United States Patent [19]

Cristal

[11] **3,754,197**

[45] **Aug. 21, 1973**

[54] **MEANDER-LINE IMPEDANCE TRANSFORMER**

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[73] Assignee: **Stanford Research Institute**, Menlo Park, Calif.

[22] Filed: **May 18, 1972**

[21] Appl. No.: **254,390**

[52] **U.S. Cl.** ..... **333/33**, 333/35, 333/84 M, 333/84 R

[51] **Int. Cl.** **H01p 3/08**, H03h 7/38

[58] **Field of Search** ..... 333/32, 33, 34, 35, 333/84, 84 M

[56] **References Cited**

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Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Marvin Nussbaum
Attorney—Samuel Lindenberg et al.

[57] **ABSTRACT**

A microwave or UHF impedance transformer is provided which is comprised of a meander-line structure, or a hybrid meander-line structure, in which coupling between some conjugate (adjacent) turns in the line is negligible, whereas for other conjugate turns it is significant.

6 Claims, 13 Drawing Figures

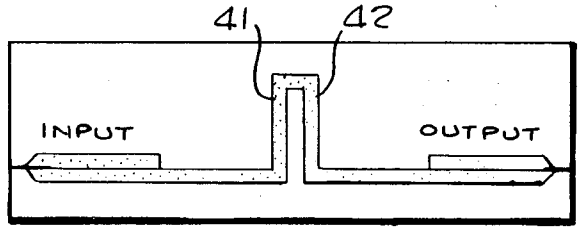


Fig. 1a

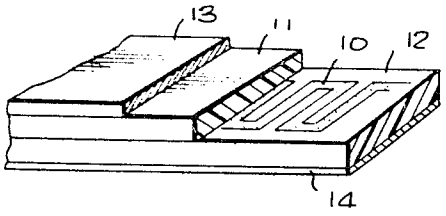


Fig. 1b

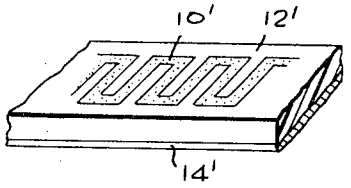


Fig. 2a

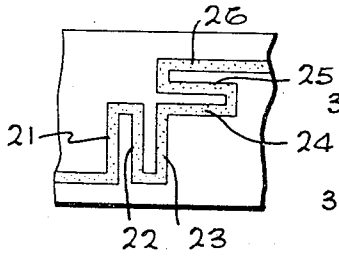


Fig. 2b

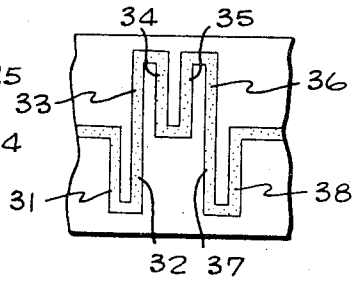


Fig. 2c

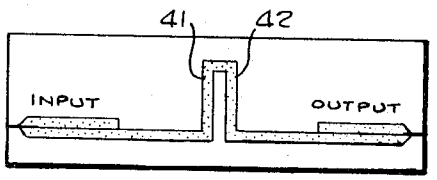


Fig. 3

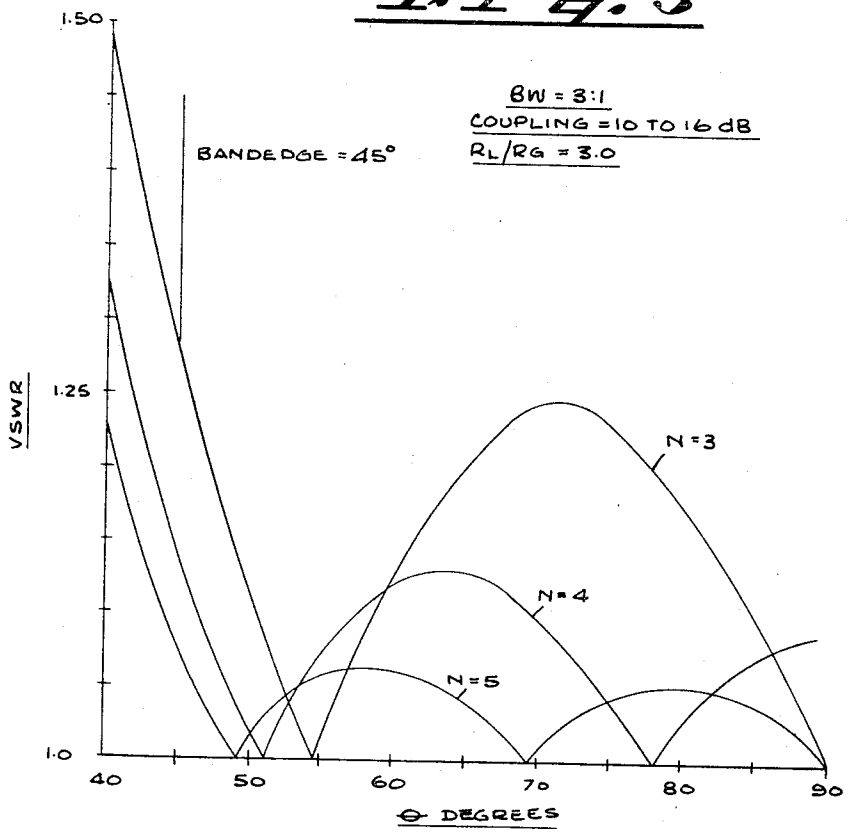


Fig. 4

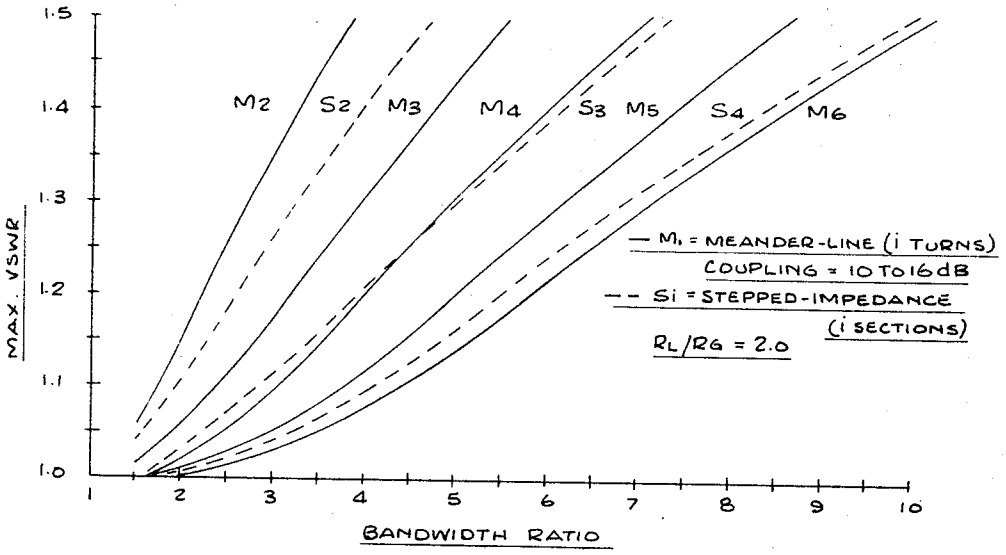


Fig. 5

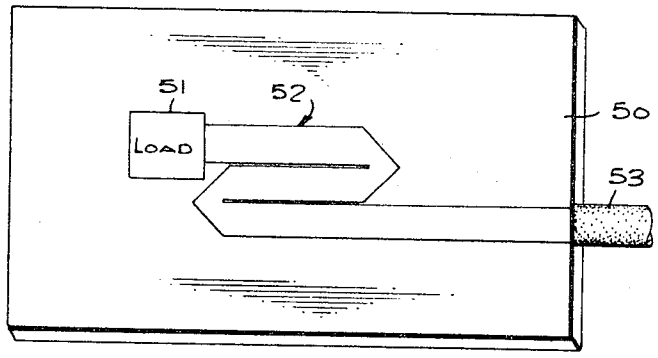


Fig. 7

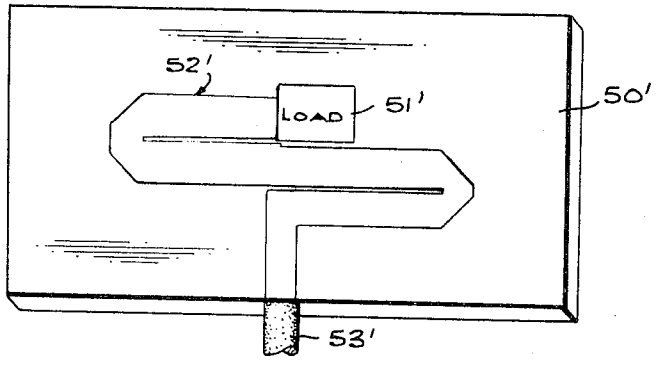


FIG. 6

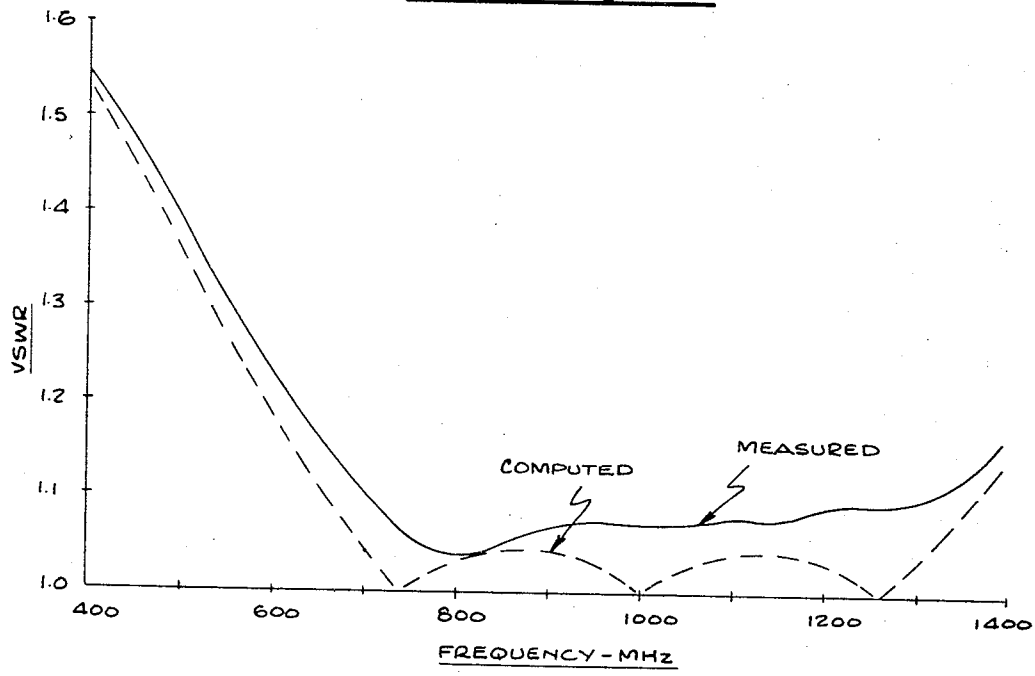
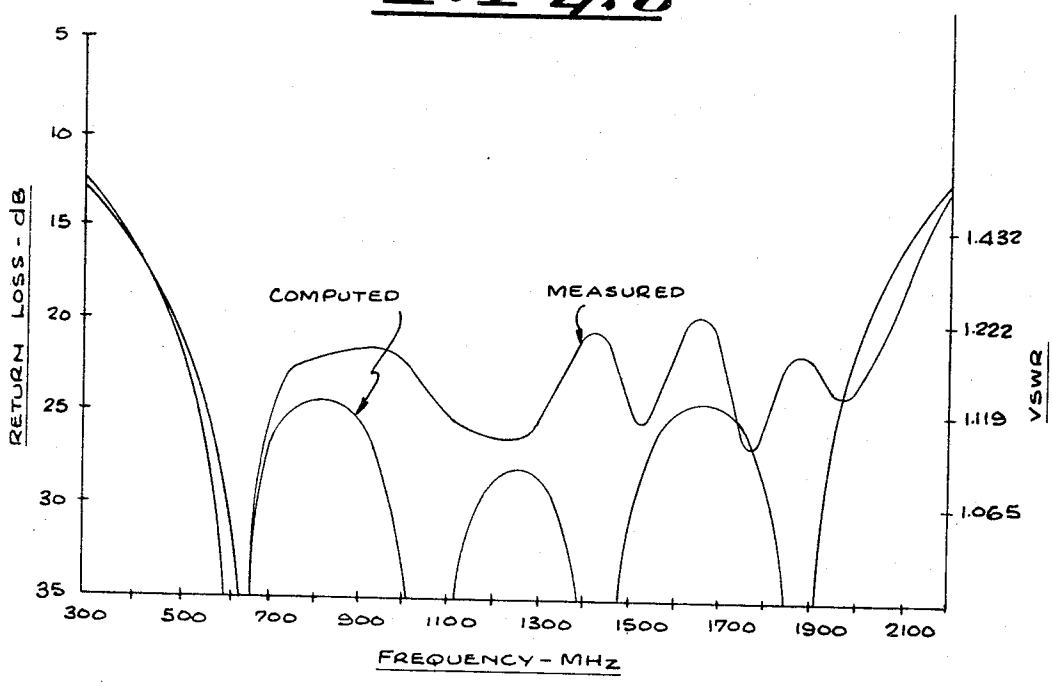

1.6
1.5
1.4
1.3
1.2
1.1
1.0
VSWR
400
600
800
1000
1200
1400
FREQUENCY - MHz
COMPUTED
MEASURED

FIG. 8


5
10
15
20
25
30
35
RETURN LOSS - dB
300
500
700
900
1100
1300
1500
1700
1900
2100
FREQUENCY - MHz
COMPUTED
MEASURED
1.432
1.222
1.119
1.065
VSWR

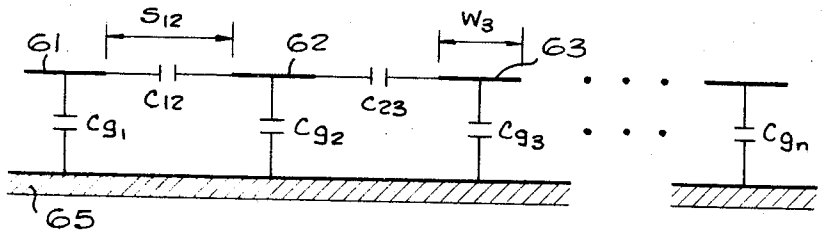
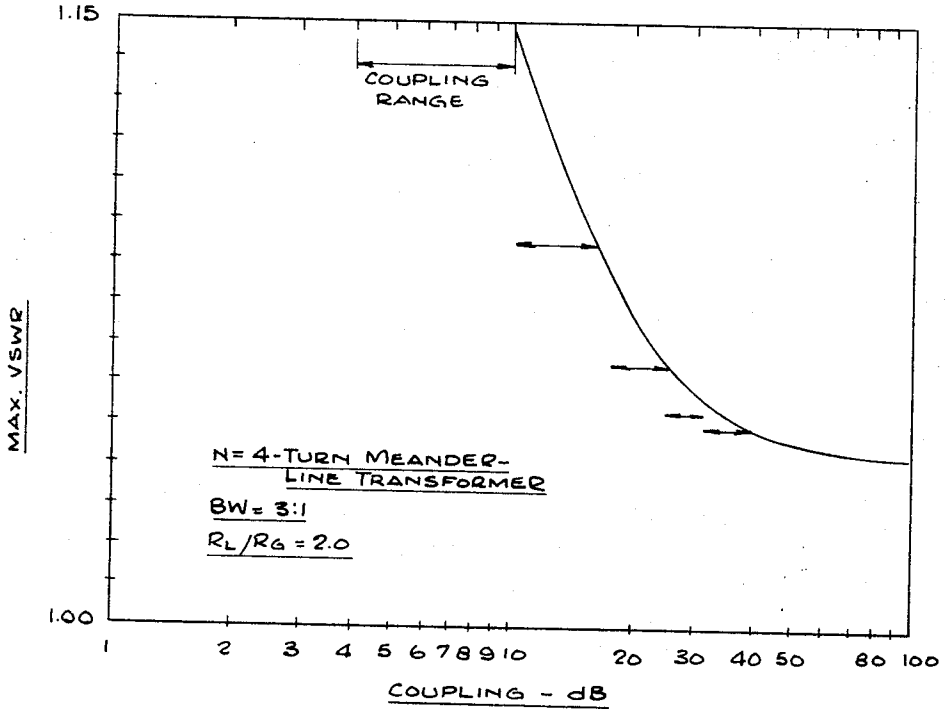

S12
W3
61
62
63
C12
C23
Cg1
Cg2
Cg3
Cgn
65

Fig. 9

Fig. 10


1.15
1.00
MAX. VSWR
COUPLING RANGE
N = 4-TURN MEANDER-LINE TRANSFORMER
BW = 3:1
RL/RG = 2.0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
80
100
COUPLING - dB

MEANDER-LINE IMPEDANCE TRANSFORMER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to impedance transformers for UHF and microwave applications, and more particularly to the use of a form of transmission line called a "meander-line" for obtaining impedance transformations.

2. Description of the Prior Art

Transformers are very often required in UHF and microwave components and systems. Coupled-transmission-line geometries, such as interdigital and-/or comb-line, are often used for purposes of obtaining impedance transformations, as described by G. L. Matthaei, et al., in *Design of Microwave Filters, Impedance-Matching Networks, and Coupling Structures* (McGraw-Hill Book Co., New York, N.Y. 1964). However, in many applications these structures are quite unsatisfactory for a variety of reasons. The required coupling between lines may not be practically realized. One or more of the coupled lines may require grounding, which is difficult in stripline and microwave-integrated-circuit (MIC) realizations. In addition to ideal transformers, the equivalent circuit for these (and other coupled-line geometries) contain shunt or series reactances that limit the bandwidth over which the transformer may be used.

The stepped-impedance transformer, consisting of a cascade of unit elements (UE), is also commonly used. The stepped-impedance transformer can transform widely differing impedances (resistances, to be strictly correct) over narrow to very wide bandwidths, and they can be constructed readily in air-line, stripline and MIC. However, each section of a stepped-impedance transformer is a quarter-wavelength long at band center, excepting the short-step transformer. Consequently, the length of a multisection transformer can be quite large. For example, a three-section stripline transformer constructed on Rexolite 1422 ($\epsilon_r = 2.54$) centered at 1,000 MHz would be 5.56 inches long.

In general, it has been shown by R. E. Collin, "Theory and Design of Wide-Band Multisection Quarter-Wave Transformers," *Proc. IRE*, Vol. 43, pp. 179–185 (February 1955), that in an *n*-section quarter-wave transformer optimum bandwidth with a minimum pass band tolerance is obtained when the power loss ratio is chosen to give Tchebycheff behavior in the pass band. H. J. Riblet has described in *IRE Transactions on Microwave Theory and Techniques*, Vol. MTT-5, pp. 36–43 (January 1957), a procedure for synthesizing an impedance transformer of *n* quarter-wave sections given an insertion loss function of permissible form, and L. Young has published in the same *IRE Transactions*, Vol. MTT-7, pp. 233–237 (April 1959), tables for cascaded homogeneous quarter-wave transformers. From these and other publications, it is evident that the art of synthesizing stepped-impedance transformers with quarter-wave sections has been well developed.

If, as is sometimes the case, transformers are required at both the input and output of a device, the overall length of the stepped-impedance transformers and device could be excessively long. An idealized solution to this problem would be to fold the stepped-impedance transformer in an accordian fashion. In order to preserve the electrical characteristics of the circuit, shielding between the folded lines would be needed. Conceptually, this technique is all right but in practice the required shielding would be impractical. On the other hand, if the shields were removed, there would be significant coupling between lines that would seriously degrade the transformer performance. In many cases, the length of the transformer is too large for practical use in stripline and MIC systems.

Various structures consisting of arrays of parallel conductors between ground planes, or above a single ground plane, have been studied as to their characteristics. See, for example, J. T. Bolljohn, et al., "A Study of the Phase and Filter Properties of Arrays of Parallel Conductors Between Ground Planes," *Proc. IRE*, Vol. 50, pp. 299–311 (March 1962). Included are meander-line structures.

OBJECTS AND SUMMARY OF THE INVENTION

An object of this invention is to provide impedance transformers using meander-line structures.

Another object is to provide impedance transformers using hybrid meander-line structures.

Briefly, it has been discovered that a meander-line structure can be used in stripline or MIC form as a folded, coupled-line, impedance transformer. For maximum flexibility in design, a hybrid meander-line structure may be used in which coupling between some conjugate (adjacent) turns in the line is negligible, whereas for other conjugate turns it is significant.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**(*a*) and **1**(*b*) depict, in isometric views, exemplary meander-line geometries in stripline and microwave-integrated circuit (MIC) forms, respectively, suitable for use as impedance transformers.

FIGS. **2**(*a*), **2**(*b*) and **2**(*c*) depict in plan views exemplary hybrid meander line geometries in stripline form suitable for use as impedance transformers.

FIG. **3** shows typical responses for 3-, 4-, and 5-turn meander-line transformers, all having 3:1 bandwidths, 3:1 impedance transformation ratios (R_L/R_G), and 10 to 16 dB coupling between turns.

FIG. **4** shows VSWR versus bandwidth of meander-line and stepped impedance transformers for comparison.

FIG. **5** shows in a perspective view of an experimental 3-turn meander-line transformer.

FIG. **6** shows a plot of measured and computed VSWR's for the experimental transformer of FIG. **5**.

FIG. **7** shows a plan view of an experimental 4-turn hybrid meander-line impedance transformer.

FIG. **8** shows a plot of measured and computed return losses and VSWR's for the experimental impedance transformer of FIG. **7**.

FIG. **9** shows schematically a cross-sectional view of an arbitrary meander-line transformer.

FIG. **10** is a graph showing the effects of varying the coupling between meander-line turns.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **1**(*a*) and **1**(*b*) depict exemplary meander-line geometries in stripline and MIC forms, respectively.

These structures may be considered as folded, coupled-line, stepped-impedance lines. Thus, from the perspective, the meander-line might be considered as comprising a class of generalized coupled-line transformers for which coupling between turns is significant.

In FIG. 1(*a*) the meander-line **10** in stripline form is shown between two layers **11** and **12** of dielectric material between two ground planes **13** and **14.** In FIG. 1(*b*), the meander-line **10'** is shown in microwave-integrated circuit (MIC) form on a layer **12'** of dielectric material over a ground plane **14'**. Coupling into and out of the meander lines, when used as impedance transformers, is by conventional methods one of which is to be described with reference to a second embodiment, the hybrid meander-line configuration shown in FIGS. 2(*a*) through 2(*c*).

A hybrid meander-line transformer is one in which coupling between some conjugate or "adjacent" turns is negligible, whereas for other conjugate turns it is significant. Several examples of hybrid meander-line transformers are shown in FIGS. 2(*a*), (*b*), and (*c*). Theoretically, the number of hybrid configurations possible is $2^{(N-1)}$ (where N is the number of turns i.e., the order of the transformer). Hybrid geometries allow the circuit designer much greater flexibility in the physical layout of the transformer than he would otherwise have with only meander-line transformers.

Each example of a hybrid meander-line impedance transformer is shown in FIGS. 2(*a*), (*b*) and (*c*) in a plan view of an MIC structure. Obviously each may be in a stripline form also by including a second ground plane separated by a layer of dielectric material on top of the meander-line. In FIG. 2(*a*), three conjugate quarter-wave turns **21** to **23** are provided with significant coupling. The next turn **24** is normal to the turn **23** and therefore, has negligible coupling with the turn **23.** The next two turns **25** and **26** are parallel to turn **24** for significant coupling between turn **24** and turn **25,** and between turn **25** and turn **26.**

In FIG. 2(*b*) a meander-line section of two turns **31** and **32** is connected to a section of four turns **33** through **36.** That section is connected to a section of two turns **37** and **38.** Each turn is provided with significant coupling between adjacent parallel turns, and negligible coupling between turns **32** and **33,** and between turns **36** and **37.**

In FIG. 2(*c*), only two parallel turns **41** and **42** are provided with significant coupling. This example is of a N=6 hybrid meander-line transformer in which only two turns are coupled via their electromagnetic fields. This example is provided to illustrate a practical application of hybrid transformers: one in which the length of a sixth order transformer is reduced to that of a fourth order transformer with very little degradation in bandwidth. All of the transformer configurations shown are coupled into and out of by direct connection to the transformer.

FIG. **3** shows typical responses for 3-, 4-, and 5-turn meander-line transformers, all having 3:1 bandwidths, 3:1 impedance transformation ratios, and 10 to 16 dB coupling between turns. The improvement in voltage-standing wave ratio (VSWR) with increasing N is evident. The VSWR's are not quite equal-ripple, but on the other hand, are so close to equal-ripple that the difference is virtually academic. Certainly, in any realization of these designs, the effect of losses, interconnections, and parasitics would completely obscure any difference between these and precisely equal-ripple designs.

FIG. **4** presents representative data of maximum VSWR versus bandwidth (BW) with the number of meander-line turns as a parameter. Also plotted is the corresponding data for stepped-impedance transformers for comparison. The impedance transformation ratio is 2:1 and the coupling between meander-line turns is 10 to 16 dB. The data shows the superiority of the stepped-impedance transformer with regard to electrical performance. However, equivalent or improved performance is always possible with meander-line transformers by adding additional turns. Again, it is emphasized that the principal advantage of meander-line and hybrid meander-line transformers is the reduction in overall length and the increased flexibility in obtaining suitable shape factors for stripline or MIC structures.

A three-turn meander-line transformer was designed to match 25 ohms to 50 ohms over a 60 percent bandwidth (BW = 1.857). It was constructed in stripline using 1 oz copper clad dielectric material (Rexolite 1422), and a ground plane spacing of 0.250 inch. The nominal center frequency was 1 GHz. The couplings between meander-line turns were mitered experimentally for a satisfactory VSWR. Four 1/8 watt, 100-ohm carbon resistors connected in parallel were used for the 25-ohm load. An isometric view of the final design is shown in FIG. **5.** The dielectric material is identified by the reference numeral **50** and the load, identified by the reference numeral **51,** is shown schematically by a block. The input to the transformer **52** was through a coaxial cable **53.** The measured and computed VSWR's are shown in FIG. **6.** It should be noted that although the center frequency of the transformer is slightly high, and although there is some degradation in the response near the upper band edge, generally speaking, there is excellent agreement between the two curves.

In order to confirm the theory and design procedure for hybrid meander-line transformers, an N=4 hybrid transformer covering a 4-to-1 bandwidth and matching 25 ohms to 50 ohms was designed. It was also constructed in stripline form using 1 oz copper clad Rexolite 1422, and a ground plane spacing of 0.250 inch. Its nominal center frequency was 1.250 GHz. A plan view of the transformer after the interconnections were mitered is given in FIG. **7.** For convenience, corresponding elements are identified by the same reference numerals, but primed. The measured and computed return loss is given in FIG. **8.** Although the measured data at the high frequency end of the passband indicate that the interconnections are not completely compensated, the correspondence with the theory is very good.

Meander-line transformer tables for selected designs can be compiled using numerical techniques by minimizing a weighted reflection-coefficient function raised to a high integer power (e.g., minimizing a least-p^{th} objective). The weighting function is constructed to assure that the coupling between meander-line turns will be within prescribed limits. The numerical techniques are well known; consequently, specific details will not be given here. For example, see J. A. Bandler, "Optimization Methods for Computer-Aided Design," *IEEE Trans. on Microwave Theory and Techniques*, Vol. MTT-17, pp 553–552 (August 1969).

To illustrate the technique of specific meander-line transformers using tables thus compiled, Tables A and B for 3 and 4 section meander-line transformers are set forth hereinafter. To understand these tables, the following definition of parameters used will be helpful.

FIG. 9 depicts a cross-sectional representation of an arbitrary meander-line transformer in any TEM or quasi-TEM medium and depicts the unnormalized distributed capacities parameters C_{g_i} and $C_{i,i+1}$ between quarter-wave turns or conductors, such as quarter-wave turns **61, 62** and **63.** These are defined as follows:

C_{g_i} = Capacitance to ground plane **65** per unit length for the i^{th} conductor. For convenience the dielectric material is not shown between the turns and the ground plane. (1)

$C_{i,i+1}$ = Mutual capacitance per unit length between the i^{th} and i^{th} = 1 conductors.

Coupling between non-adjacent turns is assumed negligible.

The dimensionless, distributed-capacitance parameters that are needed for use with Getsinger's data in order to obtain dimensional parameters from electrical parameters are as follows:

$C_{g_i} = C_{g_i}/\epsilon$

$c_{i,i+1} = C_{i,i+1}/\epsilon$

$\epsilon = \epsilon_r\epsilon_o$

ϵ_r = Relative dielectric constant of the medium.

ϵ_o = Permittivity of free space in the units of C_{g_i} and $C_{i,i+1}$. (2)

The coupling, $k_{i,i+1}$, between meander-line turns i and $i+1$ is defined as:

$$k_{i,i+1} = -20 \log_{10} \frac{C_{i,i+1}}{\sqrt{(C_{g_i}+C_{i,i+1})(C_{g_{i+1}}+C_{i,i+1})}} \, dB \quad (3)$$

The meander-line-transformer bandwidth, BW, is defined as:

$$BW = \theta_2/\theta_1 \quad (4$$

where θ_1 and θ_2 are the lower and upper passband edges, respectively, in electrical degrees or frequency. The ratio of load to source resistance, always taken as greater than 1, is denoted by the symbol RL/RG, and the peak VSWR in the passband is denoted by VSWR.

The compilation of exemplary meander-line-transformer designs is presented in the following Tables A and B for N = 3 and 4 turns, RL/RG = 1.0 to 6.0 and 20.0, and BW = 3. The normalized self and mutual capacitances are listed under the column headings Cg*i*/E and CM*ij*/E, respectively. These values may be converted to the dimensionless forms C/ϵ required by Getsinger's data, by the equation:

$$\left.\begin{matrix} C_{g_i}/\epsilon \\ \text{or} \\ C_{i,i+1}/\epsilon \end{matrix}\right\} = 376.7/RG\sqrt{\epsilon_4}\{\text{Table value}\} \quad (5)$$

where *RG* is the source resistance in ohms. Each table was terminated after the peak passband VSWR exceeded 1.5.

TABLE A.—3 SECTION MEANDER-LINE TRANSFORMER TABLE CAPACITANCES NORMALIZED TO 376.7/SQRT (EPSR)

[Coupling=10 to 16 db.—Bandwidth=3.00/1]

RL/RG	CG1/E	CG2/E	CG3/E	CM12/E	CM23/E	VSWR
1.0	.8638	.6407	.7350	.1334	.3056	1.028
1.1	.8485	.6205	.6973	.1403	.2857	1.025
1.2	.8203	.5877	.6556	.1406	.2617	1.051
1.3	.8089	.5732	.6215	.1358	.2361	1.078
1.4	.7895	.5558	.5962	.1387	.2153	1.096
1.5	.7759	.5415	.5701	.1352	.1999	1.114
1.6	.7661	.5326	.5404	.1250	.1783	1.129
1.7	.7573	.5265	.5324	.1235	.1605	1.145
1.8	.7504	.5208	.5171	.1176	.1434	1.157
1.9	.7406	.5144	.5035	.1150	.1277	1.167
2.0	.7275	.5185	.5036	.1221	.1004	1.173
2.2	.7230	.5061	.4659	.1105	.8817E-01	1.220
2.4	.7109	.4828	.4387	.1020	.8543E-01	1.226
2.6	.6991	.4701	.4175	.9746E-01	.7481E-01	1.240
2.8	.6917	.4566	.3957	.9615E-01	.7185E-01	1.268
3.0	.6766	.4362	.3730	.9228E-01	.7028E-01	1.288
3.5	.6519	.4075	.3342	.8588E-01	.6191E-01	1.326
4.0	.6302	.3757	.2941	.7795E-01	.6389E-01	1.391
4.5	.6142	.3608	.2765	.7626E-01	.5126E-01	1.414
5.0	.5979	.3413	.2542	.7155E-01	.4730E-01	1.457
6.0	.5708	.3125	.2217	.6851E-01	.4117E.01	1.550

TABLE B.—4 SECTION MEANDER-LINE TRANSFORMER TABLE CAPACITANCE NORMALIZED TO 376.7/SQRT (EPSR)

[Coupling=10 to 16 db.—bandwidth=3.00/1]

RL/RG	CG1/E	CG2/E	CG3/E	CG4/E	CM12/E	CM23/E	CM34/E	VSWR
1.0	.8551	.7455	.7433	.8526	.1591	.1388	.1621	1.000
1.1	.8269	.6817	.6690	.7761	.1755	.1659	.1638	1.014
1.2	.8122	.6666	.6516	.7287	.1772	.1440	.1430	1.027
1.3	.8151	.6589	.6209	.6789	.1589	.1344	.1360	1.039
1.4	.8114	.6421	.5926	.6391	.1503	.1329	.1264	1.050
1.5	.8062	.6294	.5696	.6026	.1443	.1257	.1194	1.060
1.6	.7979	.6147	.5483	.5704	.1423	.1202	.1139	1.068
1.7	.7941	.6043	.5297	.5424	.1363	.1151	.1079	1.075
1.8	.7864	.5908	.5128	.5178	.1351	.1116	.1021	1.082
1.9	.7832	.5821	.4973	.4948	.1303	.1070	.9729E-01	1.089
2.0	.7757	.5699	.4826	.4744	.1298	.1041	.9295E-01	1.095
2.2	.7662	.5516	.4562	.4382	.1247	.9820E-01	.8567E-01	1.107
2.4	.7566	.5351	.4334	.4076	.1213	.9283E-01	.7974E-01	1.118
2.6	.7484	.5203	.4134	.3814	.1176	.8843E-01	.7439E-01	1.129
2.8	.7406	.5068	.3955	.3587	.1144	.8477E-01	.6980E-01	1.139
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3.5	.7171	.4678	.3469	.2987	.1057	.7480E-01	.5730E-01	1.168
4.0	.7022	.4465	.3208	.2672	.1022	.6816E-01	.5172E-01	1.189
4.5	.6900	.4274	.2985	.2421	.9739E-01	.6390E-01	.4710E-01	1.206
5.0	.6794	.4112	.2800	.2219	.9319E-01	.6037E-01	.4323E-01	1.223
6.0	.6600	.3841	.2514	.1913	.8787E-01	.5481E-01	.3697E-01	1.255
7.0	.6452	.3633	.2293	.1686	.8227E-01	.5040E-01	.3264E-01	1.283
8.0	.6300	.3451	.2114	.1510	.7877E-01	.4667E-01	.2944E-01	1.310
9.0	.6183	.3305	.1973	.1373	.7525E-01	.4372E-01	.2678E-01	1.334
10.0	.6077	.3179	.1857	.1262	.7278E-01	.4122E-01	.2463E-01	1.358
20.0	.5429	.2507	.1263	.7344E-01	.5683E-01	.2738E-01	.1443E-01	1.550

For the data presented in Tables A and B the coupling between meander-line turns was arbitrarily (after some analytical experimentation) required to be within the range 10 to 16 dB. This range of coupling generally yields a realizable and compact structure for co-planar coupled turns. Tighter than 10 dB coupling tends to become difficult to realize, while greater than 16 dB coupling is entering a region that is beginning to separate the adjacent turns farther than is desirable. Since the effects of the finite-length interconnections between turns were neglected in compiling the Tables A and B, the interconnection lengths should be made as small as possible, if the measured performance of the transformer is to correspond well with the theoretical performance. In the realization of the transformers, compensation of the interconnections will generally be required.

The effects of varying the coupling between meander-line turns are shown in the graph of FIG. **10.** This graph is for the particular case of N = 4 turns, RL/RG = 2, and BW = 3:1, but is typical of the results in the general case. The graph plots maximum VSWR in the passband as a function of coupling between turns. The horizontal arrows depict the range of coupling allowed. The right-hand sides of the arrows are connected by a smooth curve. This is somewhat arbitrary, but is justified by the fact that coupling values determined by a computer tend toward weaker coupling in most cases. In any event, the qualitative result is the same regardless of the way the curve is connected. The data show that for a given bandwidth the peak VSWR is minimized when the coupling is weakest. Thus, for the class of meander-line transformers, stepped-impedance transformers yield the lowest VSWR's This is not an especially surprising result, since the coupling between turns introduces constraints on the physical realizability of the meander-line. Also, the same conclusion might be inferred from the data of R. J. Wenzel, "Small Elliptic-Function Low-Pass Filters and Other Applications of Microwave C Sections," *IEEE Trans. on Microwave Theory and Techniques*, Vol. MTT-18, pp. 1,150–1,158 (Dec. 1970), which showed that C-section transformers have smaller bandwidths than stepped-impedance transformers for a given VSWR and number of sections. A C-section transformer may also be considered a two-turn-meander-line transformer.

Since Tables A and B were developed using numerical techniques, it is worthwhile to examine the responses of the transformers in some detail. FIG. **3** shows typical computed responses for 3-, 4-, and 5-turn-meander-line transformers, all having 3:1 bandwidths, 3:1 impedance transformation ratios, and 10 to 16 dB coupling between turns. The improvement in VSWR with increasing N is evident. The VSWRs are not quite equal-ripple, but, on the other hand, are so close to equal-ripple that the difference is virtually academic. Certainly, in any realization of these designs, the effect of losses, interconnections and parasitics would completely obscure any differences between these and precisely equal-ripple designs. Note also that the peak VSWR occurs at the band edge. This is not always the case, but is usually so. Since it is the peak VSWR that is given in Tables A and B, and since the band edge performance is almost always degraded in actual hardware realizations, a user may generally assume that the maximum VSWR is slightly lower than that given in Tables A and B over the band of application. A similar table for N=5 could be compiled. The response for a 5-turn transformer is shown in FIG. **10,** along with the responses of the exemplary transformers of Tables A and B to more clearly show the result of increasing N.

The use of the meander-line transformer design Tables A and B will be illustrated in the following example. It is required to match 25 ohms to 50 ohms over a 3:1 bandwidth. The maximum VSWR allowed is 1.1. Checking Tables A and B for RL/RG = 50/25 = 2, and for N=3 and 4, shows that the maximum VSWRs are 1.288 and 1.095, respectively. Thus, N = 4 turns is sufficient. The parameters from the N = 4, BW = 3:1 tables are as follows:

$$\begin{aligned} CG1/E &= 0.7757 \\ CG2/E &= 0.5699 \\ CG3/E &= 0.4826 \\ CG4/E &= 0.4744 \\ CM12/E &= 0.1298 \\ CM23/E &= 0.1041 \\ CM34/E &= 0.09295 \end{aligned} \tag{6}$$

Assume that the transformer is to be constructed in stripline on 1-oz copper-clad Rexolite 1422, which has a relative dielectric constant of 2.54. Since the tables are calculated on the basis that the "load" is always greater than the source, the generator resistance in this case is identified as 25 ohms. Consequently, substituting Eq. 6 into Eq. 5 yields:

$$\begin{aligned} C_{g_1}/\epsilon &= (376.7/25\sqrt{2.54})\,[0.7757] = 9.454(0.7757) = 7.334 \\ C_{g_2}/\epsilon &= 9.454(0.5699) = 5.388 \\ C_{g_3}/\epsilon &= 9.454(0.4826) = 4.563 \\ C_{g_4}/\epsilon &= 9.454(0.4744) = 4.485 \\ C_{12}/\epsilon &= 9.454(0.1298) = 1.227 \\ C_{23}/\epsilon &= 9.454(0.1041) = 0.9842 \\ C_{34}/\epsilon &= 9.454(0.09295) = 0.8788 \end{aligned} \tag{7}$$

Substituting Eq. 7 into Getsinger's data yields the results given in the following Table C.

TABLE C
4-TURN-MEANDER-LINE 3:1-BANDWIDTH TRANSFORMER DESIGN (RL/RG = 2)

Conductor	w/b	s/b
1 (25 Ω end)	1.550	0.1059
2	1.224	0.1508
3	0.9911	0.1767
4	0.8137	

w/b = Strip-width-to-ground-plane spacing.
s/b = Interstrip-spacing-to-ground-plane spacing.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art. It is therefore intended that the claims be interpreted to cover such modifications and variations.

The term "quarter-wave turn" used herein, and in the claims, is intended to refer to that length of a turn or conductor that is a quarter wavelength at band center, i.e., a quarter wavelength of one turn from the center of the line connecting it to another turn at one end

to the center of the line connecting it to another turn at the other end.

What is claimed is:

1. The new use of a meander-line structure as a folded, coupled line for impedance transformation in which turns of quarter wavelength are provided with significant coupling between conjugate parallel turns in at least one section between one input port and one output port.

2. The invention as defined in claim **1** wherein at least two sections are provided with parallel turns, conjugate turns of each section being provided with significant coupling therebetween, and conjugate turns between sections being provided with insignificant coupling therebetween whereby a hybrid meander-line structure is provided for impedance transformation.

3. The invention as defined in claim **1** wherein said meander-line structure is provided in stripline form.

4. The invention as defined in claim **1** wherein said meander-line structure is provided in microwave-integrated-circuit form.

5. The invention as defined in claim **2** wherein said meander-line structure is provided in stripline form.

6. The invention as defined in claim **2** wherein said meander-line structure is provided in microwave-integrated-circuit form.

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