University of Missouri-Rolla
Electromagnetic Compatibility Laboratory

Title: EMI Effects of 90° Bends in Circuit Board Microstrip Lines

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Date: October 23, 1997

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The objective of this project was to determine if 90° bends in printed circuit board microstrip traces caused significantly more electromagnetic radiation than 45° bends. A test circuit board was provided by UltraCAD Design, Inc. The portion of the test board used in this report is shown in Figure 1. Each microstrip line was 20.3 cm long and consisted of a trace above a ground (return) plane with a 7 mil thick FR4 dielectric in between. Each line could be terminated on one end by a surface mounted resistor and on the other end by an SMA connector. The total size of the circuit board was 29.2 cm by 9.9 cm. Trace J4 had two mitered 90% corners and trace J5 had two 90° corners each formed by two 45° bends about 2 mm apart. Trace J7 contained two 135° bends. The straight trace, J2, was used as a reference. The main traces of concern were J3 consisting of two 90° bends, J6 consisting of two 45° bends, and J2 the straight reference trace.

EMI EFFECTS OF 90° BENDS IN CIRCUIT BOARD MICROSTRIP LINES

prepared by
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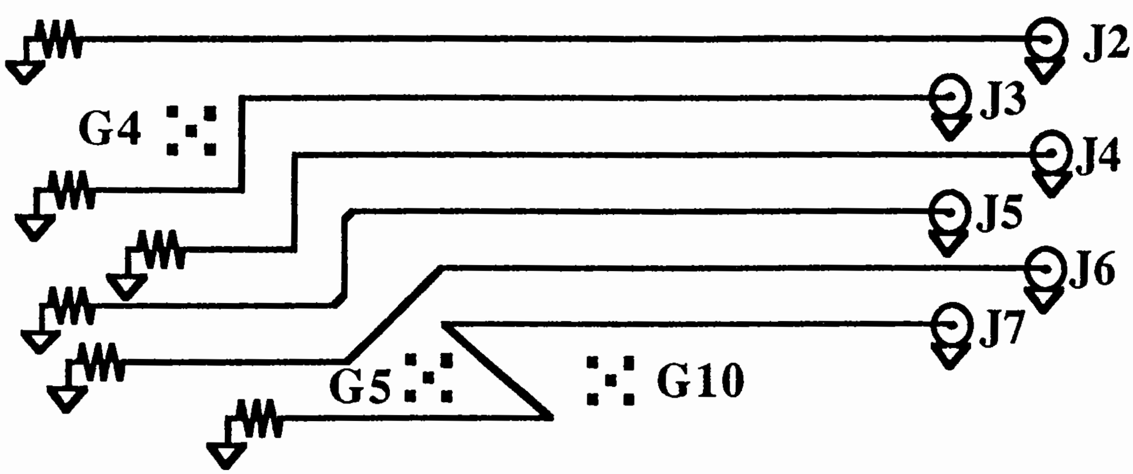

Figure 1. Configuration of the microstrip traces.

Time Domain Reflectometry (TDR) Measurements

TDR measurements were made to determine if there was a significant difference in the reflection produced by a 90° bend in a microstrip line relative to a 45° bend. A Tektronix 11801B Digital Sampling Oscilloscope with an SD-24 TDR Sampling Head was used for these measurements. This unit can resolve impedance discontinuities that occur over a length greater than about 5 mm. This spatial resolution can easily distinguish the reflections produced by two bends more than 10 mm apart. However, each individual bend may not produce a measurable reflection.

TDR measurements were made on all 6 traces. Each trace was open circuited at the far end. Figure 2 shows the result for the straight trace J2. The reflection coefficient is plotted versus time. Starting at the left, the external cable is shown to have a characteristic impedance of 45.6 Ω. The SMA connector is next, with the sharp drop indicating a lumped capacitance between the center conductor of the connector and the ground (return) plane of the circuit board. The microstrip line characteristic impedance reaches a minimum of 38 Ω near the center of the trace length. The open circuit termination is shown on the right. This TDR result is as expected, except that the microstrip line has a slightly lower impedance (38 Ω to 40 Ω) than the expected value of 50 Ω. This impedance mismatch may have a slight effect on the radiation measurements.

Figure 3 shows the TDR plot for trace J3 which contains two 90° bends. A slight increase in the characteristic impedance is shown along the bent section of the trace. The impedance change could be caused by a change in trace width, an anisotropy in the dielectric constant, the proximity of connector G4, or some other undetermined reason. The TDR data for other traces suggests that the proximity of the unused connectors G4, G5, and G10 may affect the impedance of some of the traces. Trace J7 (Figure 7) seems to be affected by G5 and G10. Trace J5 (Figure 5) is not near any of the connectors G4, G5, or G10 and does not show an impedance change along the bent section. Figures 4 and 6 show the TDR measurements for the remaining two traces.

The main conclusion from the TDR measurements is that neither 90° bends nor 45° bends produce a significant reflection compared to other transmission line perturbations. Theoretically, there should be an impedance change at both a 90° and a 45° bend. This change is not measurable with the 17 ps rise-time TDR unit used in these tests, because the impedance change does not exist over a sufficient length. A pulse would require a rise time shorter than about 5 ps to produce a resolvable reflection.

Radiation Measurements

Over 60 radiation measurements were made on 9 of the trace configurations on the test board. In some cases the traces were open-circuit terminated and in other cases the traces were match terminated. Only a small portion of the data for 5 of the trace configurations are presented in this report. The other data are similar to that shown here and do not provide any new information. The changes in radiated levels for a trace with two 90° bends relative to a trace with two 45° bends was expected to be less than a few dB, and difficult to distinguish from changes caused by uncontrollable variations in the experimental configuration.

The radiation measurements were performed in a shielded room (Figure 8) with only 3.5 of the 6 walls covered with absorbing cones. This would not be an acceptable chamber for absolute radiated measurements, but in this case only relative measurements were required. The multiple

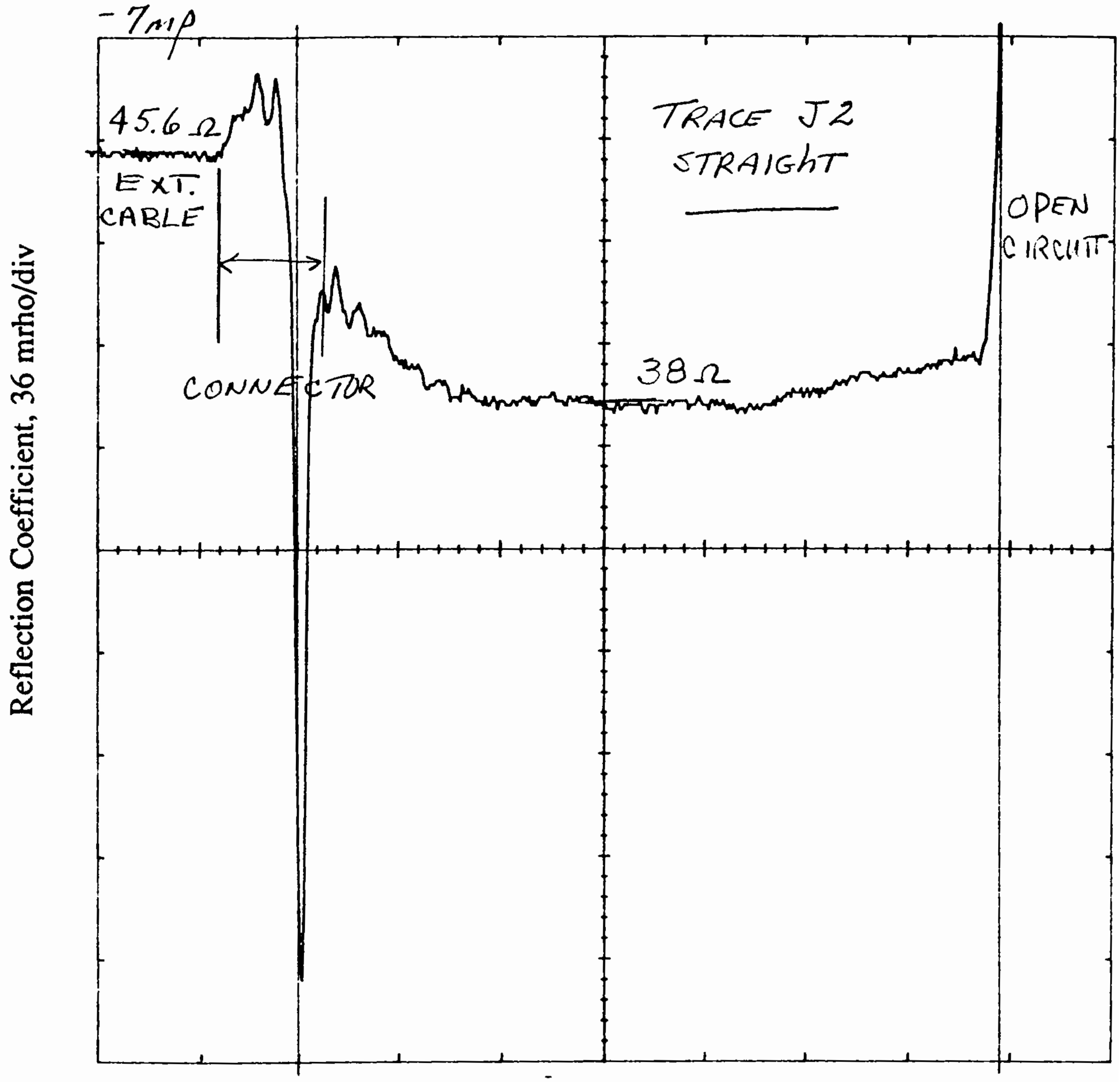

Figure 2. Reflection coefficient (characteristic impedance) versus time (distance) for trace J2.

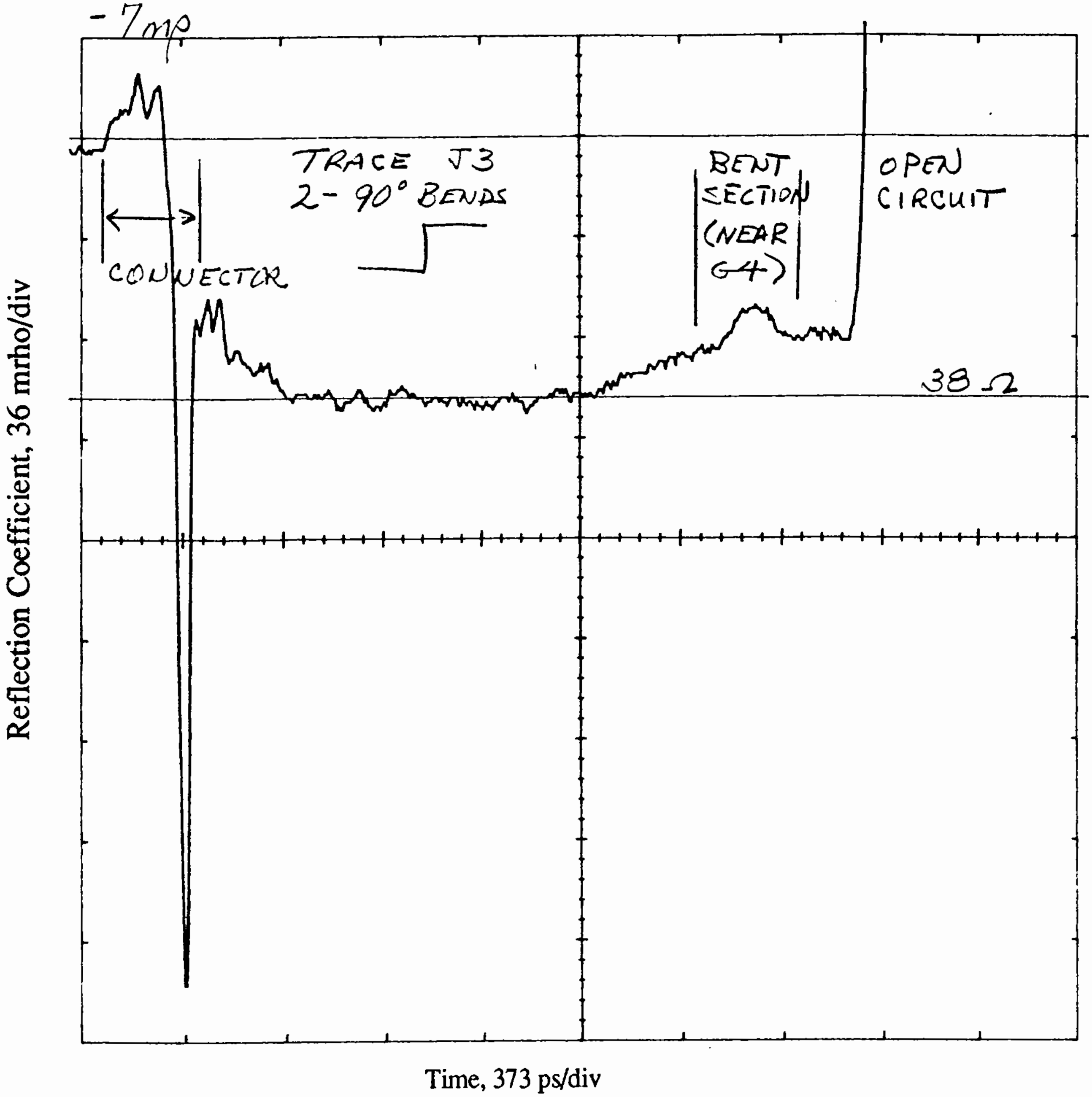

Figure 3. Reflection coefficient (characteristic impedance) versus time (distance) for trace J3.

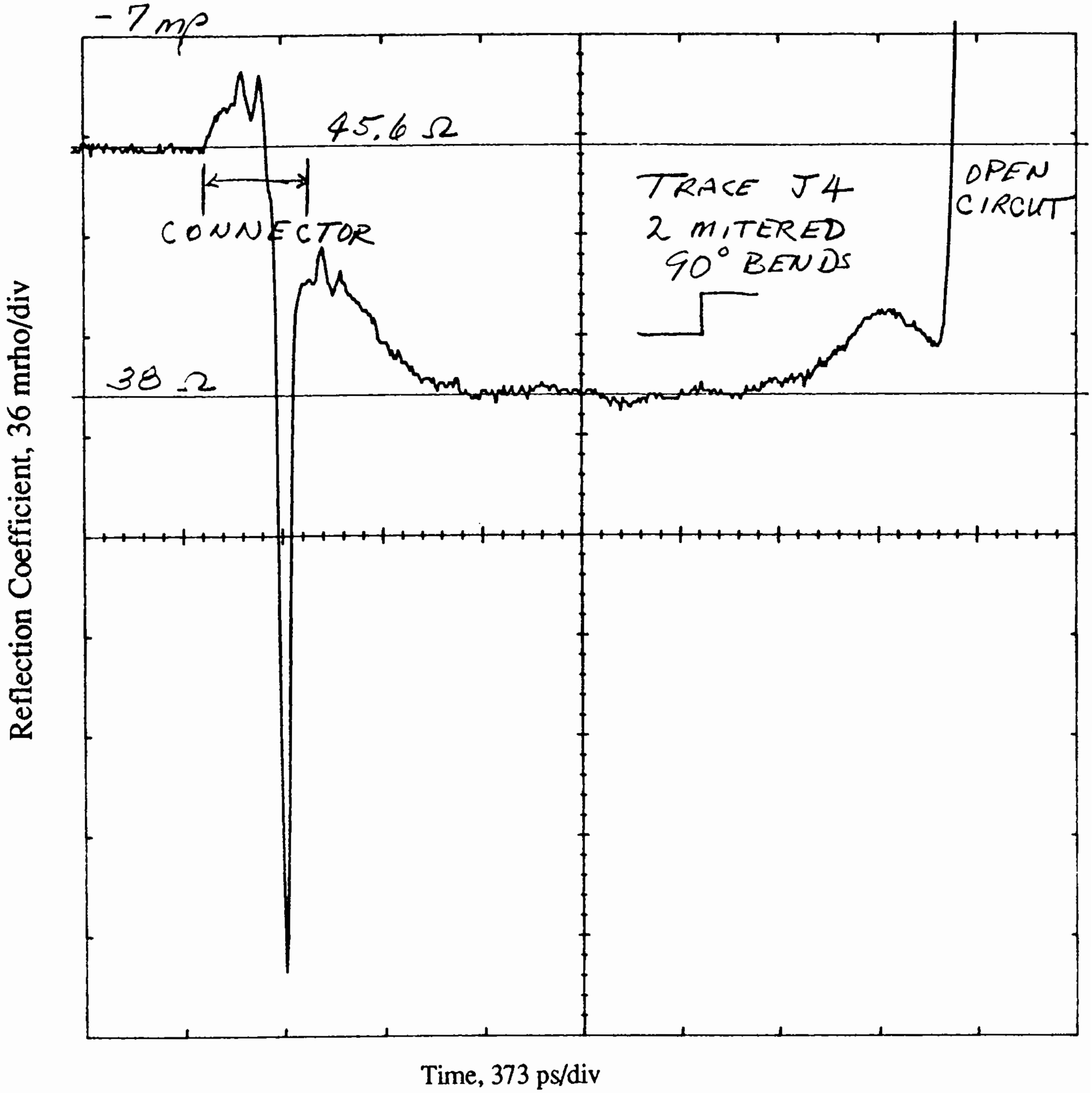

Figure 4. Reflection coefficient (characteristic impedance) versus time (distance) for trace J4.

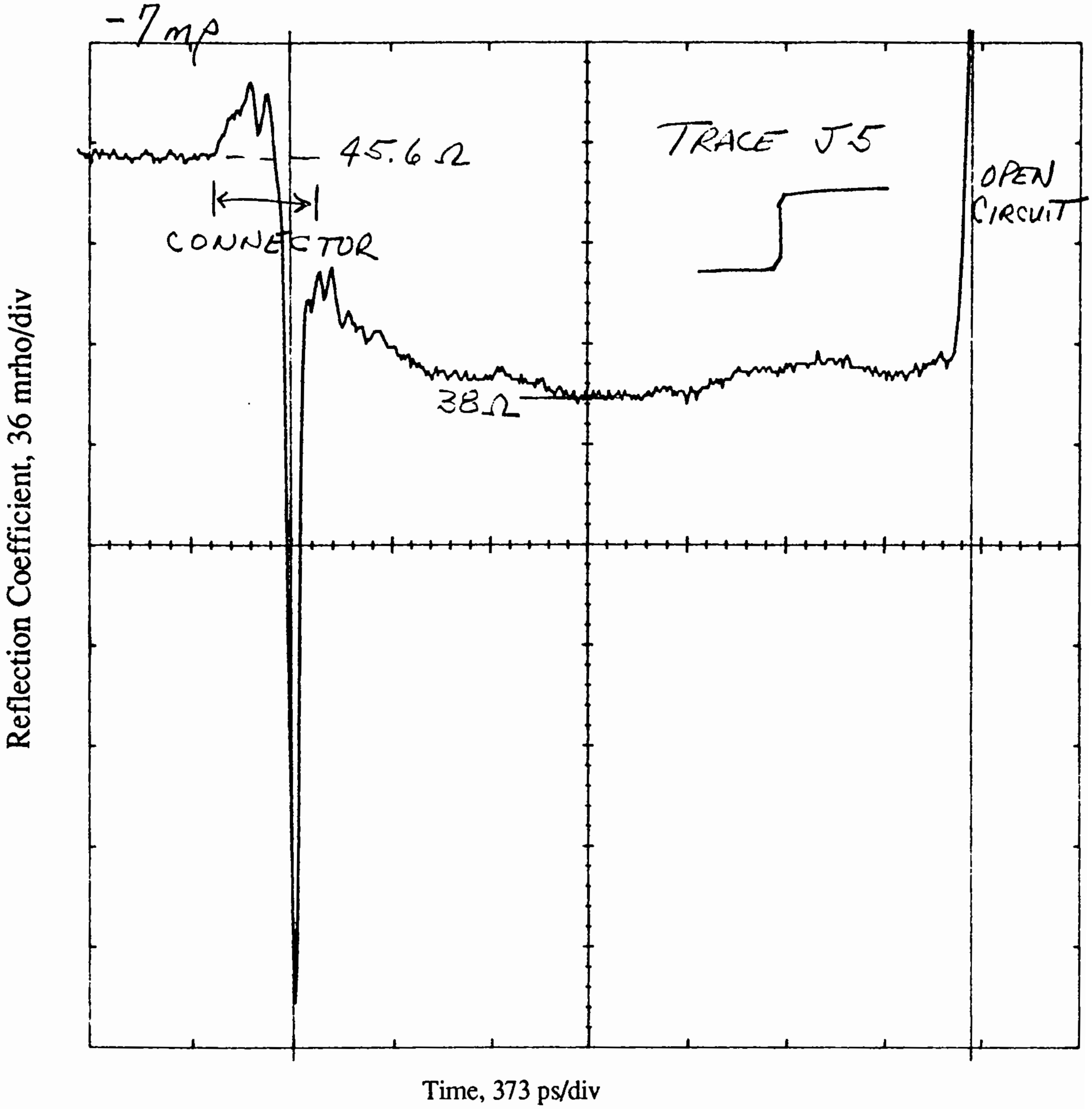

Figure 5. Reflection coefficient (characteristic impedance) versus time (distance) for trace J5.

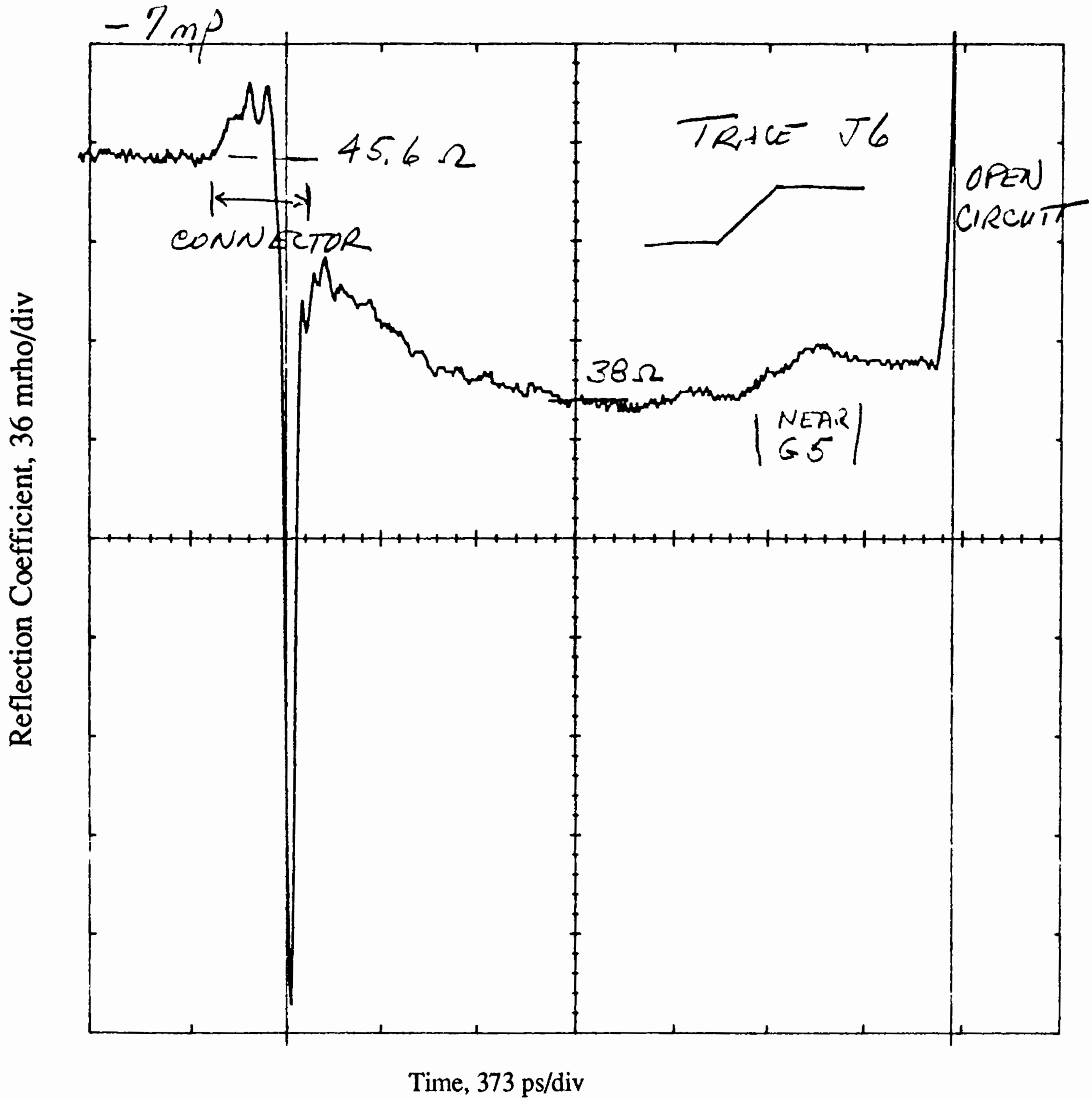

Figure 6. Reflection coefficient (characteristic impedance) versus time (distance) for trace J6.

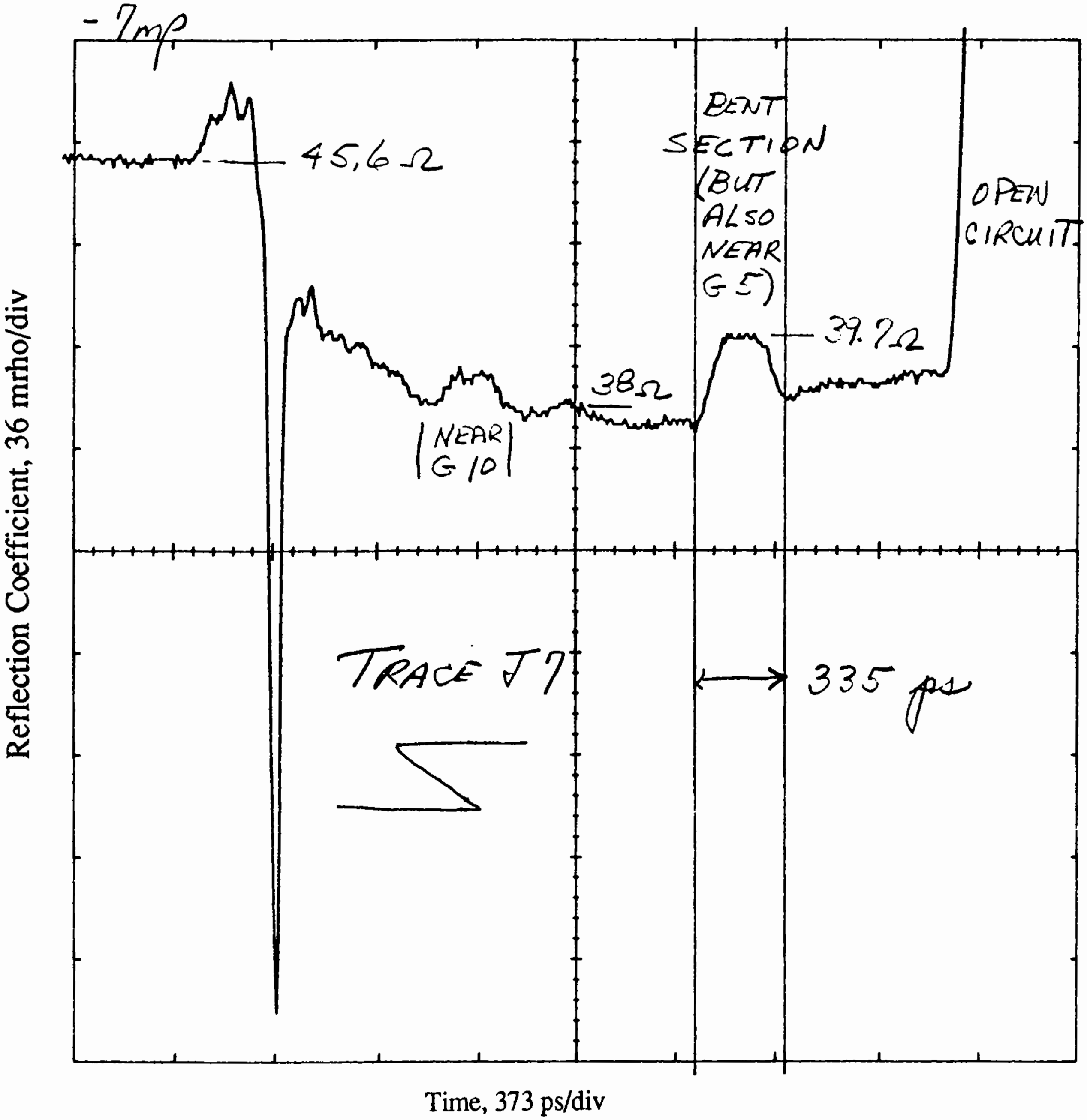

Figure 7. Reflection coefficient (characteristic impedance) versus time (distance) for trace J7.

reflections cause 20 dB variations in the radiated field, but the variations are reproducible and appear similar for all test cases. The receive antenna (port 2) was a log-periodic array placed about 1 m from the circuit board under test (port 1). The forward transmission coefficient S_{21} was used as a normalized measure of the radiated field strength. The same procedure was used for all radiated measurements. No absolute field measurements were required, since all results were compared to the straight trace J2 as a reference. The data shown is only for a horizontally polarized antenna and horizontally oriented circuit board traces. Other combinations of polarization were tested, but none showed any new results compared to the data presented here.

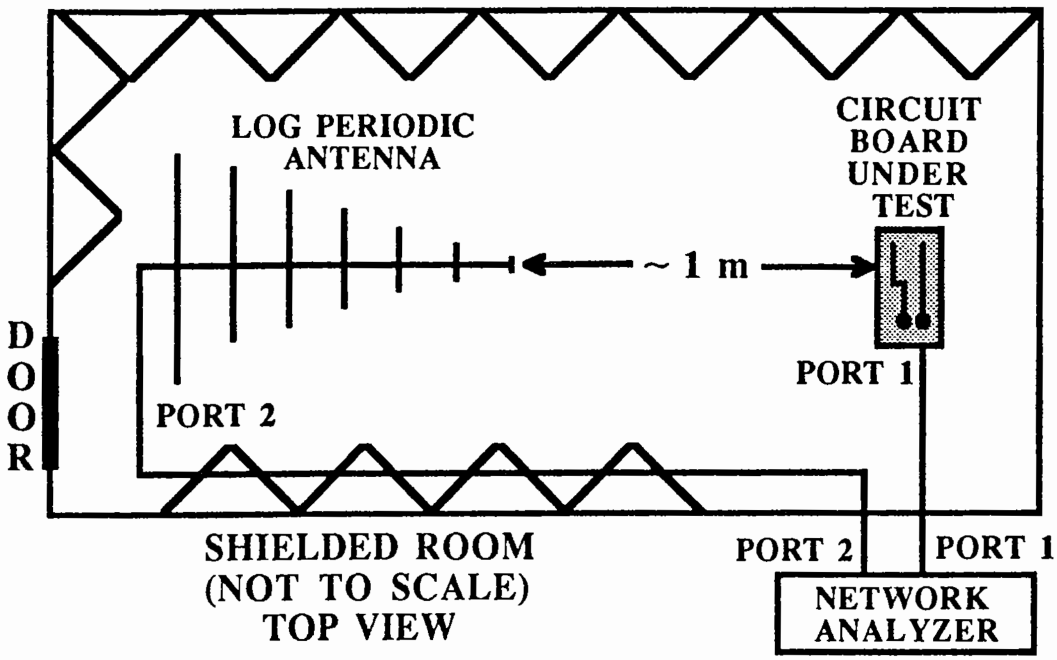

Figure 8. Test configuration for radiated measurements.

A 3 cm long extension of the center conductor of a coaxial cable was used as a reference transmitting antenna. The measured forward transmission coefficient S_{21} versus frequency for this reference antenna is shown in Figure 9. Note that the maximum value of S_{21} is -26 dB with the average value about -40 dB. This is an electrically small dipole, even at the maximum test frequency of 1.3 GHz. The S_{21} = - 40 dB level can be compared later to the S_{21} value for a straight or bent trace.

Figure 10 shows the normalized radiated emission as S_{21} versus frequency for the straight trace J2 (top curve) and for no trace connected to port 1 (bottom curve). The system noise level is indicated when no connection is made to port 1. Note that the radiated emission from the straight trace is only about 15 dB above the noise floor and is at least 35 dB below the emissions from the short reference antenna shown in Figure 9.

Figure 10 curve (a) and Figure 11 both show the radiation from the straight trace J2. The trace is horizontal in both situations, but the circuit board is vertical for Figure 10 and horizontal for Figure 11. This change in the orientation of the board caused a significant shift in the frequency of the radiation maximums and minimums, but only a few dB change in the average radiation level.

Figure 12 shows the radiation from the trace with two 90° bends and Figure 13 is for the trace with two 45° bends. There is no significant difference between the radiation levels for these two traces. Notice that the radiated level is 3-4 dB higher for the trace with two 45° bends as compared to the trace with two 90° bends. This difference is very likely caused by factors unrelated to the angle of the bends. The trace with 45° bends is 0.6 of an inch closer to the edge of the board than the trace with 90° bends. This could account for the small difference in radiation levels. This result illustrates the difficulty in attempting to measure a small effect when several other variables, that can also produce small changes, are not completely controllable. If the change in the angle of the bend produced a 10 dB change in radiation, then the effect could be easily distinguished from other variables.

When the results in Figures 12 and 13 for the traces with bends are compared with Figure 11 for the straight trace there is less than a 3 dB difference in the average radiated field levels. This change is not sufficient to be definitely attributable to the bending of the traces.

Figure 14 shows the radiated emissions for trace J7 which has two 135° bends. There is a 10 dB increase in the radiation above 800 MHz, relative to that for the straight trace J2 (Figure 11). Other data above 1.3 GHz also showed a 10 dB to 15 dB increase. This is a change that is larger than the measurement uncertainties associated with cable placement, board positioning, antenna positioning, etc. However, this trace is the closest of all the traces to the long edge of the board. It is suspected that this difference in the location of the trace on the board is more of a factor contributing to the increased radiation, than the 135° bends. This suspicion could not be verified.

Conclusions

The TDR data do not show any measurable reflections from either 45° or 90° bends in microstrip traces. There should be a change in the characteristic impedance due to a bend, but the length of the change is not sufficient to be resolvable with a 17 ps rise-time pulse.

The radiated emission measurements do not show an increase for 90° bends compared to 45° bends that is larger than the measurement uncertainty. All of the trace geometries measured produced radiated emissions that were 35-50 dB below the emissions from a 3-cm long monopole antenna. For most circuit boards, it is expected that discontinuities encountered at integrated circuit packages and connectors will produce much larger reflection or radiation effects than either 45° or 90° bends.

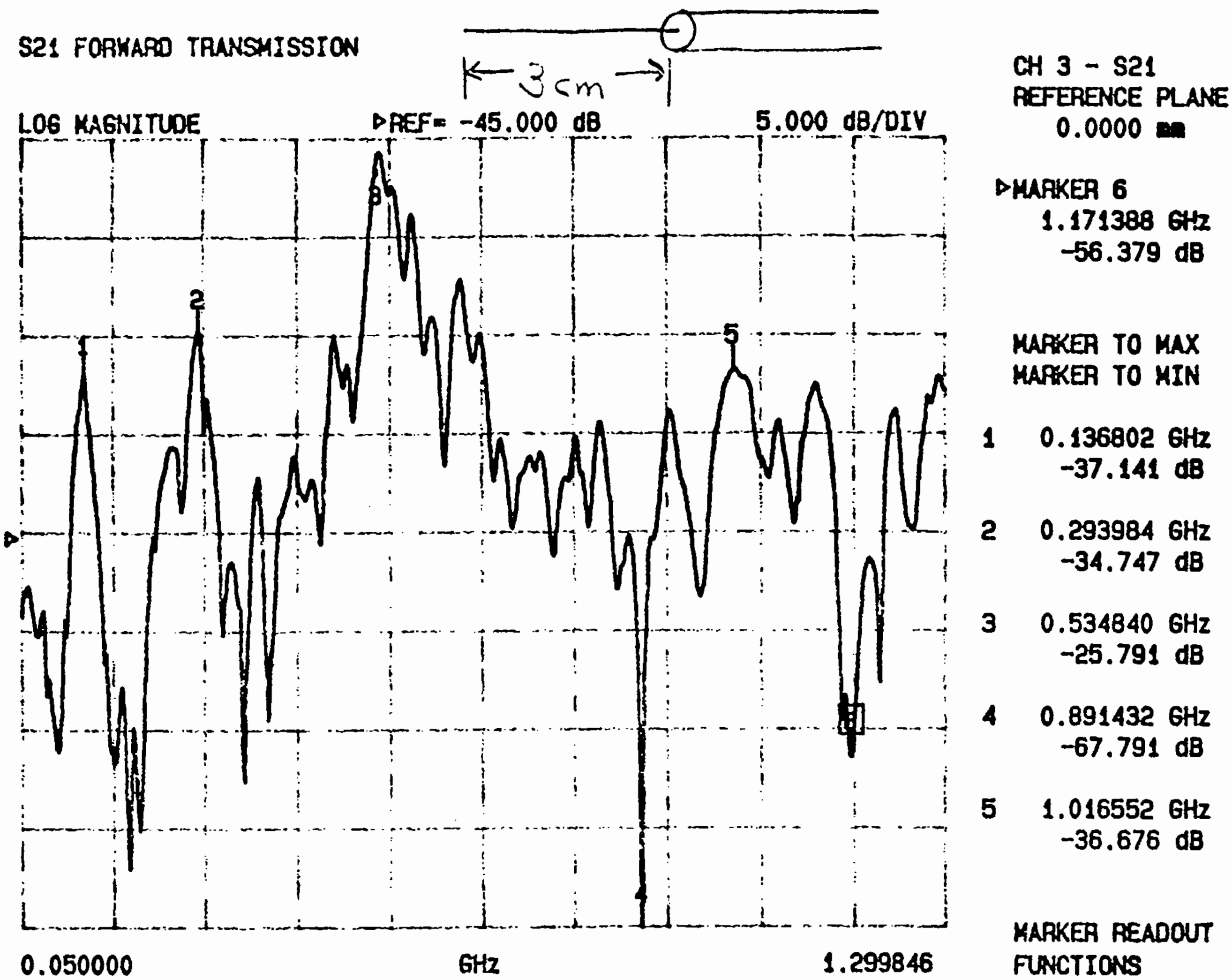

Figure 9. The forward transmission coefficient S_{21} in dB versus frequency in GHz for a 3 cm long monopole antenna.

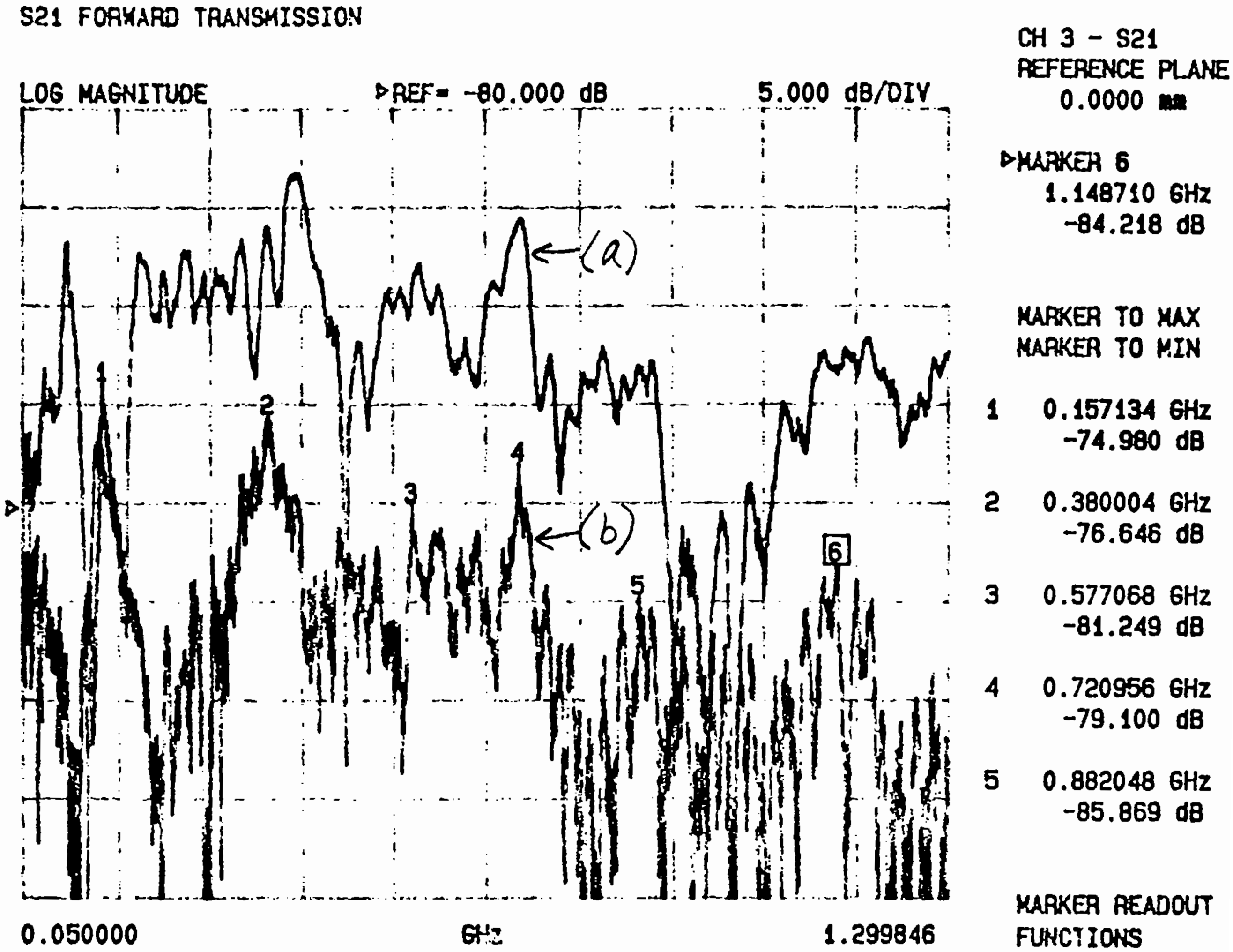

Figure 10. The forward transmission coefficient S_{21} in dB versus frequency in GHz for (a) the straight trace J2 and (b) no connection to port 1.

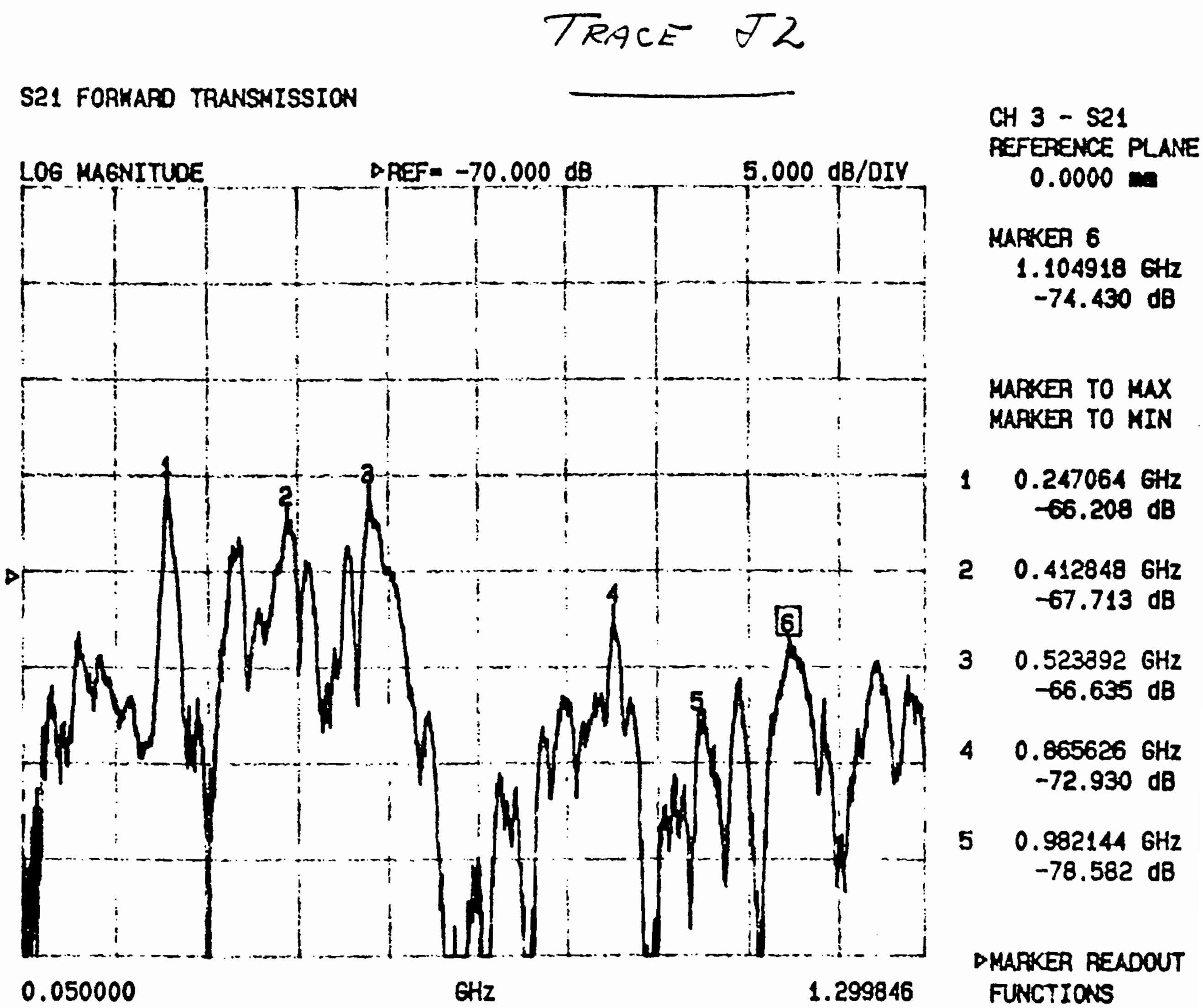

Figure 11. The forward transmission coefficient S_{21} in dB versus frequency in GHz for the straight trace J2.

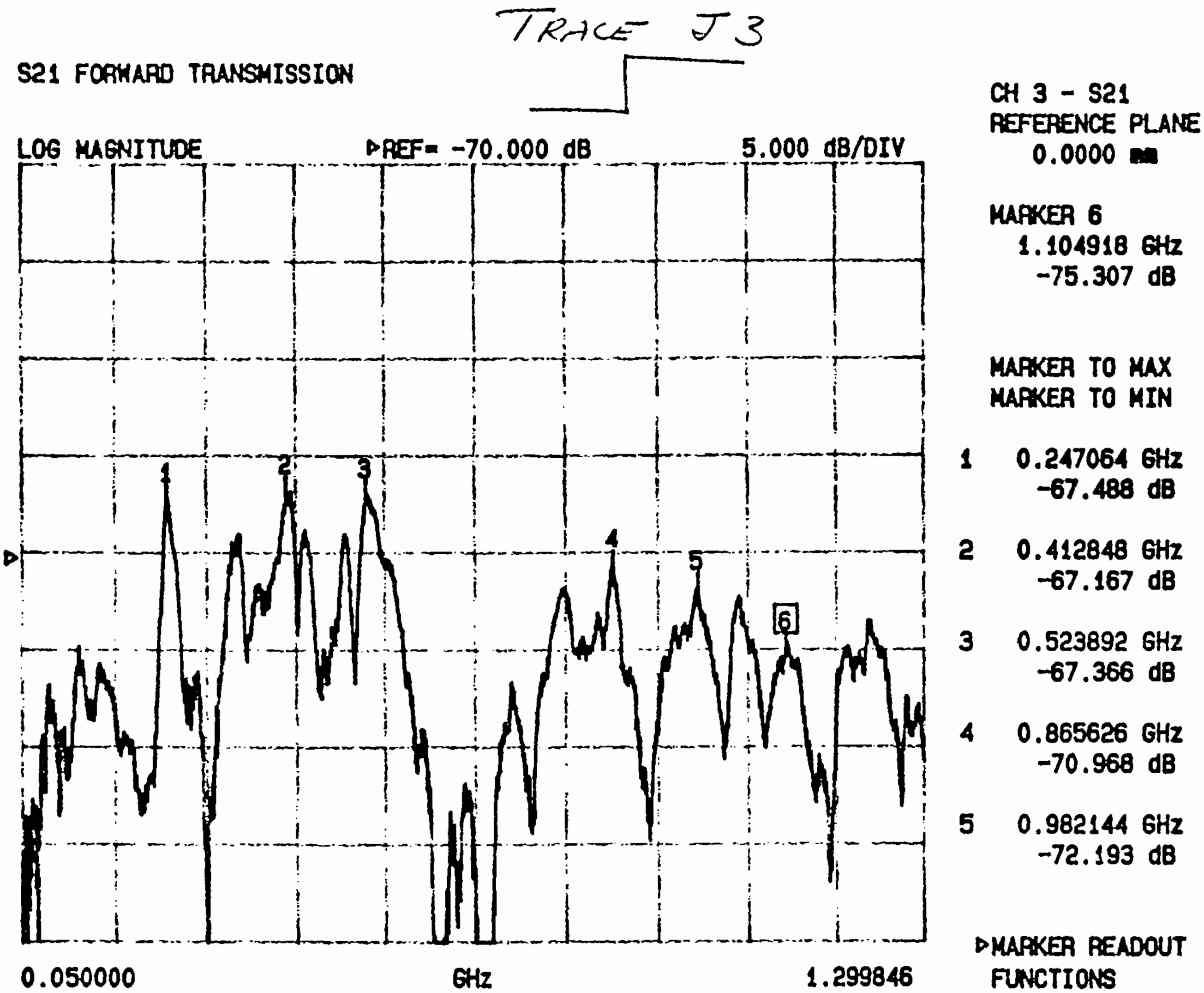

Figure 12. The forward transmission coefficient S_{21} in dB versus frequency in GHz for trace J3 containing two 90° bends.

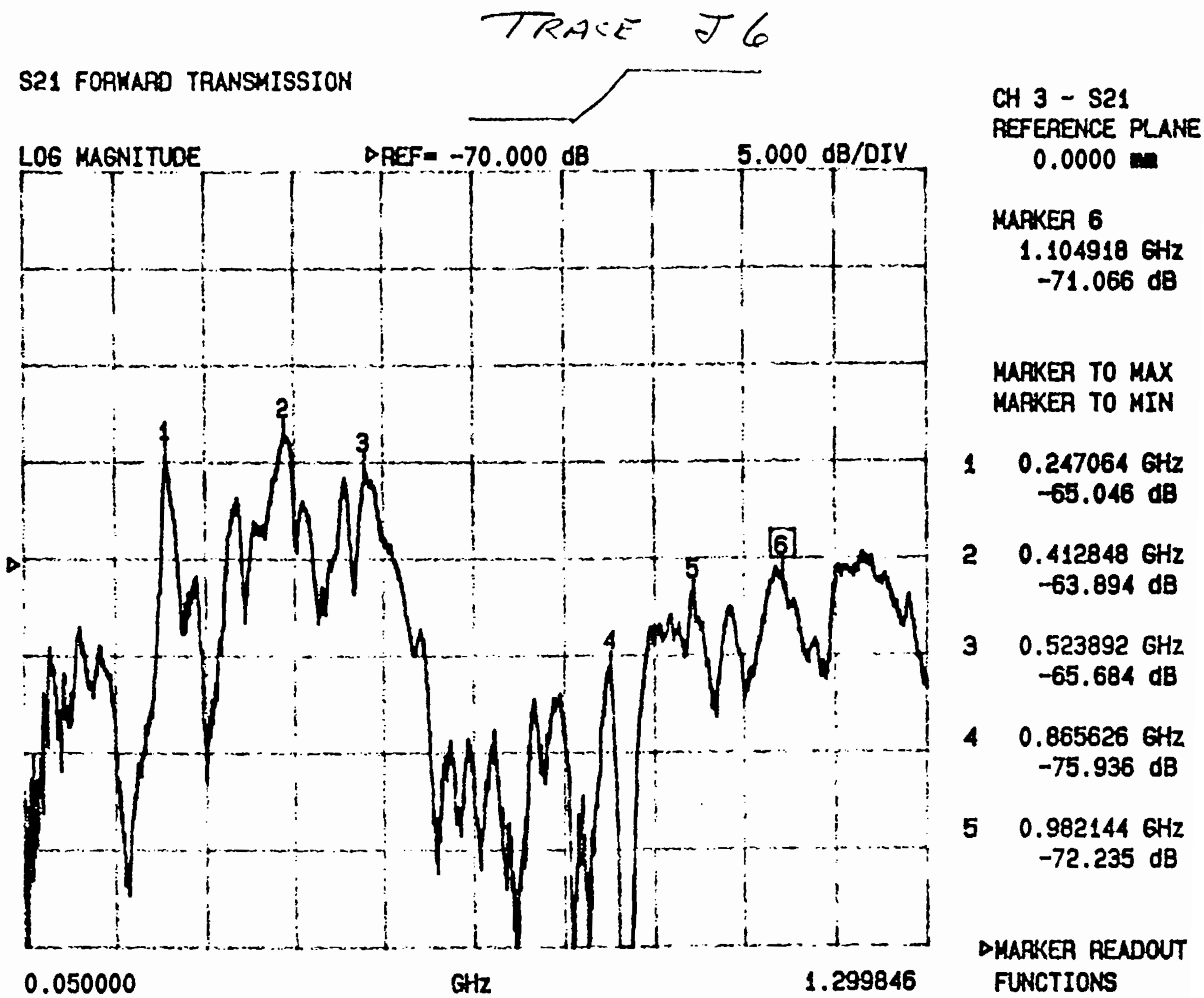

Figure 13. The forward transmission coefficient S_{21} in dB versus frequency in GHz for trace J6 containing two 45° bends.

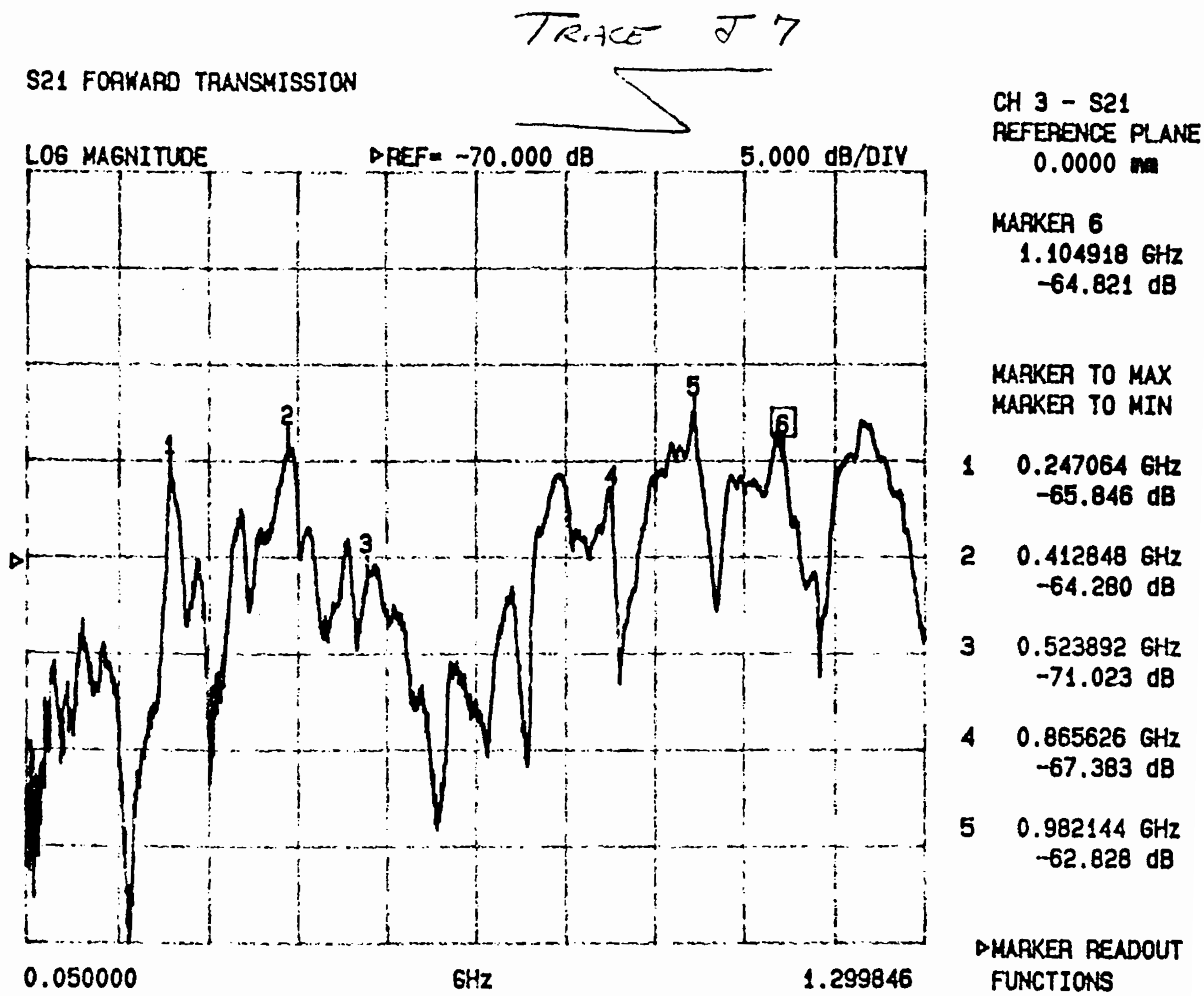

Figure 14. The forward transmission coefficient S_{21} in dB versus frequency in GHz for trace J7 containing two 135° bends.