national accelerator laboratory

TM-326
0431.00

TRAVELING-WAVE BEAM POSITION DETECTOR FOR THE MAIN ACCELERATOR RF SYSTEM

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A beam position detector that permits accurate observation of the individual proton bunches is installed in the RF Straight Section of the Main Ring. It is of the type described in UCID-10116. The RF stripline, shown schematically in Fig. 1, follows the contour of the inner surface of the beam pipe. For further reading on stripline, see references 1 to 198.

RF sum and RF difference signals from the detector are generated by electronics boxes as is customary; the difference signal $\frac{A-B}{A+B}$ controls the horizontal position of the beam during the acceleration cycle and the sum signal A+B provides rf phasing information.

These notes include the test and adjustment results. The detector is constructed according to the drawings #'s 0431.00-ME-21372, 0431.00-MD-21625, 0431.00-MB-21626, 0431.00-MC-21373, 0431.00-MB-21627, 0431.00-MB-21624, and installed according to 0434.00-MD-21576, 0430.00-LD-5024, 0335.03-MB-21438.

A noteworthy mechanical construction feature is that the striplines are pre-bent to a curvature to exert a 1-2 ounce pressure on the 99% alumina support rods. It therefore is practical to electrically "flatten" the line for wideband response from 53 MHz to over 800 MHz.

Fig. 3 (although for coax rather than stripline) illustrates the trend in voltage standing wave ratio (VSWR) with respect to one sort of misalignment. With perfect alignment, there should be no standing waves.

Figure 2 gives test data on the detector, Figure 4 on the the electronics box output voltage.

The detector properties may be summarized as follows:

1. Bunch structure may be observed over the frequency range from the fundamental (53 MHz) to about the 20th harmonic. The frequency response is reasonably flat to 800 MHz and then attenuates with $\sqrt{f}$.

2. Absolute intensity and position calibration has been done by wire and is expected to have no more than $\pm$ 5% error.

3. In-situ calibration is an intrinsic feature; coax connections for injecting standardizing test pulses exist naturally.

4. The signal pulses corresponding to individual bunches are quite separate; there is no detectable overlap or storage effect from one bunch to the next.

5. Position calibration is linear.

6. The detector, like a directional coupler, tells which direction the beam is traveling.

7. Ultimate sensitivity is set by the noise level of the input stage of the electronics.

8. Installation of the detector and associated cables includes noise suppression for incidental external RF, SCR spikes and the like, together with accurate phase matching of the A and B signal transmission paths.

9. Because the detector is some distance away in the enclosure, the frequency response of the necessary cables must be considered. Figures 5 and 6, taken from Report CC2-1B of the UCRL Counting Handbook, show the step response of representative cables. Skin-effect losses produce an attenuation whose magnitude in decibels varies as the square-root of frequency. This results in a step function response of:

$$E_{out} = E_{in} \left(1 - \text{erf} \frac{b \ell}{\sqrt{2 (t-\tau)}}\right)$$

where

E_{out} = voltage at distance ℓ from input end of semi-infinitely long uniform cable, at time t (seconds).

E_{in} = amplitude of step of voltage applied to input of cable at time t = 0.

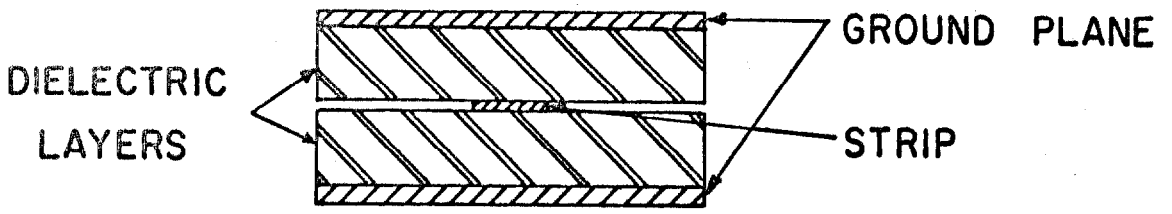
ℓ = distance from input end in feet.

b = constant for the particular cable in question.
= 1.45×10^{-8} A - feet^{-1} sec$^{\frac{1}{2}}$

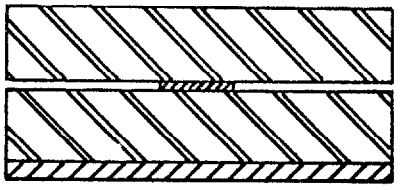
A = attenuation of cable at 1000 mc - db/100 feet (attenuation figures for coaxial cables are commonly quoted in these units).

erf = error function

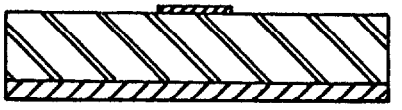
τ = transit time of cable defined as the value of t at which the voltage at ℓ first begins to change (considering only the step function occurring at t = 0, of course).



FULL SECTION



3/4 SECTION



1/2 SECTION (Open Line)

FIGURE 1.

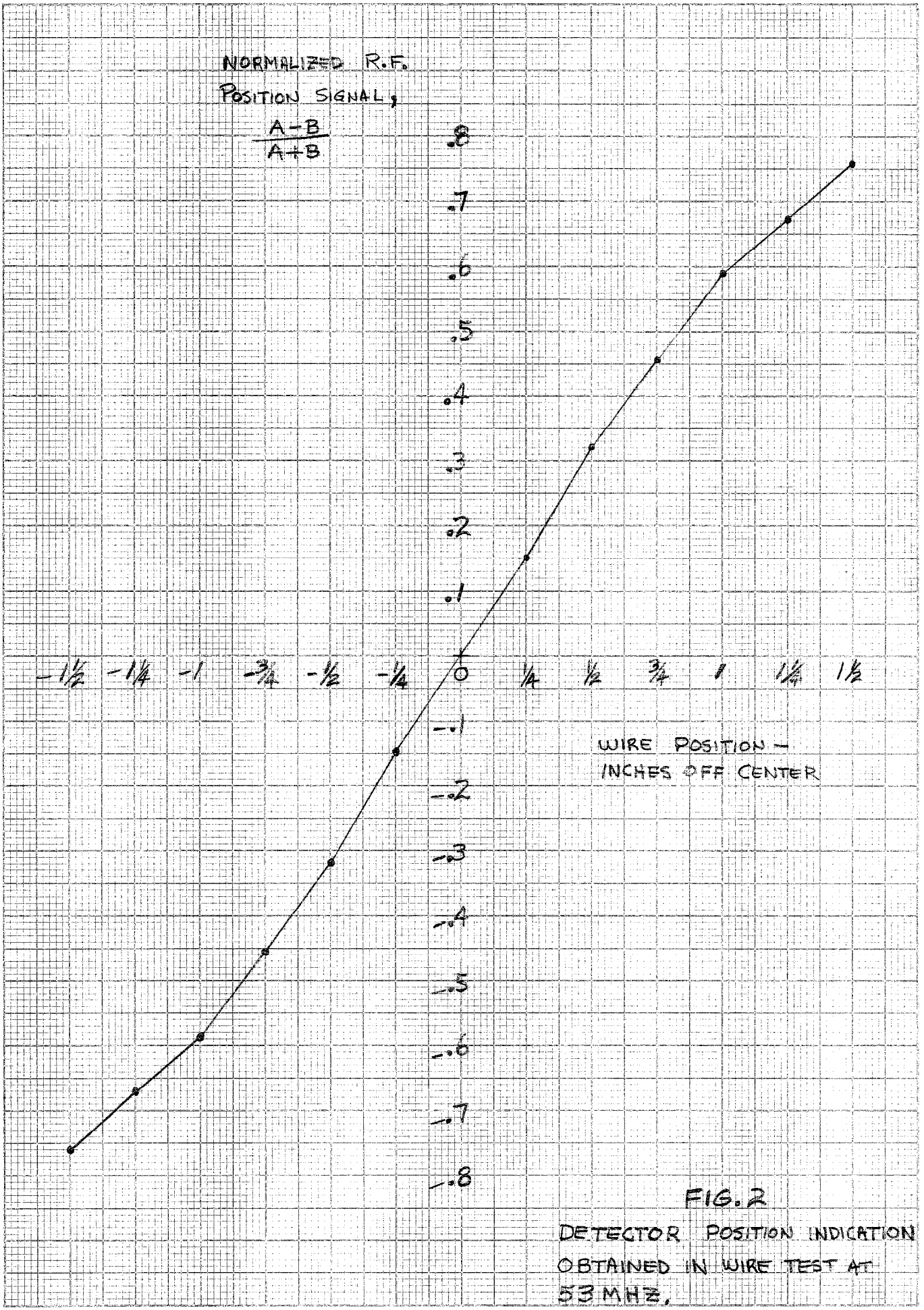


FIG. 2
DETECTOR POSITION INDICATION OBTAINED IN WIRE TEST AT 53 MHZ.

THE EFFECT OF ECCENTRICITY ON THE IMPEDANCE OF 7.000 mm (IDOC) 50 OHM AIR-FILLED COAXIAL LINE

FIG. 3

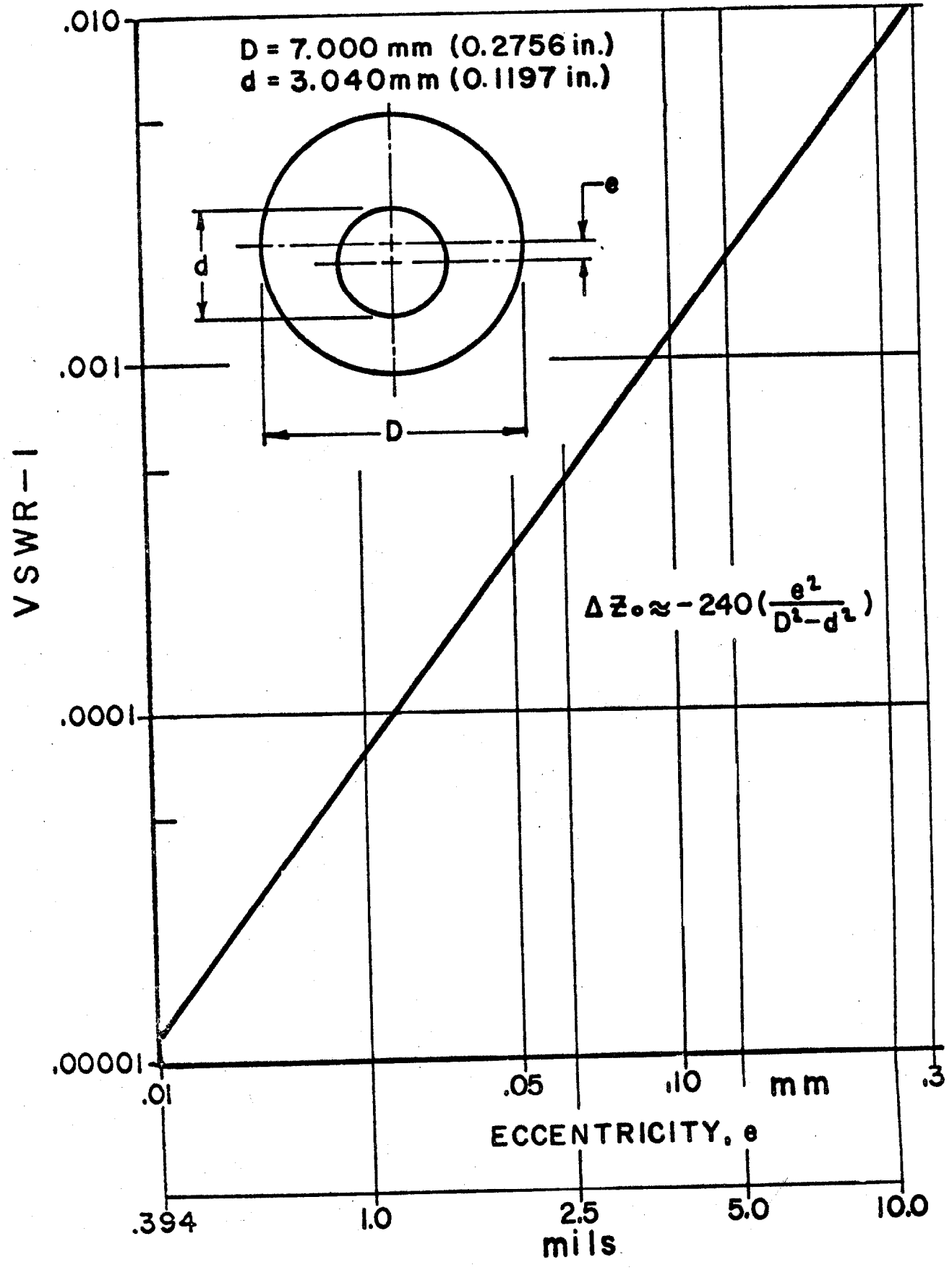
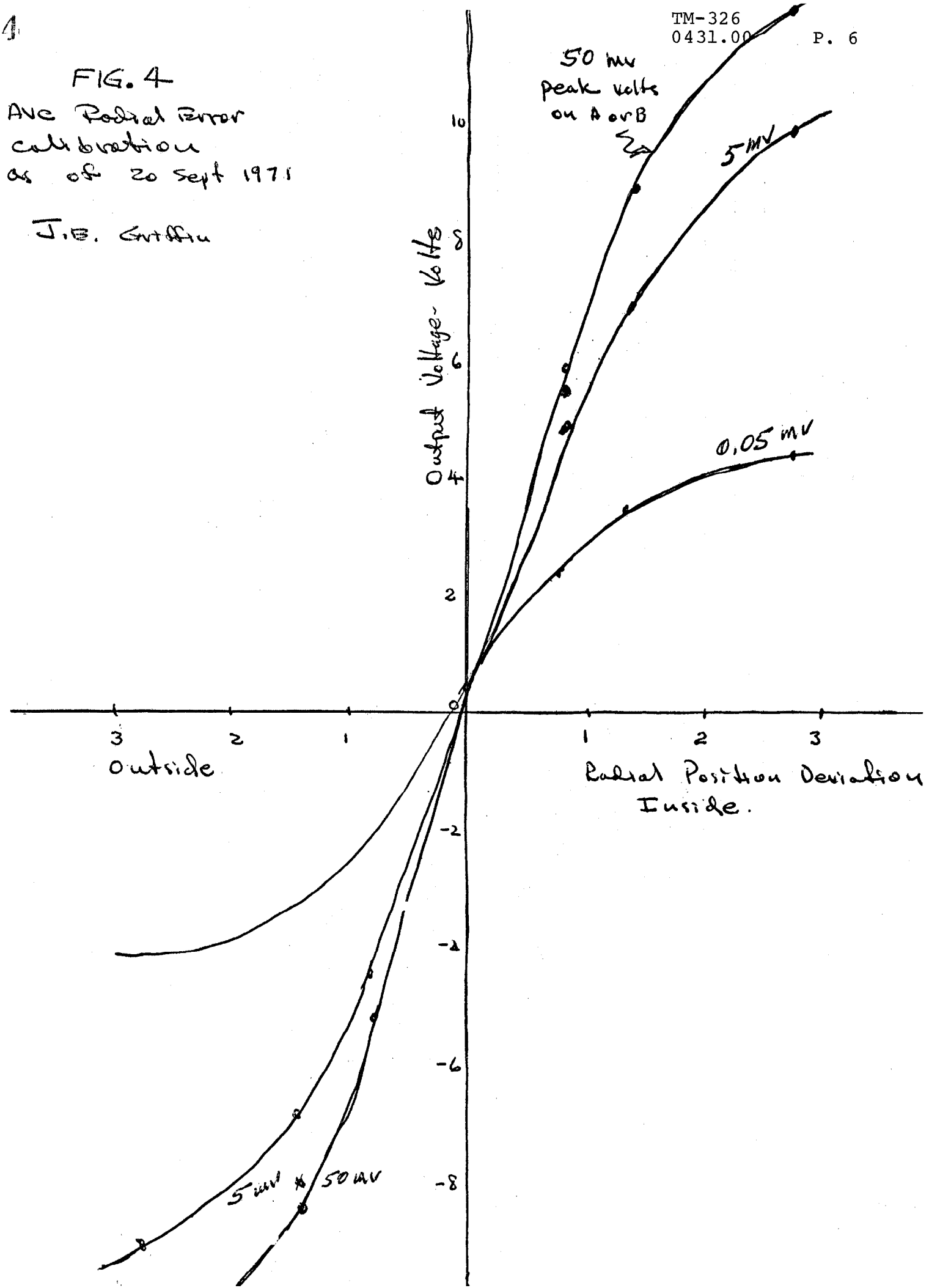


FIG. 4

ANC Radial Error
calibration
as of 20 Sept 1971

J.B. Griffin



1. Begovich, N. A., Margolin, A. R. - THEORETICAL AND EXPERIMENTAL STUDIES OF A STRIP TRANSMISSION LINE - Hughes Aircraft Co. - Internal Tech Memo 234 - May 12, 1950.

2. Hachmeister, C. A. - IMPEDANCE OF SOME TEM MODE TRANSMISSION LINES - Microwave Research Inst., Polytech Inst. Brooklyn- April 1950.

3. Southworth, G. C. - PRINCIPLES AND APPLICATIONS OF WAVEGUIDE TRANSMISSIONS - NY Van Nostrand - 1950 - 689p.

4. Feng, T. N. - DETERMINATION BY THE METHOD OF SUBAREAS OF THE PARAMETERS OF BROAD-BAND LINES AND CABLES COMPRISED OF STRIP, RECTANGULAR-TUBULAR OF CIRCULAR-TUBULAR CONDUCTORS - Doctor Diss, Univ. Wisc., 1951.

5. Sharpless, W. M. - ARTIFICIAL DIELECTRICS FOR MICROWAVES Proc. IRE 39: 1389-93 - Nov. 1951.

6. Zinke, O. - WAVE RESISTANCE, POWER VOLTAGE CURRENT FOR LONG TRANSMISSION LINES AND IN FREE SPACE (In German) - Funk Ton 5:225-38 - May 1951.

7. Assadourian, F., Rimai, E. - SIMPLIFIED THEORY OF MICROSTRIP TRANSMISSION SYSTEM - Proc. IRE 40:1651-7 - Dec. 1952 - Elec Cummun 30:36-45 - Mar. 1953.

8. Barrett, R. M. - ETCHED SHEETS SERVE AS MICROWAVE COMPONENTS - Electronics 25:114-8 - June 1952.

9. Grieg, D. D., Englemann, H. F. - MICROSTRIP - A NEW TRANSMISSION TECHNIQUE FOR THE KILOMEGACYCLE RANGE - Proc IRE 40-1644-50 - Dec. 1952.

10. Kostriza, J. A. - MICROSTRIP COMPONENTS - Proc. IRE 40:1658-63 Dec. 1952.

11. Lewin, L. - IMPEDANCE OF UNSYMMETRICAL STRIPS IN RECTANGULAR WAVEGUIDES - Proc. Inst. Elec. Engrs. London 4 99:168-76 - July 1952.

12. Reitan, D. K. - DETERMINATION OF THE CAPACITANCE OF CAPACITORS OF RECTANGULAR AND ANNULAR GEOMETRY BY THE METHOD OF SUBAREAS - Doctor Diss, Univ. Wisc. - 1952.

13. MANUFACTURE OF MICROSTRIP - Elec. Commun 29:251-9 Dec. 1952.

14. Arditi, M. - EXPERIMENTAL DETERMINATION OF THE PROPERTIES OF MICROSTRIP COMPONENTS - Inst. Radio Engrs. Conv. Rec. (10) 1:27-37 - 1953, Elec. Commun. 30:283-93 - Dec. 1953.

15. Barlow, H. M., Cullen, A. L. - SURFACE WAVES - Proc. Inst. Elec. Engrs. London 3 100:329-40 - Nov. 1953.

16. Englemann, H. F. - MICROSTRIP-A NEW MICROWAVE TRANSMISSION

TECHNIQUE - IRE Trans on Microwave Theory Tech. MTT1:22 - March 1953 - Abstract.

17. Keen, H. S. - PROGRESS REPT 2. - Airborne Instr. Lab., Inc., Sept. 1953 - AD79467 Study of Strip Transmission Lines and Surface Waves Using Stripline Techniques.

18. Oliner, A. A. - EFFECT OF THICKNESS ON THE CHARACTERISTIC IMPEDANCE OF STRIP TRANSMISSION LINE - Hughes Aircraft Co., July 31, 1953.

19. Schetzen, M. - STRIP TRANSMISSION SYSTEM - Mass. Inst. Technol. Research Lab. Electronics Quart. Progr. Rept. pt. XI Microwave Component, Oct. 15, 1953, p.55.

20. Schetzen, M. - THEORETICAL ANALYSIS OF A STRIP TRANSMISSION SYSTEM - Mass. Inst. Technol. Res. Lab. Electronics Quart. Progr. Rept. pt. XI - April 15, 1953, pg. 86.

21. Sciegienny, J. - STRIP ABOVE GROUND PLANE TRANSMISSION SYSTEM - Mass. Inst. Technol. Res. Lab. Electronics Quart. Rept. pt. X Microwave Component - Jan. 15, 1953 - p53-7

22. Sciegienny, J. - STRIP TRANSMISSION SYSTEMS - Mass. Inst. Technol. Research Lab. Electronics Quart. Rept. pt XI Microwave Component - April 15, 1956 - p83-6.

23. Sciegienny, J. - STRIP TRANSMISSION SYSTEMS - Mass. Inst. Technol. Research Lab. Electronics Quart. Prog. Rept. pt. XII Microwave Component, July 15, 1953 - p114.

24. Tischer, F. J. - LOW-LOSS MICROWAVE LINE (In German) Arch Elek Ubertragung 7:592-6 - Dec. 1953.

25. Birenbaum, L., Griemsmann, J. W. E., - STUDY OF BROADBAND MILLIMETER WAVEQUIDES AND COMPONENTS - Micro. Res. Inst. Polytech. Inst. Brooklyn Quart. Rept. 1 - April 1 - June 30, 1954 - AD48337.

26. Bittner, B. J. - PHOTETCHING TECHNIQUES FOR THE PRECISION FABRICATION OF WAVEGUIDE ANTENNA ARRAYS - In: Symp. on Microw., Strip Circuit - Oct 10-12, 1954 - Medford, Mass. 4p.

27. Black, K. G. - DETERMINATION OF THE PARAMETERS OF MICROSTRIP TRANSMISSION LINES - Doctor Diss, Univ. Wisc. - 1954

28. Cohn, S. B. - CHARACTERISTIC IMPEDANCE OF THE SHIELDED-STRIP TRANSMISSION LINE - Inst. Radio Engrs. Prof. Gp Microw. Theory Tech. Trans. MTT2:52-7 - July 1954.

29. Deschamps, G. A. - THEORETICAL ASPECTS OF MICROWAVE WAVE-GUIDES - Inst. Radio Engrs. Prof. Gp Micro. Theory Tech. Trans. MTT2:100-3 - April 1954.

30. Frost, A. D. - ELECTRICAL CHARACTERISTICS OF MICROWAVE STRIP-LINE COMPONENTS - Res. Lab. Phys. Electronics Tufts Univ. Int. Rept. 4 - Apr. 28, 1954 - AD67898.

31. Fubini, E. G., Fromm, W. E., Keen, H. S. - MICROWAVE APPLICATIONS OF HIGH-Q STRIP COMPONENTS - Inst. Radio Engrs. Conv. Rec. (8) 2:98-103 - 1954.

32. Fubini, E. G., Fromm, W. E., Keen, H. S., - NEW TECHNIQUES FOR HIGH-Q STRIP MICROWAVE COMPONENTS - Inst. Radio Engrs. Conv. Rec. (8) 2:91-7 - 1954.

33. Hayt, W. H. Jr., - STUDY OF RADIATION AND MUTUAL IMPEDANCE PROBLEMS IN STRIP TRANSMISSION LINES - Doctor Diss - Harvard Univ. - 1954.

34. McDonough, J. A., Malech, R. G. - STUDY OF PRINTED ANTENNAS - Airborne Instr. Inc. Quart. Prog. Rept. 2 Sept.-Nov. 1954 - AD64055.

35. Oliner, A. A. - RADIATION CONDUCTANCE OF A SERIES SLOT IN STRIP TRANSMISSION LINE - Inst. Radio Engrs. Conv. Rec. 2 (4): 89-90 - 1954.

36. Oliner, A. A. - THEORETICAL DEVELOPMENTS IN SYMMETRICAL STRIP TRANSMISSION LINE - In: Symp. on Mod. Adv. in Microw. Tech. - Polytech. Inst. Brooklyn - 1954 - 379-402.

37. Packard, K. S. - MACHINE METHODS MAKE STRIP TRANSMISSION LINE - Electronics 27-148-50 - Sept. 1954.

38. Pease, R. L. - CHARACTERISTIC IMPEDANCE OF STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS IN THE LOW IMPEDANCE REGION - Res. Lab. Phys. Electronics Tufts Univ. Int. Report 2 - Jan. 12, 1954 - AD67896.

39. Pease, R. L. - CHARACTERISTIC IMPEDANCE OF STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS IN THE HIGH IMPEDANCE REGION - Res. Lab. Electronics Tufts Univ. Int. Report 5 - May 10, 1954 - AD67899.

40. Pease, R. L. - CONDUCTOR HEATING LOSSES IN STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS IN THE LOW IMPEDANCE REGION - Res. Lab. Phys. Electronics Tufts Univ. Int. Report 3 - Mar. 10, 1954 - AD67897.

41. Pease, R. L. - CONDUCTOR HEATING LOSSES IN STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS - US Airforce Dept. AFCRC Tech. Note TN55-395 - Dec. 31, 1954.

42. Pease, R. L., Mingins, C. R. - APPROXIMATE UNIVERSAL FORMULA FOR CHARACTERISTIC IMPEDANCE OF STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS - Res. Lab. Phys. Electronics Tufts Univ. Int. Report 6 - Sept. 20, 1954 - AD57806.

43. Schetzen, M. - PRINTED MICROWAVE SYSTEMS - Mass. Inst. Technol. Res. Lab. Electronics Tech. Report 289:1-39 Sept. 30, 1954 - AD66376.

44. Torgow, E. N. - MICROWAVE STRIPLINE FILTER PROGRAM - Microw. Res. Inst. Polytech. Inst. Brooklyn Quart. Report 1, Jan. 1 - May 31, 1954 - AD41205.

45. Torgow, E. N., Griesmann, J. W. E., - STRIP LINE - Polytech. Inst. Brooklyn Report R-360-54 - PIB-294 - Feb. 1954.

46. Progress Report 6 - Airborne Instr. Lab., Inc. - Jan. 1954 AD140771.

47. Anderson, T. N. - PRACTICAL DIELECTRIC FILLED WAVE GUIDE - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:83-6 - Mar. 1955.

48. Arditi, M. - CHARACTERISTICS AND APPLICATION OF MICROSTRIP FOR MICROWAVE WIRING - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:31-56 - Mar. 1955.

49. Anisimov, E. V., Sovetov, N. M. - PROPAGATION OF ELECTROMAGNETIC WAVES ALONG A HELICAL STRIP IN A CIRCULAR WAVEGUIDE - (In Russian) Zh Tekh Fiz 25:1965-71 - Oct. 1955.

50. Barrett, R. M. - MICROWAVE PRINTED CIRCUIT - A HISTORICAL SURVEY - Inst. Radio Engrs. Trans. MTT3:1-9 - Mar. 1955.

51. Begovich, N. A. - CAPACITY AND CHARACTERISTIC IMPEDANCE OF STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT-3:127-33 - Mar. 1955.

52. Black, K. G., Higgins, T. J. - RIGOROUS DETERMINATION OF THE PARAMETERS OF MICROSTRIP TRANSMISSION LINES - Inst. Radio Engrs. Gp. Microw. Theory Tech. Trans. MTT3:93-113 Mar. 1955.

53. Bradley, E. H., White, D. R. J. - BAND-PASS FILTERS USING STRIPLINE TECHNIQUES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:163-9 - Mar. 1955 - Electronics 28:152-5 - May 1955.

54. Butler, Lt. J. E. - DESIGN OF STRIP TRANSMISSION LINE, SYSTEMS AND ANTENNAS - U.S. Naval Postgraduate School - Thesis 1955.

55. Carlson, E. - BROAD BAND MICROSTRIP CRYSTAL MIXER WITH INTEGRAL DC RETURN - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. MTT3:175-7 - Mar. 1955.

56. Clavin, A. - HIGH-POWER FERRITE LOAD ISOLATORS - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:38-43 - Oct. 1955.

57. Coale, F. S. - STRIP LINES - Sperry Eng. - Rev. 8:25-9 - July/Aug. 1955.

58. Coale, F. S. - STRIP LINE EXCITATION METHODS - Radio Telev. N Radio-Electronic Eng. Sect. 53-12 - Jan. 1955.

59. Cohn, S. B. - PROBLEMS IN STRIP TRANSMISSION LINES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:119-26 - Mar. 1955.

60. Cohn, S. B. - SHIELDED COUPLED-STRIP TRANSMISSION LINES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:29-38 - Oct. 1955.

61. Cooper, H. W., Ringenbach, M. E. - MEASUREMENT OF ATTENUATION AND PHASE VELOCITY OF VARIOUS LAMINATE MATERIALS AT L-BAND - IRE Trans. MTT3:87-92 - Mar. 1955.

62. Dahlman, B. A. - DOUBLE-GROUND-PLANE STRIP LINE SYSTEM FOR MICROWAVES - Instr. Elec. Engrs. Proc. (B) 102:488-92 July 1955 - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:52-7 - Oct. 1955.

63. Dukes, J. M. C. - CHARACTERISTIC IMPEDANCE OF AIR-SPACED STRIP TRANSMISSION LINE - Inst. Radio Engrs. Proc. 43:876 July 1955.

64. Fix, O. W. - BALANCED STRIPLINE ISOLATOR - Thesis, Air Force Inst. Tech. Wright-Patterson Air Force Base Report GE-55-3 - August 1955 - AD72804.

65. Fromm, W. E. - CHARACTERISTICS AND SOME APPLICATIONS OF STRIPLINE COMPONENTS - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:13-20 - Mar. 1955.

66. Frost, A. D., Mingins, C. R. - MICROWAVE STRIP CIRCUIT RESEARCH AT TUFTS COLLEGE - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:10-2 - Mar. 1955.

67. Fubini, E. G. - STRIPLINE RADIATORS - Inst. Radio Engineers Gp. Microw. Theory Tech. Trans. MTT3:149-56 Mar. 1955.

68. Hayt, W. H. Jr. - MUTUAL AND INPUT IMPEDANCE OF STRIPS BETWEEN PARALLEL PLANES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:114-8 - Mar. 1955.

69. Hayt, W. H. Jr. - POTENTIAL SOLUTION OF A HOMOGENOUS STRIpLINE OF FINITE WIDTH - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:16-8 - June 1955.

70. Keen, H. S. - STUDY OF STRIP TRANSMISSION LINES - Airborne Instr. Lab., Inc. Science Report, Dec. 1, 1955 - AD101733.

71. King, D. D. - PROPERTIES OF DIELECTRIC IMAGE LINE - Inst. Radio Engrs. Prof. Gp. Microw Theory Tech. Trans. MTT3:75-81, March 1955.

72. Kumagai, S., Kumagai, K. - FUNDAMENTAL CHARACTERISTICS OF THE MICROSTRIP TRANSMISSION - Osaka Univ. Technol. Report 5(163/187):271-88, 1955.

73. Michelson, M., Moore, H. F. - RESONATOR AND PRESELECTOR IN BALANCED STRIP LINE - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:170-4 - March 1955.

74. Mikaelian, A. L. - MAGNET-OPTICAL PHENOMENA IN RECTANGULAR WAVEGUIDES CONTAINING A FERRITE STRIP. (In Russian) Akad Nauk SSSR Izvest Otdel Tekh Nauk No. 3:139-49 - March 1955.

75. Oliner, A. A. - EQUIVALENT CIRCUITS FOR DISCONTINUITIES IN BALANCED STRIP TRANSMISSION LINE - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:134-43 - March 1955.

76. Oliner, A. A. - THEORETICAL DEVELOPMENTS IN SYMMETRICAL STRIP TRANSMISSION LINE - Proc. Symp. On Modern Advances Microwave Technique Polytech. Inst. Brooklyn 379-402 - July 1955.

77. Park, D. - PLANAR TRANSMISSION LINES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:8-12 - April 1955; 7-11 - Oct. 1955.

78. Pease, R. L. - CHARACTERISTIC IMPEDANCE OF STRIP TRANSMISSION LINES WITH PARALLEL THIN INNER CONDUCTORS - Res. Lab. Electronics Tufts Univ. Int. Report 9 - June 15, 1955 AD74087.

79. Pease, R. L. - POWER HANDLING CAPACITY OF STRIP TRANSMISSION LINES HAVING RECTANGULAR INNER CONDUCTORS WITH SEMI-CIRCULARLY ROUNDED EDGES - Res. Lab. Phys. Electronics Tufts Univ. Int. Report 8 - March 1, 1955 - AD74083.

80. Pease, R. L., Mingins, C. R. - UNIVERSAL APPROXIMATE FORMULA FOR CHARACTERISTIC IMPEDANCE OF STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:144-8 March 1955.

81. Primozich, F. G., Schatz, E. R., Woodford, J. B. - TAPERED STRIP TRANSMISSION LINE FOR PULSE TRANSFORMER SERVICE - Am. Inst. Elec. Engrs. Trans. (1)74:158-61 - 1955.

82. Ringenbach, M. E., Cooper, H. W. - MEASUREMENT OF ATTENUATION AND PHASE VELOCITY OF VARIOUS LAMINATE MATERIALS AT L-BAND - IRE Trans. MTT3:87-92 - Mar. 1955.

83. Sommers, D. J. - SLOT ARRAY EMPLOYING PHOTOETCHED TRI-PLATE TRANSMISSION LINES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:157-62 - March 1955.

84. Torgow, W. N., Griemsmann, J. W. E. - MINIATURE STRIP TRANSMISSION LINE FOR MICROWAVE APPLICATIONS - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:57-64 - Mar. 1955.

85. Torgow, E. N., Griemsmann, J. W. E. - MINIATURE STRIP TRANSMISSION LINE FOR MICROWAVE APPLICATIONS - Microw. Res. Inst. Polytech. Inst. Brooklyn - Feb. 4, 1955 - AD68546.

86. Wild, N. R. - PHOTOETCHED MICROWAVE TRANSMISSION LINES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:21-30 - Mar. 1955.

87. Zublin, K. E. - STRIP TYPE COMPONENTS FOR 2000 MEGACYCLE RECEIVER HEAD-END - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:65-74 - Mar. 1955.

88. SYMPOSIUM ON MICROWAVE STRIP CIRCUITS - Oct. 10-12 1954 - Medford, Mass - Antenna Lab. CRRDA Air Force Cambridge Res. Center, Res. Lab. Phys. Electronics Tufts College - 1954 - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT3:1-182 - Mar. 1955.

89. Bowness, C. - STRIP TRANSMISSION LINES - Electronic Eng. 28:2-7 - Jan. 1956.

90. Bradley, E. H. - DESIGN AND DEVELOPMENT OF STRIPLINE FILTERS Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT4:86-93 - April 1956.

91. Coale, F. S. - TRAVELING-WAVE DIRECTIONAL FILTER - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT4: 256-60 - Oct. 1956.

92. Cohn, S. B., Coale, F. S. - DIRECTIONAL CHANNEL - SEPARATION FILTERS - IRE (5):106-12 - 1956.

93. Coltum, L., Torgow, E. N. - DELAY CHARACTERISTICS OF BASIC STRIP TRANSMISSION LINE STRUCTURE - Microw. Res. Inst. Polytech. Inst. Brooklyn - Mar. 13, 1956

94. Dukes, J. M. C. - INVESTIGATION INTO SOME FUNDAMENTAL PROPERTIES OF STRIP TRANSMISSION LINES WITH THE AID OF AN ELECTROLYTIC TANK - Inst. Elec. Engrs. Proc. (B) 103:319-33 May 1956.

95. Fix, O. W. - A BALANCED STRIPLINE ISOLATOR - IRE NCR (5):99-105 - 1956

96. Frost, A. D. - EXPERIMENTAL AND THEORETICAL ASPECTS OF THE DESIGN OF MICROWAVE STRIP TRANSMISSION LINES - Res. Lab. Phys. Electronics Tufts Univ. Fin. Report Dec. 11, 1956 - AD111176.

97. Frost, A. D., McGoech, C. R., Mingins, C. R. - EXCITATION OF SURFACE WAVE-GUIDES AND RADIATING SLOTS BY STRIP-CIRCUIT TRANSMISSION LINES - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT4:218-222 - Oct. 1956.

98. Jones, E. M. T., Bolljahn, J. T. - COUPLED-STRIP-TRANSMISSION-LINE FILTERS AND DIRECTIONAL COUPLERS - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT4: 75-81 - April 1956.

99. Keen, H. S. - A STUDY OF STRIP TRANSMISSION LINES - Airborne Instr. Lab. Inc. Sci. Report 3 - Nov. 1955 - Oct. 31, 1956 - AD110153.

100. Keen, H. S. - THEORETICAL AND EXPERIMENTAL INVESTIGATION OF MICROWAVE PRINTED CIRCUITS - Airborne Instr. Lab. Inc. Nov. 1956 - PB131019 - AD110154.

101. Kumagia, S., Kumagia, N. - CAPACITANCE REACTANCE ELEMENT IN MICROSTRIP TRANSMISSION LINE (In Japanese) - Inst. Elec. Commun. Engrs. Jap. - J39:641-6 - July 1956.

102. Lippman, B. A. - TRANSMISSION LINE FORMULATION FOR SEMICONDUCTORS - Microw. Res. Inst. Polytech. Inst. Brooklyn Quart. Report 1, July 1 - Sept. 30 1956 - AD121526.

103. Papadopoulos, V. M. - SCATTERING BY A SEMI-INFINITE RESISTIVE STRIP OF DOMINANT-MODE PROPAGATION IN AN INFINITE RECTANGULAR WAVEGUIDE - Camb. Phil. Soc. Proc. 52:553-63 July 1956.

104. Park, D. - PLANAR TRANSMISSION LINES - IRE Trans MTT4:130 April 1956 - Correspondence.

105. Peters, R. W. - HANDBOOK OF TRI-PLATE MICROWAVE COMPONENTS Pub. Sanders Associates, Nashua, New Hampshire - 1956.

106. Purdom, L. - BAND-PASS STRIPLINE FILTER - Electronic Defense Lab. - Jan. 15, 1956 - AD83386.

107. Rabinowitz, M., Torgow, E. N. - DESIGN TECHNIQUES FOR BROAD BAND STRIP LINE - Microw Res. Inst. Polytech. Inst. Brooklyn - March 26, 1956 - AD97730.

108. Sherk, P. M., Cohn, S. B., Jones, E. M. T. - STRIP LINES AND COMPONENTS - Antenna Syst. Lab. Stanford Res. Inst. Quart, Prog. Report 5, Nov. 1, 1955 - Jan. 31, 1956 - AD101840.

109. Sherk, P. M., Cohn, S. B., Jones, E. M. T. - STRIP TRANSMISSION LINES AND COMPONENTS - Antenna Syst. Lab. Stanford Res. Inst. Quart. Prog. Report 6 - Feb. 1, April 30, 1956 - AD111959.

110. Spector, N. - EVALUATION OF POWER CAPACITY OF STRIP LINE Natl. Electronics Conf. 12:715-22 - 1956 - Sperry Eng. Rev. 9:22-6 - Sept./Oct. 1956.

111. Torgow, E. N. - MICROWAVE STRIP LINE PROGRAM - Microw Res. Inst. Polytech. Inst. Brooklyn Fin. Rept. - Apr. 2, 1956 AD97731.

112. Torgow, E. N. - MICROWAVE STRIP LINE FILTER PROGRAM - Microw. Res. Inst. Polytech. Inst. Brooklyn Addendum to Fin. Report - July 6, 1956 - AD97865.

113. Torgow, E. N. - MICROWAVE STRIP LINE FILTER PROGRAM - Polytech. Inst. Brooklyn Fin. Report R-476-56 - PIB-406 - March 1956.

114. Torgow, E. N., Griemsmann, J. W. E. - MINIATURE STRIP TRANSMISSION LINE AND TRANSMISSION LINE COMPONENTS - In: Electronic Component Symp. Proc. - Washington DC - May 1-3, 1956 - 94-101.

115. Van Patten, R. A. - DESIGN OF MICROWAVE LOW PASS FILTERS USING STRIPLINE TECHNIQUES - Rome Air Devel. Center - Oct. 1956 - AD97719.

116. Wu, T. T. - THEORY OF MICROSTRIP - Cruft Lab. Harvard Univ. - Oct. 10, 1956 - AD118572.

117. Yanai, H., Hamasaki, J. - DEGREE OF APPROXIMATION OF EQUIVALENT CIRCUITS FOR WAVE GUIDE FILTERS AND COAXIAL-TYPE FILTERS (In Japenese) - Inst. Elec. Commun. Engrs. Jap. J 39:871-7 - Oct. 1956.

118. Abeyta, L. - DESIGN TECHNIQUES FOR STRIP LINE DIRECTIONAL COUPLERS AND RESONATORS - Army Signal Eng. Lab., Fort Monmouth, N. J. - June 10, 1957 - AD146739.

119. Bawer, R., Kefalas, G. - MODIFIED EQUAL-ELEMENT BAND-PASS FILTER - Inst. Radio Engrs. Microw. Theory Tech. Trans. MTT5:175-6 - July 1957.

120. Browne, A. A. L. - RESONANT-CAVITY FILTER FOR THE S-BAND Proc. Inst. Elec. Engrs. London B 104:193-5 - 1957.

121. Cohn, S. B., Sherk, P. M. et al - STRIP TRANSMISSION LINES AND COMPONENTS - Antenna Syst. Lab. Stanford Res. Inst. Fin. Report - Feb. 1957 - AD145251.

122. Horgan, J. D. - COUPLED STRIP TRANSMISSION LINES WITH RECTANGULAR INNER CONDUCTORS - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT5:92-9 - April 1957.

123. KING, B. G., Dukes, J. M. C. - DISCUSSION ON INVESTIGATION INTO SOME FUNDAMENTAL PROPERTIES OF STRIP TRANSMISSION LINES AND THE AID OF AN ELECTROLYTIC TANK - Proc. Inst. Elec. Engrs. London B 104:72 - Jan. 1957.

124. Lewin, L. - RESONANCE ABSORPTION ISOLATOR IN MICROSTRIP FOR 4Gc/s - Proc. Inst. Elec. Engrs. London B 104 - Suppl. 6:364-5 - 1957.

125. Packard, K. S - OPTIMUM IMPEDANCE AND DIMENSIONS FOR STRIP TRANSMISSION LINE - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT5:244-7 - Oct. 1957.

126. Rascalar, H. G. - STRIP LINE HYBRID JUNCTION - Inst. Radio Engrs. Prof. Gp. Microw. Theory Tech. Trans. MTT5:23-30 - Jan. 1957.

127. Perini, H., Sferrazza, P. - RECTANGULAR WAVEGUIDE TO STRIP TRANSMISSION-LINE DIRECTIONAL COUPLERS - Inst. Radio Engrs. - WESCON Conv. Rec. 1(1):16-21 - 1957.

128. Shafer, C. G. - DOMINANT MODE OF THE MICROSTRIP TRANSMISSION LINE - Cruft Lab. Harvard Univ. - Nov. 25, 1957 AD152940.

129. Rotman, W., Karas, N. - THE SANDWICH WIRE ANTENNA A NEW TYPE OF MICROWAVE LINE SOURCE RADIATOR - Part 1 IRE NCR: 166-72 - 1957.

130. Shafer, C. G. - HIGHER MODE OF THE MICROSTRIP TRANSMISSION LINE - Cruft Lab. Harvard Univ. - Nov. 25, 1957 - AD152939.

131. Shimizu, J. K. - STRIP-LINE 3-DB DIRECTIONAL COUPLERS - Inst. Radio Engrs. WESCON Conv. Rec. (1)1:4-15 - 1957.

132. Shimizu, J. K. - STRIP-LINE 3-DB DIRECTIONAL COUPLERS - Stanford Res. Inst. Sci. Rept. - June 1957 - AD117286.

133. Van den Broek - MICROSTRIP TRANSMISSION LINES FOR HIGH FREQUENCY PRINTED CIRCUITS (In French) - L'Onde Elec. 37:190-3 - Feb. 1957.

134. Van Patten, R. A. - DESIGN OF IMPROVED MICROWAVE LOW-PASS FILTERS USING STRIP-LINE TECHNIQUES - Inst. Radio Engrs. Natl. Conv. Rec. (1)5:197-207 - 1957.

135. Wu, T. T. - THEORY OF THE MICROSTRIP - J Appl. Phys. 28:299-302 - Mar. 1957.

136. Yoshida, S. - MICROWAVE TRANSVERSE MAGNETIC TYPE UNDIRECTIONAL STRIP CIRCUITS (In Japanese) - Inst. Elec. Commun. Engrs. Jap J 40:30-3 - Jan. 1957.

137. PRINTED CIRCUIT DIRECTIONAL COUPLER - Electronic Radio Engr. 34:133-4 - April 1957.

138. SURFACE WAVE TRANSMISSION LINE - Prodelin Inc. Mo. Int. Devel. Report 6 - Jan. 1-31 1957 - AD114372.

139. Alstodter, D., Hauseman, E. O. Jr. - SOME NOTES ON STRIP TRANSMISSION LINE AND WAVEGUIDE MULTIPLEXERS - IRE Wescon Rec. Part 1:54-69 - 1958.

140. Anderson, J. C. - THE CALCULATION OF CHARACTERISTIC IMPEDANCE BY CONFORMAL TRANSFORMATION - J Brit. IRE Vol. 18:49-54 - Jan. 1958.

141. Badoyannis, G. M. - THE POWER HANDLING CAPACITY OF SLABLINES - IRE Conv. Rec. Part 1 35:38 - 1958.

142. Brodwin, M. E. - PROPAGATION IN FERRITE-FILLED MICROSTRIP IRE Trans. MTT6:150-55 - April 1958.

143. Cohn, Marvin - PROPAGATION IN A DIELECTRIC LOADED PARALLEL PLANE WAVE-GUIDE - Proc. IRE Vol. 46:1952-53 - Dec. 1958.

144. Cohn, S. B. - PARALLEL-COUPLED TRANSMISSION-LINE RESONATOR FILTERS - IRE Trans. MTT6-223-31 - April 1958.

145. De Buda, R. G. - A METHOD OF CALCULATING THE CHARACTERISTIC IMPEDANCE OF A STRIP TRANSMISSION LINE TO A GIVEN DEGREE OF ACCURACY - IRE Trans. MTT6:440-446 - Oct. 1958.

146. Duncan, B. J., Swern, L., Tomizasa, K. - MICROWAVE MAGNETIC FIELD IN DIELECTRIC LOADED COAXIAL CABLE - Proc. IRE Vol. 46:500-02 - Feb. 1958.

147. Fieri, D., Duncan, B. J. - RECIPROCAL FERRITE DEVICES IN TEM MODE TRANSMISSION LINES - IRE Trans. MTT6:91-96 - Jan. 1958.

148. Foster, K. - THE CHARACTERISTIC IMPEDANCE AND PHASE VELOCITY OF HIGH "Q" TRIPLATE LINE - J. Brit IRE Vol. 8:715-23 - Dec. 1958.

149. Jones, E. M. T., Cohn, S. B., Shimizu, J. K. - A WIDEBAND NONRECIPROCAL TEM TRANSMISSION LINE NETWORK - IRE Wescon Rec. Part 1:131-34 - 1958

150. King, B.G., McKenna, J., Raisbeck, G. - EXPERIMENTAL CHECK OF FORMULAS FOR CAPACITANCE OF SHIELDED BALANCED-PAIR TRANSMISSION LINE - Proc. IRE Vol. 46:922-23 - May 1958.

151. O'Meara, T. M., Sydnor, R.L. - A VERY-WIDE BAND BALUN TRANSFORMER FOR VHF AND UHF - Proc. IRE Vol. 46:1848-60 Nov. 1958.

152. Ozaki, H., Ishii, J. - SYNTHESIS OF A CLASS OF STRIP-LINE FILTERS - IRE Trans. CT:104-9 - June 1958.

153. Packard, K.S. - THE CUTOFF WAVELENGTH OF THE TROUGH WAVE GUIDE - IRE Trans. MTT6:455-6 - Oct. 1958.

154. Schiffman, B. M. - A NEW CLASS OF BROAD-BAND MICROWAVE 90-DEGREE PHASE SHIFTERS - IRE Trans. MTT6:232-37 - April 1958.

155. Shimizu, J. K., Jones, E. M. - COUPLED TRANSMISSION LINE DIRECTIONAL COUPLERS - IRE Trans. of MTT6:403-10 - 1958.

156. Hachemeister, C. A. - "THE IMPEDANCE AND FIELDS OF SOME TEM MODE TRANSMISSION LINE" - Poly. Tech. Inst. of Brooklyn - Res. Report R-623-57 PIB-551 - April 1958.

157. Rotman, W., Karos, N. - "SANDWICH-WIRE ANTENNA DESIGN" - AFCRC-TR-59-103 - ASTIA Doc. AD160764 - Dec. 1958.

158. Alstadter, D., Hauseman, E. O., Jr. - STRIP TRANSMISSION LINE CORPORATE FEED STRUCTURES FOR ANTENNA ARRAYS - IRE NCR (3)-113-125 - 1959.

159. Arams, F., Krayer, G., Okwit, S. - LOW LOSS S AND L BAND CIRCULATORS-IRE NCR - 126-133 - 1959.

160. Fleri, D., Hanley, G. - NONRECIPROCITY IN DIELECTRIC LOADED TEM MODE TRANSMISSION LINES - IRE Trans. MTT7: 23-27 - Jan. 1959.

161. Johnson, C. M. - FERRITE PHASE SHIFTER FOR THE UHF REGION IRE Trans. MTT7:28-31 - Jan. 1959.

162. Jones, E. M. T., Shimizu, J. K. - A WIDE BAND STRIP-LINE BALUN - IRE Trans. MTT7-128-34 - Jan. 1959.

163. Kurzrok, R. M. - SOME NOTES ON STRIP TRANSMISSION LINE AND WAVEGUIDE MULTIPLEXERS - IRE Trans. MTT7:475 - Oct. 1959.

164. Rotman, W., Karas, N. - PRINTED CIRUCIT RADIATORS THE SANDWICH WIRE ANTENNA - Microwave Journal 20-23 - Aug. 1959.

165. Wanselow, R. D., Tuttle, L. P. Jr. - PRACTICAL DESIGN OF STRIP-TRANSMISSION LINE HALF-WAVE LENGTH RESONATOR DIRECTIONAL FILTERS - IRE Trans. MTT7:168-73 - Jan. 1959.

166. Chait, H. N., Curry, T. R. - "Y CIRCULATOR" WAVEGUIDE Journal Applied Physics - Vol. 30: Sup. 1525-35 - April 1959.

167. Altschuler, H. M., Oliner, A. A. - DISCONTINUITIES IN THE CENTER CONDUCTOR OF SYMMETRICAL STRIP TRANSMISSION LINE - IRE MTT8:328-39 - May 1960.

168. Chen Tsung-Shan - DETERMINATION OF THE CAPACITANCE, INDUCTANCE AND CHARACTERISTIC IMPEDANCE OF RECTANGULAR LINES - IRE MTT8:510-19 - Sept. 1960.

169. Craven, J. H. - A NOVEL BROAD-BAND BALUN - IRE MTT8: 672-73 - Nov. 1960.

170. Frieberg, L. - LIGHTWEIGHT Y-JUNCTION STRIP-LINE CIRCULATOR - IRE MTT8:672 - Nov. 1960.

171. Davis, L. Jr. and etal - STRIP LINE L-BAND COMPACT CIRCULATOR - IRE Proc. Vol. 48 p115-16 - Jan. 1960.

172. Jones, E. M. T. - WAVE-BAND STRIP LINE MAGIC T - IRE MTT8:160-68 - March 1960.

173. Kaiser, J. A. - SPIRAL ANTENNAS - IRE Trans. AP-8 p312-323 - May 1960.

174. King, R., Harrison, C. W., Denton, D. H. Jr. - TRANSMISSION LINE MISSILE ANTENNA - IRE Trans. AP8 p88-90 Jan. 1960.

175. Matthaei, G. L. - DESIGN OF WIDE-BAND (AND NARROW-BAND) BAND-PASS MICROWAVE FILTERS ON THE INSERTION LOSS BASIS IRE MTT8:580-93 - Nov. 1960.

176. Milano, U., Saunders, J. H., Davis, L. Jr. - A Y-JUNCTION STRIP-LINE CIRCULATOR - IRE MTT8:346-51 - May 1960.

177. Robinson, S. J. - BROAD-BAND HYBRID JUNCTIONS - IRE MTT8:671-72 - Nov. 1960.

178. Yoshida, S. - "STRIP LINE Y CIRCULATOR" - IRE Proc. Vol. 48 p1337-8 July 1960.

179. Yoshida, S. - J-BAND STRIP-LINE Y CIRCULATOR - IRE Proc. Vol. 48 p1664 - Sept. 1960.

180. Duehler, G. V., Eikenberg, A. F. - STRIP LINE Y-CIRCULATORS FOR THE 100 TO 400 MC REGION - IRE Proc. Vol. 49 p518-19 - Feb. 1961.

181. Fraisse, H. J. - A DIRECTIONAL COUPLER FOR UHF - FREQUENCY Vol. 15 pp341-344 - Nov. 1961.

182. Getsinger, W. J. - A COUPLED STRIP-LINE CONFIGURATION USING PRINTED-CIRCUIT CONSTRUCTION THAT ALLOWS VERY CLOSE COUPLING - Trans. Microwave Theory and Tech. Vol. MTT-9 p535 - Nov. 1961.

183. Sukhov, V. A. - THE CHARACTERISTIC IMPEDANCE AND ATTENUATION OF TEM WAVES PROPAGATED ALONG A MULTICONDUCTOR LINE OF RECTANGULAR CONDUCTORS (In Russian) - Radiotekhnika i electronika (USSR) Vol. 6, No. 5 820-4-May 1961.

184. Tatsuguchi, I. - UHF STRIP TRANSMISSION LINE HYBRID JUNCTION - IRE Trans. MTT9:3-6 - Jan. 1961.

185. Rutz, E. M. - A STRIPLINE FREQUENCY TRANSLATOR IRE Trans. of MTT-9:158-61 - March 1961.

186. Altschuler, H. M., Oliner, A. A. - ADDENDUM TO "DISCONTINUITIES IN THE CENTER CONDUCTOR OF SYMMETRIC STRIP TRANSMISSION LINE" - MTT-10 0143 - Correspondence - March 1962.

187. Bolljahn, J. T., Mattaei, G. L. - A STUDY OF THE PHASE AND FILTER PROPERTIES OF ARRAYS OF PARALLEL CONDUCTORS BETWEEN GROUND PLANES - Proc. IRE Vol. 50 p299-311 - March 1962.

188. Cohn, S. B. - NEW THOUGHTS ON STRIP LINE - Microwave Journal Vol. 5 #7 pp13-18 - July 1962.

189. Franco, A. G., Oliner, A. A. - SYMMETRIC STRIP TRANSMISSION LINE TEE JUNCTION - Vol. MTT-10 - p118 - March 1962.

190. Getsinger, W. J. - COUPLED RECTANGULAR BARS BETWEEN PARALLEL PLATES - Trans. Microwave Theory and Tech. MTT-10 - p65 - Jan. 1962.

191. Kotsebue, K. L. - FREQUENCY-SELECTING LIMITING IN YIG FILTERS - Journal Appl. Phys. Vol. 33 p747 - Feb. 1962.

192. Kun-Mu Chen - "SANDWICH-WIRE ANTENNA" - IRE Trans. Antennas and Propagation Vol. AP-10 - p159 - March 1962.

193. Mattaei, G. L. - INTERDIGITAL, BAND-PASS FILTERS - PGMTT National Symposium - 1962.

194. Oh, L. L., Lunden, C. D. - VHF SLOW-WAVE SLOTTED LINE MTT-10 - p142 Correspondence - March 1962.

195. Sharp, E. D., Jones, E. M. T. - AN ANTENNA ARRAY OF LONGITUDINALLY - SLOTTED DIELECTRIC-LOADED WAVEGUIDES IRE Trans. on Antennas and Propagation - Vol. AP-10 - p179 - March 1962.

196. Shahan, Craig - MINIATURESTRIP-LINE TO WAVEGUIDE SLOW ADAPTER COLINEAR - Trans. Microwave Theory and Tech. - Vol. MTT-10 Correspondence p142 - March 1962.

197. Womack, C. P. - THE USE OF EXPONENTIAL TRANSMISSION LINES IN MICROWAVE COMPONENTS - MTT-10 - p124 - March 1962.

198. Suematsu, Y., Muratani, T. - EXPERIMENTS ON A QUARTER-WAVE COUPLED THREE ESAKI DIODES MICROWAVE AMPLIFIER - Proc. of IRE - Correspondence p1696 Vol. 50 - July 1962.

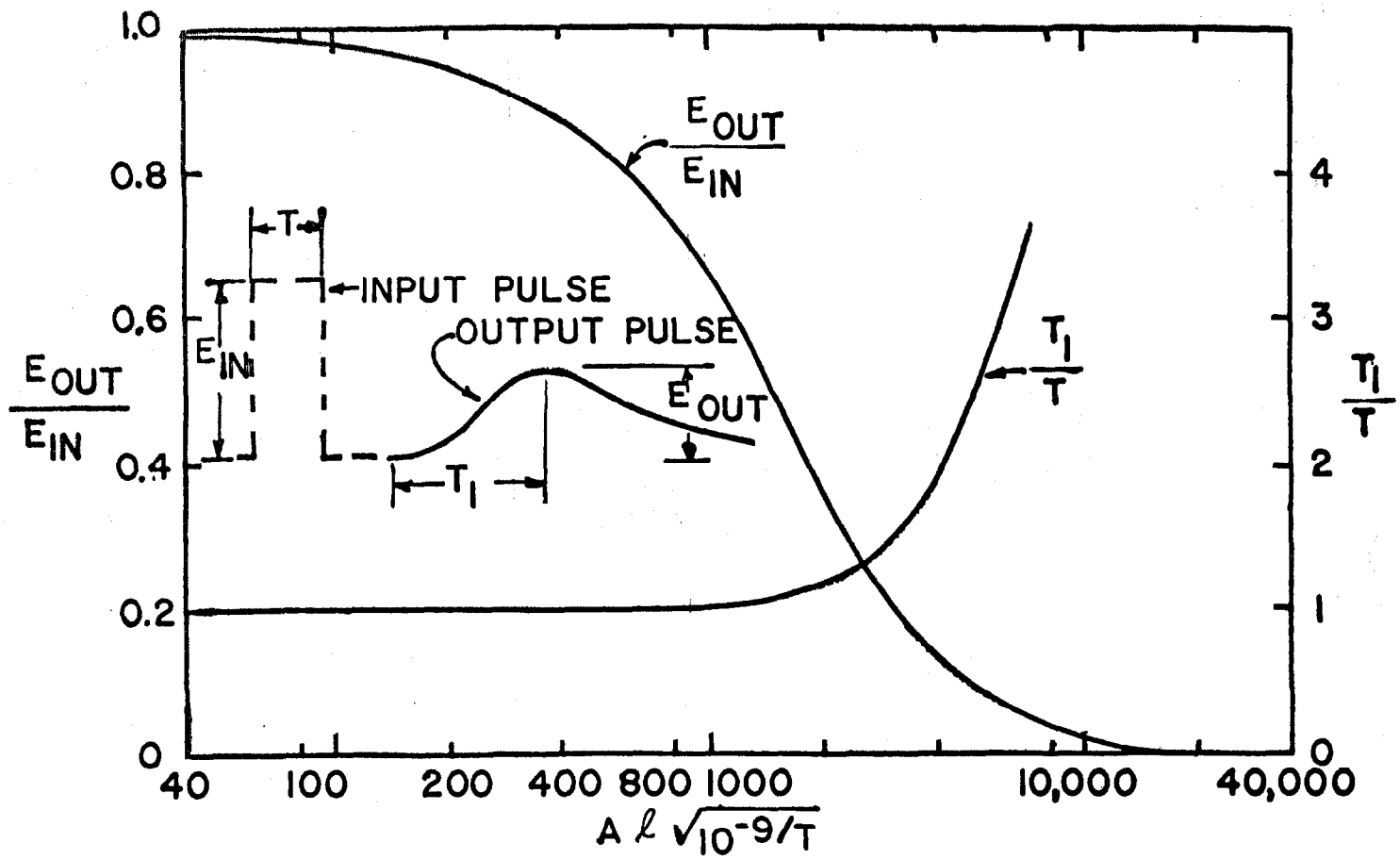
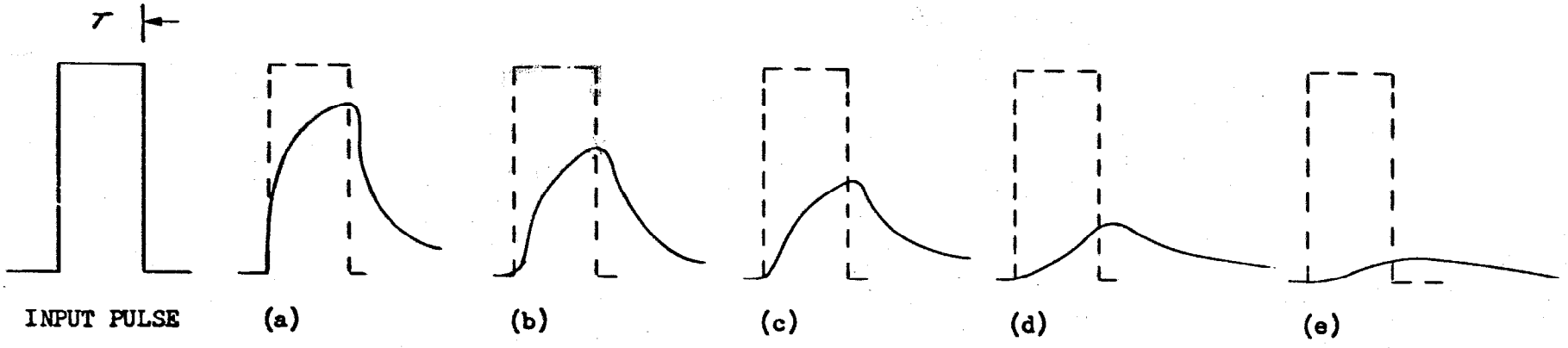


Fig. 5

The time-stretching and amplitude-reduction of an originally rectangular pulse plotted as a function of A, the attenuation of the cable at 1000 mc in db/100 ft.; ℓ, the length in feet; and T, the duration of the input pulse in seconds. Attenuation figures may be obtained from CC 2-2B. As an example, for RG63, A is 7 db/100 ft. Thus if T were 10^{-9} sec, and ℓ were 100 feet, the chart should be entered at an abcissa of 700.



For T = 10^{-9} sec., the output pulse will have the shape and amplitude shown for the following cable lengths.

CABLE TYPE	(a)	(b)	(c)	(d)	(e)
RG174	23	41	67	90	110
RG58	30	56	93	136	156
RG8	77	145	240	350	400
RG63	95	180	290	430	500
2"Styrofoam	1200	2300	3700	5500	6400
C3T	90	170	280	400	470
RG114	37	70	110	170	200
RGUCL 55B/U	39	73	118	174	203
YK198	46	88	142	211	245

Fig. 6

The above waveforms show the deterioration of an originally rectangular pulse as it travels along a transmission line for which the decibel attenuation varies as the square root of frequency. For comparison purposes, the input pulse is also shown with each output waveform. The figures listed above give the cable lengths that will cause the distortion shown when T= 10^{-9} second. To find the cable lengths for which the output pulse will have the same form relative to the input pulse for other input pulse durations, multiply the above lengths by T, where T is the input pulse duration in millimicroseconds.