IN-33
36535
P-11

NASA Technical Memorandum 105142

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K.S. Kong
University of Texas at Austin
Austin, Texas

K.B. Bhasin
Lewis Research Center
Cleveland, Ohio

and

T. Itoh
University of California, Los Angeles
Los Angeles, California

Prepared for the
Optical Engineering and Photonics in Aerospace Sensing Symposium
sponsored by the International Society for Optical Engineers
Orlando, Florida, April 1-5, 1991

NASA

E-6416

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K.S. Kong
Department of Electrical and Computer Engineering
The University of Texas at Austin
Austin, Texas 78712

K.B. Bhasin
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

T. Itoh
Department of Electrical Engineering
The University of California, Los Angeles
Los Angeles, California 90024

ABSTRACT

The high T_C superconducting microstrip line and coplanar waveguide are compared in terms of the loss characteristics and the design aspects. The quality factor "Q" values for each structure are compared in respect to the same characteristic impedance with the comparable dimensions of the center conductor of the coplanar waveguide and the strip of the microstrip line. Also, the advantages and disadvantages for each structure are discussed in respect to passive microwave circuit applications.

2. INTRODUCTION

There has been a significant effort to develop high Tc superconducting film on various substrates for low loss microwave circuit applications[1,2]. Resonator circuits based on transmission line structures, such as microstrip line and coplanar waveguide, have been used to obtain losses in superconducting films. Models have also been developed to calculate losses in these films and in some cases comparison made to experimental results[3,4]. Presently, microstrip line is more widely used because there are more design information available about the structure as compared to coplanar waveguide structure. However, it is expected that the coplanar waveguide should get more attention because it needs only one sided film as opposed to microstrip line which requires double sided film.

In this paper, we compare the two superconducting transmission line structures in respect to their application to passive microwave circuits. The loss characteristics of the two structures are compared and discussed. In order to achieve this goal, we calculate the conductor losses of the high T_C superconducting coplanar waveguide and microstrip line by Phenomenological Equivalence Method[5,6]. Also, the dielectric loss between the two structures is compared since the dielectric loss becomes a critical design aspect in the superconducting transmission line structures as the conductor loss is reduced. In conclusion, we also discuss their advantages and disadvantages.

3. CALCULATION OF THE CONDUCTOR LOSS

The phenomenological loss equivalence method[7] is used to calculate the conductor loss of the microstrip line and the coplanar waveguide. In this paper, only key steps will be explained. The main idea of this method is to transform the transmission line into the single equivalent strip which has the same conductor loss as the original transmission line structure. For each structure, the single equivalent strip is obtained by considering the field penetration into the conductors[5,6].
The width of the equivalent strip is expressed in term of G factor.

$$W_e = \frac{1.0}{G} \quad (1)$$

Then, the thickness of the equivalent strip is obtained

$$t_e = AG \text{ (Microstrip line: } A= W \times t\text{, Coplanar waveguide: } A= S \times t \text{)} \quad (2)$$

The internal impedances of the microstrip line and the coplanar waveguide are expressed as

$$Z_i = G\, Z_S \coth(Z_S \sigma_{SC} AG). \quad (3)$$

where Z_S and σ_{SC} are the surface impedance and the conductivity value of the superconductor. The surface impedance (Z_S) of the superconductor is expressed as

$$Z_s = \sqrt{\frac{j\omega\mu_o}{\sigma_{sc}}} \quad (4)$$

with the two-fluid model for the conductivity σ_{SC}. Then, the propagation constants(γ) of the structures are calculated by using the transmission line model by adding the internal impedance to the external inductance and the capacitance.

$$\gamma \text{ (propagation constant) } = \alpha \text{ (attenuation constant) } + j\beta \text{ (phase constant)} \quad (5)$$

Then, the quality factor "Q" value of the resonator is calculated as

$$Q \text{ (Quality Factor) } = \frac{\beta}{2\alpha} \quad (6)$$

4. COMPARISON OF SUPERCONDUCTING MICROSTRIP LINE AND COPLANAR WAVGUIDE STRUCTURES

In this section, the characteristics of the superconducting microstrip line and coplanar waveguide are compared in respect to the conductor loss, substrate loss and the flexibility of a design. Fig.1 shows the configurations of the microstrip line and the coplanar waveguide, and the parameters of a superconductor. The comparison of the microstrip line and the coplanar waveguide in respect to loss characterization should be done carefully since two structures have different configurations. The difficulty comes from the fact that the conductor loss depends on not only the configuration but also the size of the transmission line structure. Therefore, the dimensions of each structure in comparison should be carefully selected with a certain design criteria for the meaningful comparison.

First, we compare the conductor losses in the microstrip line and coplanar waveguide which have same characteristic impedance with comparable dimensions of the center conductor of the coplanar waveguide and the strip of the microstrip line. Fig.2 shows Q values of two structures with the variation of the frequency and the temperature. It is observed that Q values of the microstrip line are about 6.6 % higher than those of the coplanar waveguide with the given dimensions in Fig. 2.

Next, we investigate the effect of size of structures on the comparison of Q values between two structures. We compare three sets of the microstrip line and the coplanar waveguide as shown in Fig.3, where the characteristic impedance of all structures is same. In each set, dimensions of the center conductor of coplanar waveguide and the strip of the microstrip line are comparable. It is observed that differences of Q values between the microstrip line and the coplanar waveguide increase with the increased width of conductors and thickness of the substrate. Therefore, the use of a superconducting microstrip line will be more effective compared with the coplanar waveguide in terms of getting high Q as the size of the resonator becomes larger.

Now, we consider the variation of the Q values with the change of the characteristic impedance. Fig. 4 shows the comparison of the Q values between two structures with variations of characteristic impedance with a fixed substrate thickness of 254.0 μm. It is observed that the differences of the Q values between two structures decrease as the characteristic impedances of the lines increase.

As observed above, the microstrip line has higher Q values than those of the coplanar waveguide when the sizes of the conductors in each structure are comparable. Therefore, the microstrip line has an advantage in obtaining low conductor loss. However, the comparison can be carried out from the aspect of the design flexibility. When the thickness of the substrate and the characteristic impedance are given in the microwave circuit, there is only one design parameter (width of the strip) in the microstrip line while the coplanar waveguide has two parameters (the gap and the width of the center conductor). For example, with design conditions of substrate thickness of 127 μm and the characteristic impedance of 45, the microstrip line and the coplanar waveguide can be designed with parameters shown in Fig.5. In this case, the higher Q value can be obtained from the coplanar waveguide as shown in Fig. 5. Therefore, under a certain design condition, the higher Q value can be obtained by using the coplanar waveguide.

There are other aspects to consider in the application of a superconductor to transmission lines. First, the substrate loss should be considered. In superconducting transmission lines, the substrate loss becomes a important factor since the conductor loss is reduced. There have been several reported values of loss tangent of $LaAlO_3$[8,9]. However, the lack of consistency of the loss tangent values in these publications indicates the difficulty of a characterization of the substrate material for a superconducting film at the low temperature. The calculation of the substrate loss is based on the simple expression[10] and Loss tangent value of 8.3×10^{-5} is selected for the substrate loss. Fig. 6 shows the substrate losses of the microstrip line and coplanar waveguide with the given dimensions. It is observed that the substrate loss in the microstrip line is higher than the one in the coplanar waveguide. Therefore, the dielectric loss becomes more critical in the design of superconducting microstrip line compared with the coplanar waveguide. The other consideration to make is a possible degradation effect due to the high current distribution at the edges of the conductors. The coplanar waveguide has more conductor edges, where there are high current distributions.as shown in the Fig.7, compared with the microstrip line. As pointed out in [11], the conductivity of the superconductor varies with the power level. As a result, the CPW may be more affected by the degradation of the conductivity of a superconductor.

5. CONCLUSION

The comparison between the superconducting coplanar waveguide and microstrip line was presented. The superconducting microstrip line has an advantage over the coplanar waveguide structure in terms of getting less conductor loss. However, the coplanar waveguide provides the advantage over the microstrip line in the aspect of the design flexibility and the reduction of the substrate loss.

6. ACKNOWLEDGMENTS

This work was supported by U. S. Office of Naval Research under grant N00014-89-J-1006 and NASA Lewis Research Center under grant NCC3-192.

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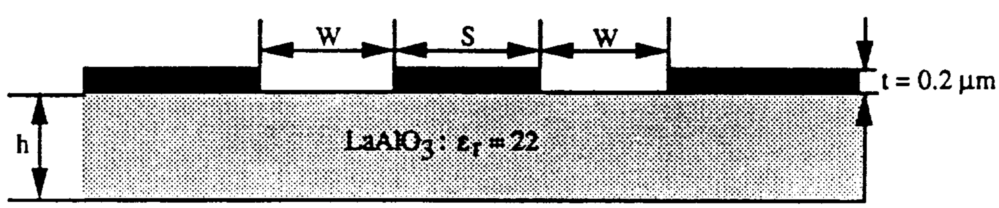
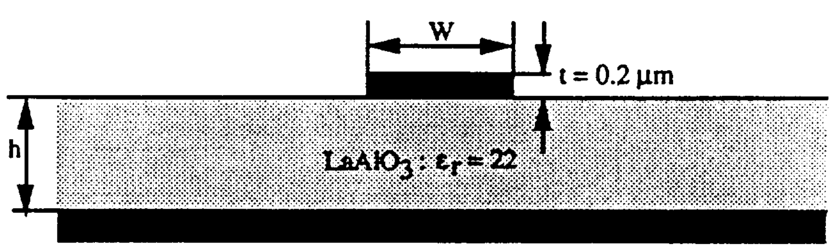
Parameters of a superconductor: $T_c = 92.5$ K, $\lambda_0 = 0.2$ μm, $\sigma_n = 1.0$ S/μm



(a) Microstrip Line.



(b) Coplanar Waveguide.

Fig. 1. Configuration of superconducting microstrip line and coplanar waveguide.

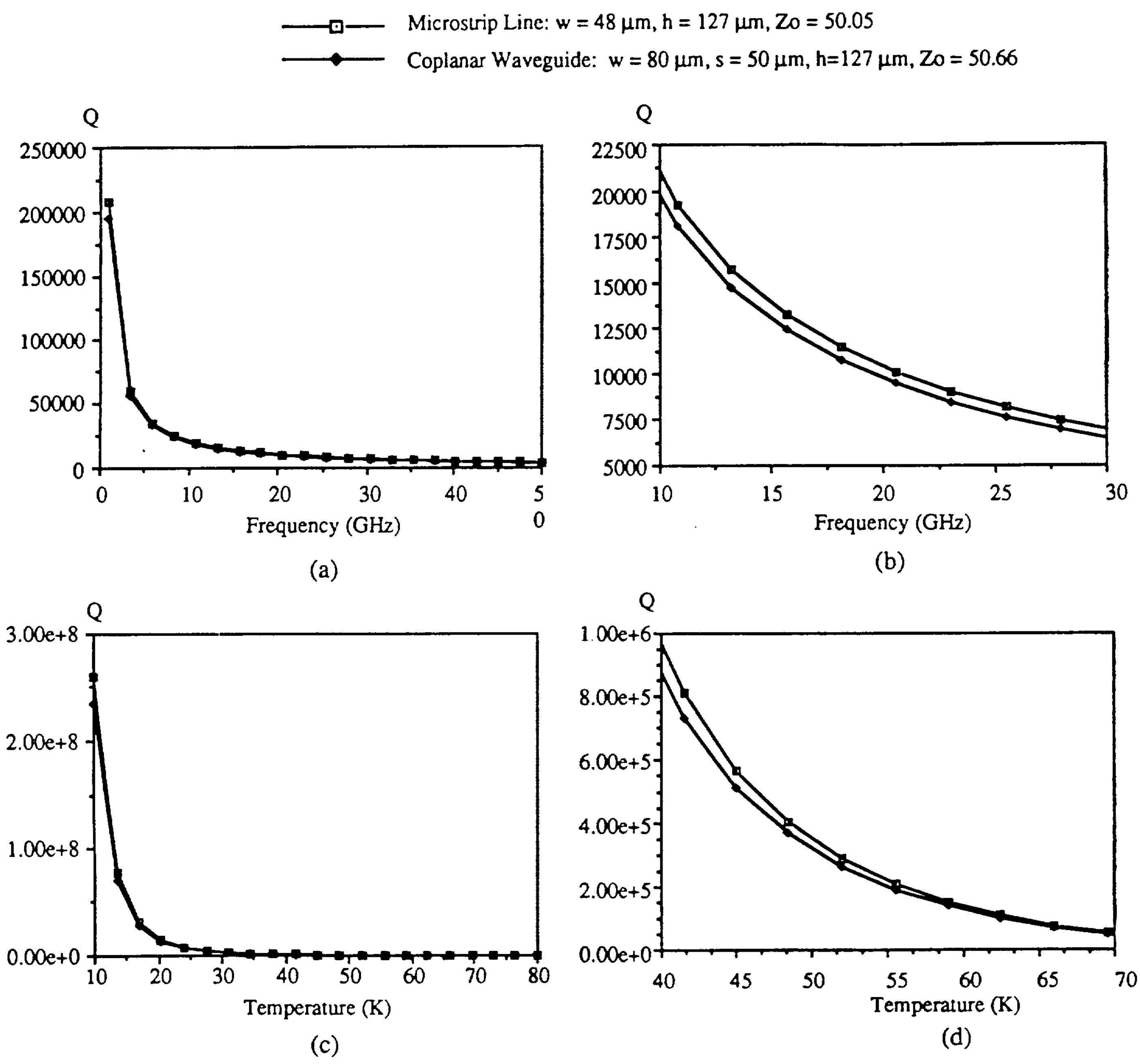
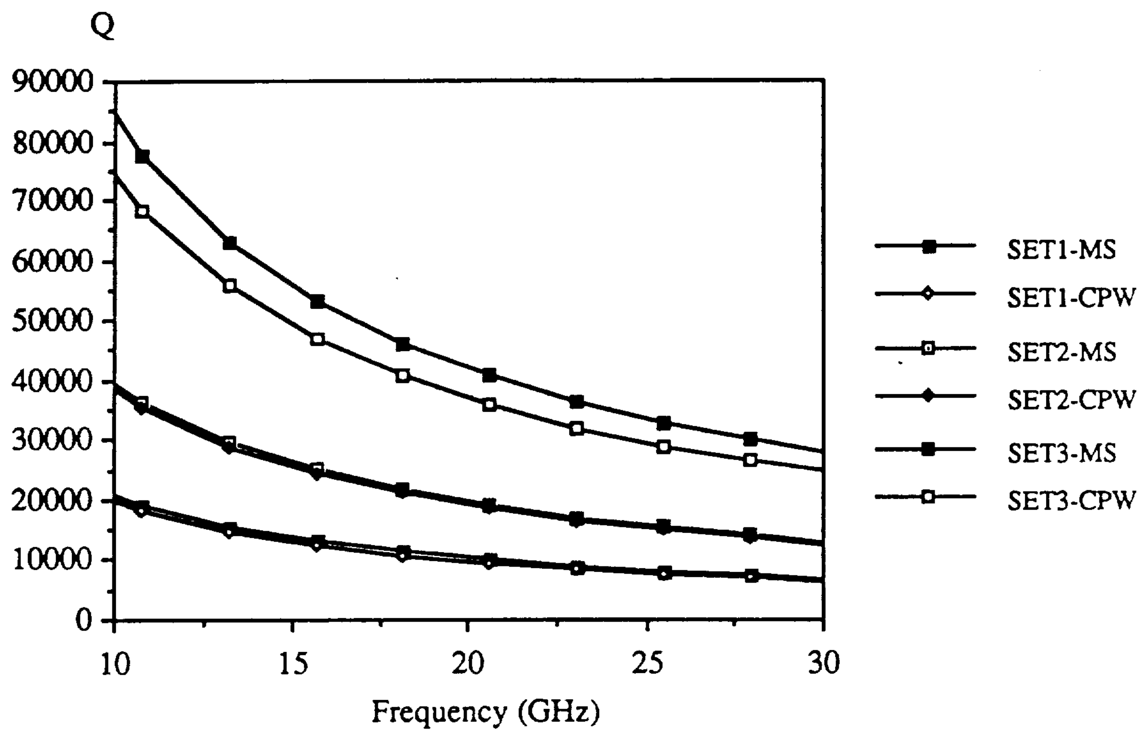
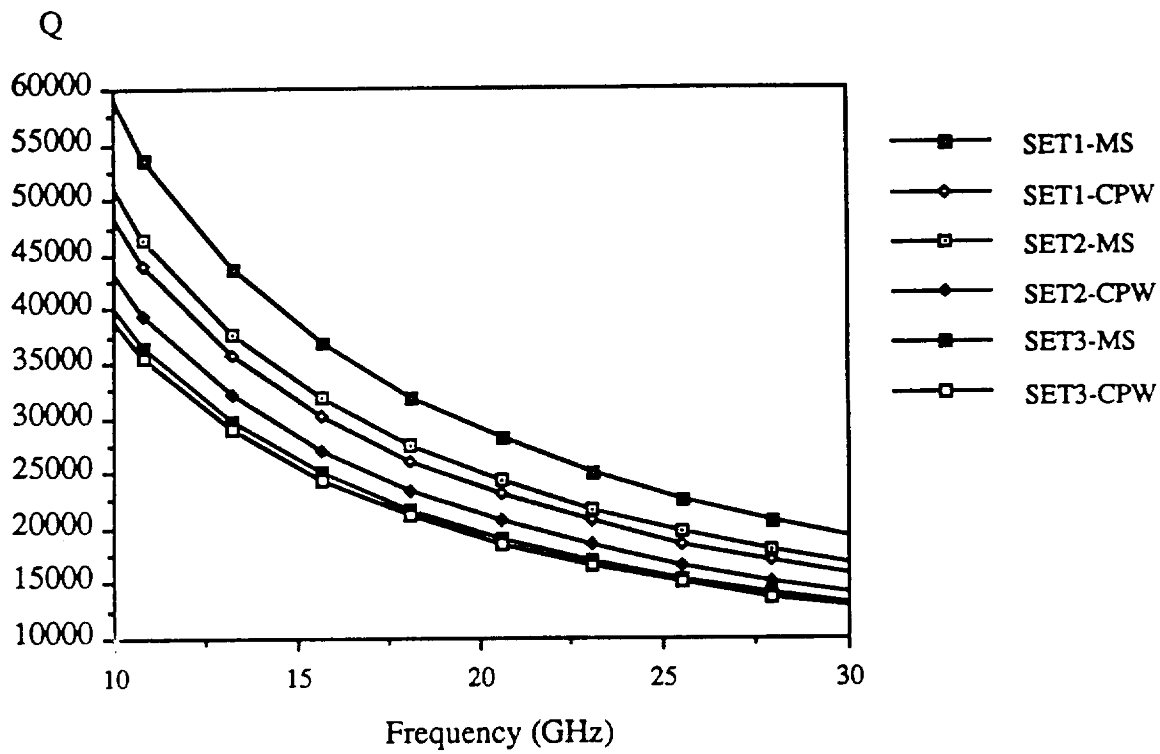


Fig. 2. Q values of the microstrip line and the coplanar waveguide.
(Parameters of the material are shown in Fig. 1)
(a) Q with the variation of the frequency.
(b) Magnified view of (a) in the frequency region from 10 to 30 GHz.
(c) Q with the variation of the temperature.
(d) Magnified view of (c) in the temperature region from 40 to 70 K.



Set 1: Microstrip Line: w = 48 µm, h = 127 µm, Zo = 50
Coplanar Waveguide: w = 80 µm, s = 50 µm, h=127 µm, Zo = 50
Set 2: Microstrip Line: w = 90 µm, h = 254 µm, Zo =50
Coplanar Waveguide: w = 160 µm, s = 100 µm, h=254 µm, Zo =50
Set 3: Microstrip Line: w = 200 µm, h = 508 µm, Zo = 50
Coplanar Waveguide: w = 300 µm, s = 200 µm, h=508 µm, Zo = 50

Fig.3 Comparison of Q values from Microstrip line and Coplanar Waveguide with with varied sizes of the structures with the characteristic impedance of 50 ohm.



Set 1 (Zo=40 ohm): Microstrip Line: w = 165 μm, h = 254 μm
Coplanar Waveguide: w = 118 μm, s =165 μm, h=254 μm
Set 2 (Zo=45 ohm): Microstrip Line: Microstrip Line: w = 130 μm, h =254 μm
Coplanar Waveguide: w = 130 μm, s = 130 μm, h=254μm
Set3 (Zo=50 ohm): Microstrip Line: w = 90 μm, h = 254 μm
Coplanar Waveguide: w = 160 μm, s = 100 μm, h=254 μm

Fig.4 Comparison of Q values from the microstrip line and coplanar waveguide with the variation of the frequency.

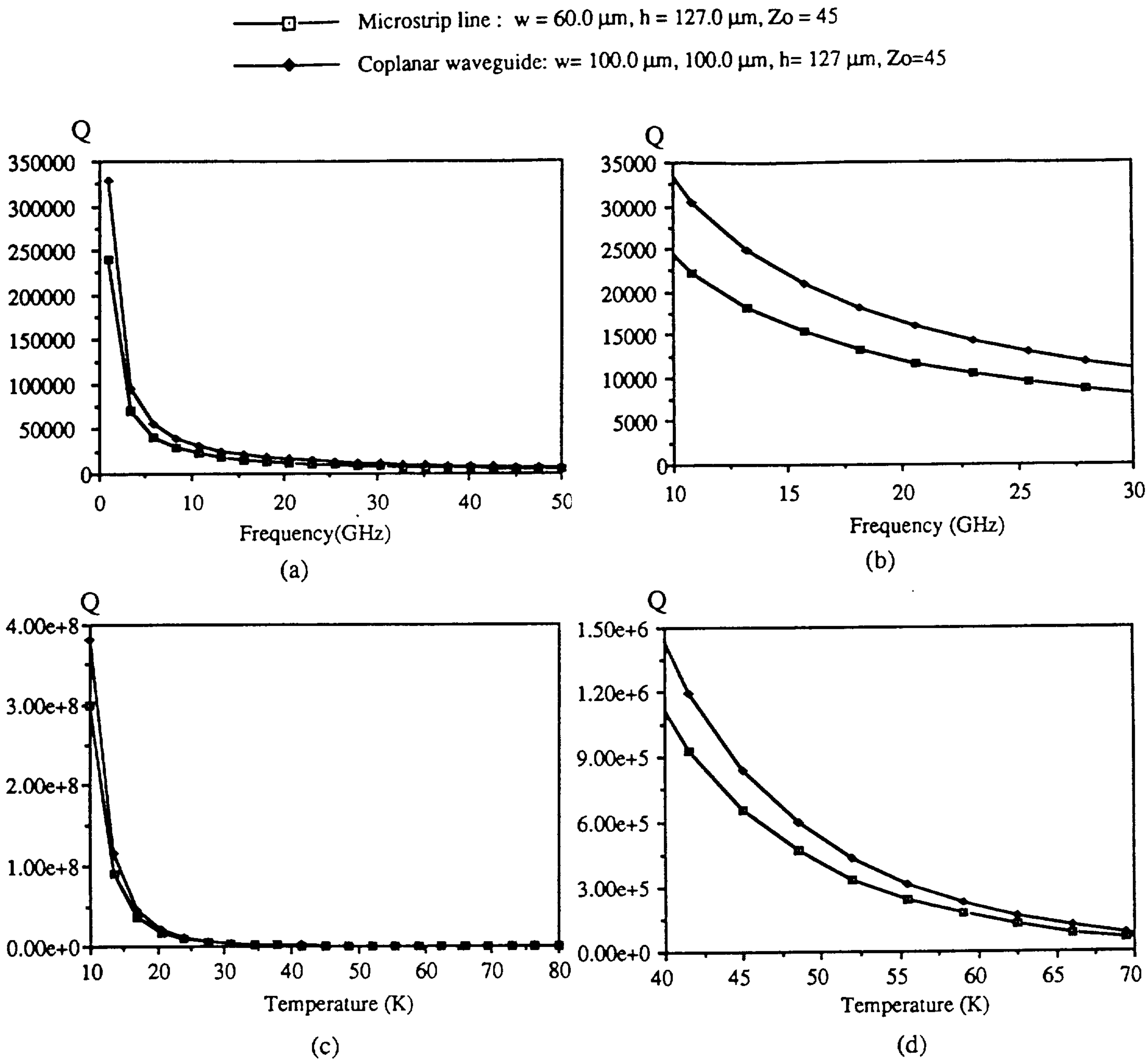
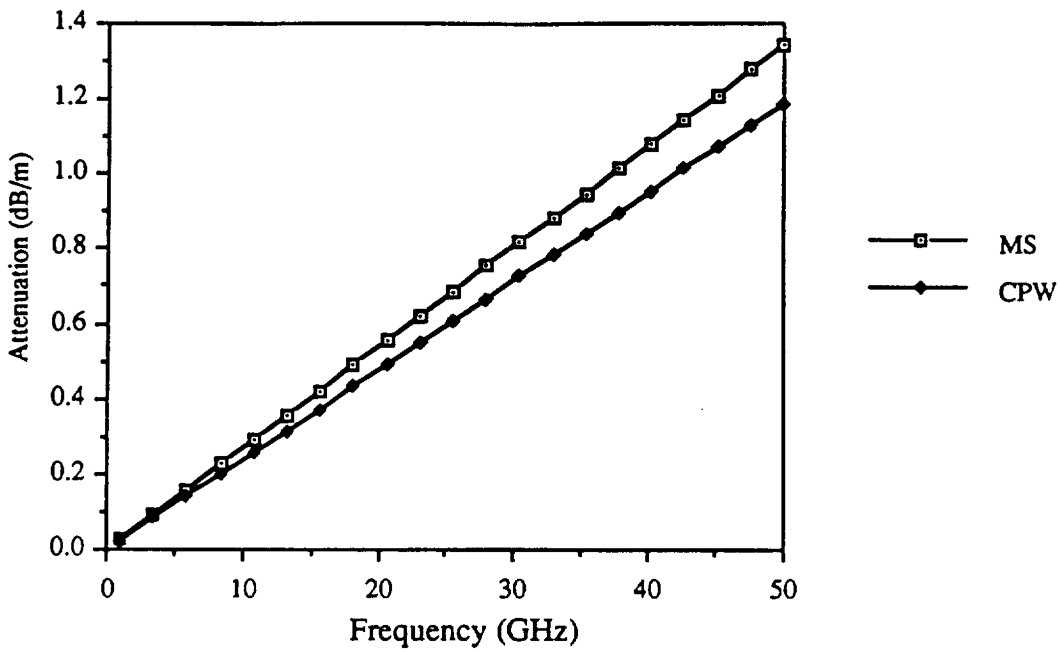


Fig. 5. Q values of the microstrp line and coplanar waveguide with same characteristic impedance but with wider dimension of the coplanar waveguide.
(Parameters of the material are shown in Fig. 1)
(a) Q with the variation of the frequency.
(b) Magnified view of (a) in the frequency region from 10 to 30 GHz.
(c) Q with the variation of the temperature.
(d) Magnified view of (c) in the temperature region from 40 to 70 K.



Microstrip Line: w = 90 μm, h = 254 μm, Zo =50
Coplanar Waveguide: w = 160 μm, s = 100 μm, h=254 μm, Zo =50

Fig. 6. The comparison of the substrate loss between the microstrip line and coplanar waveguide.

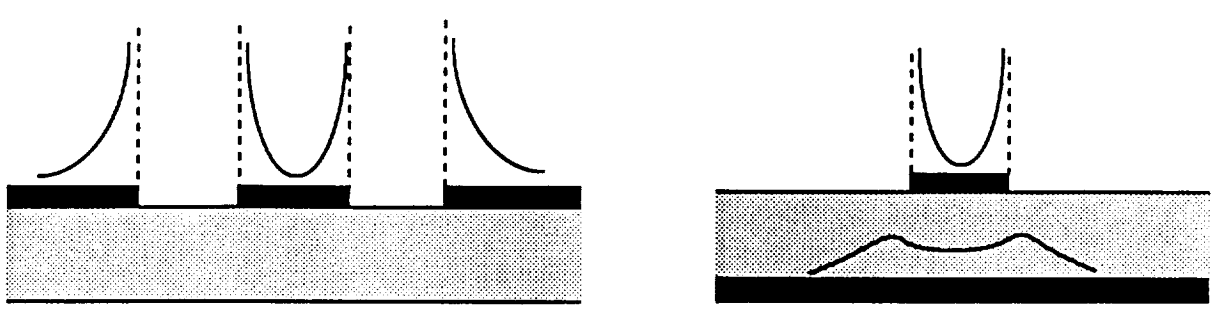


Fig.7 Current Distribution in the microstrip line and the coplanar waveguide.

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Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-105142		

4. Title and Subtitle
Design Aspects and Comparison Between High T_c Superconducting Coplanar Waveguide and Microstrip Line

5. Report Date

6. Performing Organization Code

7. Author(s)
K.S. Kong, K.B. Bhasin, and T. Itoh

8. Performing Organization Report No.
E-6416

10. Work Unit No.
506-59-4C

9. Performing Organization Name and Address
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared for the Optical Engineering and Photonics in Aerospace Sensing Symposium sponsored by the International Society for Optical Engineers, Orlando, Florida, April 1-5, 1991. K.S. Kong, University of Texas at Austin, Dept. of Electrical and Computer Engineering, Austin, Texas 78712. K.B. Bhasin, NASA Lewis Research Center, T. Itoh, University of California, Los Angeles, Dept. of Electrical Engineering, Los Angeles, California 90024. Responsible person, K.B. Bhasin, (216) 433-3676.

16. Abstract
The high T_c superconducting microstrip line and coplanar waveguide are compared in terms of the loss characteristics and the design aspects. The quality factor "Q" values for each structure are compared in respect to the same characteristic impedance with the comparable dimensions of the center conductor of the coplanar waveguide and the strip of the microstrip line. Also, the advantages and disadvantages for each structure are discussed in respect to passive microwave circuit applications.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
High temperature superconductors Microwave circuits Circuit design	Unclassified - Unlimited Subject Category 33

19. Security Classif. (of the report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	10	A02

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161