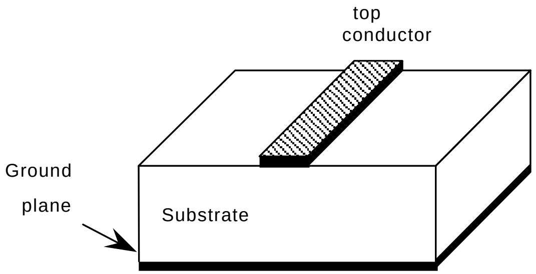
Microstrip

Materials and fabrication technologies

The figure shows the structure of a microstrip line. Broadly speaking there are 3 main technologies for fabricating microstrip circuits:-

- Copper-clad boards
- Thick-film fabrication, on ceramic substrates
- Thin-film fabrication, on ceramic substrates, other substrates (e.g. Quartz), and integrated circuits (GaAs, InP, Si, etc)



Copper-Clad Boards

Here, copper is put on large fibre-glass or other woven or PTFE-based boards, using electrodeposition or rolling. Photoresist is usually applied by laminating a preprepared film onto the substrate. It might also be applied by dipping in a tank, or by spinning (for small circuits). The photoresist is then exposed to UV via a mask, and developed. The copper is then etched away where it is not covered by photoresist. The etching process is relatively coarse, and fine lines cannot easily be fabricated. With expertise, 50 micron tracks can be made. In mass production 18 x 24 inch panel sizes are common, and costs are very low. Multilayer boards are produced by laminating different layers together. Vias can be produced by mechanical punching or laser machning. This advanced technology is referred to as MCM-L (laminate).

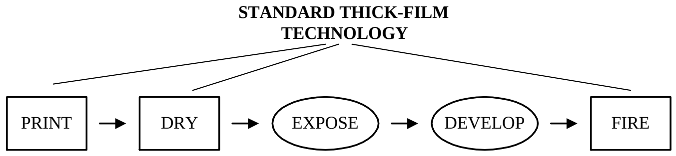
Thick-Film Fabrication

In this technology, metal and dielectric pastes are applied to a ceramic base substrate using screen printing. The screen is a fine metal wire mesh, and it has a photographic emulsion applied. The circuit pattern is reproduced onto this emulsion layer: During printing, the paste is squeezed through the mesh where there are emulsion openings onto the substrate. The paste is then dried and fired at around 850 deg C. Successive layers can be printed to form multilayer circuits.

The advent of LTCC technology (low temperature co-fired ceramic) has sparked off a renewed interest in thick-film printing. In LTCC, the ceramic is handled in its unfired “green” state, and is a flexible sheet. Via holes are made by punching or laser machining, and the metal patterns are printed onto each sheet individually. Then, the various layers are stacked together, gently pressed with an even pressure, and dried. A final “co-firing” step is used to complete the process. LTCC technology has the advantage of MCM-L that SMT resistors and capacitors are already manufactured using the same sort of process. Therefore, embedded passive components can be fabricated in the module, which reduces component count and costs.

Photoimageable Thick Film Process

The drawback of conventional thick-film technology is that the minimum conductor dimensions are limited to about 100 microns because of the screen’s jagged edges. The photoimageable process is an extension of the conventional thick film technology, in which standard thick film paste is replaced by a photosensitive material. Photosensitive thick film pastes have been developed by combining a photosensitive vehicle and metal-glass powders, both of which affect the electrical properties and resolution characteristics. The thick film paste is first printed everywhere over the total area of the substrate. As the ability to print sharp edge features is not required, the levelling properties of the photosensitive pastes are optimised to provide a uniform thick film with a very smooth and dense surface, free of pinholes and other printing defects. The paste is then exposed to UV through a mask and developed, leaving the conductor pattern.



Photoimageable thick-film process

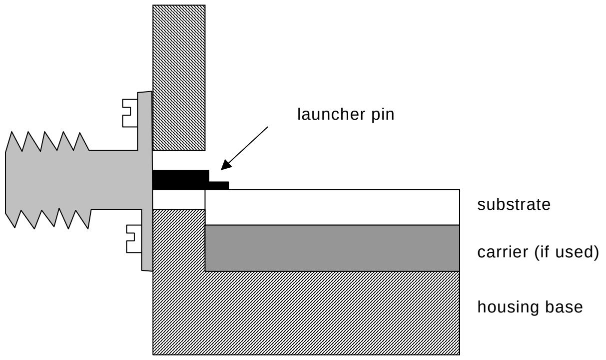
Thin-film technology

In this technology metal deposition techniques such as sputtering and evaporation are used, possibly with electroplating as well for increased metal thickness. The equipment used is relatively expensive, and the substrate must be in a vacuum. In mass production, the need to wait for the chamber pressure to drop down, and the limited substrate size, are significant drawbacks. However, thin-film technology gives the best pattern definition and the highest performance if suitable materials are used.

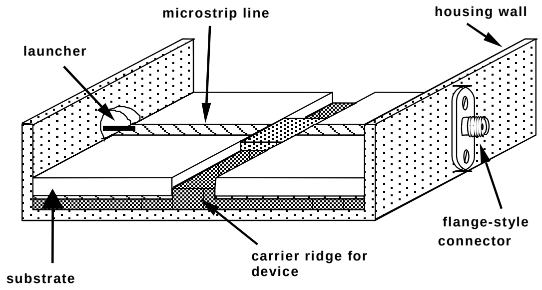
Test Fixtures

A test fixture is required as a mechanical housing and as a transition between the microstrip circuit and the co-axial connectors or rectangular waveguide flange required for connecting to the outside world. Microwave connectors, such as SMA, APC3.5, APC2.4, K, V etc, are gold plated, which is to ensure a clean connecting surface free from oxidation. It is essential to use suitable connectors to launch onto the microstrip, but the design of the transition is also crucial: to operate at high frequencies the coaxial fields must be smoothly converted to the microstrip field. The coax, however, usually has larger cross-section than the microstrip, and this requires the use of tapering, either continuously or in steps. Launchers might connect directly to the microstrip, or a “bead” might be soldered in to the housing wall. A typical launcher cross-section is shown. The main design principles are:-

1. The housing wall / centre pin should be a 50 ohm coax line: look out for eccentricity also
2. The centre pin must not be wider than the 50 ohm microstrip line
3. There must be no gap between the carrier and the side of the housing; there is a ground current flowing as well!
4. The substrate height must not be so small that the microstrip ground interferes with the coaxial fields at the launcher pin end
5. No air gaps should exist in between the microstrip ground plane and the housing base
6. The whole housing could act as a cavity resonator at some frequencies; a lid with absorbing material might be needed.
7. Always fabricate a 50 ohm through line, and measure the test fixture performance before you use it. DO NOT assume it works!

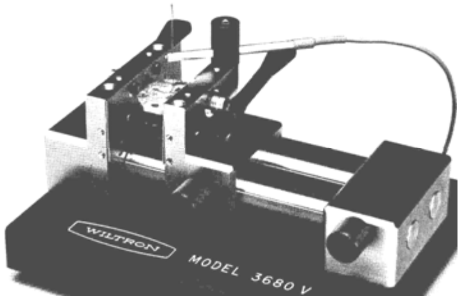


Typical coax-microstrip launcher cross-section



Typical microstrip circuit housing

To make measurements on circuits in the R&D situation, it is invaluable to have a reconfigurable microstrip test fixture, like the Anritsu one shown. With these, various sizes of circuit can be measured by moving the "jaws" apart. Also, in-fixture calibration techniques can be used to give more accurate measurements.



Anritsu 3680 microstrip test fixture

Lumped Elements in Microstrip

Inductors

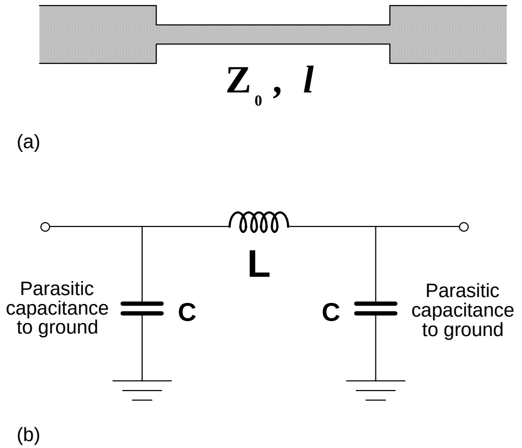
Depending on the inductance required, MIC inductors can be realised either as straight narrow tracks (ribbon inductors), as single loop inductors, or as multi-turn spiral inductors. A microstrip ribbon inductor and its equivalent circuit are shown. For short lengths ($<\lambda_g/4$), the inductance and shunt end capacitances can be calculated from the following well known equations [TC Edwards]:

$$L = \frac{Z_0}{2\pi f}\sin\left(\frac{2\pi l}{\lambda_g}\right)$$

and

$$C = \frac{1}{2\pi f Z_0}\tan\left(\frac{\pi l}{\lambda_g}\right)$$

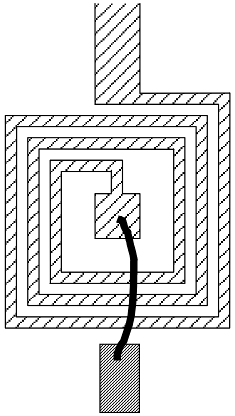
A narrow track with high Z_0 is needed to achieve high inductance with low parasitic capacitance. However, in practice the choice of track width is determined by fabrication limits, by the DC current carrying capacity and by the high resistance of very narrow tracks.



The ribbon inductor: (a) microstrip layout and (b) equivalent circuit

Spiral inductors

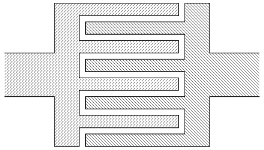
Spiral inductors are essential for values above approximately 1 nH. The mutual inductance between turns yields a significant increase in the spiral inductor's overall inductance and higher *Q*. Either a bond-wire or a second metal layer is required to connect to the centre.



Microstrip spiral inductor

Interdigital capacitors

These consist of a number of interleaved microstrip fingers coupled together as shown. The maximum value of an interdigital capacitor is limited by its physical size, and its maximum usable operating frequency is limited by the distributed nature of the fingers. They are ideal as tuning, coupling and matching elements, where small capacitor values are required and precise values are necessary.



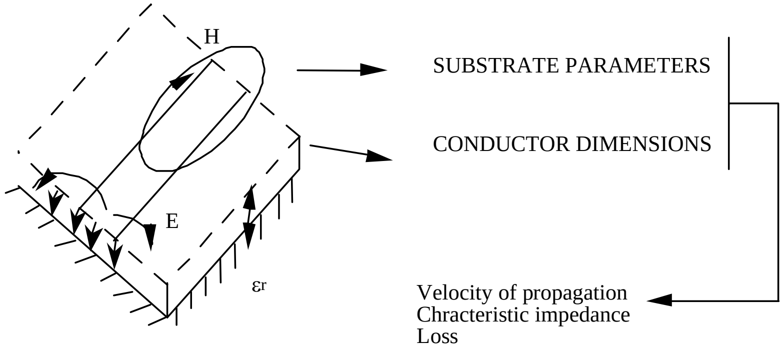
Interdigital capacitor

Resistors

Resistors on MICs use a deposited resistive layer, fabricated either with thin-film techniques (sputtering) or thick-film printing. The most commonly used materials are Tantalum Nitride, Cermet, and Nickel Chrome. In either case, since the layer or film thickness is fixed it is very convenient to quote resistivity in terms of an ohms-per-square figure. Hence, the value of the resistor is chosen by selecting a suitable aspect ratio.

MICROSTRIP ANALYSIS AND DESIGN

The most basic function of CAD packages for microstrip design is to calculate the electrical parameters for a line of given dimensions:-



Tools such as “Linecalc” or “TX-LINE” perform this function. With some CAD, the electrical parameters are not calculated on any field-modelling basis. They are calculated from closed-form expressions, drawn from simplified models with ‘fitting factors’ added to give close agreement to some measured data.

The models that are used do not work for

1. Data outside a certain range.
2. Higher order modes of propagation (non TEM).

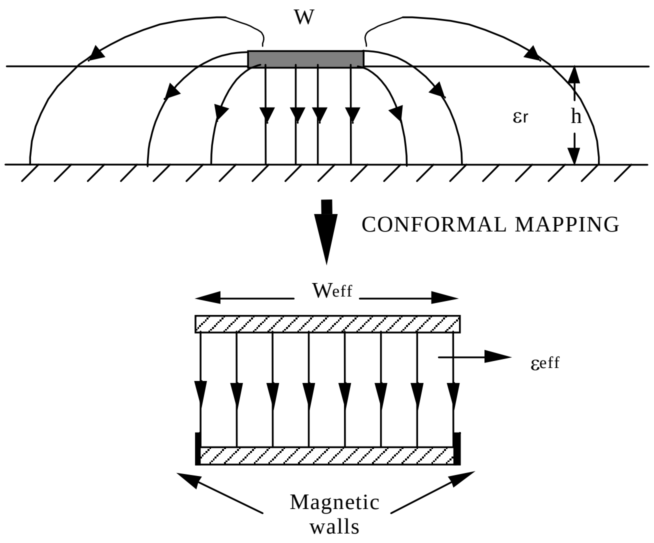
THE ‘MAGNETIC WALL’ MODEL OF MICROSTRIP

The fields in microstrip are too complicated to solve for directly. A common technique is to use “conformal mapping” to map the structure into a parallel-plate waveguide. This is assumed to have no fringeing fields at the edge – they are “magnetic walls”. Thus the field pattern is obvious. By reverse-mapping these field lines into the original microstrip domain, the microstrip fields are found.

From the effective width and effective dielectric constant, the characteristic impedance can be calculated:-

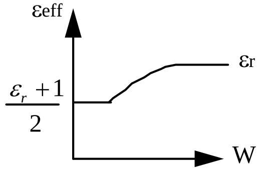
$$Z_0(f) = \frac{h\eta}{W_{eff}(f)\sqrt{\varepsilon_{eff(f)}}}$$

Z_0 changes slightly with frequency.



εeff is found to vary width strip width. For example for the “wide strip approximation”:-

$$\varepsilon_{off} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{h}{w}\right)^{-0.555}$$



$$\frac{\varepsilon_r + 1}{2} \le \varepsilon_{eff} \le \varepsilon_r$$

Narrow lines, field is equally in substrate and air.

Wide lines, it is similar to a parallel plate capacitor.

In fact ε_{eff} also varies with frequency because the field profile changes.

MICROSTRIP FREQUENCY LIMITATIONS

(1) **The lowest order transverse resonance.**

- Occurs when the width of the line (plus a fringing field component) approaches a half-wavelength in the dielectric:-

$$f_{CT} = \frac{C}{\sqrt{\varepsilon_r}\,(2W + 0.8h)}$$

Avoid wide lines

(2) **TM mode propagation**

- This is not width dependant; TM modes are supported by the substrate itself with a lower cut-off:-

$$f_{TM} = \frac{C \tan^{-1}\varepsilon_r}{\sqrt{2}\pi h\sqrt{\varepsilon_r - 1}}$$

usually specified as:- $h_{\max} = \frac{0.354\lambda_o}{\sqrt{\varepsilon_r - 1}}$

For higher and higher frequencies of operation, the substrate must be made thinner and thinner.

The ultimate limits are:-

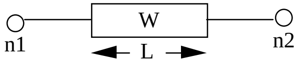
(i) Tolerances
(ii) Losses due to narrow conductors.

Microstrip can be used to over 100 GHz on MMICs (GaAs integrated circuits). “Thin film microstrip” uses a deposited dielectric layer only a few microns thick and has been shown to work to several hundred GHz. BUT it is very lossy.

For low loss above 100 GHz, use rectangular waveguides, some form of dielectric waveguide, or one of a huge range of other more esoteric waveguiding structures.

MICROSTRIP CAD CIRCUIT ELEMENTS

Straight Transmission Line



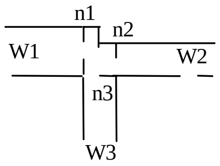
IN TOUCHSTONE^{TM} net list format:--

MSUB ER=… H= T=… RHO=…. RGH=…….
this global statement defines the substrate parameters

MLIN n1 n2 W=1 L=20
this is a straight section between nodes n1 and n2

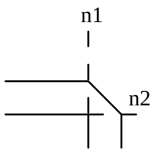
In addition, circuits will have discontinuities such as Tee junctions, bends, steps, etc (for example see the simple lowpass filter described earlier):-

Tee-Junction



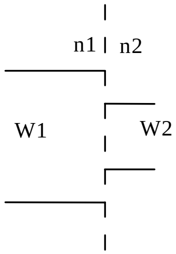
MTEE n1 n2 n3 W1=… W2=… W3=…

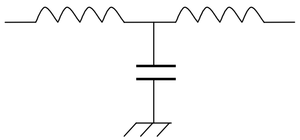
Bend



MBEND n1 n2 W=…

Step

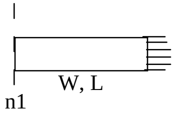




typical model

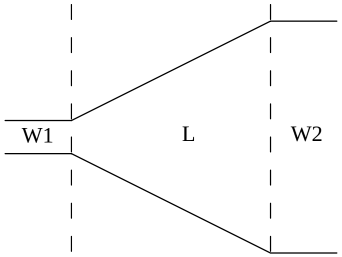
MSTEP n1 n2 W1=… W2=…

Open Stub



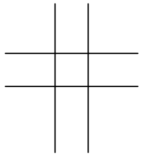
MLEF n1 W=… L=…
Includes a model of the fringing end effect

Taper



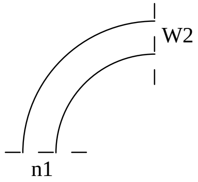
MTAPER n1 n2 W1 W2 L

Cross-Junction



MCROSS n1 n2 n3 n4 W1 W2 W3 W4

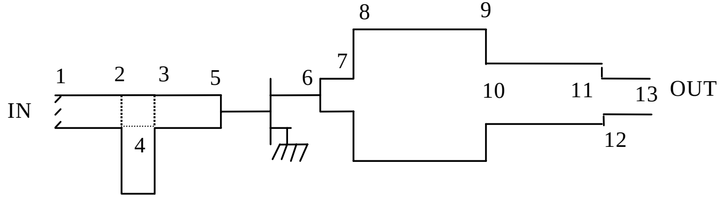
Curve



MCURVE n1 n2 W=… L=… R=…

EXAMPLE **NETLIST ENTRY**

Fictitious amplifier:-

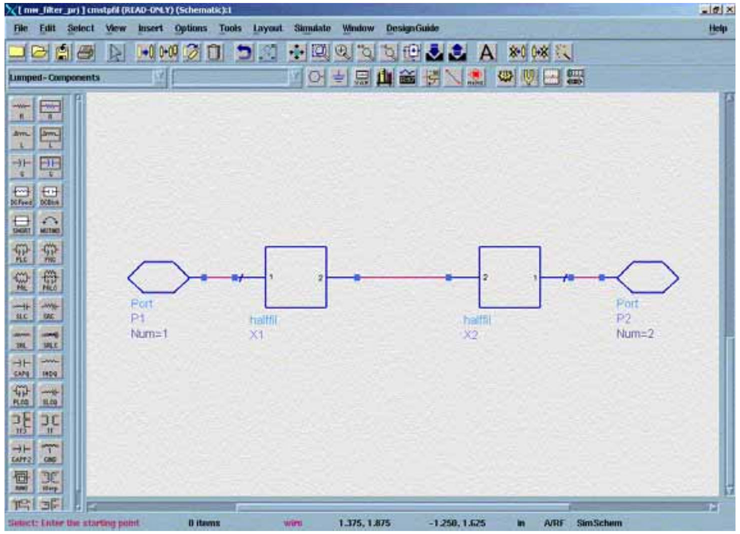


```
CKT
MSUB        ER = 10     H = 0.635   T = 0.005
MLIN        1     2     W = 0.6     L=3
MTEE        2     3     4     W1 = 0.6    W2 = 0.6    W3 = 0.6
MLEF        4           W = 0.6     L = 3
MLIN        3     5     W = 0.6     L = 2.6
FET         5     6      datafilename……
MLIN        6     7     W = 1  L = 1.5
MSTEP       7     8     W1 = 1      W2 = 3
MLIN        8     9     W = 3  L = 4
MSTEP       9     10    W1 = 3      W2 = 1
MLIN        10    11    W = 1  L = 3.6
MSTEP       11    12    W1 = 1      W2 = 0.6
MLIN        12    13    W = 0.6     L = 2
DEF   2P    1     13    AMP
```

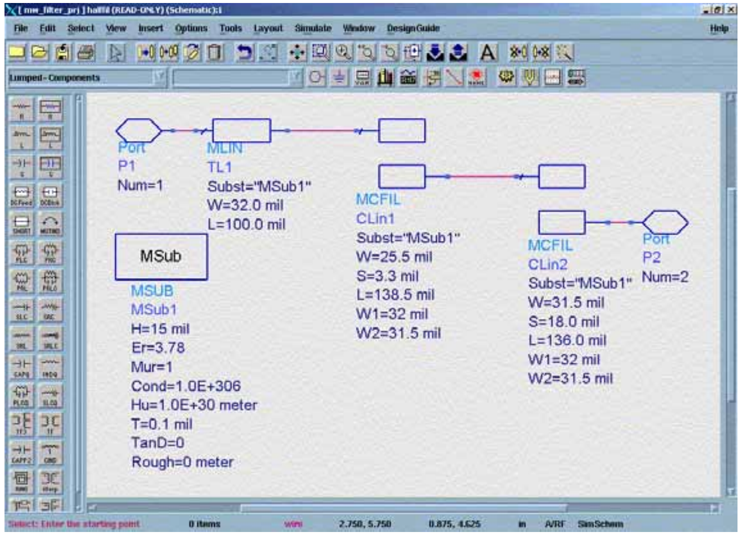
Schematic entry has replaced the netlist approach but it is important to see the origins and realise that the CAD does not consider interactions between components.

Advanced Microstrip CAD Techniques

Schematic Capture is a means of entering designs directly into a circuit diagram using symbols. This is now a fundamental part of all major CAD packages, and the old "net-list" is often not accessible. The advantages of schematic capture are that it is easy to visualise your circuit and prevent mistakes. Designs should use hierarchy extensively in order to keep them tidy and easy to follow. The ADS™ schematic of a parallel-coupled microstrip filter is shown: In the high-level schematic, two identical filter halves (sub circuits) are connected together with the input and output ports. The detail within the sub-circuit is shown in the second window; each microstrip CAD element has its own symbol and these are wired together on the circuit page. An MSub data block defines the substrate parameters as before. Since the microstrip CAD elements are all desribed in terms of physical dimensions, the computer can easily draw a layout of the circuit, as shown.



Two "halfil" subckts connected together



Port
P1
Num=1

MLIN
TL1
Subst="MSub1"
W=32.0 mil
L=100.0 mil

MSUB
MSub1
H=15 mil
Er=3.78
Mur=1
Cond=1.0E+306
Hu=1.0E+30 meter
T=0.1 mil
TanD=0
Rough=0 meter

MCFIL
CLin1
Subst="MSub1"
W=25.5 mil
S=3.3 mil
L=138.5 mil
W1=32 mil
W2=31.5 mil

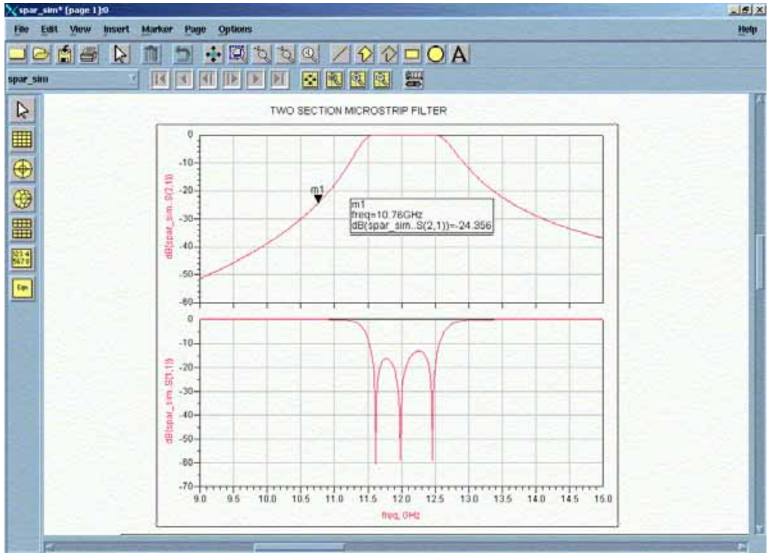
MCFIL
CLin2
Subst="MSub1"
W=31.5 mil
S=18.0 mil
L=136.0 mil
W1=32 mil
W2=31.5 mil

Port
P2
Num=2

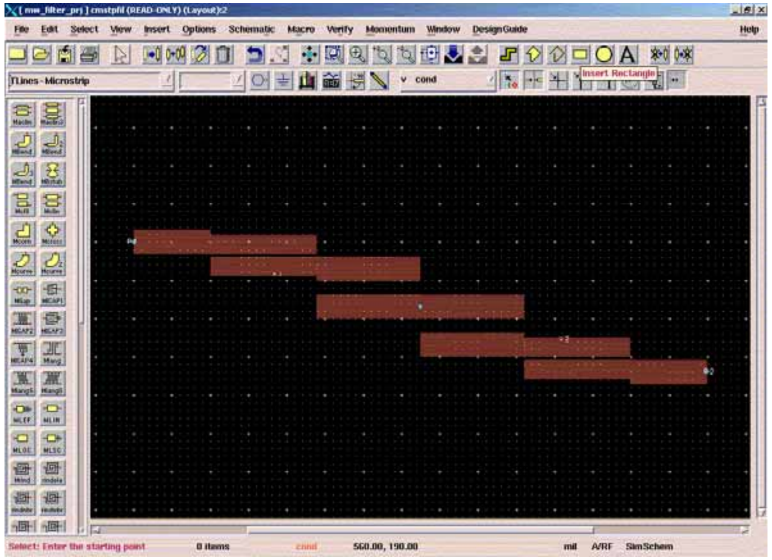
The detail within the "halfil" sub ckt

Linear Frequency-Domain Analysis

This type of simulator generally uses Y-parameter matrix techniques to solve for the steady-state frequency response of linear circuits. Since individual components are treated essentially as frequency-dependant admittances within a nodal matrix, solution for the overall circuit response is a case of using matrix reduction techniques to end up with an overall set of Y-parameters. These can then be converted to S-parameters, etc., for display. The simulator does not need to calculate the currents or voltages in the circuit, and the analysis is very fast as a result. In particular, working in the frequency-domain means that only the steady-state response of distributed elements (transmission-lines) needs to be considered. This is very important, because the multiple reflections encountered in a microwave circuit would take a lot of time to solve in the time-domain. Furthermore, frequency-dependence of transmission-line parameters (e.g. dispersion, resulting in a change of Z_O with frequency) can easily be handled. However, non-linear elements cannot be modelled since the currents and voltages in the circuit are not calculated. The shareware programs RFSim99, SCALC, and PUFF all use this method. The linear simulator "engines" within ADS, Serenade, and Microwave Office will also all be based on this method, although it is not the only analysis method available in these cases.



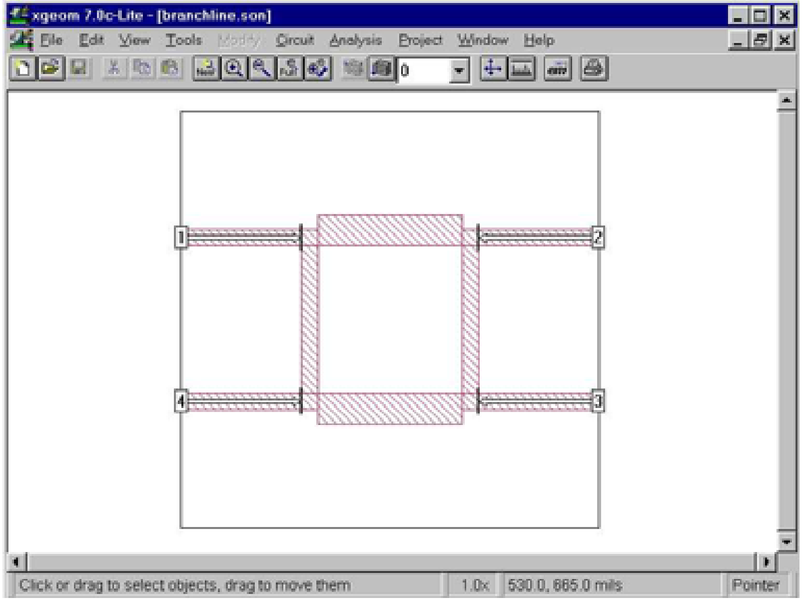
S-parameter simulated results



Automatically-generated layout

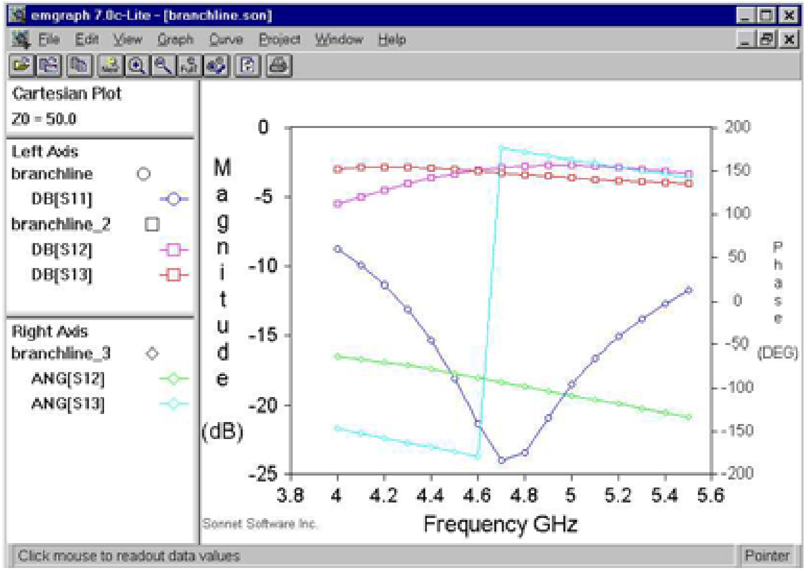
Planar Electromagnetic Analysis

These programmes are intended to solve for the S-parameters of arbitrarily shaped microstrip or CPW structures. Usually, the circuit conductors are divided into subsections and the method of moments is used for the electromagnetic analysis. Examples of this type of simulator are *em*™ (Sonnet), Ensemble™, and Momentum™. Often, many metal and dielectric layers can be handled, but these are assumed to be planar, and so the term 3D planar has been coined (there are also carefully-defined cases of 2.5D, 2.6D…2.9D simulation!). These simulators cannot analyse true 3-D structures, such as microstrip-to-stripline transitions where the dielectrics are not planar. 3D planar simulators are used extensively in MMIC design to analyse non-standard microstrip structures such as coupled bends and meandered lines. The layout of a branch-line coupler on *xgeom* ™ by Sonnet Software is shown. The simulator *em*™ can handle any number of ports and metal or dielectric layers.



Click or drag to select objects, drag to move them

Screenshot of Sonnet Lite 7



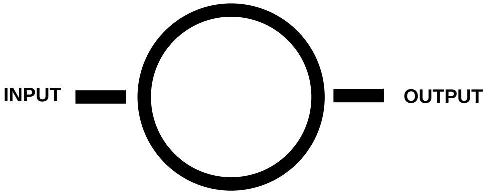
Click mouse to readout data values

EM simulation of the branch-line coupler

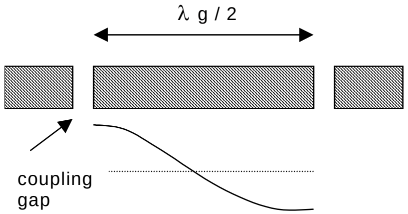
3D Electromagnetic Simulation

The High Frequency Structure Simulator (HFSS™) has dominated this market for many years and is now a product unique to Ansoft. This uses finite element techniques to analyse completely arbitrary metal and dielectric structures and can thus be used for analysing components such as waveguide-to-microstrip transitions and MMIC packages. However, this type of analysis is extremely demanding of CPU time and memory. Since most MIC and MMIC components are at present basically planar in nature, 3-D simulation is not used extensively. Other notable 3D simulators include CST Microwave Studio and Microstripes. Microstripes uses the transmission-line matrix (TLM) method which is a fast technique requiring less memory than finite element methods. For the design of structures like microstrip-coax launchers, 3D simulation is essential.

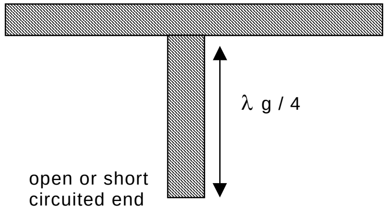
MICROSTRIP RESONATORS & FILTERS



Microstrip Ring Resonator



Half Wavelength Resonator

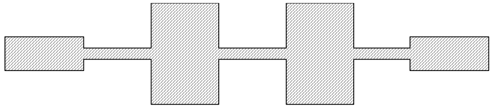


Quarter Wavelength Resonator

The 5 microstrip filters illustrated are:-

(1) Low-Z/High-Z Lowpass
(2) Lowpass using shunt stubs
(3) Parallel-coupled bandpass
(4) End-coupled bandpass
(5) Branch-line bandpass

1



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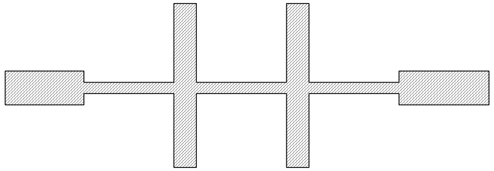

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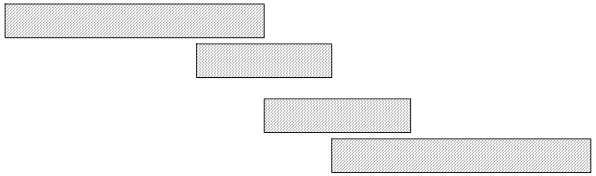

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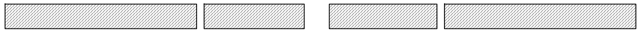

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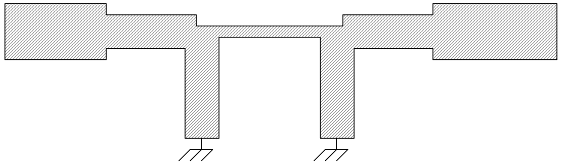


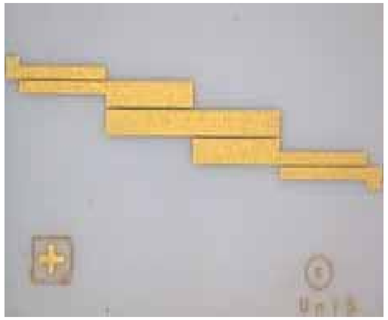
See “Matthei, Young and Jones” for more information.

<u>GENERAL FEATURES</u> of microstrip filters are:-

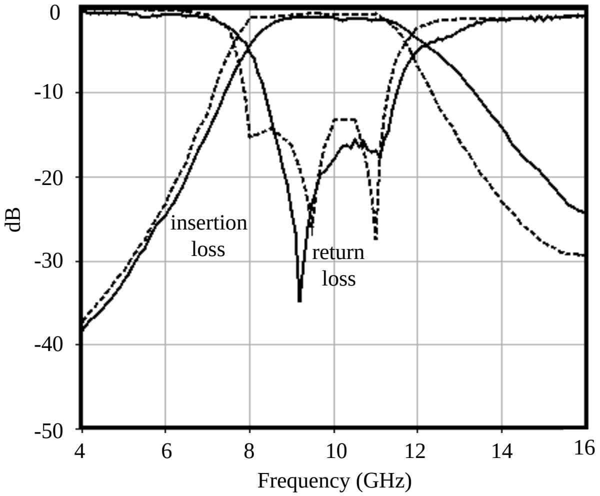
- low cost
- easily integrated with active devices

BUT

- lossy, low Q, hence performance often not good enough
- low power handling
- Often poor ‘spurious free range’



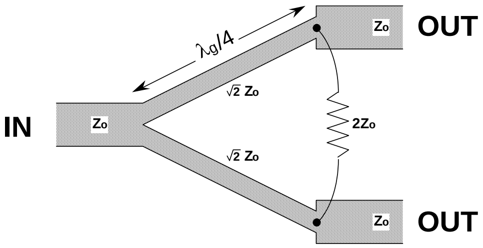
X-band bandpass filter on 635μm alumina (12 x 12 mm)



Simulated (- - - -) and measured (———) performance of the fabricated filter

Microstrip power splitters

It is not possible to achieve power division in RF & microwave circuits just by using a Tee-junction because it does not maintain 50 Ohm matching. Indeed, it can be shown that it is theoretically impossible for a lossless 3-port circuit to be matched at all ports. The Wilkinson power splitter is a convenient solution. It consists of two quarter-wave matching sections, with 70.7 Ohm characteristic impedance (for a 50 Ohm system), and a 100 Ohm isolation resistor connected across the outputs, as shown below. Note that the Wilkinson can also be used for power combining; if two equal phase, equal amplitude signals are input to the two arms, then there is no voltage across the isolation resistor and no loss in the combining process (except of course the normal transmission line losses). If the two inputs are not identical, there is a combining loss.

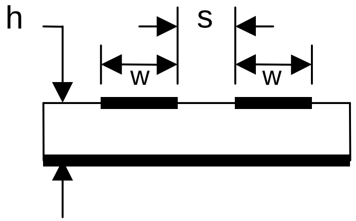


Microstrip layout of the Wilkinson power splitter

Microstrip Couplers

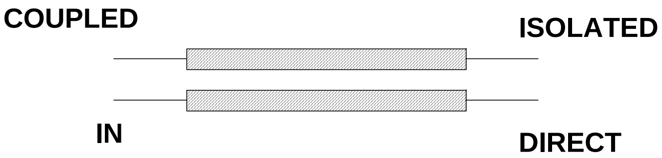
There are many situations that require a *directional* coupler, or which require a quadrature (90 degree) equal power split. A directional coupler can be used, for example, to separate waves according to their direction of travel for measuring reflection coefficient. A quadrature coupler is used in the balanced amplifier.

A directional coupler can be realised in transmission-line form by placing two signal conductors in close proximity so that the signal couples from one to the other. In microstrip form, this is shown below:-



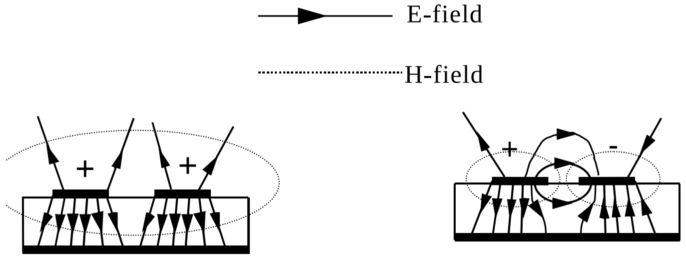
Parallel-coupled microstrip lines in cross-section, indicating key parameters

If the directional coupler is chosen to have a length of one quarter-wavelength, it can be shown that maximum power is transferred in the reverse direction to the **coupled** arm, whilst very little is coupled in the forward direction. This output is called the **isolated** port, as shown below. The remaining power travels straight out of the **direct** port. The coupler is often called a **backward wave** coupler because of its directional property. A remarkable feature of the coupler is that the phase difference between the signals from the coupled and direct ports is exactly 90 degrees over a huge frequency range – although the amplitudes vary with frequency.



Parallel-coupled microstrip lines from above, showing port definitions

The backward-wave coupler can be explained using standing-wave principles. It involves the superposition of two modes of propagation in the coupled line structure. In one mode, the **even mode**, the two conductors are at equal potentials, and there are no electric field lines from one to the other. In the other, the **odd mode**, the conductors have opposite polarity and electric field lines run direct from one to the other. In microstrip, the different field patterns of the two modes mean that different proportions are in the air & dielectric. So, the two modes have different velocities and different characteristic impedances (Z_{oe} and Z_{oo}). In coaxial line, and stripline, the dielectric is homogenous (and the fields pure TEM) and the two modes have identical phase velocities. The differing phase velocities have a big effect on the isolation that is achieved: to achieve high isolation (e.g. 30dB), a pure TEM transmission medium is best.



(a) Even mode (b) Odd mode

Approximate field patterns for even and odd mode in microstrip

For coupling factors up to 10dB, approximately, the values of Z_{oe} and Z_{oo} must satisfy the following:-

$$C' = 20\log\left|\frac{Z_{0e}-Z_{0o}}{Z_{0e}+Z_{0o}}\right|$$

where C is the coupling factor in dB, and

$$Z_0^2 \approx Z_{0e}Z_{0o}$$

which yields:-

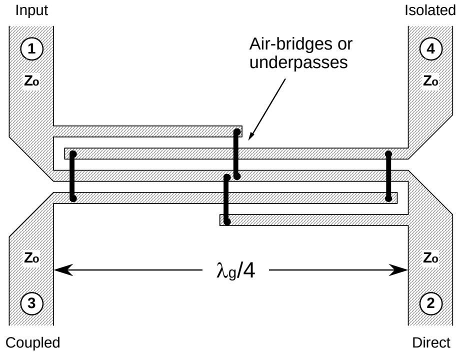
$$Z_{0e} \approx Z_0\sqrt{\frac{1+10^{C'/20}}{1-10^{C'/20}}} \quad \text{and} \quad Z_{0o} \approx Z_0\sqrt{\frac{1-10^{C'/20}}{1+10^{C'/20}}}$$

Design curves for Z_{oe} and Z_{oo} are available, or CAD packages can be used.

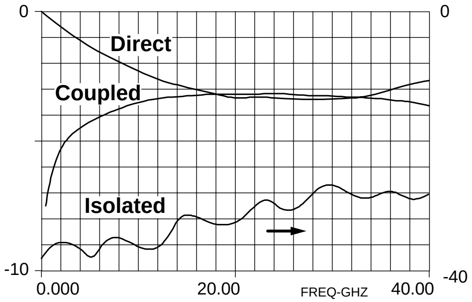
The parallel-coupled line structure also finds application in filters; then Z_{oe} and Z_{oo} are the parameters which are synthesised from filter theory, in a similar manner to the L's and C's in the lumped-element bandpass filters. Other applications include DC blocks, phase shifters, and matching networks.

The Lange Coupler

The parallel-coupled microstrip structure cannot be used to realise an equal power split (a 3dB coupler); even with a conductor spacing close to zero, the coupling is limited to 6 dB approximately. In order to overcome this limit, the two lines must overlap. This can be done easily with a multilayer structure, but with ordinary microstrip it has to be done by interleaving the two conductors. Each arm consists of a number of "fingers" which alternate, and this was first proposed by Julius Lange. Depending on the achievable conductor dimensions, and on the subtrate height and Er, either 4, 6, or 8-finger Lange couplers are used. To keep the fingers of a particular arm at the same potential, straps must be connected across using bond-wires, air-bridges, or underpasses. In the Lange coupler shown, the structure is flipped at the centre, so that the Coupled and Direct ports are on the same side for convenience. The typical frequency response of a Lange coupler is shown.



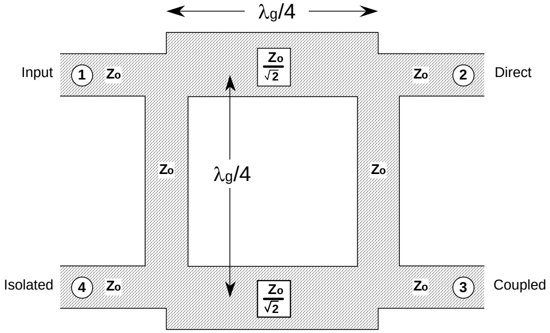
Layout of the Four Finger Lange coupler



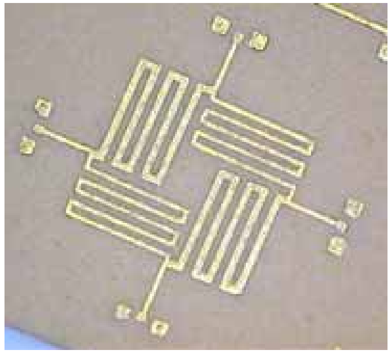
TYPICAL QUADRATURE COUPLER FREQUENCY RESPONSE

Other Couplers

Coupled-line and Lange couplers can be difficult to realise because they require narrow tracks and/or gaps. So, for many applications the branch-line coupler is used when a 90 degree 3dB split is required. In fact, this can also be analysed in terms of odd- and even-modes, but more in circuit terms than as fields. The standard layout is shown below; the ports can be interchanged to remove the step in width. A single-section branch-line coupler is rather narrowband, but multi-section versions can be designed for more bandwidth.

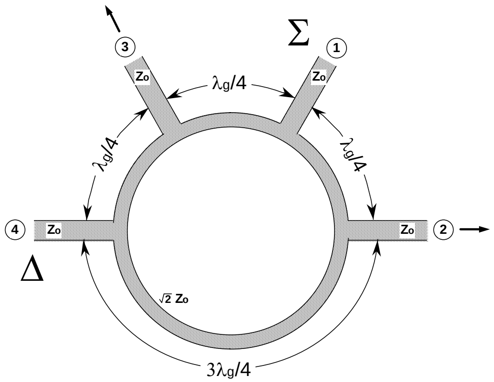


The microstrip branch-line coupler



Miniature meandered branch-line coupler at 10 GHz using photoimageable thick film technology (approx 1 x 1 mm !)

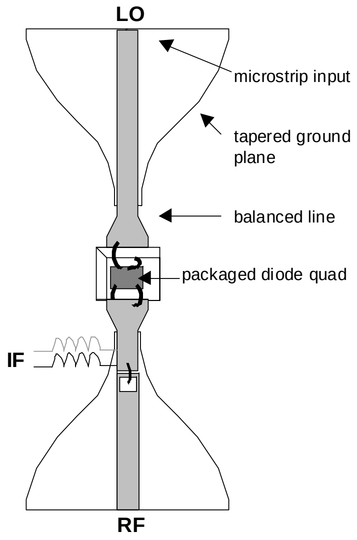
When a 180 degree 3dB split is required, which is often the case in mixers and modulators, the rat-race coupler can be used.



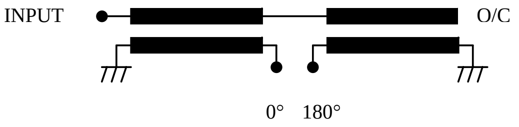
The microstrip rat-race coupler

TRANSMISSION LINE BALUNS

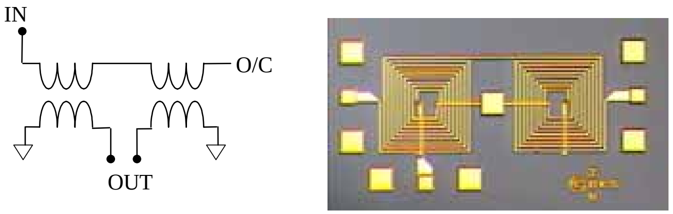
In MIC mixers, the main forms of balun are wire-wound ones on ferrite cores, or suspended microstrip structures. A double-balanced mixer using a suspended microstrip balun is illustrated. The wire-wound type is widely used for drop-in modular mixers, most notably from Mini-Circuits™, who founded a successful business on DBMs, with the "SBL-1" being perhaps of historical importance. With ferrite cores or suspended microstrip, there is some intricate manual assembly required and various planar balun configurations have been proposed, most notably the planar version of the Marchand balun which has wideband performance. It consists of two coupled sections, which may be realised using microstrip coupled lines, Lange couplers, multi-layer coupled structures or spiral coils· These baluns are usually designed through circuit simulations using full-wave electromagnetic analysis. The new Mini-Circuits™ mixer product line – the "Blue-Cell™" range – uses various forms of this planar Marchand balun, fabricated in multilayer thick-film technology. The balun using spiral transformers is a compact form of the planar Marchand balun. The frequencies that this technique can be used at are limited by the size and DC resistance at low frequency, and the inter-spiral capacitances at higher frequencies.



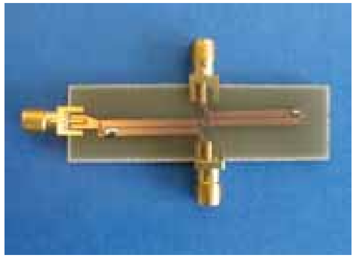
DBM using suspended microstrip baluns



Planar Marchand balun

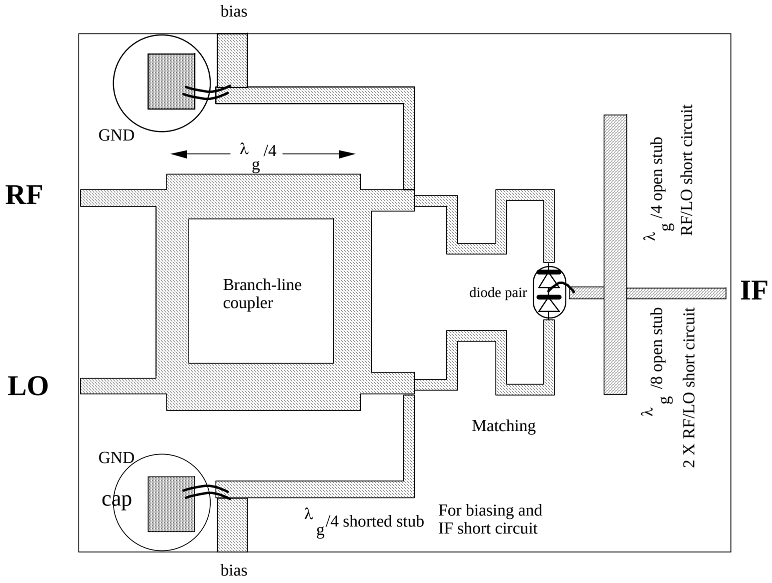


Spiral balun (GaAs MMIC, 1 x 0.5 mm approx)

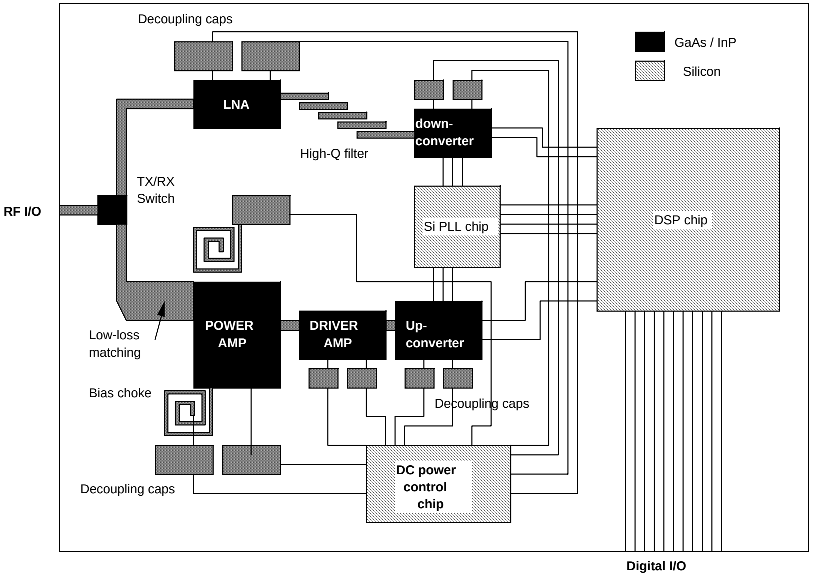


Marchand balun on FR-4 at 2 GHz with SMA connectors

TWO EXAMPLE MICROSTRIP CIRCUITS



Microstrip balanced diode mixer



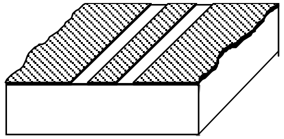
Multi-chip module using microstrip

Coplanar Waveguide

The major attraction of coplanar waveguide (CPW) is that through-substrate via-holes are not required for grounding purposes. The structure of a CPW transmission line is shown: It consists of a signal conductor placed between two ground planes. The dominant mode of CPW is quasi-TEM and there is no low frequency cut-off. The principal advantages of CPW are:

1. No via-holes needed for grounding
2. low dispersion
3. tapers with constant characteristic impedance can be realised by varying the track width and gap combination
4. the ground planes can provide some shielding between lines
5. chip components may exhibit less parasitic capacitance.

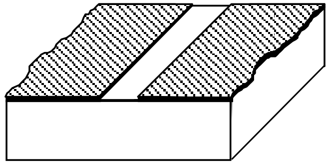
Many CAD packages now have CPW elements in their libraries. These models include bends, steps, T-junctions and many other common elements. One of the major problems with CPW is that the mode of propagation can easily degenerate from quasi-TEM into a balanced coupled-slotline mode. This happens very often at discontinuities, but can be avoided by incorporating grounding straps between the ground planes, using either bond-wires or a second metal layer.



Coplanar waveguide

Slotline

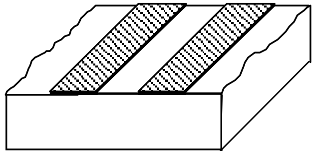
Slotline consists of a pair of ground planes with a narrow slot between them, as shown, and the signal propagates in a TE (transverse electric) mode. This means that slotline is not an ideal general purpose transmission-line medium, but this mode makes it very useful for circuits such as balanced mixers and amplifiers, where push–pull operation is required. Also, since CPW has the quasi-TEM mode and slotline has the TE mode, a number of useful hybrid junctions and transition circuits can be produced. The most popular of these is the CPW-to-slotline transition. This type of transition has demonstrated balun operation over more than two octaves of bandwidth, and has been used in miniaturised uniplanar mixers and amplifiers.



Slotline

Coplanar strips

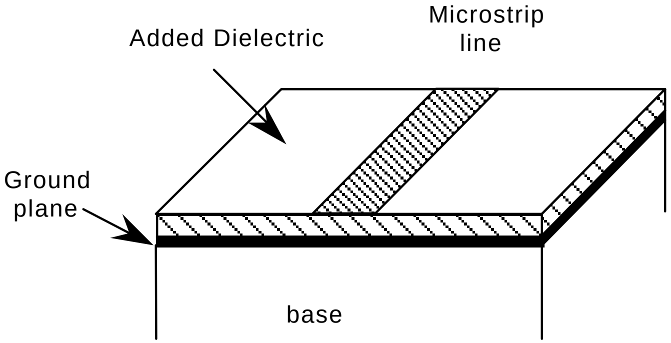
The coplanar strip (CPS) transmission medium consists of a pair of closely coupled parallel strips, as shown below. It is essentially a planar equivalent to the twisted pair or Lecher line. As a balanced transmission line, it is ideally suited to balanced mixers and push–pull amplifiers. However, the lack of design information has severely restricted its use.



Coplanar strips

Multilayer Transmission Lines, Couplers & Baluns

Multilayer techniques are now widely used, since circuit size can be reduced and more complex modules can be realised. A simple example is the use of “Thin Film Microstrip” (TFMS), where miniature lines can be fabricated by using a thin added dielectric:-



Thin-film microstrip transmission line medium

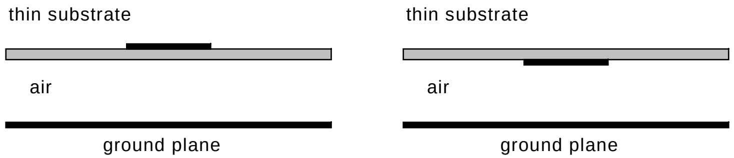
The Lange coupler has an interdigitated structure in order to achieve the tight coupling required for a 3 dB directional coupler. The potential use instead of overlaid structures on MMICs was first recognised by Marczewski and Niemyjski. With multilayer structures very tight coupling can be achieved more easily by employing one of a number of broadside or offset-broadside coupling structures.

The use of multilayer structures for the realisation of monolithic Marchand baluns was first demonstrated by Pavio and Kikel. The multilayer structure makes it possible to access the ground plane of the input unbalanced transmission line, without any complex suspended microstrip structure.

Other Transmission Line Structures

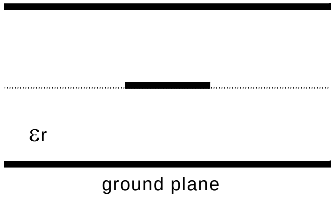
These are only mentioned briefly. You need to know they exist and their main advantages – if you need more information, head for the library!

Suspended microstrip



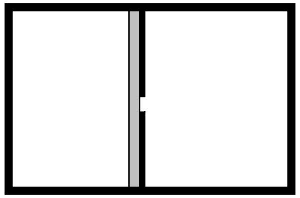
- low loss (air dielectric)
- low parasitics in chip components (e.g. wideband DC block)

Stripline



- pure TEM: coupled lines have equal even & odd mode phase velocities
- high directivity couplers
- also better for coupled line filters

Finline



E-plane circuit in a rectangular waveguide, fabricated on a thin substrate
- for low cost mm-wave circuits

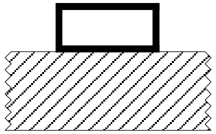
Dielectric waveguides

- various forms
- lower loss than metal guides
- very good > 100 GHz
- fields less confined generally

Micromachined Lines

Micromachined silicon components, using selective crystallographic etching techniques, have been widely developed for high volume commercial markets such as air-bag sensors, displays, disk drives and print-heads. These miniature components are classified as micro-electromechanical systems (MEMS) or microsystems. For microwave circuits, MEMS technology has the important feature of being able to realise moving parts for switching, tuning and steering as well as structures using air as the main dielectric, leading to low loss. The thick photoresist "SU-8" has been widely applied to the fabrication of air-based transmission lines.

Micromachined suspended microstrip



Micromachined RWG