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TABLES OF DESIGNS FOR N-WAY IN-PHASE POWER DIVIDERS/COMBINERS.(U)
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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

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TABLES OF DESIGNS FOR N-WAY IN-PHASE POWER DIVIDERS/COMBINERS

RUSSELL A. GILSON
ROBERT A. WECK

DECEMBER 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the design and resulting performance of an N-way in-phase power divider/combiner that was first devised and described by U. Gysel. Since closed form solutions for the transmission line elements do not exist, computer aided design and optimization were used to generate design tables for 2- to 8-way divider/combiners with up to 50 percent bandwidths. The design tables along with a CAD program listing are presented.

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TABLES OF DESIGNS FOR N-WAY IN-PHASE POWER DIVIDERS/COMBINERS

INTRODUCTION

Solid state transmitter modules for use in military systems generally require power well in excess of that available from a single semiconductor device. High output power is achieved by combining the outputs from a number of lower power modules that employ devices such as bipolar transistors, IMPATT diodes, or GaAs FETs. The performance and reliability of such a transmitter is critically dependent on the characteristics of the combining circuitry. The combining circuit design must meet a number of important criteria: (1) the bandwidth of the combiner must be wide enough to satisfy the system needs, (2) circuit losses must be as small as possible so that combining efficiency does not seriously degrade overall efficiency, (3) there must be port-to-port isolation sufficient to prevent spurious oscillations and moding problems, (4) power handling capability of the circuit must be sufficient to handle imbalances created by failure of one or more devices in the combiner, and (5) the parasitics associated with the combiner must be minimized.

Over the past decade considerable progress has been made in developing new divider/combiner circuits for microwave power applications. Many of the commonly used approaches for combining microwave amplifiers/oscillators are based on either (1) the Wilkinson power combiner[1] or (2) a corporate type combiner composed of a tree of cascaded 3 dB hybrids.[2]

This report describes the design and resulting performance of an N-way in-phase divider/combiner that was devised and described by Ulrich Gysel.[3] The Gysel circuit, shown in Figure 1a is a modification of a Wilkinson combiner (Figure 1b). The Gysel circuit differs from the Wilkinson circuit in that the normal star connected balanced isolation resistors in the Wilkinson design are replaced by a combination of transmission lines (Z_3 and Z_4) and unbalanced grounded resistors (R_d) in the Gysel design. The balanced resistor configuration in the Wilkinson design limits the upper frequency capability due to the shunt capacitance associated with the isolation resistors, and the power handling capability due to the

1. E. J. Wilkinson, "An N-Way Hybrid Power Divider," MMT-8, No. 1, pp 116-118, January 1960.
2. A. Presser and H. S. Veloric, "High Power Transistor Combining Networks," US Army ERADCOM Research and Development Technical Report ECOM-75-1359-F, Contract No. DAAB07-75-C-1359, RCA Laboratories, January 1977.
3. U. Gysel, "A New N-Way Power Divider/Combiner Suitable for High Power Applications," MTT-S Symposium Digest, pp 116-118, 1975.

difficulty in heat sinking the floating isolation resistors. With Gysel's circuit configuration, these limitations are removed but at the expense of a somewhat reduced bandwidth. The Gysel circuit is, however, more difficult to design, and as Gysel pointed out in his paper, closed form solutions for the optimum values of the transmission line elements do not exist. The element values are dependent on the bandwidth and the number of devices to be combined(N).

In his paper, Gysel described the performance of a 20 percent bandwidth eight-way divider/combiner, but he did not include the values of the transmission line elements. In this report the performance and the optimal element values for divider/combiners with splits from N = 2 to 8 and normalized bandwidths from 10 to 50 percent are provided. These designs were optimized using a computer aided design (CAD) program. Appendix A contains a listing of the inputs for the CAD analysis and optimization.

DESIGN CONSIDERATIONS AND COMPUTER MODELLING

The efficient N-way combining of solid state power modules requires a circuit that satisfies the following design constraints:

a. low insertion loss (typically <.5 dB)

b. equal or near equal coupling to the output ports

c. low port voltage standing wave ratios (VSWRs) (typically <1.25:1)

d. high isolation between output ports (typically >20 dB)

When used to sum or combine power, the VSWR of the input to the combiner is generally the most important design constraint. VSWRs of less than 1.25 to 1 are required if amplifier performance is to be unaffected by the combiner. In order to develop the design equations for the Gysel divider/combiner, even and odd mode analysis were used. Input and output VSWRs, along with coupling, are determined from the even mode analysis of the circuit. Both even and odd mode analyses are required to compute the isolation.

In order to minimize computer processing time and to find optimum solutions, it is generally necessary that the range over which the circuit elements are varied be restricted. Clearly this design range must include the optimum circuit element values. To determine the design range for the transmission line impedances (Z1 thru Z4) used in the Gysel circuit, the even and odd mode equivalent circuits were qualitatively analyzed. In the even mode circuit of Figure 2, transmission line segments Z3 and Z4 are used to decouple the dump resistor, R_d, from the load port. The action of the transmission lines can be seen by examining the circuit at the midband frequency, fo. Transmission line segment, Z4, which is shown open circuited is used to short out the resistor, R_d. Transmission line segment Z3 is used to transform the short at R_d to an open circuit at the load terminal, thus decoupling the dump resistor from the load.

At frequencies where the transmission lines are no longer a quarter wavelength long the decoupling action can be preserved if Z4 is a low impedance line and Z3 is a high impedance line. As long as the dump resistors are sufficiently decoupled, the input VSWR and coupling coefficient will be principally determined by the characteristic impedance of transmission line segments Z1 and Z2. Their values will be similar to those used in a standard Wilkinson divider/combiner. If the input VSWR and coupling were the only constraints then a design could be simply generated, but because output VSWR and isolation are also important the design becomes more complex.

An analysis of the circuit for the output VSWR (Figure 3) leads to essentially the same conclusions regarding the values of the transmission lines as were gained from examining the even mode circuit for input VSWR. The isolation constraint, however, leads to a different conclusion regarding element design ranges. For isolation between ports to remain high, it is necessary that the driving point impedance of the load port be near equal in both the even and odd mode equivalent circuits. The output VSWR constraint requires that this impedance be near 50 ohms. The driving point impedance at the load port of the odd mode circuit (Figure 4) will be near 50 ohms if transmission lines Z2 and Z4 have high characteristic impedances and transmission line Z3 is near 50 ohms. Based on these considerations the following element design ranges were used in the computer design program:

Z1	30 to 60 ohms
Z2	60 to 110 ohms
Z3	40 to 60 ohms
Z4	25 to 70 ohms

The Gysel divider/combiner circuit of Figure 1a was computer designed using the element design ranges shown above with the following constraints imposed:

a. VSWR (divider) < 1.35:1

b. VSWR (combiner) < 1.35:1

c. Coupling deviation from nominal < .5 dB

d. Isolation > 17 dB

The CAD program first searched for a design which met these constraints and, once an acceptable design was found, the program optimized the element values to minimize port VSWRs.

DESIGN TABLES

Tables 1 thru 7 show the normalized frequency response of the N-way Gysel divider/combiner circuit. For each value of N, the circuit was optimized for a specific percentage bandwidth. Designs for bandwidths of 10, 20, 30, 40 and 50 percent are provided. The characteristic impedance of the transmission lines for each design is also shown. The lines are commensurate and are a quarter wavelength long at the center frequency, fo. The performance (VSWR, isolation, and coupling) of each design is shown over the full 50 percent bandwidth, even though the optimization was carried out for a lesser bandwidth. The designer is often interested in knowing the out-of-band performance and, since the in-band performance is a well behaved function of frequency, especially for narrow bandwidths, this format of presentation is the most useful.

As an example, Table 5 shows that a six-way divider/combiner designed for a 40 percent bandwidth would have a worst case coupling of 8.14 dB and terminal VSWR of less than 1.25 to 1 over the full 40 percent bandwidth. The minimum isolation across the band would be 29 dB. Performance out to 50 percent bandwidth shows minor degradation in coupling and isolation, but VSWRs as high as 1.6 to 1 occur. (This should be compared with the 50 percent BW design, where 1.3 to 1 VSWRs are achieved at band edge.)

It is to be noted that, particularly in the narrow band cases, other designs could be generated which would use lower impedance transmission lines and would meet the designers required performance. These would, of course, be more easily fabricated and would minimize the circuit losses encountered. But, within the constraints placed on the transmission line impedance values, which are noted in Section II above, the design tables represent the optimum solution. Individual design applications must weigh overall performance against ease of fabrication in order to arrive at the best design for a given case.

Finally, the calculations in Tables 1 through 7 are for lossless transmission line elements. Consideration of circuit losses will result in minor perturbations to the optimum performance but, as can be seen from reference 2, which shows both the design and actual performance for a 2-way divider/combiner, the variations are small.

CONCLUSIONS

The Gysel divider/combiner offers several important advantages over the conventional Wilkinson for power applications. However, its design is more difficult owing to the lack of closed form solutions for its elements. In this report we have presented a technique for the otpimized design of the Gysel circuit.

A computer program, Constrained Optimal Design (COD)[4], was used to generate a family of design tables. Circuit designs, along with performance, are shown in these tables. From the tables it can be seen that the Gysel circuit may be used for bandwidths as large as 40 percent and still have terminal VSWRs of less than 1.25 to 1. If VSWRs in the 1.5 to 1 range can be tolerated the divider/combiner can be used to a 50 percent bandwidth. Should higher VSWRs be tolerable in a given application, even wider bandwidths can be achieved.

The design tables are representative of optimized solutions for most practical applications of this type of combiner. Combining of more than eight devices and bandwidths in excess of 50 percent result in designs which are difficult to realize in practice. Where greater powers are required some combination of chip/device level and circuit level combining is usually necessary. The design data presented in this report was constrained to be compatible with hybrid MIC technology.

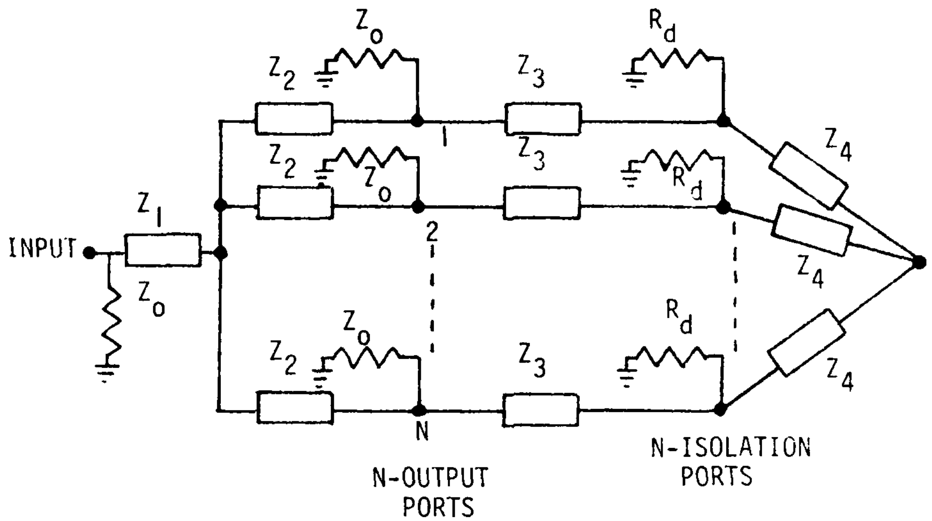
4. COD, Optimal Systems Research, Inc., Manasquan, NJ 08736.

APPENDIX

```
*CONTROL SECTION
AC
TITLE, 7-WAY HYBRID DESIGN
*PREPARATION SECTION
       REAL ISOL,MINI
       COMPLEX VBEE,IBEE,VCEE,ICEE,Z,VBOO,IBOO,VCOO,ICOO
       COMPLEX ZLEE,ZC,ZIEE,ZIOO,ZLOO,ZCC
       IIN=1.
       RT=50.
       RLL=50.
       GND=0.
       DEG=90.
       RNORM=10.05
       MINI=17.
       SI=1.5
       SO=1.5
       CON1=7.
*DEFINITION SECTION
       RO1=X(1)
       RO2=X(2)
       RO3=X(3)
       RO4=X(4)
*TOPOLOGY SECTION
       VIN
       GND
       RT,VIN-VOUT
       RLL,VOUT-GND
*RELATION SECTION
       RO=RO4
       RL=10.E6
       XL=0.
       RADS=RFREQ(NF)
       CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
       ZLEE=CMPLX(RI,XI)
       Z=50.*ZLEE/(50.+ZLEE)
       RL=REAL(Z)
       XL=AIMAG(Z)
       RO=RO3
       CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
       Z=50.*CMPLX(RI,XI)/(50.+CMPLX(RI,XI))
       ZCC=CMPLX(RI,XI)
       ZC=Z
       RL=REAL(Z)
       XL=AIMAG(Z)
       RO=RO2
```

```
CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
RL=RI/CON1
XL=XI/CON1
RO=RO1
CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
RIN=RI
XIN=XI
RO=50.
CALL VSWR(RIN,XIN,RO,SWR)
SWRI(NF)=SWR
RL=50.
XL=0.
RO=RO1
CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
RL=CON1*RI
XL=CON1*XI
RO=RO2
CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
ZIEE=CMPLX(RI,XI)
Z=ZIEE*ZCC/(ZIEE+ZCC)
VBEE=Z/(50.+Z)
IBEE=1./(50.+Z)
VCEE=VBEE
ICEE=IBEE
RL=0.
XO=0.
RO=RO2
CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
ZIOO=CMPLX(RI,XI)
RL=0.
XO=0.
RO=RO4
CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
Z=50.*CMPLX(RI,XI)/(50.+CMPLX(RI,XI))
RL=REAL(Z)
XL=AIMAG(Z)
RO=RO3
CALL TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
ZLOO=CMPLX(RI,XI)
Z=ZLOO*ZIOO/(ZLOO+ZIOO)
VBOO=Z/(Z+50.)
IBOO=1./(Z+50.)
VCOO=-VBOO
ICOO=-IBOO
Z=(VBEE+(CON1-1.)*VBOO)/(IBEE+(CON1-1.)*IBOO)
RIN=REAL(Z)
XIN=AIMAG(Z)
RO=50.
CALL VSWR(RIN,XIN,RO,SWR)
SWRO(NF)=SWR
VC=CABS(VCEE+VCOO)
```

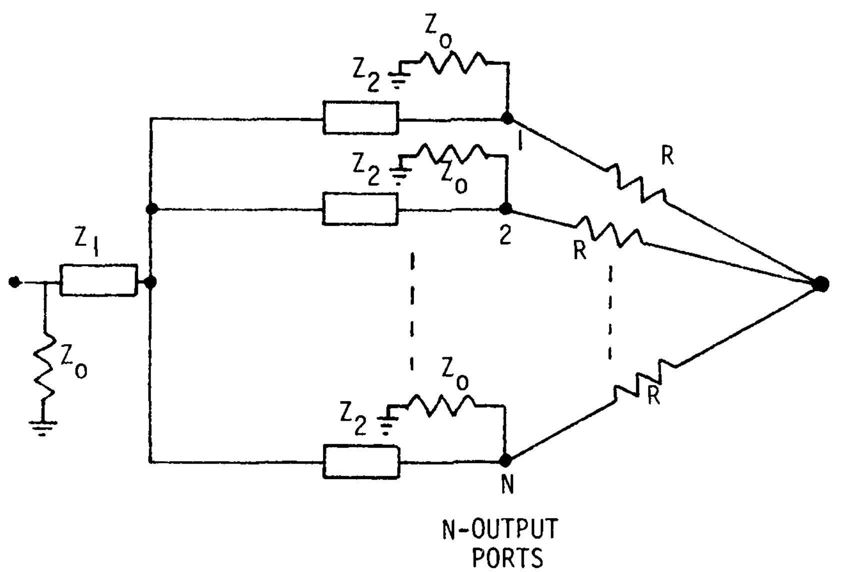
```
      ISOL(NF)=10.*ALOG10(.25*((CON1/VC)**2.))
      REF=(SWRI(NF)-1.)/(SWRI(NF)+1.)
      PT=(1.-REF**2.)/CON1
      REQ=REAL(1./ZC)
      REQ=1./REQ
      COUP(NF)=-10.*ALOG10(50./(PT*REQ))
      H(1)=SI-SWRI(NF)
      H(2)=SO=SWRO(NF)
      H(3)= ISOL(NF)-MINI
      H(4)=COUP(NF)+8.5
*SPECIAL SECTION
      SMOXO=FMAX(SWRO)
      SMOXI=FMAX(SWRI)
      IF(SMOXI-SMOXO)2,2,1
  1   BIG=SMOXI
      GO TO 3
  2   BIG=SMOXO
  3   CONTINUE
      PHIO=-BIG
*OUTPUT SECTION
FREQUENCY DEPENDENT OUTPUTS
      SWRI(NF)
      SWRO(NF)
      ISOL(NF)
      COUP(NF)
*END

      SUBROUTINE TRANS(RO,RL,XL,RADS,RNORM,DEG,RI,XI)
      COMPLEX ZI,NUMX,DENX
      RANG=DEG*RADS/(RNORM*57.3)
      ANG=SIN(RANG)/COS(RANG)
      NUMX=CMPLX(RL,XL+RO*ANG)
      DENX=CMPLX(RO-XL*ANG,RL*ANG)
      ZI=RO*NUMX/DENX
      RI=REAL(ZI)
      XI=AIMAG(ZI)
      RETURN
      END
      SUBROUTINE VSWR(RIN,XIN,RO.SWR)
      COMPLEX REFL
      REFL=(CMPLX(RIN,XIN)-RO)/(CMPLX(RIN,XIN)+RO)
      SWR=(1.+CABS(REFL))/(1.-CABS(REFL))
      RETURN
      END
```



ALL LINES λ/4 at F_o

ALL Z_o = 50 ohms

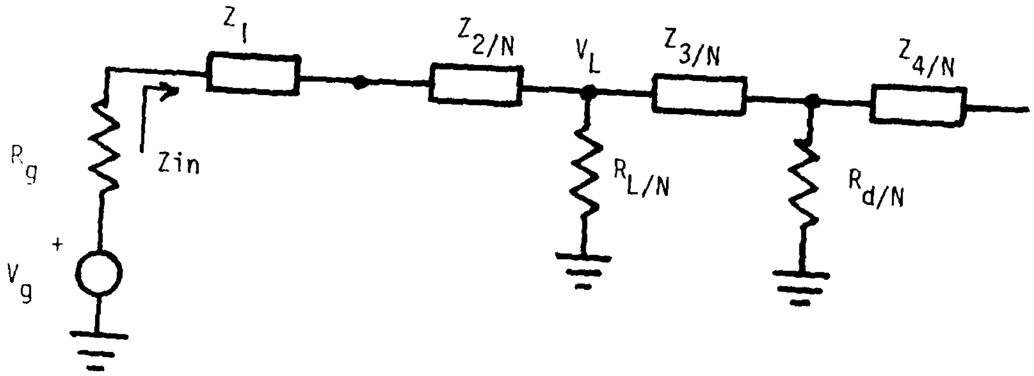
FIGURE 1a. GYSEL N-WAY COMBINER/DIVIDER



ALL LINES λ/4 at F_o

ALL Z_o = 50 ohms

FIGURE 1b. N-WAY WILKINSON DIVIDER/COMBINER



All lines $\lambda/4$ at F_o

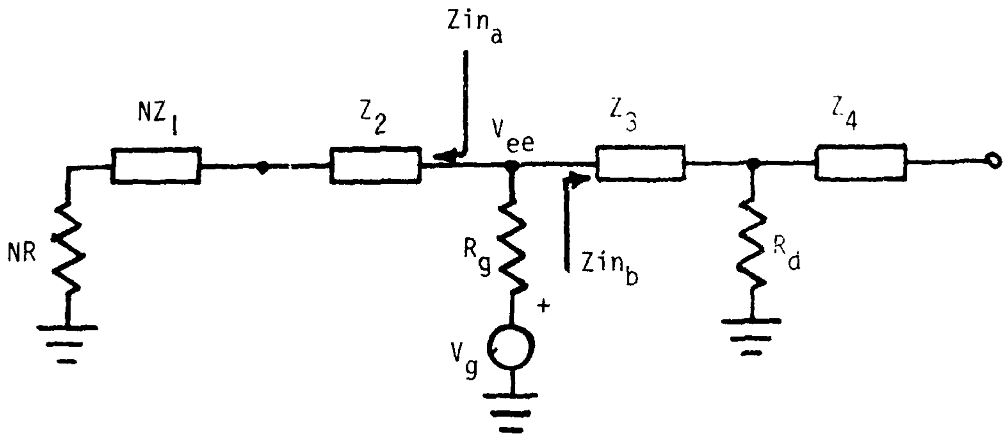
$R_g = R_L = R_d = 50$ ohms

$$\text{Coupling} = 20 \text{ LOG } \frac{2\ V_L}{V_g}$$

$$\Gamma = \frac{Zin - 50}{Zin + 50}$$

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

FIGURE 2. Even mode equivalent circuit used to determine input VSWR and coupling coefficient.



All lines $\lambda/4$ at F_o

$R = R_g = R_d = 50$ ohms

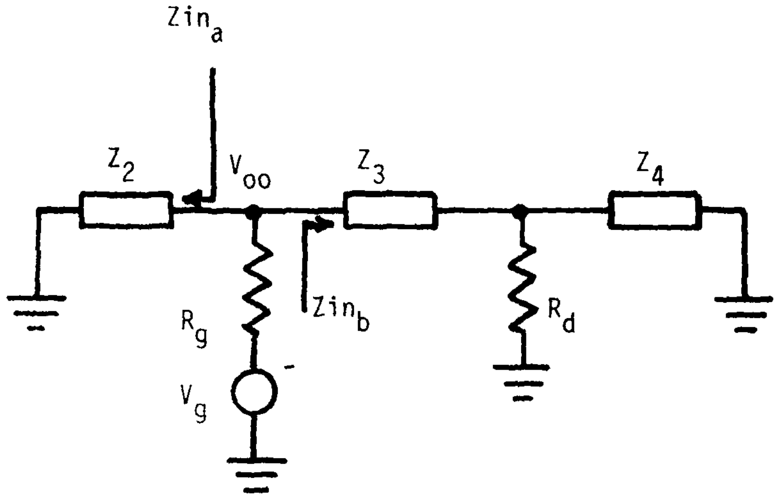
N = Order of Divider/Combiner

$$Zin_{ee} = \frac{Zin_a \, Zin_b}{Zin_a + Zin_b}$$

$$\Gamma = \frac{Zin_{ee} - 50}{Zin_{ee} + 50} \qquad VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

$$V_{ee} = \frac{Zin_{ee}}{Zin_{ee} + R_g} V_g$$

FIGURE 3. Even mode equivalent circuit used to determine the output VSWR and even mode contribution to isolation.



All lines $\lambda/4$ at F_o

$R_g = R_d = 50$ ohms

$$Zin_{oo} = \frac{Zin_a \; Zin_b}{Zin_a + Zin_b}$$

$$V_{oo} = - \frac{Zin_{oo}}{Zin_{oo} + R_g} \; V_g$$

$$\text{ISOLATION} = 20 \text{ LOG } \frac{V_{ee} + V_{oo}}{V_g}$$

FIGURE 4. Odd mode equivalent circuit used to determine odd mode contribution to isolation.

TABLE 1   2-WAY DIVIDER/COMBINER

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
10% BW	1.00	1.024	3.011	1.024	81.363	
	.95	1.021	3.022	1.038	30.783	
	.90	1.068	3.064	1.105	24.626	Z1=55.6 ohms
	.85	1.172	3.163	1.239	20.883	Z2=77.7 ohms
	.80	1.335	3.368	1.459	18.092	Z3=49.4 ohms
	.75	1.572	3.746	1.802	15.817	Z4=30.3 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
20% BW	1.00	1.018	3.016	1.075	31.373	
	.95	1.021	3.024	1.061	28.292	
	.90	1.072	3.058	1.068	24.177	Z1=55.5 ohms
	.85	1.176	3.143	1.175	20.966	Z2=75.7 ohms
	.80	1.337	3.324	1.374	18.391	Z3=50.9 ohms
	.75	1.572	3.672	1.688	16.213	Z4=31.4 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
30% BW	1.00	1.097	3.028	1.137	35.003	
	.95	1.080	3.033	1.109	30.642	
	.90	1.054	3.058	1.046	25.793	Z1=58.5 ohms
	.85	1.124	3.138	1.133	22.166	Z2=77.6 ohms
	.80	1.283	3.331	1.362	19.199	Z3=48.6 ohms
	.75	1.521	3.724	1.733	16.625	Z4=30.8 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
40% BW	1.00	1.140	3.058	1.233	28.159	
	.95	1.119	3.059	1.208	26.355	
	.90	1.065	3.071	1.140	23.242	Z1=55.6 ohms
	.85	1.083	3.120	1.093	20.457	Z2=70.8 ohms
	.80	1.235	3.256	1.230	18.11	Z3=48.7 ohms
	.75	1.475	3.554	1.517	16.087	Z4=29.5 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
50% BW	1.00	1.223	3.141	1.416	22.866	
	.95	1.199	3.133	1.379	22.558	
	.90	1.135	3.120	1.272	21.714	Z1=58.9 ohms
	.85	1.077	3.136	1.113	20.478	Z2=70.0 ohms
	.80	1.184	3.244	1.103	18.937	Z3=48.6 ohms
	.75	1.416	3.541	1.417	17.120	Z4=31.2 ohms

TABLE 2 3-WAY DIVIDER/COMBINER

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
10% BW	1.00	1.012	4.771	1.007	57.36	
	.95	1.028	4.797	1.032	42.96	
	.90	1.156	4.899	1.084	34.18	Z1=60.7 ohms
	.85	1.405	5.149	1.167	27.98	Z2=104.5 ohms
	.80	1.838	5.660	1.281	23.31	Z3=49.9 ohms
	.75	2.543	6.544	1.422	19.77	Z4=48.2 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
20% BW	1.00	1.065	4.776	1.049	48.41	
	.95	1.039	4.791	1.044	38.14	
	.90	1.069	4.851	1.062	31.68	Z1=55.0 ohms
	.85	1.241	5.004	1.137	27.10	Z2=92.3 ohms
	.80	1.538	5.329	1.262	23.33	Z3=49.0 ohms
	.75	2.021	5.933	1.437	20.13	Z4=40.0 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
30% BW	1.00	1.132	4.788	1.103	44.05	
	.95	1.116	4.795	1.092	33.76	
	.90	1.091	4.826	1.079	27.95	Z1=49.5 ohms
	.85	1.142	4.903	1.135	24.34	Z2=80.6 ohms
	.80	1.310	5.073	1.276	21.65	Z3=47.9 ohms
	.75	1.601	5.408	1.498	19.44	Z4=30.7 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
40% BW	1.00	1.230	4.818	1.174	38.63	
	.95	1.211	4.822	1.156	32.51	
	.90	1.160	4.839	1.115	27.30	Z1=48.8 ohms
	.85	1.126	4.894	1.114	23.87	Z2=76.2 ohms
	.80	1.226	5.029	1.234	21.31	Z3=46.7 ohms
	.75	1.479	5.318	1.458	19.24	Z4=29.2 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
50% BW	1.00	1.365	4.876	1.273	35.27	
	.95	1.351	4.880	1.249	30.50	
	.90	1.312	4.897	1.181	25.69	Z1=45.2 ohms
	.85	1.263	4.942	1.094	22.42	Z2=67.0 ohms
	.80	1.253	5.047	1.136	20.02	Z3=45.1 ohms
	.75	1.370	5.275	1.351	18.18	Z4=28.7 ohms

TABLE 3   4-WAY DIVIDER/COMBINER

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
10% BW	1.00	1.006	6.021	1.000	59.983	
	.95	1.038	6.041	1.037	39.720	
	.90	1.092	6.113	1.127	33.245	Z1=50.3 ohms
	.85	1.176	6.280	1.295	28.959	Z2=100.6 ohms
	.80	1.297	6.612	1.581	25.491	Z3=49.8 ohms
	.75	1.463	7.211	2.045	22.519	Z4=41.1 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
20% BW	1.00	1.028	6.026	1.076	42.362	
	.95	1.036	6.044	1.046	39.632	
	.90	1.074	6.114	1.060	34.934	Z1=51.6 ohms
	.85	1.148	6.286	1.235	30.448	Z2=99.5 ohms
	.80	1.262	6.647	1.542	26.461	Z3=49.7 ohms
	.75	1.415	7.312	2.047	23.043	Z4=44.3 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
30% BW	1.00	1.038	6.041	1.146	35.636	
	.95	1.040	6.054	1.114	35.130	
	.90	1.069	6.110	1.033	33.402	Z1=50.8 ohms
	.85	1.142	6.254	1.150	30.457	Z2=94.9 ohms
	.80	1.257	6.572	1.425	26.960	Z3=49.9 ohms
	.75	1.417	7.179	1.883	23.580	Z4=44.0 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
40% BW	1.00	1.076	6.068	1.233	32.940	
	.95	1.068	6.076	1.208	32.012	
	.90	1.066	6.110	1.141	29.959	Z1=46.8 ohms
	.85	1.124	6.198	1.088	27.650	Z2=84.3 ohms
	.80	1.245	6.400	1.228	25.336	Z3=49.3 ohms
	.75	1.429	6.812	1.537	23.016	Z4=38.8 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
50% BW	1.00	1.368	6.123	1.360	60.061	
	.95	1.344	6.128	1.348	34.484	
	.90	1.276	6.145	1.314	28.462	Z1=42.1 ohms
	.85	1.190	6.187	1.267	24.943	Z2=72.2 ohms
	.80	1.186	6.284	1.250	22.481	Z3=42.7 ohms
	.75	1.368	6.499	1.358	20.631	Z4=26.4 ohms

TABLE 4 5-WAY DIVIDER/COMBINER

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
10% BW	1.00	1.032	6.991	1.013	52.49	
	.95	1.031	7.012	1.034	41.63	
	.90	1.100	7.090	1.081	35.41	Z1=46.8 ohms
	.85	1.258	7.265	1.156	31.19	Z2=103.0 ohms
	.80	1.533	7.613	1.265	27.72	Z3=49.8 ohms
	.75	1.988	8.243	1.415	24.71	Z4=44.6 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
20% BW	1.00	1.071	6.995	1.068	70.12	
	.95	1.045	7.016	1.062	43.17	
	.90	1.076	7.099	1.063	36.32	Z1=48.4 ohms
	.85	1.257	7.295	1.109	31.59	Z2=104.6 ohms
	.80	1.579	7.701	1.202	27.70	Z3=48.4 ohms
	.75	2.119	8.441	1.336	24.43	Z4=46.3 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
30% BW	1.00	1.126	7.005	1.146	52.98	
	.95	1.109	7.016	1.137	39.45	
	.90	1.079	7.057	1.123	33.43	Z1=44.6 ohms
	.85	1.140	7.156	1.148	29.68	Z2=94.0 ohms
	.80	1.332	7.369	1.249	26.79	Z3=46.6 ohms
	.75	1.675	7.795	1.430	24.28	Z4=34.1 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
40% BW	1.00	1.226	7.035	1.199	51.03	
	.95	1.216	7.045	1.184	37.72	
	.90	1.190	7.081	1.148	31.83	Z1=41.2 ohms
	.85	1.172	7.159	1.131	28.32	Z2=83.1 ohms
	.80	1.235	7.319	1.208	25.78	Z3=45.8 ohms
	.75	1.446	7.640	1.389	23.72	Z4=32.9 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
50% BW	1.00	1.341	7.083	1.360	55.16	
	.95	1.341	7.094	1.337	35.77	
	.90	1.338	7.129	1.274	29.80	Z1=37.8 ohms
	.85	1.325	7.190	1.195	26.34	Z2=73.0 ohms
	.80	1.308	7.295	1.191	23.96	Z3=42.8 ohms
	.75	1.350	7.497	1.360	22.23	Z4=27.6 ohms

TABLE 5 6-WAY DIVIDER/COMBINER

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
10% BW	1.00	1.018	7.782	1.000	54.86	
	.95	1.032	7.804	1.040	43.01	
	.90	1.107	7.883	1.094	36.85	Z1=44.4 ohms
	.85	1.260	8.058	1.172	32.75	Z2=107.8 ohms
	.80	1.525	8.401	1.283	29.40	Z3=50.1 ohms
	.75	1.971	9.022	1.434	26.45	Z4=44.9 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
20% BW	1.00	1.081	7.788	1.058	53.69	
	.95	1.059	7.809	1.057	43.69	
	.90	1.066	7.885	1.070	37.48	Z1=44.9 ohms
	.85	1.216	8.063	1.124	33.16	Z2=105.8 ohms
	.80	1.499	8.427	1.220	29.55	Z3=48.7 ohms
	.75	1.981	9.102	1.359	26.39	Z4=45.7 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
30% BW	1.00	1.143	7.801	1.026	39.35	
	.95	1.119	7.820	1.033	38.23	
	.90	1.067	7.890	1.067	35.75	Z1=43.6 ohms
	.85	1.142	8.051	1.134	32.88	Z2=99.9 ohms
	.80	1.380	8.381	1.236	29.91	Z3=49.9 ohms
	.75	1.798	9.000	1.380	26.96	Z4=47.9 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
40% BW	1.00	1.222	7.825	1.201	55.41	
	.95	1.199	7.832	1.190	41.62	
	.90	1.133	7.863	1.164	35.62	Z1=42.6 ohms
	.85	1.083	7.944	1.160	31.91	Z2=94.4 ohms
	.80	1.235	8.138	1.233	29.01	Z3=45.7 ohms
	.75	1.575	8.555	1.397	26.40	Z4=34.4 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
50% BW	1.00	1.315	7.863	1.194	40.40	
	.95	1.313	7.879	1.179	36.40	
	.90	1.301	7.929	1.137	31.97	Z1=36.8 ohms
	.85	1.273	8.021	1.100	28.90	Z2=78.6 ohms
	.80	1.247	8.182	1.159	26.67	Z3=46.2 ohms
	.75	1.322	8.486	1.325	24.91	Z4=37.0 ohms

TABLE 6 7-WAY DIVIDER/COMBINER

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
10% BW	1.00	1.034	8.452	1.005	52.35	
	.95	1.041	8.474	1.039	43.23	
	.90	1.096	8.551	1.092	37.45	Z1=41.4 ohms
	.85	1.223	8.714	1.169	33.67	Z2=107.7 ohms
	.80	1.455	9.032	1.279	20.63	Z3=50.0 ohms
	.75	1.855	9.613	1.431	27.89	Z4=44.9 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
20% BW	1.00	1.084	8.458	1.022	46.17	
	.95	1.070	8.479	1.038	42.26	
	.90	1.068	8.552	1.080	37.63	Z1=41.6 ohms
	.85	1.118	8.713	1.151	34.05	Z2=105.7 ohms
	.80	1.413	9.033	1.256	30.98	Z3=49.7 ohms
	.75	1.824	9.632	1.404	28.13	Z4=45.9 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
30% BW	1.00	1.139	8.469	1.019	40.63	
	.95	1.126	8.491	1.030	38.85	
	.90	1.101	8.565	1.068	35.78	Z1=39.9 ohms
	.85	1.143	8.720	1.135	32.97	Z2=98.9 ohms
	.80	1.322	9.022	1.238	30.45	Z3=50.0 ohms
	.75	1.670	9.583	1.383	28.00	Z4=48.0 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
40% BW	1.00	1.219	8.493	1.091	40.78	
	.95	1.222	8.514	1.083	37.48	
	.90	1.224	8.576	1.072	33.40	Z1=35.8 ohms
	.85	1.218	8.688	1.108	30.48	Z2=85.8 ohms
	.80	1.231	8.880	1.212	28.33	Z3=48.3 ohms
	.75	1.360	9.230	1.380	26.61	Z4=40.7 ohms
	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
50% BW	1.00	1.322	8.535	1.183	40.75	
	.95	1.317	8.553	1.169	37.60	
	.90	1.296	8.606	1.132	33.56	Z1=35.9 ohms
	.85	1.252	8.706	1.101	30.69	Z2=82.6 ohms
	.80	1.211	8.884	1.156	28.53	Z3=46.4 ohms
	.75	1.313	9.231	1.310	26.76	Z4=39.6 ohms

TABLE 7 8-WAY DIVIDER/COMBINER

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
10% BW	1.00	1.012	9.031	1.015	75.523	
	.95	1.044	9.053	1.047	43.819	
	.90	1.099	9.126	1.111	37.771	Z1=39.0 ohms
	.85	1.179	9.276	1.223	34.143	Z2=109.5 ohms
	.80	1.294	9.560	1.424	31.371	Z3=49.7 ohms
	.75	1.455	10.083	1.783	28.908	Z4=42.6 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
20% BW	1.00	1.037	9.035	1.065	54.415	
	.95	1.047	9.057	1.061	44.117	
	.90	1.082	9.131	1.085	38.335	Z1=39.4 ohms
	.85	1.150	9.288	1.189	34.667	Z2=108 ohms
	.80	1.254	9.594	1.403	31.754	Z3=49.2 ohms
	.75	1.404	10.166	1.791	29.098	Z4=44.6 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
30% BW	1.00	1.034	9.048	1.135	43.531	
	.95	1.038	9.072	1.122	41.135	
	.90	1.065	9.150	1.096	37.532	Z1=38.8 ohms
	.85	1.126	9.315	1.145	34.508	Z2=103 ohms
	.80	1.223	9.637	1.338	31.854	Z3=49.5 ohms
	.75	1.362	10.238	1.714	29.288	Z4=48.8 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
40% BW	1.00	1.110	9.065	1.195	45.643	
	.95	1.103	9.086	1.200	40.026	
	.90	1.092	9.147	1.205	35.116	Z1=34.9 ohms
	.85	1.122	9.257	1.202	31.993	Z2=90.3 ohms
	.80	1.220	9.447	1.223	29.790	Z3=47.7 ohms
	.75	1.386	9.801	1.374	28.039	Z4=39.6 ohms

	F/FØ	VSWR(DIV)	COUP(DB)	VSWR(COM)	ISOL(DB)	
50% BW	1.00	1.403	9.150	1.394	67.210	
	.95	1.382	9.164	1.397	39.715	
	.90	1.326	9.201	1.396	33.800	Z1=33.1 ohms
	.85	1.262	9.256	1.367	30.462	Z2=79.3 ohms
	.80	1.260	9.337	1.290	28.258	Z3=42.2 ohms
	.75	1.408	9.500	1.219	26.747	Z4=27.7 ohms