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Analysis and Determination of Equivalent circuit of E-plane Metallic Strip in Rectangular Waveguides
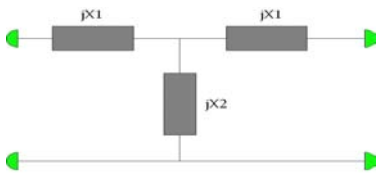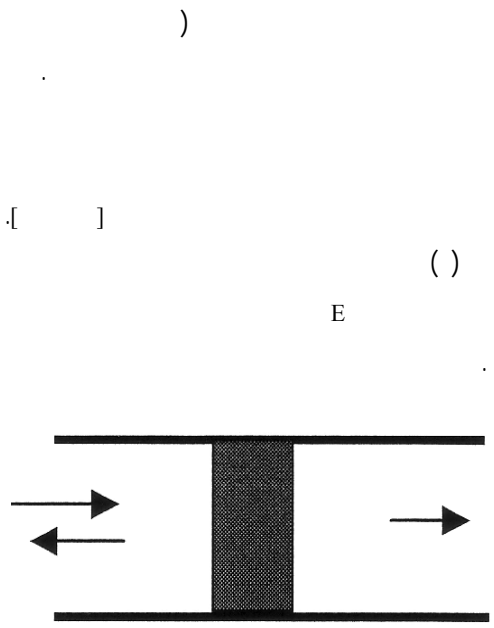
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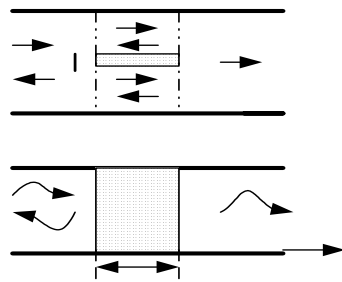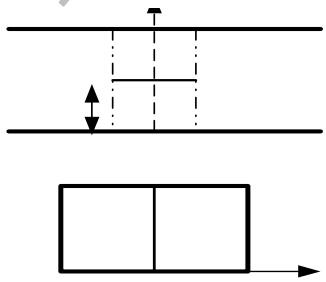
Abstract

Discontinuities are used to produce impedance and transfer functions in microwave devices. Various types of filters, phase shifters, mixers and high frequency oscillators may employ some kind of discontinuity. The longitudinal E-plane metallic strip is the main part of pure metal insert (PMI) and fin-line filters. In this paper, the least squares boundary residual method (LSBRM) is employed as an effective procedure for the analysis of longitudinal E-plane thick and thin metallic strips inside waveguides. The fields inside every section of the waveguide are expanded in terms of modal functions. Then, the boundary conditions on the tangential electric and magnetic fields over the waveguide interfaces (together with a weighting factor) are used to construct an error function. The minimization of the error function determines the amplitude of the excited modes and finally the equivalent circuit of the metallic strip. The numerical results obtained by the computer simulation agree very well with those derived by other methods, in cases available in the literature. The present method is effectively employed for the design of microwave band pass filters.

Key words: Discontinuity, E-plane fin, LSBRM, Mode matching, Modal expansion, Waveguide filter.

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jX1 jX1

jX2

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E

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$$\overline{F} = \hat{u}_z \Phi^h \quad , \quad \overline{A} = 0 \qquad (\ )$$

$$\overline{E} = -\nabla \times \overline{F} \quad , \quad \overline{H} = -\hat{y}\overline{F} + \frac{1}{\hat{z}}\nabla(\nabla.\overline{F})$$

$$(\ )$$

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$\overline{A}$ $\overline{F}$ α

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( ) TM^z

TM^z . TE^z .

. $\overline{A} = \hat{u}_z \Phi^e$ $\overline{F}$ $\sqrt{\alpha}$

α .

. H E

α .

. TE^z_{10} [ ]

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$$E_y^{(i)} = \sin(\frac{\pi}{a}x)e^{-j\beta_{10}z} \qquad (\ )$$

MATLAB

.

$$H_x^{(i)} = \frac{-\beta_{10}}{\omega\mu}\sin(\frac{\pi}{a}x)e^{-j\beta_{10}z} \qquad (\ )$$

-

$$\beta_{10}^2 = k^2 - (\pi/a)^2$$

H E

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$$\nabla^2\Phi^h + k^2\Phi^h = 0 \qquad (\ )$$

I $\hat{z} = j\omega\mu$ $k = \sqrt{-\hat{z}\hat{y}}$

. I $\hat{y} = j\omega\varepsilon$.

: $(z \quad)\,TE^z$ Φ^h

$$E_y\big|_{x=0,a} = 0 \quad , \quad E_x\big|_{y=0,b} = 0 \qquad (\ )$$

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TE^z ( ) ( )

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TE^z ( )

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$$\Phi_{rs}^{III\,h} = \cos(k_{rx}^{III}(x-x_1)).\cos(\alpha_s y).$$
$$\left\lfloor C_{1\,rs}^- e^{j\beta_{rs}^{III}z} + C_{1rs}^+ e^{-j\beta_{rs}^{III}z} \right\rfloor \quad (\ )$$

. TM^z

IV

z

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$$\Phi_{tv}^{IVh} = D_{1tv}^+ \cos(\alpha_v y).\cos(K_{tx}^{IV} x).e^{-j\beta_{v}^{IV}\left(z-\frac{w}{2}\right)}$$
( )

( ) $K_{tx}^{IV} = \dfrac{t\pi}{a}$.

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$$(\alpha_{L2}^u)^2 + (\beta_{L1L2}^u)^2 = K^2 - (K_{L1x}^u)^2 \quad (\ )$$
$$K = \omega\sqrt{\mu\varepsilon}$$

$u = I, II, III, IV$
$L_1 = m, p, r, t$, $L_2 = n, q, s, v$

y

y

TE_{m0}^z TE_{10}^z

.[ ]

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H_x E_y

: $Z = -W/2$ $W/2$

$$\Phi_{Im\,n}^{Ih} = A_{1\,Im\,n}^- \cos(\alpha_n y).\cos(k_{mx}^I x).e^{j\beta_{mn}^I \left(z+\frac{w}{2}\right)}$$
( )

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$$E_y^I = \frac{\partial}{\partial x}\Phi^{I\,h} \quad (\ )$$

$$H_x^I = \frac{1}{\hat{z}_1}\frac{\partial}{\partial z}E_y^I \quad (\ )$$

I $\alpha_n = \dfrac{n\pi}{b}$ $K_{mx}^I = \dfrac{m\pi}{a}$

TM^z .

. ( )

$$\Phi_{mn}^{Ie} = (A_{1mn}^-)' \sin(K_{mx}^1 x).\sin(\alpha_n y).e^{j\beta_{mn}\left(Z+\frac{W}{2}\right)}$$
( )

II

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TE^z ( )

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$$\Phi_{pq}^{II\,h} = \cos(K_{px}^{II}x).\cos(\alpha_q y)$$
$$\left\lfloor B_{1pq}^- e^{j\beta_{pq}^{II}z} + B_{1pq}^+ e^{-j\beta_{pq}^{II}z} \right\rfloor \quad (\ )$$

$\alpha_q = \dfrac{q\pi}{b}$ $k_{px}^{II} = \dfrac{p\pi}{x_1}$

( ) ( )

TM^z .

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III

$$T$$

$$\left(\sum_m E_y^I + E_y^{(i)}\right)\Bigg|_{Z=w/2} = \left(\sum_t E_y^{II}\right)\Bigg|_{Z=-w/2} \quad (\ )$$

$$\overline{F} \qquad (\qquad)$$

$$L$$

$$\left(\sum_m H_x^I + H_x^{(i)}\right)\Bigg|_{Z=-w/2} = \left(\sum_t E_x^{II}\right)\Bigg|_{Z=-w/2} \quad (\ )$$

$$\begin{bmatrix} L_{1.1} & . & L_{1.6} \\ . & . & . \\ . & . & . \\ L_{8.1} & . & L_{8.6} \end{bmatrix}_{8\times6[\ ]} \cdot \begin{bmatrix} . \\ . \\ . \\ . \end{bmatrix}_{6[\ ]\times1} = \begin{bmatrix} . \\ . \\ . \\ . \end{bmatrix}_{8\times1} \quad (\ )$$

$$(S1) \qquad 0 \le y \le b \qquad 0 \le x \le x_1$$

$$(S2) \qquad 0 \le y \le b \qquad x_1 \le x \le a$$

$$0 \le x \le x_1 \qquad (\ ) \quad (\ )$$

$$IV, III, II, I \qquad N, Q, P, M$$

$$x_1 \le x \le a \qquad\qquad S3 \qquad 0 \le y \le b$$

$$(8)\times(M+2P+2Q+N) \quad L \qquad\qquad S4 \qquad 0 \le y \le b$$

$$\left(\sum_P E_y^{II}\right)\Bigg|_{Z=w/2} = \left(\sum_t E_y^{IV}\right)\Bigg|_{Z=w/2} \quad (\ )$$

(LSBRM)

$$(\ ) \qquad\qquad (\ )$$

$$\left(\sum_P H_y^{II}\right)\Bigg|_{Z=w/2} = \left(\sum_t H_y^{IV}\right)\Bigg|_{Z=w/2} \quad (\ )$$

$$: \qquad\qquad \varepsilon$$

$$\overline{u} = L\overline{V} - \overline{F} \qquad\qquad (\ )$$

$$.[\ ]$$

$$<\overline{u}^*, \overline{u}> = \int_{B.S.} \overline{u}^* . \overline{u} \; ds \qquad (\ )$$

$$(\ ) \qquad\qquad (\ ) \quad (\ )$$

$$\varepsilon = <(L\overline{V} - \overline{F})^*, (L\overline{V} - \overline{F})> \quad (\ )$$

$$(\ ) \quad (\ ) \qquad\qquad (\ )$$

$$\overline{V} \qquad\qquad \varepsilon$$

$$0 \le y \le b \quad c \le x \le c+t$$

$$(\ ) \qquad\qquad (\overline{V}^*$$

$$\left(\sum_{In} E_y^I + E_y^{(i)}\right)\Bigg|_{Z=-w/2} = 0 \qquad (\ )$$

$$\overline{V}_{min} = <L^*, L>^{-1} \cdot <L^*, \overline{F}> \qquad (\ )$$

$$\left(\sum_n E_y^{IV}\right)\Bigg|_{Z=w/2} = 0 \qquad (\ )$$

$$\overline{F} \qquad L$$

$$<L^*, \overline{F}> \qquad <L^*, L>$$

$$.[\quad]$$

$$(\ ) \quad (\ )$$

$$L\overline{V} = \overline{F} \qquad\qquad (\ )$$

$$\overline{V}$$

$$)$$

$$(S_i) \qquad\qquad L$$

$$\overline{V} = [A_m^-, \ B_p^+, \ B_p^-, \ C_q^+, \ C_q^-, \ D_n^+]^T \quad (\ )$$

$$<L^*, L>, <L^*, \overline{F}> \qquad .[\ ] (\ $$

E_y - field matching

E_y (v/m) ... **x/a**

( ) - a

H_x -field

H_x (A/m) ... **x/a**

( ) - b

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PMIF [ ].

[ ]

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X

$b = 0.4(inch)$ $a = 0.9(inch)$.

(   ) b w .

.   (( )   .) $x1 = c$

( ) (t)

.

T

:   (   )

$$< L^*, L >_{1,1} = (1 + \frac{\alpha}{Z_{1r}^* Z_{1m}})$$

$$. \left| \iint_{S = S1+S2} \Phi_r^{I*}(x, y) . \Phi_m^I(x, y) . ds \right]$$

$$< L^*, L >_{2,1} = -(1 - \frac{\alpha}{Z_{1r}^* Z_{2m}})$$

$$. \left[\int_{S1} e^{\gamma_{PO}^{II} \frac{w}{2}} . \Phi_r^{I*}(x, y) . \Phi_p^{II}(x, y) ds \right]$$

( )

$$\Phi_{L1}^u(x, y)$$

.   ( )

( ) $(\overline{V})$

.

A_1^- .

Γ

:[ ] $A_1^+ = 1$.

$$\overline{Y}_{in} = \frac{1 - \Gamma}{1 + \Gamma} = \frac{1 - A_1^-}{1 + A_1^-}$$ ( )

T ( )

( )   . E

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$$\overline{Y}_{in} = G_{in} + jB_{in}$$ ( )

$\overline{Y}_{in}$ X_2 X_1

:[ ]   ( ) ( )   (   )

$$X_1 = \mp X_2 + \frac{B_{in}}{G_{in} - (B_{in}^2 + G_{in}^2)}$$ ( )

$$X_2 = \pm[(X_1 \pm X_2)^2] + \frac{G_{in} - 1}{B_{in}^2 + G_{in}^2 - G_{in}}$$ ( )
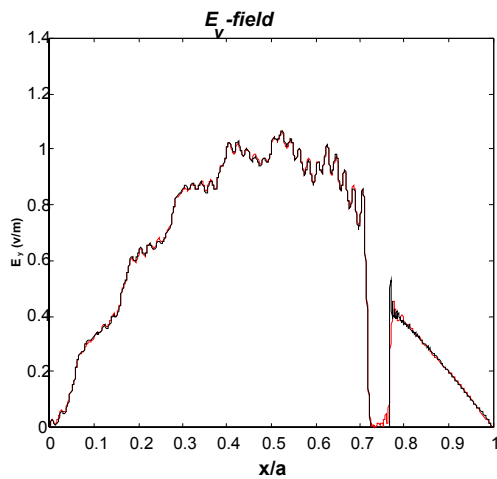
$(c = a / 2)$ ((a,b) . .))   [ ]

[ ]

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(b)   )

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$< L^*, L >$

( ) α .

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( )

α .

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(a,b)

H, E

a
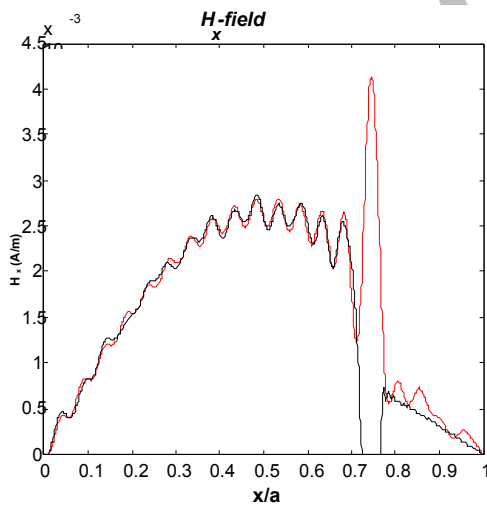
( )   - a $.(M = N = P = Q = 20)$

(a,b)

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( )

$Q = 50$ $P = 60$ $M = N = 40$

$(t / a = 0.05)$.

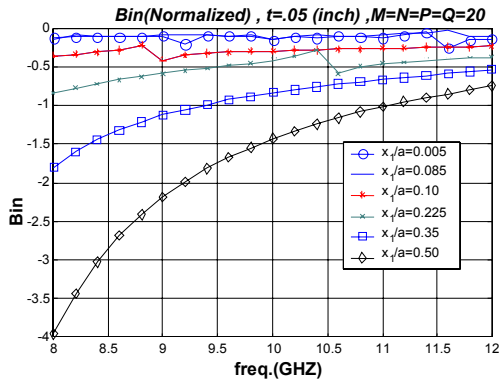. $x1 / a = 0.725$

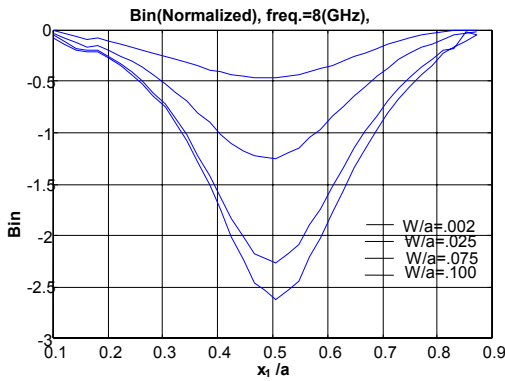H, E

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( )   - b   .[ ]
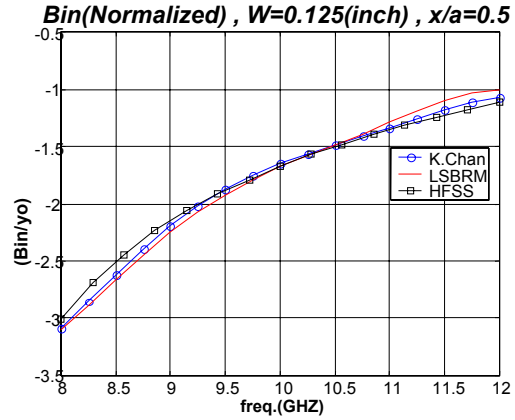
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TE_{m0}^z

(a)

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(b)   (a) .((b) . .)

.

Bin(Normalized) , t=.05 (inch) ,M=N=P=Q=20

x₁/a=0.005
x₁/a=0.085
x₁/a=0.10
x₁/a=0.225
x₁/a=0.35
x₁/a=0.50

M=N=P=Q=20

W=.15(inch)

- b

Bin(Normalized) , W=0.125(inch) , x/a=0.5

K.Chan
LSBRM
HFSS

- a

M=N=P=Q=30   c=a/2

(b)   (a)

$x1$. (W)

Bin(Normalized), freq.=8(GHz),

W/a=.002
W/a=.025
W/a=.075
W/a=.100

- a

freq.=8(GHZ)   M=N=P=Q=20   **X1**

Freq.=8(GHz) ,
M=N=P=Q=30

(x1)-LSBRM
(x2)-LSBRM
(x1)-
(X2)----

- b

(x2)   (x1)

freq.=8(GHZ)   c=a/2

M=N=P=Q=30

Bin(Normalized) ,freq.=8(GHz) ,M=N=P=Q=20

W/a=0.002
W/a=0.05
W/a=0.10
W/a=0.07

alfa fac. =
t /a = 0.075

- b

M=N=P=Q=20   **X1**

Freq.=8(GHZ)

Bin(Normalized)-compration

LSBRM(Narrow
K.Chang
LSBRM(Thick
t =.05 (inch)
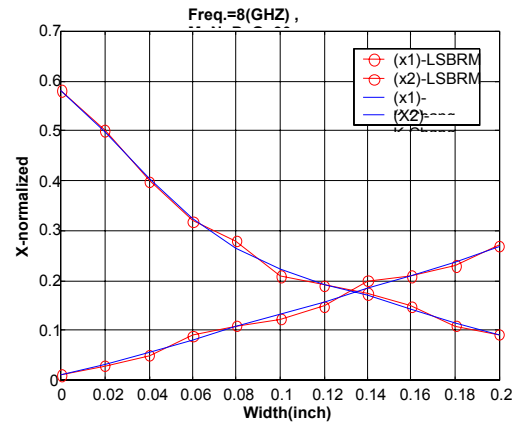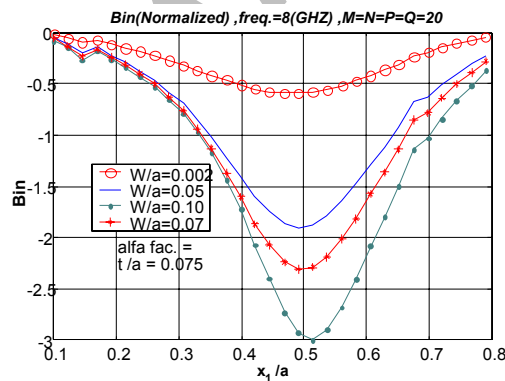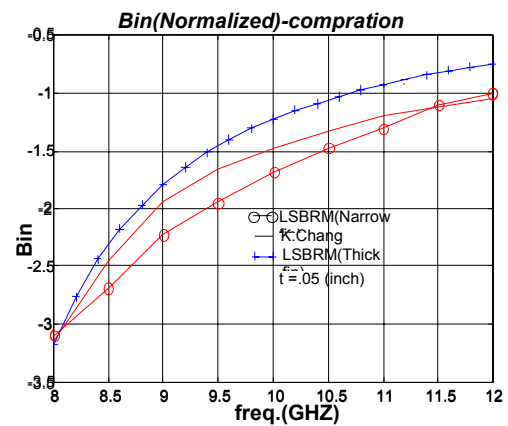
- a

W=.125(inch)   M=N=P=Q=2   c=a/2

HFSS (a)
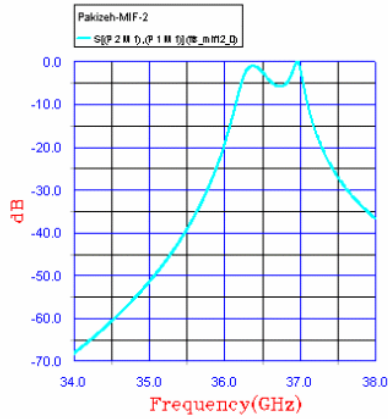
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(b) (*A*)*I* (*TE*)

a - S2l PMI

ka : xl=a/2 t=0.35(mm)

a=7.112(mm) b=3.556(mm). (HFSS)

b - PMI

ka : x1=a/2 t=0.35(mm)

a=7.112(mm) b=3.556(mm)

-
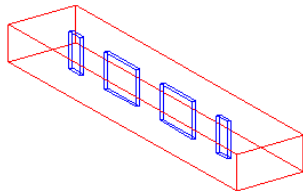
E

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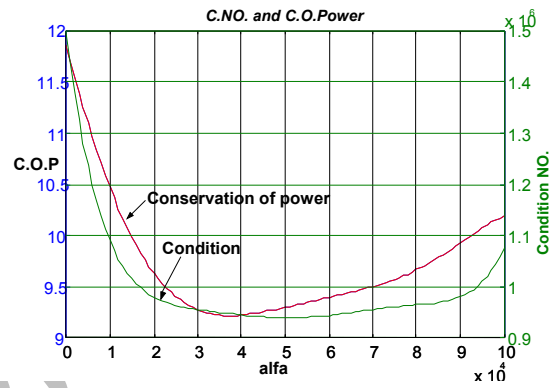
a -

x1=0.45(inch)

M=N=P=Q=30

b -

x1=0.3(inch) t/a=0.05 (A)

M=N=P=Q=20

64MB, P.II

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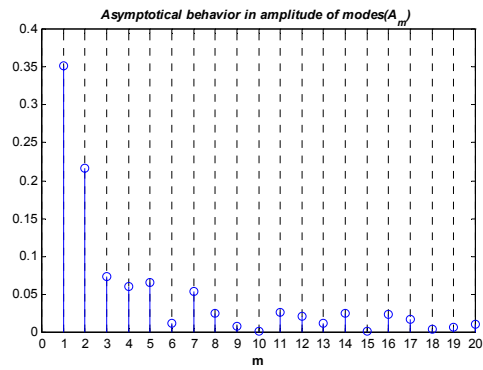[6]   Q. Zhang and T. Itoh, "Spectral-Domain Analysis of scattering from E-plane circuit elements"; IEEE Trans Microwave Theory and Tech., vol. MTT-35, pp.138-150, Feb. 1987.

E-plane Fin   " .   [ ]

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Bin (   ), t=.05 (   ) M=N=P=Q=20

. (GHZ)

-   -

Bin (   ),   =8(GHZ), M=N=P=Q=20   E-

Bin (   ), (   ) =8(GHZ), M=N=P=Q=20   H-

-   -

E-

H-

-

Bin (   ) W=0.125(inch),x/a=0.5

.(GHZ)

-

=8(GHZ), M=N=P=Q=30

(   )

-

Bin (   ) -   , M=N=P=Q=20

(GHZ)