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Technical Report

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MSTRIP2: Parameters of Microstrip Transmission Lines and of Coupled Pairs of Lines — 1978 Version and Its Application

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4 June 1982

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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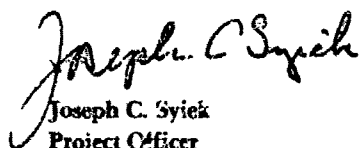
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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**MSTRIP2: PARAMETERS OF MICROSTRIP
TRANSMISSION LINES AND OF COUPLED
PAIRS OF LINES — 1978 VERSION
AND ITS APPLICATION**

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ABSTRACT

MSTRIP has undergone a succession of improvements since its original publication in 1968. Performance of the 1974 and later versions relating to aspects including weakly coupled (<-30 dB) pairs, low shield heights (closer than substrate thickness), and extremely low-impedance lines will be discussed. A FORTRAN list of the 1978 version is appended.

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MSTRIP2: PARAMETERS OF MICROSTRIP TRANSMISSION
LINES AND OF COUPLED PAIRS OF LINES -
1978 VERSION AND ITS APPLICATION

I. INTRODUCTION

The "quasi-TEM" numerical analysis of the normal modes of propagation on coupled pairs of microstrip transmission lines named MSTRIP, published¹ by T.G. Bryant and J.A. Weiss in 1968, incorporated a Green's-function representation of "bound charge" at the upper surface of the dielectric substrate. For a wide range of applications, generally those in which the cross-sectional dimensions are small enough relative to wavelength, the accuracy of this method is very good; in fact, results of MSTRIP have been widely cited over the years as a standard for assessment of the accuracy of other microstrip algorithms. MSTRIP has been used, apparently without modification, in commercially available linear circuit analysis packages.²

The principal approximations (other than the usual substitution of discrete in place of certain continuous variables) are (a) the quasi-TEM assumption, whereby the results of the analysis are all based on the determination of static capacitance, and (b) the assumption of zero thickness and perfect conductivity of the conductors. Numerous papers have appeared in which this basic analysis has been adopted as the starting point for determination of the influences of dispersive effects and of finite conductivity and thickness of the strips.

The program has had some revisions for improved speed, accuracy, and range of applicability during the years since its original publication. We present this report in order to bring to the attention of microstrip circuit users the current version of MSTRIP and its capabilities and to address some questions which have arisen in relation to recent application requirements.

In 1970 and 1971, an improved program was formulated^{3,4} in which the tabulated dielectric Green's function was replaced by a Fourier-integral evaluation. This change resulted in a very substantial improvement in speed and simplicity, better accuracy, and removal of the limitations on the range

of substrate dielectric constant values. It also introduced the option of including the influence of a shield, or upper ground plane, above the circuit surface. The geometry of the shielded, coupled pair of microstrip lines is illustrated in Fig.1. A detailed review of methods and results, with a FORTRAN list of the version of the program then current, was published⁵ in 1974. Following some improvements made in 1978, the program name was modified to MSTRIP2. The FORTRAN source of this program is shown in the Appendix.

In more recent times, users have brought up questions relating to the applicability and accuracy of MSTRIP for specific application requirements. Examples: the questions of upper limits on substrate dielectric constant and on strip widths; usability of the program for shielded microstrip with the

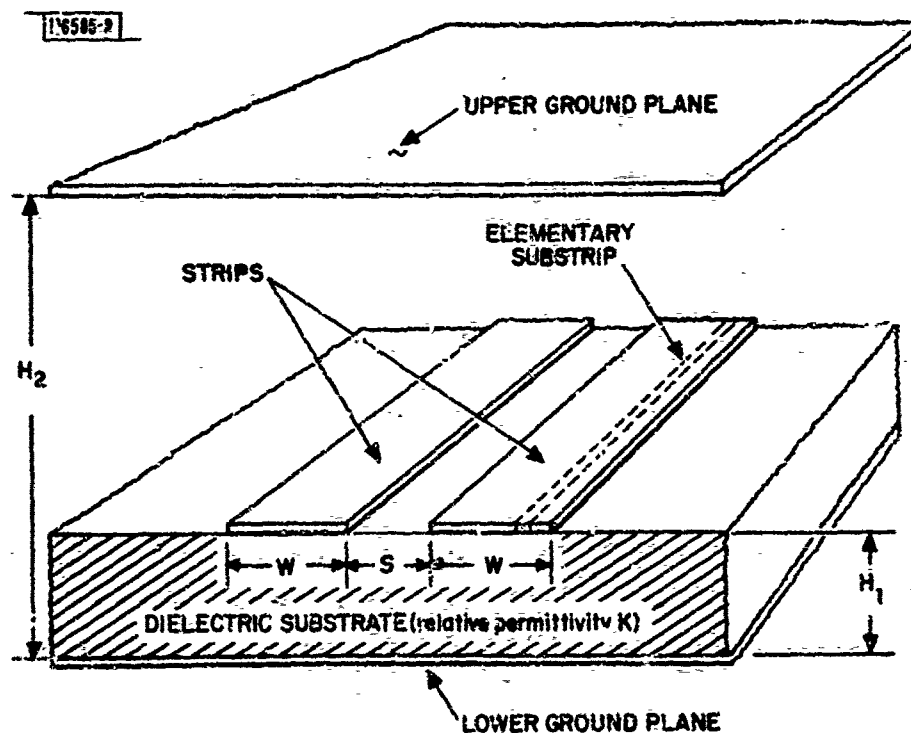


Fig.1. Shielded microstrip structure.

shield very close to the substrate surface ($H_2/H_1 < 2$); the accuracy of the program in cases of very weakly coupled pairs of lines, for which the differences between the two normal-mode characteristic impedances and velocities, which determine the backward- and forward-wave coupling coefficients, are very small.

Applications of these unusual microstrip structures have arisen in various contexts. For example, low-impedance (hence wide-line) transmission lines are needed to match the low impedance of Josephson-junction logic elements in superconducting computers.⁶ Low shield heights can be used to correct the even- and odd-mode velocity differences of coupled lines on anisotropic dielectrics such as sapphire.⁷ Weakly coupled pairs of lines are used as directional couplers in large time-bandwidth dispersive filters.⁸

In the following sections, information is presented relating to such structures and to some tests of accuracy of the program which their consideration provides.

II. SUBSTRATE DIELECTRIC CONSTANT

Nothing in MSTRIP2 imposes a limit on the substrate dielectric constant K . The program has served successfully with K values from 1 to 6000 (in fact, values of K less than unity have been used in order to represent an inverted structure - see Sec.III).

III. APPLICATION TO CASES OF A CLOSELY SPACED SHIELD

For values of H_2/H_1 less than 2 (see Fig.1), the gap between the shield and circuit surface is smaller than the substrate thickness. In such cases, MSTRIP2 loses accuracy. For example, with $H_2/H_1 = 1.25$, $S/H_1 = 3.5$, $W/H_1 = 0.50$, and $K = 9.6$ (alumina), MSTRIP2 gives the physically unreasonable result that $Z_{oe} < Z_{oo}$.

TABLE I

TRANSFORMATION FROM STANDARD TO INVERTED COMPUTATION
IN THE CASE OF A CLOSELY SPACED SHIELD*

Unprimed: Parameters of interest as used in the standard computation (Fig.1).

Primed: Input/output parameters to be used to analyze the same structure by inverted computation.

$$R \equiv \frac{H_2}{H_1}$$

$$\text{MSTRIP Input: } H_1' = H_2 - H_1 \quad \left(\frac{W}{H_1}\right)' = \frac{W/H_1}{R-1}$$

$$R' = \frac{R}{R-1} \quad \left(\frac{S}{H_1}\right)' = \frac{S/H_1}{R-1}$$

$$K' = \frac{1}{K}$$

To interpret MSTRIP output, transform tabulated values as follows.
(Primed variables are output of the inverted computation, unprimed variables are those of the actual structure of interest.)

$$K_{\text{eff}} = K'_{\text{eff}} K \quad Z = \frac{Z'}{\sqrt{K}}$$

$$C = C' K \quad V = \frac{V'}{\sqrt{K}}$$

*See Sec.III.

This deficiency may be circumvented by inverting the problem, placing the gap ($K = 1$) on the bottom, and the substrate ($K > 1$) above, so that $H_2/H_1 > 2$. Because MSTRIP incorporates the assumption that the gap has a dielectric constant of unity, the input and output parameters must be transformed according to the system shown in Table I.

Using this procedure as a check, it may be verified that MSTRIP2 is accurate to H_2/H_1 values less than 1.5. For example, for a 50- Ω pair of coupled lines on sapphire with $H_2/H_1 = 1.5$, $S/H_1 = 3.5$, the two methods agree to within 0.01 percent in impedances and 0.02 percent in velocities. The two agree to within 0.04 dB in backward coupling, even though it is a weak -64 dB. With the shielding height reduced to $H_2/H_1 = 1.25$, the discrepancy in impedance between the standard computation and the inverted structure increases to 0.3 percent, unacceptable for the calculation of coupling in this weakly coupled structure.

IV. COMPARISON WITH ANALYTIC CALCULATION

In the special case $H_2/H_1 = 2$, the quasi-static electric field in the shielded (coupled) microstrip structure with zero conductor thickness may be shown to be symmetric about the dielectric/air interface. Consequently, the quasi-static characteristics of the microstrip (MS) are identical to those of a balanced stripline (SL) structure of the same dimensions filled with a material of dielectric constant $K_{SL} = (1/2) (K_{MS} + 1)$.

This equivalency provides a convenient check on shielded microstrip calculations, as analytical expressions for coupled striplines are well known. In Table II are shown the results of calculations for several values of S/H_1 and W/H_1 , using MSTRIP and MSTRIP2 for shielded microstrip ($K_{MS} = 9.6$) and an analytic approximation for the stripline ($K_{SL} = 5.3$). A transcendental approximation valid to 8 parts in 10^6 compared to the exact elliptic integral expression for stripline impedances was used, given as Eqs. 6.3.1, 6.3.2, 3.2.7, and 3.2.8 in the book by Gunston.⁹ Both MSTRIP and MSTRIP2

TABLE II

IMPEDANCE, COUPLING, AND EFFECTIVE DIELECTRIC CONSTANT VALUES
CALCULATED BY MSTRIP, MSTRIP2, AND BALANCED STRIPLINE METHODS, $H_2/H_1 = 2$;
K = 9.6 FOR MICROSTRIP, 5.3 FOR STRIPLINE

S/H ₁	W/H ₁	Z _{oe} (Ω)			Z _{oo} (Ω)			-k _B (dB)			(K _{eff}) _{even} (MSTRIP)
		MSTRIP	MSTRIP2	Strip- line	MSTRIP	MSTRIP2	Strip- line	MSTRIP	MSTRIP2	Strip- line	
0.5	0.3	90.29	89.82	89.36	58.26	58.26	57.77	13.3	13.4	13.4	5.346
	0.8	57.72	57.25	56.84	40.60	40.60	40.07	15.2	15.4	15.2	5.372
	1.3	42.94	42.46	42.12	32.43	32.43	31.90	17.1	17.5	17.2	5.397
1.0	0.3	81.75	81.27	80.81	67.29	67.29	66.81	20.3	20.5	20.5	5.351
	0.8	53.55	53.07	52.65	45.63	45.63	45.16	22.0	22.5	22.3	5.378
	1.3	40.55	40.07	39.70	35.60	35.60	35.16	23.7	24.6	24.3	5.403
2.0	0.3	76.25	75.77	75.31	72.88	72.89	72.42	32.9	34.2	34.2	5.354
	0.8	50.69	50.22	49.78	48.68	48.68	48.23	33.9	36.2	36.0	5.382
	1.3	38.87	38.39	38.00	37.47	37.47	37.06	34.7	38.3	38.1	5.407
4.0	0.3	74.87	74.39	73.93	74.27	74.27	73.80	47.9	61.5	61.5	5.355
	0.8	49.96	49.48	49.05	49.42	49.42	48.98	45.2	63.5	63.3	5.383
	1.3	38.43	37.95	37.55	37.91	37.91	37.51	43.4	65.6	65.3	5.408
10:0	0.3	74.81	74.33	73.87	74.33	74.33	73.87	49.9	>100	>100	5.355
	0.8	49.93	49.45	49.01	49.45	49.45	49.01	46.4	>100	>100	5.383
	1.3	38.41	37.93	37.53	37.93	37.93	37.53	44.1	>100	>100	5.408

were run with $M = 20$ substrips per strip. In addition to the even- and odd-mode impedances, the backward-wave coupling strength for a quarter-wave length of line is shown, given by the expression

$$k_B \text{ (dB)} = 20 \log_{10} \frac{Z_{oe} - Z_{oo}}{Z_{oe} + Z_{oo}} .$$

The even-mode effective dielectric constant given by MSTRIP is also shown. The odd-mode constant given by MSTRIP and both mode constants given by MSTRIP2 exhibit the proper value of 5.3.

It is evident that both versions of MSTRIP give reliable impedance and backward coupling values for k_B in the range of stronger coupling ($S/H_1 < 1$, $k_B > -25$ dB). Impedances are within 1Ω of the stripline values and coupling strengths are within 1 dB. In the -30- to -40-dB range ($S/H_1 \sim 2$) MSTRIP2 retains its accuracy in coupling strength, while errors of more than 3 dB appear in MSTRIP. For $S/H_1 > 2$, MSTRIP rapidly loses accuracy, never predicting coupling weaker than -50 dB. MSTRIP2 remains within a few tenths of one decibel of the stripline value.

It is noteworthy that, over the whole range of S/H_1 and W/H_1 tested, the odd-mode impedances given by MSTRIP and MSTRIP2 are identical and exceed the stripline values by 0.4 to 0.5 Ω . MSTRIP2 gives Z_{oe} values which are similarly 0.4 to 0.5 Ω higher than stripline values, while MSTRIP gives Z_{oe} values about 1 Ω too high. Thus, even- and odd-mode impedance errors given by MSTRIP2 track each other, giving accurate coupling values, while a roughly 0.5- Ω difference exists between the MSTRIP even- and odd-mode impedance errors, resulting in large errors in coupling strength for weakly coupled lines.

There is also a significant error in the even-mode effective dielectric constant given by MSTRIP. This error is positive, opposite in sign to that expected on the basis of the Z_{oe} error. The error results in a predicted even-mode phase velocity less than that of the odd mode. On this basis, a forward coupling strength of -40 to -50 dB over a 90° line segment would be predicted for all lines considered in Table I.

MSTRIP is adequate for design of couplers tighter than -25 dB, although it may give inaccurate values of directivity. For calculation of cross talk between closely spaced lines in applications such as MICs where space is at a premium, the current, more accurate version, MSTRIP2, is needed.

V. APPLICATION TO EXTREMELY LOW-IMPEDANCE LINES

In 1980 an MSTRIP user, J.C. Cozzie, pointed out¹⁰ a flaw which he had discovered when he attempted to determine microstrip parameters for extremely low-impedance lines: $Z_0 < 3 \Omega$, which requires strip widths of $W/H_1 > 70$ in the case $K = 2.45$ which was of interest to him. Cozzie located the flaw in the subroutine MGREEN, recognized it as a consequence of an approximation embedded in the integration procedure, and described how he eliminated it with changes including the substitution of a Gaussian quadrature procedure. (Cozzie was working with the 1971 or 1974 version of MSTRIP. By coincidence we had also converted MGREEN to Gaussian quadrature integration, calling IBM Scientific Subroutine DQG32, in the 1978 version.)

At Cozzie's instigation, we modified certain details of MGREEN to remove the flaw. At the time, we had the following further thoughts regarding very wide strips. First: if the scale of dimensions is such that the width becomes comparable to a half-wavelength (in a medium of dielectric constant K_{eff} as evaluated by MSTRIP2) in the frequency range of interest, then spurious propagation effects and coupling problems are to be expected. In that case, it would probably be advisable to seek some alternative means to obtain the circuit function contemplated. Second: for widths of $W/H_1 > 20$ or so, very accurate results can be obtained by decomposing the strip capacitance into the sum of W/H_1 times a parallel-plate part per unit increment of W/H_1 plus an edge contribution. Once suitable limiting values of those two capacitance parameters have been determined by a few trials, the microstrip parameters for all cases of wider strips with the same substrate K value can be quickly determined. Cozzie noted this suggestion and briefly presented his version of it in his paper.¹⁰

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APPENDIX

```

C*****MST00010
C
C                                     MST00020
C                                     -MSTRIP2-
C                                     MST00030
C                                     MST00040
C                                     PARAMETERS OF MICROSTRIP TRANSMISSION LINES AND
C                                     OF COUPLED PAIRS OF MICROSTRIP LINES
C                                     MST00050
C                                     MST00060
C                                     MST00070
C                                     IMPROVED -- VERSION OF AUG. 1 , 1978
C                                     MST00080
C                                     MST00090
C REFERENCES - 1. T.G. BRYANT AND J.A. WEISS, IEEE TRANS MTT-16 1021
C                                     (DECEMBER 1968).
C                                     MST00100
C                                     MST00110
C                                     2. J.A. WEISS AND T.G. BRYANT, ELECTRONICS LETTERS
C                                     VOL. 5 P. 517 (OCTOBER 16, 1969).
C                                     MST00120
C                                     MST00130
C                                     3. J.A. WEISS AND T.G. BRYANT, ELECTRONICS LETTERS
C                                     VOL. 6 P. 462 (JULY 23, 1970); SEE ALSO ERRATUM,
C                                     ELECTRONICS LETTERS VOL. 6 P. 560 (AUGUST 20, 1970).
C                                     MST00140
C                                     MST00150
C                                     4. T.G. BRYANT AND J.A. WEISS, IEEE TRANS MTT-19 418
C                                     (APRIL, 1971).
C                                     MST00160
C                                     MST00170
C                                     5. J.A. WEISS, ADVANCES IN MICROWAVES, VOL. 8,
C                                     PP. 295-320; ACADEMIC PRESS, 1974.
C                                     MST00180
C                                     MST00190
C                                     MST00200
C                                     MST00210
C                                     FOR MICROSTRIP COMPRISING - A DIELECTRIC SUBSTRATE OF RELATIVE
C                                     DIELECTRIC PERMITTIVITY K AND THICKNESS H1 LYING ON A CONDUCTING
C                                     GROUND PLANE; A SINGLE STRIP OF WIDTH W OR TWO PARALLEL STRIPS OF
C                                     EQUAL WIDTH W WITH INNER EDGES DISTANCE S APART, LYING ON THE UPPER
C                                     SURFACE OF THE SUBSTRATE; THICKNESS OF THE STRIP MATERIAL ASSUMED
C                                     TO BE NEGLIGIBLE; AN UPPER GROUND PLANE LOCATED PARALLEL TO AND
C                                     DISTANCE H2 ABOVE THE LOWER GROUND PLANE (OPTIONAL).
C                                     MST00220
C                                     MST00230
C                                     MST00240
C                                     MST00250
C                                     MST00260
C                                     MST00270
C                                     MST00280
C                                     MST00290
C                                     THE PROGRAM COMPUTES THE FOLLOWING TRANSMISSION-LINE PARAMETERS
C                                     FOR A SINGLE STRIP OR FOR BOTH THE EVEN AND ODD MODES OF A COUPLED
C                                     PAIR OF STRIPS -
C                                     MST00300
C                                     MST00310
C                                     MST00320
C                                     MST00330
C                                     CHARACTERISTIC IMPEDANCE;
C                                     MST00340
C                                     PHASE VELOCITY;
C                                     MST00350
C                                     EFFECTIVE DIELECTRIC CONSTANT K-EFF;
C                                     MST00360
C                                     CAPACITANCE PER UNIT LENGTH PER STRIP (OPTIONAL).
C                                     MST00370
C                                     MST00380
C                                     THE CALCULATION EMBODIES THE QUASI-STATIC APPROXIMATION, AS
C                                     EXPLAINED IN REFERENCE 1; THE APPROXIMATION IS ACCURATE PROVIDED
C                                     H1 IS NO GREATER THAN A FEW PERCENT OF THE WAVELENGTH IN AN UN-
C                                     BOUNDED MEDIUM OF PERMITTIVITY K.
C                                     MST00390
C                                     MST00400
C                                     MST00410
C                                     MST00420
C                                     MST00430
C                                     THE PROGRAM ACCEPTS ANY VALUE OF K, S/H1, AND W/H1.
C                                     MST00440
C                                     MST00450
C                                     INPUT AND OUTPUT MEDIA ARE IDENTIFIED IN THE PROGRAM BY THE
C                                     FOLLOWING NAMES - INPUT (USUALLY A CARD READER), IV; OUTPUT (USU-
C                                     ALLY A LINE PRINTER), IW.
C                                     MST00460
C                                     MST00470
C                                     MST00480
C                                     MST00490

```

C INPUT DATA - THE INPUT DATA CARD IS WRITTEN IN NAMELIST FORMAT MST00500
 C AND CONTAINS SIX DECIMAL NUMBERS AND ONE INTEGER NUMBER, ALL MST00510
 C SEPARATED BY COMMAS, AS IN THE FOLLOWING EXAMPLE. MST00520
 C MST00530
 C &CONST WH1=0.1,DELW=0.2,NT=20,R=0.0,DIEK=9.6,SH1=0.4,AIR=1.0, &END MST00540
 C MST00550
 C THIS CARD SPECIFIES THE VALUES OF PROGRAM VARIABLES HAVING THE FOLLOWING NAMES - MST00560
 C LOWING NAMES - MST00570
 C MST00580
 C WH1,DELW,NT,R,DIEK,SH1,AIR MST00590
 C MST00600
 C WH1 IS THE STARTING VALUE OF W/H1; DELW IS THE INCREMENT OF W/H1; MST00610
 C NT IS THE NUMBER OF LINES IN THE OUTPUT TABLE (EQUAL TO THE NUMBER OF VALUES OF W/H1); R IS THE GROUND PLANE RATIO H2/H1 (FOR THE MST00620
 C OPTION OF NO UPPER GROUND PLANE, SET R = 0.0); DIEK IS THE RELATIVE DIELECTRIC PERMITTIVITY K OF THE SUBSTRATE; SH1 IS THE VALUE MST00630
 C OF S/H1; AIR TAKES ONE OF THE TWO VALUES 0.0 (SINGLE STRIP) OR MST00640
 C 1.0 (COUPLED STRIPS). THUS IN THE EXAMPLE THE OUTPUT TABLE WILL REPRESENT TO THE EVEN AND ODD MODES OF COUPLED STRIPS WITH SPACING S/H1 MST00650
 C = 0.4 ON SUBSTRATE OF PERMITTIVITY K = 9.6, NO UPPER GROUND PLANE, MST00660
 C AND WILL LIST 20 LINES, FROM W/H1 = 0.1 THROUGH W/H1 = 2.0 IN MST00670
 C STEPS OF 0.2. MST00680
 C MST00690
 C MST00700
 C MST00710
 C MST00720
 C OUTPUT - THE OUTPUT FORMAT IS ILLUSTRATED IN THE FOLLOWING TABLE SHOWING THE FIRST LINE OF OUTPUT DATA FOR THE ABOVE EXAMPLE. MST00730
 C MST00740
 C MST00750
 C MST00760
 C H2/H1 = 0.0 K = 9.60 COUPLED STRIPS S/H1 = 0.4 MST00770
 C MST00780
 C MST00790
 C W/H1 ZO(E) ZO(O) V(E) V(O) K-EFF(E) K-EFF(O) MST00800
 C OHMS E+08 M/SEC MST00810
 C MST00820
 C 0.100 141.210 77.250 1.214 1.299 6.102 5.328 MST00830
 C MST00840
 C MST00850
 C SUBROUTINES REQUIRED - THE PROGRAM CALLS THREE SUBROUTINES OBTAINED FROM THE IBM SCIENTIFIC SUBROUTINE PACKAGE (SSP). THEY ARE DGBLS, SICI, AND DQG32. FOR DESCRIPTIONS AND LISTS OF THESE PROGRAMS SEE THE IBM SSP MANUAL. IN ADDITION, THE PROGRAM INCLUDES FIVE SUBROUTINES OF ITS OWN - OUTPUT, XGEN, AMAT, MPHI, AND MGREEN AND ONE FUNCTION SUBPROGRAM - GINT. NOTE ON THE IMPROVEMENT DATED AUG. 1, 1978: THE INTEGRATION SUBROUTINE DQG32 (32-POINT GAUSSIAN QUADRATURE METHOD) REPLACES THE SUBROUTINE DQSF (SIMPSON'S RULE), RESULTING IN ACCURACY SUBSTANTIALLY BETTER THAN ONE PERCENT IN ALL CASES TESTED. REVISIONS AND TESTS PERFORMED BY R. C. LEWIS.
 C
 C NOTE ON DIMENSION REQUIREMENTS - FOR THE DETERMINATION OF CHARGE DISTRIBUTION EACH STRIP IS DIVIDED INTO M SUBSTRIPS. IN THE PRESENT PROGRAM M = 20, BUT THE PARAMETER M CAN BE INCREASED

C	FOR IMPROVED ACCURACY OR REDUCED FOR IMPROVED SPEED OF EXECU-	MST01000
C	TION. THE DIMENSIONS OF THE VARIABLES DEPEND ON THE VALUE OF M	MST01010
C	AS FOLLOWS -	MST01020
C		MST01030
C	V(M),AUX(M-1),X(3M-1),PHI(3M-1),A(M(M+1)/2),B(M(M+1)/2)	MST01040
C		MST01050
C	*****	MST01060
C		MST01070
	IMPLICIT REAL*8(A-H,O-Z)	MST01080
	DIMENSION V(20),AUX(19),GO(2)	MST01090
	COMMON/DIM/X(59),PHI(59),A(210),B(210)	MST01100
	NAMBLIST/CONST/WH1,DRLW,NT,R,DIEK,SH1,AIR	MST01110
	DATA GO/'Y','N'/	MST01120
	CALL TIMES(DATE,TIME)	MST01130
	IV=5	MST01140
	IW=1	MST01150
	M=20	MST01160
	N=1	MST01170
	WRITE(IW,104)	MST01180
801	DO 901 NREP=1,25	MST01190
	EPS=1.0E-07	MST01200
	IF(NREP.EQ.1) GO TO 91	MST01210
92	WRITE(6,102)	MST01220
	READ(IV,103) GOYN	MST01230
	IF(GOYN.EQ.GO(1)) GO TO 91	MST01240
	IF(GOYN.NE.GO(1).AND.GOYN.NE.GO(2)) GO TO 92	MST01250
	GO TO 999	MST01260
91	WRITE(6,101)	MST01270
	READ(IV,CONST)	MST01280
	IF(AIR) 38,7,8	MST01290
7	WRITE(IW,105) R,DIEK	MST01300
	WRITE(IW,106)	MST01310
	GO TO 802	MST01320
8	WRITE(IW,107) R,DIEK,SH1	MST01330
	WRITE(IW,108)	MST01340
802	DO 902 K=1,NT	MST01350
	AK=K	MST01360
	WH=WH1+(AK-1.0)*DELR	MST01370
	CALL XGEN(M,WH,SH1)	MST01380
	NN=AIR+1	MST01390
	ADIEK=DIEK	MST01400
803	DO 903 IJ=1,2	MST01410
	IF(IJ.EQ.1) DIEK=1.0	MST01420
	IF(IJ.EQ.2) DIEK=ADIEK	MST01430
	IF(R.EQ.0.0.AND.DIEK.EQ.1.0) GO TO 39	MST01440
	CALL MGREEN(M,WH,SH1,DIEK,R)	MST01450
	GO TO 804	MST01460
39	CALL MPHI(WH,M,AJR)	MST01470
804	DO 903 JJ=1,NN	MST01480
	CALL AMAT(AIR,M)	MST01490
	DO 23 I=1,M	MST01500

23	V(I)=1.0	MST01510
	IF(JJ .EQ. 1) CALL DGELS(V,A,M,N,EPS,IER,AUX)	MST01520
	IF(JJ .EQ. 2) CALL DGELS(V,B,M,N,EPS,IER,AUX)	MST01530
	IF(IER.NE.0) WRITE(IW,111) IER,EPS	MST01540
111	FORMAT(' IER= ',I3,', IN SUBROUTINE DGELS, SO THE CHARGE DENSITY	MST01550
2	COULD NOT BE CALCULATED TO THE PRECISION OF ',E13.6,' DIGITS')	MST01560
	CAPSUM=0.0	MST01570
	DO 21 I=1,M	MST01580
21	CAPSUM=CAPSUM+V(I)	MST01590
	CC=CAPSUM*111.256	MST01600
	IF(JJ .EQ. 1 .AND. IJ .EQ. 1) CAPLE=CC	MST01610
	IF(JJ .EQ. 1 .AND. IJ .EQ. 2) CAPKE=CC	MST01620
	IF(JJ .EQ. 2 .AND. IJ .EQ. 1) CAPLO=CC	MST01630
	IF(JJ .EQ. 2 .AND. IJ .EQ. 2) CAPKO=CC	MST01640
903	CONTINUE	MST01650
	CALL OUTPUT(CAPLE,CAPKE,CAPLO,CAPKO,WH,IW,NE)	MST01660
902	CONTINUE	MST01670
	WRITE(IW,110) DATE,TIME	MST01680
	WRITE(IW,199)	MST01690
	GO TO 901	MST01700
38	WRITE(6,109)	MST01710
101	FORMAT(/,3X,'CONST: WH1,DELM,NT,R,DIEK,SH1,AIR ?',/)	MST01720
102	FORMAT(/,3X,'CONTINUE? ('YES' OR 'NO')',/)	MST01730
103	FORMAT(A1)	MST01740
104	FORMAT('1',/,5X,'J.A. WEISS, ',	MST01750
2	'ADVANCES IN MICROWAVES, VOL. 8',/7X,'PP. 295-320; ',	MST01760
3	'ACADEMIC PRESS, 1974.',/,10X,'PARAMETERS OF MICROSTRIP ',	MST01770
4	'TRANSMISSION LINES',/12X,'AND OF COUPLED PAIRS OF ',	MST01780
5	'MICROSTRIP LINES')	MST01790
105	FORMAT(/,11X,'H2/H1 = ',F6.3,5X,'K = ',F6.3,4X,'SINGLE STRIP')	MST01800
106	FORMAT(/,10X,'W/H1',12X,'ZO',14X,'V',12X,'K-EFF',11X,'C',/,	MST01810
2	10X,15X,'OHMS',8X,'E+08 M/SEC',23X,'PF/M',/)	MST01820
107	FORMAT(/,3X,'H2/H1 = ',F6.3,4X,'K = ',F6.3,4X,'COUPLED STRIPS',	MST01830
2	5X,'S/H1 = ',F5.2)	MST01840
108	FORMAT(/,3X,'W/H1',6X,'ZO(E)',4X,'ZO(O)',6X,'V(E)',4X,'V(O)',4X,	MST01850
2	'K-EFF(E) K-EFF(O)',4X,'C(E)',5X,'C(O)',/18X,'OHMS',12X,	MST01860
3	'E+08 M/SEC',30X,'PF/M',/)	MST01870
109	FORMAT(/, 'AIR SHOULD BE 0.0 OR +1.0',/)	MST01880
110	FORMAT(/,5X,2(A8,2X),/)	MST01890
199	FORMAT(///)	MST01900
901	CONTINUE	MST01910
999	CONTINUE	MST01920
	CALL EXIT	MST01930
	STOP	MST01940
	END	MST01950
C		MST01960
C		MST01970
	SUBROUTINE OUTPUT(CAPLE,CAPKE,CAPLO,CAPKO,WH,IW,NN)	MST01980
C		MST01990
	IMPLICIT REAL*8(A-H,O-Z)	MST02000
	DATA C/2.99792458/	MST02010

BFFKE=CAPKE/CAP1E	MST02020
RKE=DSQRT(BFFKE)	MST02030
ZOE=1.0E+04/(C*CAP1E*RKE)	MST02040
VELE=(1.0/RKE)*C	MST02050
IF(NN.EQ.1) WRITE(IW,101) WH,ZOE,VELE,BFFKE,CAPKE	MST02060
IF(NN.EQ.1) GO TO 3	MST02070
EFFKO=CAPKO/CAP1O	MST02080
RKO=DSQRT(BFFKO)	MST02090
ZOO=1.0E+04/(C*CAP1O*RKO)	MST02100
VELO=(1.0/RKO)*C	MST02110
WRITE(IW,103) WH,ZOE,ZOO,VELE,VELO,BFFKE,BFFKO,CAPKE,CAPKO	MST02120
101 FORMAT(5(5X,F10.3))	MST02130
102 FORMAT(2X,F6.3,4X,F7.3,1X,F7.3,4X,F6.3,2X,F6.3,5X,F6.3,2X,F6.3)	MST02140
103 FORMAT(2X,F6.3,4X,F7.3,1X,F7.3,4X,F6.3,2X,F6.3,5X,F6.3,2X,F6.3,	MST02150
2 4X,F8.3,1X,F8.3)	MST02160
3 RETURN	MST02170
END	MST02180
C	MST02190
C	MST02200
SUBROUTINE XGEN(M,WH,SH1)	MST02210
C	MST02220
IMPLICIT REAL*8(A-H,O-Z)	MST02230
COMMON/DIM/X(59),PHI(59),A(210),B(210)	MST02240
AM=M	MST02250
WHM=WH/AM	MST02260
801 DO 901 I=1,M	MST02270
AI=I	MST02280
901 X(I)=(AI-1.0)*WHM	MST02290
IF(SH1.EQ.0.0) GO TO 1	MST02300
MM=2*M-1	MST02310
802 DO 902 I=1,MM	MST02320
AI=I	MST02330
902 X(I+M)=AI*WHM+SH1	MST02340
1 RETURN	MST02350
END	MST02360
C	MST02370
C	MST02380
SUBROUTINE AMAT(S,M)	MST02390
C	MST02400
IMPLICIT REAL*8(A-H,O-Z)	MST02410
COMMON/DIM/X(59),PHI(59),A(210),B(210)	MST02420
803 DO 903 I=1,M	MST02430
INDEX1=M+1-I	MST02440
904 DO 904 J=1,INDEX1	MST02450
NF1=0	MST02460
805 DO 905 K=1,J	MST02470
905 NF1=NF1+K	MST02480
NF2=0	MST02490
IF(I.LE.2) GO TO 10	MST02500
INDEX2=I-2	MST02510
806 DO 906 L=1,INDEX2	MST02520
906 NF2=NF2+L	MST02530

10	N=NF1+NF2+(I-1)*J	MST02540
	INDEX3=3*M+2*(1-J)-I	MST02550
	A(N)=PHI(I)+S*PHI(INDEX3)	MST02560
	B(N)=PHI(I)-S*PHI(INDEX3)	MST02570
904	CONTINUE	MST02580
903	CONTINUE	MST02590
	RETURN	MST02600
	END	MST02610
C		MST02620
C		MST02630
	SUBROUTINE MPHI(WH,M,S)	MST02640
C		MST02650
	IMPLICIT REAL*8(A-H,O-Z)	MST02660
	COMMON/DIM/X(59),PHI(59),A(210),B(210)	MST02670
	AM=M	MST02680
	INDEX1=3*M-1	MST02690
	IF(S.EQ. 0.0) INDEX1=M	MST02700
	EXWON=WH/(2.0*AM)	MST02710
	WYWON=1.0D 00	MST02720
807	DO 907 K=1,INDEX1	MST02730
	XO=X(K)	MST02740
	EXP=XO+EXWON	MST02750
	EXN=XO-EXWON	MST02760
	WYP=2.0*WYWON	MST02770
	PHI(K)=(EXN/(2.0*EXWON))*DLOG((EXN**2)/(EXN**2+WYP**2))-(EXP	MST02780
	2 / (2.0*EXWON))*DLOG((EXP**2)/(EXP**2+WYP**2))+ (WYP/EXWON)	MST02790
	3 *(DATAN(EXP/WYP)-DATAN(EXN/WYL))	MST02800
907	CONTINUE	MST02810
	RETURN	MST02820
	END	MST02830
C		MST02840
C		MST02850
	SUBROUTINE MGREEN(M,WH,SH1,DIEK,R)	MST02860
C		MST02870
	IMPLICIT REAL*8(A-H,O-Z)	MST02880
	COMMON/DIM/X(59),PHI(59),A(210),B(210)	MST02890
	COMMON /PASS/ R1,CO,BO,DIEK1	MST02900
	EXTERNAL GINT	MST02910
	AM=M	MST02920
	R1=R	MST02930
	DIEK1=DIEK	MST02940
	CO=WH/AM*0.5	MST02950
	X1=5.0	MST02960
	INT=2	MST02970
	H=X1/DFLOAT(INT)	MST02980
	IF(SH1.EQ. 0.0) MA=M	MST02990
	IF(SH1.NE. 0.0) MA=3*M-1	MST03000
808	DO 908 M4=1,MA	MST03010
	BO=X(M4)	MST03020
	YTOT=0.0D0	MST03030
	XU=0.0	MST03040
	XL=0.0	MST03050

C		MST03060
C	COMPUTE FIRST INTEGRAL	MST03070
C		MST03080
	809 DO 909 I=1,INT,1	MST03090
	XU=XU+H	MST03100
	CALL DOG32(XL,XU,GINT,YRESUL)	MST03110
	YTOT=YTOT+YRESUL	MST03120
	XL=XL+H	MST03130
	909 CONTINUE	MST03140
	AI1=YTOT	MST03150
C		MST03160
C	COMPUTE SECOND INTEGRAL	MST03170
C		MST03180
	S1=(CO+BO)*X1	MST03190
	S2=(BO-CO)*X1	MST03200
	CALL SICI(S1,CI,S1)	MST03210
	AI2A=DSIN(S1)/X1-(CO+BO)*CI	MST03220
	CALL SICI(S1,CI,S2)	MST03230
	AI2B=DSIN(S2)/X1-(BO-CO)*CI	MST03240
	AI2=AI2A-AI2B	MST03250
	PHI(MZ)=4.0*(AI1+1.0/((1.0+DIK)*CO*2.0)*AI2)	MST03260
	908 CONTINUE	MST03270
	RETURN	MST03280
	END	MST03290
	FUNCTION GINT(U)	MST03300
	IMPLICIT REAL*8(A-H,O-Z)	MST03310
	COMMON /PASS/ R,CO,BO,DIK	MST03320
	V=(R-1.0)*U	MST03330
	W1=CO*U	MST03340
	W2=DCOSH(U)	MST03350
	W3=DSINH(U)	MST03360
	W4=DCOS(BO*U)	MST03370
	IF(R .NE. 0)W4=W4*DSINH(V)	MST03380
	IF(R .EQ. 0)DEN=W3+DIK*W2	MST03390
	IF(R .NE. 0)DEN=W3*DCOSH(V)+DIK*W2*DSINH(V)	MST03400
	GINT=DSIN(W1)/W1*W3/U*W4/DEN	MST03410
	RETURN	MST03420
	END	MST03430

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MSTRIP has undergone a succession of improvements since its original publication in 1968. Performance of the 1974 and later versions relating to aspects including weakly coupled (< -30 dB) pairs, low shield heights (closer than substrate thickness), and extremely low-impedance lines will be discussed. A FORTRAN list of the 1978 version is appended.										