Triplate Directional Couplers

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(Translated by F6HYE)

Abstract

This article presents the constitution, determination and performances of triplate directional couplers. Such couplers permit measurements, monitoring and sampling of forward or reverse power on the main transmission line.

This study applies to low coupling (Coupling loss >15dB) couplers for use as reflectometers in the UHF and SHF bands.

Kurzfassung

Der Artikel beschreibt die Wirkungsweise und Konstruktion von Stripline-Richtkopplern. Diese Koppler sind einsetzbar fuer die richtungsselektive Messung von Leistung auf Koaxial-Leitungen. Es werden Koppler mit niedrigen Koppelfaktor (< -15 dB) beschrieben, die als Reflektometer auf den SHF-Baendern eingesetzt werden koennen.

1. Theory of Triplate Couplers

The triplate structure is constituted of microstrip lines between two equidistant groundplanes separated with dielectric. The propagation mode is TEM and ($\lambda_G = \lambda\sqrt{\varepsilon_R}$). Characteristic impedance computation uses special techniques involving first order elliptical functions, but one can find charts giving Zo vs W/b for some thicknesses t (See Appendix C).

The triplate structure provides a very good shielding against strong fields but the presence of dielectric near the lines dictates that the dielectric must be a very good one.. (i.e .PTFE or better). Transitions between triplate lines and coax needs a special connector, but a carefully designed semirigid cable can also do the job.

A directional coupler is constituted of two lines, width W, length L separated by s. Access to the four ports is made by taperised lines.

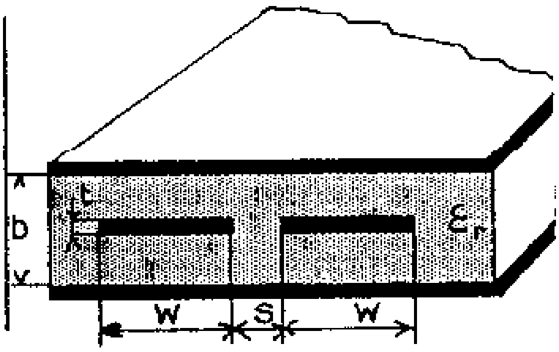
1. Theorie

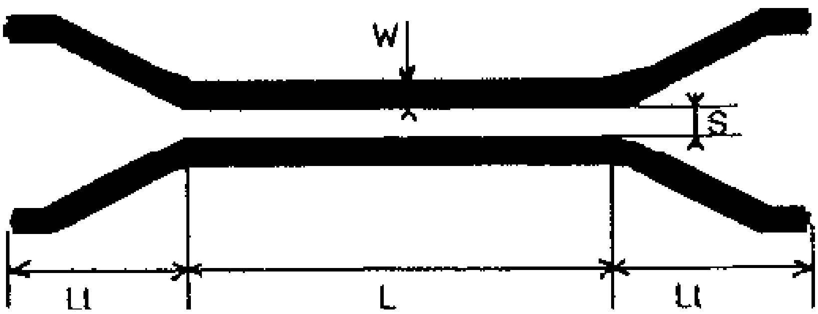
Die Koppler sind als Stripline in einem Dielektrikum zwischen zwei Masseflaechen ausgebildet. Der Ausbreitungsmodus ist TEM mit einer Wellenlaenge von $\lambda_G = \lambda\sqrt{\varepsilon_R}$. Um den Wellenwiderstand solcher Leitungen zu bestimmen kann man die Nomogramme in Anhang C benutzen.

Die Stripline-Struktur hat eine gute Schirmung der Felder im Gegensatz zur Micro-Stripline, die nur eine Masseflaeche hat, zur Folge. Das Dielektrikum muss einen geringen Verlustfaktor aufweisen. Zum Uebergang auf Koaxial-Leitung sind spezielle Buchsen erforderlich.

Die Laenge der gekoppelten Leitungen wird meistens zu $L = \lambda_G/4$ gewaehlt, da dann die Spannung ein erstes Maximum hat. Bei einem Breitband-Koppler nimmt man das geometrische Mittel der Grenzfrequenzen als Mittenfrequenz. Im Folgenden sind der Aufbau eines Kopplers (Bild 1) und die Gleichungen fuer die Bestimmung der Abmessungen zu erkennen. Wem die Gleichungen zu kompliziert sind (Vielleicht macht jemand ein kleines Programm?), kann auch die Nomogramme im Anhang A bzw. B benutzen.

Figure 1/Bild 1: Triplate Coupler





The coupling length L of the two lines depends on the desired frequency range. The voltage given by one line is maximum for $L = \lambda_G/4$. The effective coupling length is slightly greater than L due to the taperisation lines.

Dimensioning the coupler:

If k is the coupling attenuation let's define:

Z_{oe}: even mode impedance (ie: impedance of one of the two lines when both carry equal currents in the same direction).

Z_{oo}: odd mode impedance (ie: impedance of one of the two lines when both carry the same current but in opposite directions).

Z_c is 50 ohms (for lines and terminations).

It holds:

$$Z_{oe} = Z_c\sqrt{\frac{1+k}{1-k}} \qquad [1]$$

$$Z_{oo} = Z_c\sqrt{\frac{1-k}{1+k}} \qquad [2]$$

One can obtain W/b and S/b either from charts or from computation. For people with good pocket computers or PCs the following equations are given:

$$x_e = Z_{oe}\frac{\sqrt{\varepsilon_r}}{30\pi}$$

For $1 \le x_e \le \infty$:

$$k_e = \sqrt{1-\left[\frac{e^{\pi x_e}-2}{e^{\pi x_e}+2}\right]^4}$$

For $0 < x_e < 1$:

$$k_e = \left[\frac{e^{\frac{\pi}{x_e}}-2}{e^{\frac{\pi}{x_e}}+2}\right]^2$$

In an analog way:

$$x_o = Z_{oo}\frac{\sqrt{\varepsilon_r}}{30\pi}$$

For $1 \le x_o \le \infty$:

$$k_o = \sqrt{1-\left[\frac{e^{\pi x_o}-2}{e^{\pi x_o}+2}\right]^4}$$

For $0 \le x_o < 1$:

$$k_o = \left[\frac{e^{\frac{\pi}{x_o}}-2}{e^{\frac{\pi}{x_o}}+2}\right]^2$$

With these definitions it follows:

$$W/b = \tanh^{-1}\left[\sqrt{k_e k_o}\right] \qquad [3]$$

and

$$S/b = \tanh^{-1}\left[\frac{1-k_o}{1-k_e}\sqrt{k_e k_o}\right] \qquad [4]$$

The solution for the non mathematical minded amateur can be found from Appendix A and B.

2. Author's Prototype

For the author's prototype the following coupling ratios have been measured:

Coupling [dB]	Frequency [MHz]
-32dB	432
-25dB	1296
-22dB	2320
-23dB	5760
-22dB	10368

Constructional details:

L = 20 mm

W = 2.5mm

S = 1.2mm

b = 3.05mm (we use 2 pcb's Er=2.55 1.6mm front to front).

Taperised lines on 10 to 15mm.

Connectors SMA R 125 541.

Both ground planes soldered together with copper foil.

Terminations SMA R 404 212 1W 0-18GHz 50 Ohms.

Detector HP8470B 0.1-18GHz.

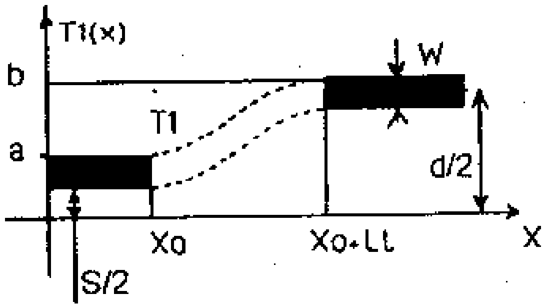
Fuer den Prototypen wurden die obigen Werte gemessen.

3. Exact computation of the taperisations.

Transition between coupled zones and output ports must be without any characteristic impedance modification.

In order to achieve this, spacing S in the coupled zone is increased to spacing d at the output ports. Spacing variation vs distance law must be continuous and also the first derivative.

$$T_1(x) = a + (b-a)\sin^2\left[\frac{(X-X_0)\pi}{2L_t}\right]$$



W is constant in the range from X_0 to X_0+L_t.

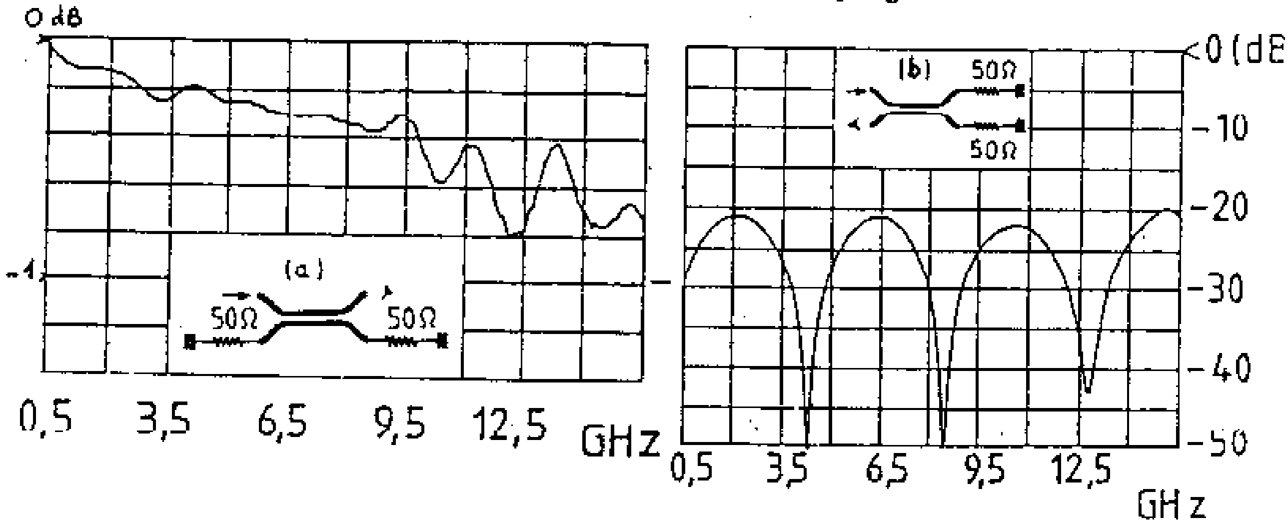
3. Exakte Berechnung der Uebergangszone

Um die Anschluss-Ports zu verbinden, muss sich der Abstand der gekoppelten Leitungen in kontrollierter Weise ohne Impedanzaenderungen vergroessern. Das wird durch ein "Tapering" erreicht, wie es im obigen Bild dargestellt und durch die Gleichung definiert wird.

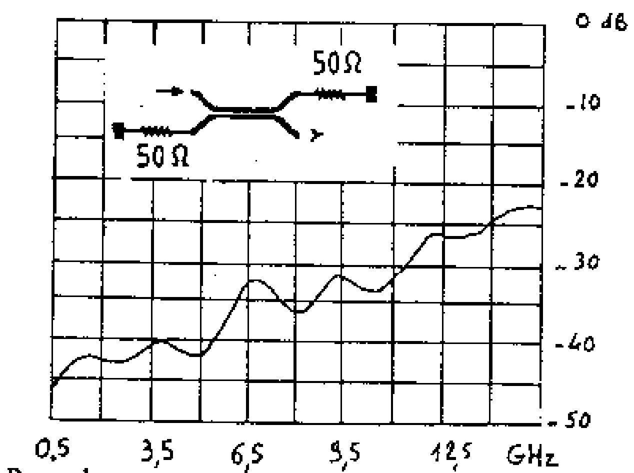
4. Measured Results

The following results have been measured:

Figure 2/Bild 2: Insertion Loss, Forward Coupling, Reverse Coupling



Couplage inverse



Remarks:

- Insertion loss show a dissipative component and some parasitic resonances owing to the impedance desadaptation. The distance between two peaks gives the total strip length.
- The direct coupling periodicity gives the possibility to get the effective coupling length.
- The inverse coupling lowering vs frequency is generated by impedances mismatches and parasitic coupling on the taperisation lines, taking in account the physical dimensions of the lines vs guided signal wavelength. (5 mm microstrip equals a quarter wave on 3 cm with this substrate).

4. Gemessene Werte

Bild 2 zeigt die Resultate. Die Einfuegungsdaempfung zeigt eine Verlustkomponente, die von Resonanzen, die durch Impedanzspruenge verursacht werden, ueberlagert sind. Die Abnahme der Richtschaerfe (Reverse Coupling - Forward Coupling) wird durch parasitaere Kopplungen verursacht.

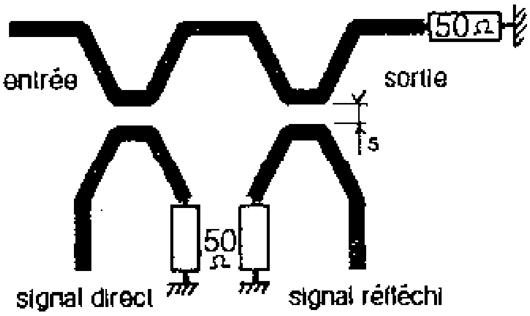
5. Coupler for the SHF-Bands

For this specific device, L is computed to give a coupler usable on 6 and 3 cm with a 23 dB coupling figure.

The substrate is 1.6mm ptfe with ε_r = 2.55. The two coupling zones must be very identical, so drawing are made at 4:1 scale and later photo-reduced to the 1:1 scale.

In order to lower the side effects, the distance between the lines and the board side must be at least 10 times the line width. On the border of the PCB, both ground planes are soldered together with copper foil.

Figure 3/Bild 3: SHF Dual Directional Coupler



Performance:

Insertion loss	0.21dB @ 6cm	0.5dB @ 3cm
Direct coupling	24dB @ 6cm	25dB @ 3cm
Reverse coupling	44dB @ 6cm	45dB @ 3cm.

The coupler is giving a 20 dB directivity (probably greater because the measurements were made very near the noise level -see curve- the drive level was too low).

Dissymmetry produces an error on forward coupling of less than 1dB. A parasitic resonance can be seen in the vicinity of 3.5GHz??

With a good detector, one can measure with as low as 10mW on the main line.

This kind of coupler can be used as a reflectometer but also to split an LO power between two mixers (TX and RX) at different injection levels (even if low coupling theory is not respected).

5. SHF-Koppler

Fuer diesen Koppler wurde die Laenge so gewaehlt, dass eine Koppeldaempfung von 23 dB erreicht wird und die Richtschaerfe befriedigend auf dem 6 cm und 3 cm Amateurband ist (> 20 dB).

Das Substrat ist aus 1,6 mm dickem Teflon-Material mit einem ε_r = 2,55. Um die Koppelzonen exakt zu definieren wird das Layout im Masstab 4:1 gezeichnet. Der Abstand zwischen den Leitungen und den Raendern ist 10 mal so gross wie die Breite der Leitungen. Die Raender werden mit Kupferfolie durchkontaktiert.

Die folgenden Abbildungen zeigen die gemessenen Werte der Einfuegungsdaempfung, des Koppelfaktors (Forward Coupling) und der Isolation (Reverse Coupling). Die Richtschaerfe, d.h. Isolation - Koppelfaktor, betraegt ca. 20 dB.

Measured Performance of SHF-Coupler

Figure 4/Bild 4: Insertion Loss

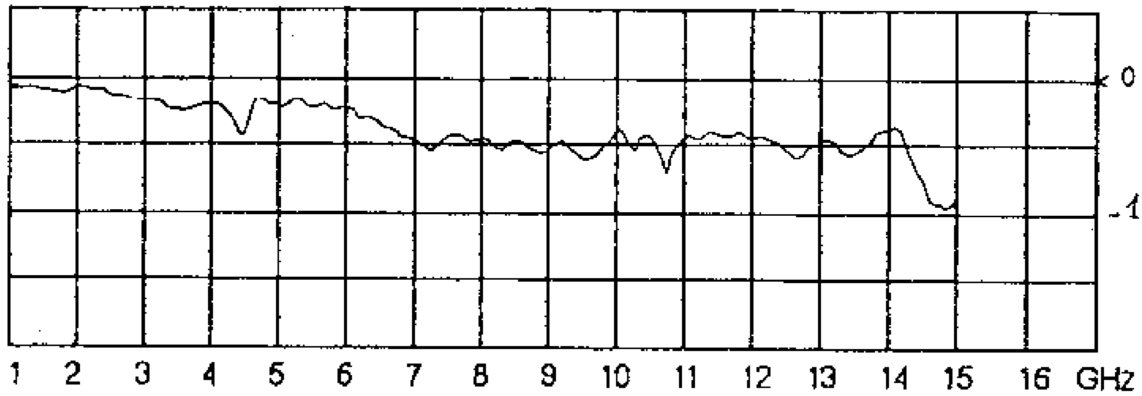


Figure 5/Bild 5: Forward Coupling

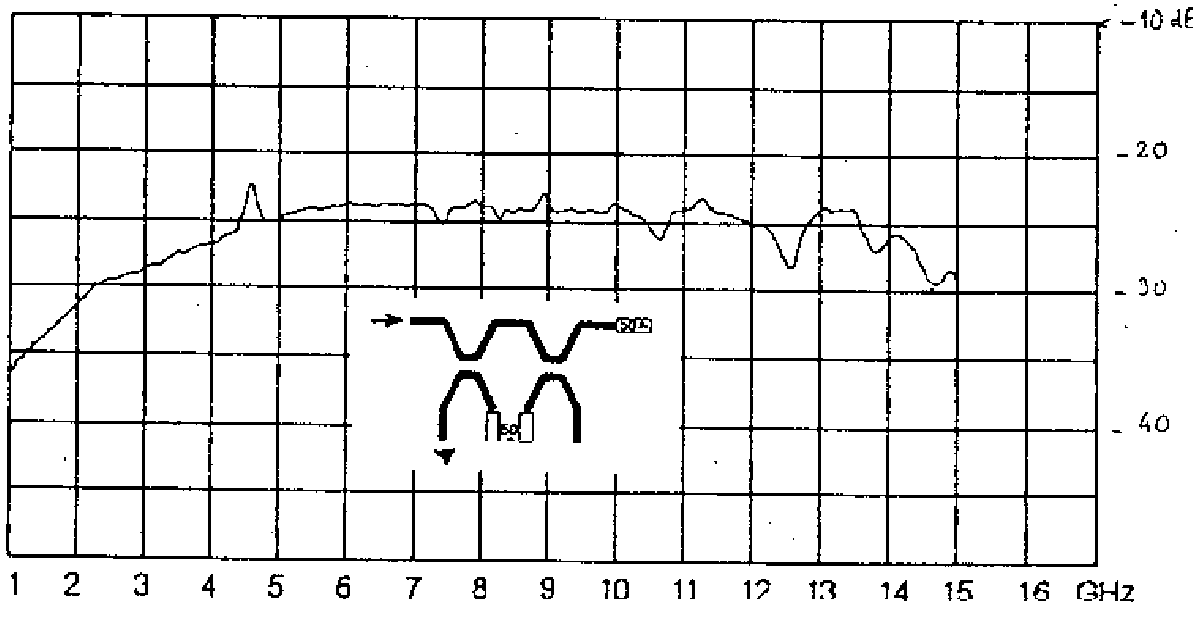
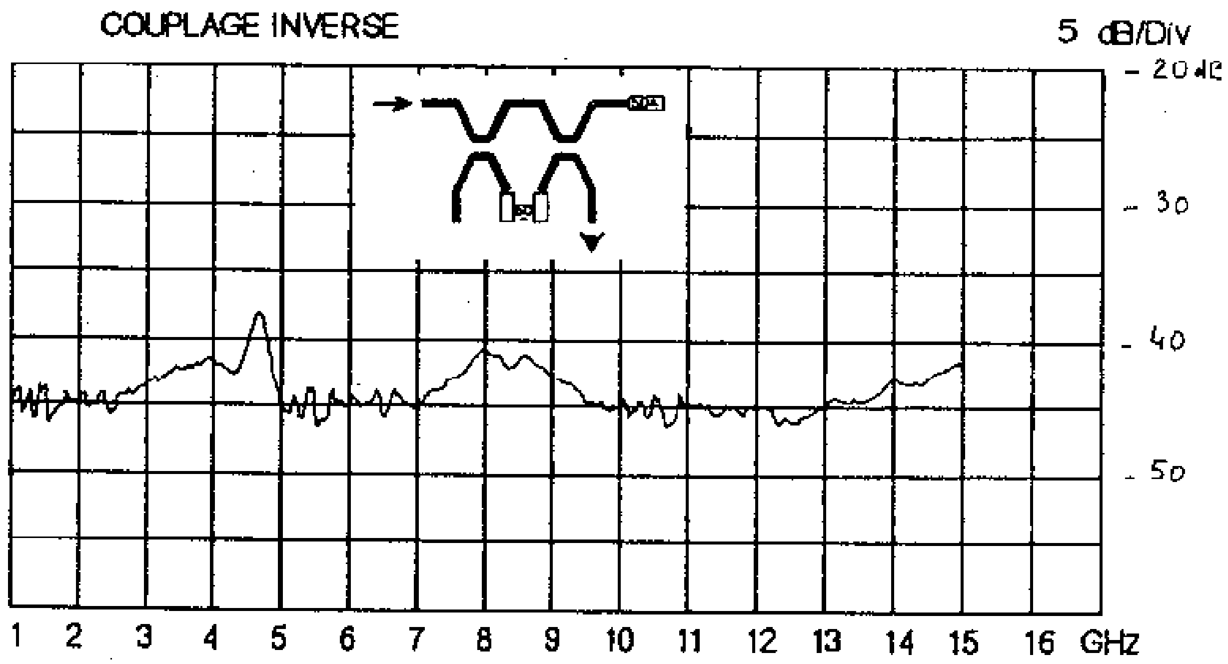
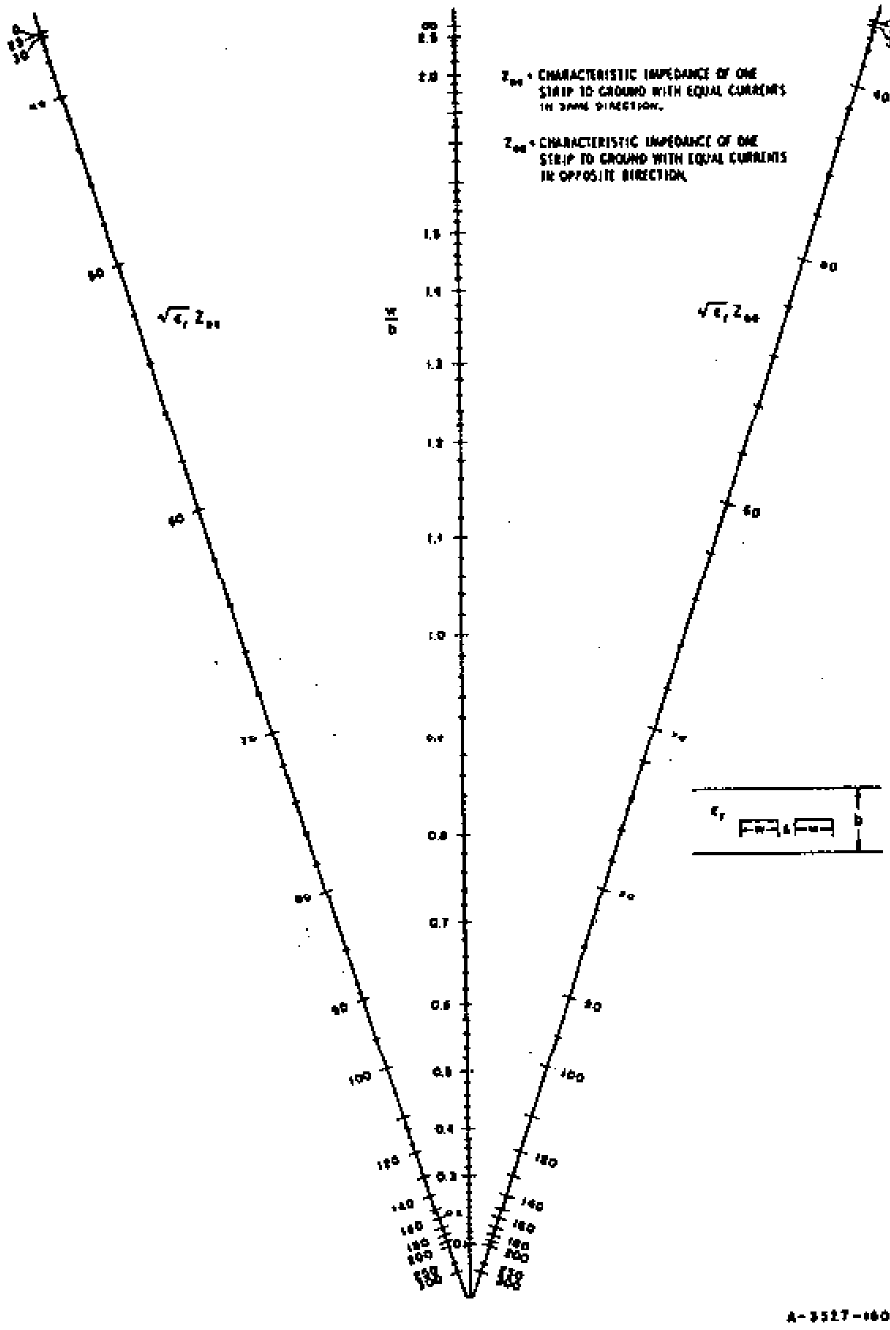


Figure 6/Bild 6: Reverse Coupling



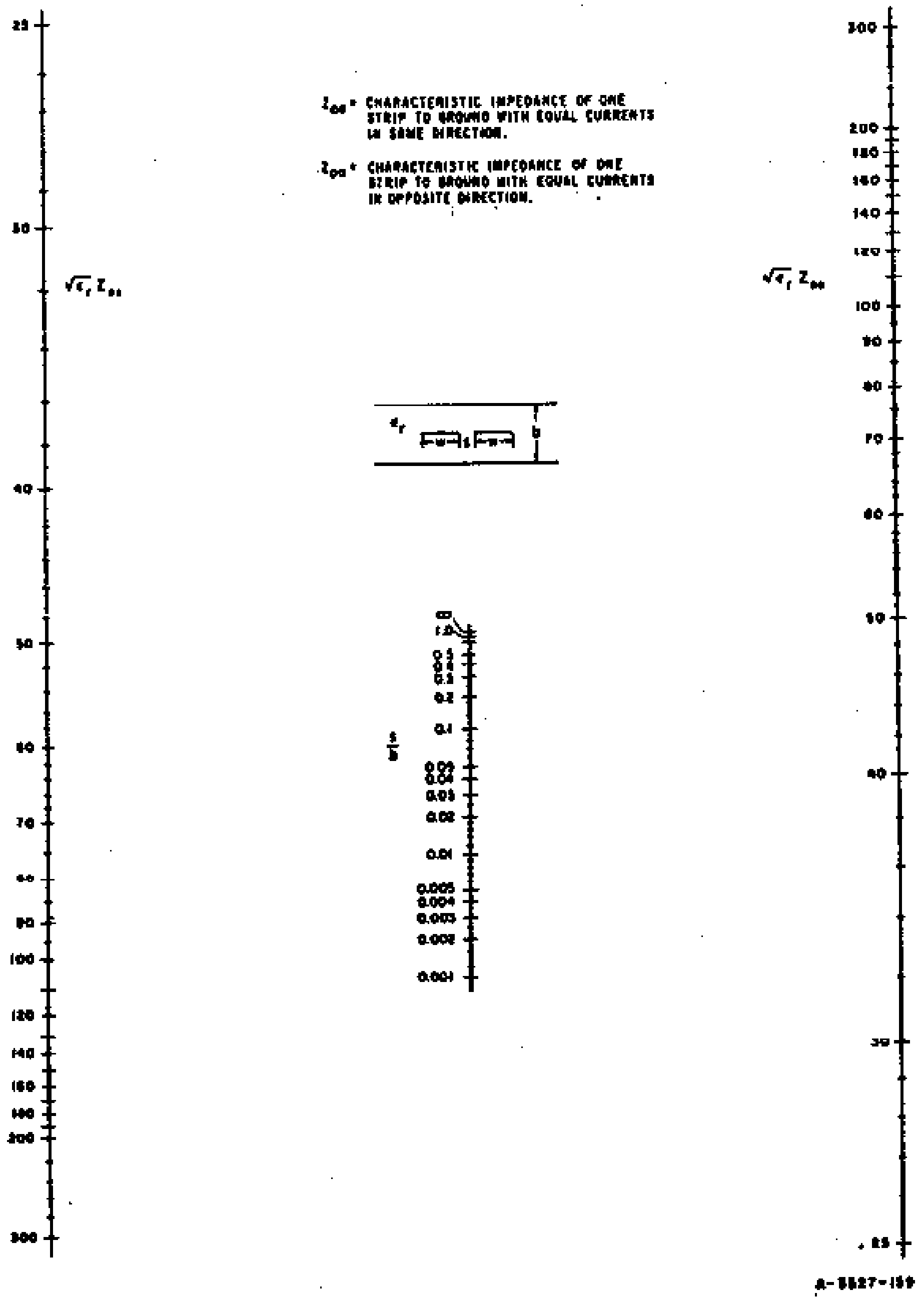
Appendix A/Anhang A



SOURCE: Final Report, Contract DA 36-039 SC-63232, SRI; reprinted in *IRE Trans., PGMTT* (see Ref. 4, by S. B. Cohn).

FIG. 5.05-3(b) NOMOGRAM GIVING w/b AS A FUNCTION OF Z_{oe} AND Z_{oo} IN COUPLED STRIP LINE

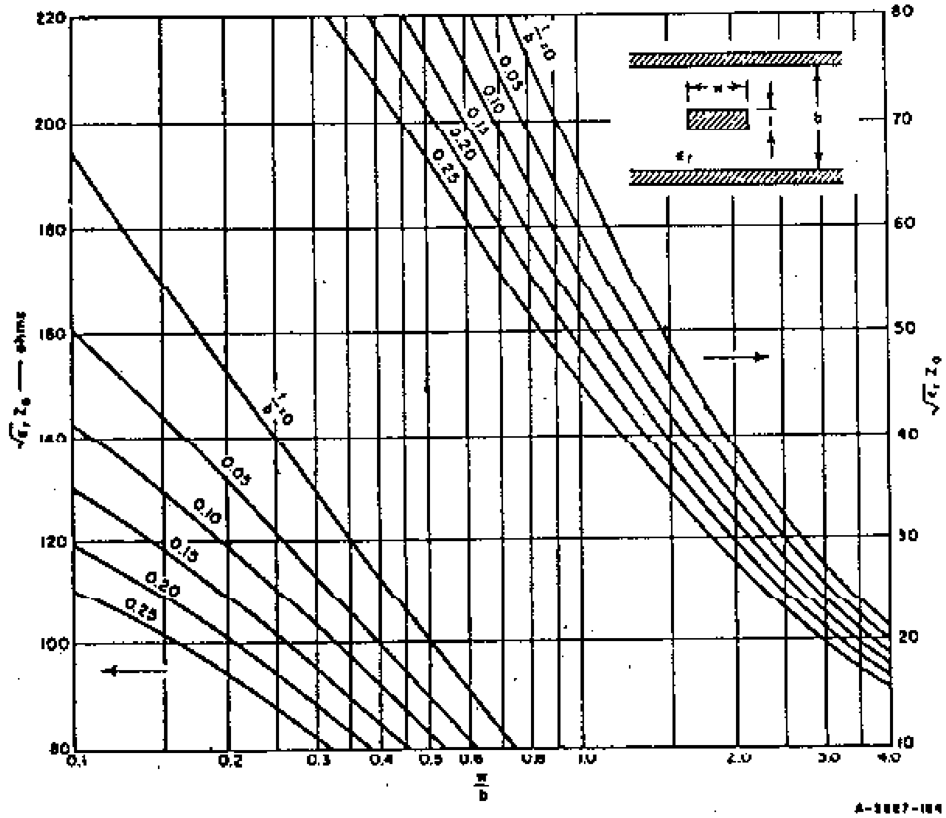
Appendix B/Anhang B



SOURCE: Final Report, Contract DA 36-039 SC-63232, SRI; reprinted in *IRE Trans., PGMTT* (see Ref. 4, by S. B. Cohn).

FIG. 5.05-3(a) NOMOGRAM GIVING s/b AS A FUNCTION OF Z_{oe} AND Z_{oo} IN COUPLED STRIP LINE

Appendix C/Anhang C



SOURCE: Final Report, Contract DA 36-039 SC-63232, SRI; reprinted in *IRE Trans., PGMTT* (see Ref. 2, by S. B. Cohn).

GRAPH OF Z_0 vs. w/b FOR VARIOUS VALUES OF t/b

BIBLIOGRAPHIE :

-Pascale VINCENSINI
"Dispositifs a dispersion controlée"
Thèse de doctorat INPG 1988

-HA WHEELER
"Transmission line properties of parallel strips separated by a dielectric sheet"
IEEE MTT 13 1965
"Transmission line properties of stripline between parallel planes"
IEEE Trans MTT 26 1978

-SB COHN
IRE Trans MTT 1954

-MICROWAVE engineering HANDBOOK

P GRIVET
"Pysique des lignes de haute fréquence et d'ultra haute fréquence"
Tome 1 MASSON 1969