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Heng et al.

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[54] **MICROWAVE STRIPLING CIRCUITS WITH SELECTIVELY BONDABLE MICRO-SIZED SWITCHES FOR IN-SITU TUNING AND IMPEDANCE MATCHING**

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[21] Appl. No.: **163,367**

[52] **U.S. Cl.** .... **333/84 M,** 333/7, 333/73 S, 333/81 A

[51] **Int. Cl.** **H01p 3/00,** H01p 3/08

[58] **Field of Search** .... 333/11, 73 S, 81 A, 84 M, 333/7

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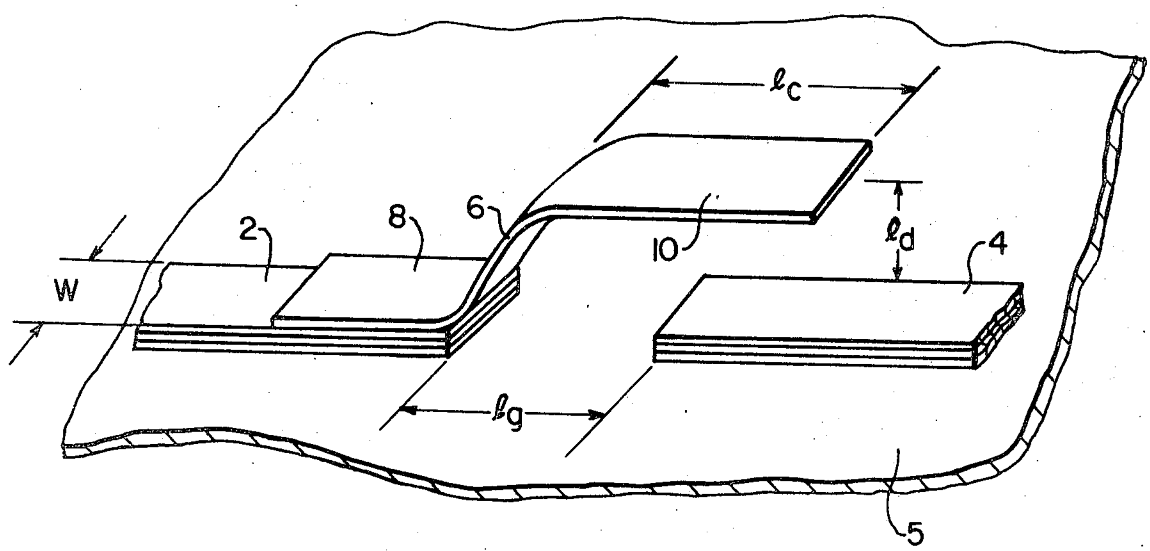
[57] **ABSTRACT**

A microstrip line is divided into a number of short sections, each capacitively coupled to its neighbor by a cantilever switch. The coupling of each switch depends on the separation between sections and the spacing between the catilever switch and an adjoining section. The cantilever switches are sufficiently flexible to allow test contact between adjacent sections and is permanently bondable where desired. In such a manner sections having lengths chosen to be predetermined fractions of a desired wavelength are connected together to shift the phase of energy propagating therealong to provide tuning and impedance matching of microstrip circuits.

11 Claims, 10 Drawing Figures



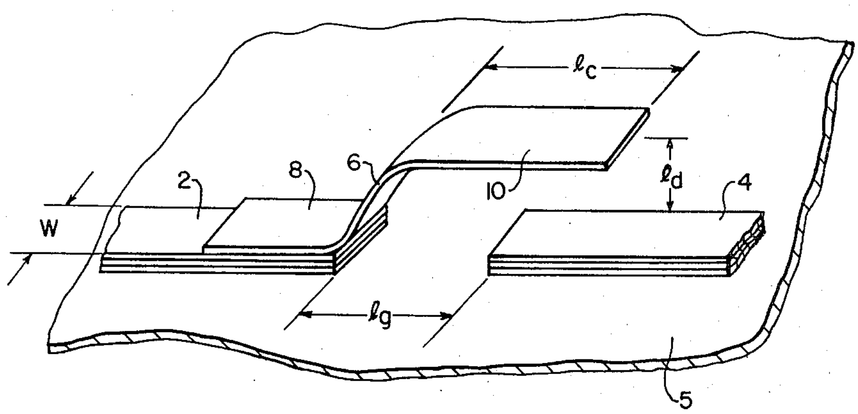


FIG. 1.

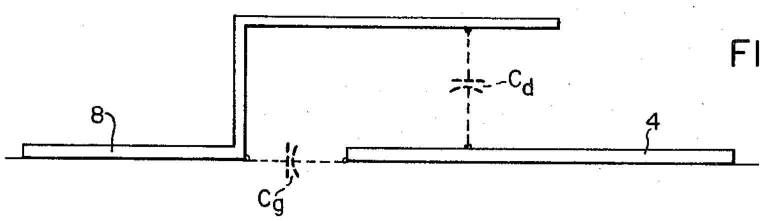


FIG. 2.

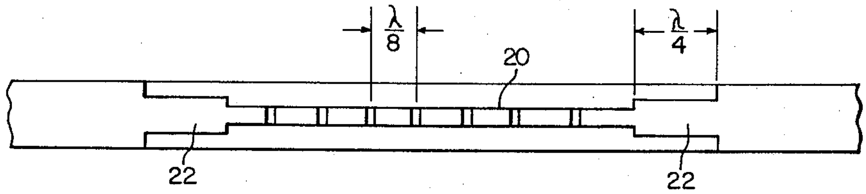


FIG. 3.

WITNESSES

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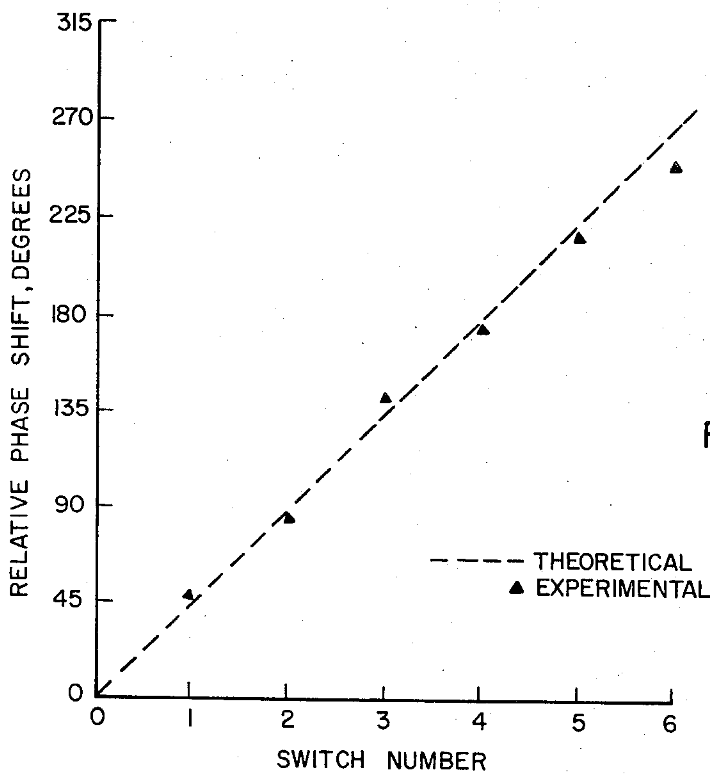

FIG. 4.

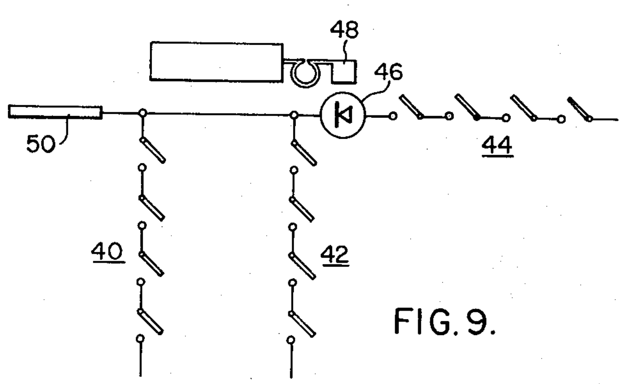

FIG. 9.

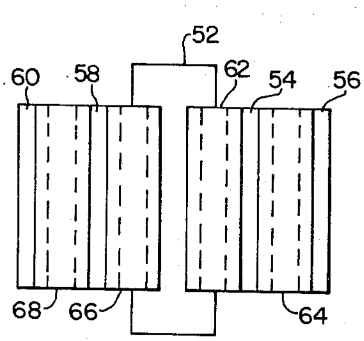

FIG. 10.

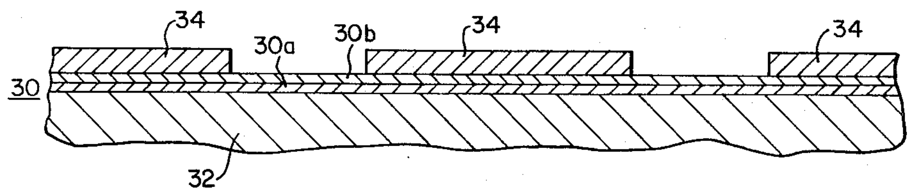

FIG.5.

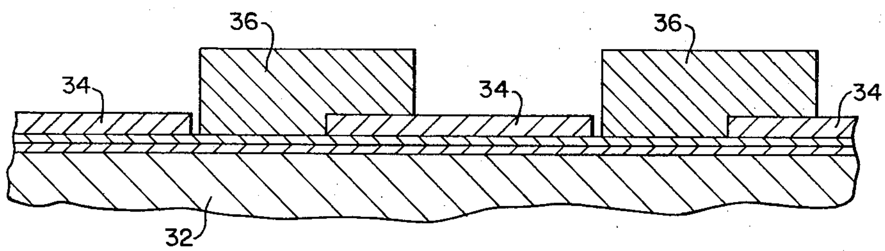

FIG.6.

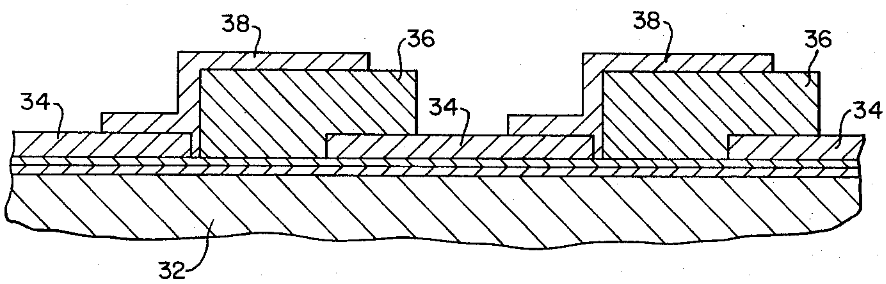

FIG.7.

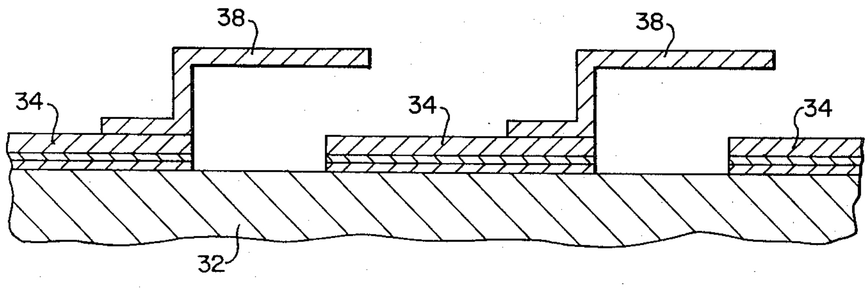

FIG.8.

MICROWAVE STRIPLING CIRCUITS WITH SELECTIVELY BONDABLE MICRO-SIZED SWITCHES FOR IN-SITU TUNING AND IMPEDANCE MATCHING

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to microstrip circuits and more particularly relates to microwave striplines capable of in-situ tuning.

2. Description of the Prior Art

The lack of an efficient and reliable means for tuning has always been a major problem in microwave integrated circuit technology. For passive circuits this problem has been eliminated to some degree by imposing a high degree of tolerance and fabrication, usually at an increased cost. The situation becomes even more serious, however, for active circuits, in both monolithic and hybrid configurations. In the former case, the effective impedance of the active device is generally different from theoretical design and the need for matching is evident. The common practice in hybrid circuits is to characterize the active device prior to insertion of the device into the circuit. In this way the range of device parameters can be accommodated by sequence of circuit designs. This involves the availability of costly high quality, sophisticated test equipment and computer facilities, and a full understanding of device-circuit interaction. In short, the approach is not economically feasible for small production runs.

At present, a limited number of tuning techniques exist which fall into two broad categories: (i) active tuning, and (ii) mechanical tuning. The use of varactor and p-i-n diodes as tunable capacitive elements, and YIG spheres as tunable inductive elements, fall into the first category. Mechanical tuning by screw and movable magnetic slugs have also been used, in addition to the simple technique of line scraping by laser or other means. With the exception of the latter, all these techniques involve the introduction of an external element into the circuit. As such, the electrical and mechanical stabilities of these elements are of concern in a large number of applications.

CROSS REFERENCE TO RELATED APPLICATIONS AND PATENTS

U.S. Pat. No. 3,539,705, entitled "Microelectronic Conductor Configuration and Method of Making the Same" by Harvey C. Nathanson and John R. Davis, and assigned to the present assignee, discloses and claims a microelectronic conductor configuration wherein two conductive layers are spaced apart, the second layer including a plurality of projecting paths that can be selectively, permanently bonded to the first layer to effect electrical connection therewith.

In patent application Ser. No. 40,627 which is a divisional application of the aforementioned patent the method of forming such configurations is described and claimed.

In U.S. Pat. No. 3,413,573 issued Nov. 26, 1968, entitled "Microelectronic Frequency Selective Apparatus with Vibratory Member and Means Responsive Thereto" by Harvey C. Nathanson and Robert A. Wickstrom, and assigned to the present assignee, there is described and claimed structures and methods of making such structures involving spaced metal members on integrated circuits, such as for cantilever beams and resonant gate transistors and for conductive crossovers.

SUMMARY OF THE INVENTION

Briefly, the present invention allows in-situ tuning and impedance matching of microstrip circuits by providing a microwave stripline of a length related to the wavelength of the desired operating frequency, which stripline is divided into a plurality of sections, each of a length chosen to be a selected fraction of the wavelength. A plurality of cantilever switches of material similar to the sections are positioned to interconnect sections. Each cantilever switch has a first portion affixed to its associated section and a second portion extending over but spaced from an adjacent section. The over extending portion can be selectively permanently bonded to the adjacent section. The cantilevers are selected to be sufficiently flexible to allow temporary electrical contact to be made for tuning and impedance matching. The number of sections so connected together determines the amount of phase shift imparted to energy propagating along the stripline.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, reference may be had to the preferred embodiment, exemplary of the invention, shown in the accompanying drawings, in which:

FIG. 1 is a perspective view of a cantilever switch utilized in the inventive embodiment;

FIG. 2 is an elevational view of such a cantilever switch;

FIG. 3 is a diagrammatic illustration of an illustrative embodiment of the present invention;

FIG. 4 is a graphical illustration of the performance of the illustrative embodiment shown in FIG. 3;

FIGS. 5 through 8 are partial sectional views of a structure at successive stages in fabrication in accordance with the present invention;

FIG. 9 is a plan view of microwave circuitry embodying the present invention; and

FIG. 10 is a plan view of an alternate embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Simple in-situ trimming of a microwave strip is accomplished by dividing the line into a number of short sections, each capacitively coupled to its neighbor by a cantilever switch as shown in FIG. 1. Sections **2** and **4** are spaced apart a certain distance l_g. A cantilever switch **6** has a first part **8** secured to section **2** and a second portion **10** extending over but spaced from the adjacent section **4**. The part **10** is based a distance l_d from the section **4**. The coupling of each switch depends on the dimensions l_d and l_g for a given line and substrate, and can be approximated by

$$C_s \approx C_d + C_g \qquad (1)$$

$$C_d = \epsilon_o W (l_c - l_g)/l_d \qquad (2)$$

where:

C_d and C_g are capacitances illustrated in FIG. 2

ϵ_o is permittivity of free space and C_g is approximately equal to

$$C_g \approx W \epsilon_{eff} K(m)/K(n) \qquad (3)$$

where $K(m)$ is a complete elliptical integral of the first kind of modulus m. The modulus constants m and n are related to the geometries of the gap in a microstrip line in the following way:

$$m = (b^2 - a^2)^{1/2}/b \text{ and } n = a/b \quad (4)$$

where:

$2a = l_g$

$b = 1.5h/\epsilon_{eff}$

h = thickness on dielectric substrate

$\epsilon_{eff} = 1 + Q(d - 1)$

ϵd = dielectric constant of substrate

q = Wheeler filling factor.

For a 0.020 inch wide microstrip line of a 0.020 inch substrate having a dielectric constant of 8.875 such as sapphire for example, the calculated value of C_g is 0.0146 pf, which agrees very closely with the measured results set forth in Microwave Engineers Handbook and Buyers Guide, Horizon House Inc. 1967 by H. Stinehelfer.

For a switch of dimensions: 1_g = 0.004 inch, l_d = 0.0002 inch, a width W of 0.002 inch, a length l_c of 0.007 inch and a dielectric constant $\epsilon_d = 10$, the theoretical capacitance is of the order of 0.9×10^{-14} farads, corresponding to a reactance of 2.94 kilohms at 6 GHz or a reflection coefficient of 0.945. The measured value was 0.9. The lower measured value is due to the fringing fields at the gap which have been ignored in the calculation, and finite losses of the line and connector sections. A low capacitance can be obtained by increasing the switch height L_d, and gap separation l_g, and decreasing the cantilever length for a given line.

To investigate the loss and reflection properties of a number of such switches, a simple circuit was constructed as shown in FIG. **3.** The center line section **20** consisted of an 85 ohm (0.002 inch) line of one wavelength at 6 GHz, which was divided into $\lambda/8$ sections interconnected by seven switches. Matching at both ends of the line to 50 ohm miniature connectors was achieved by quarter-wave (65 ohm) transformers **22.** The relative phase-shift introduced by the closing of each switch is shown in FIG. **4.** When all the switches were closed, the input voltage standing wave ratio was measured to be 1.4 and the insertion loss was 1.9 db at 6 GHz, of which at least 1.2 db is attributed to line and connector losses at this frequency. The average loss is therefore less than 0.1 db per switch for the dimensions given which are by no means optimized.

More particularly, referring to FIG. **4** it can be seen that as each switch is closed the energy propagating along the line is shifted in phase the desired 45°. Of course, the stripline may be divided into a plurality of sections of any chosen number to provide incremental phase shift and impedance matchings as may be desired.

When the switches are fabricated of gold, bonding is readily achieved with a wedge bonder at room temperature. The cantilever switches are sufficiently flexible to allow temporary contact between sections without permanently bonding by the application of a slight pressure with the bonder. On removal of this pressure, the cantilever springs back to its original position without deterioration of electrical characteristics. Thus, it is possible to effect a test contact without bonding to determine optimum matching. Calculations have also been made to determine the stability of the switches under external stress. Suffice it to say, for the dimensions stated, an external acceleration of 20,000 G's would be required to cause contact to be made by a cantilever switch to an adjacent section.

A further understanding of the invention on the flexibility with which it may be used will be aided by consideration of the following description of preferred methods for carrying out the present invention. FIGS. **5** through **8** show steps in the fabrication process. In FIG. **5** a first continuous interfacial bonding material **30** is deposited upon a suitable substrate **32** such as sapphire, alumina, quartz to name a few. The interfacial bonding material **30** may be a metallization layer such as titanium **30**_a_ and gold **30**_b_. A pattern of sections **34** of another metal layer is deposited upon the layer **30** to define the switch gaps with the rest of the circuitry.

In FIG. **6** spacing material **36** is then placed in the gaps and onto a portion of each section **34.** This is followed by the plating of metal cantilevers **3** as shown in FIG. **7.** Sections **34** and cantilevers **38** may be of a metal selected from the group consisting of nickel, copper, silver, cadmium, gold, tin, palladium, aluminum and nickel-iron alloys.

The spacers and excess metalization are then removed by successive etching to form the switches as illustrated in FIG. **8.** Because the steps involved are the same for one or a number of switches, batch fabrication is therefore possible. For a total switch length L, a lower limit on the separation between adjacent switches would probably be twice that length. Using the 0.010 inch switches fabricated above, line length trimming in steps 0.020 inch, or 8.6 for an 85 ohm line at 6 GHz, is possible. The resolution could be improved further with smaller switches of lengths say one-half of those previously stated.

The present invention has application in tuning and impedance matching of microstrip circuits. For example, in FIG. **9,** strip lines **40, 42** and **44** may be lengthened for desired tuning of the microstrip IMPATT oscillator circuit by closing selected cantilever switches. More particularly, the solid state IMPATT diode is mounted in position **46** on a heat sink and d.c. is brought in by the bias pad **48.** Connection to the diode is made by wire bonding from pad **48.** Tuning of the IMPATT diode is achieved by varying lines **42** and **44,** and impedance matching of the oscillator to load line **50** is provided by line **40.**

An alternate embodiment of the present invention is as illustrated in FIG. **10.** As shown therein, a center line conductor **52** may be increased in width by the addition of adjacent lying conductors **54, 56, 58** and **60.** By simply permanently bonding the cantilever switch **62** disposed to connect the conductor **52** to the conductor **54** the effective electrical cross-section of the conductor will be increased accordingly. The closing of additional switches **64, 66** and **68** will insert additional sections **56, 58** and **60,** respectively, to increase the effective width of the conductor **52** with respect to current flow therethrough.

While the present invention has been described with a degree of particularity for the purposes of illustration, it is to be understood that all modifications, alterations and modifications within the spirit and scope of the present invention are herein meant to be included. Other possible applications are in the area of microwave integrated circuit interconnection and aligned bridging, in certain circuits where capacitive couplings are required.

It will, therefore, be apparent that there has been disclosed a reliable method of tuning microwave integrated circuit line connection which has a potential up to the expand. The advantages of this concept are: (1) high open circuit impedance, VSWR greater than 20, (2) low short-circuit insertion loss, less than 0.1 db, (3) high trim resolution, approximately 8° or lower at 6GHz, (4) low line perturbations, (5) high stability under mechanical stress, and (6) in-situ fabrication with the rest of the microwave integrated circuitry.

We claim as our invention:

1. A stripline conductor for tuning and impedance matching of microwave circuitry comprising, in combination; a plurality of line sections, each of a length chosen to be a selected fraction of a wavelength; a plurality of cantilever switches each associated with their respective one of said sections and having a first portion affixed thereto and a second section extending over but spaced from an adjacent section but which second section can be selectively permanently bonded to said adjacent section whereby the phase shift along said stripline is a function of the number of switches which are bonded closed.

2. A microwave stripline of substantially one wavelength at the desired frequency of operation comprising, in combination; a plurality of sections, each of a length chosen to be a selected fraction of said wavelength; a plurality of cantilever switches each associated with a respective one of said sections and capacitively coupling said one of said sections to an adjacent section; each said cantilever switch having a first portion affixed to said one of said sections and a second portion extending over but spaced from its adjacent section; the capacitive coupling between sections being related to the separation between adjacent sections and the space between the overhanging second portion and said associated adjacent section as well as the extent to which said second section extends over said associated adjacent section; said plurality of cantilever switches being sufficiently flexible to effect a test contact between adjacent portions upon application of slight pressure thereupon; each of said plurality of cantilever swithces being selectively, permanently bondable to its associated adjacent section whereby the capacitative coupling between adjacent sections is electrically shorted and the energy propagating along said stripline is shifted in phase in accordance with the number of sections so connected to accomplish tuning and impedance matching.

3. The subject matter of claim 2 including impedance matching means at each end of said stripline.

4. The subject matter of claim 3 wherein said impedance matching means includes quarter-wave transformers.

5. The subject matter of claim 2 wherein the neighboring sections are at least twice the length of their associated cantilever switch length.

6. A microelectronic component comprising, in combination; a substrate; a first pattern of conductors on a surface of said substrate; a plurality of cantilever switches each associated with a respective one of said conductors and having a first portion affixed thereto and a second portion extending over but spaced from an adjacent conductor; each of said cantilever switches being sufficiently flexible to effect a test contact between adjacent conductors; each of said flexible switches being selectively, permanently bondable to its associated adjacent conductor to widen the current path whereby adjacent conductors are selectively connected in parallel circuit relationship whereby the width of the resultant electrical path is increased.

7. A method of making a microwave stripline with selectively cold-flow bondable micro-sized switches for in-situ tuning on a substrate comprising the steps of; depositing a first continuous metal layer on a surface of said substrate; depositing a pattern of conductive sections of a second metal layer on said first layer to define switch gaps between said sections; depositing a layer of spacing material in the gaps between said sections and onto a portion of each said section; depositing a third metal layer over a portion of each said section and a part of said spacing material to an extent that the third metal layer overlaps a part of said second metal layer; removing the spacers and excess metalizations by successive etchings to form the cantilever switches.

8. The method of claim 7 wherein; said substrate is a member selected from the group consisting of sapphire, alumina and quartz.

9. The method of claim 8 wherein the second and third layers are of gold.

10. The method of claim 9 wherein said second and third metals are the members selected from the group consisting of nickel, copper, silver, cadmium, gold, tin, palladium, aluminum and nickel-iron alloys.

11. A microwave stripline switch arrangement for use at an operating wavelength, comprising: a first stripline section, at least a second stripline section spaced from said first section, a cantilever switch section connected to said first stripline section and extending over and spaced from said second stripline section and connectable therewith, said sections being of a combined length to effect phase shifting of microwave energy of said wavelength when contact is effected between said cantilever switch section and said second stripline section.

* * * * *