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ACLR Improvement of a 5-GHz Power Amplifier Using High-Temperature Superconducting Reaction-Type Transmitting Filters

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Abstract— **Adjacent channel leakage power ratio (ACLR) improvement method of a 5-GHz power amplifier using high-temperature superconducting reaction-type transmitting filters (HTS-RTF) is proposed. The aim of this paper is to clarify the amount of ACLR improvement which is offered by HTS-RTFs. Firstly, measurement results of ACLR improvement using a prototype filter is introduced. The prototype filter has an about 10 dB improvement up to 40 dBm Wideband CDMA (W-CDMA) four-carrier signal, even though the suppression band is one side and the bandwidth is narrow. Secondly, to achieve wider suppression band, their resonator structures are optimized. The split-open ring resonator is modified to obtain higher unloaded Q-factor and lower current density. In addition, 5-GHz HTS-RTFs which have 3.5 MHz suppression bands in both sides of the W-CDMA carrier signal are designed. Finally, the ACLR improvement obtained by the newly designed filter is estimated based on numerical analysis. The ACLR is improved by about 10 dB in the both sides. Furthermore, the results show that amplifiers' back-off can be reduced by 5 dB when the HTS-RTFs applied to power amplifiers.**

I. INTRODUCTION

Microwave planar filters employing high-temperature superconducting (HTS) thin-films are superior to room temperature devices in terms of achieving very low surface resistance, high-Q performance, small volume and weight at the same time [1]-[4]. However, it is difficult to obtain high-power handling capability due to HTS critical current density and a generation of nonlinear distortion noise [5], [6]. To apply HTS planer filters for transmitting circuits, we have proposed an HTS reaction-type transmitting filter (HTS-RTF) [7], [8].

An HTS-RTF is a bandstop filter which suppresses the adjacent channel noise generated by a transmitting power amplifier. This is feasible because the intermodulation distortion noise (IMD), which is generated by power amplifiers, is considerably low compared to fundamental carrier signals; -50 dBc to -20 dBc lower than fundamental signals depending on an output power. We have confirmed the feasibility of the HTS-RTF and reported in the previous paper [8]. The HTS-RTFs can be applied for power amplifiers instead of nonlinear compensation circuits. By suppressing IMD using the sharp cutoff characteristic of the HTS filter, simpler power amplifier circuit construction and low energy operation will be achieved.

In this paper, an adjacent channel leakage ratio (ACLR) improvement method of a 5-GHz power amplifier using HTS-RTFs is presented. Firstly, measurement results of ACLR improvement are introduced and some issues for practical applications are investigated. Secondly, to obtain wider suppression band and further improvement of ACLR, their resonator structures are optimized. The split open-ring resonator (SORR), which is used in the filter, is adjusted to obtain higher unloaded Q-factor and lower surface current density. In addition, 5-GHz HTS-RTFs which have 3.5 MHz suppression bands in both sides of the Wideband CDMA (W-CDMA) signal are designed. Finally, ACLR improvement is estimated based on numerical analysis. In the ACLR estimation, the newly designed filters are applied to the W-CDMA four-carrier signal.

II. MEASUREMENT RESULT OF ACLR IMPROVEMENT

In this section, the effects of ACLR improvements offered by HTS-RTFs are discussed. The feasibility of HTS-RTF for the ACLR improvement of the high-power amplifier having maximum output powers of more than 40 dBm, is demonstrated. Furthermore, some problems for practical application are investigated based on additional results.

The HTS-RTFs shown in this section is aims to suppress one side of the adjacent channel noise. Fig. 1 shows $|S_{21}|$ parameter of the fabricated filters. Each filter consists of three SORRs. HTS-RTF No. 1 is the filter described in the previous paper [8] and has a 3 dB bandwidth of 1.78 MHz. HTS-RTF No. 2 has a 3 dB bandwidth of 3.31 MHz. It has a wider bandwidth compared to the filter No. 1. However, strong ripples exist in the stopband.

The HTS-RTFs is connected just after the power amplifier. The W-CDMA four–carrier signal specified in the 3GPP document [9] is inputted at the amplifier. Fig. 2 shows the typical output spectrum obtained with and without the HTS-RTF No. 1. The frequency of the W-CDMA four-carrier signal is chosen so that the upper edge of the adjacent channel

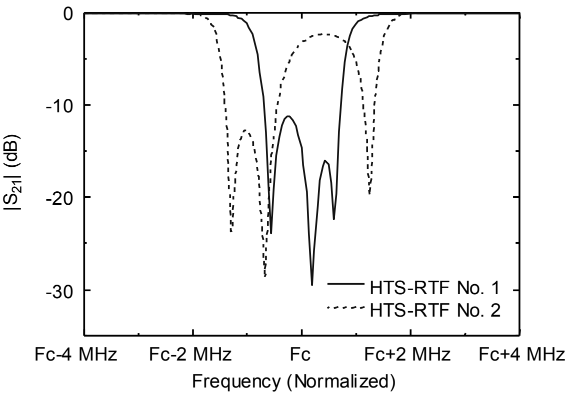

Fig. 1 The measured $|S_{21}|$ parameters of the fabricated filters. (The designed centre frequency of the filter is 4.95 GHz. However, centre frequency of fabricated filter is different due to variations of dielectric constant of the MgO substrate. This is because the frequency is normalized.)

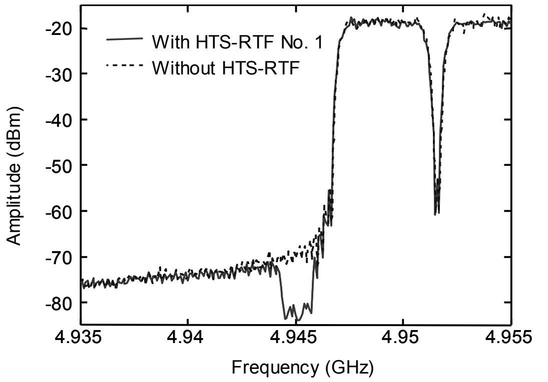

Fig. 2 The typical measured output spectrum obtained with and without the HTS-RTF No. 1 [8].

and that of the upper 3 dB edge of the filter are the same.

Since the HTS-RTFs have very sharp cutoff characteristics whose slopes are better than 60 dB/MHz, the filters suppress only noise without any effects on carrier signals. In addition, Fig. 3 shows measured ACLR values obtained by using HTS-RTFs. Note that the bandwidth for the ACLR evaluation is 3 dB bandwidth of each filter. It is the different point than that specified [9]. However, the important point is that the ACLR improvement effects are constant up to the 40 dBm output power. The maximum improvements of the HTS-RTF No. 1 and No. 2 are 11.0 dB and 4.4 dB, respectively.

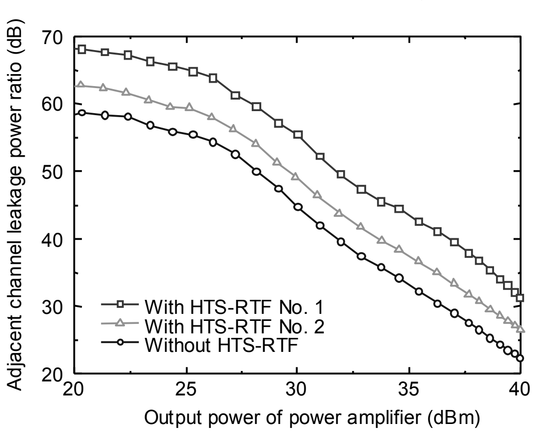

Fig. 3 The measured ACLR values obtained by the HTS-RTFs. (Note that the bandwidth for the ACLR evaluation is 3 dB bandwidth of the each filter.)

From these measured ACLR values, we can clarify the following points. The HTS-RTF is capable of suppressing IMD generated by a high-power amplifier which has more than 40 dBm output power. The maximum improvement is more than 10 dB. For further improvements, the suppression band should be wider as much as possible. In addition, as the ACLR values obtained using HTS-RTF No. 2 show, strong ripples in the stopband greatly reduce the improvement.

III. ENHANCEMENT OF ACLR IMPROVEMENT PERFORMANCE

A. Optimization of split open-ring resonator structure

To achieve wider suppression band and further improvement of the ACLR, the resonator structures are optimized. The SORR is employed in the HTS-RTF. The SORR is adjusted to achieve low surface current density in the passband signal and high unloaded Q-factor (Q_u) as well as low radiation [10].

To maintain sharp skirt properties while offering the wider suppression band, Q_u values should be higher. Fig 4 shows the structure of the SORR and the open-ring resonator. The width of the resonator element *w* and the resonator gap *g* are changed to achieve high Q_u values and low surface current density. Fig. 5 shows calculated Q_u values and maximum induced current densities when *w* and *g* are changed. The method of moments is used for the analysis. For current density analysis, the input signal is a sinusoidal wave with 1V amplitude and 5 MHz offset away from resonance frequency, which assumes the passband signal. The SORR with w = 0.4 mm and g = 0.3 mm is used for the HTS-RTF so far [8]. As shown in Fig. 5, we can obtain 25 % higher Q_u values (60,200) and 19 % lower current density by using the SORR with w = 0.8 mm and g = 0.4 mm.

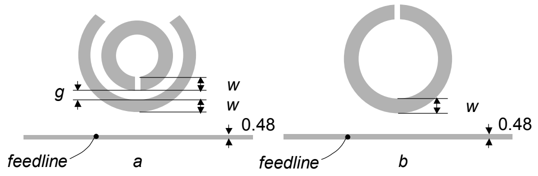

Fig. 4 The structure of (a) the split open-ring resonator and (b) the open-ring resonator. (Each resonator is adjusted diameter to resonate at 4.95 GHz. All dimensions in millimetres.)

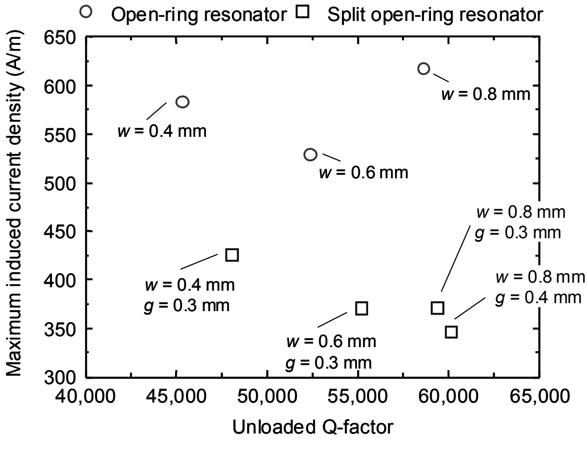

Fig. 5 The calculated unloaded Q-factor and maximum induced current density of the split open-ring resonator and the open-ring resonator.

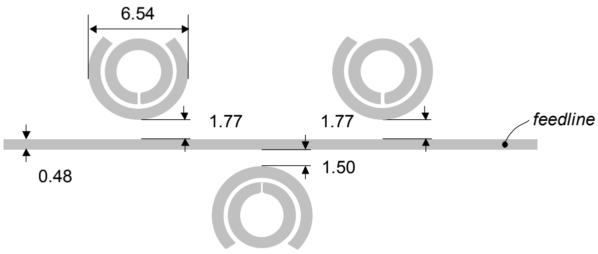

Fig. 6 The geometry of the 5-GHz HTS-RTF using the SORR with $w = 0.8$ mm and $g = 0.4$ mm. (The HTS-RTF for higher suppression band is shown. All dimensions in millimetres.)

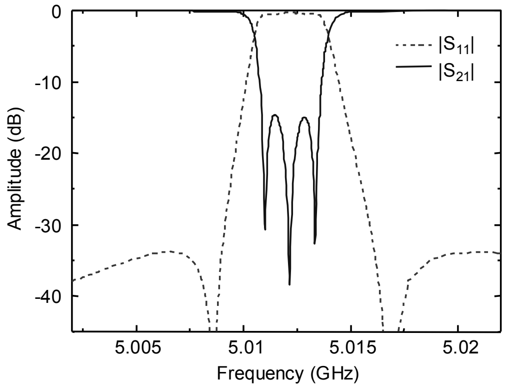

Fig. 7 The calculated frequency response of the 5-GHz HTS-RTF using the SORR. (HTS-RTF for higher suppression band.)

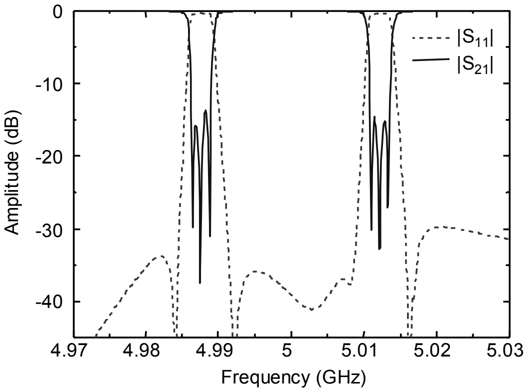

Fig. 8 The calculated frequency response of the series-connected two HTS-RTFs by quarter wavelength line.

B. Design of a 5-GHz HTS-RTF using the optimum SORR

A 5-GHz HTS-RTF using the SORR with $w = 0.8$ mm and $g = 0.4$ mm has been designed. The purpose of the new design is to increase the suppression band by using a high-Q_u resonator without degrading skirt properties. In addition, to suppress either the lower or higher adjacent channel, two filters are connected by a quarter wavelength line. The spacing between the two suppression bands is 20 MHz. This is because the filters are applied to the W-CDMA four-carrier signal.

The filters are designed to have a bandwidth of 3.5 MHz, a stopband centre frequency of $f_0 = 4.988$ GHz and 5.012 GHz and a three-pole Chebyshev response with 0.01 dB response [11]. The geometry of the filter, which has a higher suppression band, is shown in Fig. 6. The calculated frequency response based on the method of moments is shown in Fig. 7. As shown in the figure, a wider bandwidth compared to the HTS-RTF No. 1, while keeping very sharp cutoff characteristics, is obtained. Fig. 8 shows the frequency response of the series-connected two HTS-RTFs.

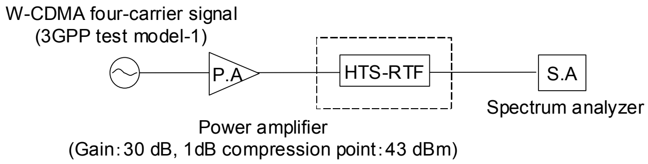

Fig. 9 The schematic diagram of the ACLR estimation using W-CDMA four-carrier signal.

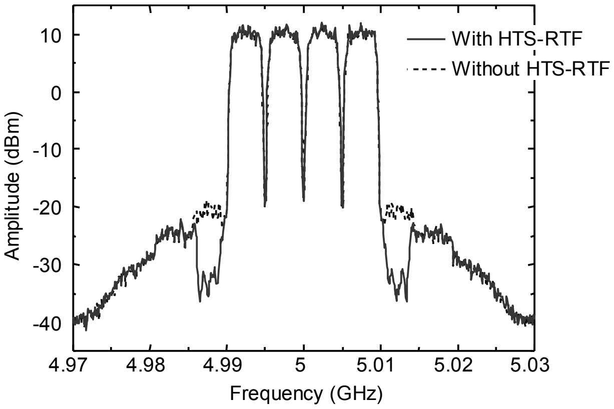

Fig. 10 The typical analysed output spectrum with and without the designed HTS-RTFs. (The total input power: 8 dBm. The power amplifier output back-off: 5 dB.)

IV. ACLR IMPROVEMENT AND POWER AMPLIFIER BACK-OFF

To investigate ACLR improvement offered by the newly designed HTS-RTFs, the ACLR values are analysed. In addition, improvement of amplifiers' back-off is discussed based on the obtained results.

The data flow analysis provided from Agilent technologies' Ptolemy simulator [12] is used for the estimation. Fig. 9 shows the schematic diagrams for the ACLR estimation. The W-CDMA four-carrier signal (3GPP test model-1) and quasi-linear power amplifier, which have a gain of 30 dB and a 1 dB compression point of 43 dBm, are modelled. In addition, the S-parameters of the HTS-RTFs are inserted just after the power amplifier, in the same way as the ACLR measurements described in section II.

Fig. 10 shows the typical analysed spectrum obtained with and without the designed HTS-RTFs. The IMD in the higher and lower 5 MHz adjacent channel, which is generated by the power amplifier, is suppressed by the filters. In addition, Fig. 11 shows the ACLR values of the lower 5 MHz adjacent channel. This ACLR is evaluated for 3.84 MHz. This is the same bandwidth as the specification [9], and was not evaluated for the 3 dB filter. The maximum improvement of ACLR is 10.0 dBm. For the lower 5 MHz adjacent channel, the average improvement between output powers of 25 dBm to 42 dBm is 9.2 dB. Furthermore, as shown in Fig 11, we can obtain the same ACLR value at about 5 dB increased output power when the HTS-RTFs are used for the amplifier.

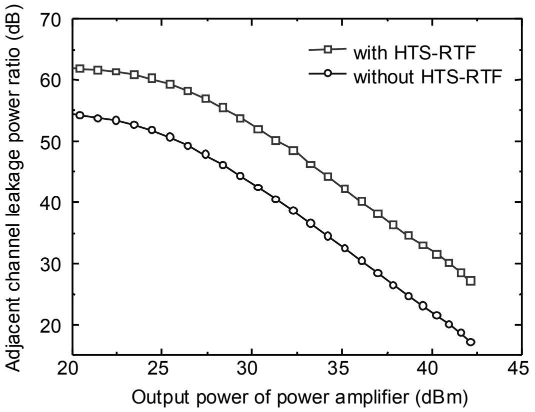

Fig. 11 The analysed ACLR values of lower 5 MHz adjacent channel obtained by the HTS-RTFs. (Note that the bandwidth for the ACLR evaluation is same as the specification [9].)

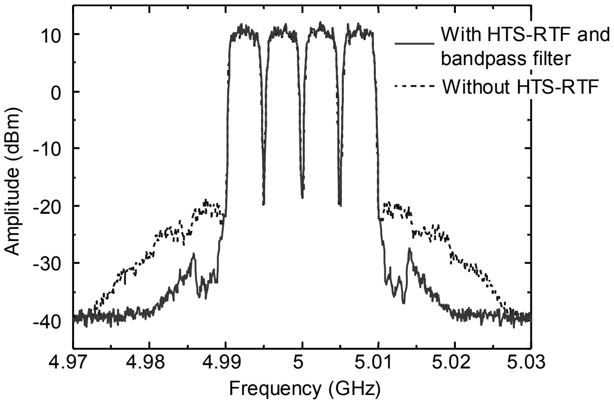

Fig. 12 The typical analysed output spectrum with and without the designed HTS-RTFs with additional band pass filter. (The total input power: 8 dBm. The power amplifier output back-off: 5 dB.)

The amplifiers' back-off can be reduced by 5 dB when the HTS-RTFs are applied for the power amplifier. As an HTS-RTF achieves ACLR improvement without using the nonlinear compensation technique, this advantage will lead to transmitting circuits with simple and low energy operation.

The IMD of 10 MHz adjacent channel cannot be suppressed by the HTS-RTFs shown in Fig. 8. One solution is to increase the number of the HTS-RTFs' resonator, in order to further widen the stopband. Another solution is to combine the use of an HTS-RTF and a bandpass filter. We are carrying out investigations for the combination of the HTS-RTFs and HTS transmitting bandpass filter. Fig. 12 shows the analysed output spectrum with an additional bandpass filter with 15 dB/5 MHz slope. In this case, it is confirmed that the ACLR of 5 MHz adjacent channels improved by about 12 dB. In addition, the ACLR of 10 MHz adjacent channels improved by about 14 dB.

V. CONCLUSIONS

An ACLR improvement method of a 5-GHz power amplifier using HTS-RTF was proposed. The measurement results of ACLR improvement were introduced and some issues relating to practical applications were discussed. To achieve a wider suppression band, the structure of the SORR was investigated based on numerical analysis. The 5-GHz HTS-RTF with 3.5 MHz suppression bands in both sides of the carrier signal was designed using optimum SORRs. In addition, to investigate the applicability for spread spectrum signal and actual transmission circuits, ACLR improvements offered by the HTS-RTF were analysed. The ACLR was improved by about 10 dB in the both sides. Furthermore, the results show that amplifiers' back-off can be reduced by 5 dB when the HTS-RTFs were applied for the power amplifiers.

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