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In-House Report
March 1990



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**VALIDATION OF SHIELDING
EFFECTIVENESS OF CABLES WITH
PIGTAILS**

Timothy W. Blocher

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Air Force Systems Command
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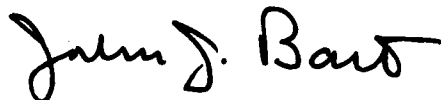
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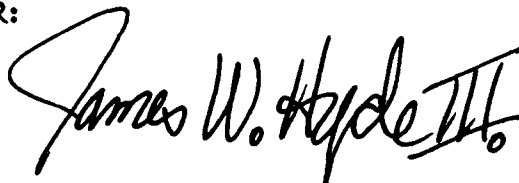
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report focuses on the validation of experimental data used to develop the field-to-wire coupling algorithm in the Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP). IEMCAP is a computer code used to assess the electromagnetic compatibility (EMC) of Air Force systems. The experimental data of interest was obtained by measuring, in a mode tuned reverberation chamber (MTRC), the shielding effectiveness (SE) of coaxial cables terminated in pigtails. The results of these measurements indicate that a coaxial cable terminated in a pigtail has no shielding from electromagnetic interference (EMI). When repeating these measurements, it was found that coaxial cables terminated in pigtails can have a degree of SE. Due to the opposing results, the various characteristics of pigtails, such as length and construction, are investigated to determine which pigtail attributes critically reduce the SE of coaxial cables. From this investigation, the parameters that critically reduce the SE of coaxial cables are identified. Recommendations are then made regarding the field-to-wire coupling algorithm in IEMCAP and regarding follow-up investigations.						
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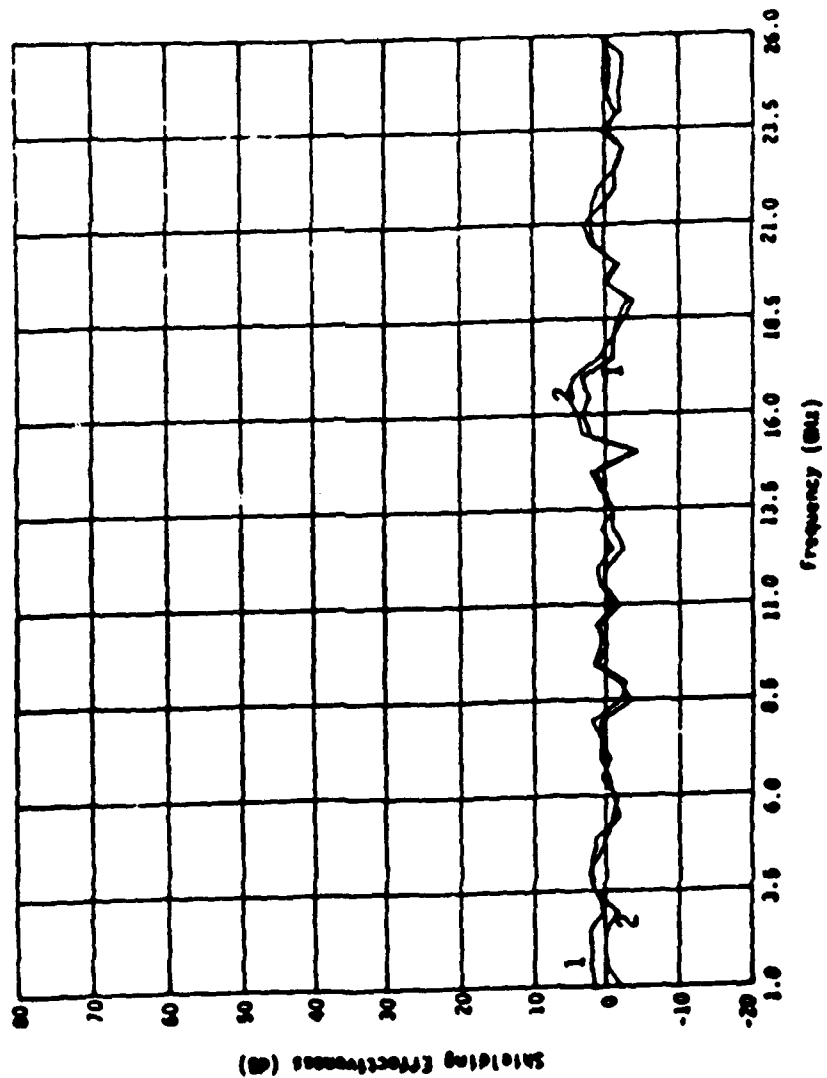
INTRODUCTION

The purpose of this in-house effort was to validate and expand on the results of research conducted in reference [1]. The research in [1] was performed to determine how the various attributes of coaxial cables grounded by pigtails affect the shielding effectiveness (SE) of those cables at microwave frequencies and to develop, based on their findings, a field-to-wire coupling algorithm for the Intrasytem Electromagnetic Compatibility Analysis Program (IEMCAP). The IEMCAP computer code is used to determine the electromagnetic compatibility of Air Force systems throughout their life cycle.

This effort focuses on a finding of the experimental phase in [1] that implies that a cable having any length of pigtail at the end where the measurements are being made has no SE at 1 GHz and above (see Figure 1). One might expect that as the pigtail becomes electrically long the SE of the cable will decrease but, at 1 GHz, the pigtail described in Figure 1 only has an electrical length of $1/60$ of a wavelength. Since the pigtail discussed in [1] is electrically short at 1 GHz, the aforementioned conclusion of [1] is intuitively questionable.

The scope of this test was to confirm or dispute the intuitive assertion that pigtails do not necessarily reduce the

SE of a cable to zero. In order to validate the results found in [1], the test must be repeated as precisely as possible. If the findings of this test differ significantly from the previous test, steps will be taken to determine how the various pigtail attributes do, indeed, effect the SE of coaxial cables.



Curve	Description
1	0.5 cm pigtail
2	0.5 cm exposed center conductor

Type:	RG-58C/U
Length:	1 m
Load:	50 ohm
Far Ground:	yes
Near Ground:	variable
Far Pigtail:	---
Near Pigtail:	variable
Twists:	---

Figure 1: RESULTS IN QUESTION FROM REFERENCE 1

TEST FACILITIES AND CONFIGURATION

The test configuration is shown in Figure 2. This experiment was conducted in the RADC mode tuned reverberation chamber (MTRC) (see Figure 3) which, being significantly larger than Kaman's MTRC, allows measurements to be made down to 150 MHz [2]. However, for this test, the frequency band of interest ranges from 300 MHz to 8 GHz with measurements taken in 100 MHz steps. This wide frequency band leads to the use of 4 bi-directional couplers, 4 horn antennas and 2 power amplifiers due to the limited availability of wide band devices.

The MTRC paddle was controlled by an HP 9000 while the test equipment was controlled by an HP 1000 in order to make use of existing code. To expose the cable under test (CUT) to all possible modes from all incident angles, the paddle of the MTRC was turned in 1.8 degree steps resulting in 200 paddle positions for one full turn as recommended in [3]. Note that the end of the CUT terminated in a 50 ohm load is referred to as the far end of the cable and the end with the pigtail where measurements were made is called the near end of the cable.

Since [1] did not cite input power levels, the decision was made to use the lowest powers that could be picked up at the output. These are on the order of a milliwatt. These low input power levels are produced by solid state amps that

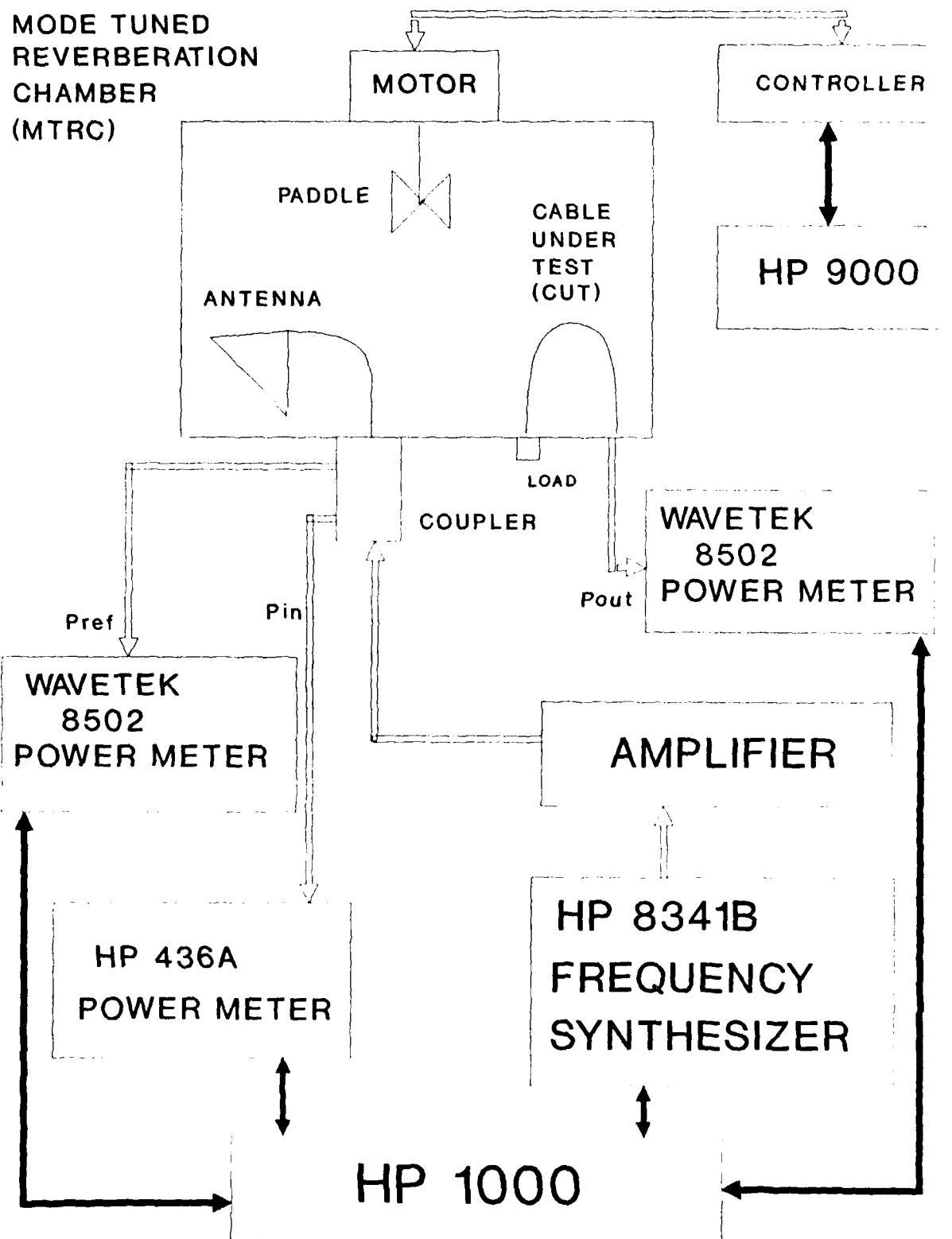


Figure 2: TEST CONFIGURATION



Figure 3: RADC MTRC

generate insignificant harmonics therefore, filters are not necessary for the power meters to measure only the power at the frequency of interest.

This set up differs from the one used in [1], most notably, in that Kaman used a network analyzer to measure the s-parameters required to calculate the coupling factor (CF). A network analyzer was not available for this test therefore, since s-parameters are calculated from values of power, the power meters shown in Figure 2 were used to measure power into the antenna, power reflected back from the antenna and power picked up by the CUT instead. The validity of this equipment substitution will become apparent when the coupling factor is defined in the next section.

MEASUREMENT METHODOLOGY

The measurement setup shown in Figure 2 was designed to collect the data required to calculate the CF, defined in Figure 4, of a CUT at each of the desired frequencies for every paddle position. More simply, while the paddle is in one position the HP 1000 code calculates a CF data point at each desired frequency; the paddle is then stepped to the next position where another CF data point is calculated for each frequency and so on until all required paddle positions have been reached. The HP 1000 code then averages the many CFs per frequency in order to produce a plot of CF versus frequency.

As stated in the previous section, at least 200 paddle positions per rotation are recommended to obtain a "complete" set of data however, for this effort only 100 paddle positions for half a rotation were used. This time reduction technique can be employed due to the symmetry of the RADC MTRC paddle and due to the data requirements. Since the paddle is nearly symmetrical, the modes set up in the first 180 degrees of paddle rotation are very similar to the modes set up in the second 180 degrees of rotation causing the data to be similar. For very precise measurements this method is not recommended; but since this test only requires a trend in the data 100 paddle positions per 180 degrees are sufficient. The data in Figure 5 supports this decision. Therefore, this technique should not void a comparison between these results and those of



Pin = POWER INTO ANTENNA

Pref = POWER REFLECTED BACK FROM ANTENNA

Pout = FRACTION OF POWER COUPLED TO C.U.T. THAT IS
MEASURED BY OUTPUT POWER METER

$$\text{COUPLING FACTOR (CF)} = \frac{10^{(S_{21}/10)} P_{\text{out}}}{1 - 10^{(S_{11}/10)} P_{\text{in}} - P_{\text{ref}}}$$

Figure 4: COUPLING FACTOR DEFINITION

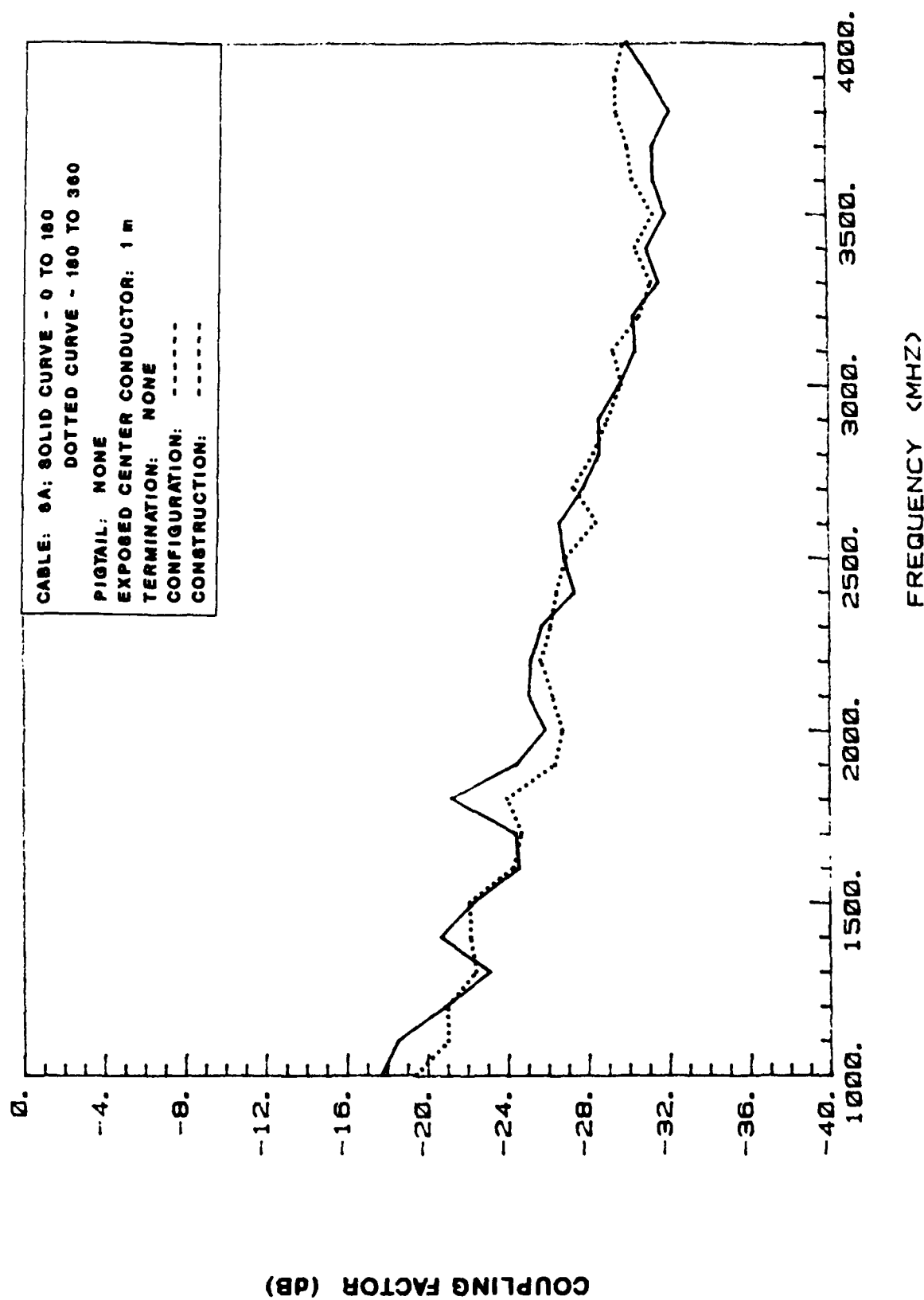


Figure 6: CABLE 8A COMPARISON FROM 0 TO 180 AND 180 TO 360

Kaman.

The frequency range of this test was from 300 MHz to 8 GHz in which measurements were made every 100 MHz. Within the frequency band of 1 GHz to 8 GHz, a direct comparison was made between the data of the two efforts. Within the 300 MHz to 1 GHz band, additional SE data was obtained with respect to Kaman's effort. Collecting data at these lower frequencies produces a more complete set of information allowing a more thorough investigation of this topic.

The purpose of making these measurements was to determine the shielding effectiveness of various CUTs. The SE of a cable having a pigtail was calculated by subtracting the CF plot of the CUT from the CF plot of a reference cable to be defined later (see Figure 6).

A number of methodology considerations had to be taken into account regarding the cables. The first issue was cable mounting. For the measurements made in [1], the cables were mounted on the bulkhead which is not consistent with the method for proper use of the RADC MTRC. Equipment under test should be placed in the center of the MTRC in order to be exposed to the maximum fields. Bulkhead configuration, however, does seem to represent the actual environment that a cable having a pigtail would encounter. Since both of these considerations are valid, the cables are tested on both the bulkhead (Figure

$$SE = CF_{\text{reference}} - CF_{\text{cut}}$$

SE = SHIELDING EFFECTIVENESS OF
CABLE UNDER TEST

$CF_{\text{reference}}$ = COUPLING FACTOR OF REFERENCE CABLE

CF_{cut} = COUPLING FACTOR OF CABLE UNDER TEST

Figure 6: SHIELDING EFFECTIVENESS DEFINITION

7a) and in the center of the chamber (Figure 7b) with an emphasis on the bulkhead measurements.

Cable positioning was another concern. The cables tested, whether mounted on the bulkhead or in the center of the chamber, were placed on styrofoam platforms in which grooves were channeled. The CUT was then laid in these grooves to ensure the uniform positioning of each cable (see Figure 7a). Care also has to be taken to insure that the CUT was never directly radiated by the side lobes of the antennas.

To place the CUT in the center of the MTRC to make measurements, a piece of hard line was connected between the cable's near end and the bulkhead while the cable's far end was then terminated inside the chamber (see Figure 7b). The attenuation along the length of hard line must also be considered. This loss was measured over the frequency range, averaged over each frequency band and was then accounted for in each CF calculation.

An attempt was made to acquire the original cables from Kaman; but of the ones received, only the reference cable could be used. As in [1] all the cables used in this effort are type RG-58C/U having lengths of 1 meter with SMA type connectors.

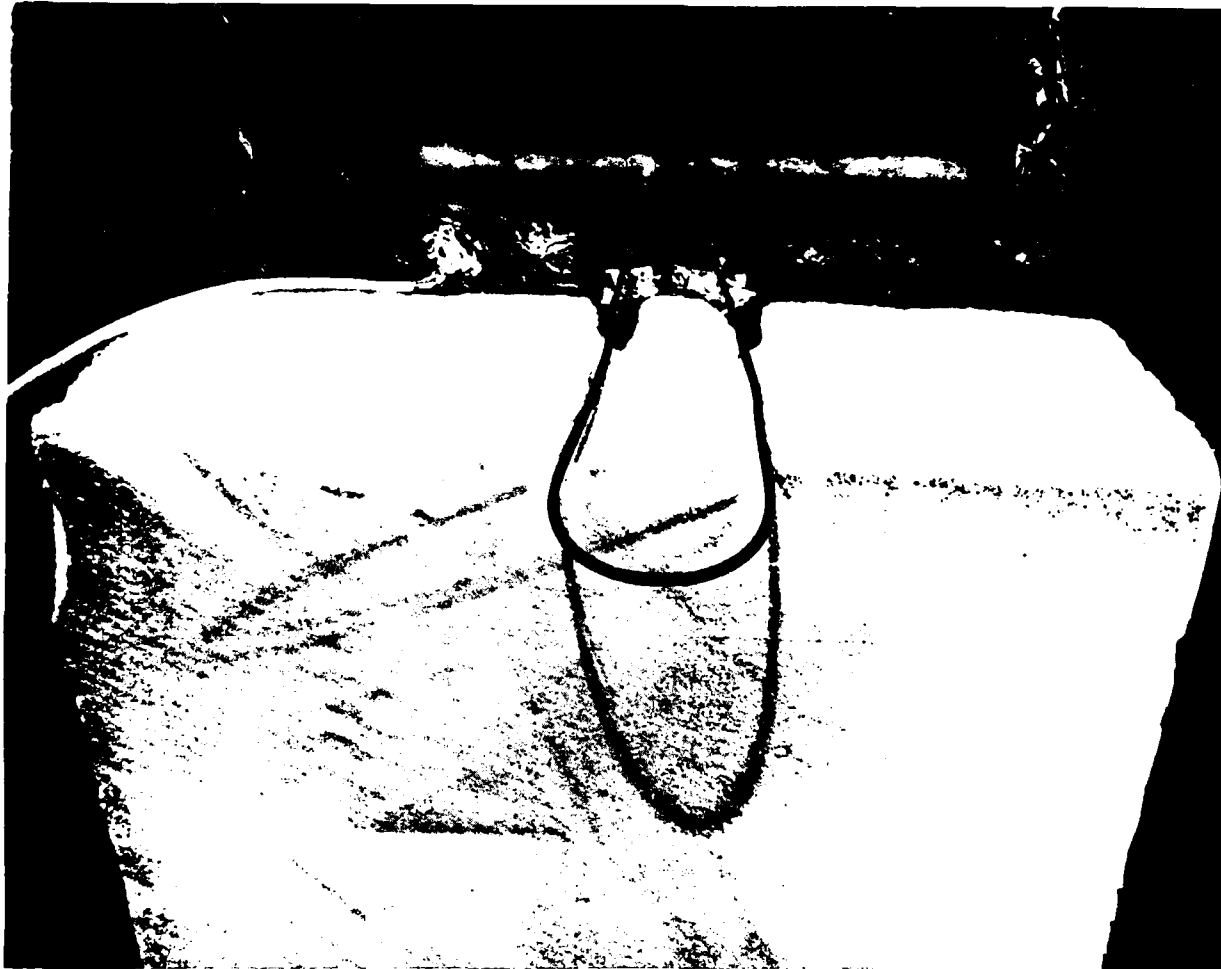


Figure 7a: CABLE MOUNTED ON BULKHEAD



Figure 7b: CABLE IN CENTER OF MTRC

RESULTS

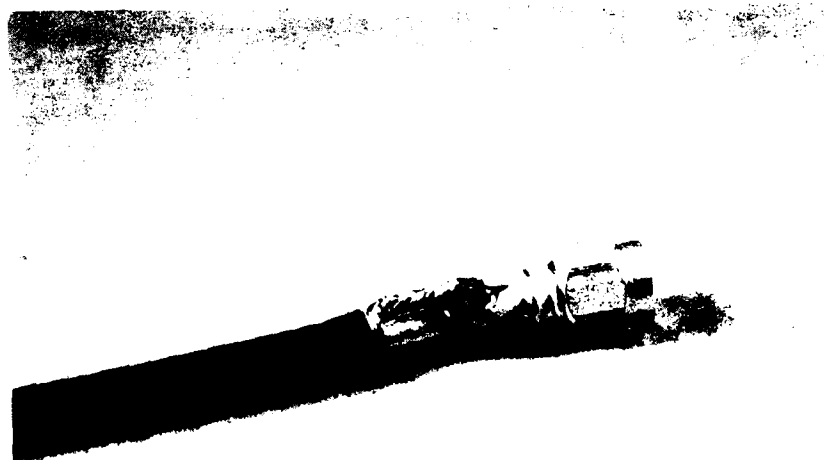
The reference cable, upon which the SE of every cable was based, is shown in Figure 8a. This cable has had its shield removed so that only its center conductor remains. This cable was chosen to be the baseline since it is considered to have zero SE. Figure 9 shows the CF vs. frequency plot for cable 8a. Figure 10 shows three different CFs for cable 8a to depict the repeatability of measurements in the RADC MTRC. The uncertainty of measurements in a MTRC is less than plus or minus 4 dB [3].

The cable in Figure 8b has a 0.5 cm exposed center conductor and an 0.5 cm pigtail grounded to the SMA connector. A cable having these attributes produced the questionable results for Kaman. Figure 11 compares the CF of the reference cable and this cable. By subtracting the CF of cable 8b from the CF of cable 8a the SE curve of cable 8b results as shown in Figure 12. Notice that this cable has a significant amount of shielding whereas the original data in curve 1 of Figure 1 indicates that there is none.

After a discussion with Kaman, it was determined that their test cables were constructed by cutting off the shield and attaching a wire for the pigtail which was grounded under the bulkhead feedthrough connector. Since the actual pigtail length for Kaman's effort was not known, a shortened 1 cm



(a)



(b)

Figure 8: TEST CABLES



(c)

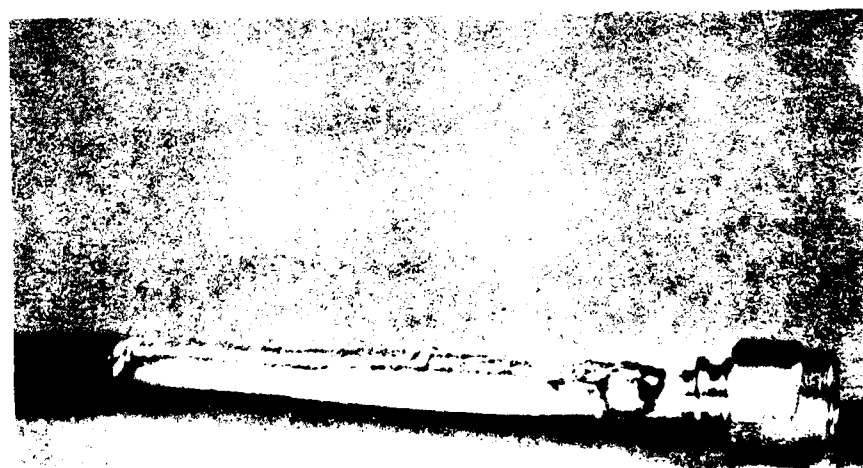


(d)

Figure 8: TEST CABLES

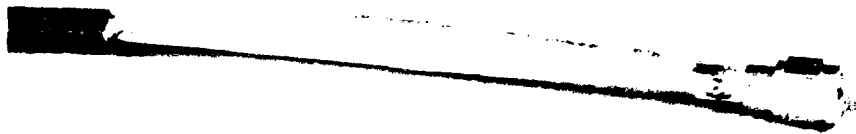


(e)



(f)

Figure 8: TEST CABLES



(h)

Figure 8: TEST CABLES

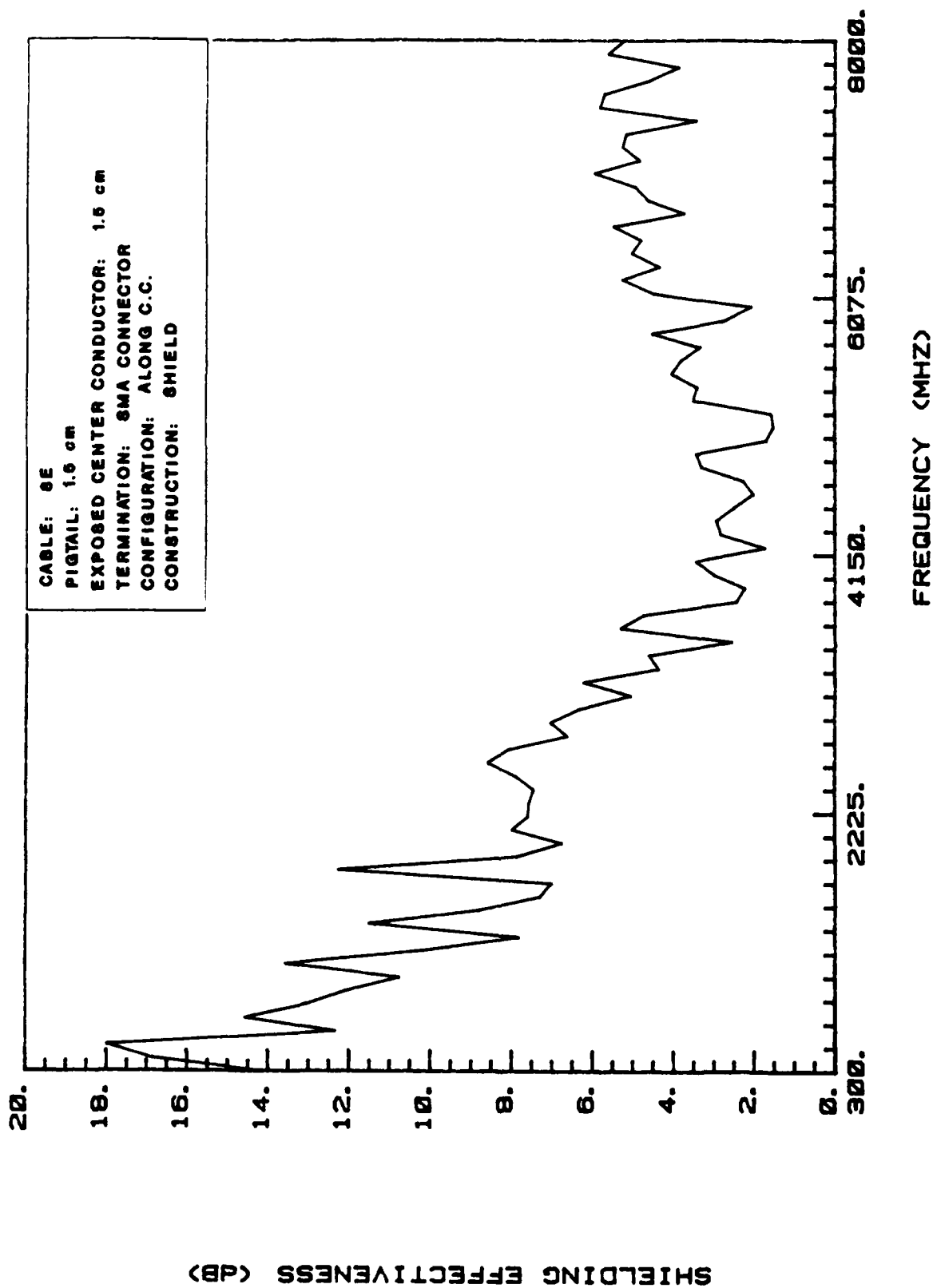


Figure 17: SE OF CABLE 8E

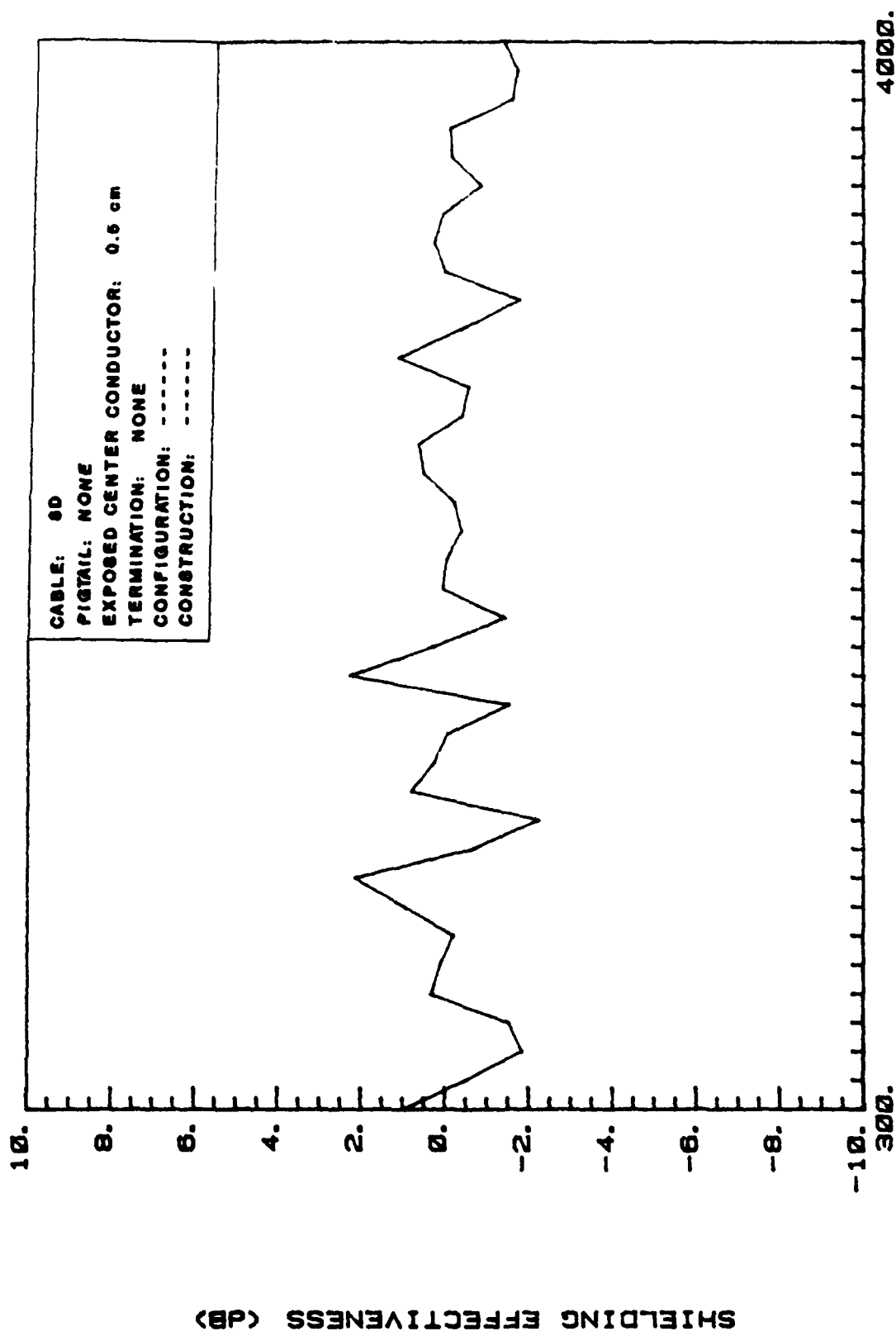


Figure 16: SE OF CABLE 8D

measurement uncertainty factor (plus or minus 4 dB) which means that the SE of these cables is statistically identical. This outcome, while not conclusive, suggests that the material from which the pigtail was constructed and how it was terminated has only a slight influence on the SE of the CUT.

The change in SE due to pigtail length was explored next. The SE curve of cable 8d, which has 0.5 cm of exposed center conductor and no pigtail, is shown in Figure 16. The fact that this cable has no SE is in complete agreement with curve 2 of Figure 1. Cable 8e has 1.5 cm of exposed center conductor and a 1.5 cm pigtail made from the shield grounded to the SMA connector. Figure 17 represents the SE of cable 8e. The SE of this cable is less than that of cable 8b but still has a significant amount of shielding at frequencies lower than 4 GHz. Cable 8f has 4 cm of exposed center conductor and a 4 cm pigtail. As can be seen in Figure 18, the SE of this cable, while still evident, is less than that of both 8b and 8e. Finally, cable 8g, having 8 cm of exposed center conductor and an 8 cm pigtail, is shown in figure 19 to have some SE at various frequencies. Figure 20 demonstrates the decline in cable SE as the pigtail becomes longer and also shows, contrary to Kaman's findings, that a cable with an 8 cm long pigtail still has some SE at and above 1 GHz.

Pigtail configuration was the next attribute to be tested.

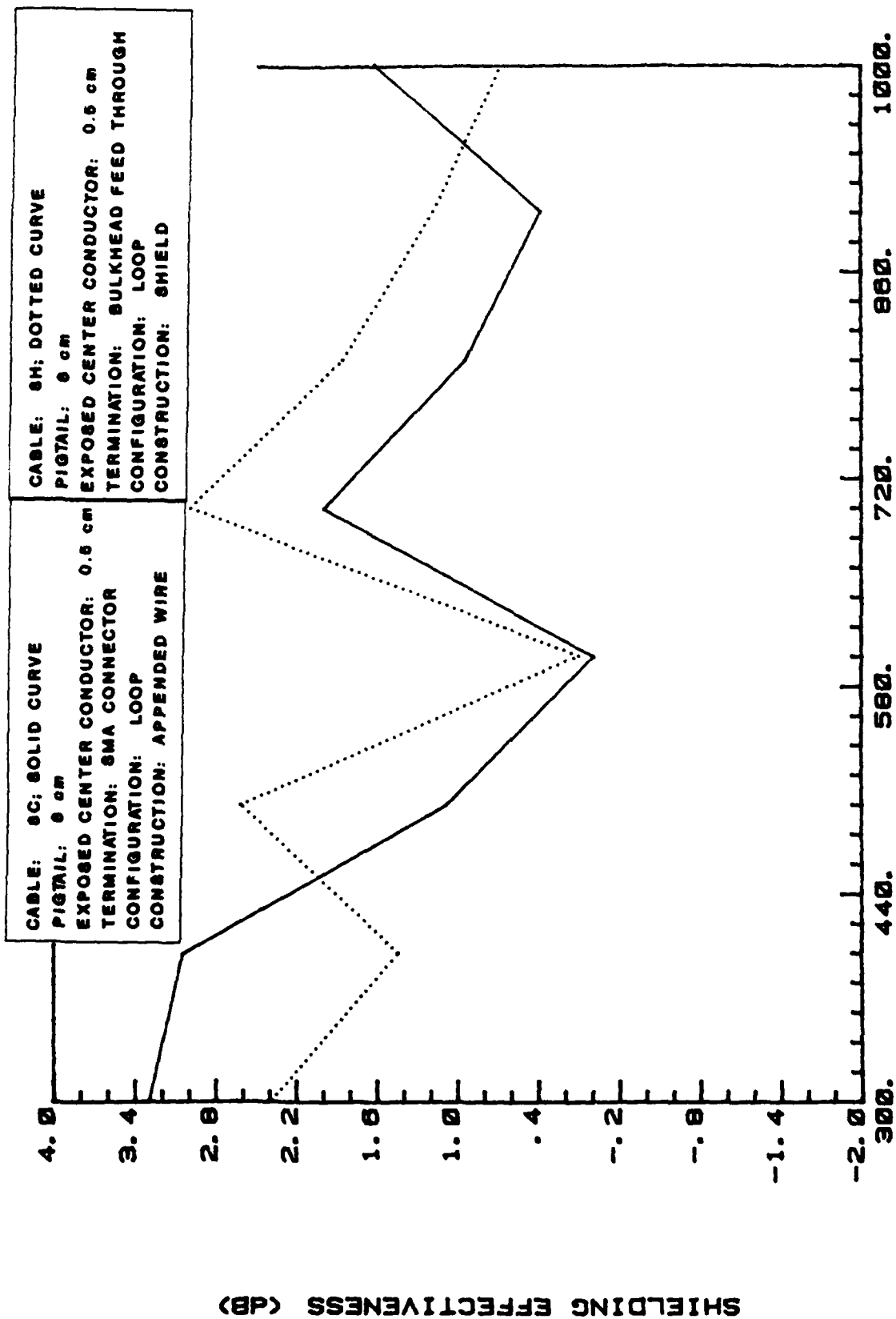


Figure 15: CABLE 8C (SOLID) AND CABLE 8H (DOTTED)

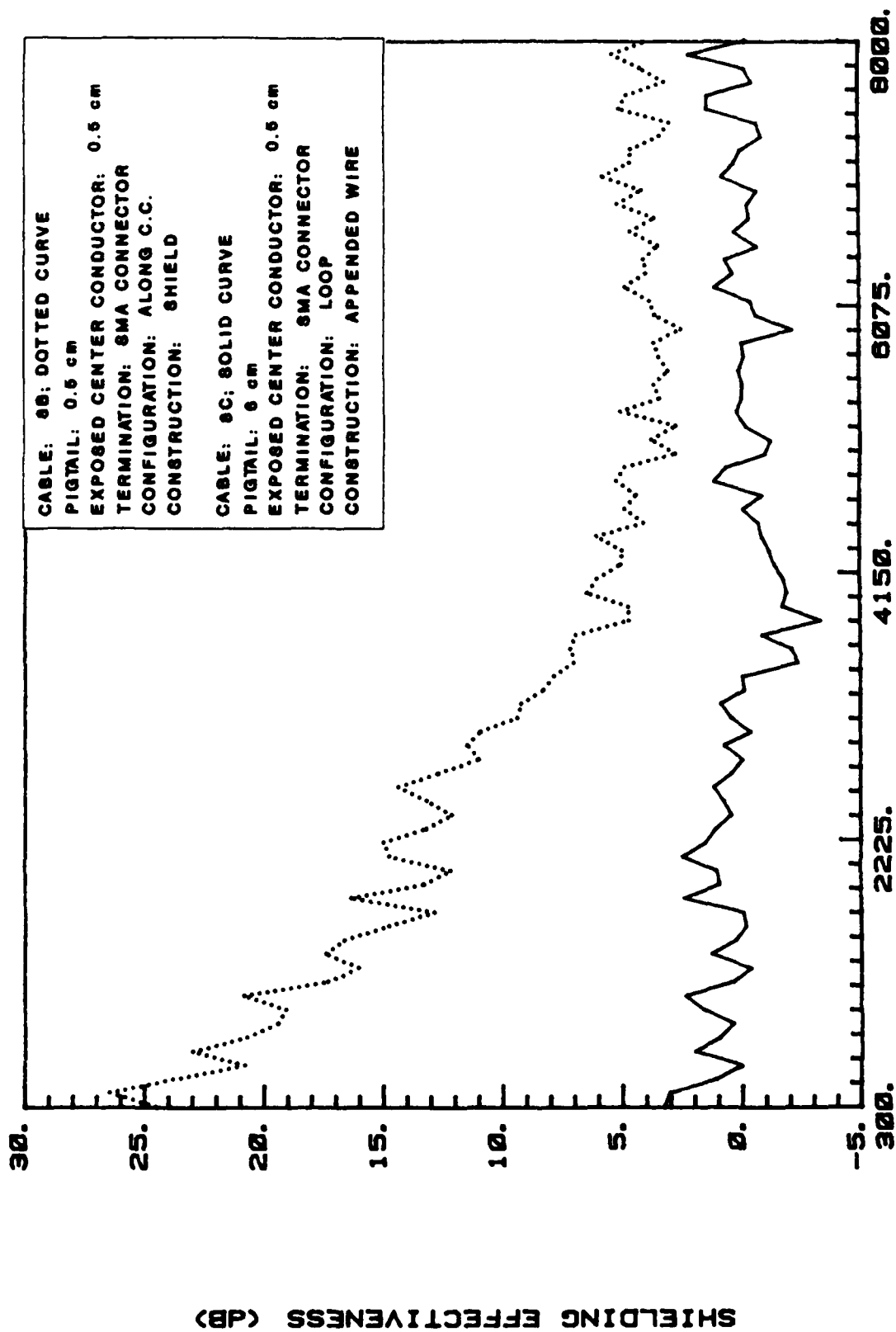


Figure 14: SE OF CABLE 8C (SOLID) AND CABLE 8B (DOTTED)

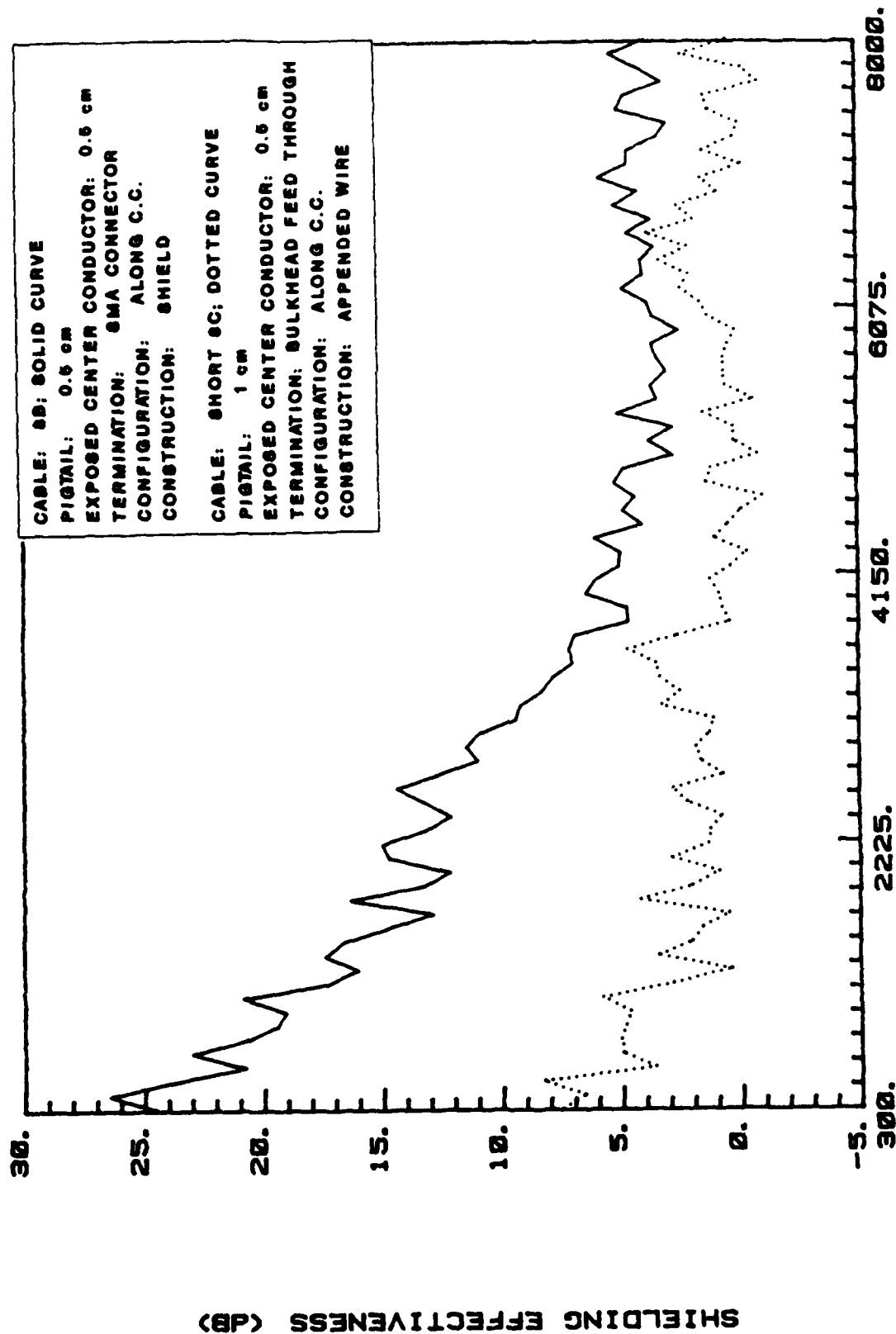


Figure 13: CABLE 8B (SOLID). SHORT VERSION OF 8C (DOTTED)

version, the pigtail shown in Figure 8c, was terminated under the bulkhead feedthrough connector. The results are compared to those of 8b in Figure 13 to better appreciate the large differences.

The SE of this CUT over the range of frequencies is very nearly zero, just as with curve 1 in Figure 1. Due to the large differences between the SEs of cables 8b and the short version of 8c, many questions arise as to which pigtail attributes reduce the SE of cables most dramatically. The attributes investigated are pigtail length, pigtail configuration, pigtail termination, pigtail construction and length of exposed center conductor.

The study began with pigtail construction. The cable in Figure 8c has a 0.5 cm exposed center conductor and a 6 cm looped pigtail made from a wire appended to the broken shield which was grounded to the SMA connector. The SE of 8c is centered around zero for this frequency range as depicted in Figure 14, which compares the SEs of 8b and 8c. This outcome is very similar to that of the short version of 8c.

Cable 8h has a 0.5 cm exposed center conductor and a 6 cm pigtail made from shield-like material grounded under the bulkhead feedthrough connector. Figure 15 compares the SE of 8h and 8c over the frequency range of most interest. At each frequency the SE of each cable was within the MTRC's

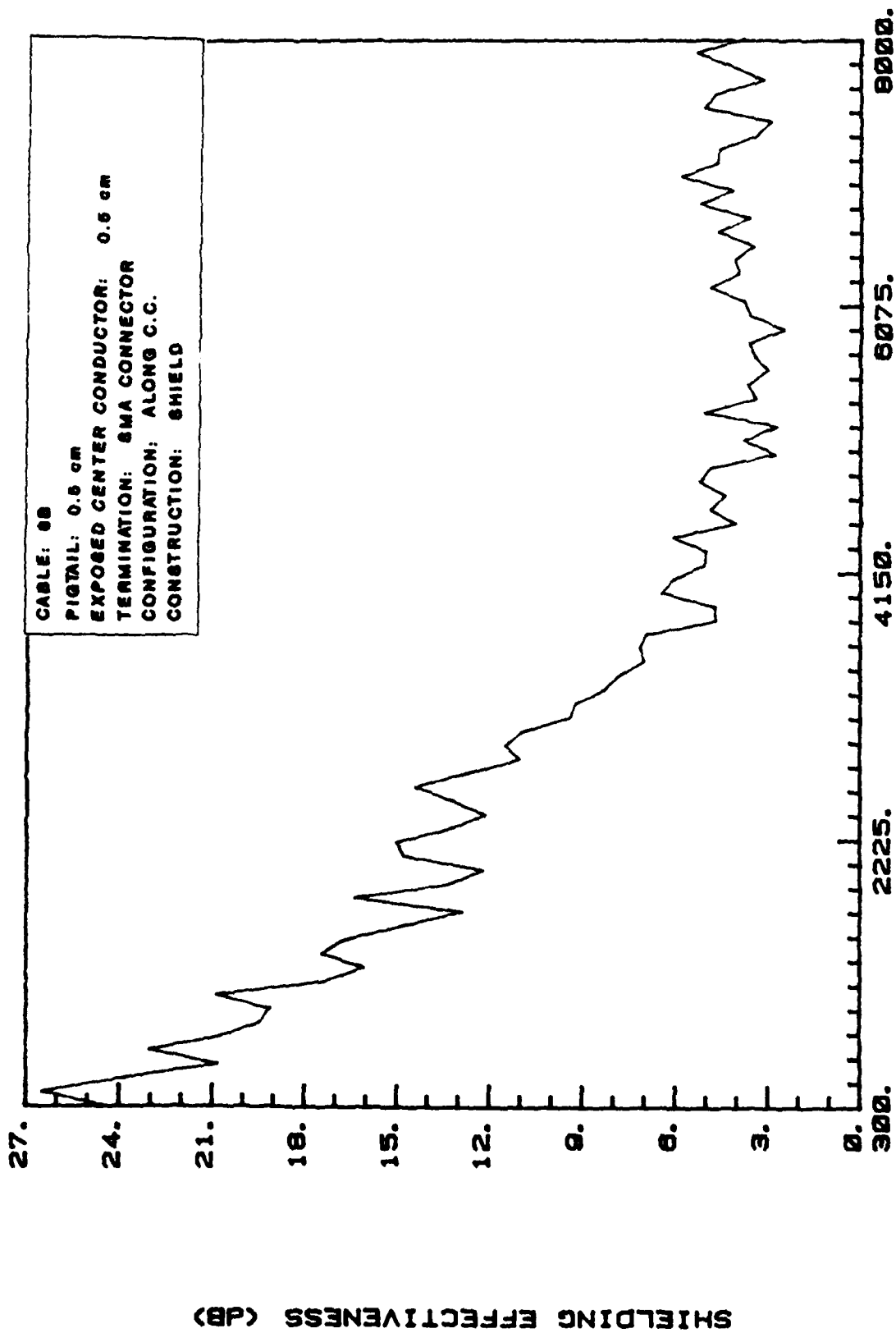
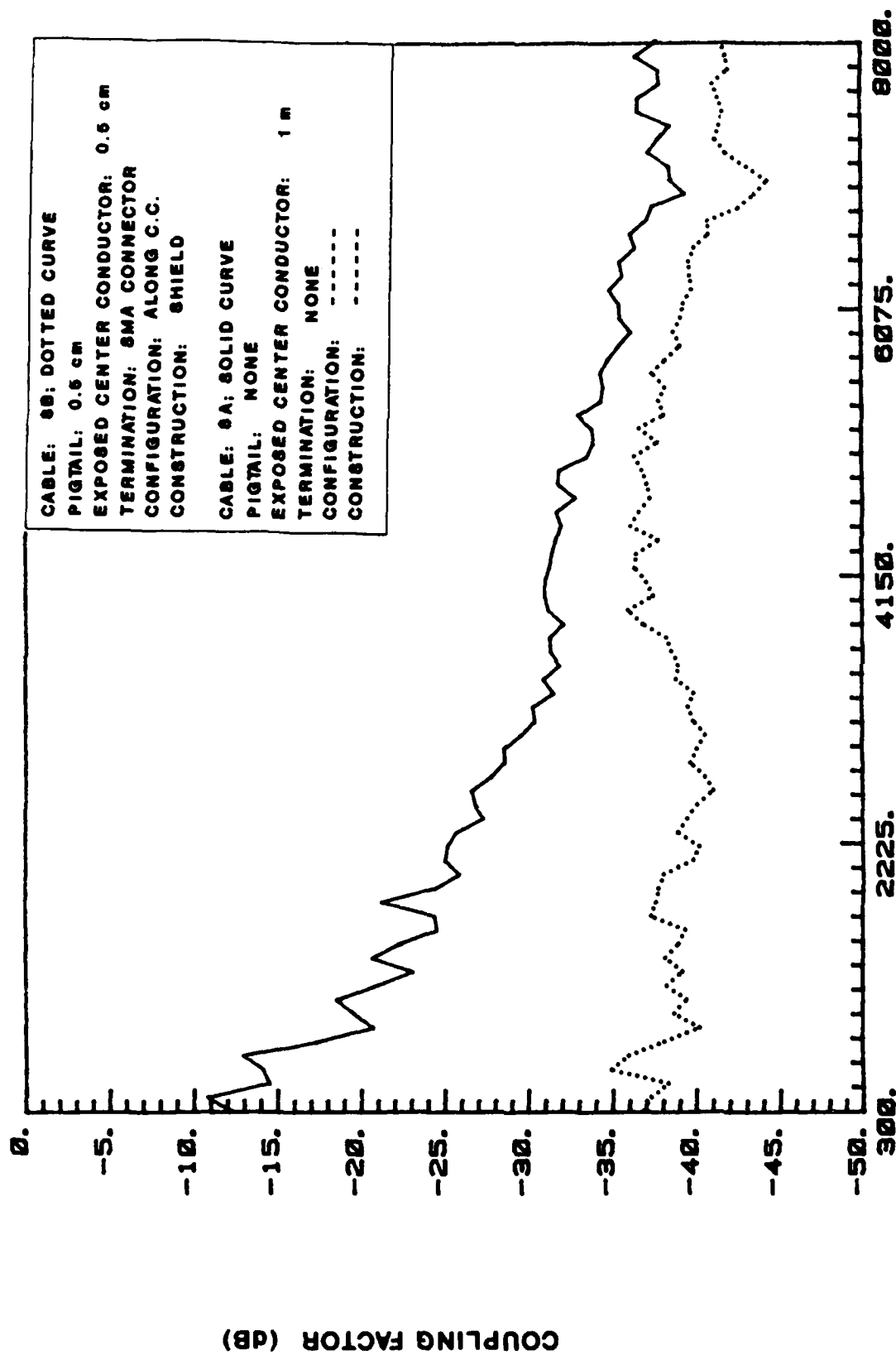


Figure 12: SE OF CABLE 8B



FREQUENCY (MHZ)

Figure 11: CABLE 8A (SOLID LINE) AND CABLE 8B (DOTTED LINE)

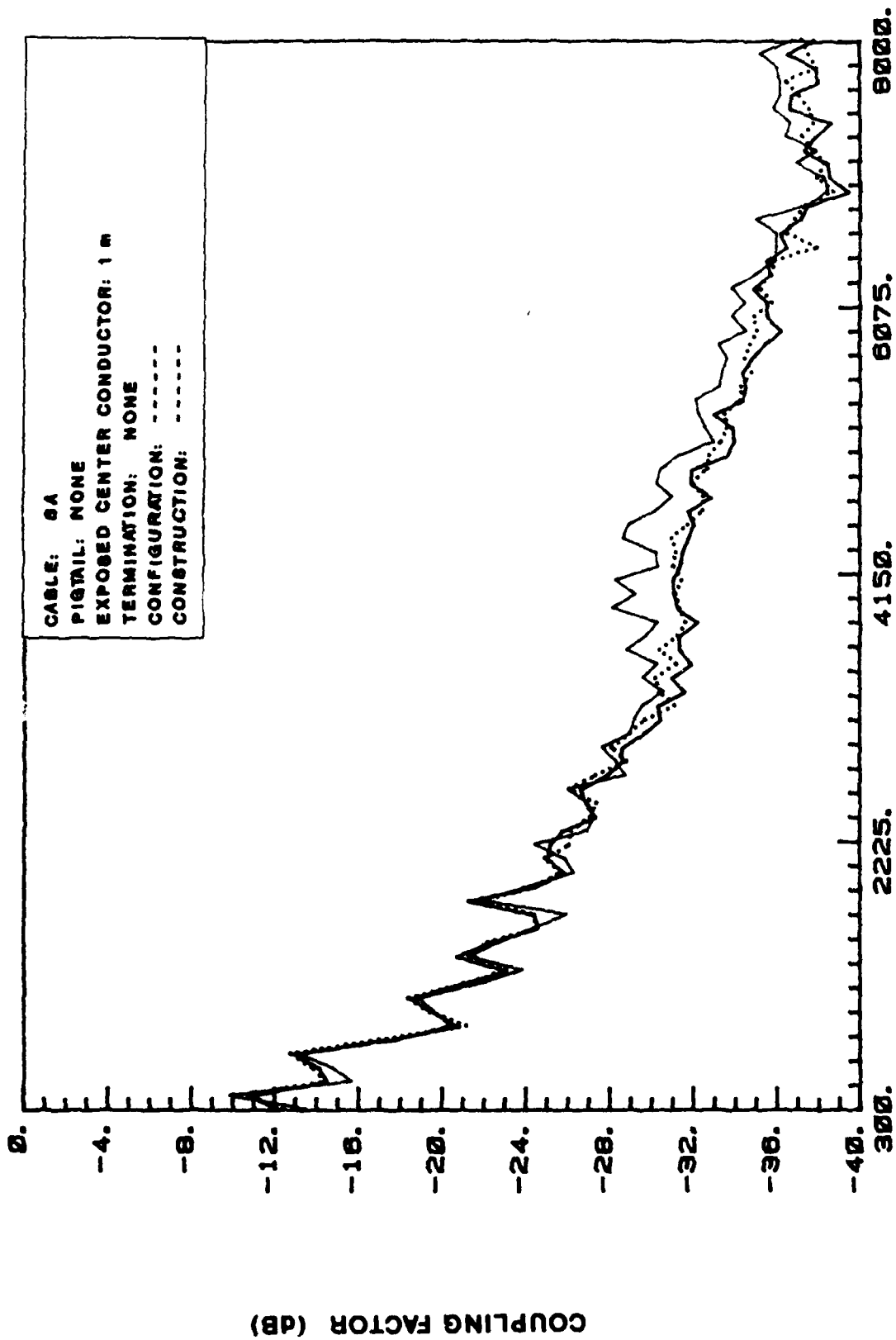


Figure 10: CABLE 8A USED IN MTRC REPEATABILITY TEST

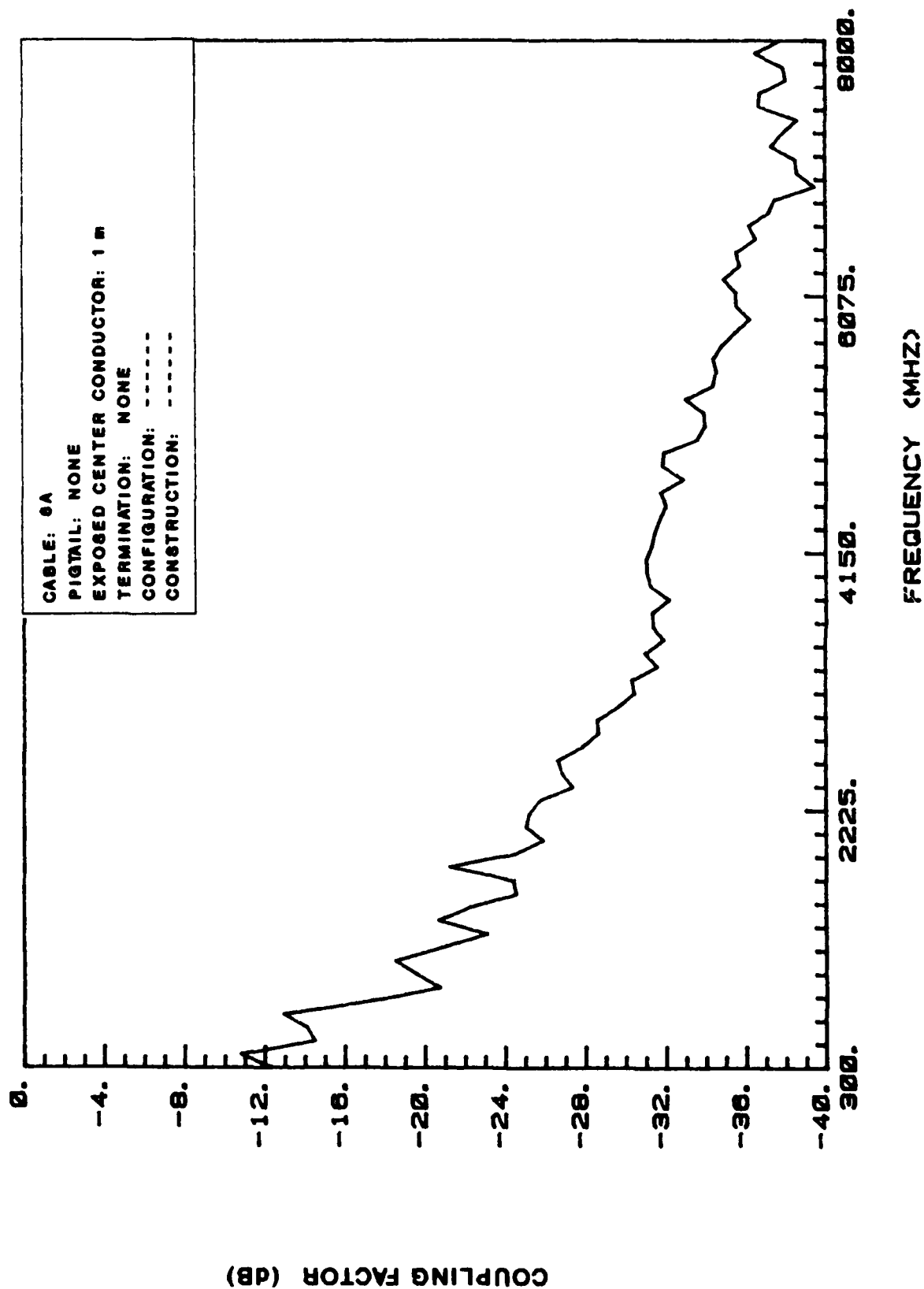


Figure 9: CABLE 8A, REFERENCE CABLE



(i)



(j)

Figure 8: TEST CABLES

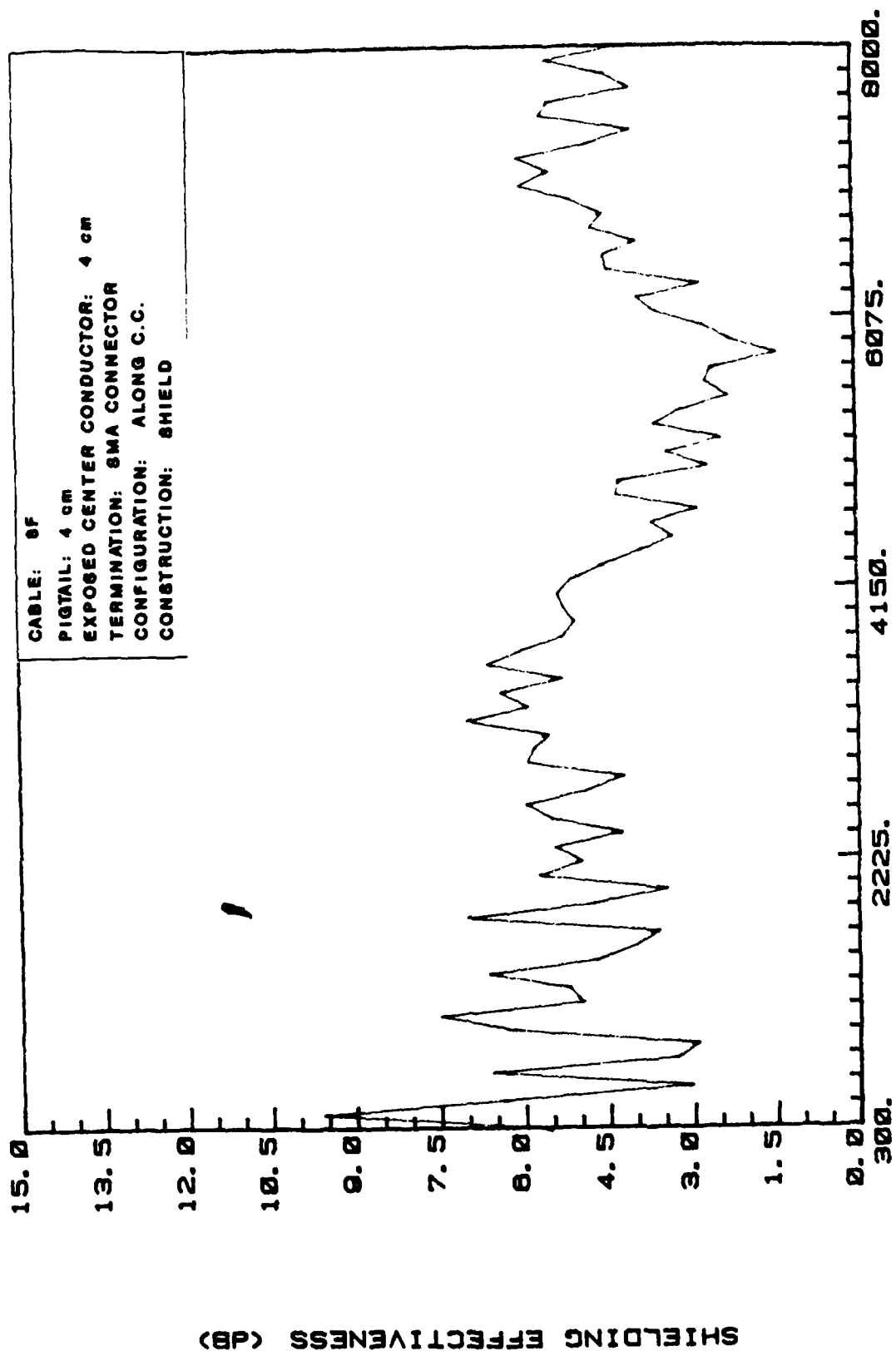


Figure 18: SE OF CABLE 8F

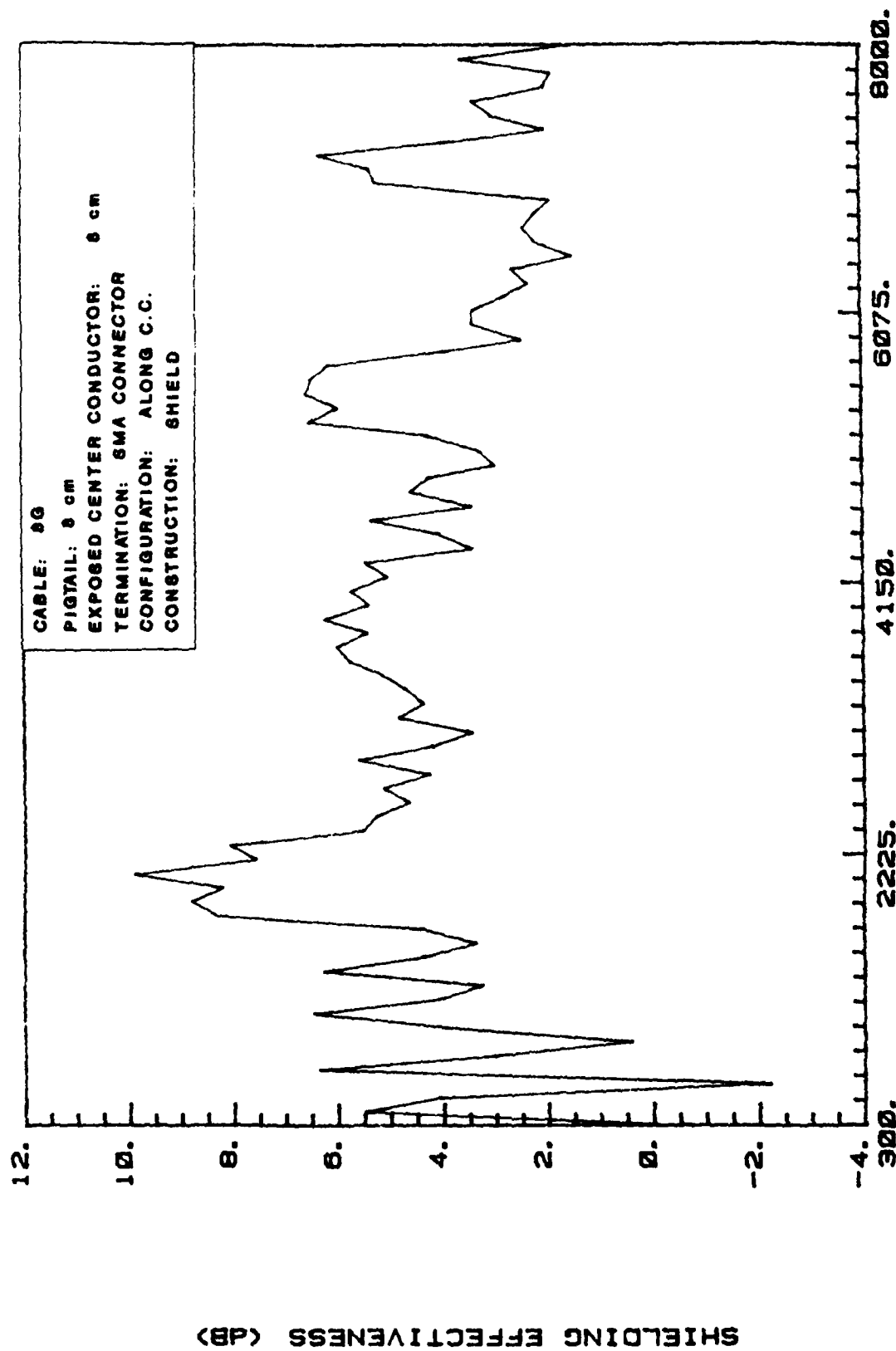


Figure 19: SE OF CABLE 8G

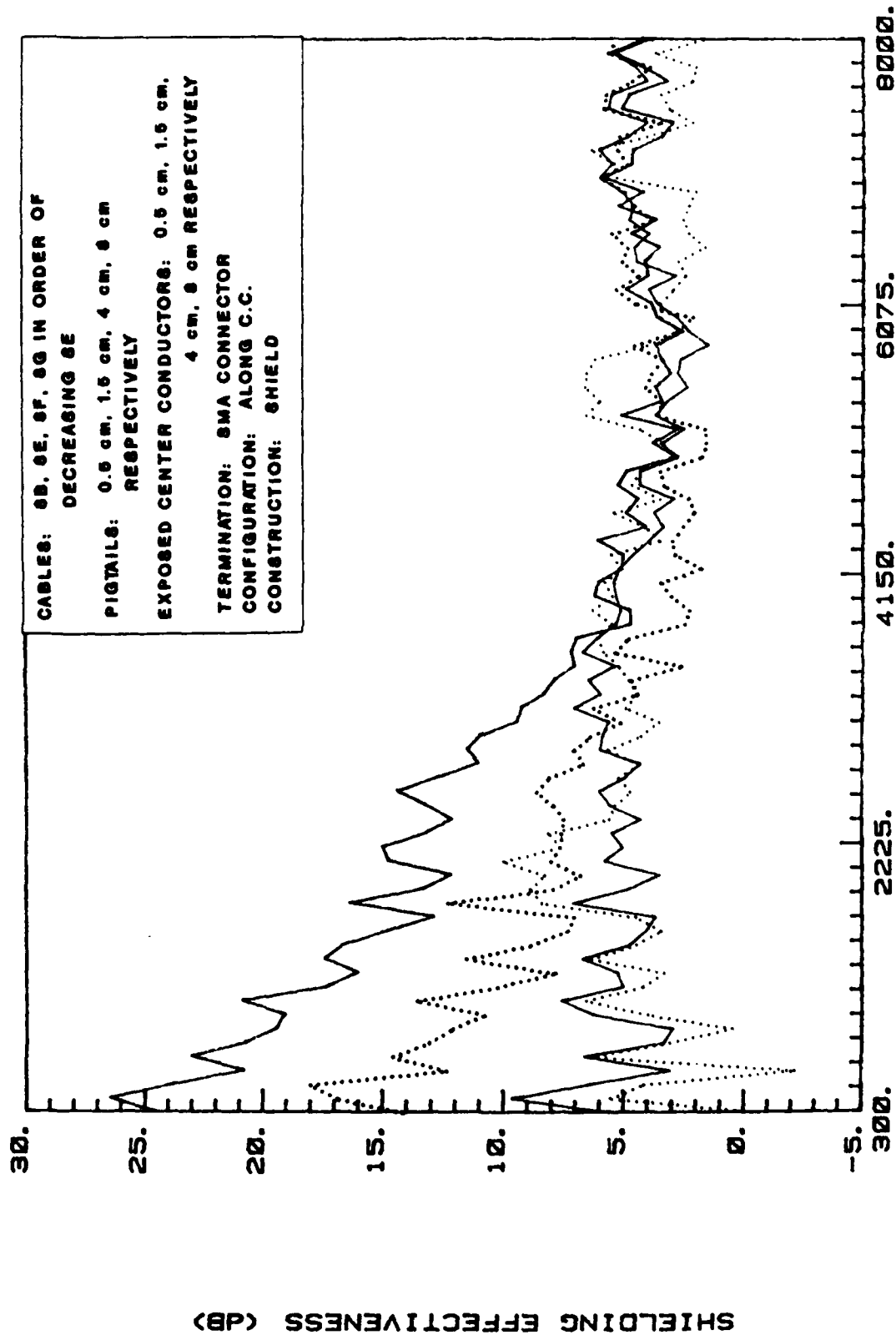


Figure 20: SE OF CABLES BB, BE, BF AND BG

Cables 8c and 8h have pigtails that are configured in loops where as, cables 8b, 8e, 8f and 8g run along the center conductor. Note that the looped pigtails eliminate the cable's SE while the flat pigtails result in some SE up to an undetermined length. Cable 8i was constructed to determine if a pigtail destroys the SE of a cable when configured such that it does not run along the center conductor and is not a loop. Cable 8i has 0.5 cm of exposed center conductor and a 9 cm pigtail that was run diagonally to the center conductor and grounded under a bolt on the bulkhead. Figure 21 shows that this cable also has no SE in this frequency band.

The final attribute to be looked at was the length of exposed center conductor. Thus far, the length of the exposed center conductor has been the same size as or smaller than the length of the pigtail. Cable 8j has 2 cm of exposed center conductor while having a 0.5 cm pigtail. Figure 22 shows that this cable has a moderate degree of SE at the lower frequencies.

To determine whether the method of mounting the cables on the bulkhead produces valid results in the RADC MTRC, cables 8a, 8b, and 8f were tested in the center of the chamber. Figures 23, 24 and 25 compare the SE of these cables on the bulkhead and in the center of the chamber. The actual SE values vary slightly at each frequency but the general trends of the curves still exist. In light of this fact, the

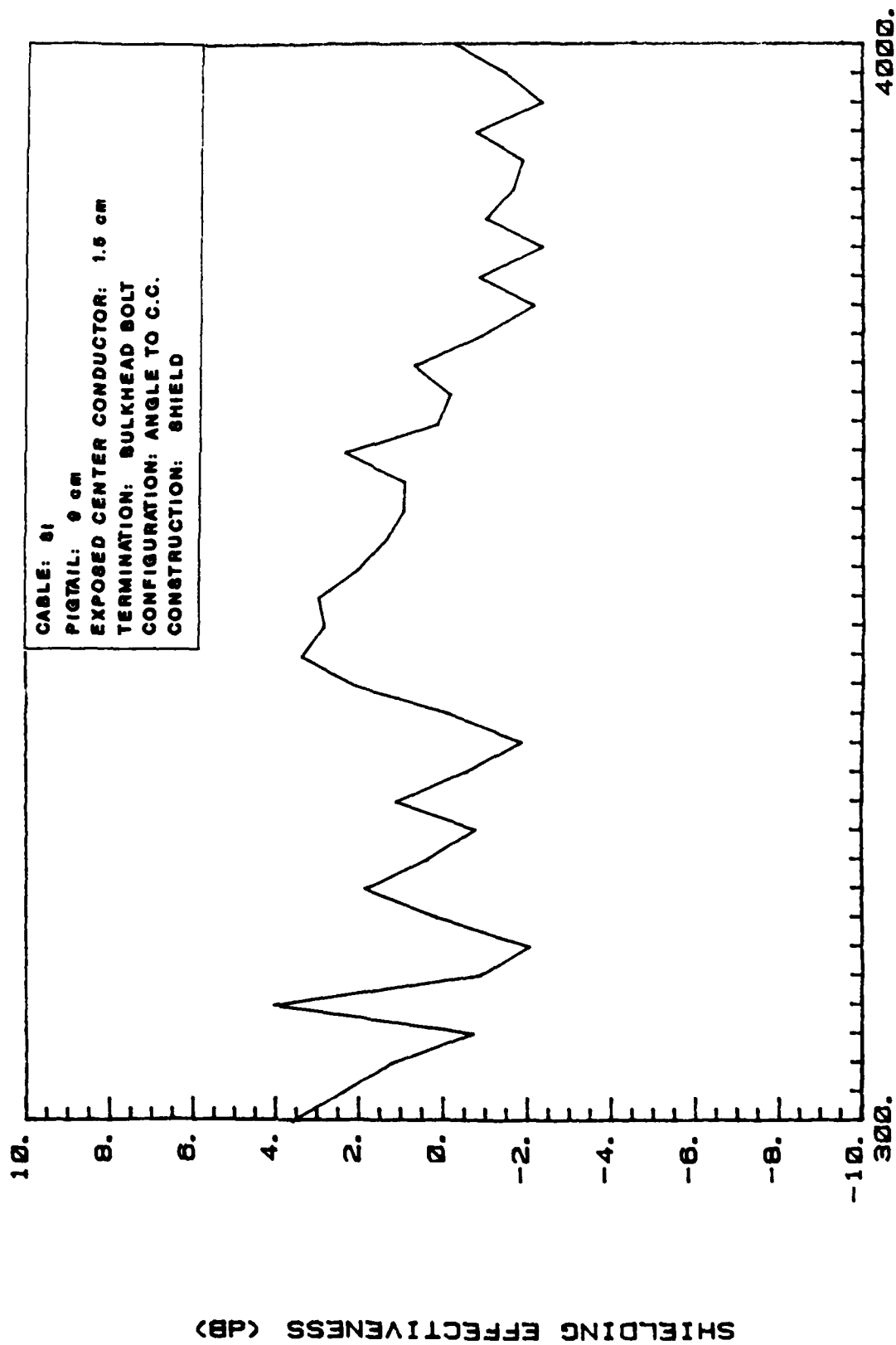


Figure 21: SE OF CABLE 81

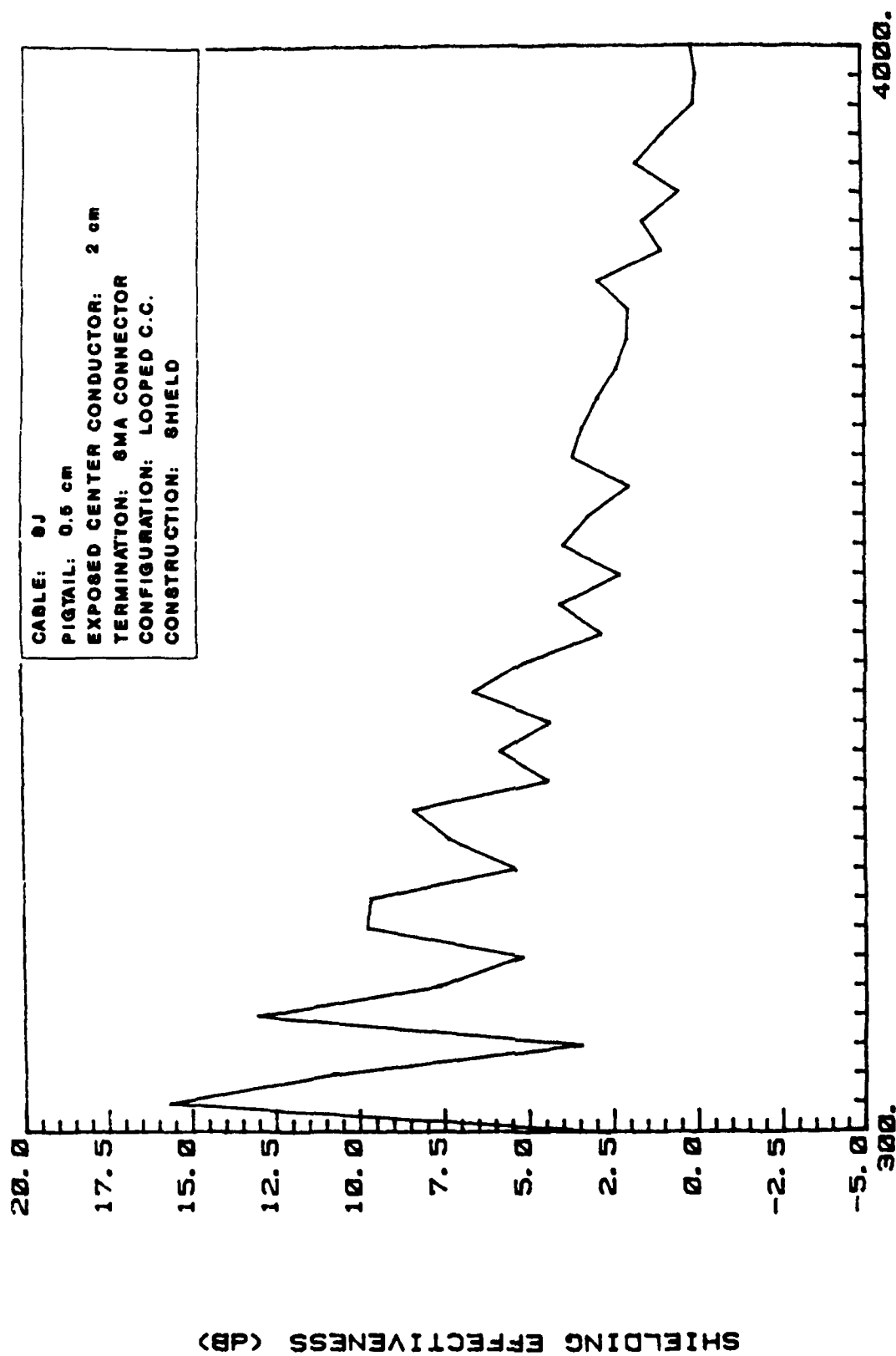


Figure 22: SE OF CABLE 8J

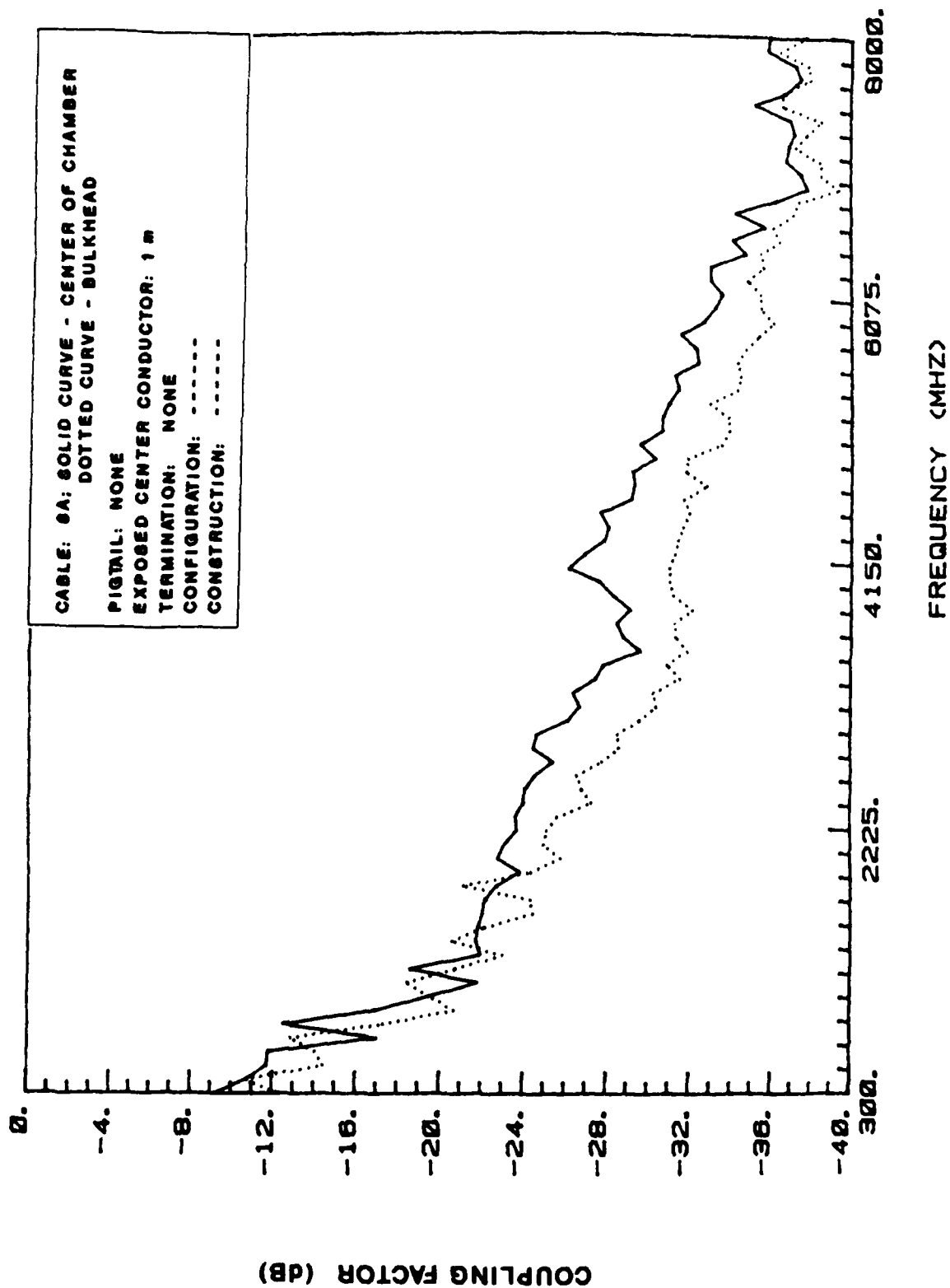


Figure 23: CABLE 8A: CENTER OF CHAMBER (SOLID), BULKHEAD (DOTTED)

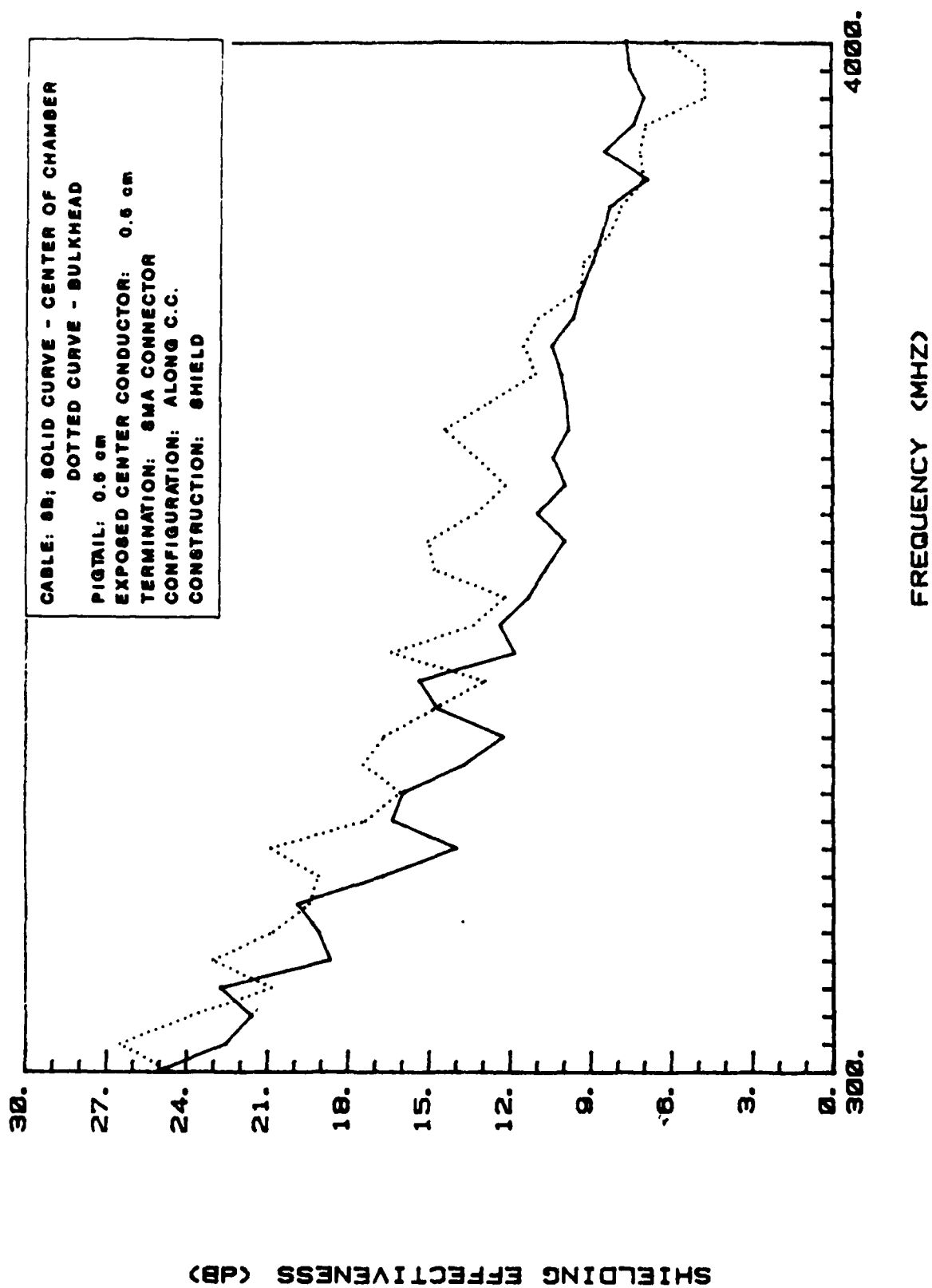
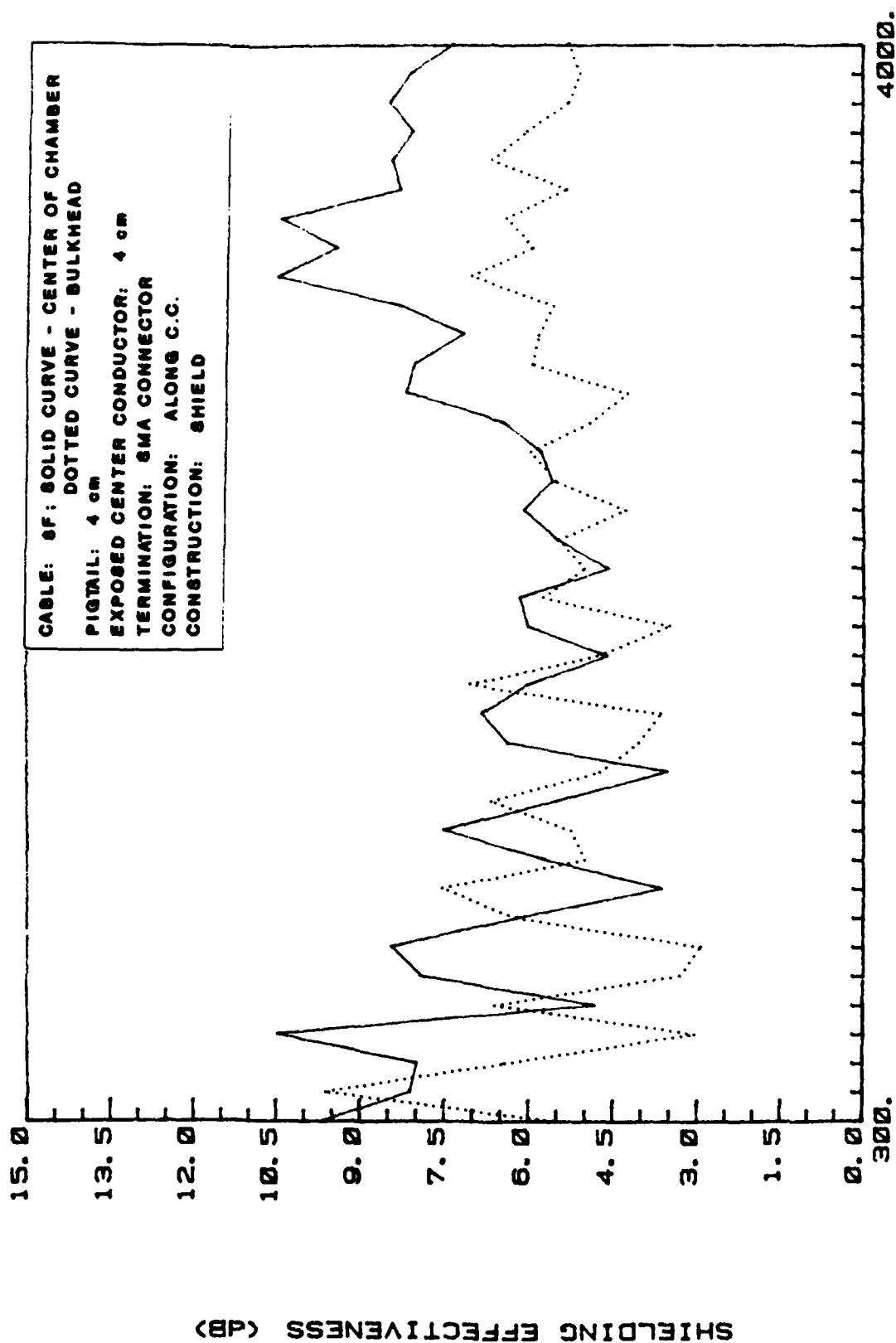


Figure 24: CABLE 88: CENTER OF CHAMBER (SOLID). BULKHEAD (DOTTED)



FREQUENCY (MHZ)

Figure 25: CABLE 8F, CENTER OF CHAMBER (SOLID), BULKHEAD (DOTTED)

measurements made on the cables while they were mounted on the bulkhead are considered valid for this test.

CONCLUSIONS

The results of this effort differ greatly from the results obtained [1]. The measurements made in this study indicate that pigtails do not necessarily reduce the shielding effectiveness of coaxial cables to zero at the frequencies under consideration.

The studied attributes that reduce the SE of cables most drastically are pigtail configuration and pigtail length. In the cables where the pigtails run parallel to the exposed center conductor (8b, 8e, 8f and 8g), the pigtail had to become relatively long before the SE was diminished to near zero at the lower frequencies. Notice that in these cases the pigtail and the exposed center conductor of a cable have approximately the same length.

The cables whose configurations are such that the pigtails are not parallel to the exposed center conductor (8c, 8h, 8i and 8j) have no SE at the test frequencies even when the pigtails are short. Cable 8j is however, an exception to this statement. 8j has a pigtail that does not run parallel to its looped center conductor but still exhibits some SE at the lower frequencies. Of these cables, 8j is not only the sole cable that has some SE, but is also the sole cable whose pigtail is significantly shorter than the exposed center conductor.

These results indicate that the factors that destroy a cable's SE are the absolute length of the pigtail and the ratio of pigtail length to exposed center conductor length. If the pigtail is approximately the same length as or shorter than the exposed center conductor, the cable will have some degree of SE until the pigtail becomes too long as in the case of cable 8g. If the pigtail becomes significantly longer than the exposed center conductor, as in the cases of the looped and diagonal pigtails, the cable will have no SE. See TABLE 1 for summary.

These measured results differ from those presented in [1]. The differences are difficult to explain since many of the test conditions were not documented in [1] making it difficult to duplicate them in this effort. Subsequently, this topic should be investigated again with a different measurement system and the same cables to confirm the results of one of the previous efforts. The approach of this third study could involve testing a real system to determine the validity of the field-to-wire coupling algorithm. Regardless of the approach taken, the third study should be designed such that its results can be used, if necessary, to rework the field-to-wire coupling algorithm developed for the IEMCAP code.

PGTL CONSTRUCT	PGTL TERM	PGTL LENGTH >> LENGTH OF EXPOSED CENTER CONDUCTOR	PGTL LENGTH < LENGTH OF EXPOSED CENTER CONDUCTOR < 8 cm
LITTLE OR NO EFFECT ON SE	X	X	
NO SE		X	
SIGNIFICANT SE AT LOWER FREQUENCIES			X

Figure 26: STUDY SUMMARY

REFERENCES

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*1. Although this report is limited, no limited information has been extracted. The distribution statement is: "USGO agencies and their contractors; critical technology, Jul 88. Other requests RADC(RBET) Griffiss AFB NY 13441-5700."