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Energy efficiency increase of NQR spectrometer transmitter at pulse resonance excitation with noise signals

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ABSTRACT

The specific feature of NQR is expansion of spectral lines which is caused not only by dipole-dipole interaction of nuclei, but also by local field nonuniformity caused by the defects and deformation in crystal matrix. Considerable line expansion, which is typical of crystals, requires in pulsed NQR method the optimization of pulse shape and the reserve of transmitter power output. Parametric computer identification was used to study a dependence of parameters of the energy spectra of the output signal of pulsed NQR spectrometer transmitter on the duration of excitation pulses with sine and noise occupation. The energy efficiency of a linear amplifier was calculated and experimental investigations of its temperature conditions were carried out. The energy-efficient broadband transmitter was proposed that can be used in portable setups for the pursuance of research in the field of pulsed NQR spectroscopy, for instance when studying isotopes with quadrupole moments ^{14}N, ^{35}Cl, ^{63}Cu, ^{69}Ga, ^{71}Ga, ^{113}In, ^{115}In and others.

1. Introduction

Research on the physicochemical properties of materials with the aid of electromagnetic pulse radiation has become a frequent practice nowadays. Advances in pulse resonance methods are most evident in the applied fields of optical and radio-wave spectroscopy [1–5].

The concept of pulsed nuclear quadruple resonance (NQR) Fourier-spectroscopy is similar to nuclear magnetic resonance (NMR) spectroscopy. It consists in excitation of quadruple nuclei with high-power radio frequency (RF) pulses and recording of free induction decay signals, or spin echo. Visualization of the resonance spectra is made with the use of the Fourier transform [6–8]. The majority of existing methods use short δ - like radio pulses for resonance excitation [7]. As long as the envelope of such pulse is shaped as a rectangular video pulse, it can be considered in certain approximation to be broadband and used for resonance excitation in a relatively broad frequency range. This method is employed in the study of sensor properties, structure and crystal defects of compounds based on A^3B^6 (GaS, GaSe, InSe and other elements) [4]. Certainly, such investigations should be continued, especially on the basis of modified methods of NQR pulsed spectroscopy, as long as it will give a chance to study temperature- and pressure-sensitive dynamic characteristics of crystal lattice, introduction of impurities and effect of crystal structure defects on the physicochemical properties of devices developed on the basis of these materials [5]. For the identification of nuclei with unknown beforehand frequencies of the transition between quadruple energy levels it is necessary to perform scanning in a wide frequency range. This increases significantly the time of the experiment.

A promising solution to the problem of rapid identification of NQR frequencies is the use of signals whose frequency bandwidth does not depend or weakly depends on the duration of excitation pulse. Such properties are inherent in steady-state random signals with independent at arbitrary points of time instantaneous values, in particular, "white noise". The use of these signals places a number of restrictions on the operation of energy-efficient switchmode RF power amplifiers that are often used recently in radio communication systems based on pulse or harmonic carrier. The need for amplification of broadband signal requires double frequency rise for switchmode amplifier. Technically, it is a rather complex task [9]. On the other hand, the need for creation of portable small-size spectrometers requires their energy efficiency increase, namely reduction of power consumption, stable temperature conditions and reliable operation [10,11]. This paper proposes a solution to the problem of energy efficiency of RF transmitter of portable NQR spectrometer at pulse resonance excitation with the noise signals.

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2. Structural development of RF transmitter of NQR spectrometer

2.1. Parametric simulation modeling

The specific feature of NQR is considerable expansion of lines caused by dipole-dipole interaction of nuclei on substance solid phase. In addition, local field inhomogeneity caused by defects and tension in the crystal matrix also makes a significant contribution to the line width. To study by pulsed NQR method the objects with a low content of quadruple nuclei, it is desirable to form high-power excitation pulses ($P_{out} \approx 1000$ W) which, in turn, requires coefficient of amplification of radio-frequency transmitter of NQR spectrometer 50 dB. Consider the structure of transmitter for a pulsed NQR spectrometer by the example of its simulation model [12] shown in Fig. 1. The transmitter model comprises a pulse shaper [13] and a linear power amplifier whose output is loaded by LC oscillating circuit – the sensor of NQR spectrometer.

As is evident from the proposed model, the RF transmitter comprises three stages with total amplification ~46.6 dB. To improve energy efficiency, the second and third stages of the transmitter are most important, since they work in linear amplification modes and, hence, the largest amount of thermal energy is dissipated on their active elements. Based on the proposed model, parametric computer identification (simulation) was performed with maximum possible account of real experimental parameters for the cases of amplification of excitation pulses with a sinusoidal and a noise carrier. The source of noise signals is a "Band-Limited White Noise" unit. The profiles of instantaneous values in the output circuits of active elements of RF transmitter output stage are shown in Fig. 2. It is seen that with a relatively simple circuit design the transmitter simulates equally well the shape of sine and noise-like signals.

Operating frequency band is an important characteristic of pulsed spectrometer RF transmitter. Power spectral density of white Gaussian noise is constant in the infinitely broad frequency range. To reproduce the real experimental conditions, the transmitter pass band was set at the level of $\Delta F_{TX} = 0.5$–50 MHz due to the use of "Bandpass Filter" units. Signal bandwidth Δf at transmitter output was studied as a function of pulse duration $\Delta\tau = 1$–100 μs with sine (Fig. 3.1) and noise (Fig. 3.2) filling. In modeling the maximum spectral width was limited by the radio spectrometer receiving channel bandwidth ($\Delta F_{RX} = 1$ MHz) with central frequencies of 20 MHz and 50 MHz.

In the case of amplification of radio pulses, efficiently and independently of the receiving channel center frequency, the following condition is relevant – the shorter pulse duration, the broader its spectrum. For noise signals two steps can be singled out. For a short duration of probe pulse ($\tau_1 \sim 1$ μs) occupied by noise with the band ΔF_{TX}, its energy spectrum (Fig. 4a) is an averaged characteristic of frequency properties of the number of random signal implementations restricted in the interval τ_1. As long as the latter in the case of short pulses is low, in the receiving channel with the band ΔF_{RX} one can observe a dependence $\Delta f(\tau_1)$ inherent in the pulses with sine occupation. With increasing duration of probe pulse ($\tau_2 \to 100$ μs) occupied by noise with a band restricted to ΔF_{TX}, the energy spectrum becomes more uniform (Fig. 4b) due to increased number of implementations. In this case the dependence $\Delta f(\tau_2)$ (Fig. 3) increases to 600–700 kHz and is actually restricted to radio spectrometer receiver's pass band ΔF_{RX}.

2.2. Basic structure of a broadband RF transmitter

Based on the results of simulation modeling, the basic structure of a broadband RF transmitter of pulsed NQR spectrometer was developed (Fig. 5), which comprises the pre-drive, driver and final (power) amplification stages, as well as the matching blocks of the input, output and interstage impedances. The use of a three-stage circuit is dictated by the need to amplify weak signals whose power level is about −2 dBm.

The circuit diagram of the proposed broadband RF transmitter is shown in Fig. 6. A preamplifier provides amplification of weak signals from the output of the spectrometer frequency synthesizer [7,13], as well as matching between the latter's output resistance and the input resistance of transmitter. Pre-amplification stage is based on a low-power high-frequency (HF) transistor and operational amplifier with a low noise level. Class A high-linearity drive stage is implemented according to a push-pull circuit based on HF transistors RD16HHF1 [14]. It assures

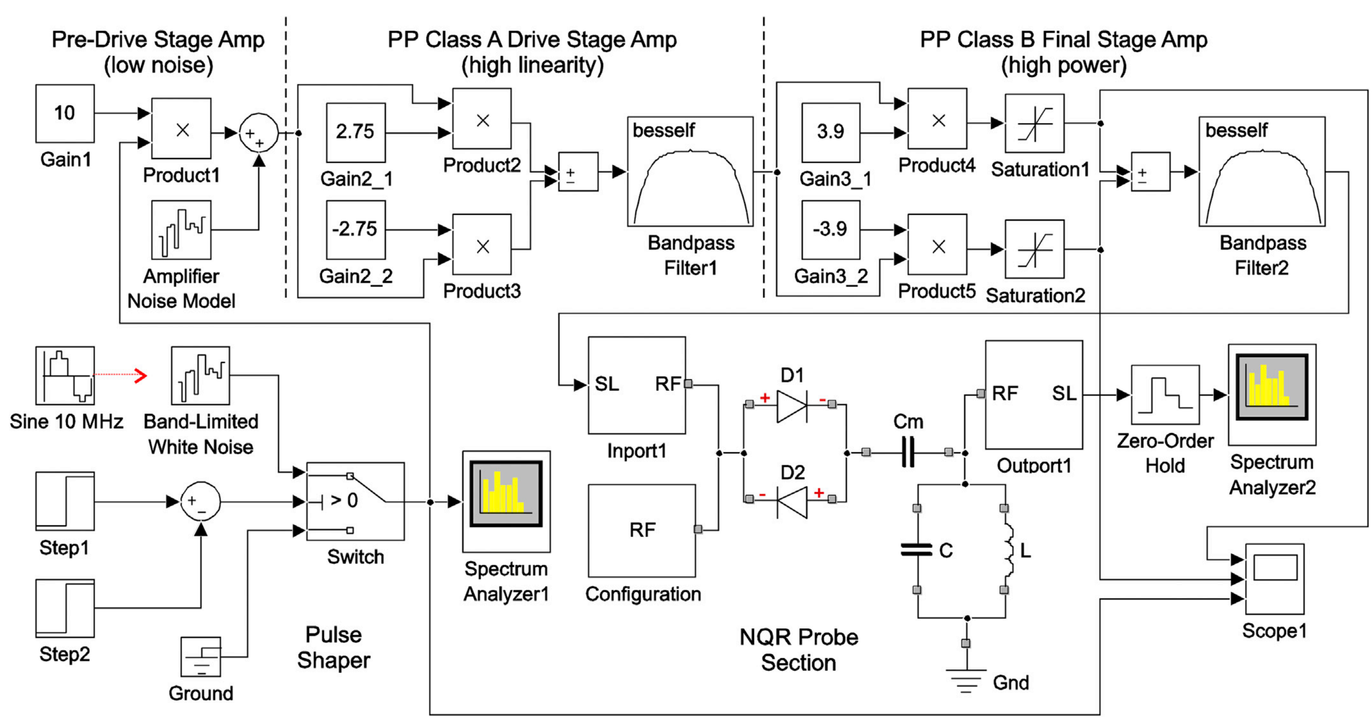

Fig. 1. Simulation model of RF transmitter of pulsed NQR spectrometer.