Design and performance of superconducting filter with a linear phase for CDMA2000 communication system

JI LaiYun1, MA Jie1,2, SUN Jun1, WANG Lang1, LI YanQi1, XU KaiWei1, XIAO GuoDong1 & REN JianCheng1

1 Tianjin Hi-Tech Superconducting Electronic Technologies Co. Ltd, Tianjin 300384, China; 2 Department of Information Engineering, Hebei University of Technology, Tianjin 300130, China

Received June 14, 2009; accepted August 22, 2009

Abstract A high temperature superconducting (HTS) filter with a linear phase is designed for CDMA2000 communication systems. The principle and equivalent model of the filter have been presented. The theoretical result, coupling matrix, and the simulated result with Sonnet software have also been demonstrated. The desired filter with 12-pole and 2 cross couplings has a center frequency of 830 MHz. The measurement results show that the response of practical filters is in good agreement with that of simulated results and theoretical analysis, the group delay variation is less than ±10 ns over 60% of the filter bandwidth, and the skirt slope of the filter is about 37 dB/MHz.

Keywords HTS filter, linear phase, group delay, CDMA2000 communication system

1 Introduction

With the development of high temperature superconducting materials in recent years, filter systems will have considerably improved performance over conventional systems. An HTS filter is superior to a traditional filter in low insertion loss and good frequency selectivity. The sensitivity of receiver subsystem in mobile systems will be increased, thus expanding the coverage area increasing call clarity, reducing the number of dropped calls, and improving interference rejection and the quality of service. Therefore, HTS filters will have wider applications to wireless communication systems, satellite communication system, and high-sensitivity receiving system. STI has developed HTS filter subsystems for mobile base station applications in North America and over 6000 HTS subsystems are operating today in public wireless networks. In China, Hi-Tech Superconducting Technology Co. and Tsinghua University have carried out related researches on HTS filters and constructed filter subsystems [1, 2] based on HTS method for cellular CDMA base stations.

In 2 G/2.5 G mobile communication systems, HTS filters must meet the requirements of high selectivity rather than a linear phase. However, a flat group delay filter will be demanded in addition to its selectivity.

*Corresponding author (email: jilaiyun@hstnets.com; jilaiyun@163.com)
in 3G mobile communication systems. Consider a standard Chebyshev filter, in which high degree model will have a high attenuation slope at passband edges. There is a big variation of the group delay between its center frequency and upper/lower sideband. Consequently, high frequency signal will have a high phase distortion when it is filtered by HTS filters with severe distortion of the group delay. If these filters are used for the receiver subsystem, distortion of the group delay will impact communication quality and increase error code rate in digital mobile systems.

We have developed an HTS linear phase filter with high degree and narrow band. According to a low-pass prototype filter, a practical 12-pole linear phase filter with 2 cross couplings has been fabricated and skit slope of the filter has been improved at the same time to achieve the group delay self-equalization. Finally, measurement results show that the described filter meets the requirements of linear phase specification.

2 The basic theory of linear phase filters

Two approaches are used to solve the distortion of group delay in RF communication systems. The first method is called external equalization, which uses an external phase shift equalizer cascaded with band pass filter. In this case, the external equalizer has an opposite delay characteristic to that of the cascaded band pass filter and flat group delay of a band pass filter would be ideally achieved. The second approach is referred to as a self-equalized filter. In this method, cross coupling is introduced between nonadjacent resonators, the transmission zeros are placed on the real axis of a complex frequency plane by controlling the sign of the cross coupling, and a flat group delay characteristic would be generated automatically. In the last few years, HTS scientists have carried out a lot of researches [3, 4] on the design of HTS linear phase filters and some good achievements have been obtained.

Traditionally, external group delay equalizer would be cascaded with a circulator or 3 dB directional coupler and return resonators. Thus, this external equalization system will have a large volume and can cause some problems for miniaturization of HTS filters. In this paper we present a self-equalized HTS filter at a center frequency of 830 MHz, which is designed for CDMA2000 mobile communication systems with group delay characteristics of linear phase. To further consider practical applications at RF frequency and lower sensitivity to fabrication tolerances, we use broader passband bandwidth in the design of the HTS filter.

Rhodes [5] developed a lowpass prototype network for the design of linear phase bandpass filters with an even degree of \( n = 2m \). Figure 1 shows this lowpass network. The characteristic admittance \( J \) of main line immittance inverters is normalized to a unity value. The characteristic admittance \( J_{i} \) to \( J_{m-i+1} \) represents the cross coupling between nonadjacent resonators, whereas the characteristic admittance \( J_{m} \) stands for the direct coupling of two symmetrical parts.

We firstly can get an equivalent model of the filter circuit for implementation with microwave structures. Then a 12-pole linear phase filter for CDMA2000 is designed, which has 2 cross couplings. The circuit elements of equivalent model in filter synthesis are optimized using CAD software and the desired lowpass prototype parameters can further be obtained.

From the circuit elements of the lowpass prototype filter, the external quality factor and coupling coefficients for the linear phase filters can be written as (see [6])

\[
Q_e = \frac{g_{1}}{FBW},
\]

\[
M_{i,i+1} = M_{n-i,n-i+1} = \frac{FBW}{\sqrt{g_{i} g_{i+1}}}; \quad i = 1, 2, \ldots, \frac{n}{2} - 1,
\]

\[
M_{i,n+1-i} = \frac{FBW \cdot J_{i}}{g_{i}}, \quad i = 1, 2, \ldots, \frac{n}{2},
\]

where \( n \) is the resonator number and \( FBW = \Delta f / f_{0} \) is the fractional bandwidth of the filter.

If we substitute the circuit elements of the lowpass prototype filter into eqs. (1)–(3), a coupling matrix of the 12-pole filter with 2 cross couplings may be demonstrated as follows: