Fourier Transform technique in place of analogue or digital filtering. The test system layout is shown in figure 21.

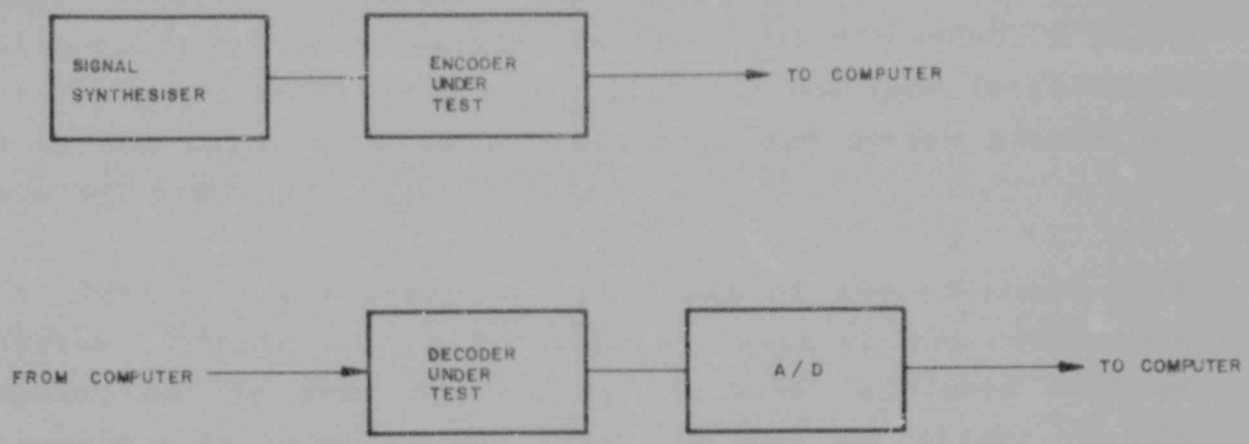

FIGURE 21 TEST SYSTEM LAYOUT AS PROPOSED BY DELL

All measurement processing is done on a computer. In addition, the stimulus required to excite the decoder is generated in software. The input signal for the encoder is generated using a commercially available digital sinewave synthesizer.

1.6 Layout of the present work

It is the intention here to give a brief resume of the sections that are to follow.

Chapter 2 deals with the proposed test system strategy and parameters. The requirements for the test strategy are defined. The proposed test system layout follows closely the system architecture proposed by Dell [1982], for half channel measurements on a codec. The test system takes the form of two separate sections; one for testing the encoder section of the codec and one for testing the decoder section of the codec. All signal generation and signal processing, for both sections, is done in software. The proposed CCITT half channel measurement specification for quantization distortion and gain tracking is given and discussed. A study of the performance of a codec with various imperfections is done and using this as a basis the test system parameters are defined.

In chapter 3 a description is given of the proposed test system together with a detailed analysis of the components making up the test system. An adaptive reference voltage technique is proposed and discussed and its effect on D/A component selection is illustrated. Results are presented,obtained from computer simulation,to illustrate the operation of the proposed test system.

In chapter 4 the two software simulation packages used in the present work are described. TESTS is a software package used to simulate various encoder and decoder configurations. TSTRAT is a package which was used to simulate the proposed test system layout.

Finally,chapter 5 concludes with a review of the present work showing the effectiveness of the proposed test strategy and system layout for the production testing of integrated circuit codecs. Areas were future work is required are indicated.

2 PROPOSED TEST STRATEGY AND TEST SYSTEM PARAMETERS

2.1 Requirements of a test strategy

Accuracy and fast test time are the two basic requirements for a production test strategy. For an ideal test system we require absolute measurement certainty and zero test time. However, this condition is not possible owing to the fact that the above two requirements are conflicting. In order to obtain very accurate measurements the test time must, of necessity, be longer. Conversely, a shorter test time would be accomplished at the expense of measurement accuracy. Thus a compromise between the two requirements is needed. In order to determine the level of compromise required we need to look at how accuracy and test time affect the productivity of the test system. The productivity of a test system is dependent upon two important criteria, yield and throughput.

The yield of a test system is defined as the number of good devices obtained out of the total number of devices tested. The test system itself cannot alter the yield of a sample of devices as this is determined by the manufacturing process involved. However, a test system can cause a loss of yield by calling a good device bad or, worse, calling a bad device good. Therefore, the accuracy of the test system must be such so as to guard against a loss of yield.

The throughput of a test system is defined as the number of devices that can be tested in a given time period.

Integrated circuit manufacturing techniques have advanced to such a stage that a large number of devices can be produced on a daily basis. As a result, device test times must be kept as short as possible in order to accomplish a fair degree of throughput.

The integrated circuit codec differs from other integrated circuits, such as the operational amplifier for example, in two ways. Firstly, the codec must fit into an existing well established telecommunication system. That is to say the design of the system cannot be changed so as to accomodate the device. Instead the device must mature so as to be used in the system. Secondly, the codec must not be considered as a circuit building element as is the case, for example, with an operational amplifier. Rather, it performs a system function defined by exacting international telecommunication standards. Any test strategy that is developed must take these factors into consideration.

To summarise, what is required is a test strategy that demonstrates the codec performance within a telecommunication environment, while obtaining the best compromise possible between measurement accuracy and measurement test time. The three objectives that a codec test strategy must meet are:

1. It must guarantee performance to telecommunication industry specifications i.e. the CCITT. The measurement results delivered by the test system must be presented directly in CCITT terminology thus eliminating the need for translating the results into industry standards.

2. It must avoid relying on simplifying assumptions. Assuming that a device will never operate in a particular configuration or manner

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2. It must avoid relying on simplifying assumptions. Assuming that a device will never operate in a particular configuration or manner

can bring the measurement certainty into question.

3. The time required to conduct the tests must be as short as possible so as to provide maximum throughput.

It is worth noting that the test time has three components:

(a) Stimulation and data acquisition

(b) Processing

(c) Mechanical handling by operator or otherwise

Times represented by (a) and (b) may well overlap with the time represented by (c) being the limiting factor

2.2 The CCITT specification

The CCITT specifications governing the implementation and performance of a PCM codec are given in recommendations G711 [1976a] and G712 [1976b] respectively. Of recent a draft recommendation, G71X [1982], has emerged which discusses the separate performance measurements of the encoder and decoder. The specifications that define the performance of a codec have developed with the telecommunications system and are based on years of extensive research and on-line experience.

CCITT recommendation G712 [1976b] addresses the question of quantization distortion and gain tracking, the two tests proposed in the present work. The recommendation discusses the methods to be used and gives the performance requirements to be met. The tests are based on an analogue end to end basis, i.e. encoder to decoder combination.

For quantization distortion and gain tracking measurements, two methods are recommended, viz. one method using a suitable noise signal as stimulus and another method using a sinusoidal signal as stimulus. As stated previously, only the latter method will be considered in the present work.

For quantization distortion a sine-wave in the frequency range 700-1100Hz (excluding submultiples of the 8kHz sampling frequency) must be applied to the input of the encoder. The ratio of signal to quantization distortion power measured at the output of the decoder using the recommended noise weighting (psophometric weighting) must lie above the limits shown in Figure 22. In the work done by Tsividis and Zee, which is very relevant in the present work reported here, use was made of the C-message weighted filter which is the Bell standard equivalent to psophometric weighting.

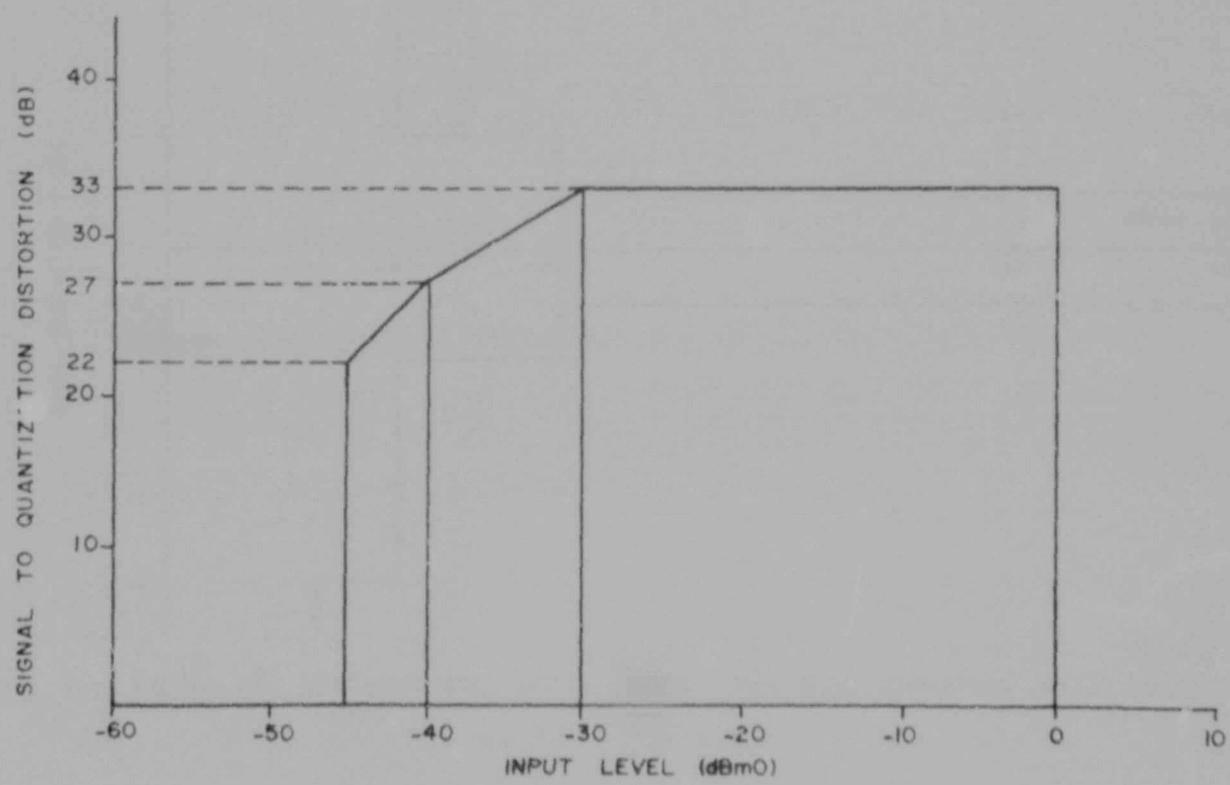

FIGURE 22 RECOMMENDED CCITT MASK FOR SIGNAL TO QUANTIZATION DISTORTION RATIO AS A FUNCTION OF INPUT LEVEL.

For gain tracking or gain variation a sine-wave signal in the frequency range 700-1100 Hz (excluding submultiples of the 8kHz sampling frequency) must be applied to the input of the encoder at a level between -55 dBmO and +3 dBmO. The gain variation, relative to the gain at an input level of -10dBmO, must lie within the limits of the mask shown in figure 23.

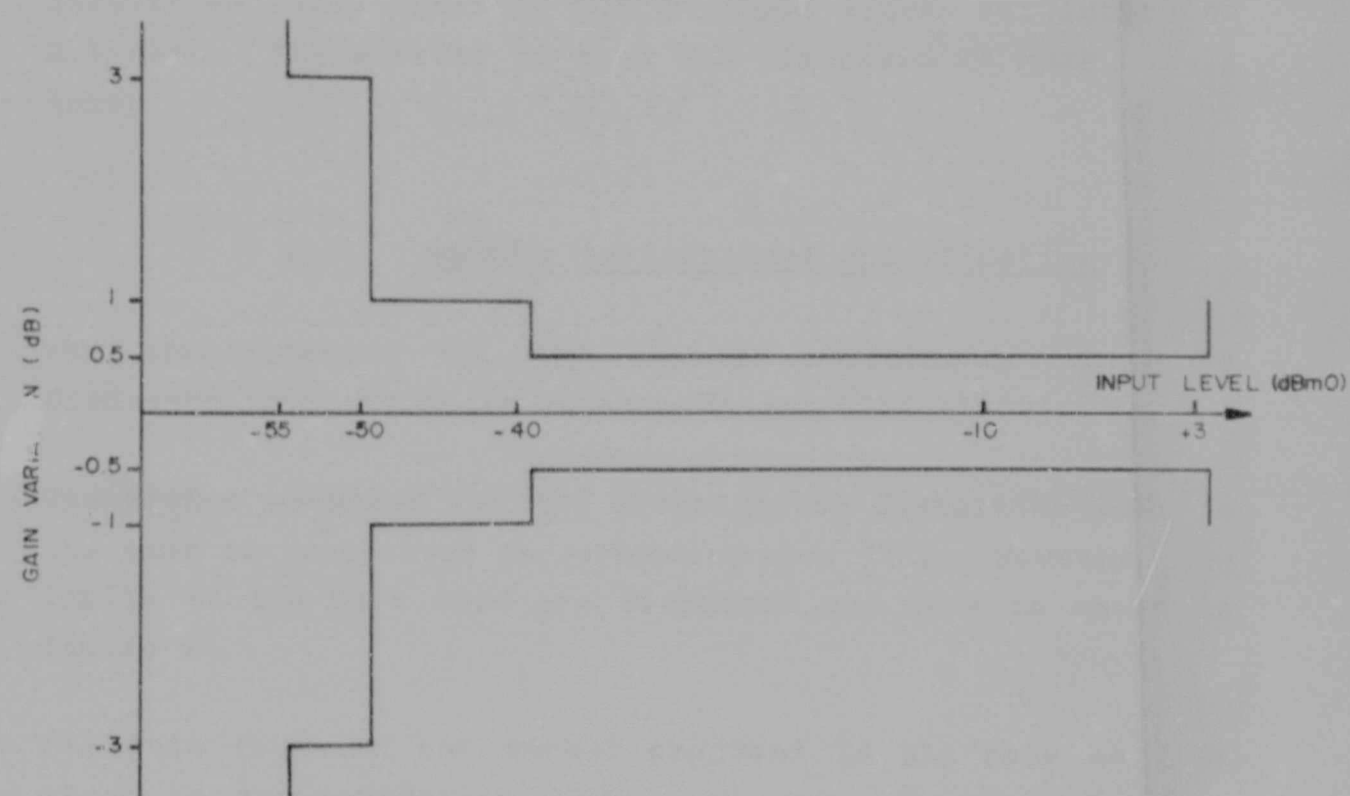

FIGURE 23. RECOMMENDED CCITT MASK FOR GAIN VARIATION WITH INPUT LEVEL.

An ideal encoder - decoder combination was simulated on a computer using the TESTS simulation package discussed in chapter 4. The reference curves obtained for the signal to quantization distortion ratio and gain tracking are shown in figures 24 and 25 respectively. A plot of the signal to quantization distortion for the same ideal combination using a finer resolution, 0.1dBm0, is shown in figure 26.

From the figures it can be seen that the ideal device characteristic curves fall well within the limits set by the specification. For quantization distortion, approximately a 6dB margin exists between the CCITT mask and the theoretical reference curve obtained. This is shown in Figure 24.

A point that needs mention at this stage is the complexity of the curves obtained, especially the quantization distortion curve obtained for an input signal resolution of 0.1 dBm0. The effects of this are discussed in more detail later.

2.2.1 Encoder half channel specification

The specification for the encoder performance alone is discussed in CCITT draft recommendation G71X [1982].

The method proposed for the quantization distortion test is the same as that given in recommendation G712. However, the limits of the mask used are different and this is shown in figure 27.

For gain tracking the method proposed is the same as that given in recommendation G712. However, the mask for the encoder performance has, as yet, not being finalized by the CCITT and various suggestions are still under study.

An important function of the present work is to propose a test strategy which conforms to the CCITT specifications for system performance. Therefore deciding on the best mask to

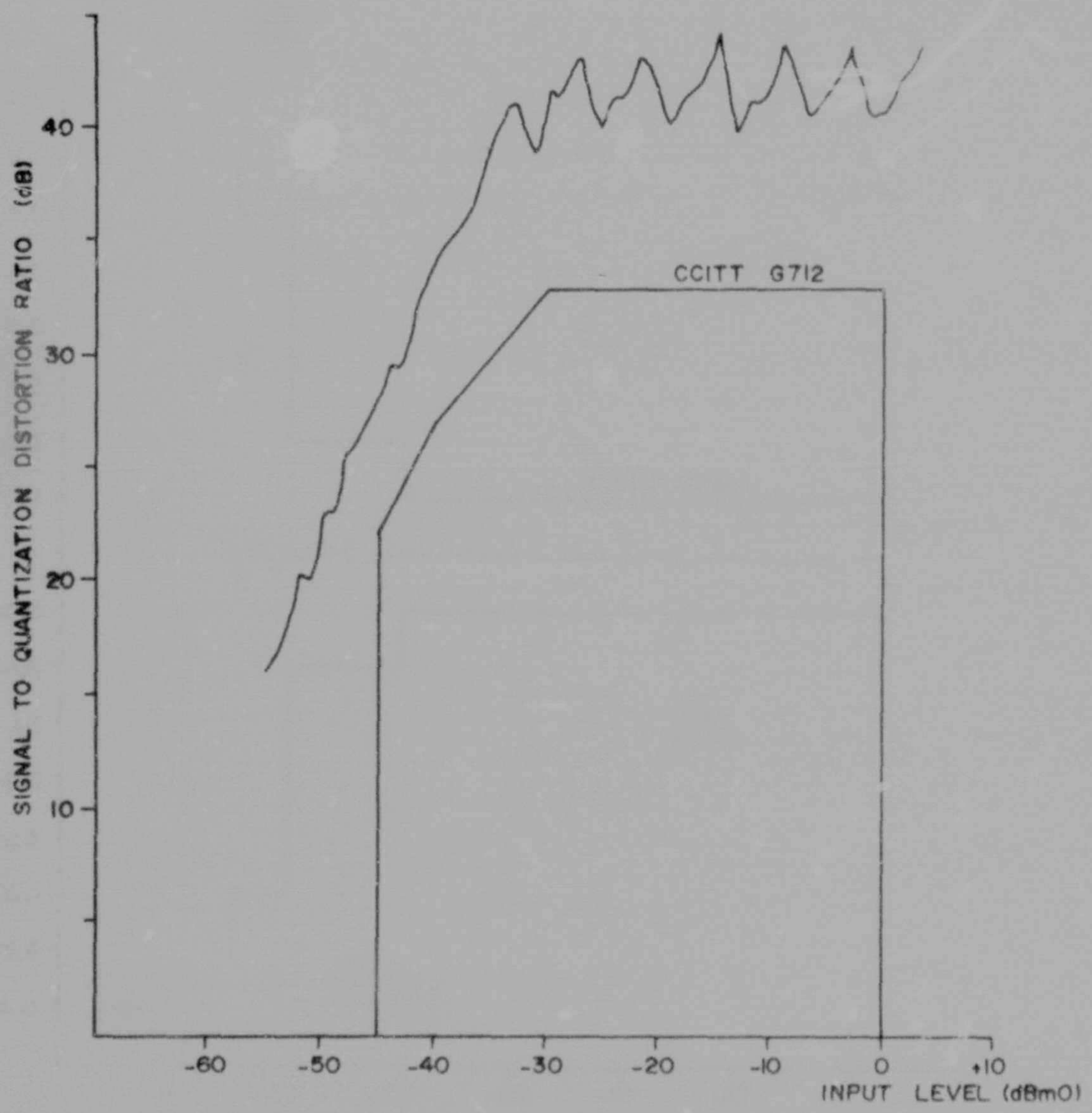

FIGURE 24 SIGNAL TO QUANTIZATION DISTORTION PERFORMANCE FOR AN IDEAL ENCODER IDEAL DECODER COMBINATION.

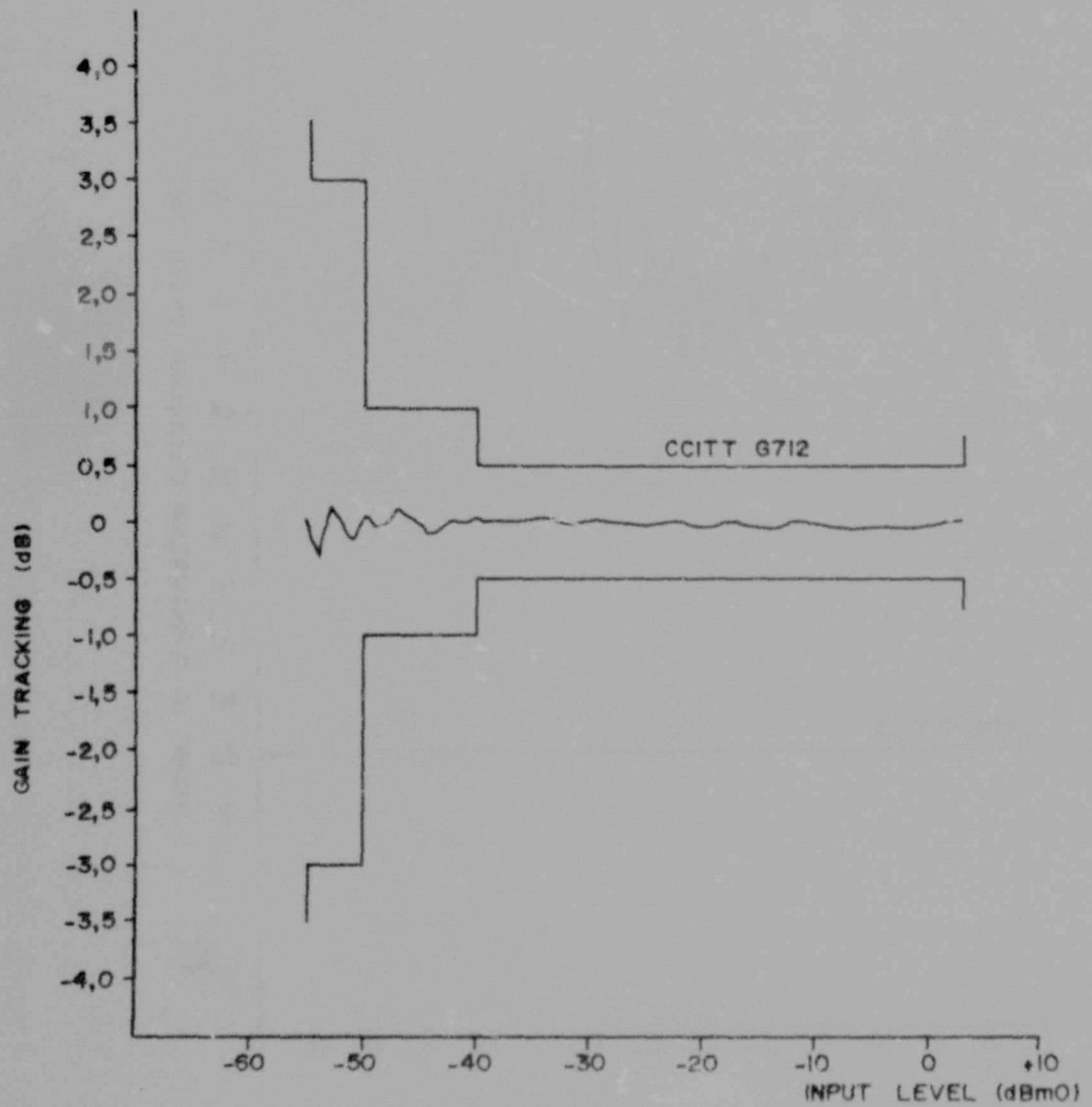

FIGURE 25 GAIN TRACKING PERFORMANCE FOR AN IDEAL ENCODER - IDEAL DECODER COMBINATION

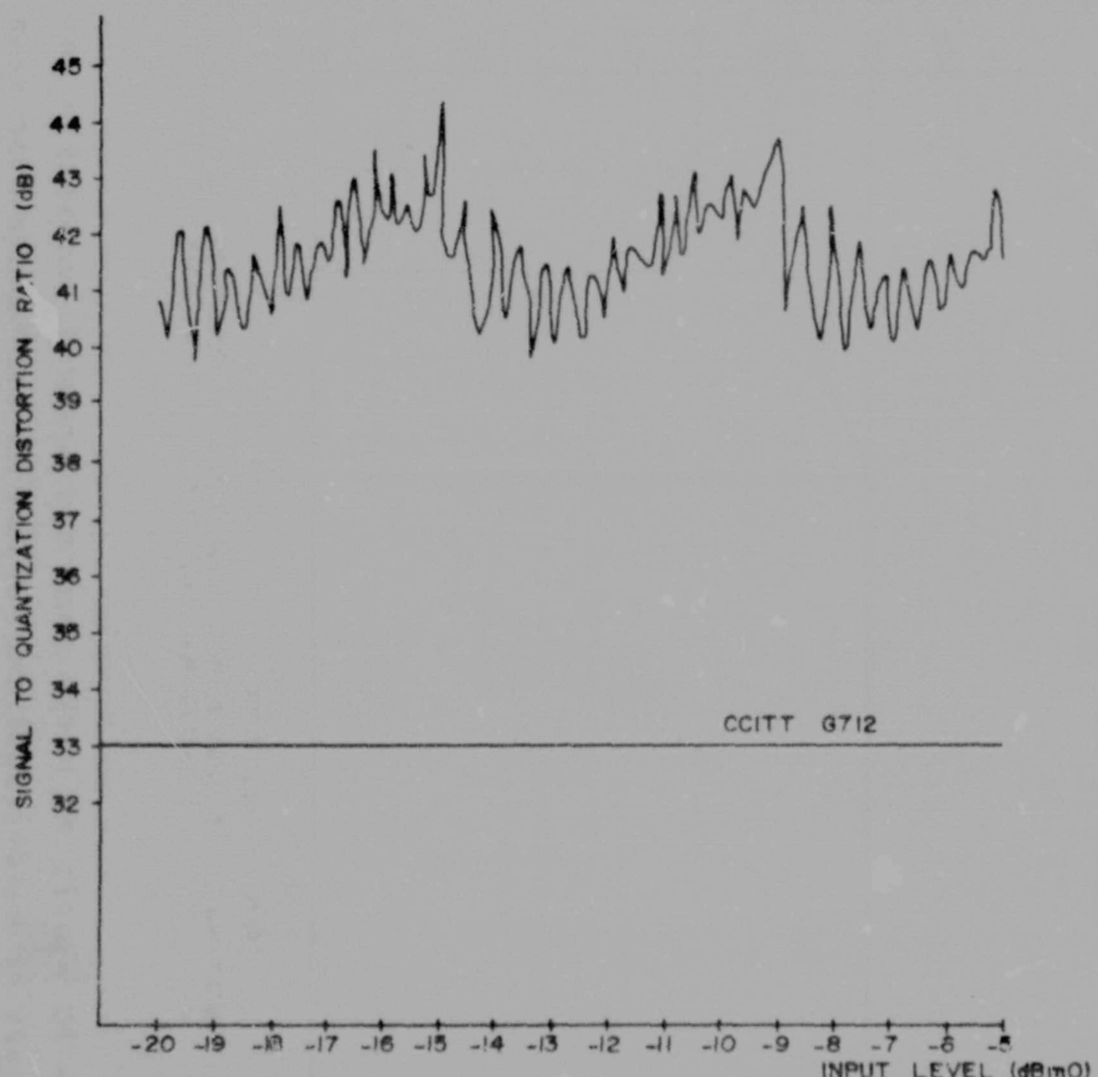

FIGURE 26 SIGNAL TO QUANTIZATION DISTORTION PERFORMANCE FOR AN IDEAL ENCODER – IDEAL DECODER COMBINATION USING 0.1dBmO RESOLUTION.

use for gain tracking performance is not an aspect of the present work. In order to illustrate the operation of the proposed test system and strategy the mask for gain tracking, proposed by the Italian Administration [1982], was used and this is shown in figure 28. In the present work no assumption is made implying that the Italian Administration mask is better than the CCITT official version.

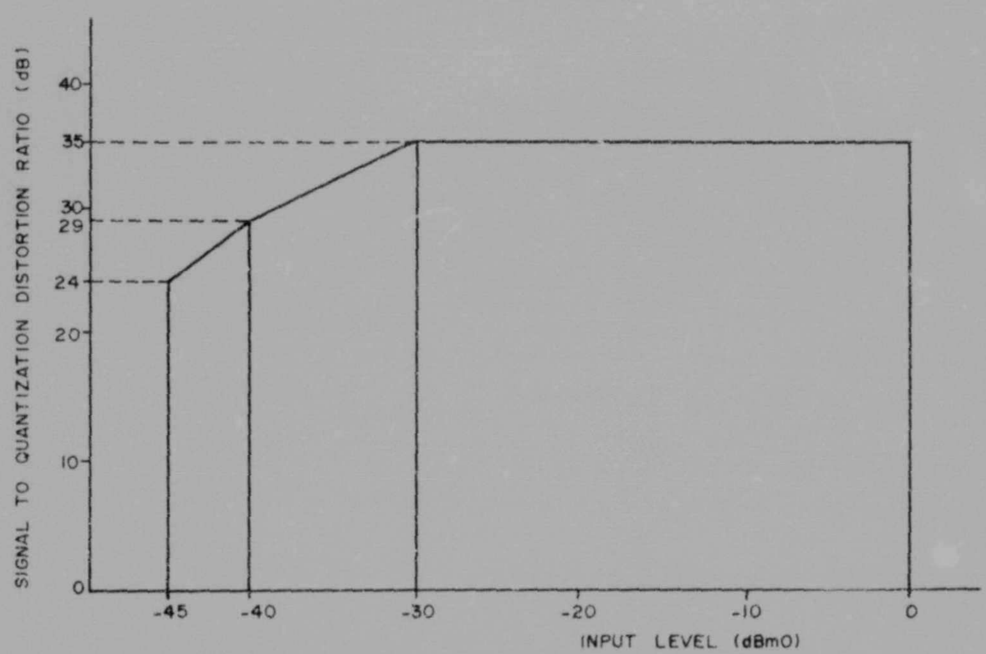

FIGURE 27 RECOMMENDED CCITT MASK FOR SIGNAL TO QUANTIZATION DISTORTION RATIO FOR THE ENCODER ALONE

The difference between the mask given in figure 28 and the mask recommended for an end to end test, shown in figure 23, is only in the input range -55dBmO to -50 dBmO. For the encoder performance alone, the gain tracking limit over this input range is ± 2.2 dB as compared with ± 3dB for the end to end measurement.

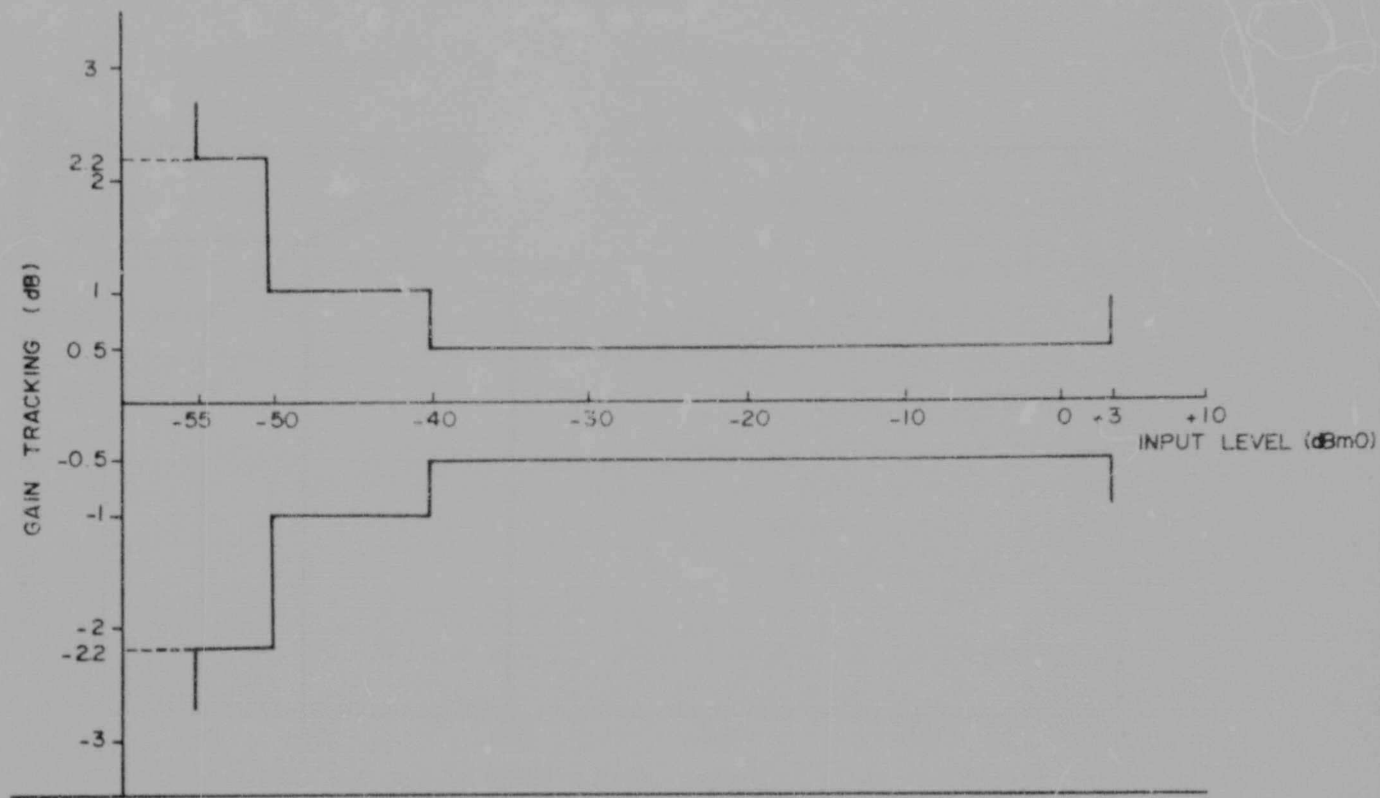

FIGURE 28 MASK OF LIMITS FOR VARIATION OF GAIN WITH INPUT LEVEL, AS PROPOSED BY THE ITALIAN ADMINISTRATION, FOR THE GAIN TRACKING PERFORMANCE OF AN ENCODER ALONE

2.2.2 Decoder half channel specification

The performance specifications for the decoder alone are also discussed in draft recommendation G71X. The methods proposed for the quantization distortion and gain tracking tests are the same as those proposed for the encoder half channel test and the end to end test. As is the case with the encoder half channel specification, only the mask for quantization distortion performance is given, and this is shown in figure 29. The mask for gain tracking performance is still under study.

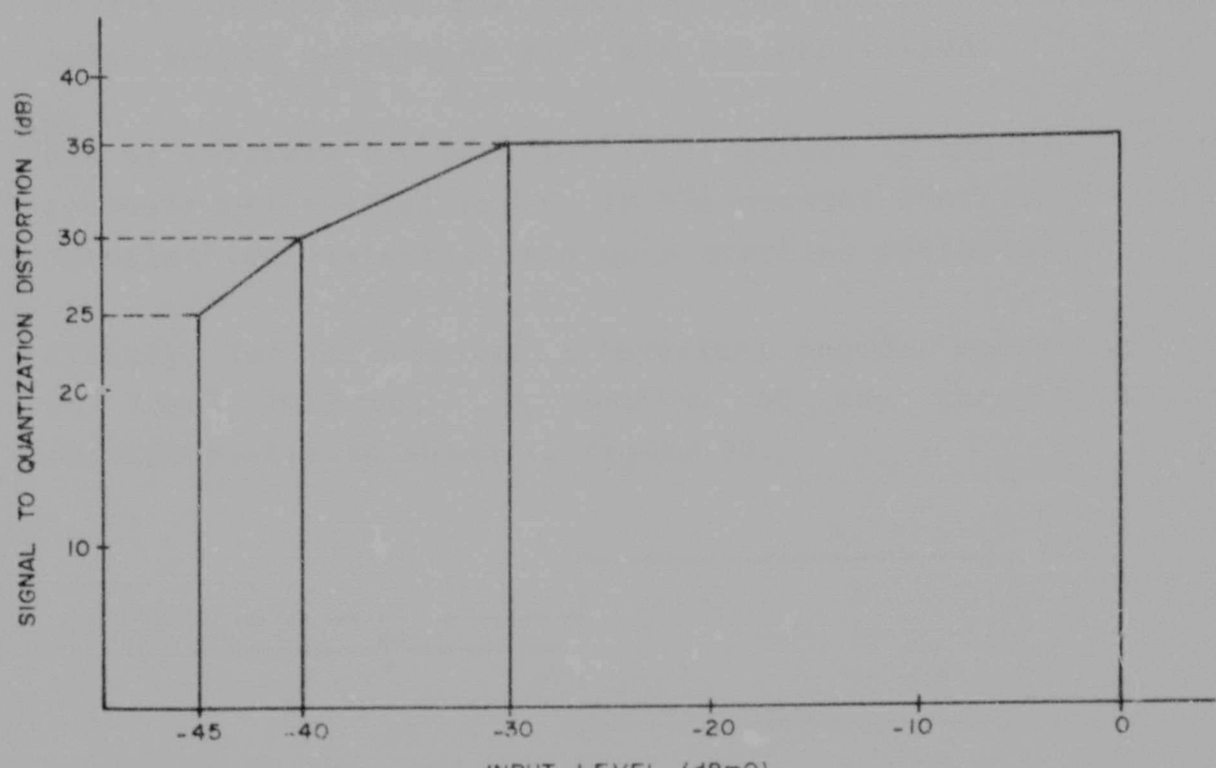

FIGURE 29 RECOMMENDED CCITT MASK FOR SIGNAL TO QUANTIZATION DISTORTION RATIO FOR DECODER ALONE.

For gain tracking performance the mask proposed by the Italian administration [1982], shown in figure 28, is used for both the decoder and encoder half channel specification.

2.3 The operation of a codec with various imperfections.

To develop a test strategy an understanding of the operation of the codec for various imperfections is necessary. The theory behind the practical implementation of a typical codec was given in chapter 1. The purpose of this section is to give an idea of how decision level errors in the encoder and reconstruction level errors in the decoder affect the quantization distortion and gain tracking curves. In the present work it is assumed that only decision and reconstruction level errors contribute to the imperfection of the codec. Thus the contributions due to circuit noise, power supply variations etc. are not considered.

Let us consider how decision level errors in the encoder and reconstruction level errors in the decoder contribute to the quantization distortion and gain tracking performance.

Firstly, let us consider a imperfect encoder operating with an ideal decoder. A section of the codec transfer characteristic is shown in figure 30.

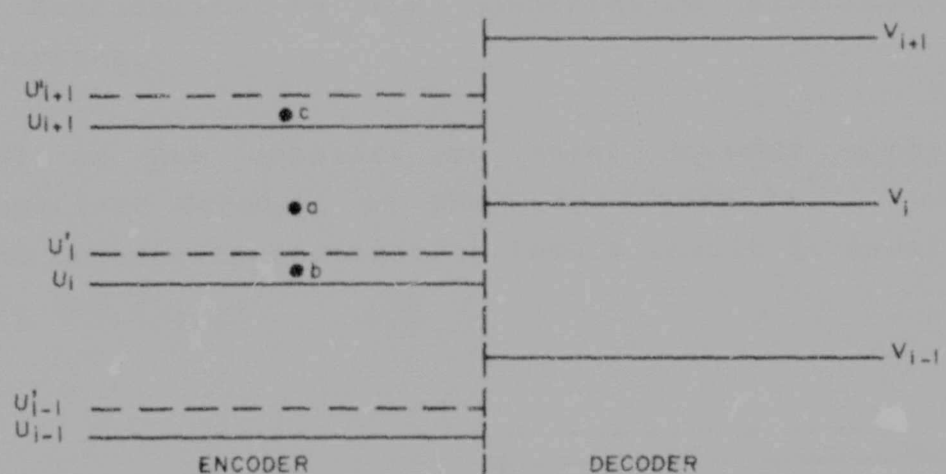

FIGURE 30 SECTION OF CODEC TRANSFER CHARACTERISTIC FOR A IMPERFECT ENCODER AND IDEAL DECODER COMBINATION

The encoder has ideal decision levels given by U_{i-1}, U_i and U_{i+1}. The decoder has reconstruction levels given by V_{i-1}, V_i and V_{i+1}. In the ideal case, for a sampled instantaneous voltage falling between U_i and U_{i+1}, a value of V_i would be present at the output of the decoder.

As the encoder is considered to be imperfect, the errors associated with the ideal encoder decision levels would result in decision levels at U'_{i-1}, U'_i and U'_{i+1}, as shown in figure 30. If a sampled instantaneous voltage fell at position a, the resulting decoder output would be V_i which is the same as in the ideal case. Thus there would be no degradation to the quantization distortion or gain tracking. If the sampled value fell at position b, it would be placed into the lower quantizing interval and the decoder output would be V_{i-1}. This would result in a degradation in the quantization distortion value and to a certain extent in the gain tracking value. If the sampled value fell at position c, it would be quantized into the i^{th} interval resulting in a decoder output value of V_i instead of V_{i+1}, as would be the case in an ideal combination. This too would result in a degradation in the quantization distortion and gain tracking.

Let us now consider an ideal encoder working with a imperfect decoder, as shown in figure 31. The errors on the decoder reconstruction levels result in levels at V'_{i-1}, V'_i and V'_{i+1}.

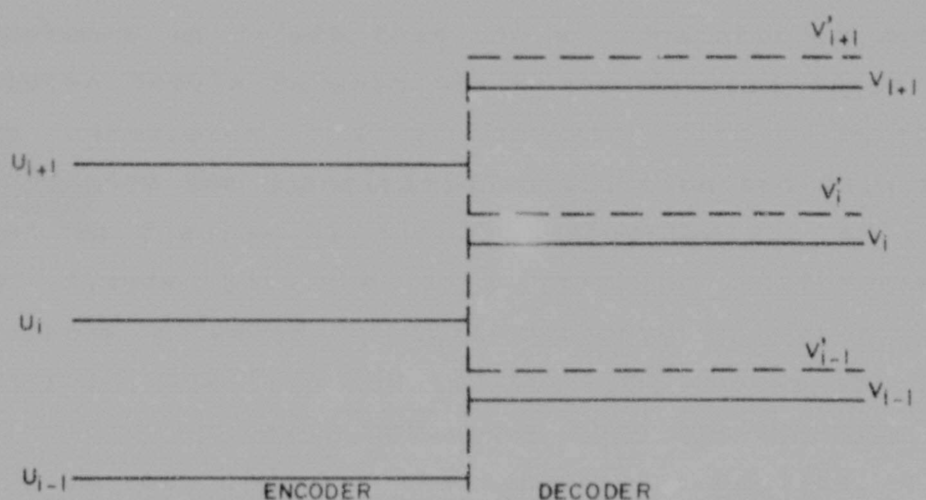

FIGURE 31 SECTION OF CODEC TRANSFER CHARACTERISTIC FOR A IDEAL ENCODER AND IMPERFECT DECODER COMBINATION

The error on the decoder output levels is equivalent to that of adding a dc component. This mainly affects the gain tracking performance of the codec.

The above discussion shows clearly that the main contribution to quantization distortion is in the encoder section of the codec. Contribution to gain tracking degradation is partly due to the encoder section but mainly due to the decoder.

Three different categories of imperfections of both the encoder and decoder were simulated using the TESTS simulation computer package described in chapter 4. The imperfections where suggested by Tsivides and Zee [1979]. A description of the imperfections together with simulation results follows.

2.3.1 Decision and reconstruction level shift error

For the encoder section this involved shifting all the decision levels by a fixed amount. This is a common occurrence in codecs that use a comparator to determine the decision levels between which the sampled input lies, when this comparator has a non-zero offset voltage. The performance for quantization distortion and gain tracking is shown in figures 32 and 33 respectively. As can be seen from figure 33, the gain tracking performance is not adversely affected by this category of error. Looking at figure 32, the five and ten per cent curves are in the same range more or less, but worse than the one per cent curve which is very close to the reference condition.

As stated previously for the decoder section, having all the reconstruction levels shifted by the same amount is equivalent to a dc component at the output. This does not result in any degradation to quantization distortion as is shown in figure 34. The gain tracking performance however

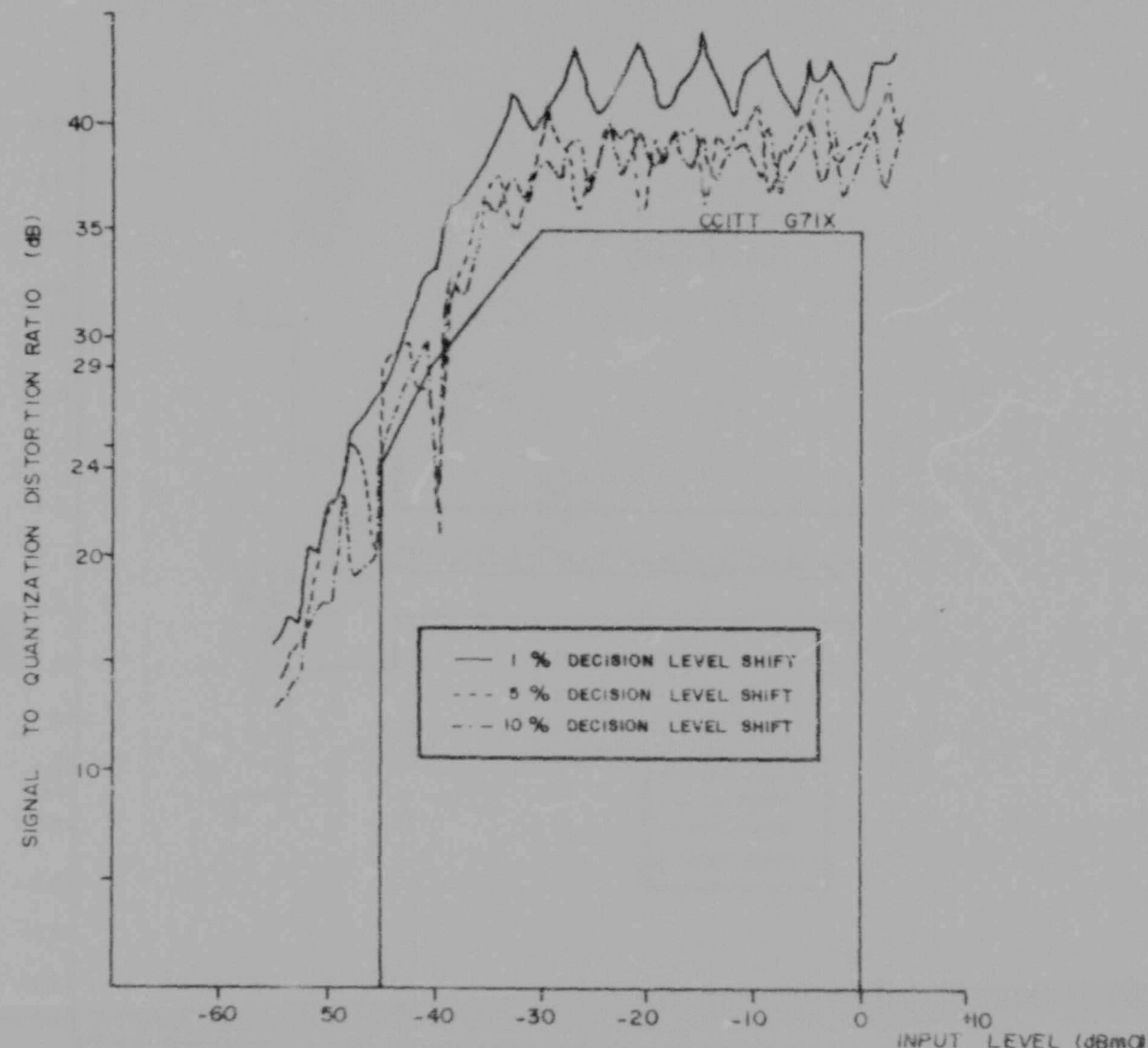

FIGURE 32 SIGNAL TO QUANTIZATION DISTORTION PERFORMANCE FOR A IMPERFECT ENCODER WITH DECISION LEVEL SHIFT ERROR.

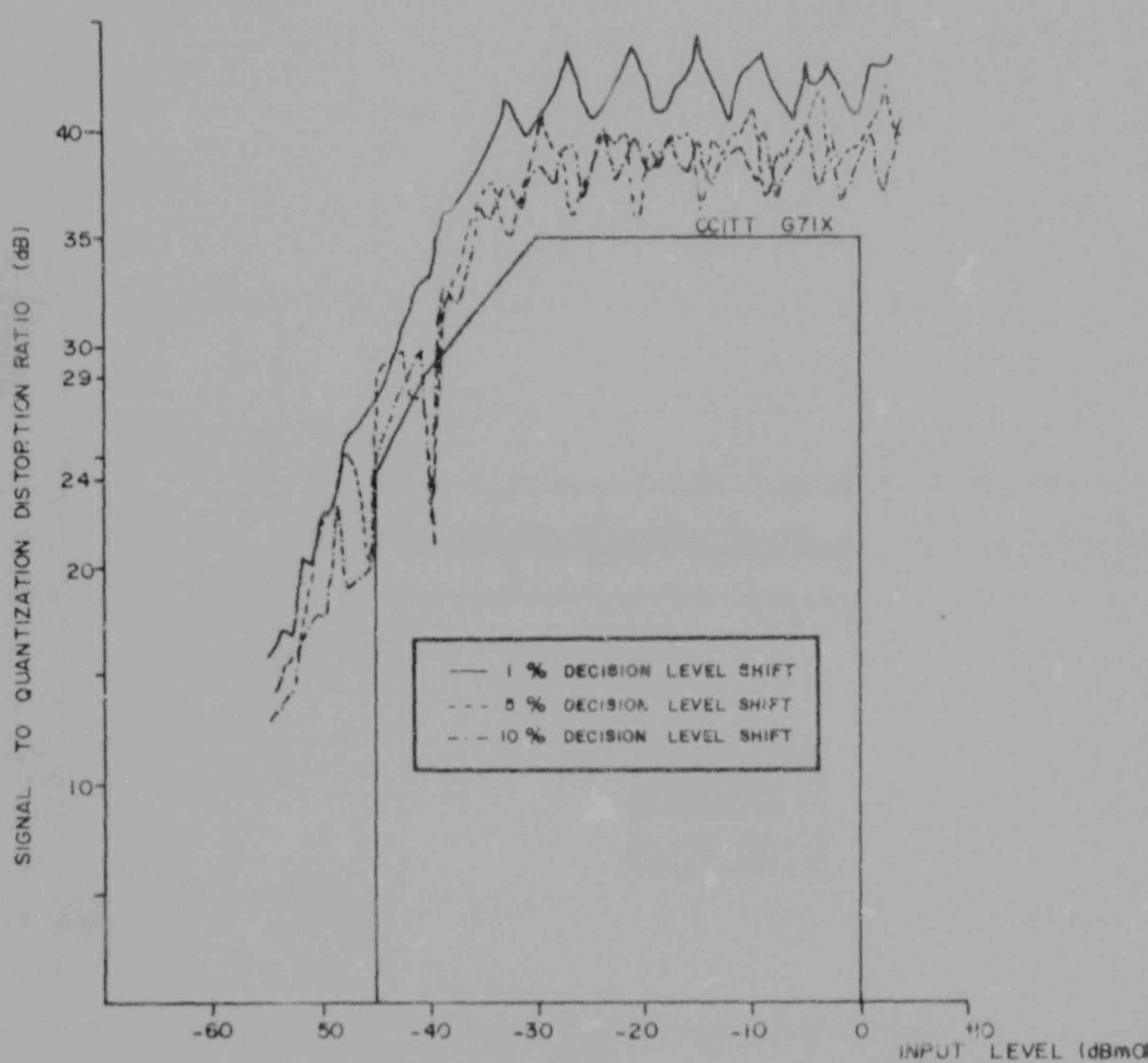

FIGURE 32 SIGNAL TO QUANTIZATION DISTORTION PERFORMANCE FOR A IMPERFECT ENCODER WITH DECISION LEVEL SHIFT ERROR

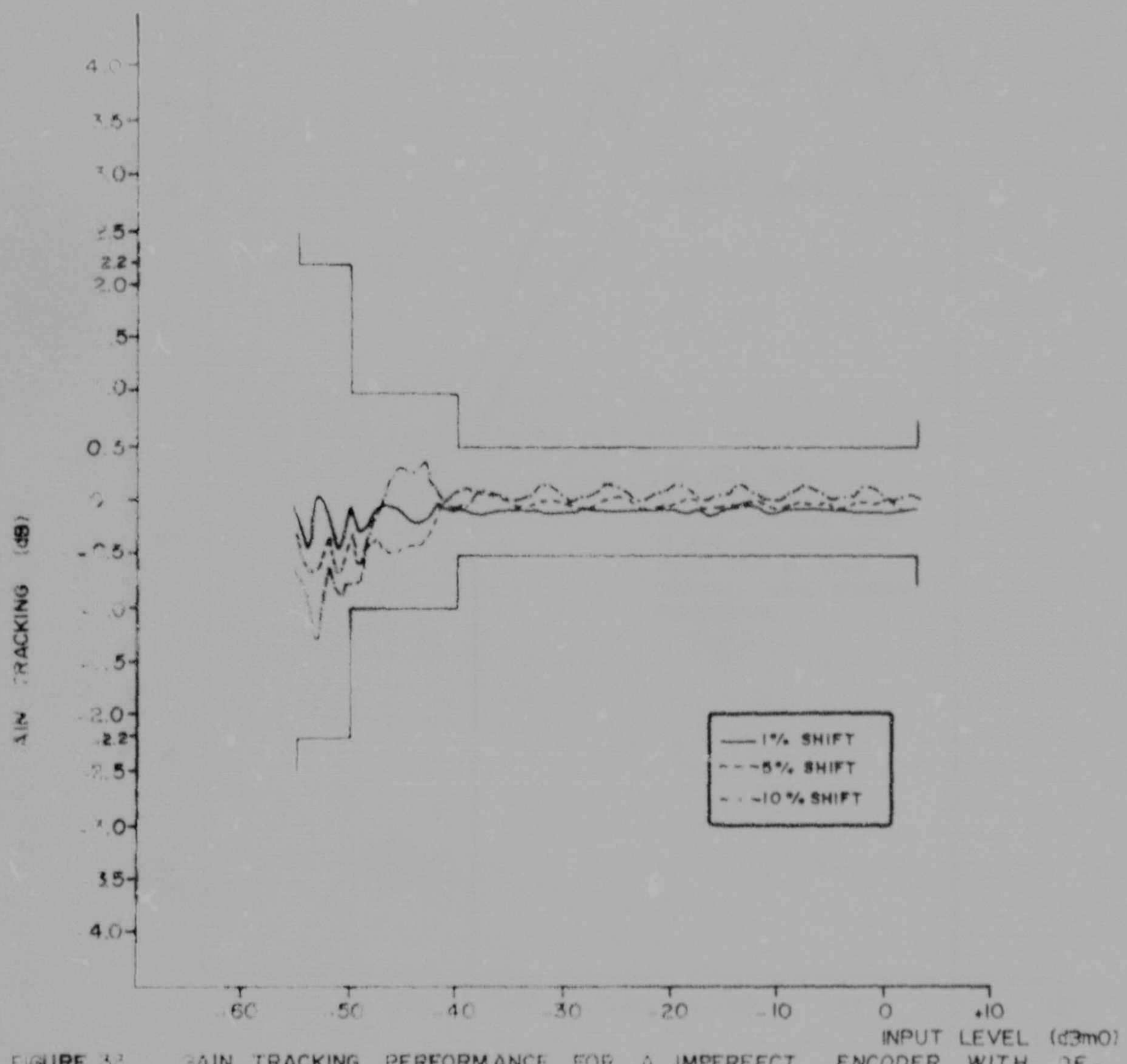

FIGURE 32 GAIN TRACKING PERFORMANCE FOR A IMPERFECT ENCODER WITH DECISION LEVEL SHIFT ERROR

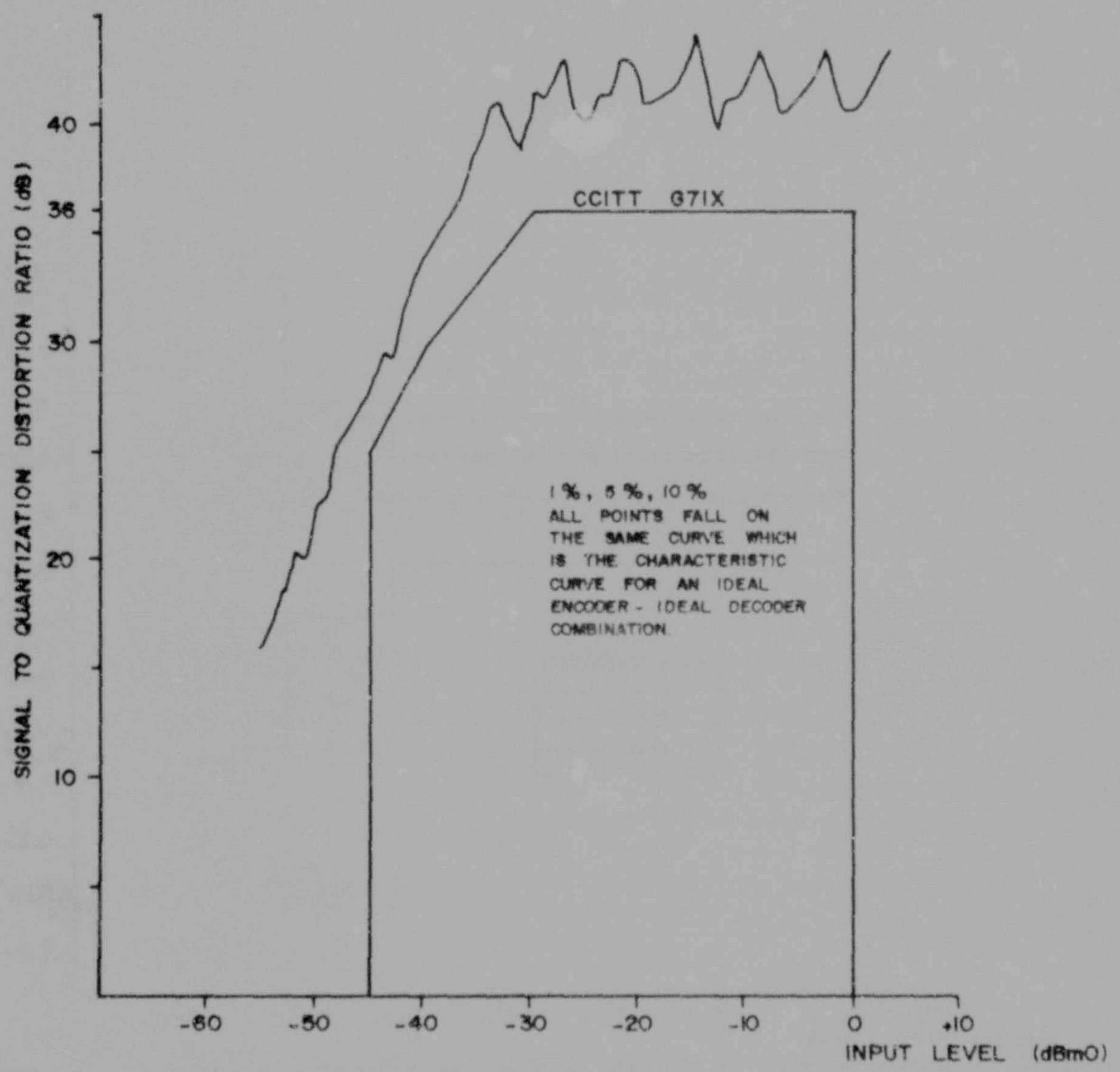

FIGURE 34 SIGNAL TO QUANTIZATION DISTORTION PERFORMANCE FOR A IMPERFECT DECODER HAVING A RECONSTRUCTION LEVEL SHIFT ERROR.

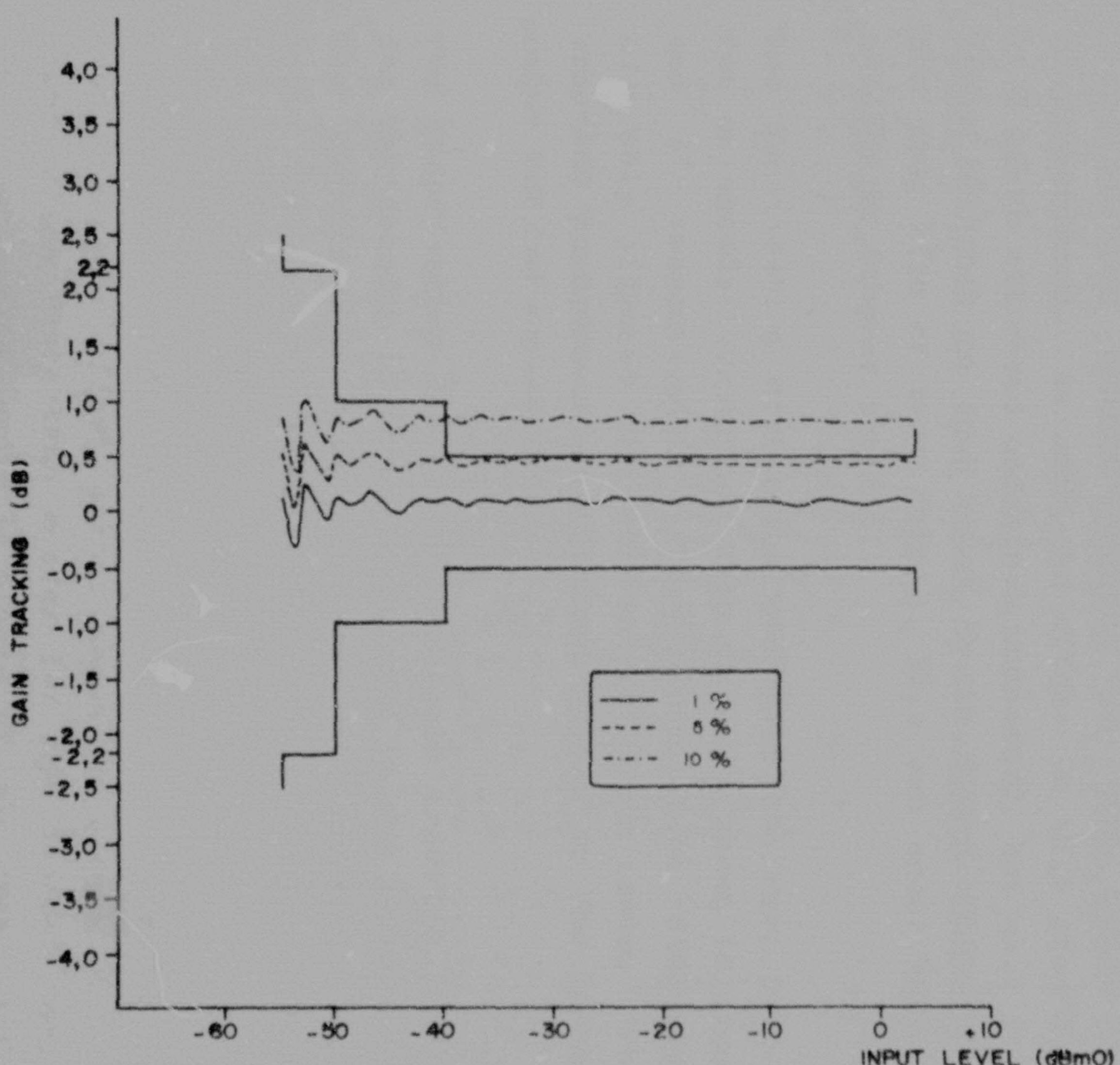

FIGURE 35 GAIN TRACKING PERFORMANCE FOR A IMPERFECT DECODER HAVING A RECONSTRUCTION LEVEL SHIFT ERROR.

is effected as is shown in figure 35.

2.3.2 Step generator offset error

The operation of the step generator was described in chapter 1. Its function is to generate the linear steps internal to each of the chords present in the A-law transfer characteristic. As such, an offset in this step generator will leave all chord endpoints unchanged, but will shift all steps internal to each chord by an amount proportional to the step size of that chord. This can occur both in the encoder or decoder section.

The quantization distortion and gain tracking performance for an encoder exhibiting this error is shown in figures 36 and 37 respectively. The quantization distortion is adversely affected over the entire input range. The gain tracking performance is affected mainly at the lower input range i.e. up to -40dBm0.

The quantization distortion and gain tracking performance for the decoder is shown in figures 38 and 39 respectively. The quantization distortion is not adversely affected. Again the gain tracking performance is mainly affected at the lower input range.

The quantization distortion curves for the encoder having a step generator offset error, shown in figure 36, and the quantization distortion curves for the decoder having the same imperfection, shown in figure 38, are vastly different. This illustrates the fact that the quantization distortion for a codec is mainly derived from the encoder section.

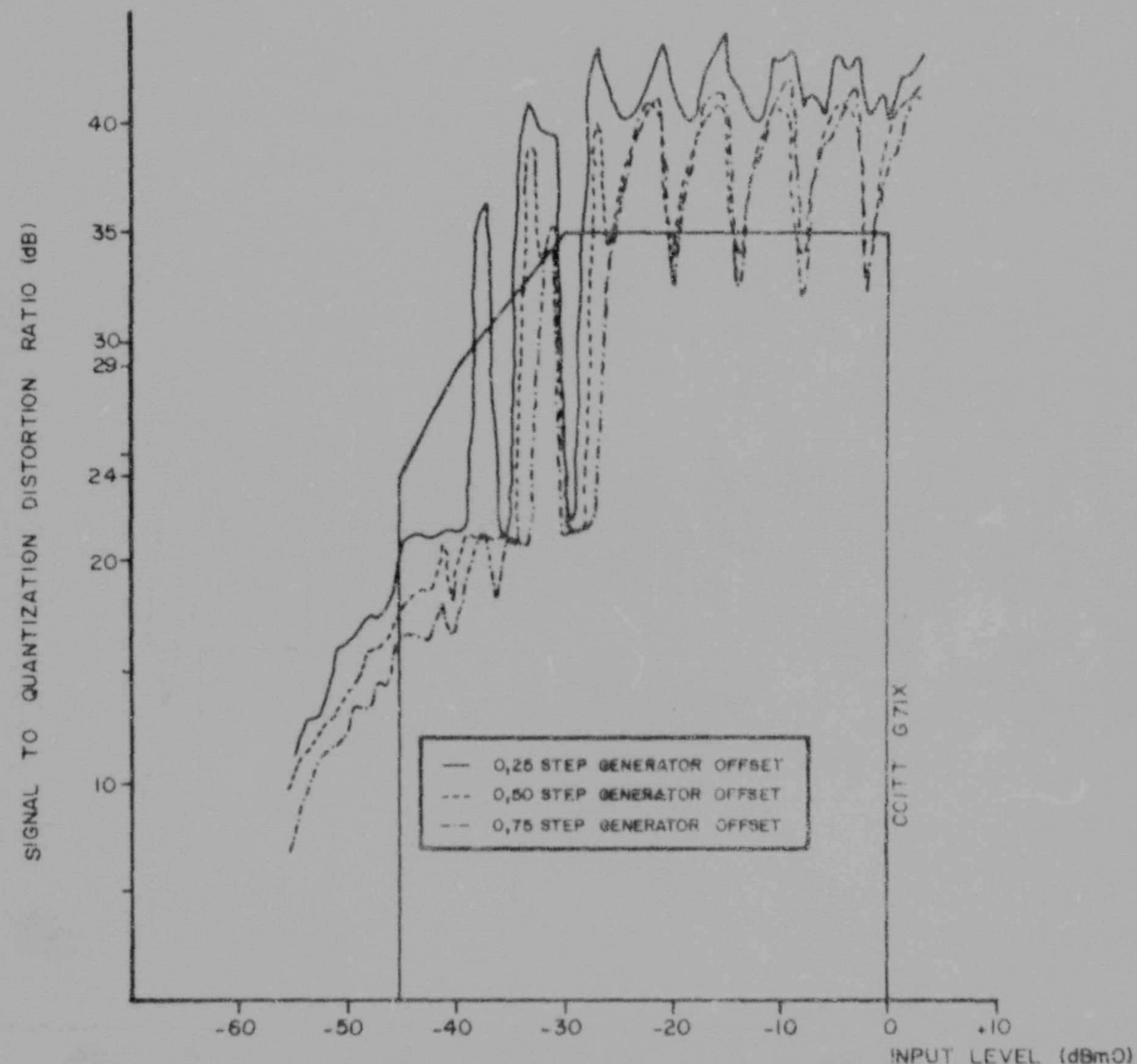

FIGURE 35 SIGNAL TO QUANTIZATION DISTORTION PERFORMANCE FOR A IMPERFECT ENCODER WITH STEP GENERATOR OFFSET ERROR

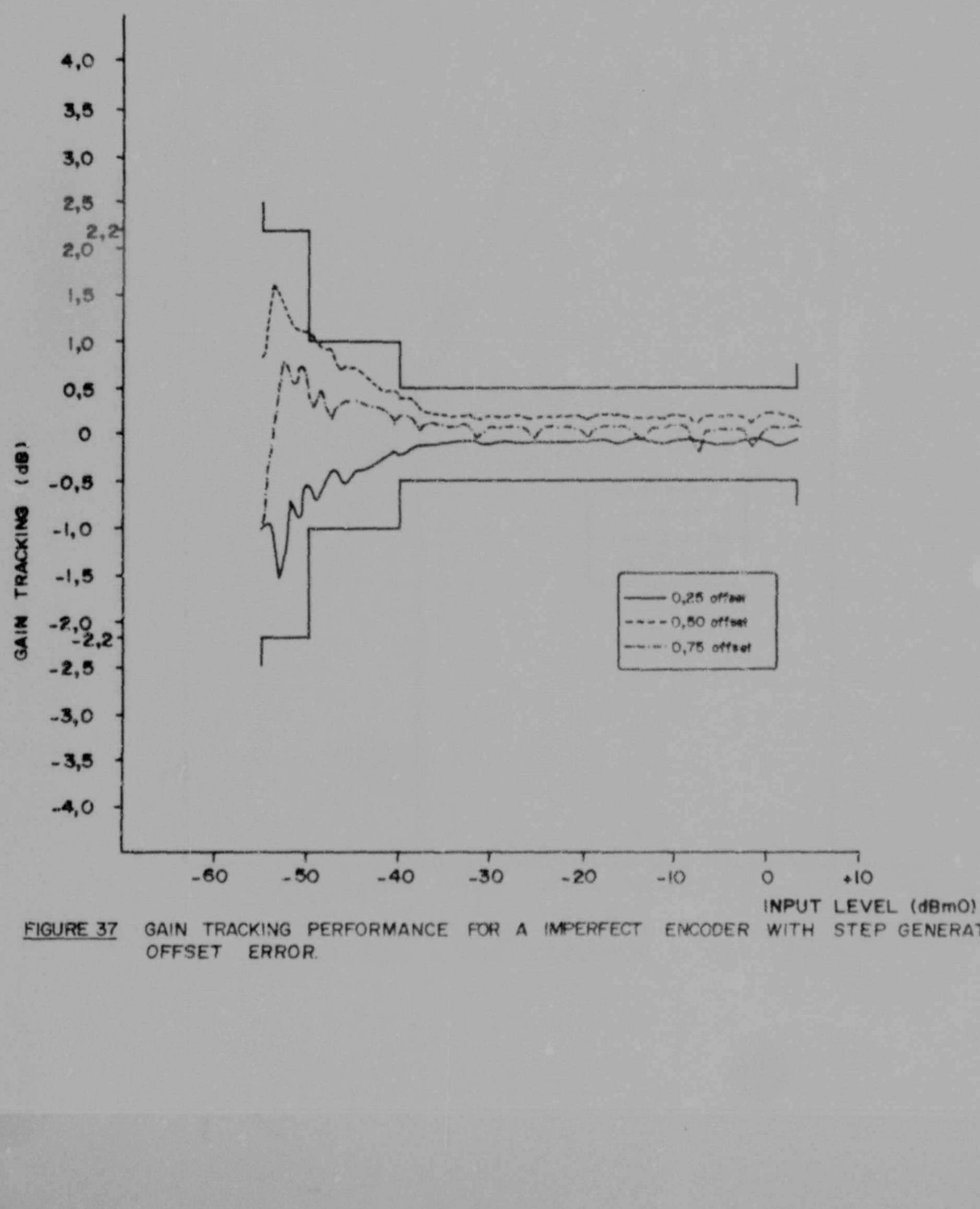

FIGURE 37 GAIN TRACKING PERFORMANCE FOR A IMPERFECT ENCODER WITH STEP GENERATOR OFFSET ERROR.