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Material and Circuit Evaluation for Millimetre-Wave Applications: 3 dB Fin-Line Printed Probe Coupler for 31 GHz*

Abstract A 3 dB printed probe coupler has been designed for a 31.3 GHz midband frequency using a printed-circuit, seven-element, low-cost coupling structure. RT/duroid substrate material is used and an isolation of about 20 dB has been achieved.

Résumé On a conçu un coupleur de sonde de 3 dB pour une fréquence médiane de 31,3 GHz à l'aide d'une structure de couplage sur circuit imprimé à sept éléments à faible prix de revient. Avec un substrat en RT/duroid, on obtient une isolation de l'ordre de 20 dB.

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Introduction

A variety of coupling structures and circuits have already been developed for centimetre wavelengths (e.g. Refs. 1 and 2). For millimetre waves, however, suitable couplers, which are based on low-cost photo-etching techniques, are still very rare[3, 4].

Although common microstrip lines can also be used in the millimetre-wave region[5], some problems arise due to critical tolerances and dispersion, which may considerably reduce directivity, if other than the 3 dB hybrid ring coupling techniques are used. A very attractive new MIC coupler design principle for millimetre waves is still the printed probe coupler, suggested by Meier[3,4], in which an array of printed probes is placed in the E-plane common to parallel waveguides. The coupler in Reference 3 is designed for only 7.75 dB midband coupling at 35 GHz and there seems to be a paucity in this frequency range as far as the commonly sought 3 dB coupling is concerned.

It is therefore the purpose of this paper to provide a design suggestion for a 3 dB coupler to operate at about 31 GHz midband frequency (Fig. 1) based on the printed probe principle given in Reference 4.

The low-cost, seven-element printed probe design presented provides exact 3 dB coupling at midband frequency between ports 1 and 2, and 3, respectively. The isolation from port 4 is about 20 dB.

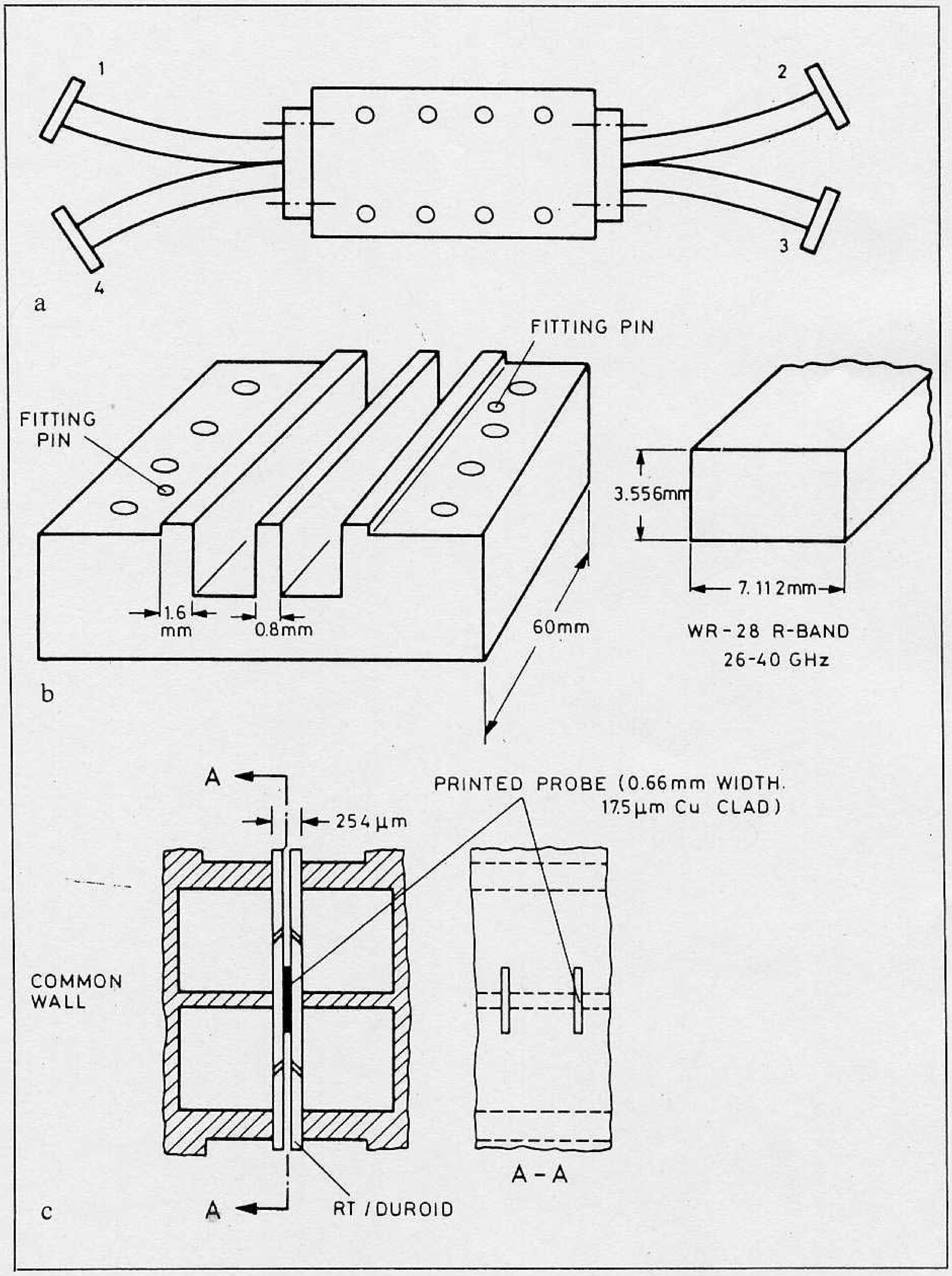


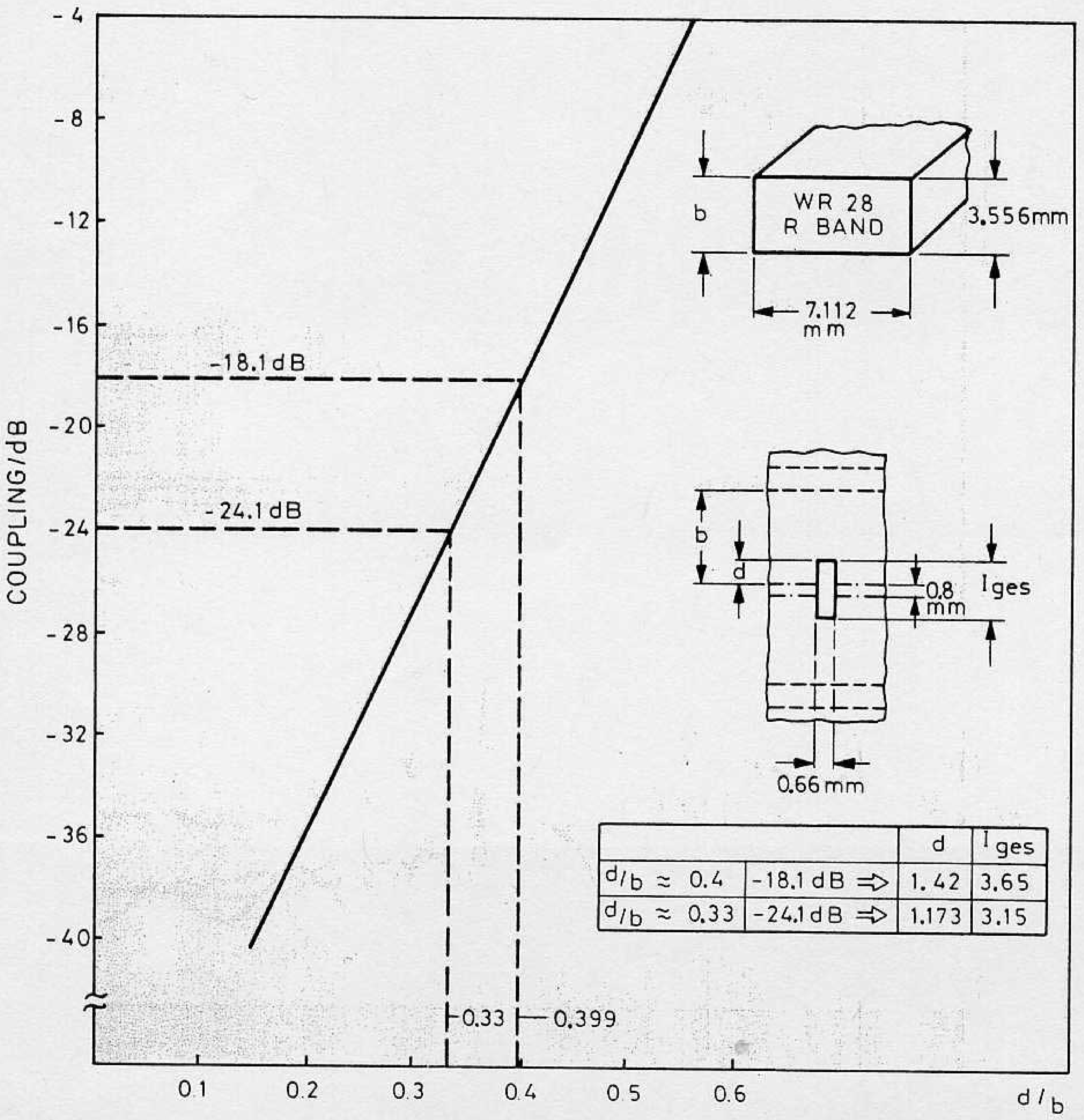
Figure 1. Fin-line coupler (printed probe) for 31.31 GHz
(a) plan view
(b) housing
(c) cross-section

Figure 1 shows the printed probe fin-line coupler (plan view, housing and in cross-section) that has been designed. In this configuration, two parallel waveguides form a common housing with E-plane symmetry. Four waveguide bends are incorporated for compatibility with standard WR-28 instrumentation. The common broad wall of the two waveguides is slotted to accept a pair of dielectric RT/duroid boards. Directional coupling between the waveguides is achieved via an array of probes which is printed on one of the boards. Radiation from the outer board walls, which also contain the slot in order to simplify the manufacturing of the coupler, is negligible, because the wall thickness is chosen to be a quarter wavelength in the dielectric (about 1.6 mm, cf. Fig. 1b), providing almost a short circuit at the inner margin of the broad walls. This has been confirmed by measuring the insertion losses of the two coupled waveguides alone (with only the dielectric boards, without any probes), which gives a value of only about 0.3 dB.

After initial experiments with several probe widths, the latter was chosen to be 0.66 mm, since this value gave less variation in the coupling-response/frequency characteristic than other widths. The basic design information was also checked experimentally by measuring the midband coupling for one probe for various d/b ratios (Fig. 2). According to calculations in Reference 4 based on equivalent-circuit considerations, the midband coupling of elements 1 and 7 should be −24.1 dB, whereas the coupling of elements 2 to 6 should be −18.1 dB, if a seven-probe coupler is sought. The corresponding overall lengths l_{ges} of the probe types are shown in Figure 2.

Figure 3a shows the photo-etched, printed probe, seven-element coupling structure. The distance between the printed probe elements is $\lambda_{eff}/4 = 1.96$ mm, and this provides a midband frequency of 31.31 GHz.

Photographs of the printed probe coupler and the coupling element that have been designed are shown in Figures 3b and 3c, respectively.



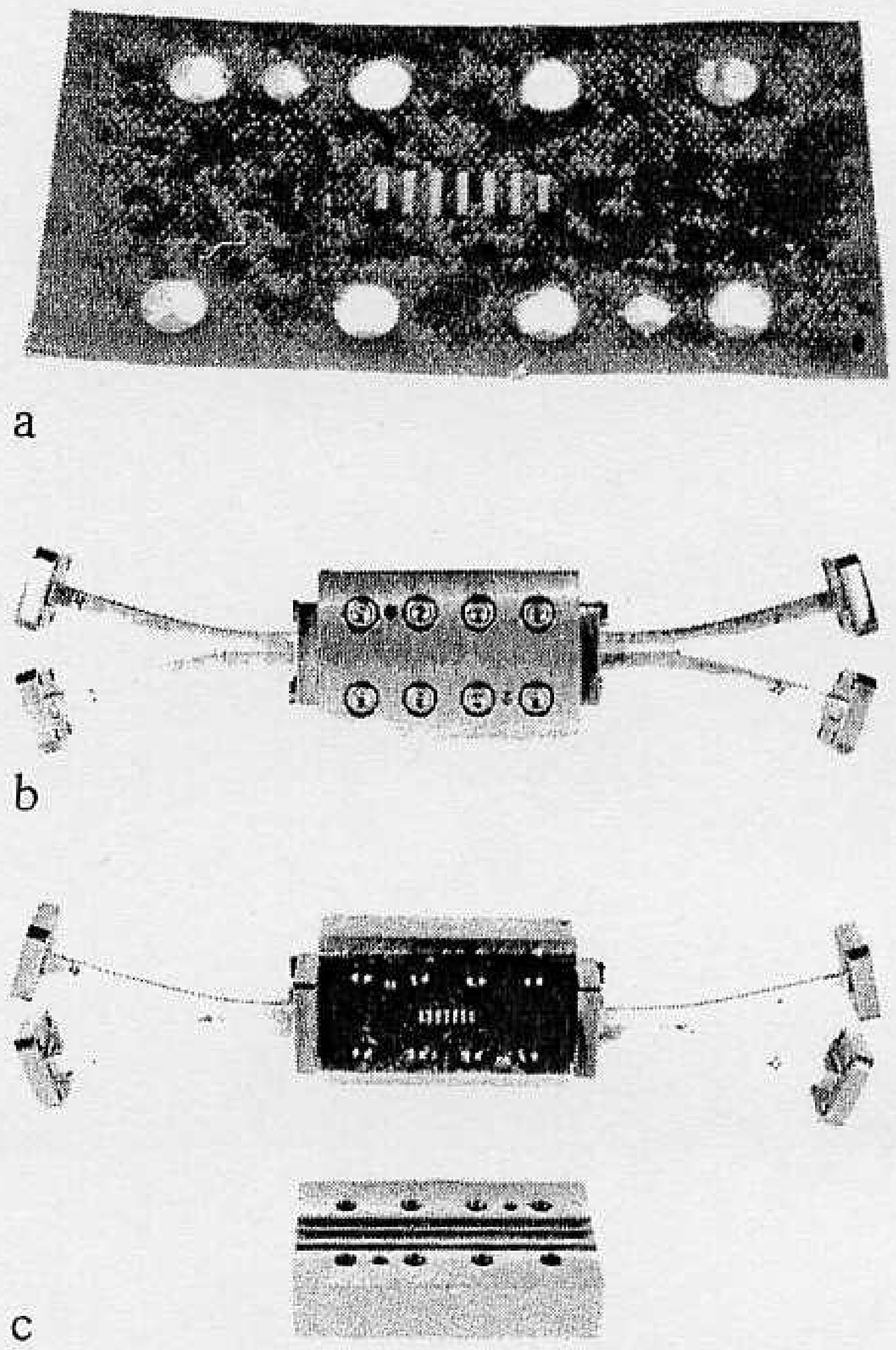


Figure 3. The coupler design (3 dB, 31.31 GHz, 20 dB isolation)
(a) seven-step printed probe coupling section (1st and 7th probe: 3.15 mm long, others: 3.65 mm long, width 0.66 mm, Cu 17.5 μm thick, substrate material RT/duroid)
(b) the complete coupler
(c) cross-section

Figure 2. Measured printed probe coupling as a function of probe length (one probe only) at 31 GHz

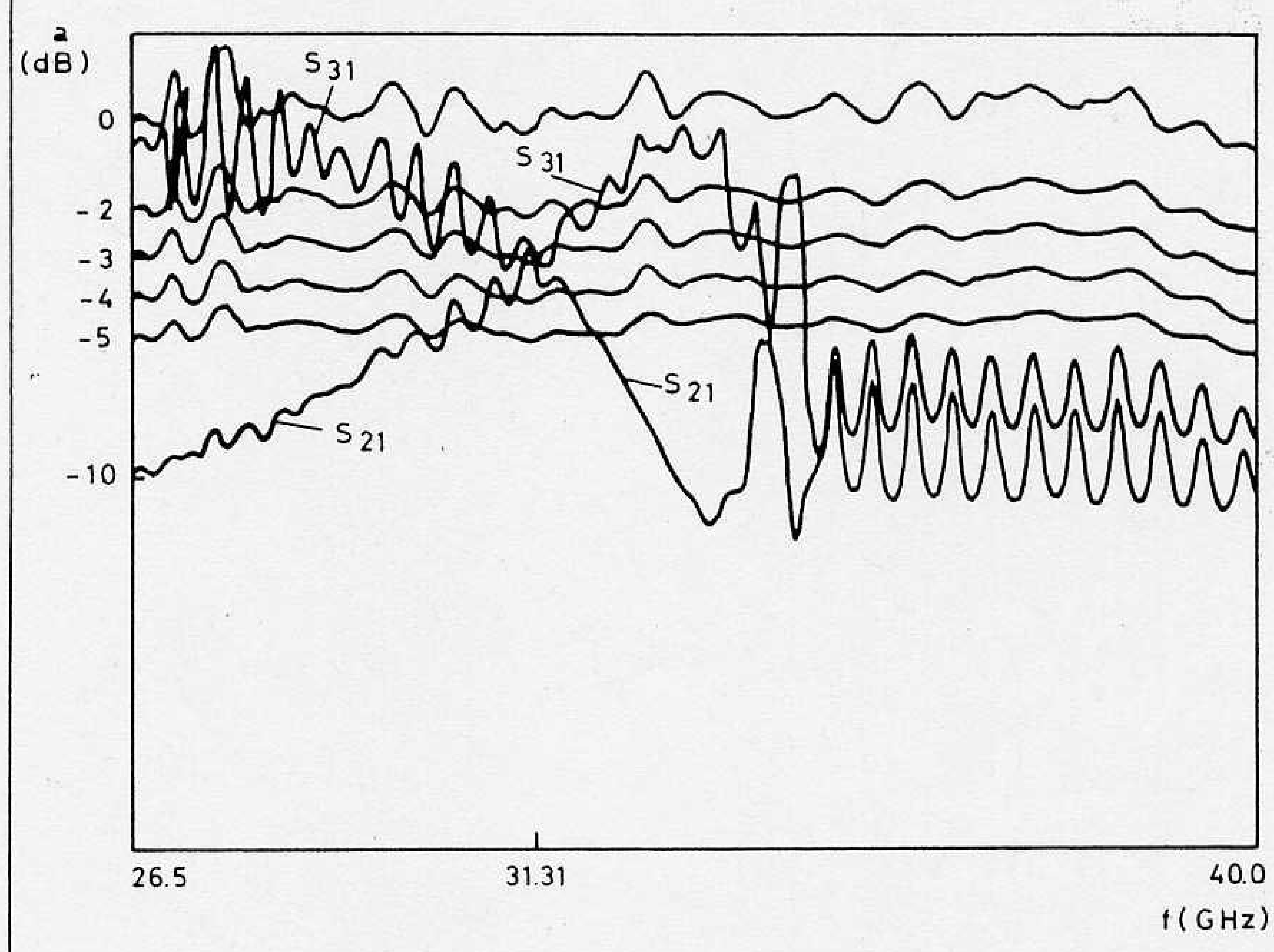


Figure 4. Measured transmission coefficients to ports 2 and 3 (S_{21}, S_{31}) of the 3 dB printed probe coupler (cf. Fig. 1a)

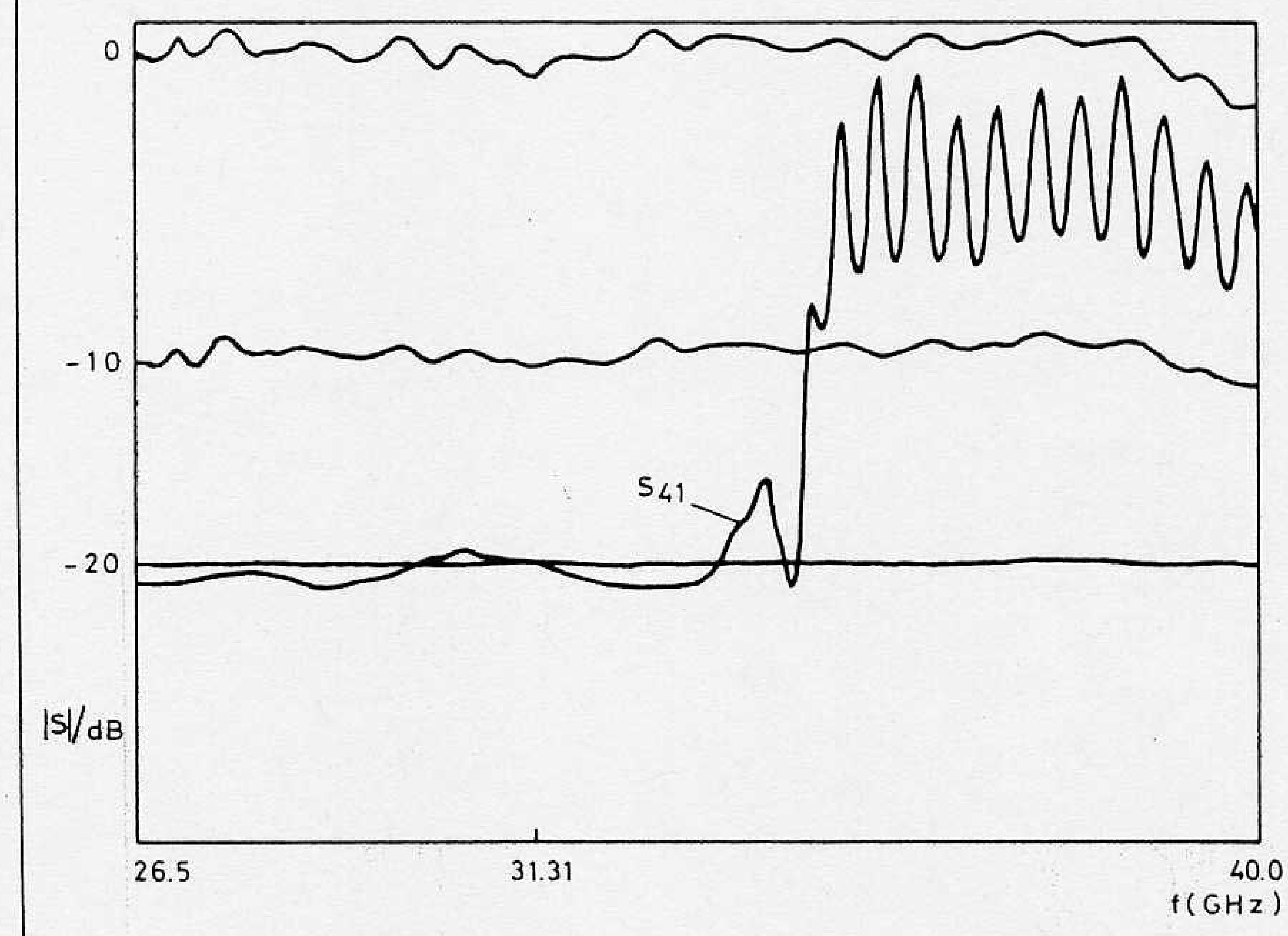


Figure 5. Measured isolation to port 4 of the 3 dB printed probe coupler

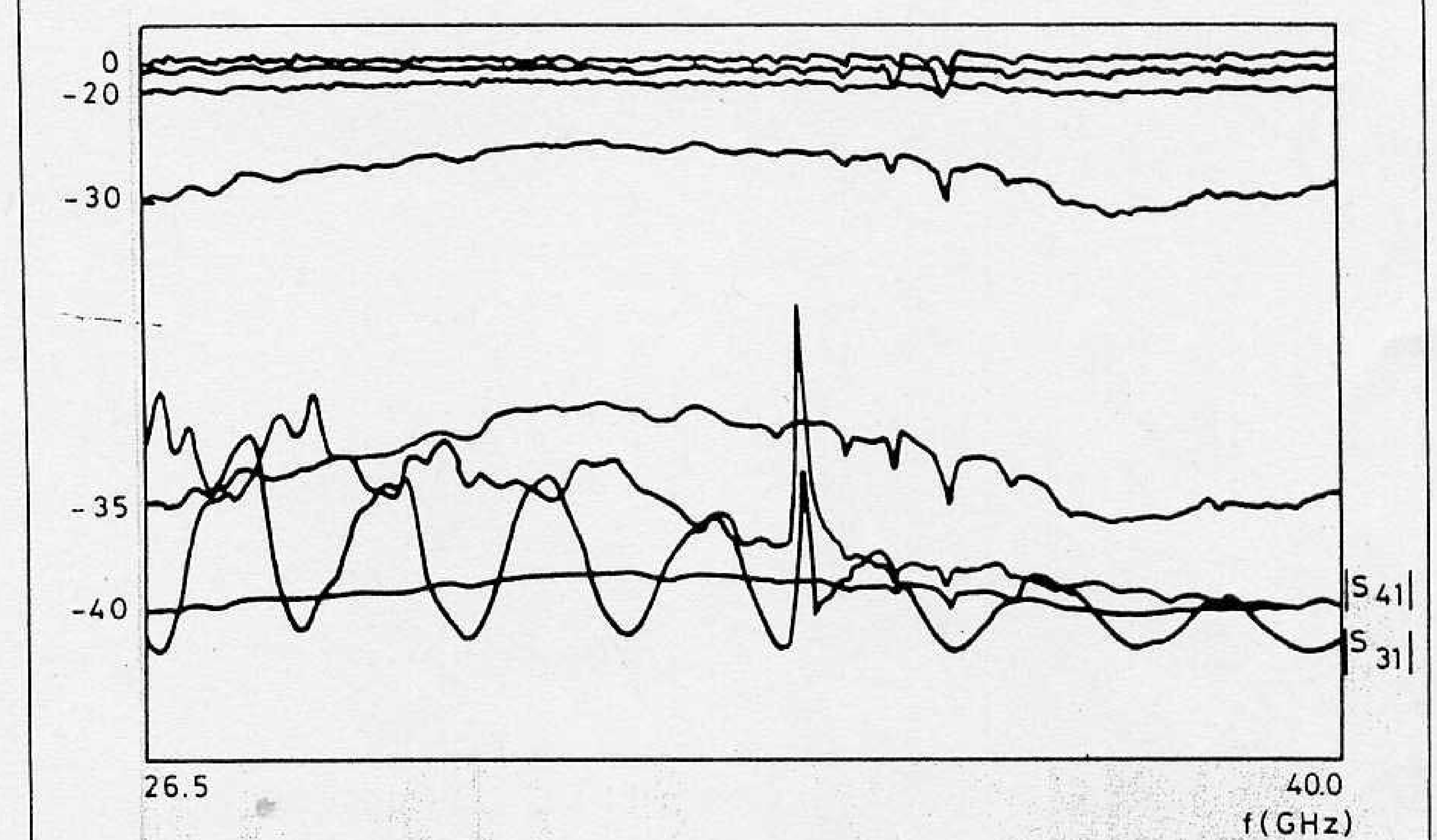


Figure 6. Measured transmission coefficients S_{31} and S_{41} of the printed probe coupler (cf. Fig. 1a) without metallic probes (with only the substrate) for comparison

Results

The measured couplings from port 1 to ports 2 and 3 (cf. Fig. 1) are shown in Figure 4. This coupler design provides exact 3 dB coupling at 31.31 GHz. If a 3 dB $\pm$ 1 dB limit is tolerated, the corresponding frequency band is about 1.48 GHz.

The isolation between ports 1 and 4 is shown in Figure 5. The measured value of about 20 dB is judged to be very good, since this measured isolation includes the effects of waveguide bends, flange discontinuities, etc.

For comparison purposes, the transmission coefficients from port 1 to ports 3 and 4 have been measured without the metallic probes, with only the dielectric boards (Fig. 6). The coupling, as well as the directivity effect, is clearly due to the printed probe arrangement, and a superimposed slot coupling effect can be neglected.

Conclusion

A seven-element printed probe coupler for 31.31 GHz has been designed based on a low-cost photo-etching technique applied on an RT/duroid substrate. This design provides exact 3 dB coupling at midband frequency, with an isolation of about 20 dB.

References

1. Matthaei G L, Young L & Jones E M T, 1964, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*, McGraw Hill Book Co, New York
2. Itoh T, 1978, Generalized Spectral Domain Method for Multiconductor Printed Lines and its Application to Tunable Suspended Microstrips, *IEEE Trans*, **MTT-26**, pp 983-977
3. Meier P J, 1978, Millimeter integrated circuits suspended in the E-plane of rectangular waveguide, *IEEE Trans*, **MTT-26**, pp 726-733
4. Meier P J, 1979, Printed Probe Hybrid Coupler for the 3 mm Band, *Proc 9th European Microwave Conference*, Brighton, pp 443-447
5. Arndt F, Bornemann J, Grauerholz D, & Vahldieck R, 1981, Material and Circuit Evaluation for Millimetre-Wave Applications: A Microstrip 3 dB-Hybrid Coupler with Low-Dielectric Substrate for Millimetre Waves, *ESA Journal* **5**, No. 2, pp 127-132

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