Experimental investigation of single pulse matched filtration on the spin-wave active ring resonator

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Abstract. Experimental investigation of single square pulse matched filtration in the active ring resonator is described in this work. Features of spin-wave delay line with metal screen in the active ring resonator are discussed. Influence of the microwave amplifier on formation of the active ring resonator impulse response was described. It is shown that the side peaks of impulse response depend on full energy in the ring circuit. Measurements of the ring response on input mixed signal with high $S/N$ ratio are presented. Dependence of the output signal amplitude on signal to noise ratio is showed and discussed. Formation of the noise part of output signal is showed and influence of spin-wave dispersion on it is described.

1. Introduction
Devices based on ferrite media are integral part of microwave technology and engineering at the present time. Ferrite delay lines and filters are division of this industry [1]. General usage of ferrite delay lines for signal processing is well known. Features of signal functional conversion may be determined as main for such devices. Large values of delay time and inherent dispersion provide possibility for correlators designing [2]. In other hand close-loop circuits on dispersive delay lines are used for low phase noise oscillators design [3]. From the point of view of resonant nature, they can be regarded as linear filters in pre-generation mode [4]. In this state, it has a narrow comb shape of the amplitude-frequency characteristics (AFC). Each band has a high quality factor (more than thousand) and linear (or quasi-linear) phase behaviour. Main difference between all such schemes is an in-band angle of phase slope. Narrow comb AFC of close-loop circuits is similar to power spectrum of signals with manipulations on amplitude in time domain. This feature may be used to very high selective filtration or matched filtration. Theoretical investigation of the matched filtration of periodic square pulses was presented in [5].

2. Experimental setup
Purpose of this work is an experimental investigation of matched filtration in active ring resonator (ARR) based on ferrite film delay line. In measurement setup close-loop circuit consisted passive ferrite delay line based on yttrium-iron garnet (YIG) single crystal thin film with 18 um thickness and grown on a gadolinium gallium garnet (GGG) substrate by the liquid phase epitaxy. $4\pi M_s$ of the delay line was equal to 780 G. The delay line was located between the poles of permanent magnet and bias magnetic field $H_0 = 1150$ Oe was oriented parallel to the plane of the YIG. This orientation provides excitation of the surface spin waves in the YIG film. For excitation and reception was used two short-circuited meander-type microstrip antennas. Metal screen was placed between antennas to provide
more linear dispersion. Variable attenuator and wideband amplifier was connected in series after delay line to provide power level control. Two directional couplers were placed in loop for input and output signals. Each band corresponds to resonant frequency determined by the dispersion law in the ferrite delay line. For such frequencies the phase shift of the microwave signal circulating in the scheme is equal to $2\pi n$, where $n$ is a number of the signal circulations. Therefore, the resonant condition for the spin-wave (SW) wavenumbers is $k(f_{\text{res}}) = \frac{2\pi}{d}$, where $k(f_{\text{res}})$ is a dispersion relation for the SW, $d$ is the efficient length of the delay line.

Length of spin-wave propagation has a limit definable by distance between antennas. In overall it can be controlled depending on the situation. Note that in this case the delay time of all other electrical interconnections is negligibly small.

![Figure 1. Scheme of the active ring resonator](image)

Passband of the delay line was tuned to 80 MHz. This width of passband provided 4 resonant frequencies. Influence of metal screen on spin-wave group velocity produced quasi-equidistant free spectral ranges (FSR) between resonances. Linearity of the FSRs is important to adjustment resonant frequencies with spectral harmonics of signal.

Input signal was generated by Rohde&Schwarz SMW200A vector signal generator which provide arbitrary sequences with short pulse duration. For measurements of the output signal was used Tektronix digital oscilloscope with passband of 3 GHz. In addition, control of the output power spectrum was carried out by signal analyzer.

For investigation of matched filtration were produced series of measurements of the time responses on mix of signal and white Gaussian noise. Input signal had a structure of sequence of 1 square pulse and 63 «zeros» which means that the full duty cycle was 1/64. Duration of pulse was defined by the delay time of the ARR and equal 47 ns. Signal to noise ratio was set relative to carrier frequency as -10, -7, -3 dB. At the same time signal generator provided constant output power at 5 dBm.

3. Measurement results

Figure 2 represents oscillogram of the ARR response on clear signal. Pulse duration of 44 ns corresponded to group delay time in ARR ($1/\Delta f$) and equivalent period of impulse response of the ARR.

Output signal represents first high peak and sequence of faded pulses after. Damping of this pulses is connected to small mistuning between input pulse duration and group delay time of ARR. In other hand, dispersion of surface spin-waves has influence on group delay in ARR and dependence on frequency is nonconstant. In case of nondispersion media, ARR should provide regime of repeater without pulse fading. Amplitude of each output pulse depends on instantaneous energy in the closed-loop. This energy can be expressed in two parts: gain from microwave amplifier and energy of input pulse. In such circuits amplifier sets up amplitude balance and AFC level. Impulse response of any linear device connected with complex transmission coefficient by the inverse Fourier transform and define fading of input signal. Therefore, signal fades with each circulation, with taking into account that the energy of input pulse much less then energy from amplifier.

Period of output pulses was nearly equal to input pulse duration, that allows to consider output signal as impulse response.

Figure 3 represent results of measurements of ARR the time response on signal/noise mix with various $S/N$ ratios where signal had the same structure as at figure 1. As can be seen, output signal
consists noise part and one high peak. Amplitude of this peak was variable in time, but never less value of noise. Such distribution corresponds to mismatching between instantaneous phases of signal and noise inside of the ARR. Intrinsic dispersion of surface spin-waves enhances this feature due to aperiodic behavior of the input noise and does not allow performance of the phase balance between signal and noise.

Figure 2. Time response of the ARR on pulse with 47 ns duration

Figure 3. Time response of the ARR on signal mixed with noise
   a) -10 dB S/N; b) -7 dB S/N; c) -3 dB S/N
Insertions on figures 3 a,b,c represent range of the impulse response. As in case of clear pulse, response on signal/noise mix consists sequence of side peaks. Side peaks are a noise-like results of superposition of the past signal and another input signal/noise mix. Strictly speaking, peaks can be divided into two groups - before and after the main one. The so-called "predecessors" are the result of a chaotic addition of noise amplitudes that are close in duration to the useful signal. Such peaks are not stable over time, and their amplitude may not fit into the envelope of the impulse response. However, the period of their repetition imposed by the time delay in the ARR and must be constant. Figure 3(b) clearly shows how two “predecessors” arise, but the next one is not formed. The second group - peaks, following the main. Such peaks are formed by the signal that passed through ARR, subjected to dispersion effects and added to noise. The amplitude of this group of peaks is more constant, but can be suppressed by the following noise.

Reduction of the input S/N ratio reduces the energy of the input and, accordingly, the output signal level. Since the input signal was signal-to-noise with respect to the spectral power of the carrier frequency, therefore, the noise level can be considered large already at zero decibels. The measured levels are characterized by a decrease in the average noise level relative to the central peak with an increase in the signal-to-noise ratio, that is the canonical property of the matched filter.

Figure 4 shows the output spectrum, with a signal-to-noise ratio of −7 dB at the input. The spectrum clearly shows that the noise component fills the allowed resonant frequency regions. The numbers indicate FSR and their values are given in the table below. It is noteworthy that the four maxima are lagging behind each other at the same frequencies. The equivalent periods of these frequencies correspond in value to the period of the impulse response of the resonator.

![Figure 4](https://example.com/figure4.png)

**Figure 4.** Spectrum of the ARR output signal with S/N=−7 dB.

| № | Δf  | Frequency, MHz | Period of the impulse response 1/(Δfn), ns |
|---|-----|----------------|------------------------------------------|
| 1 | 21.72 | 46             |                                          |
| 2 | 21.72 | 46             |                                          |
| 3 | 21.72 | 46             |                                          |
| 4 | 20.97 | 47.7           |                                          |
4. Conclusion
In conclusion, matching filtration of the single pulse in active ring resonator was experimental investigated in this work. Results of the ARR impulse response measurements were described and discussed. It is shown that the result of filtering a mix of a signal and noise with a large S/N ratio is a stationary peak with a noise component. With various S/N ratios amplitude of this peak depends on full energy of the input signal. Such behavior of filtration allows to consider active ring resonator as matched filter in full sense of term.

References
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