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⑦① Applicant: **COMMUNICATIONS SATELLITE CORPORATION**, 950 L'Enfant Plaza, S.W. Washington, D.C. 20024 (US)

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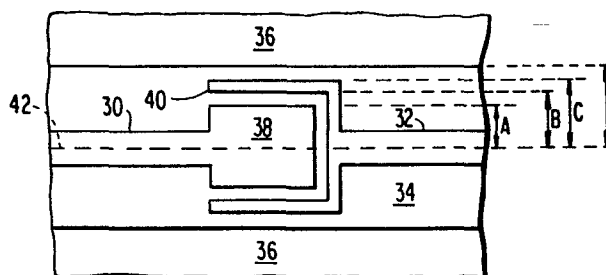
⑦② Inventor: **Stegens, Ronald E.**, 3401 Briars Road, Brookville Maryland 20729 (US)
Inventor: **Hawisher, Gary G.**, 18211 Kitchen House Court, Germantown Maryland 20767 (US)

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⑦④ Representative: **Lehn, Werner, Dipl.-Ing. et al, Hoffmann, Eitle & Partner Patentanwälte**
Arabellastrasse 4 (Sternhaus), D-8000 München 81 (DE)

⑤④ **Symmetrical coupled line coplanar waveguide filter.**

⑤⑦ A coplanar waveguide filter is disclosed including a pair of grounded conductors (36) disposed on a surface (34) of a dielectric substrate equidistant from a transmission center line (42), and first (30) and second (32) conductors on said substrate surface (34) between said grounded conductors (36) and symmetrically disposed with respect to the transmission center line (42) by virtue of one conductor (32) being bifurcated, and the other not. The structure produces coupled sections of coplanar waveguide transmission lines which are both physically and electrically symmetrical. Solutions for the even and odd-mode impedance are given, allowing synthesis of a wide range of filter functions.



SYMMETRICAL COUPLED LINE COPLANAR WAVEGUIDE FILTER

BACKGROUND OF THE INVENTION

This invention is directed to microwave filters, and more particularly to such filters having a coplanar waveguide (CPW) construction.

5 Edge-coupled bandpass filters of the stripline or microstrip variety are well-known. These may typically comprise a configuration as shown in figures 1 and 2 in which first and second stripline conductors 10 and 12 are deposited on the upper surface of a
10 dielectric substrate 14 having a ground plane 16 on the lower surface thereof. In such a filter configuration, a signal on one of the conductors, for example conductor 10, will be coupled across a gap 18 to the other conductor 12, and these filters perform substantially as desired even when the transmission lines are
15 asymmetrical. The design techniques for microstrip filters are well-known and are described, for example, in Design of Microwave Filters, Impedance-Matching Networks, and Coupling Structures, by Matthaei et al,
20 Section 8.09. The synthesis procedure generally begins from a low pass prototype, and yields required values for even and odd mode impedances Z_{oe} and Z_{oo} , respectively, for each coupled section.

25 For purposes of discussion, the odd mode impedance Z_{oo} can be considered the impedance of either conductor when both conductors have opposite potentials (i.e., +1 and -1 volt), while the even mode impedance Z_{oe} can be considered the impedance of either conductor when both have the same potential.
30 In obtaining a desired filter response, it is important that each of the conductors 10 and 12 have substantially the same even mode impedance Z_{oe} , and odd mode impedance Z_{oo} ; this is generally not difficult in a microstrip configuration since each of the conductors
35 10 and 12 is separated from the same ground plane

by the same thickness of dielectric 14.

5 In a CPW configuration, the input and output
conductors and the ground plane are all coplanar. As
shown in figures 3 and 4, conductors 20 and 22 are
disposed on the upper surface of the dielectric 24 in
a configuration similar to that of Figure 1, and the
ground plane 16 in Figure 2 is replaced by a pair of
grounded conductors 26 on the upper surface of the
dielectric and on either side of the conductors 20
10 and 22. CPW edge-coupled filters as shown in Figure 3
using two edge-coupled lines exhibiting the desired
 Z_{oe} and Z_{oo} values perform poorly due to their asym-
metrical construction. Note that in the center-coupl-
ing section of the filter of Figure 3, the conduc-
tor 20 will be closer than the conductor 22 to the
upper ground conductor 26, and conversely the conduc-
tor 22 will be closer than the conductor 20 to the
lower ground conductor 26. This asymmetrical coupling
of the conductors 20 and 22 to the different ground
conductors can cause field asymmetry about the center
line of transmission 28, and this may result in the
excitation of an odd mode of propagation between the
ground planes. This odd mode of propagation tends to
cause unwanted transmission responses which are diffi-
cult to predict, and some type of suppression, e.g.
25 the use of bond wires placed over the line from one
ground plane to the other, is usually required to
obtain even partially satisfactory performance.

As a consequence of the above difficulties, the
30 use of CPW filters has been limited to applications
where high quality filters are not required, and
improvements in CPW filter technology are needed.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a
35 coplanar waveguide (CPW) filter which is substantially
free of the above difficulties and performs satisfac-
torily even where high quality filters are required.

5 Briefly, the CPW filter according to the present invention comprises first and second conductors and first and second ground planes all disposed on the same surface of a dielectric substrate, the first conductor having an enlarged coupling portion and the second conductor having a bifurcated coupling portion interposed between said first conductor and each of said ground planes. The first and second conductors are symmetrical with respect to the transmission center line at all points.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Figure 1 is a plan view of a conventional strip-line microwave filter;

Figure 2 is a sectional view along lines II-II in Figure 1;

20 Figure 3 is a plan view of a prior art coplanar waveguide microwave filter;

Figure 4 is a sectional view along lines II-II in Figure 3;

Figure 5 is a plan view of a coplanar waveguide filter according to the present invention;

25 Figures 6 and 7 are diagrams for explaining the design of a filter according to the present invention;

Figure 8 is a plan view of a three section filter according to the present invention; and

30 Figure 9 is a graphical illustration of the measured and theoretical response of the filter of Figure 8.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

35 The filter according to the present invention is based on the recognition that the odd mode propagation resulting in spurious filter response characteristics in known CPW filters could be substantially eliminated

by utilizing a filter structure which is symmetrical about the center line of transmission. Figure 5 illustrates a "threefinger" CPW filter construction utilizing symmetrical interleaved transmission lines.

5 In this filter structure, a first conductor 30 and second conductor 32 are disposed on a dielectric substrate 34 between ground planes 36. The conductors 30 and 32 are each provided with coupling portions 38 and 40, respectively, and the coupling portion 40 is bifurcated and extends around either side of the portion 38. The conductors 30 and 32 and their respective coupling portions 38 and 40 are symmetrically disposed with respect to the center line of transmission 42 so that all electric and magnetic fields will have even field symmetry about the center line 42. Due to the symmetrical construction, the filter shown in Figure 5 will not tend to excite unwanted transmission modes, and no mode suppression is required.

20 In order to maintain equal even and odd mode impedances Z_{oe} and Z_{oo} for each of the conductors 30 and 32, the dimensions of the interleaved portions 38 and 40 of the transmission lines are chosen so that the total capacitances from each line to the CPW grounds planes 36 will be equal. Since the bifurcated portion 40 is much closer than the inner portion 38 to each of the ground planes 36, the dimensions of the bifurcated portions will generally be much narrower than the enlarged portion 38, i.e., the dimension (C-B) will be much less than the dimension A in Figure 5.

35 The line structure shown in Figure 5 can be designed using conformal mapping techniques for a zero conductor thickness, infinite dielectric and equal line capacitance for the pair of coupled lines. The design can be implemented according to the following

procedure which can be used to map the three-finger structure of Figure 5 from a coupled stripline model.

The symmetric coupled line problem revolves around the conformal mapping of a cross sectional capacitance problem, using elliptic integrals. The cell in Figure 6 represents the capacitance problem as a part of a stripline model of the coupled transmission lines in cross section. The cell, shown on the complex plane, is in reality part of a structure periodic along both real and imaginary axes. This is mapped into the coupled CPW line shown in Figure 7.

The steps used to solve the symmetric coupled CPW line problem are summarized below. The dimensions of the coupled line are determined from the desired even and odd mode impedances.

1) Express the even and odd mode impedances in terms of the normalized line capacitances C_e/ϵ and C_o/ϵ using equations (1), (2) and (3).

$$\frac{C_e}{\epsilon} = \sqrt{\frac{\mu_o}{\epsilon_o}} \frac{1}{4Z_{oe} \sqrt{\epsilon_e}} \quad (\text{even mode}) \quad (1)$$

$$\frac{C_o}{\epsilon} = \sqrt{\frac{\mu_o}{\epsilon_o}} \frac{1}{4Z_{oo} \sqrt{\epsilon_e}} \quad (\text{odd mode}) \quad (2)$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} \quad (3)$$

where Z_{oe} , and Z_{oo} are the even and odd mode impedances, $\sqrt{\mu_o/\epsilon_o}$ is the free space impedance, ϵ_r is the relative dielectric constant of the CPW substrate.

2) Define K_{2e}/K'_{2e} and K_{2o}/K'_{2o} from C_e/ϵ and C_o/ϵ using equations (4) and (5).

$$\frac{K_{2e}}{K'_{2e}} = \frac{C_e}{\epsilon} \quad (4)$$

$$\frac{K_{2o}}{K'_{2o}} = \frac{C_o}{\epsilon} \quad (5)$$

- 3) Find K_{2e} and K_{2o} from K_{2e}/K'_{2e} and K_{2o}/K'_{2o} using the general definitions of the complete elliptic integral given in equations (6) and (7). This will require numeric techniques of the type described in
- 5 Jacobi and Elliptic Functions, L.M. Milne-Thomas, Dover Publ., 1950.

$$K(k) = \int_0^1 \frac{dy}{\sqrt{(1-y^2)(1-k^2y^2)}} \quad (6)$$

$$K'(k) = K(\sqrt{1-k^2}) \quad (7)$$

- Basically, for example, $(K(k)/K'(k)) = Ce/\varepsilon$ can
- 10 be solved for k by simultaneously solving Equations (6) and (7) and k can be plugged back into each of equations (6) and (7) to obtain $K(k)$ and $K'(k)$ corresponding to K_{2e} and K'_{2e} , respectively.

- 4) Define k_1 from k_{2e} and k_{2o} using equation
- 15 (8).

$$k_1 = \frac{k_{2e}}{k_{2o}} \quad (8)$$

- 5) Find K_1 and K'_1 from k_1 using the complete elliptic integral definitions in equations (6) and (7).

- 20 6) Define K_o/K'_o from K_1 and K'_1 using equation (9).

$$\frac{K_o}{K'_o} = 2 \frac{K_1}{K'_1} \quad (9)$$

- 7) Find K_o and k_o from K_o/K'_o using the complete elliptic integral definitions given in equations (6) and (7).
- 25

- 8) Define the quantity $\frac{c}{a}$ (shown in Figure 1) from K_1 , k_1 and k_{2o} using equation (10), and the definition of the incomplete elliptic integral given in equation (11).

30

$$\frac{c}{a} = \frac{1}{K_1} F(k_{2o}, k_1) \quad (10)$$

$$F(x, k) = \int_0^x \frac{dy}{\sqrt{(1-y^2)(1-k^2y^2)}} \quad (11)$$

9) The final dimensions D, A, B and C, shown in Figures 5 and 7, are obtained from K_0 , k_0 and c/a using equations (12), (13), (14) and (15). The Jacobi elliptic function $\text{sn}(x, k)$ is the inverse of the incomplete elliptic integral function in equation (11). This relationship is shown in equation (16).

$$D = \frac{1}{k_0} \quad (12)$$

$$A = \text{sn} \left(K_0 \frac{c}{2a}, k_0 \right) \quad (13)$$

$$B = \text{sn} \left(K_0 \frac{2a-c}{2a}, k_0 \right) \quad (14)$$

$$C = 1 \quad (15)$$

$$X = \text{sn} (F(x, k), k) \quad (16)$$

A computer program using this procedure will generate tabulated output data as shown in the following TABLES I-V where ER is the dielectric constant of the substrate, ZE is the even mode impedance Z_{oe} , ZO is the odd mode impedance Z_{oo} , and A through D represent the dimensions illustrated in Figure 5.

Results are shown for a popular dielectric material (Al_2O_3) for which $\text{ER} = 10$.

TABLE I

SQRT(ZO*ZE)= 30.0		ER=10.00		
ZE	ZO	A/D	B/D	C/D
35.0	25.7	0.880	0.986	0.997
40.0	22.5	0.862	0.952	0.988
45.0	20.0	0.834	0.907	0.973
50.0	18.0	0.801	0.856	0.951
55.0	16.4	0.762	0.803	0.922

TABLE II

		SQRT(ZO*ZE)= 40.0			ER=10.00	
		ZE	ZO	A/D	E/D	C/D
5		45.0	35.6	0.704	0.984	0.992
		50.0	32.0	0.689	0.943	0.971
		55.0	29.1	0.667	0.888	0.940
		60.0	26.7	0.640	0.827	0.902
		65.0	24.6	0.609	0.763	0.858
10		70.0	22.9	0.576	0.700	0.812
		75.0	21.3	0.541	0.640	0.763

TABLE III

SQRT(ZO*ZE)= 40.0					ER=10.00
	ZE	ZO	A/D	E/D	C/D
15	55.0	45.5	0.520	0.983	0.988
	60.0	41.7	0.509	0.939	0.955
	65.0	38.5	0.493	0.880	0.911
	70.0	35.7	0.474	0.813	0.858
	75.0	33.3	0.452	0.743	0.802
20	80.0	31.3	0.429	0.675	0.745
	85.0	29.4	0.405	0.610	0.689
	90.0	27.8	0.380	0.550	0.635
	95.0	26.3	0.355	0.496	0.584

TABLE IV

SQRT(ZO*ZE)= 40.0					ER=10.00
25	ZE	ZO	A/D	E/D	C/D
	65.0	55.4	0.367	0.983	0.985
	70.0	51.4	0.360	0.938	0.946
	75.0	48.0	0.349	0.875	0.892
30	80.0	45.0	0.337	0.805	0.829
	85.0	42.4	0.322	0.731	0.764
	90.0	40.0	0.307	0.660	0.699
	95.0	37.9	0.290	0.593	0.637
	100.0	36.0	0.274	0.530	0.579
35	105.0	34.3	0.257	0.474	0.525
	110.0	32.7	0.240	0.423	0.476

TABLE V

SQRT(ZO*ZE)= 40.0		ER=10.00			
	ZE	ZO	A/D	E/D	C/D
5	75.0	65.3	0.253	0.982	0.984
	80.0	61.3	0.249	0.936	0.940
	90.0	54.4	0.234	0.799	0.811
	95.0	51.6	0.225	0.723	0.740
	100.0	49.0	0.214	0.650	0.670
10	105.0	46.7	0.204	0.580	0.603
	110.0	44.5	0.193	0.517	0.542
	115.0	42.6	0.182	0.459	0.487
	120.0	40.8	0.171	0.407	0.436

A two-pole filter utilizing two of the filter sections of Figure 5 coupled in cascade and designed for a 1 GHz bandwidth and centered at 5.0 GHz was built by first utilizing prior art filter synthesis techniques to determine the required even and odd-mode impedances for each filter section and then utilizing the conformal mapping techniques of the above-described program to calculate the pattern dimensions. After the proper dimensions were calculated, the filter was fabricated using gold conductors on a 50 mil thick alumina substrate. The filter layout and dimensions are shown in Fig. 8. A 100 mil thickness of resistive material was added to the bottom of the substrate for further odd mode suppression, and the measured filter response agrees very closely with theoretical calculations as shown in Figure 9.

The filter according to the present invention may have either semi-infinite or finite ground planes on either side of the center conductors, and it should be appreciated that patterns other than that shown in Figure 5 may be used as long as symmetry is preserved. Other modifications could also be made to the

disclosed filter structure without departing from the spirit and scope of the invention as defined in the following claims.

CLAIMS:

1. A coplanar waveguide filter having at least one filter section formed of a pair of grounded conductors (36) disposed on a substrate surface (34) and first (30) and second (32) conductors disposed on said substrate surface (34) between
5 said grounded conductors (36), characterized in that
 - a) said pair of grounded conductors (36) is equidistant from a transmission center line (42), and that
 - 10 b) each of said first (30) and second (32) conductors is symmetrically disposed with respect to said transmission center line (42).
2. A coplanar waveguide filter as defined in claim 1,
15 characterized in that said first (30) and second (32) conductors include longitudinally overlapping end portions (38, 40).
3. A coplanar waveguide filter as defined in claim 1,
20 characterized in that said first (30) and second (32) conductors include interleaved end portions (38, 40).
4. A coplanar waveguide filter as defined in claim 1,
characterized in that said first conductor (30) includes
25 an end portion (38) and said second conductor (32) includes at least first and second end portions (40) disposed on either side of said first conductor end portion (38) between said first conductor (30) and each of said grounded conductors (36).
30
5. A coplanar waveguide filter as defined in any one of claims 2, 3 or 4, characterized in that each of said first (30) and second (32) conductors has the same total capacitance to ground.

6. A coplanar waveguide filter as defined in claim 5,
characterized in that the total width ($2[C-B]$) of said
second conductor (32) is less than the total width (2A) of
said first conductor (30), said widths being measured in
5 a direction along said substrate (34) perpendicular to said
transmission center line.

7. A coplanar waveguide filter as defined in any one of
claims 1, 2 or 3, characterized in that said least one
10 filter section comprises a plurality of filter sections
(Fig. 8) connected in cascade.

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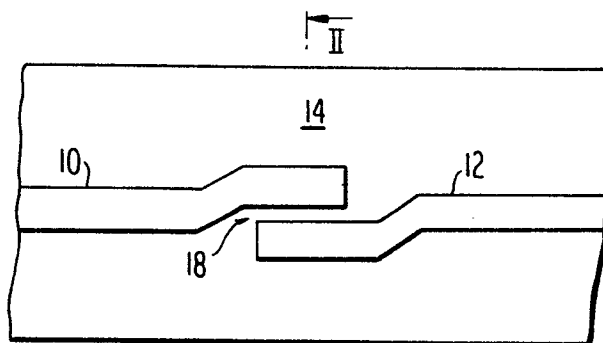
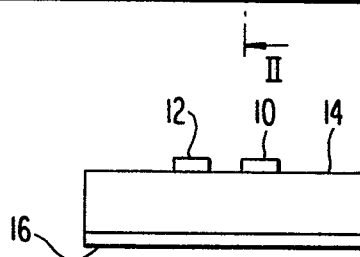
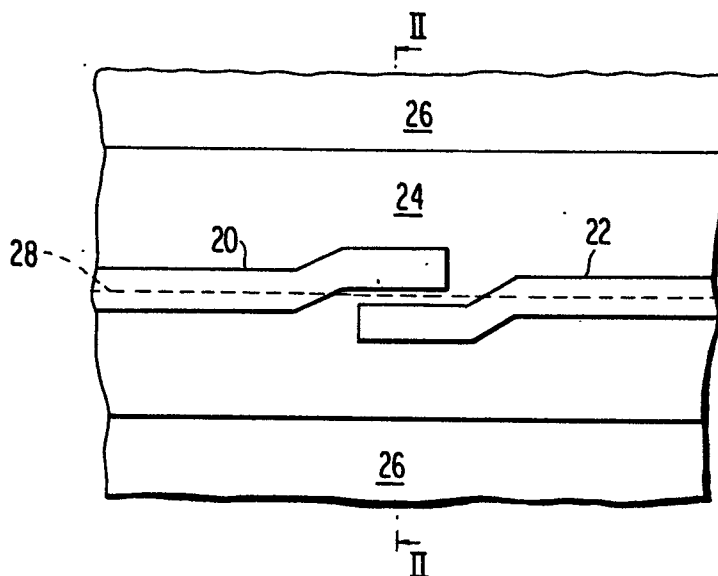
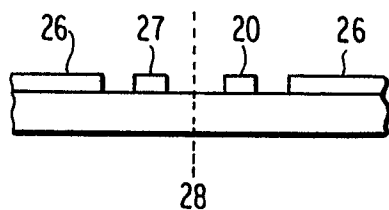
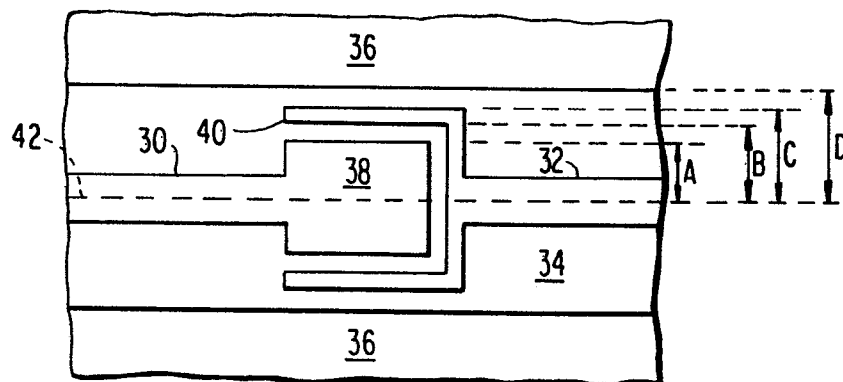
FIG. 1**FIG. 2****FIG. 3****FIG. 4****FIG. 5**

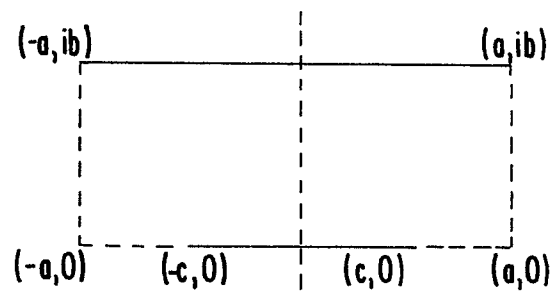
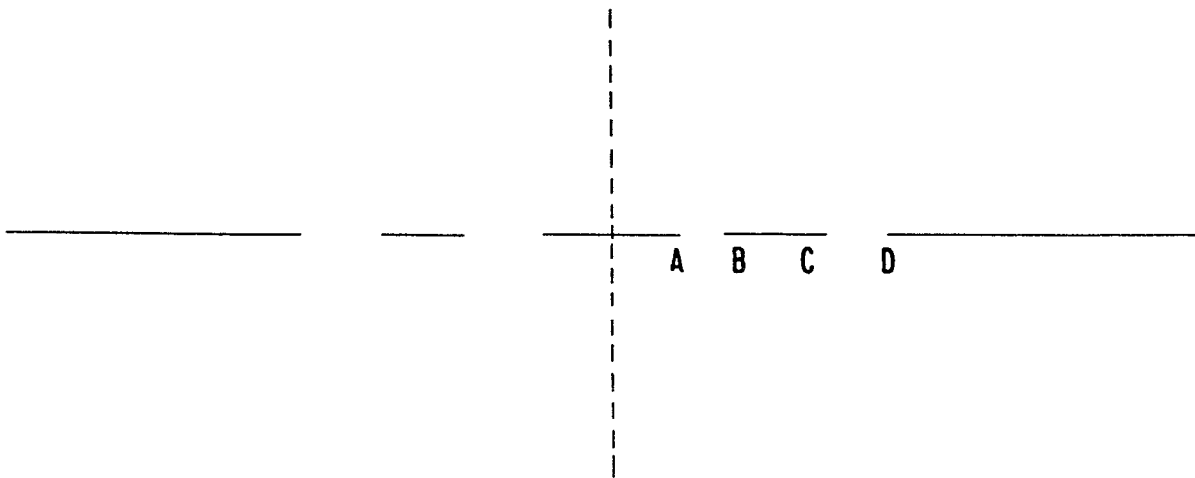
FIG. 6**FIG. 7**

FIG. 8

SECTIONS 1 & 3	
$Z_{oe} = 76.1$	$Z_{oo} = 23.8$
$\frac{a}{d} = .514$	$\frac{b}{d} = .649$
$\frac{c}{d} = .258$	
SECTION 2	
$Z_{oe} = 52.1$	$Z_{oo} = 20.6$
$\frac{a}{d} = .764$	$\frac{b}{d} = .853$
$\frac{c}{d} = .942$	

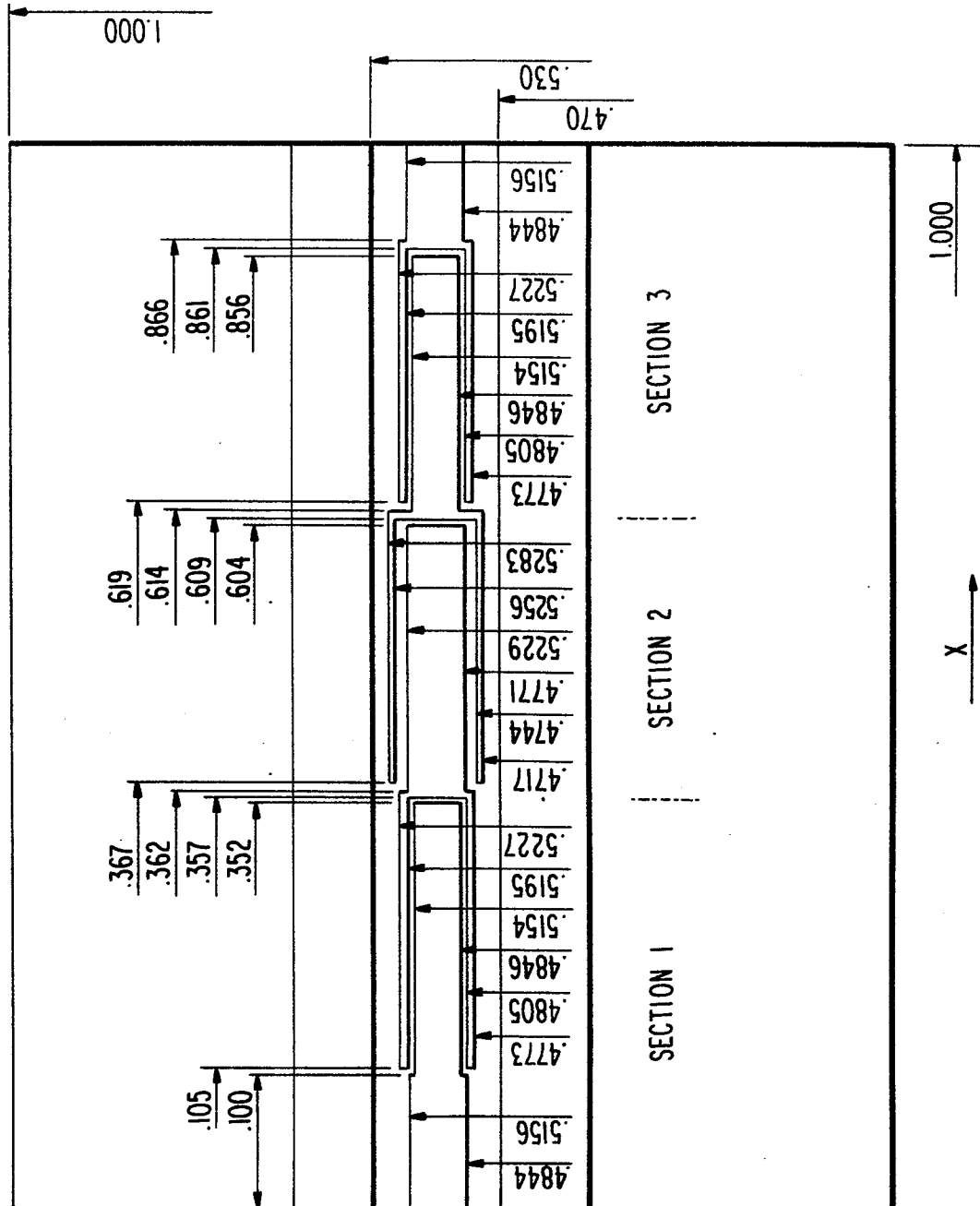
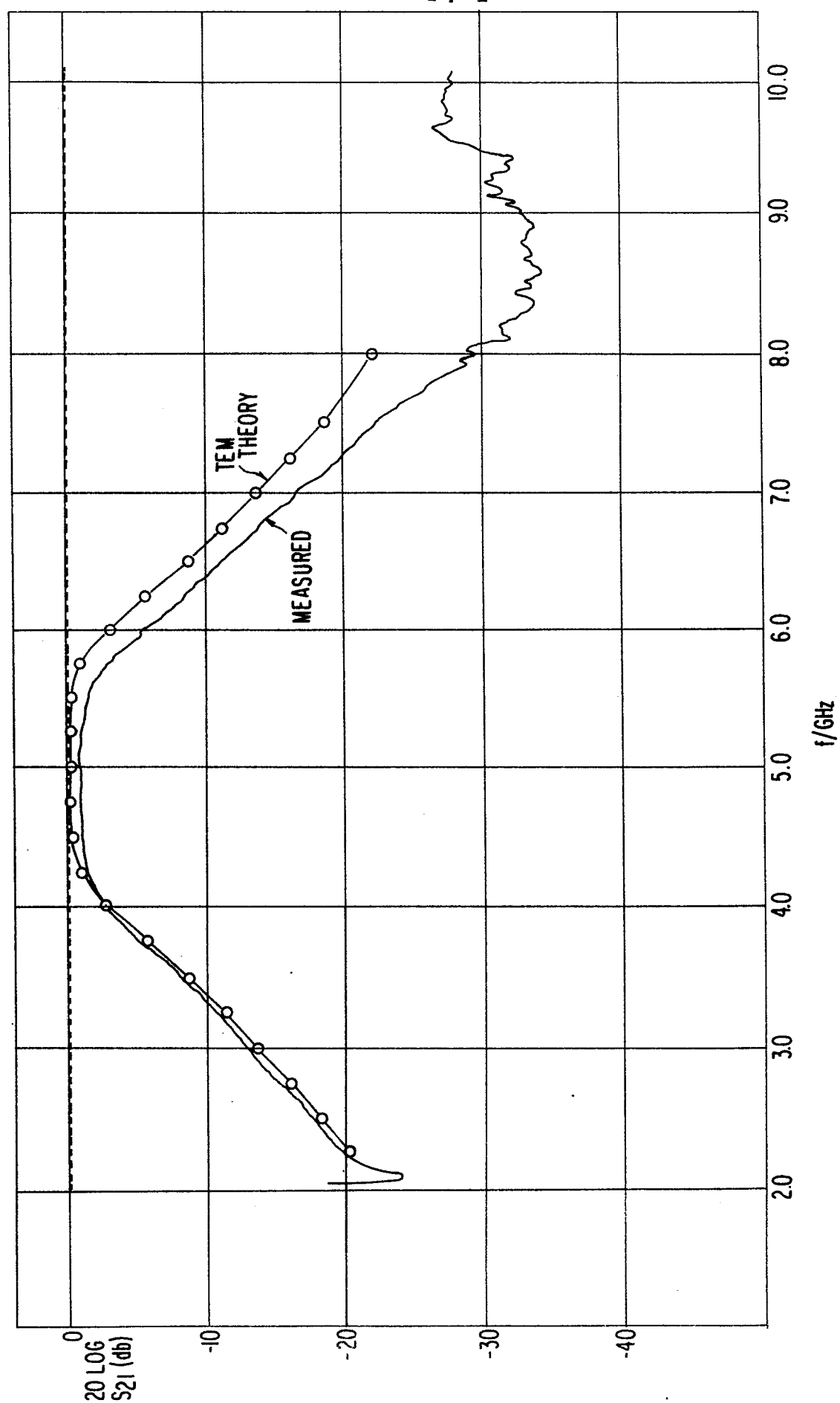


FIG. 9



European Patent
Office

EUROPEAN SEARCH REPORT

0068345
Application number

EP 82 10 5340

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 3)
X	CONFERENCE PROCEEDINGS OF THE 6th EUROPEAN MICROWAVE CONFERENCE, 14th/17th September 1976, pages 49-53, Sevenoaks (GB); M.HOUDART: "Application to broadband microwave integrated circuits". *Table 2; (column: coplanar)*	1-4	H 01 P 1/203
A	--- US-A-2 859 417 (M.ARDITI) *Figure 13*	7	
A	--- US-A-3 820 041 (J.W.GEWARTOWSKI et al.) *Figures 1,4*		
			TECHNICAL FIELDS SEARCHED (Int. Cl. 3)
			H 01 P
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 05-10-1982	Examiner VAN DER PEET H.
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			