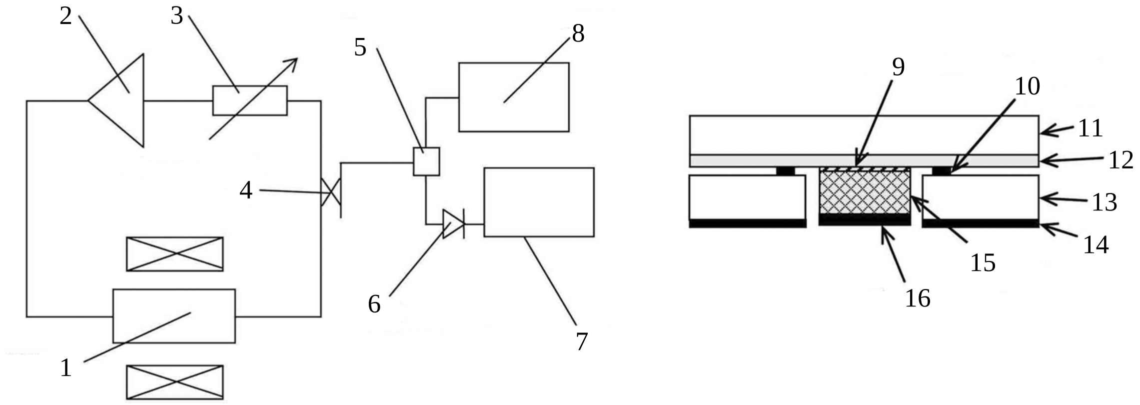

Fig. 1: Schematic diagram of the active resonance ring (left), ferrite- ferroelectric delay line (right). 1 - delay line, 2 - microwave amplifier, 3 - tunable attenuator, 4 - directional coupler, 5 – splitter, 6 – detector, 7 – oscilloscope, 8 – spectrum analyzer, 9 -upper electrode, 10- microstrip antennae, 11 – GGG, 12 – YIG, 13 – substrate, 14 – metallization, 15 – ferroelectric layer, 16 – bottom electrode.

As was noted above, the nonlinear properties of the active resonance ring were determined by nonlinearity of the multiferroic waveguiding structure. An important feature of the multiferroic DL was a relatively low microwave power (on the order of several dozen milliwatts) of the transition to a nonlinear spin-wave propagation regime. It should be emphasized that the amplifier always operated in a linear regime for all microwave signal levels.

3. Experimental investigation

Experimental investigation was made in two steps. On the first step, the dependence of signal parameters on the gain coefficient for the different magnetization directions was measured. In order to study the parameters of the generated signal, we have measured the frequency spectra and amplitude profiles as functions of time for the various gain levels. As the gain coefficient G was gradually increased, the complete compensation of microwave losses was achieved at a certain level and then a monochromatic microwave signal was self-generated in the ring. In terms accepted previously [3], [4], this level of the gain value is conditionally referred to as zero. The further increase in the gain led to a change of generation regimes. In the frequency domain, these regimes can be subdivided into three main types, including the generation of a monochromatic signal, a set of frequencies, and a dynamical chaos.

In order to describe the system dynamics and to determine parameters of the self-generated signals, the experimental data were used to construct the phase trajectories for all regimes of microwave generation in the active ring. The attractors were reconstructed using the delay method. In particular, the generation of a monochromatic signal corresponds to a point, while the generation of solitons corresponds to a limit cycle. The regime of chaotic signal generation corresponds to the so-called strange attractor. The reconstructed attractors were used to estimate the parameters of chaotic signals by Grassberger-Procaccia algorithm. On Fig. 2 the dependences between the gain coefficient and the fractal dimension taken for the different directions of the magnetic field are shown. Fractal dimension describes complexity of dynamical chaos. Increasing the gain coefficient leads to increase of the fractal dimension for all cases of the magnetization directions. Careful tuning of the slope of this dependence can be done by varying the magnetization direction. The fastest increase of the dependence corres-

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ponds to the case of forward volume waves. The highest value of the fractal dimension in this case was 11.6. Thus, one can adjust characteristics of the generated dynamical chaos complexity by varying the magnetic field.

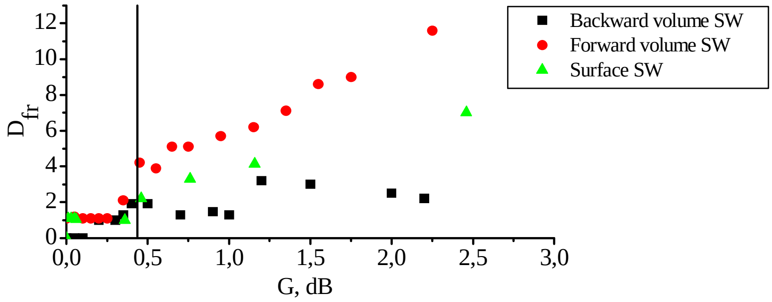

Fig. 2: Dependence of fractal dimension on gain coefficient.

On the second step, ferroelectric slab was pressed from below to the surface of the YIG film (see Fig. 1). It was found that such multiferroic structure can generate different types of signal, namely, c.w. signal, periodic signal, and dynamical chaos. Altering of the generation regimes can be done by changing the gain coefficient, as in the previous case. Also it was shown that the value of the fractal dimension of dynamical chaos can be changed by applying the electrical bias voltage. In Fig. 3 one can see that increasing of voltage up to 800V leads to increase of the fractal dimension.

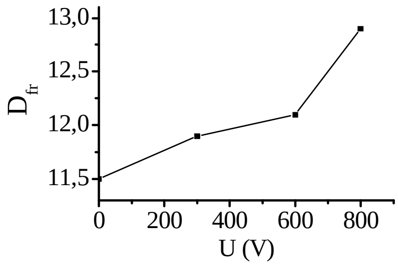

Fig. 3: Dependence of fractal dimension on bias voltage.

4. Conclusion

Thus, the investigated structures can generate different types of microwave signals. The kind of the generation regime can be changed by varying the gain coefficient. One can tune parameters of the chaotic signal auto-generated in the case of high gain coefficient by varying both magnetic and electric bias fields.

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