NARROWBAND FILTER AND ANNULAR SLOT ANTENNA FOR PCS APPLICATIONS

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ABSTRACT

A new narrowband filter has been developed for PCS applications. This filter has a 0.2 dB passband ripple bandwidth of 0.568% and is 60% smaller than the normal parallel coupled design. The filter can be integrated with the microstrip feedline of a novel annular slot antenna (ASA). The ASA has a 4.5% bandwidth and a planar structure. This antenna can be conveniently located on the chassis of a mobile PCS unit.

I. INTRODUCTION

A narrowband filter with high skirts and low insertion loss is essential for reducing the noise and improving the signal quality of mobile PCS units. A number of high temperature superconducting filters with large number of poles have been proposed and demonstrated with excellent performances[1, 2]. These filters have applications in the base stations where the size, weight and power considerations are not very critical. Here, the size and power consumption of the cryogenic units required to cool the filters can be accommodated. Alternate design methods must be used for filters used in mobile units.

In this paper, we present a narrowband filter and an annular slot antenna (ASA) for PCS applications. A wideband (2%) filter prototype is changed into a narrowband filter by the frequency transformation technique[1] in this paper. The monopole antenna used in present mobile units is of mechanical design (moving parts) that has reduced reliability and increased cost. An planar antenna that is flush with the body of the mobile unit makes the mobile unit more compact and increases the reliability. Also, if the antenna can be integrated with the other components of the system, then savings in cost can be realised. The ASA presented in this paper has a 4.5% 2:1 VSWR bandwidth and is centered at 1.95 GHz.

II. NARROWBAND FILTER

A bandwidth of 15 MHz in the 1.93-1.945 GHz PCS band corresponds to a fractional bandwidth of 0.77%. The filters for PCS applications must have narrow passband bandwidth, high skirt selectivity, low insertion loss and good stopband attenuation. Classical designs using parallel coupled sections require the number of sections to be high and the coupling between resonators to be loose, in order to achieve the required specifications. At these relatively low frequencies of operation, these requirements make the size of the filter to be large [1]. High temperature superconducting filters have been proposed and demonstrated with excellent performances [1, 2]. Similar, suitable filters for the mobile units are required.

A lumped element microstrip filter using capacitively loaded inductors was demonstrated to have narrow bandwidth after it was frequency transformed from a wideband prototype[1]. The wideband prototype requires relatively tight coupling between the parallel coupled sections that form the impedance/admittance invertors [1, 3]. This reduces the distance between the coupled sections and also the size of the circuit. Choosing a wideband filter with a fractional bandwidth of 2%, passband ripple less than 0.2 dB, center frequency at 1.9375 GHz and an attenuation

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greater than 30 dB at 2.015 GHz, from design charts we determine the order of the filter to be three [3]. The lowpass prototype values are also available from [3].

After a standard lowpass to bandpass transformation, it is seen that the invertors and the lumped capacitors can be realized easily by parallel coupled sections that have relatively tight coupling as compared to the classical parallel coupled filters. The inductors of the bandpass prototype are transformed into frequency dependent inductive elements whose change in inductance with frequency is given by following equation[1]:

$$\frac{\Delta\omega}{\omega_0} = \frac{1}{1 + \frac{\omega_0}{2L}\frac{dL'(\omega_0)}{d\omega}} \frac{\Delta\omega_0}{\omega_0} \qquad (1)$$

$\Delta\omega/\omega_0$ is the fractional bandwidth of the narrowband filter, $\Delta\omega_0/\omega_0$ is the fractional bandwidth of the wideband prototype, $L'(\omega)$ is the frequency dependent element, ω is the radian frequency, ω_0 is the center radian frequency and L is the inductance of $L'(\omega)$ at ω_0. The slope of the frequency dependent inductor can be calculated from equation (1). This element can be realised by a parallel capacitance and inductance. A interdigital capacitor and a thin inductive line in parallel can be realised easily in microstrip circuits. Once this element is designed, the design of the rest of the filter is trivial.

For low frequency operations, simple simulation software like EEsof's Libra can be used for circuit simulation, provided the required circuit element models are available. The results presented in this paper have been simulated on EEsof's Libra and the agreement is good. After preliminary handcalculated design of the elements, optimization routines were used to obtain the required center frequency and input matching. The filter is shown in Fig. 1. The circuit was fabricated on a RT-Duroid substrate of thickness 1.27 mm, relative dielectric constant ϵ_r=10.8 and 1 oz. metallization. The inductive line was designed to be 0.113 mm wide. The simulated performance of the filter is shown in Fig. 2. The 0.2 dB passband ripple bandwidth was 0.57% and insertion loss at the center frequency was 4.85 dB. The return loss for the simulation was less than 20.0 dB in the passband. The insertion loss is predominantly due to the dielectric loss ($\tan\delta$=0.0023) and the metallization loss. Table 1 gives the simulated insertion loss for various substrates. Dielectric loss contributes to about 2 dB of insertion loss. Attenuation of the filter was at least 38 dB down at 1.66 GHz and 2.2 GHz.

After fabrication, the inductive line width was found to vary between 0.15 mm and 0.175 mm. Similar variations were observed in the dimensions of the interdigital capacitors and other elements. The circuit on measurement was seen to exhibit two distinct resonances at 1.9475 GHz and 2.045 GHz. Simulation of the circuit with the actual etched dimensions, yielded results identical to the measured ones, with two resonances. After tuning the circuit, the measured performance shown as Fig. 3 was obtained. The center frequency shifted to 2.052 GHz and the insertion loss was 5.0 dB. The measured 0.2 dB ripple passband bandwidth was 0.45%. The measured return loss was less than 15.0 dB in the passband. Tighter tolerances for the circuit dimensions should result in performance identical to Fig. 2. The circuit is 54.3 mm by 65 mm and is at least 60% smaller than a parallel coupled bandpass filter of similar specifications.

III. ANNULAR SLOT ANTENNA

In PCS applications, the mobile unit requires an omnidirectional radiation pattern. Annular slot antennas (ASA) as shown in Fig. 4 can be used for PCS applications. These antennas when operated in the TM_{11} mode have broadside radiation patterns and good gain. These antennas are planar and can be fabricated on the outer surface of the mobile unit, with or without a radome. These are excited easily by a microstrip feedline on the back side of the antenna. The narrowband filter can be integrated into the microstrip feedline. The metallization of the ASA serves as the ground plane for the microstrip lines. The ASA can be designed easily using the approximations given in [4]. For a good microstrip-slotline transition, the microstrip line must terminate with an open circuit and the slotline must terminate with a short circuit, each a quarter-wavelength from the transition. It has been shown that a short on the slotline ring at 90^0 from the transition results in a circular polarization for the ASA radiation and increases the impedance bandwidth of the ASA to about 10% [5]. Also, theoretically this short results in a good transition. In practice, the matching at the transition depends on the inner and outer radii of the slotline ring and the width of the microstrip line.

In our design, the inner and outer radii of the ASA were 14.79 mm and 18.29 mm respectively. The thickness of the substrate was 1.27 mm and the relative dielectric constant, ϵ_r was 10.8. A 50Ω microstrip line was used to excite the antenna. The short was at an angle, θ of 30^0 from the transition. The measured return loss is shown in Fig. 5. The return loss at 1.9375 GHz is -16.3 dB which makes the ASA suitable for PCS applications. In published literature, the gain of a 10 GHz slot antenna was 6.5 dB [4] and that of a 900 MHz antenna was 9 dBic [5]. These figures compare favourably with those of the monopole antenna (an ideal directivity of 5.1 dB).

IV. CONCLUSIONS

The narrow bandwidth obtained for the frequency transformed filter shows that miniature filters with good performance can be designed for PCS applications. The use of low loss, high dielectric constant substrates is essential in obtaining the savings in size. The cost of these materials is high. However, by integrating many functions such as the planar annular slot antenna, narrowband filter and an amplifier to form a high performance front end block, savings in cost may be obtained.

References

[1] D. Zhang, G. C. Liang, C. F. Shih, and R. S. Withers, "Narrowband lumped-element microstrip filters using capacitively-loaded inductors," in 1995 *IEEE Int. Microwave Symp. Digest*, May 1995, pp. 379-382.

[2] D. Zhang, G. C. Liang, C. F. Shih, Z. H. Lu, and M. E. Johansson, "A 19-pole cellular bandpass filter using 75-mm-diameter high-temperature superconducting thin films," *IEEE Microwave and Guided Wave Lett.*, vol. 5, no. 11, pp. 405-407, Nov. 1995.

[3] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*, Norwood, MA.: Artech House.

[4] K. D. Stephan, N. Camilleri, and T. Itoh, "A Quasi-optical polarization-duplexed balanced mixer for millimeter-wave applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, no. 2, pp. 164-170, Feb. 1983.

[5] H. Morishita, K. Hirasawa, and K. Fujimoto, "Analysis of a cavity-backed annular slot antenna with one point shorted," *IEEE Trans. Antennas Propagat.*, vol. AP-39, no. 10, pp. 1472-1478, Oct. 1991.

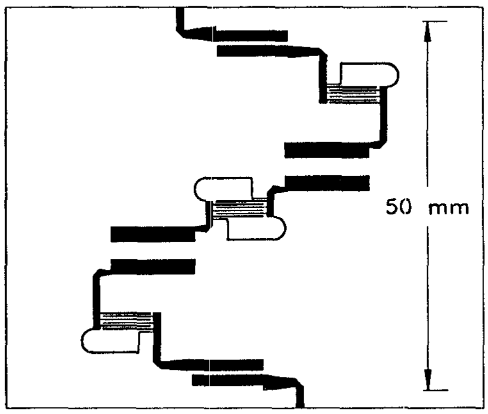

Figure 1: Narrowband Filter for PCS Applications

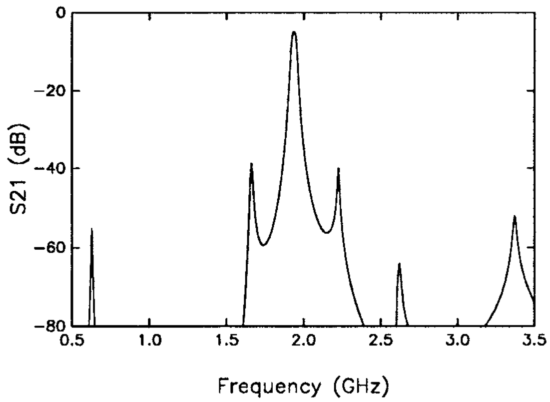

Figure 2: Simulated S21 results of filter

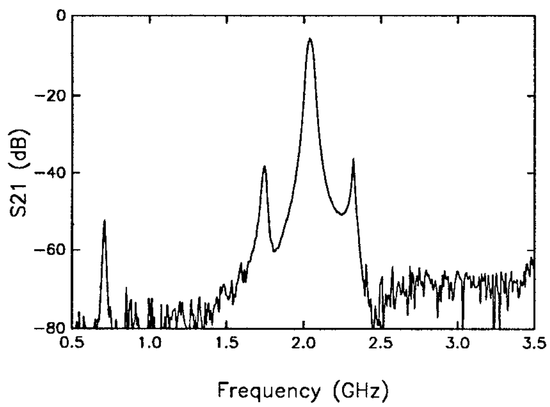

Figure 3: Measured S21 results of filter

Substrate	Dielectric Loss (dB)	Total Insertion Loss (dB)
RT-Duroid $\epsilon_r = 10.8$ $\tan\delta = 0.0023$	2.02	4.85
CB $\epsilon_r = 29$ $\tan\delta = 0.0004$	0.4	3.23
MCT-40 $\epsilon_r = 40$ $\tan\delta = 0.002$	1.75	4.58
D-50 $\epsilon_r = 50$ $\tan\delta = 0.0005$	0.47	3.3

Table 1: Simulated loss of narrowband filter on various substrates

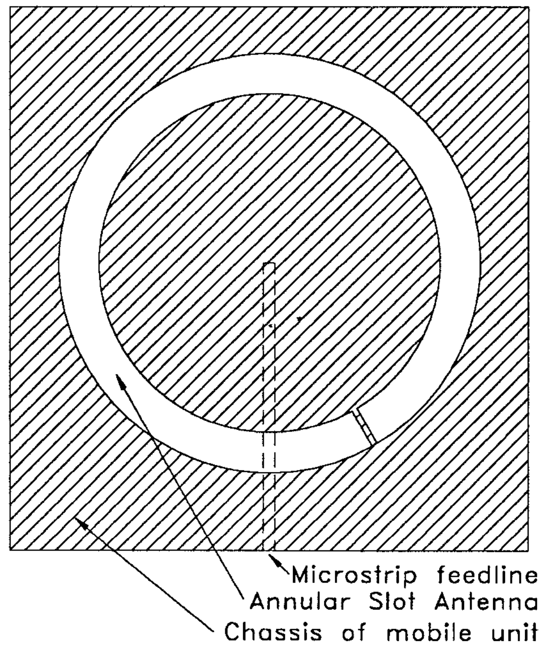

Figure 4: Annular slot antenna

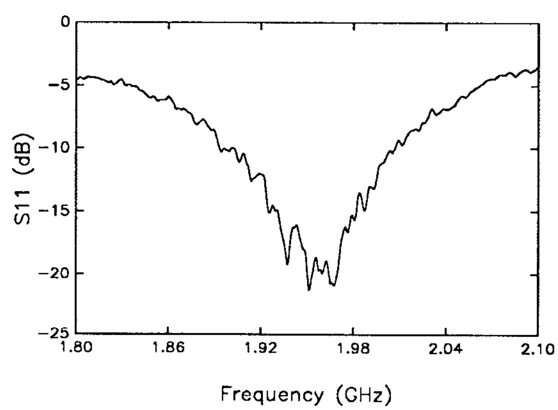

Figure 5: Return loss of annular slot antenna