AN OCTAVE - WIDE MATCHED IMPEDANCE STEP AND - QUARTERWAVE TRANSFORMER

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ABSTRACT

An impedance step can now be matched $-\Gamma\leq 0.02-$ over a frequency band corresponding to at least an octave in wavelength by using a shunt inductor before and -capacitor behind, but almost a quarterwavelength apart.
A shortened quarterwave impedance transformer could be matched with the shunt capacitor only. For high transformer ratios,part of a taper was used.
Ultra-short X-band transformers and-transducers could be realized from rectangular w.g.to flat-square-,circular-, ridge w.g.,finline and partly or fully dielectric-filled w.g.
Although realized in X-band w.g.,its principle is very general and can be applied to any dominant-mode transmission line.

INTRODUCTION

Up to now an impedance step is matched by a similar one, a quarter wavelength apart.These two form a quarterwave transformer,but matched at one frequency only. Over a waveguide band the reflection is reduced to about half the reflection of one large step,so still rather high. This can be reduced by using more, but smaller steps, separated by a quarter wavelength: a multistep transformer.
Making the step infinitely small,we end up with a taper. Many efforts have been made to optimize the transformer as well as the taper. However,usually they become rather long, even for an octave-wide match.
Now it will be shown how the basic discontinuity - the step - can be matched using a shunt inductance and - capacitance.
An impedance transformer - a double step - can be matched in a similar way even without using the shunt inductor.
Although developed in waveguide, the method can be applied to all types of dominant-mode transmissionlines.
Mode transducers always have an impedance transformer built in, so these can be made very short as well.

THE IMPEDANCE STEP

A parallel-plane transmissionline step with its reflectioncoefficients Γ_+ and Γ_- and t.l.equivalent [1,2] is given in Fig. 1a

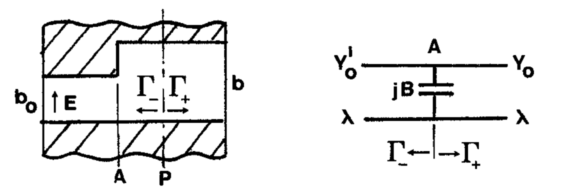

Fig.1 a Step with equivalent circuit

At very low frequencies,where the discontinuity capacitance hardly plays a role,$-\Gamma_-=\Gamma_+$ (I) for plane A. For microwaves this no longer holds,the higher-order modes penetrate deeper in the high-impedance guide than in the low one, even over a waveguide band. It can be shown -by theory and experiment-that a plane P can be found, for which (I) holds again. By definition we will call this the <u>reference plane</u> of the discontinuity. Its position depends on Γ,b and ω,being very important for fullband matching and can easily be measured. (see fig. 1b)

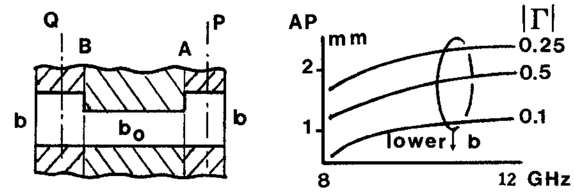

Fig. 1 b Position of reference plane

If $PQ = n\lambda_0/2$ no reflection occurs at f_0
Resonance for AB at f_1 if $AB=n\lambda_1/2$.Then $f_1 - f_0$ gives AP. (AB as a loosely coupled resonator).

The influence of jB on the magnitude of Γ is negligeable.
For small steps,the reflection coefficient is almost real,so can never be compensated by a shunt inductor, -capacitor or a series one . These give an almost imaginary reflection, so at $\lambda/8$ away from the reference plane it is possible to match. This is very frequency dependant,unless we apply this principle from <u>both</u> sides,starting from reflections with opposite sign.

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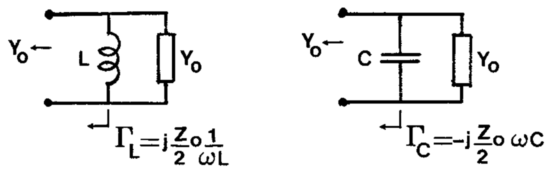
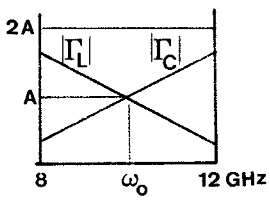
MATCHING ELEMENTS FOR A STEP

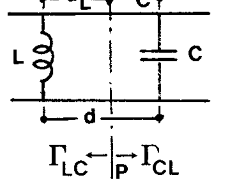
A combination of matching elements, formed by a shunt capacitor and -inductor, separated by a quarterwave transmission line has an almost constant reflection over the band and a reference plane almost halfway. This will be shown in a simple way, making approximations, justified by the experiment. Multiple reflections will be neglected, being rather small. For the reflection of a shunt inductor and -capacitor on a matched loaded transmission line, we then have :



$$\Gamma_L = j\frac{Z_o}{2}\frac{1}{\omega L} \qquad \Gamma_C = -j\frac{Z_o}{2}\omega C$$

Fig.2 a. Equivalent circuits





$$d_L = \frac{d}{2}[1+\delta]; \; d_C = \frac{d}{2}[1-\delta]$$

b. freq,curves c. combination of m.e.

$|\Gamma_L| = |\Gamma_C| = A$ for ω_o so with $\frac{\omega}{\omega_o} = 1+\epsilon$ we may write.

$\Gamma_L = jA(1-\epsilon)$ and $\Gamma_C = -jA(1+\epsilon)$

The matching combination has the vectorial sum of both reflections, transferred to its reference plane P (see fig. 2c): Γ_{LC} or Γ_{CL} coming from the other side, for which holds: $\Gamma_{CL} = -\Gamma_{LC}$
This condition is fulfilled for :

$$-\epsilon = \tan\beta d \tan\delta\beta d$$

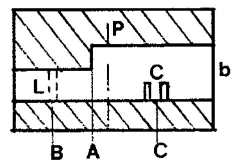
Then Γ_{LC} is real and becomes:

$$\Gamma_{LC} = -2A\frac{\sin\beta d}{\cos\delta\beta d}$$

For ω_o $\epsilon = 0$ so $\delta = 0$ and the total reflection is located just halfway L and C.
$|\Gamma_{LC}|$ has its smallest variation over the band of max. 13 % if the quarterwave is chosen at 10 GHz. This can easily be corrected by a small frequency dependency of L and C. δ varies from 0.1 at 8.2 GHz via 0 to 0.07 at 12 GHz.
The maximum shift of the reference plane P becomes 0.5 δd=+ 0.5 mm, similar to the shift of the reference plane of the step. Similar performance can be obtained by using series matching elements instead of shunt ones, however, the series capacitor is not attractive for waveguide.

FULL - BAND MATCHED STEPS

Excellent identical reflection-in magnitude as well as in phase - was measured over the band for the M.E.combination compared with the step for $|\Gamma|$ = 0.1 - 0.2 - 0.3 - 0.4 and 0.5.
Due to minor interaction we had to change the dimensions of these elements only slightly for matching. For L and C we used continuously variable inductive - and capacitive diaphragms, but also pins could be used, therefore we will only give the positions of L and C in a full-band matched step (see fig. 3)

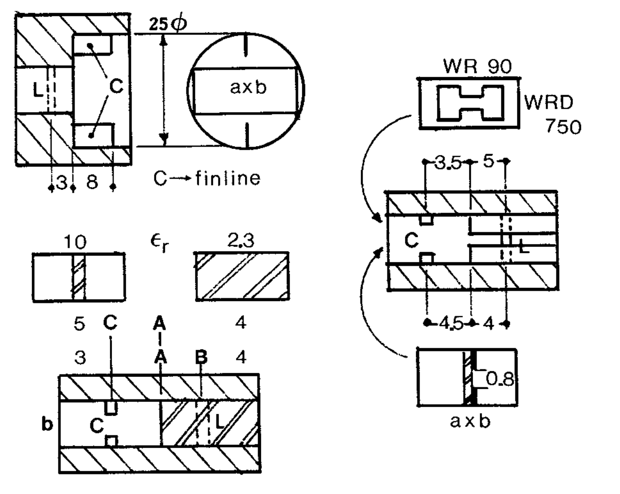


Γ	AB	AC	BC mm
0.1	3.5	5.5	9
0.25	3	5.5	8.5
0.5	3	4.5	7.5

Fig.3 F.B.M.Step BC<d due to cap.loading by the step
C on lower side to prevent H.M.interaction

Above Γ= 0.5 it becomes difficult to match, probably because AP becomes less freqeuncy dependant. (see fig. 1b) Therefore we have developed another solution to be treated in the next chapter.
Steps have been matched already this way in other transmissionlines like ridge w.g.and finline.
Not only steps between identical transmissionlines - usually called impedance transformers - but also between non-identical ones - modetransducers - have been matched. They often behave similar if the mode patterns are not too different. Ultra-short transducers from rectangular w.g. to other w.g.'s as circular, ridge, fully and partly dielectric filled as well as to finline have been realized. (see fig. 4)

a) rect. → circ. w.g. b) rect. → d.r. w.g.



d)rect. → diel.filled w.g. c)rect. → finline

Fig. 4 Step modetransducers for rect.w.g. (dim. in mm)

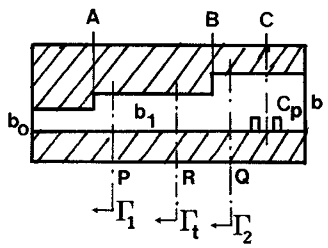
THE QUARTERWAVE IMPEDANCE TRANSFORMER

Impedance ratios more than three become rather difficult to match in one step and a less critical design might be preferred to minimum length. A double step proves easier to match, even without a shunt inductor, so more suitable for planar circuitry. For the steps we may write:

$\Gamma_1 = \Gamma_o(1-\gamma)$ and $\Gamma_2 = \Gamma_o(1+\gamma)$, see Fig. 5a. Here we approximate in a similar way as before. Writing : $PR = \frac{d}{2}(1+\delta)$ and $QR = \frac{d}{2}(1-\delta)$ can easily show that the position of the reference plane R for Γ_t - the vectorial sum of Γ_1 and Γ_2 - is determined by

$\tan\delta\beta d = \gamma\tan\beta d$ and for Γ_t we obtain:

$$\Gamma_t = 2\Gamma_o \frac{\cos\beta d}{\cos\delta\beta d}$$



b_o	b_1	AB	BC
7	8	6.5	4.0
6	7.2	|	3.5
5	6.7	6	4.5
3.3	5.5	|	3.5

b = 10.15 mm

a. Steps A and B with their ref.planes P and Q

b. Dim.of double step with position of M.E.

Fig.5. F.B.M.double step

For $d \approx \lambda g/4$ Γ_t becomes zero and changes sign around the corresponding frequency. This well-known behaviour of a quarterwave transformer is difficult to match. Therefore we shift this point just above ω_{max} so that Γ_t becomes a monotonous function of frequency in our band. For identical steps $\gamma=0$, so $\delta=0$. R is just halfway PQ. Its frequency dependency comes from the positions of P and Q. For higher frequencies R moves towards B, because $b>b_1$, so BQ>AP, see Fig. 1b.

For different steps R moves towards the highest reflection, because γ and δ have the same sign. Making $\Gamma_2>\Gamma_1$ moves R towards B for higher frequencies as well. This way it proved possible to find a plane C for which RC is $\lambda g/8$ for almost the whole w.g. band, so we can match if capacitor C_p has the right frequency curve for its reflection. [3,4]

In Fig. 5b several double steps are given which are matched this way.

For modetransducers it is preferable to chose section AB to fit both modes. In the rect.- to circular w.g. transducer (See Fig. 4a) the section with the fins forms a finline in circular w.g. and a shunt inductance is sufficient for matching. Fig. 4d can be fullband matched without the inductance if a shortened quarterwave section is used in a similar way instead of a normal one [5] and matched with a double capacitor C [3]

So it is evident that by the right choice of AB either L or C can be omitted.

A QUARTERWAVE TAPER

A very frequency dependent position of the reference plane R can be obtained if AB is non-uniform, inhomogeneous or even both. A constant-radius taper (see Fig. 6a), easy to be realized, can be seen as a multistep transformer with closely spaced steps. Their reflections cancel in proportion with increasing frequency and accordingly R moves towards B, especially if the taper is truncated. (see Fig. 6b) This is needed for full-band matching with only a capacitance C_p or inductance L.

A tangential transition of the taper at A prevents reflection, so is very practical for going to low impedances [4]

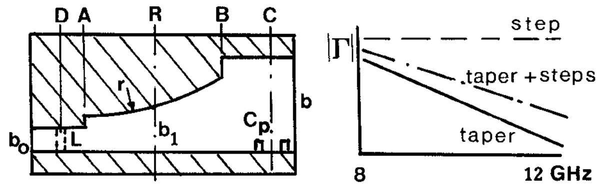


Fig. 6

a) A constant-radius taper b) Freq.curves of c.R. taper

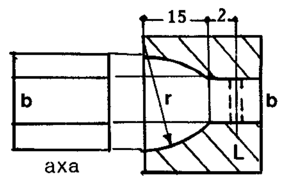
Going to a high-impedance w.g., non-evanescent higher-order modes might be excited at the slightest asymmetry: M.E.'s must be prevented, so we prefer just a shunt inductance. For planar t.l. the higher mode risk is just at the low impedance side, so fortunately we are able to match without the shunt inductance [3]. The combination of taper and steps - a truncated taper - has a great matching flexibility as will be shown in the following examples. (See Fig. 7)

a) Rect. → flat w.g. b) Rect. → square w.g.

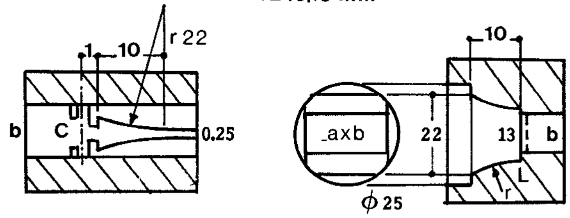
b_o	3.3
b_1(A)	3.8
b_1(B)	6

AB	7.4
AD	3
BC	5

see Fig.6a



b=10,15 mm



c) Rect.w.g. → finline d) Rect. → circ.w.g.

Fig. 7 F.B.M.const.radius tapered transitions

CONCLUSION

An impedance step corresponds to a real reflectioncoefficient with an almost constant magnitude vs.frequency.
The standard matching elements,being reactive, have almost imaginary reflectioncoefficients with a frequency dependent magnitude.
It has now been shown that a simple combination of a shunt inductor and - capacitor can have a reflectioncoefficient identical to the one of an impedance step and it can be used for matching.
If the asymmetrical discontinuity has a rather frequency dependent reference plane, use can be made of just one matching element one eighth of a wavelength apart.
A single step and a constant radius taper offer excellent possibilities for full-band matching.
Almost ideal transitions can now be made ultra short. This reduces losses and allows for miniaturisation.

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