NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

Electronics Division Technical Note No. 148

Title: **PROGRAMS FOR ANALYSIS OF WIRE GRID BEAM-SPLITTERS AND THE FOLDED MACH-ZEHNDER DIPLEXER**

Author(s): A. R. Kerr

Date: October 20, 1988

Distribution:

GB	CV	TUC	VLA
GB Library	ER Library	Library Downtown	VLA Library
R. Norrod	IR Library	Library Mountain	P. Napier
R. Weimer	M. Balister	J. Payne	J. Campbell
D. Schiebel	S. Weinreb	R. Freund	W. Brundage
E. Childers	C. Burgess	J. Lamb	
R. Lacasse	S.-K. Pan	D. Emerson	
C. Brockway	A. R. Kerr	P. Jewell	
J. Coe	Nancyjane Bailey	J. Cochran	
W. Albing	L. D'Addario	A. Perfetto	
S. White	N. Horner		
G. Behrens	S. Srikanth		
R. Fisher			
F. Crews			
B. Peery			

PROGRAMS FOR ANALYSIS OF WIRE GRID BEAM-SPLITTERS AND THE FOLDED MACH-ZEHNDER DIPLEXER

A. R. Kerr
20 October 1988

Grids of uniformly spaced wires are widely used at millimeter wavelengths as beam-splitters and polarizers. Frequency diplexers based on wire grids are used in millimeter wave receivers for introducing the LO and filtering out the unwanted image frequency. Such diplexers are the Martin-Puplett interferometer [1] which uses polarizing grids, and the folded Mach-Zehnder interferometer [2] which uses half-reflecting grids. This report describes four programs:

GRID001 computes the frequency response of an inductive wire grid, in which the incident E-field is parallel to the grid wires and the plane of incidence is perpendicular to the grid wires.

GRID002 computes the frequency response of a capacitive wire grid, in which the incident E-field is perpendicular to the grid wires but parallel to the plane of the grid.

DPLXR004 computes the frequency response of a folded Mach-Zehnder diplexer using inductive wire grids.

DPLXR005 computes the through-path and side-path transmission maxima and minima for a folded Mach-Zehnder diplexer using inductive wire grids.

The programs are written as Lotus 1-2-3 worksheets, and should operate on any PC equipped with Lotus 1-2-3 Release 2 (or later).

Theory

The programs are based on the formulas for arrays of straight wires in free space given by Marcuvitz [ref. 3, secs. 5.20 and 5.21].

Marcuvitz's formulas for the inductive grid assume a plane wave with an angle of incidence θ, polarized with the E-field parallel to the wires but perpendicular to the plane of incidence.

Marcuvitz's formulas for the capacitive wire grid are derived from his analysis of a capacitive post in a rectangular waveguide. He only considers the case of normal incidence to the grid, which implies $\lambda_g = \lambda$ (i.e., plane wave propagation down the waveguide). By using $\lambda_g = \lambda/\cos\theta$ his formulas can be extended to the case in which the angle of incidence is θ and the E-field is perpendicular to the grid wires but parallel to the plane of the grid.

All grids are assumed lossless.

The theory of the folded Mach-Zehnder diplexer is given in Appendix 1.

Operation of the Programs

The programs operate as standard 1-2-3 worksheets. With 1-2-3 running, type /fr and respond with the name of the program (e.g., A:\GRID001). Enter the desired input parameters in the appropriate cells, following each entry with the return key. To start the program, invoke macro \A by typing Alt-A. To view results displayed graphically, type /GNU and select the desired graph format name.

GRID001 -- Inductive Wire Grid

The equivalent circuit elements in Fig. 1 are evaluated using eqns. 1(a) and 2(a) in section 5.21 of Marcuvitz:

$$x_a = \frac{a \cos \theta}{\lambda} \left\{ \ln \frac{a}{\pi d} + \frac{1}{2} \sum_{\substack{m=-\infty \\ m \neq 0}}^{\infty} \left[\left[m^2 + \frac{2ma}{\lambda} \sin \theta - \left(\frac{a \cos \lambda}{\lambda}\right)^2 \right]^{-\frac{1}{2}} - \frac{1}{|m|} \right] \right\} \qquad \text{M5.21/1(a)}$$

$$x_b = \frac{a \cos \theta}{\lambda} \left(\frac{\pi d}{a}\right)^2 \qquad \text{M5.21/2(a)}$$

In the program, the sum is taken for $-20 \leq m \leq 20$, which gives an accuracy of four significant figures in x_a and x_b for the cases tested.

Restrictions

To avoid higher order diffracted beams, it is necessary that $a < \lambda/(1 + \sin \theta)$. The expressions for x_a and x_b are within 10% for $d/a \leq 0.2$.

Example 1

Figs. 2 and 3 show results from GRID001 for a 100 GHz half-reflecting grid of 0.002" dia. wires with 24 wires/inch and an angle of incidence $\theta = 45°$. The input quantities are indicated by boxes in Fig. 2. The following quantities are calculated:

wl	λ -- the free-space wavelength (mm)
x_a, x_b	normalized impedances in Fig. 1
$\|\rho\|^2$	power reflection coefficient
$\|\tau\|^2$	power transmission coefficient
RL	reflected path loss, dB
TL	through path loss, dB

Example 2

Fig. 4 shows results from GRID001 for a 300 GHz polarizing grid of 0.001" dia. wires with 250 wires/inch and an angle of incidence of 45°.

GRID002 -- Capacitive Wire Grid

Marcuvitz's analysis of a capacitive grid (his section 5.20) is based on the analogy to a capacitive post in a rectangular waveguide. Considering the waveguide walls as perfect reflectors, the waveguide-mounted capacitive post is equivalent to a free-space capacitive grid. Marcuvitz considers only the case of normal incidence ($\theta = 0$). However, by choosing the guide wavelength $\lambda_g = \lambda/\cos\theta$, the angles of incidence of the two plane waves in the waveguide (which constitute the TE_{10} mode) are $\pm\theta$, and the waveguide model is analogous to a free-space capacitive grid with an angle of incidence equal to θ. The equivalent circuit elements in Fig. 5 are evaluated using equations 1(a) and 2(a) in section 5.13 of Marcuvitz, with $\lambda_g = \lambda/\cos\theta$:

$$b_a = \frac{2b}{\lambda_g}\left(\frac{\pi d}{2b}\right)^2 \frac{1}{A_2} \qquad \text{M5.13/1(a)}$$

$$b_b = \frac{\lambda_g}{2b}\left(\frac{2b}{\pi d}\right)^2 A_1 - \frac{b}{\lambda_g}\left(\frac{\pi d}{2b}\right)^2 \frac{1}{A_2} \qquad \text{M5.13/2(a)}$$

where $$A_1 = 1 + \frac{1}{2}\left(\frac{\pi d}{\lambda_g}\right)^2 \left[\ln\left(\frac{b}{\pi d}\right) + \frac{3}{4}\right] + \left(\frac{\pi d}{\lambda_g}\right)^2 S_1$$

with $$S_1 = \sum_{m=2,4,..}^{\infty} \left[\frac{1}{\sqrt{m^2 - \left(\frac{2b}{\lambda_g}\right)^2}} - \frac{1}{m}\right],$$

and $$A_2 = 1 + \frac{1}{2}\left(\frac{\pi d}{\lambda_g}\right)^2 \left[\frac{11}{4} - \ln\left(\frac{b}{\pi d}\right)\right] + \frac{1}{6}\left(\frac{\pi d}{2b}\right)^2 - 2\left(\frac{\pi d}{2b}\right)^2 S_2$$

with $$S_2 = \sum_{m=2,4,...}^{\infty} \left[m - \frac{1}{2m}\left(\frac{2b}{\lambda_g}\right)^2 - \sqrt{m^2 - \left(\frac{2b}{\lambda_g}\right)^2}\right].$$

In the program, S_1 and S_2 are taken for m = 2, 4, ..., 40, which appears to give four significant figure accuracy for b_a and b_b in the cases tested.

Restrictions

The equivalent circuit of Fig. 5 is valid for $a < \lambda/(2 \cos \theta)$. The expressions for b_a and b_b are within 10% for $d/a \le 0.3$ and $(a \cos \theta/\lambda < 0.2)$.

Example 3

Fig. 6 shows results from GRID002 for the 100 GHz half-reflecting grid used in Example 1 but oriented here as a capacitive grid. The grid has 24 wires/inch using 2 mil wire and the angle of incidence $\theta = 45°$. The input quantities are indicated by boxes in Fig. 6. The following quantities are calculated:

gd wl	λ_g -- the equivalent guide wavelength (mm)
b_a, b_b	normalized admittances in Fig. 5
$\|\rho\|^2$	power reflection coefficient
$\|\tau\|^2$	power transmission coefficient
RL	reflected path loss, dB
TL	through path loss, dB

Example 4

Fig. 7 shows results from GRID002 for the 300 GHz polarizing grid used in Example 2 but oriented here as a capacitive grid. The grid has 250 wires/inch using 1 mil wire and the angle of incidence $\theta = 45°$.

DPLXR004 -- Frequency Response of Folded Mach-Zehnder Diplexer

The folded Mach-Zehnder diplexer, attributed to Kislyakov, has been widely used in millimeter wavelength receivers. Payne and Wordeman [2] describe such a diplexer with wire grid beam-splitters which they used as a tunable LO diplexer.

The present program is based on GRID001 for inductive wire grids. The diplexer theory outlined in Appendix 1 gives the power transmission coefficients in the through- and side-paths:

$$P_{through} = (t^2 - r^2 \cos \Delta\phi)^2 + r^4 \sin^2\Delta\phi$$

$$P_{side} = r^2t^2[(1 + \cos \Delta\phi)^2 + \sin^2\Delta\phi].$$

Here, r and t are the magnitudes of ρ and τ, the (amplitude) reflection and transmission coefficients of the individual grids. $\Delta\phi$ is the electrical path (phase) difference between the two arms of the interferometer.

Restrictions

The restrictions on the grid dimensions are the same as for program GRID001 above. In addition, it is assumed that beam divergence through the two paths of the interferometer will not contribute significantly to the loss.

Example 5

Figs. 8-10 show results from DPLXR004 for a 230 GHz diplexer using 0.0015" dia. wires spaced 48 wires/inch. The following quantities are calculated:

wl	λ -- the free-space wavelength (mm)
x_a, x_b	normalized impedances in Fig. 1
$\lvert\rho\rvert^2$	grid power reflection coefficient
$\lvert\tau\rvert^2$	grid power transmission coefficient
P_{th}	power transmission coeff., through path, dB
P_{sd}	power transmission coeff., side path, dB.

Near 230 GHz, where the grids divide the power almost equally, the insertion loss is very small in both through- and channels. However, by 270 GHz the side-channel insertion loss is 0.4 dB, while the maximum attenuation in the through-channel is ~10 dB.

DPLXR005 -- Transmission Maxima & Minima of Folded Mach-Zehnder Diplexer

In designing inductive diplexer grids to cover a particular frequency range, it is useful to know the transmission maxima and minima in the through- and side-channels. From the equations in Appendix 1 it is clear that:

$$P_{through}|_{max} = 1$$

$$P_{through}|_{min} = (t^2 - r^2)^2$$

$$P_{side}|_{max} = 4r^2t^2$$

$$P_{side}|_{min} = 0$$

These quantities are the maxima and minima obtainable at the given frequency by appropriately adjusting the grid-to-mirror vertex spacing.

Restrictions

The restrictions on the grid dimensions are the same as for program GRID001. In addition, it is assumed that beam divergence through the two paths of the interferometer will not contribute significantly to the loss.

Example 6

Figs. 11 and 12 show results from DPLXR005 for the variation over the range 200-300 GHz of the maximum and minimum loss in the through- and side-channels for a 250 GHz diplexer. The inductive grids use 0.001" (Fig. 11) and 0.0015" (Fig. 12) dia. wire with spacing chosen to give equal power division at 250 GHz. The following quantities are calculated:

wl	λ -- the free-space wavelength (mm)
x_a, x_b	normalized impedances in Fig. 1
$\lvert\rho\rvert^2$	grid power reflection coefficient
$\lvert\tau\rvert^2$	grid power transmission coefficient
$P_{th}\|_{max}$	max. power transmission coeff., through path, dB
$P_{th}\|_{min}$	min. power transmission coeff., through path, dB
$P_{sd}\|_{max}$	max. power transmission coeff., side path, dB
$P_{sd}\|_{min}$	min. power transmission coeff., side path, dB.

APPENDIX 1

Theory of the Folded Mach-Zehnder Diplexer:

The diplexer is shown schematically in Fig. A-1. The incident beam is split at I1 into components A and B. These components are split again at I2. The resulting "through" beam consists of compoments A1 and B2 and the resulting "side" beam consists of components A2 and B1. The path difference 2ℓ between beams A and B gives a phase difference $\Delta\phi = 2\pi(2\ell/\lambda)$.

The splitting of a beam at a lossless grid is depicted in Fig. A-2. The currents in the grid generate waves which are superimposed on the (unperturbed) incident wave. In the direction of the reflected beam the grid radiates a wave V_r, and in the direction of the transmitted wave it radiates an identical wave V_r which adds to the incident beam to give a transmitted wave $V_t = V_i + V_r$. These phasors are depicted in Fig. A-3. Conservation of energy requires $V_i^2 = V_r^2 + V_t^2$, which implies that V_t and V_r are in quadrature. Relative to the incident wave, the phases of the transmitted and reflected waves are ϕ_t and $\phi_r = \phi_t + \pi/2$. The voltage transmission and reflection coefficients of the grid can be written

$$\tau = t \exp\{j\phi_t\}$$

and

$$\rho = r \exp\{j\phi_r\} = r \exp\{j(\phi_t + \pi/2)\}.$$

From Fig. A-2 it is apparent that $t = \cos \phi_t$ and $r = \sin \phi_t$.

For the whole diplexer shown in Fig. A-1, considering the "through" path, and referring phases to the input wave at point I2 in the absence of the diplexer,

$$B2 = t^2 \exp\{j2\phi_t\}$$

and

$$A1 = r^2 \exp\{j(2\phi_t + \pi)\} \exp\{-j\Delta\phi\}$$

It follows that the "through" path power transmission coefficient

$$P_{through} = |B2 + A1|^2 = (t^2 - r^2 \cos \Delta\phi)^2 + r^4 \sin^2\Delta\phi.$$

For the "side" path,

$$B1 = rt \exp\{j(2\phi_t + \pi/2)\}$$

and

$$A2 = rt \exp\{j(2\phi_t + \pi/2)\} \exp\{-j\Delta\phi\} ,$$

from which the "side" path power transmission coefficient

$$P_{side} = |B1 + A2|^2 = r^2t^2[(1 + \cos \Delta\phi)^2 + \sin^2\Delta\phi].$$

<u>REFERENCES</u>

[1] D. H. Martin and E. Puplet, "Polarized Interferometric Spectrometry for the Millimeter and Submillimeter Spectrum," <u>Infrared Physics</u>, vol. 10, pp. 105-109, 1969.

[2] J. M. Payne and M. R. Wordeman, "Quasi-Optical Diplexer for Millimeter Wavelengths," <u>Rev. Sci. Instrum.</u>, vol. 49, no. 12, pp. 1741-1743, Dec. 1978.

[3] N. Marcuvitz, Editor, "Waveguide Handbook," MIT Rad. Lab. Series, vol. 10, New York: McGraw-Hill, 1951.

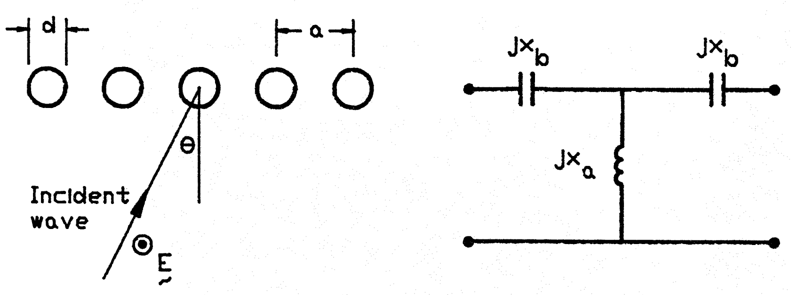

Fig. 1 Inductive wire grid and equivalent circuit.

```
GRID001.WK1                          7 Oct 88
Inductive grid of parallel wires at angle theta to incident wave.
Ref:  Marcuvitz, p. 286 & my notes of 14 Mar 76.

Wire dia.     d =    0.002 inches =    0.051 mm          pi = 3.141592
Spacing       a = 0.041666 inches =    1.058 mm         TPI =    24.00
Theta        th =       45 degrees     cos = 0.707106   sin = 0.707106
    fa =        70 GHz           fb =  120.01 GHz        Df =        5 GHz

      f         n       m      xs       xc      sqrt       fn    sigma
  125.000      21     -20   0.300    0.300    19.696    0.000  0.34214

\A      {goto}F0~{calc}             \F      {let sigma,0}
        {for f,fa,fb,df,\B}                 {for n,1,20,1,\C}
        {calc}

\B      /rvf~~{right 2}             \C      {let m,n}{recalc d11..g11}
        {recalc a26..e130}                  {let sigma,sigma+fn}
        /rv~xs~{right}                      {let m,-n}{recalc d11..g11}
        /rv~xc~{recalc f11..g11}            {let sigma,sigma+fn}
        {\F}~{right}/rvsigma~~              {return}
        {recalc a26..e130}
        {down}{left 4}
        {return}
```

f GHz	wl mm	a*sin/wl	a*cos/wl	sum	xa	xb	|rho|^2	|tau|^2	RL dB	TL dB
70.000	4.283	0.175	0.175	0.08294	0.3451	0.0040	0.676	0.324	1.70	4.90
75.000	3.997	0.187	0.187	0.09717	0.3724	0.0043	0.642	0.358	1.93	4.46
80.000	3.748	0.200	0.200	0.11308	0.4004	0.0045	0.608	0.392	2.16	4.06
85.000	3.527	0.212	0.212	0.13088	0.4292	0.0048	0.574	0.426	2.41	3.70
90.000	3.331	0.225	0.225	0.15083	0.4589	0.0051	0.540	0.460	2.67	3.38
95.000	3.156	0.237	0.237	0.17325	0.4897	0.0054	0.508	0.492	2.94	3.08
100.000	2.998	0.250	0.250	0.19856	0.5218	0.0057	0.476	0.524	3.23	2.80
105.000	2.855	0.262	0.262	0.22728	0.5554	0.0060	0.444	0.556	3.52	2.55
110.000	2.725	0.275	0.275	0.26011	0.5909	0.0062	0.414	0.586	3.83	2.32
115.000	2.607	0.287	0.287	0.29797	0.6286	0.0065	0.384	0.616	4.16	2.10
120.000	2.498	0.300	0.300	0.34214	0.6692	0.0068	0.354	0.646	4.51	1.90

Fig. 2 Example 1. Results from GRID001 for a 100 GHz half-reflecting inductive grid of 0.002" dia. wires with 24 wires/inch and an angle of incidence $\theta = 45°$.

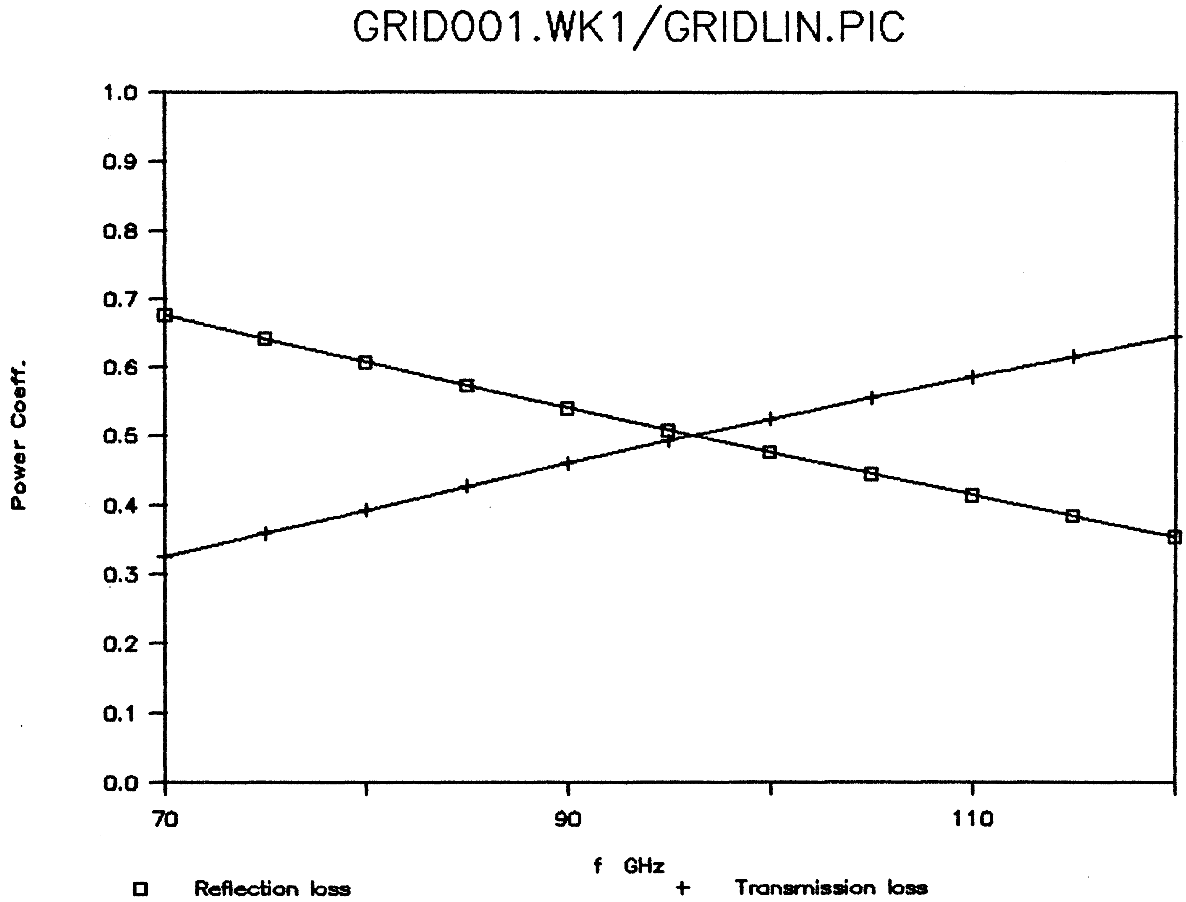

Fig. 3 Example 1. Graph of results.

```
GRID001.WK1                        10 Oct 88
Inductive grid of parallel wires at angle theta to incident wave.
Ref:  Marcuvitz, p. 286 & my notes of 14 Mar 76.

Wire dia.     d =   0.001 inches =    0.025 mm          pi = 3.141592
Spacing       a =   0.004 inches =    0.102 mm         TPI =   250.00
Theta        th =      45 degrees     cos = 0.707106   sin = 0.707106
   fa =      300 GHz         fb =   300.01 GHz          Df =        10 GHz

      f         n        m       xs       xc     sqrt       fn     sigma
 310.000       21      -20    0.072    0.072   19.928    0.000   0.01265

\A      {goto}F0~{calc}            \F       {let sigma,0}
        {for f,fa,fb,df,\B}                 {for n,1,20,1,\C}
        {calc}

\B      /rvf~~{right 2}            \C       {let m,n}{recalc d11..g11}
        {recalc a26..e130}                  {let sigma,sigma+fn}
        /rv~xs~{right}                      {let m,-n}{recalc d11..g11}
        /rv~xc~{recalc f11..g11}            {let sigma,sigma+fn}
        {\F}~{right}/rvsigma~~              {return}
        {recalc a26..e130}
        {down}{left 4}
        {return}
```

f GHz	wl mm	a*sin/wl	a*cos/wl	sum	xa	xb	|rho|^2	|tau|^2	RL dB	TL dB
300.000	0.999	0.072	0.072	0.01265	0.0183	0.0443	0.999	0.001	0.01	28.75

Fig. 4   Example 2. Results from GRID001 for a 300 GHz polarizing grid of 0.001" dia. wires with 250 wires/inch at an angle of incidence of 45°.

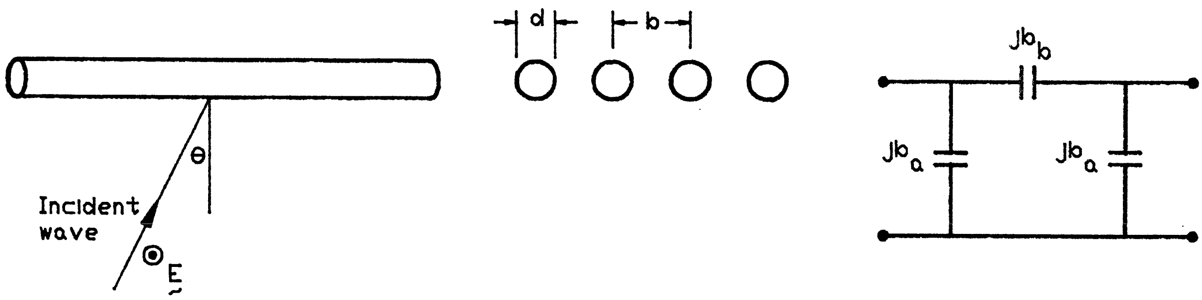

Fig. 5 Capacitive wire grid and equivalent circuit.

```
GRID002.WK1                          10 Oct 88
Capacitive grid of parallel wires at angle theta to incident wave.
Ref:  My notes of 4 Oct 88.

Wire dia.     d =   0.002 inches =    0.051 mm          pi = 3.141592
Spacing       b = 0.041666 inches =   1.058 mm         TPI =    24.00
Theta        th =      45 degrees    cos = 0.707106    sin = 0.707106
    fa =       70 GHz        fb =   120.01 GHz     Df =             5 GHz

      f        lg         m      sqrt      fnA       fnB    sigma1    sigma2
 125.000    3.392        42    41.995 2.63E-06 2.56E-07 2.86E-02 2.52E-03

\A      {goto}F0~{calc}              \F      {let sigma1,0}{let sigma2,0}
        {for f,fa,fb,df,\B}                  {for m,2,40,2,\C}
        {calc}

\B      /rvf~~{recalc b11}           \C      {recalc d11.f11}
        {\F}                                 {let sigma1,sigma1+fnA}
        {right 3}/rvsigma1~~                 {let sigma2,sigma2+fnB}
        {right}/rvsigma2~~                   {return}
        {down}{left 4}
        {return}
```

f GHz	gd wl	AAA	sum1	sum2	AA	AB	ba	bb	|tau|^2	|rho|^2	TL dB	RL dB
					aa	ab	ba	bb				
70.000	6.057	2.6418	9.35E-03	2.84E-04	1.0029	1.0012	0.0020	504.84	1.0000	0.0000	-0.00	-50.54
75.000	5.653	2.6418	1.08E-02	3.74E-04	1.0029	1.0013	0.0021	471.18	1.0000	0.0000	-0.00	-49.94
80.000	5.300	2.6418	1.23E-02	4.86E-04	1.0030	1.0013	0.0023	441.73	1.0000	0.0000	-0.00	-49.38
85.000	4.988	2.6418	1.39E-02	6.21E-04	1.0030	1.0014	0.0024	415.75	1.0000	0.0000	-0.00	-48.85
90.000	4.711	2.6418	1.57E-02	7.82E-04	1.0030	1.0014	0.0025	392.66	1.0000	0.0000	-0.00	-48.36
95.000	4.463	2.6418	1.75E-02	9.73E-04	1.0030	1.0015	0.0027	371.99	1.0000	0.0000	-0.00	-47.89
100.000	4.240	2.6418	1.95E-02	1.20E-03	1.0030	1.0015	0.0028	353.39	1.0000	0.0000	-0.00	-47.44
105.000	4.038	2.6418	2.16E-02	1.46E-03	1.0030	1.0016	0.0030	336.57	1.0000	0.0000	-0.00	-47.02
110.000	3.854	2.6418	2.38E-02	1.76E-03	1.0030	1.0017	0.0031	321.27	1.0000	0.0000	-0.00	-46.62
115.000	3.687	2.6418	2.62E-02	2.11E-03	1.0030	1.0017	0.0033	307.30	1.0000	0.0000	-0.00	-46.23
120.000	3.533	2.6418	2.86E-02	2.52E-03	1.0030	1.0018	0.0034	294.50	1.0000	0.0000	-0.00	-45.86

Fig. 6 Example 3. Results from GRID002 for the 100 GHz half-reflecting grid used in Example 1 but oriented here as a capacitive grid. The grid has 24 wires/inch using 2 mil wire with an angle of incidence $\theta = 45°$.

GRID002.WK1 10 Oct 88

Capacitive grid of parallel wires at angle theta to incident wave.

Ref: My notes of 4 Oct 88.

Wire dia.	d =	0.001	inches =	0.025 mm		pi =	3.141592
Spacing	b =	0.004	inches =	0.102 mm		TPI =	250.00
Theta	th =	45	degrees	cos = 0.707106		sin =	0.707106
fa =	300 GHz		fb =	300.01 GHz	Df =		10 GHz

f	lg	m	sqrt	fnA	fnB	sigma1	sigma2
310.000	1.368	42	42.000	1.49E-07	8.22E-10	1.56E-03	8.04E-06

```
\A      {goto}F0~{calc}              \F      {let sigma1,0}{let sigma2,0}
        {for f,fa,fb,df,\B}                  {for m,2,40,2,\C}
        {calc}

\B      /rvf~~{recalc b11}           \C      {recalc d11.f11}
        {\F}                                 {let sigma1,sigma1+fnA}
        {right 3}/rvsigma1~~                 {let sigma2,sigma2+fnB}
        {right}/rvsigma2~~                   {return}
        {down}{left 4}
        {return}
```

f GHz	gd wl	AAA	sum1	sum2	AA aa	AB ab	ba ba	bb bb	|tau|^2	|rho|^2	TL dB	RL dB
300.000	1.413	0.9916	1.56E-03	8.04E-06	1.0017	1.0297	0.0221	45.17	0.9989	0.0011	-0.00	-29.58

Fig. 7 Example 4. Results from GRID002 for the 300 GHz polarizing grid used in Example 2 but oriented here as a capacitive grid. The grid has 250 wires/inch using 1 mil wire with an angle of incidence $\theta = 45°$.

```
DPLXR004.WK1                          10 Oct 88
Folded Mach-Zehnder diplexer with inductive wire grids.
Based on program GRID001.WK1 of 29 Sep 88.
Ref:  My notes of ~29 Sep 88.

Wire dia.      d = [ 0.0015] inches =    0.038 mm          pi = 3.141592
Wire spacing   a = [0.02083] inches =    0.529 mm         TPI =   48.000
Theta         th =      [45] degrees     cos = 0.707106   sin = 0.707106
Vertex spcng   l = [ 2.8346] inches =   72.000 mm
    fa =      [229] GHz     fb =     [231.51]     GHz      Df =      [0.1] GHz

      f         n        m       xs        xc     sqrt       fn    sigma
 231.600       21      -20    0.289     0.289   19.707    0.000  0.30416

\A      {goto}F0~{calc}              \F      {let sigma,0}{recalc h11}
        {for f,fa,fb,df,\B}                  {for n,1,20,1,\C}
        {calc}

\B      /rvf~~{right 2}              \C      {let m,n}{recalc c13..g13}
        {recalc a30..e130}                   {let sigma,sigma+fn}{recalc h11}
        /rv~xs~{right}                       {let m,-n}{recalc c13..g13}
        /rv~xc~{recalc d13..g13}             {let sigma,sigma+fn}{recalc h11}
        {\F}~{right}/rvsigma~~               {return}
        {recalc a30..e130}
        {down}{left 4}~
        {return}
```

f GHz	wl mm	a*sin/wl	a*cos/wl	sum	xa	xb	|rho|^2 rr	|tau|^2 tt	RL dB	TL dB	D(phi) dp	Pth dB	Psd dB
229.000	1.309	0.286	0.286	0.29393	0.5088	0.0146	0.484	0.516	3.15	2.87	691.11	-28.30	-0.01
229.100	1.309	0.286	0.286	0.29433	0.5092	0.0146	0.484	0.516	3.16	2.87	691.41	-17.48	-0.08
229.200	1.308	0.286	0.286	0.29473	0.5095	0.0146	0.483	0.517	3.16	2.87	691.71	-11.09	-0.35
229.300	1.307	0.286	0.286	0.29514	0.5098	0.0146	0.483	0.517	3.16	2.86	692.01	-7.54	-0.84
229.400	1.307	0.286	0.286	0.29554	0.5102	0.0146	0.483	0.517	3.16	2.86	692.32	-5.18	-1.57
229.500	1.306	0.286	0.286	0.29594	0.5105	0.0147	0.482	0.518	3.17	2.86	692.62	-3.48	-2.59
229.600	1.306	0.287	0.287	0.29635	0.5109	0.0147	0.482	0.518	3.17	2.86	692.92	-2.23	-3.97
229.700	1.305	0.287	0.287	0.29675	0.5112	0.0147	0.481	0.519	3.17	2.85	693.22	-1.31	-5.85
229.800	1.305	0.287	0.287	0.29716	0.5115	0.0147	0.481	0.519	3.18	2.85	693.52	-0.66	-8.52
229.900	1.304	0.287	0.287	0.29757	0.5119	0.0147	0.481	0.519	3.18	2.85	693.82	-0.24	-12.71
230.000	1.303	0.287	0.287	0.29797	0.5122	0.0147	0.480	0.520	3.18	2.84	694.13	-0.03	-21.66
230.100	1.303	0.287	0.287	0.29838	0.5126	0.0147	0.480	0.520	3.19	2.84	694.43	-0.02	-23.35
230.200	1.302	0.287	0.287	0.29879	0.5129	0.0147	0.480	0.520	3.19	2.84	694.73	-0.21	-13.27
230.300	1.302	0.287	0.287	0.29920	0.5132	0.0147	0.479	0.521	3.19	2.84	695.03	-0.61	-8.84
230.400	1.301	0.288	0.288	0.29961	0.5136	0.0147	0.479	0.521	3.20	2.83	695.33	-1.23	-6.07
230.500	1.301	0.288	0.288	0.30002	0.5139	0.0147	0.479	0.521	3.20	2.83	695.64	-2.12	-4.13
230.600	1.300	0.288	0.288	0.30043	0.5143	0.0147	0.478	0.522	3.20	2.83	695.94	-3.34	-2.71
230.700	1.300	0.288	0.288	0.30084	0.5146	0.0147	0.478	0.522	3.20	2.82	696.24	-4.98	-1.66
230.800	1.299	0.288	0.288	0.30125	0.5149	0.0147	0.478	0.522	3.21	2.82	696.54	-7.26	-0.90
230.900	1.298	0.288	0.288	0.30167	0.5153	0.0147	0.477	0.523	3.21	2.82	696.84	-10.62	-0.39
231.000	1.298	0.288	0.288	0.30208	0.5156	0.0148	0.477	0.523	3.21	2.82	697.14	-16.42	-0.10
231.100	1.297	0.288	0.288	0.30250	0.5160	0.0148	0.477	0.523	3.22	2.81	697.45	-26.57	-0.01
231.200	1.297	0.289	0.289	0.30291	0.5163	0.0148	0.476	0.524	3.22	2.81	697.75	-15.74	-0.12
231.300	1.296	0.289	0.289	0.30333	0.5167	0.0148	0.476	0.524	3.22	2.81	698.05	-10.27	-0.43
231.400	1.296	0.289	0.289	0.30374	0.5170	0.0148	0.476	0.524	3.23	2.80	698.35	-7.03	-0.96
231.500	1.295	0.289	0.289	0.30416	0.5173	0.0148	0.475	0.525	3.23	2.80	698.65	-4.82	-1.74

Fig. 8   Example 5. Results from DPLXR004 for a 230 GHz diplexer using 0.0015" dia. wires spaced 48 wires/inch.

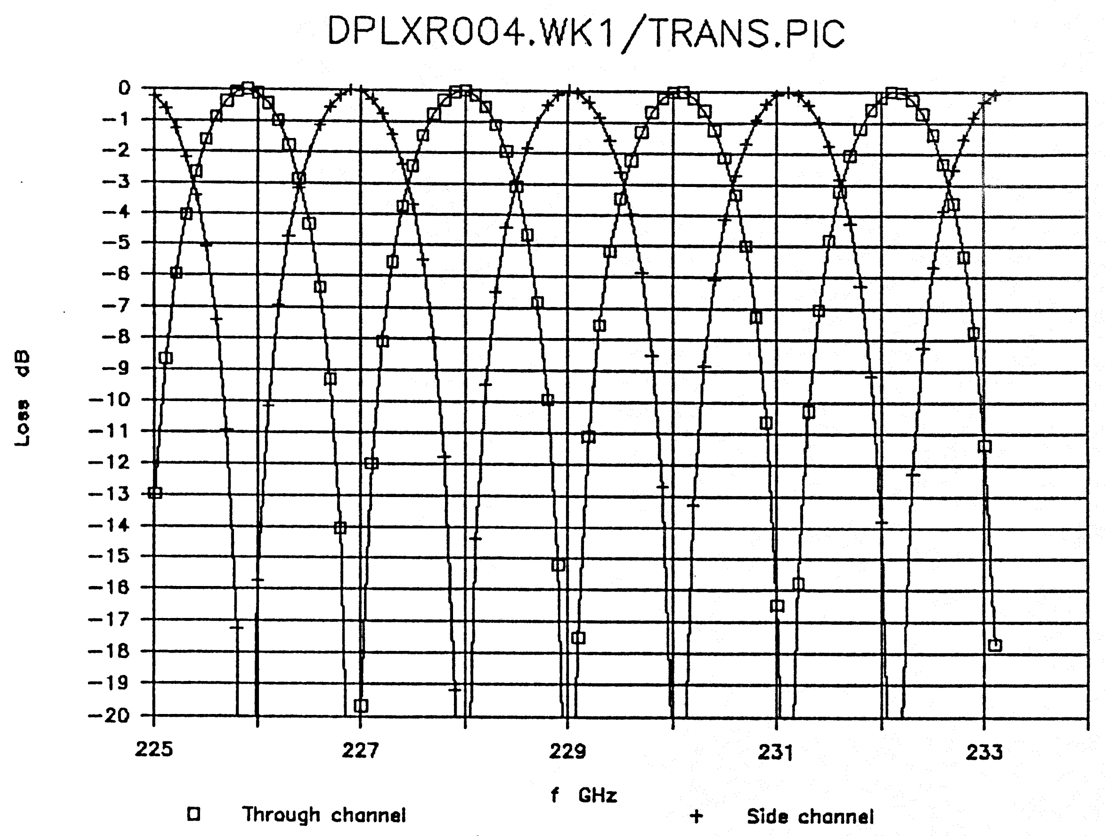

Fig. 9 Example 5. Graph of results near 230 GHz.

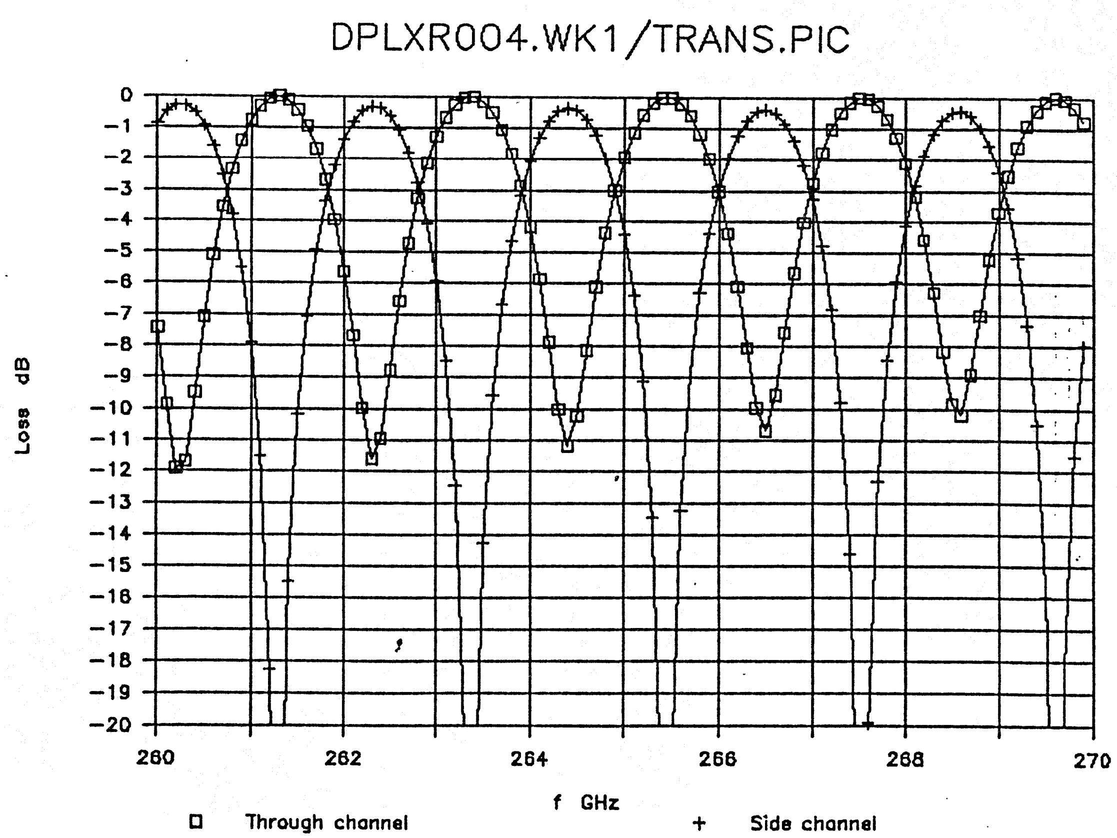

Fig. 10 Example 5. Graph of results near 270 GHz.

DPLXR005.WK1 13 Oct 88

Min. loss and max. isolation of folded Mach-Zehnder diplexer with inductive wire grids.

Based on program GRID001.WK1 of 29 Sep 88.

Ref: My notes of ~29 Sep 88.

Wire dia.	d =	0.0015 inches =	0.038 mm	pi = 3.141592
Wire spacing	a =	0.02083 inches =	0.529 mm	TPI = 48.000
Theta	th =	45 degrees	cos = 0.707106	sin = 0.707106

fa = 200 GHz fb = 300.01 GHz Df = 50 GHz

f	n	m	xs	xc	sqrt	fn	sigma
350.000	21	-20	0.374	0.374	19.618	0.000	0.95894

```
\A     {goto}F0~{calc}                  \F     {let sigma,0}{recalc h11}
       {for f,fa,fb,df,\B}                     {for n,1,20,1,\C}
       {calc}

\B     /rvf~~{right 2}                  \C     {let m,n}{recalc c13..g13}
       {recalc a30..e130}                      {let sigma,sigma+fn}{recalc h11}
       /rv~xs~{right}                          {let m,-n}{recalc c13..g13}
       /rv~xc~{recalc d13..g13}                {let sigma,sigma+fn}{recalc h11}
       {\F}~{right}/rvsigma~~                  {return}
       {recalc a30..e130}
       {down}{left 4}~
       {return}
```

f GHz	wl mm	a*sin/wl	a*cos/wl	sum	xa	xb	|rho|^2 rr	|tau|^2 tt	Pth max dB	Pth min dB	Psd max dB	Psd min dB
200.000	1.499	0.250	0.250	0.19856	0.4206	0.0128	0.580	0.420	0.00	-15.87	-0.11	-99.99
250.000	1.199	0.312	0.312	0.39440	0.5868	0.0160	0.412	0.588	0.00	-15.04	-0.14	-99.99
300.000	0.999	0.374	0.374	0.95894	0.9156	0.0192	0.217	0.783	0.00	-4.96	-1.67	-99.99

Fig. 11 Example 6. Results from DPLXR005 showing the variation over the range 200-300 GHz of the maximum and minimum loss in the through- and side-channels of a 250 GHz diplexer. The grids are of 0.001" dia. wire with spacing chosen to give equal power division near 230 GHz.

```
DPLXR005.WK1                    13 Oct 88
Min. loss and max. isolation of folded Mach-Zehnder diplexer with inductive wire grids.
Based on program GRID001.WK1 of 29 Sep 88.
Ref:  My notes of ~29 Sep 88.

Wire dia.       d = [0.0015] inches =    0.038 mm         pi = 3.141592
Wire spacing    a = [0.02083] inches =   0.529 mm         TPI =   48.000
Theta          th =      [45] degrees    cos = 0.707106   sin = 0.707106

    fa =    [260] GHz      fb =    [270.01]     GHz    Df =      [2] GHz

       f          n        m       xs        xc     sqrt       fn    sigma
   272.000       21      -20    0.337     0.337   19.657    0.000  0.53524

\A      {goto}F0~{calc}                   \F      {let sigma,0}{recalc h11}
        {for f,fa,fb,df,\B}                       {for n,1,20,1,\C}
        {calc}

\B      /rvf~~{right 2}                   \C      {let m,n}{recalc c13..g13}
        {recalc a30..e130}                        {let sigma,sigma+fn}{recalc h11}
        /rv~xs~{right}                            {let m,-n}{recalc c13..g13}
        /rv~xc~{recalc d13..g13}                  {let sigma,sigma+fn}{recalc h11}
        {\F}~{right}/rvsigma~~                    {return}
        {recalc a30..e130}
        {down}{left 4}~
        {return}
```

f GHz	wl mm	a*sin/wl	a*cos/wl	sum	xa	xb	|rho|^2 rr	|tau|^2 tt	Pth max dB	Pth min dB	Psd max dB	Psd min dB
260.000	1.153	0.325	0.325	0.45740	0.6308	0.0166	0.376	0.624	0.00	-12.11	-0.28	-99.99
262.000	1.144	0.327	0.327	0.47162	0.6403	0.0167	0.369	0.631	0.00	-11.62	-0.31	-99.99
264.000	1.136	0.329	0.329	0.48646	0.6500	0.0169	0.362	0.638	0.00	-11.15	-0.35	-99.99
266.000	1.127	0.332	0.332	0.50197	0.6601	0.0170	0.354	0.646	0.00	-10.71	-0.39	-99.99
268.000	1.119	0.334	0.334	0.51822	0.6705	0.0171	0.347	0.653	0.00	-10.28	-0.43	-99.99
270.000	1.110	0.337	0.337	0.53524	0.6812	0.0172	0.339	0.661	0.00	-9.87	-0.47	-99.99

Fig. 12 Example 6. Results from DPLXR005 showing the variation over the range 200-300 GHz of the maximum and minimum loss in the through- and side-channels of a 250 GHz diplexer. The grids are of 0.0015" dia. wire with spacing chosen to give equal power division near 230 GHz.

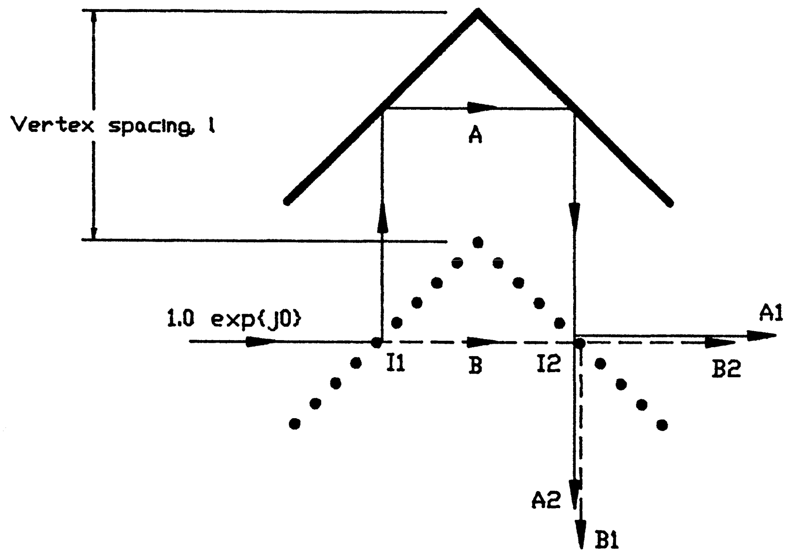

Fig. A-1 Power splitting and recombination in a folded Mach-Zehnder diplexer.

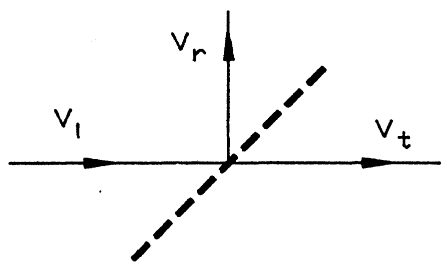

Fig. A-2 The splitting of a beam at a lossless grid.

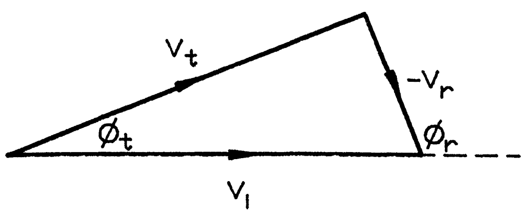

Fig. A-3 Phasor diagram showing incident, reflected, and transmitted waves at a lossless grid.