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MSW Signal-to-Noise Enhancers for Noise Reduction in DBS Reception

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Abstract The RF performance of MSW signal-to-noise enhancers is characterized by operational power level and frequency, frequency-selectivity, and transient response in MSW saturation. The frequency selectivity and transient response characteristics are especially important for noise reduction in frequency-modulated signals such as DBS reception signals. However, it is difficult to make both the characteristics good at the same time. In this paper three types of signal-to-noise enhancers with difference structures are discussed from the viewpoint of DBS application. We show that using an MSBVW/SW hybrid mode is an effective approach to lowering the operational frequency.

1. INTRODUCTION

MSW (magnetostatic wave) devices such as delay lines, resonators and filters have been investigated in the past 20-30 years. The nonlinearity of MSWs, especially the MSSW (magnetostatic surface wave) mode has contributed unique devices such as signal-to-noise enhancers and frequency-selective limiters [1], [2]. However, lack of thermal stability and the necessity for a bias magnetic field have hindered enhancers in applications to signal processing. As a result, until now a devices for practical use has not been reported.

DBS (direct broadcast satellite) systems using a small antenna (less than 40 cm in diameter) have recently become very popular in Japan (more than 10 million receivers). Carrier-to-noise ratio (C/N) reduction of the received signal caused by rain attenuation frequently generates significant impairment of a TV picture in rainy countries like Japan. In the DBS system frequency-modulated (FM) signals are handled differently from noise reduction in frequency memory loops, where only fixed frequency signals are handled. If the signal-to-noise enhancers act as a narrow bandpass filter automatically tracking an instantaneous frequency of the FM signal, significant noise reduction is expected. We have therefore paid attention to the application of signal-to-noise enhancers to compensation for C/N reduction in DBS reception, even if they have some defects. To achieve the noise reduction, the enhancers must have a short transient response in time in MSW saturation as well as good frequency selectivity. However, making both characteristics good at the same time is because they have a contrary relationship to input power [3]. Another important condition is whether the enhancer can be easily applied to the current DBS receiving system, where frequencies of 403 MHz with a 27-MHz bandwidth and 1 to 1.3 GHz are used as the IF bands (Fig. 1). In addition, low-power operation is needed to lower the power range of the enhancer driving circuit.

Fig. 1 Block diagram of the current DBS receiver.

The signal- to- noise enhancers can be formed with three different types of structures. We call them the transmission enhancer [1], the cancellation enhancer [3] and the reflection enhancer [5]. The transmission type enhancer has the most simple structure of the three, followed by the reflection enhancer and then the cancellation enhancer. However, because they display a different RF performance, the most suitable enhancer should be selected according to the application without reference to the structure.

In this paper the above three types of enhancers are compared from the viewpoint of an application to the current DBS receiving system. It also discusses using an MSBVW/SW (magnetostatic backward volume wave and surface wave) hybrid mode to make the operational frequency lower.

2. DESIGN

Figures 2(a), 2(b) and 2(c) show the geometries of the different types of MSW signal-to-noise enhancers using MSSW modes. In operation of the transmission enhancer [Fig. 2(a)], a microwave input signal gradually launches MSWs into the YIG film along the microstrip line from the input toward the output. The microwave signal is then attenuated at the output for a small signal input. However, for a large signal input above the threshold level, conversion from the microwave to MSWs saturates resulting in no more attenuation of the microwave signal. In this enhancer the conversion may not be limited near the output, even if the conversion is saturated near the input, and then a steep enhancement characteristic may not be anticipated. The sum of the enhancement is determined by the length of the YIG film contact with the microstrip line.

The cancellation enhancer [Fig. 2(b)] comprises two MSW filters, two 90° hybrids and two attenuators. A microwave input signal is divided into two signals by the hybrid 1, one of which directly goes to the MSW filter 2, while the other goes to MSW filter 1 through the Att 1. Both the signals through filters 1 and 2 are recombined by the hybrid 2 with a 180° phase difference resulting in combination with equal amplitude and opposite phase for a small signal input. The signals therefore cancel each other out and no signal appears at the output. However, for a large signal input above the threshold of filter 2, the loss of path 2 is much larger than that of path 1, resulting in combination without equal amplitude. Thus, most of the signal through path 1 appears at the output. This enhancer achieves infinite enhancement and excellent thermal stability theoretically, if both the filters have the exactly same characteristics.

Fig. 2 Geometries of the signal-to-noise enhancers. (a) Transmission type. (b) Cancellation type. (c) Reflection type.

Fig. 3 Typical input-to-output relationships of the enhancers. (a) Transmission type. (b) Cancellation type. (c) Reflection type.

The reflection enhancer [Fig. 2(c)] comprises a microstrip line, one terminal of which is short-circuited, and a directional coupler (or a circulator). Its operation is similar to that of the transmission enhancer, and only a reflected signal is extracted as an output signal through the directional coupler. The sum of the enhancement depends heavily on the matching of the microwave and MSWs, but does not depend too much on the length of the YIG film. This is a significant difference from the transmission enhancer.

Thus all these circuits frequency-selectively exhibit a high loss for small signals and a low loss for large signals; then they are called a signal- to- noise enhancer. The typical RF performance and effects on the DBS application are explained in the following sections.

3. RF PERFORMANCE

The three types of signal- to- noise enhancers exhibit a different RF performance. Figures 3(a), 3(b) and 3(c) show the typical input-output relationships of the enhancers, which have about an enhancement of 20 dB. The smaller the level difference between P_H and P_L is, the lower the C/N signal can be handled because we usually set a desired signal above P_H and set noise below P_L (P_H and P_L are defined in Ref. 3). If the absolute level of P_H is low, the power driving the enhancer also becomes small. In this viewpoint, the cancellation enhancer is best and the transmission enhancer may not be so good. We should be careful about the absolute level at the output because of the large insertion loss by the MSW filter and the attenuator.

Figures 4(a) and 4(b) are spectra showing frequency selectivity at the enhancer output, and Figures 5(a) and 5(b) are oscilloscope traces showing transient response of the enhancer when the input microwave is pulse-modulated [3]. The frequency selectivity (B_a) conduces to reduction of noise neighboring a desired signal. The transient response in time (T_s), which is caused by conversion from MSWs to half-frequency spin waves excited in the YIG film, determines the ability to track instantaneous frequency shift of the signal. During the time T_s , a desired signal as well as noise is reduced resulting in no improvement of the signal C/N. With an increase of input power, B_a increases but T_s decreases. This shows that the product U_p of B_a and T_s is approximately constant and that U_p is in proportion to the MSW group- velocity V_g [4]. The U_p should be as small as possible to achieve a good transient response. Controlling V_g while the MSWs propagate from the input to the output inside the filter is relatively easy in the cancellation enhancer (changing the distribution of a bias magnetic field, for example). From this viewpoint the cancellation enhancer may also be best.

The IF frequencies handled for the current DBS receivers, on the other hand, are the 403- MHz and 1- to 1.3-GHz bands. The enhancer should directly operate in these bands without frequency conversion. However, MSSW modes are generally not used in operational frequencies below 2 GHz (bias magnetic field is below 100 Oe) because of random domain formation caused by incomplete magnetic saturation in a pure YIG film with saturation magnetization of 1780 G. Reduction of the saturation magnetization is a good approach to lowering the operational frequency. Another is using a combination of MSBVW and MSSW modes; that is, an MSBVW/SW hybrid mode, where the magnetic bias field is applied between the directions for the pure MSBVW and MSSW modes. Figure 6 shows the reflection characteristic of the MSW filter using the hybrid mode. We found that with a

Fig. 4 Spectra showing the frequency selectivity of the enhancer. (a) Input power of -6dBm. (b) Input power of +4 dBm.

Fig. 5 Oscilloscope traces showing the transient response of the enhancer. (a) Input power of -6 dBm. (b) Input power of +4 dBm.

Fig. 6 Reflection of the MSW filter using the MSBVW/SW hybrid mode.

Fig. 7 Relationship between the received C/N and the video S/N.

decrease in the angle ϕ ($\phi = 0^\circ$ for the pure MSBVW mode), the matching (small reflection) frequency shifts lower. A small reflection means that efficient conversion from the microwave to the MSWs is made. At the same time we showed that v_g becomes slow theoretically using the hybrid modes. In this way the hybrid mode is a very attractive approach for low frequency operation and good tracking ability. We should thoroughly investigate the hybrid mode.

4. EFFECTS ON NOISE REDUCTION IN DBS RECEPTION

We have developed signal- to- noise enhancers operating in the 403- MHz and 1- to 1.3- GHz bands using MSSW modes propagating into doped YIG films with saturation magnetization of 360 G [5] and 1320 G [3], respectively. Figure 7 shows the relationship between a received signal C/N and a video S/N measured by the 1- to 1.3- GHz cancellation enhancer. Below the FM threshold of 9 dB, the S/N is enhanced by 2 to 10 dB; thus this enhancer performed what is called FM threshold extension. Even above the C/N of 9 dB, a slight enhancement of 1 to 2 dB is obtained. Little improvement is achieved in the densely colored parts of a TV picture, such as the red part in the color bar of the NTSC video signal, where the color-subcarrier (3.58 MHz) amplitude is large. In these parts, the carrier frequency of an FM signal is shifted rapidly and largely by the color-subcarrier. This is probably because the transient response in the MSW saturation is not so quick, and so the reduction of U_p is needed for more improvement. In practice, however, densely colored parts rarely appear in normal TV pictures and therefore our developed enhancer is very effective in noise reduction in DBS reception. If the C/N is enhanced by 3 dB, the size of the receiving antenna is reduced to $1/\sqrt{2}$. The 1- to 1.3 GHz enhancer is stable despite temperature changes and the driving power is only -5 dB; thus it is suitable for practical use and will be commercially available in the very near future. The size of the practical enhancer is $18 \times 18 \times 11 \text{ cm}^3$.

Also, a similar performance can be obtained in the 403-MHz enhancer. We cannot but adopt the reflection enhancer, because the transmission loss inside the MSW filter is too large (over 50 dB) and the driving power needs to be as small as possible. The details of this enhancer are reported in Ref. 5. The 403-MHz enhancer operates with a driving power below 0 dB, but it is too sensitive to temperature change. The thermal stability of the enhancer must be improved first for practical use. To this end, we are now considering optimizing the saturation magnetization of the YIG film by using the MSBVW/SW hybrid mode.

5. CONCLUSION

We have compared three types of signal- to- noise enhancer with different structures. The results showed that the cancellation enhancer was best for noise reduction in DBS application. Cancellation and reflection enhancers were respectively developed for the 1- to 1.3- GHz and 403-MHz bands for noise reduction. It was shown that the video S/N was significantly improved and the 1- to 1.3- GHz enhancer was suitable for practical use. We also explained that using the MSBVW/SW hybrid mode was effective in reducing the operational frequency of the enhancers.

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