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AVIONICS SYSTEM ENGINEERING

NAS 9-13970

TASK ORDER NO. C0104

DESIGN NOTE

# MIA Computer Simulation Test Results Report

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(NASA-CR-147772) MIA COMPUTER SIMULATION TEST RESULTS REPORT (MCDONNELL-DOUGLAS CORP.) 26 P HC $4.00 CSCL 01D

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1. Summary

This report contains the results of the first noise susceptibility computer simulation tests of the complete MIA receiver analytical model. Computer simulation tests have been conducted with both Gaussian and pulse noise inputs. The results of the Gaussian noise tests have been compared to results predicted previously (Ref. JSC-09083) and have been found to be in substantial agreement. The results of the pulse noise tests will be compared to the results of planned analogous tests in the Data Bus Evaluation Laboratory at a later time. The MIA computer model is considered to be fully operational at this time although refinements and modifications will be made as further information on the Singer MIA design becomes available.

2. Introduction

This report has been prepared to present the initial results from the MIA analytical model and to act as an interim status report.

3. Discussion

A. The computer model of the Singer MIA receiver has been described in a previous paper (Ref. 1.3-DN-C0104-002). In that paper the MIA filter had been described in general terms, but had not been implemented in the computer model. The entire MIA simulation program, including the MIA filter has now been implemented and is described below.

B. Decoder model and input circuitry

1. The decoder section of the computer model has not been changed. (This section is described in Ref. 1.3-DN-C0104-002).

2. The clipper level has been chosen to be ± 16 volts. This value has been chosen to minimize the effects of high amplitude noise while allowing the largest permissible signal voltage (± 15 volts) to pass unattenuated. The actual clipper level used by the Singer design is still unknown.

3. The transformer and threshold detector are as described previously. (Ref. 1.3-DN-C0104-002)

C. Filter Models

1. Two filter models have been developed using bi-linear Z transform techniques. (See Appendix A). A 6-pole Butterworth low-pass filter and a 6-pole Bessel low pass filter have been implemented.

2. The Butterworth filter has been tested using sine wave and step response inputs. The results are shown in Figures 1 and 2 respectively. These results indicate that the filter is functioning as desired.

3. The Bessel filter has also been tested using sine wave and step response inputs. The results are shown in figures 3 and 4. These results also agree with expected results.

4. At the time of the implementation of the MIA simulation program, the type of filter being used by the MIA was uncertain. The first filter modeled was of the Butterworth type. The Bessel filter was modeled in order to make comparisons with the results of a previous analysis of data bus noise effects (Ref. JSC-09083). The Gaussian tests were run using the Bessel filter, while the pulse tests were run using both types of filter.

4. Results

A. Gaussian Noise tests

1. The Gaussian noise tests were undertaken as an attempt to verify the operation of the MIA computer model. A paper by George Proch of LEC (Ref. JSC-09083, referred to hereafter as the JSC paper)

was prepared which predicted the performance of the MIA with Gaussian noise input. It was desired to run simulations with the MIA model and compare the results with the predictions in order to confirm the accuracy of both the JSC paper and the MIA model.

2. The results of the Gaussian tests using the Bessel filter are plotted in figure 5 together with the predictions from the JSC paper. The probability of an incorrect word transmission vs RMS noise amplitude is the quantity compared. Other quantities predicted by the JSC paper (such as undetected word errors or bit decision errors) result in numbers which would require an inordinate number of computer runs and vast amounts of computer time. Two sets of curves are plotted for the JSC results. The dashed lines plot the original predictions. It was subsequently determined that the equivalent noise bandwidth of the filter analysed by the paper should be approximately 1.06 x $F_c$ and not 1.66 x $F_c$ as calculated originally. This has been confirmed by Mr. Proch, and the solid lines represent the revised data.

3. As shown in figure 5, the results from the MIA model tests agree quite closely with the dependent sample case from the JSC paper. The following information should be taken into consideration when comparing the results:

a. The JSC prediction should be considered to be optimistic. The assumptions used to get the results (square input data plus Gaussian noise) have been undercut by the recalculation of the step-response rise time of the input filter. The original assumption made was that the rise time was fast enough to allow the assumption of square data input. A comparison of figure 5 in this report with figure 6 in the JSC report indicates that the rise time of the filter is over 2 times slower than predicted by the JSC paper. (This slower rise time has been confirmed by Mr. Proch in a lab test of an analog Bessel filter.) This new rise time will tend to round the input data and cause more "no decision" samples than predicted.

b. The JSC paper predicted that the actual results would fall somewhere between the dependent and independent sample cases which were to be considered as limiting cases. It is felt that due to the fairly slow rise time of the filter, it would be expected that the actual results would fall closer to the dependent sample case since the low-pass filter acts to limit the change between samples.

c. Gaussian noise was simulated by using a random number generator which produces a Gaussian distribution with zero mean and a variance of one. These numbers are generated at a simulated rate of 96 megasamples per second. This gives a band-limited noise spectrum which is white to 48 megahertz. In order to conform to the JSC paper's assumption of a 4 megahertz noise bandwith, the RMS value of the generated noise was multiplied by $\sqrt{4/48}$ or .289.

4. It is felt that the comparison of the JSC paper predictions and the MIA model test results, together with the detailed analysis which went into the resolving of initial discrepancies, has resulted in a high level of confidence in both the JSC paper (as modified) and the MIA computer model.

B. Pulse tests

1. A series of pulse tests have been run with the MIA computer model. Each test consists of the reception of a specified number of 28 bit words with one noise pulse added per word.. The noise pulse is positive polarity, and its position in the word is selected at random. Each subseries of tests consists of adding pulses of constant width while varying the pulse amplitudes. The results obtained using the Bessel filter are plotted in figure 6, and those obtained using the Butterworth filter are plotted in figure 7. In both cases the quantity plotted is the probability (in percent) of a word error vs the pulse amplitude in decibels relative to one volt. Pulse widths are integer multiples of 10.4 nanoseconds (resulting from the 96 megasample/second rate).
2. The results in both tests are qualitatively as expected. For very short pulse widths, the pulse amplitude required to cause a word error is high due to the filter attenuating the pulse. As the pulse width increases, the amplitude needed to cause a word error decreases. For very long pulse widths, the probability of a word error approaches 100% for any amplitude above the error threshold level (approximately 1 volt).
3. The results of the Bessel and Butterworth tests are plotted together in figure 8 to compare the results in the two cases. It is apparent that both filters operate similarly at high noise levels. However, for pulse amplitudes close to the threshold level it can be seen that the Bessel filter performs better in all cases. This is attributable to the better phase characteristics

of the Bessel filter. A comparison of the step responses of the two filters (figures 2 and 4) shows that the Butterworth filter exhibits considerable overshoot and ringing resulting in substantial degradation of the data wave form. The Bessel filter exhibits virtually no overshoot and the waveform is less distorted.

3. The results of these pulse tests will be compared with analogous tests to be carried out in the Data Bus Evaluation Laboratory. These two sets of data will then be used in conjunction with a data bus impulse noise model currently being developed to determine error probabilities on the data bus lines.

5. Conclusion

This report has presented the results of the initial computer simulation runs using the complete MIA receiver model. Results have been given for both Gaussian and pulse type noise and for both Bessel and Butterworth type input filters. Based on these results, the MIA computer model is considered fully operational at this time. The results illustrated in Figures 5-8 provide a basis for the evaluation of the results of planned tests on the MIA in the Data Bus Evaluation Laboratory. It appears that a Bessel type input filter has a slight advantage over a Butterworth filter for pulse type noise. It should be noted that in no case did a noise pulse of peak amplitude less than 1 volt cause a word error. This indicates that only noise waveforms with peak amplitudes greater than or equal to 1 volt will be capable of causing errors on the data bus lines.

The results presented in this report are tentative since the MIA computer model is based on preliminary information (albeit the most current available). Further updates to the computer model will be made as information becomes available.

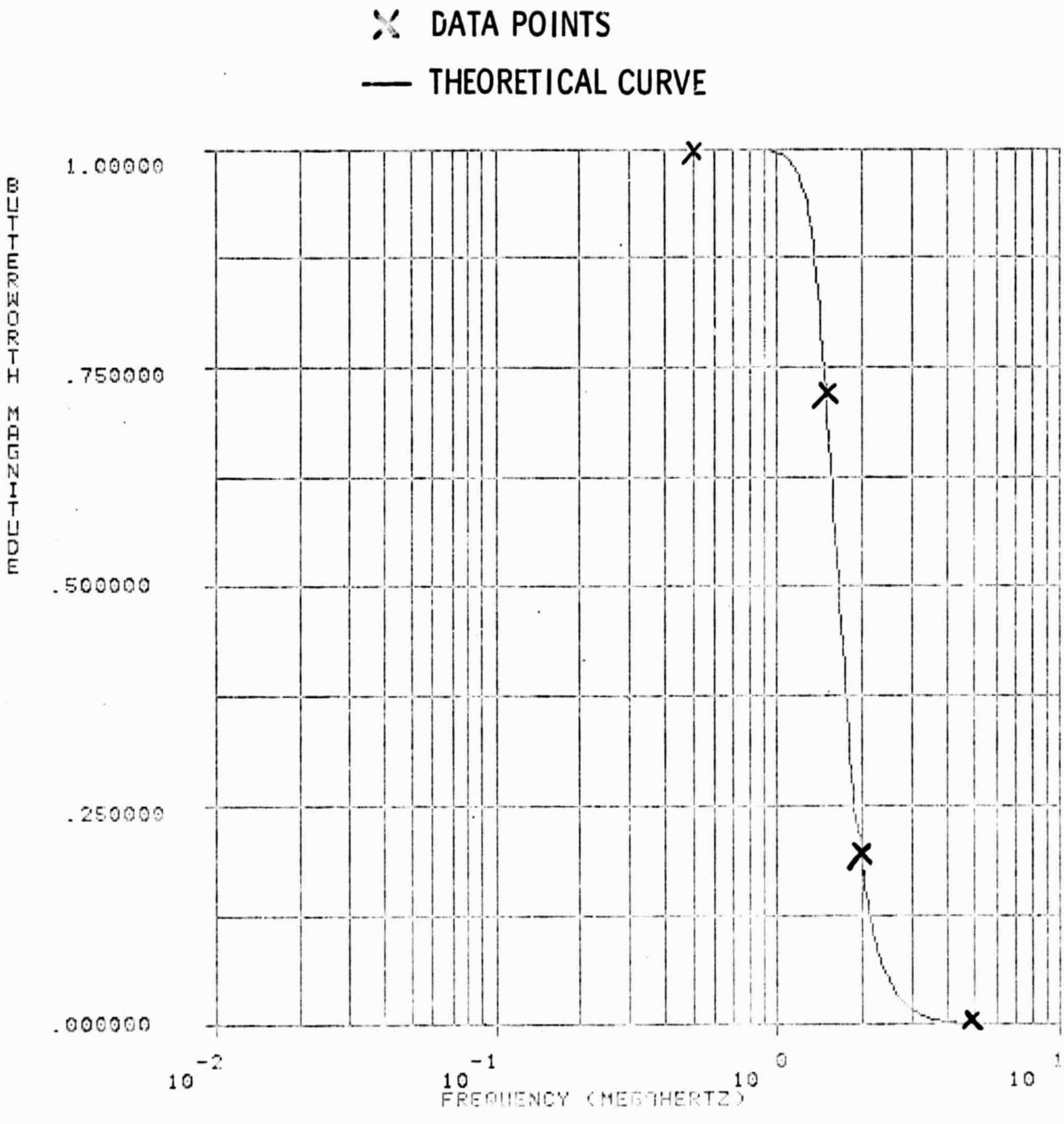
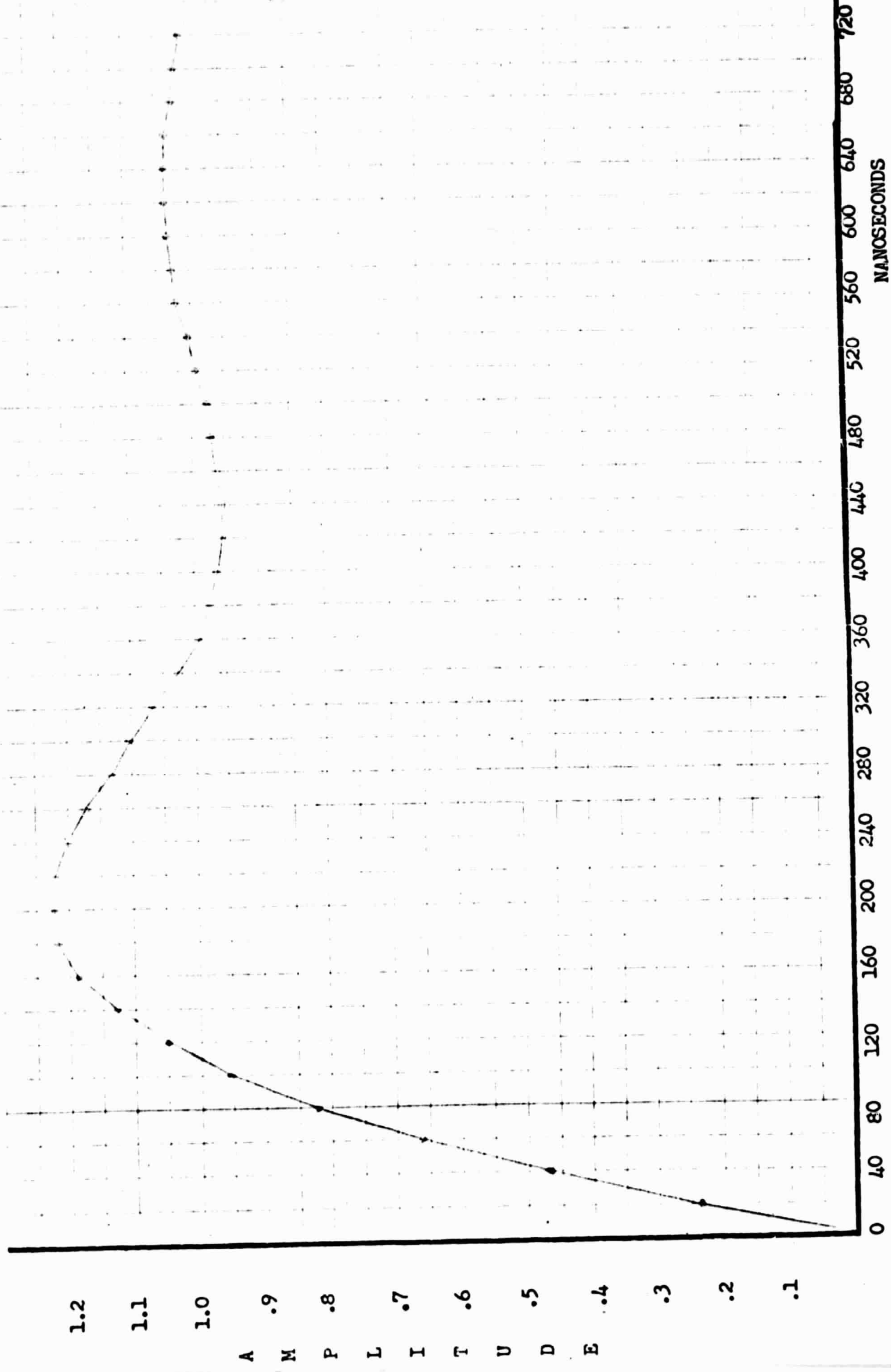

X DATA POINTS
— THEORETICAL CURVE
BUTTERWORTH MAGNITUDE
1.00000
.750000
.500000
.250000
.000000
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
FREQUENCY (MEGAHERTZ)

Figure 1




6-pole Butterworth Filter Step Response ($f_c$ = 1.5 MHz)

Figure 2

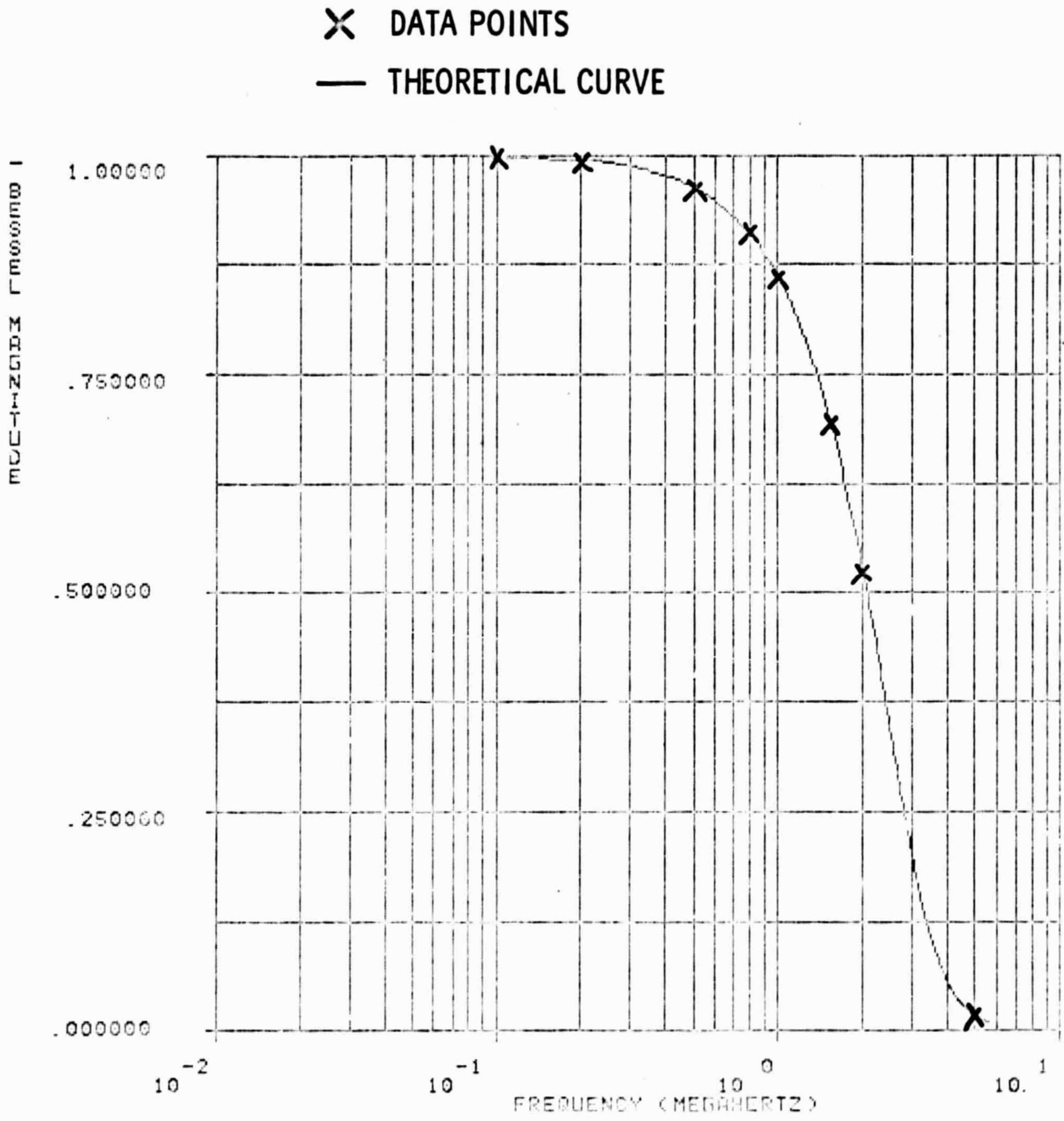
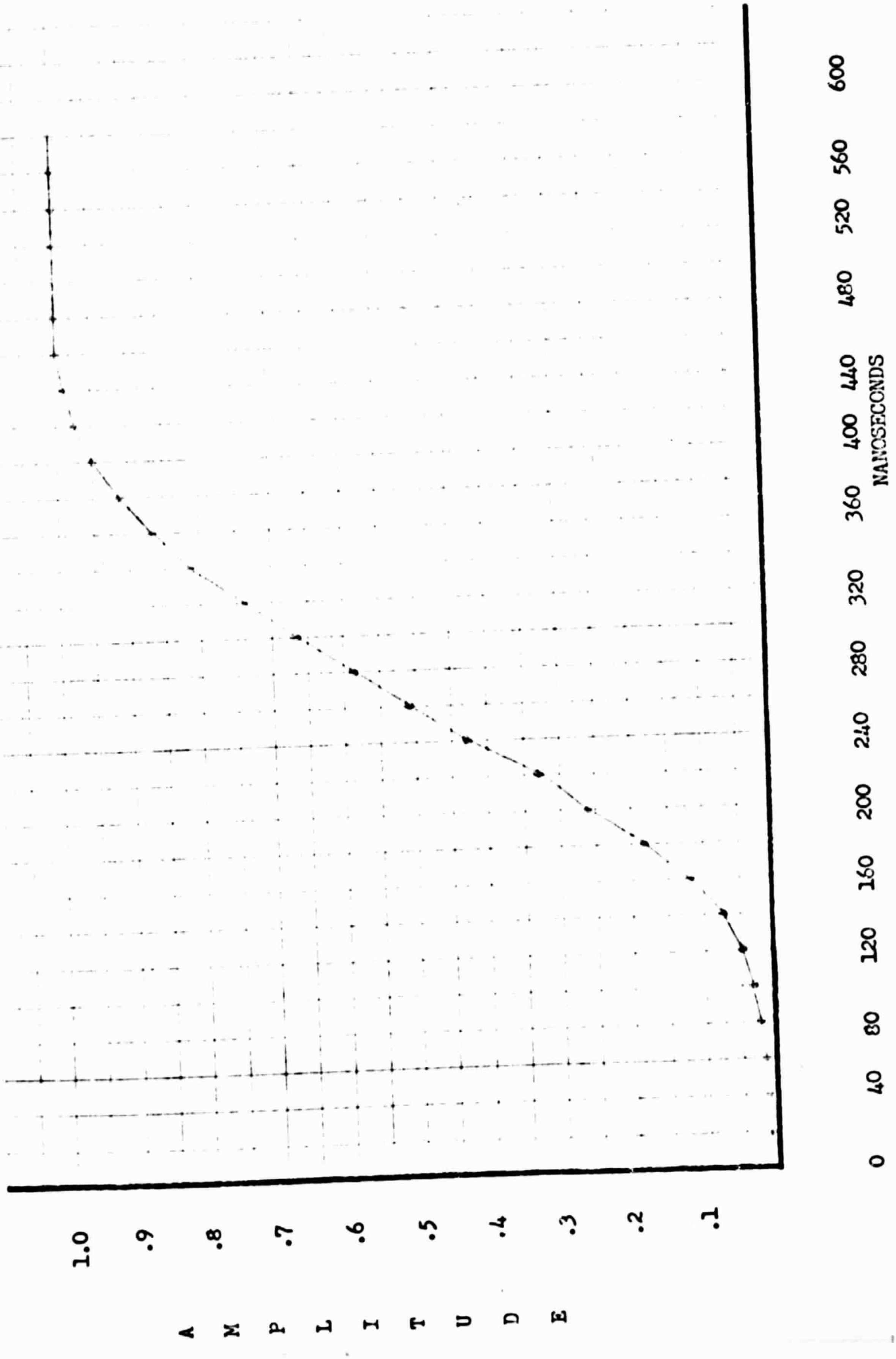

DATA POINTS
THEORETICAL CURVE
1.00000
.750000
.500000
.250000
.000000
BESSEL MAGNITUDE
$10^{-2}$
$10^{-1}$
$10^{0}$
$10.^{1}$
FREQUENCY (MEGAHERTZ)

Figure 3




6-pole Bessel Filter Step Response ($f_c$ = 1.5 MHz)
Figure 4

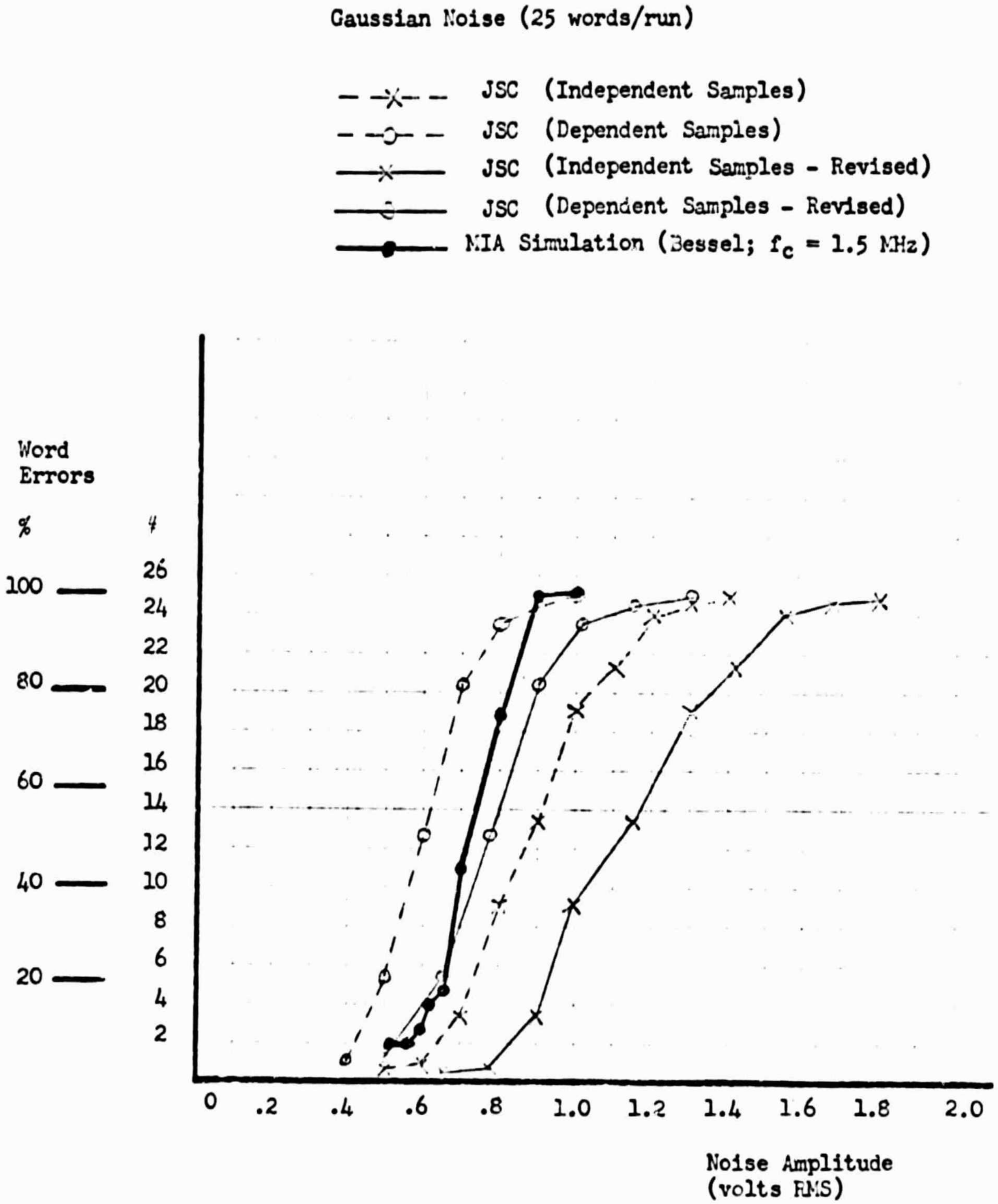
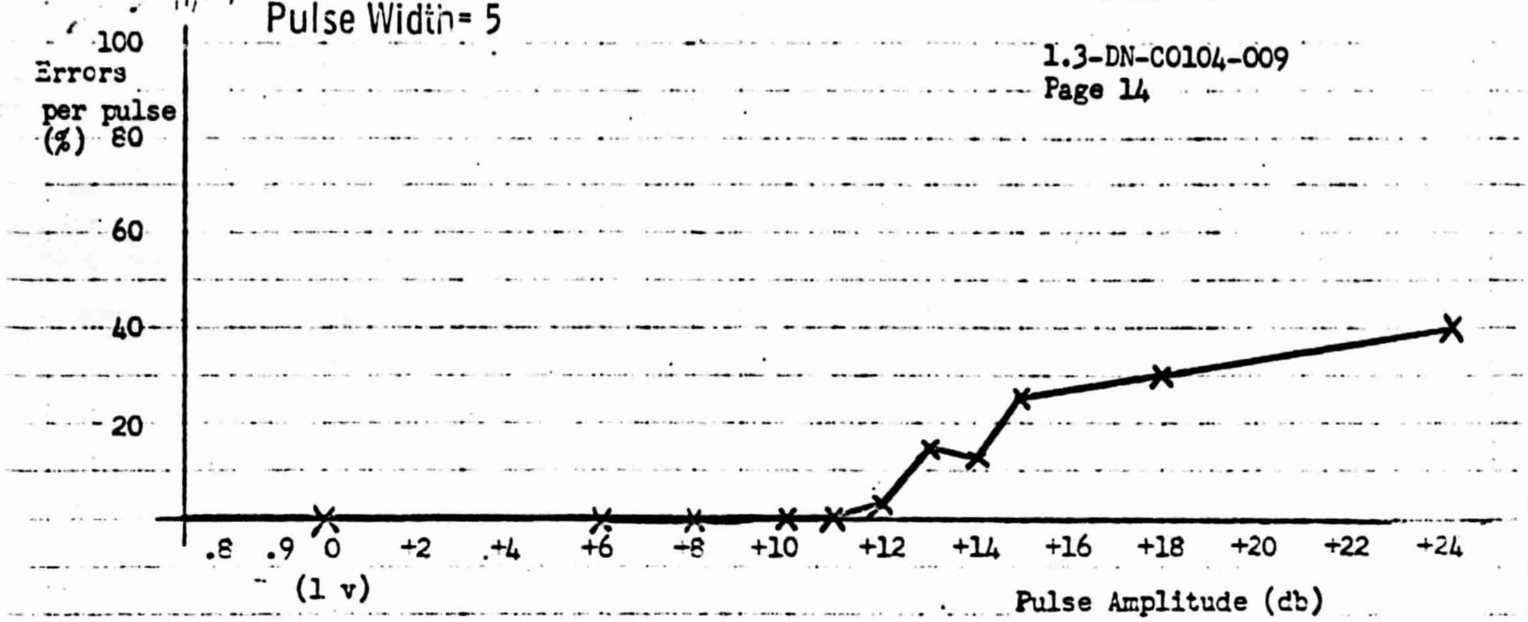
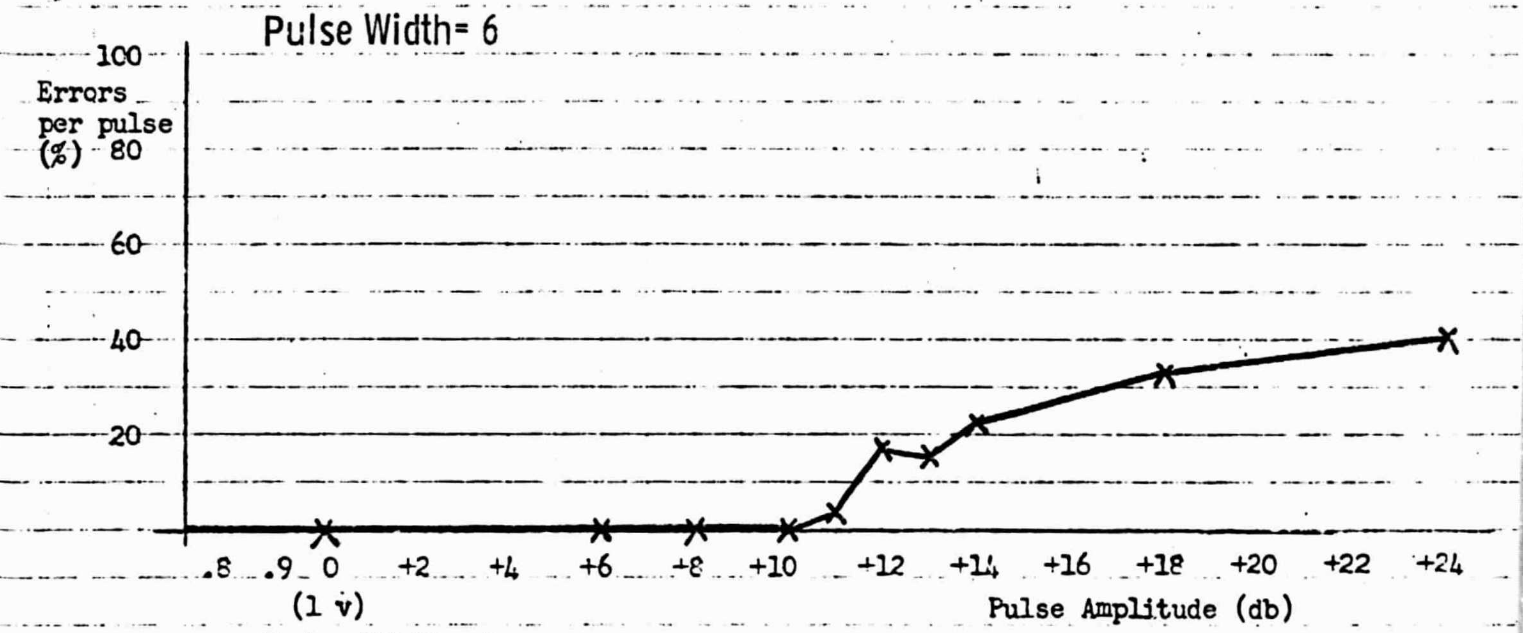
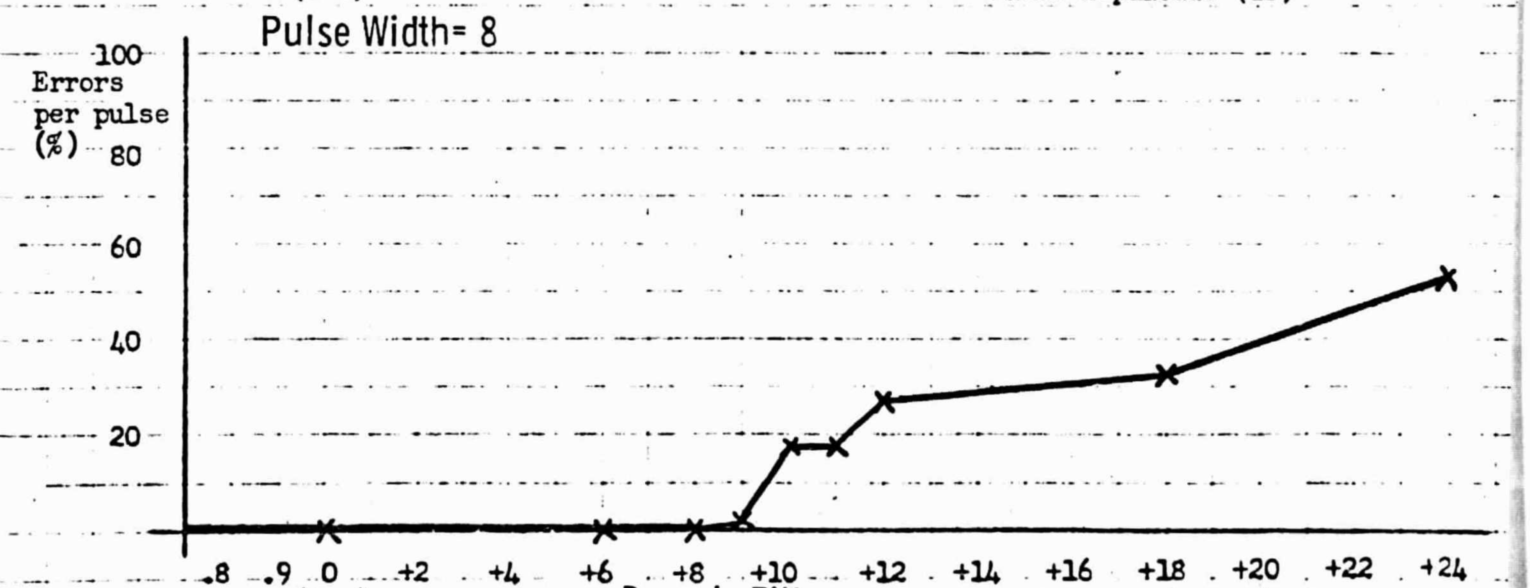

Gaussian Noise (25 words/run)
JSC (Independent Samples)
JSC (Dependent Samples)
JSC (Independent Samples - Revised)
JSC (Dependent Samples - Revised)
MIA Simulation (Bessel; $f_c$ = 1.5 MHz)
Word Errors
%
#
100
80
60
40
20
26
24
22
20
18
16
14
12
10
8
6
4
2
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Noise Amplitude (volts RMS)

Figure 5

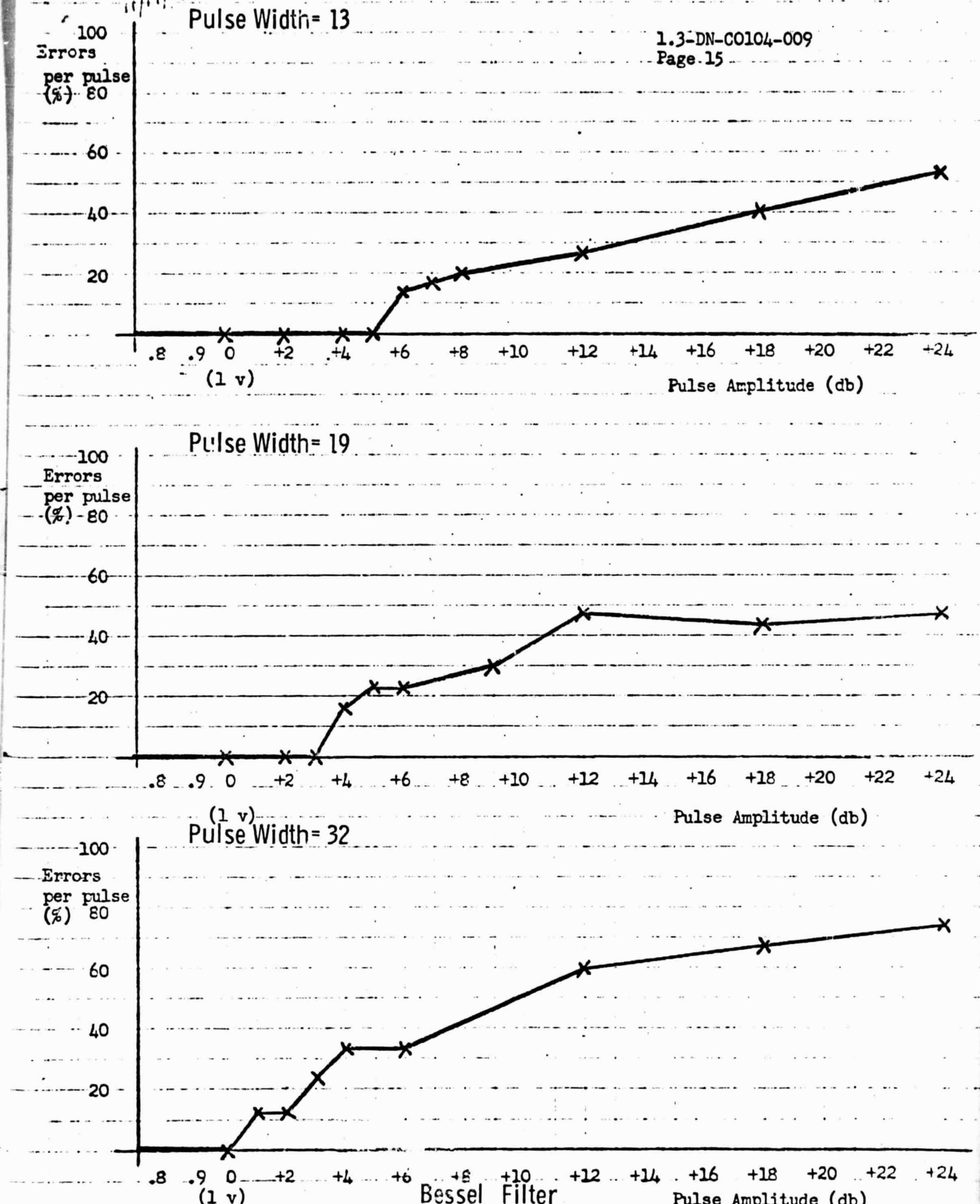


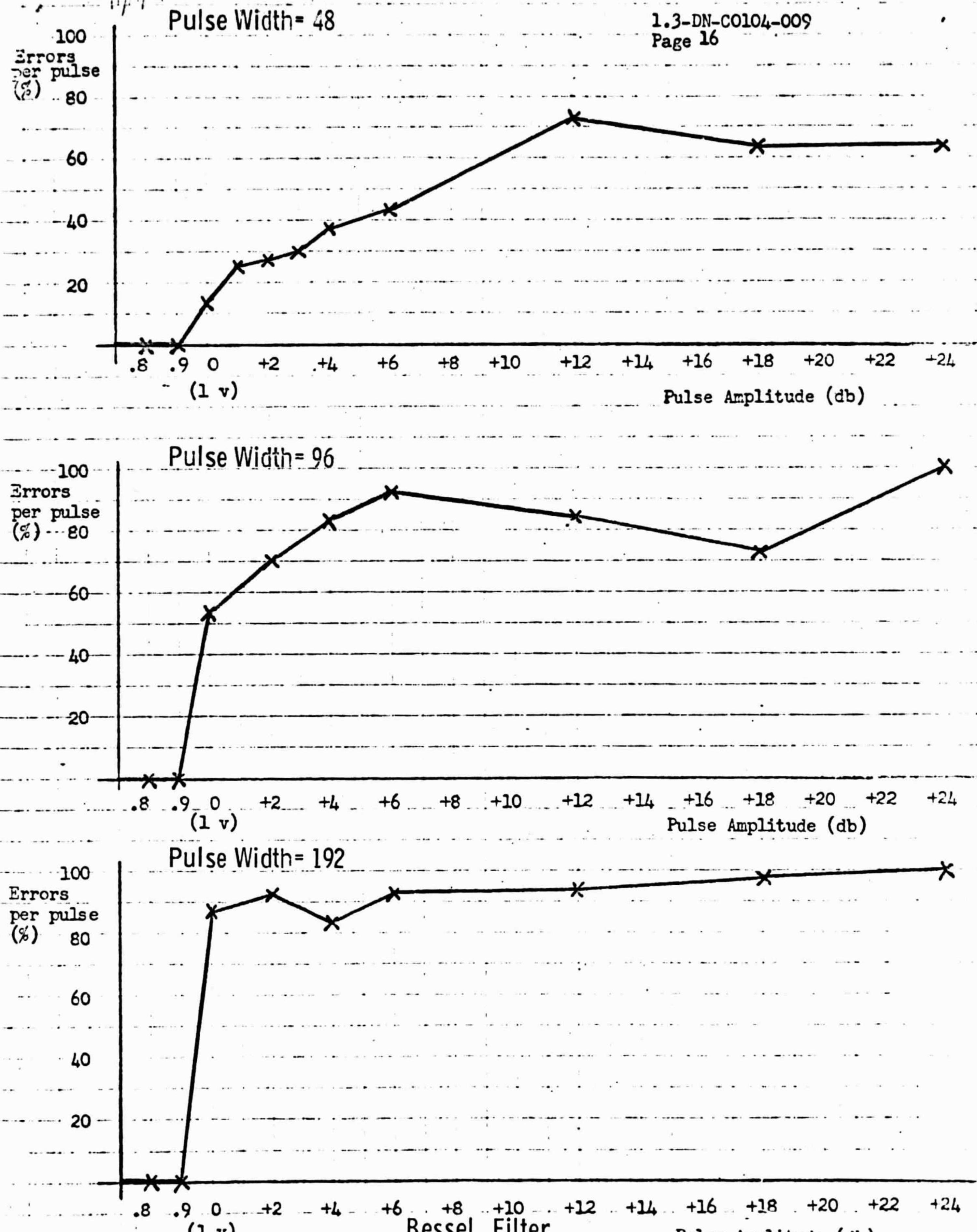

Bessel Filter

Figure 6

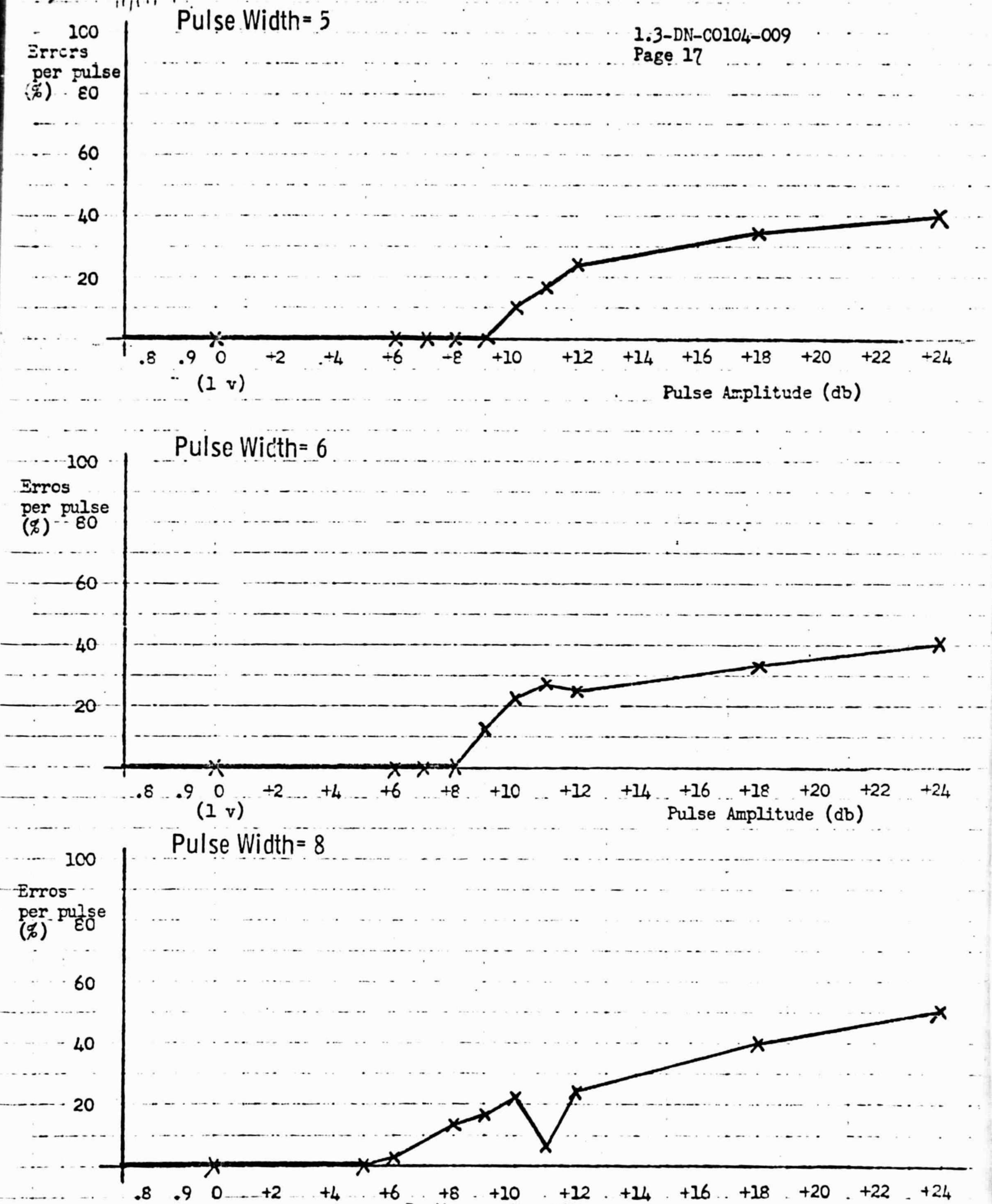



Bessel Filter

Figure 6 (cont)

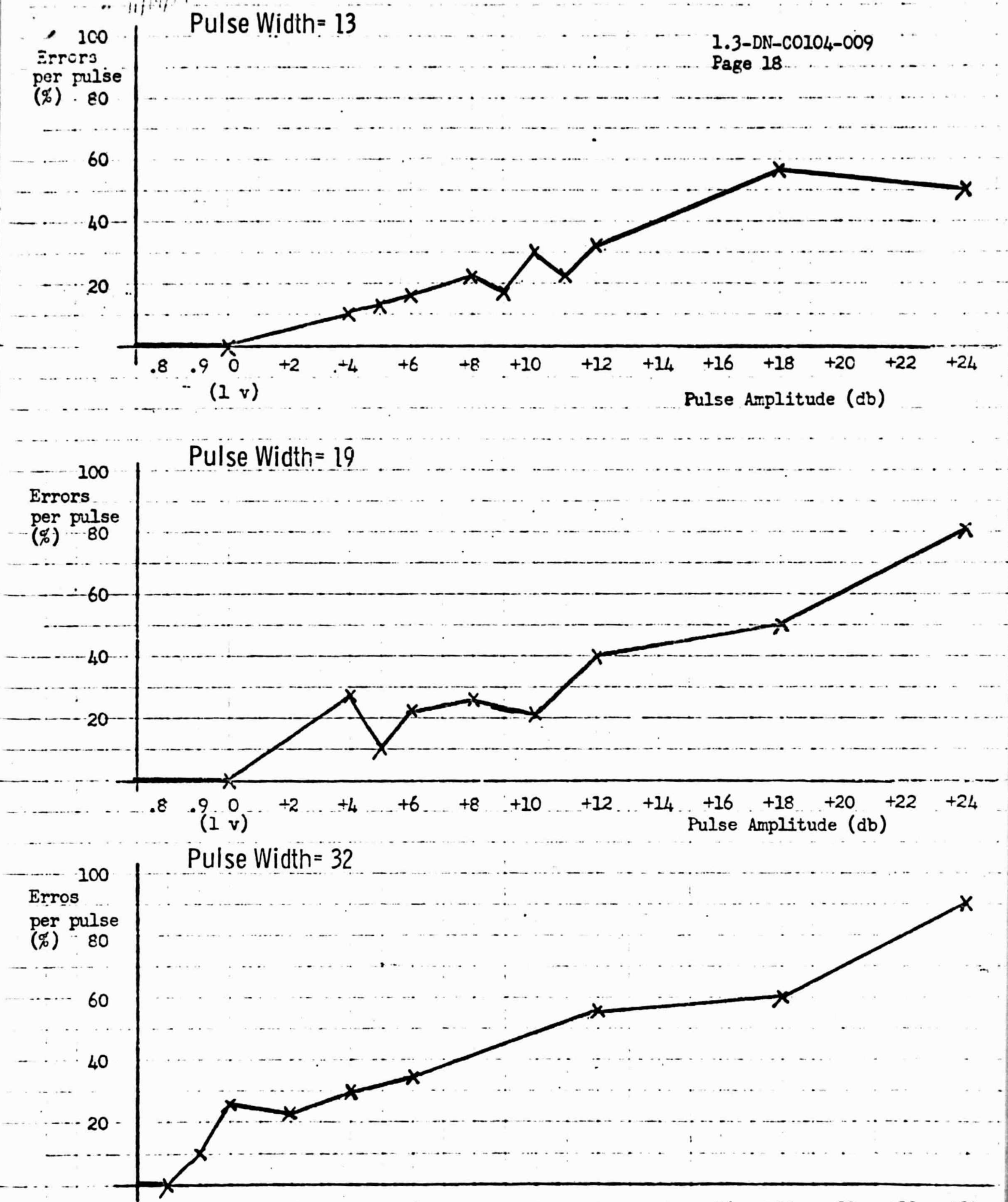



Bessel Filter
Figure 6 (cont)

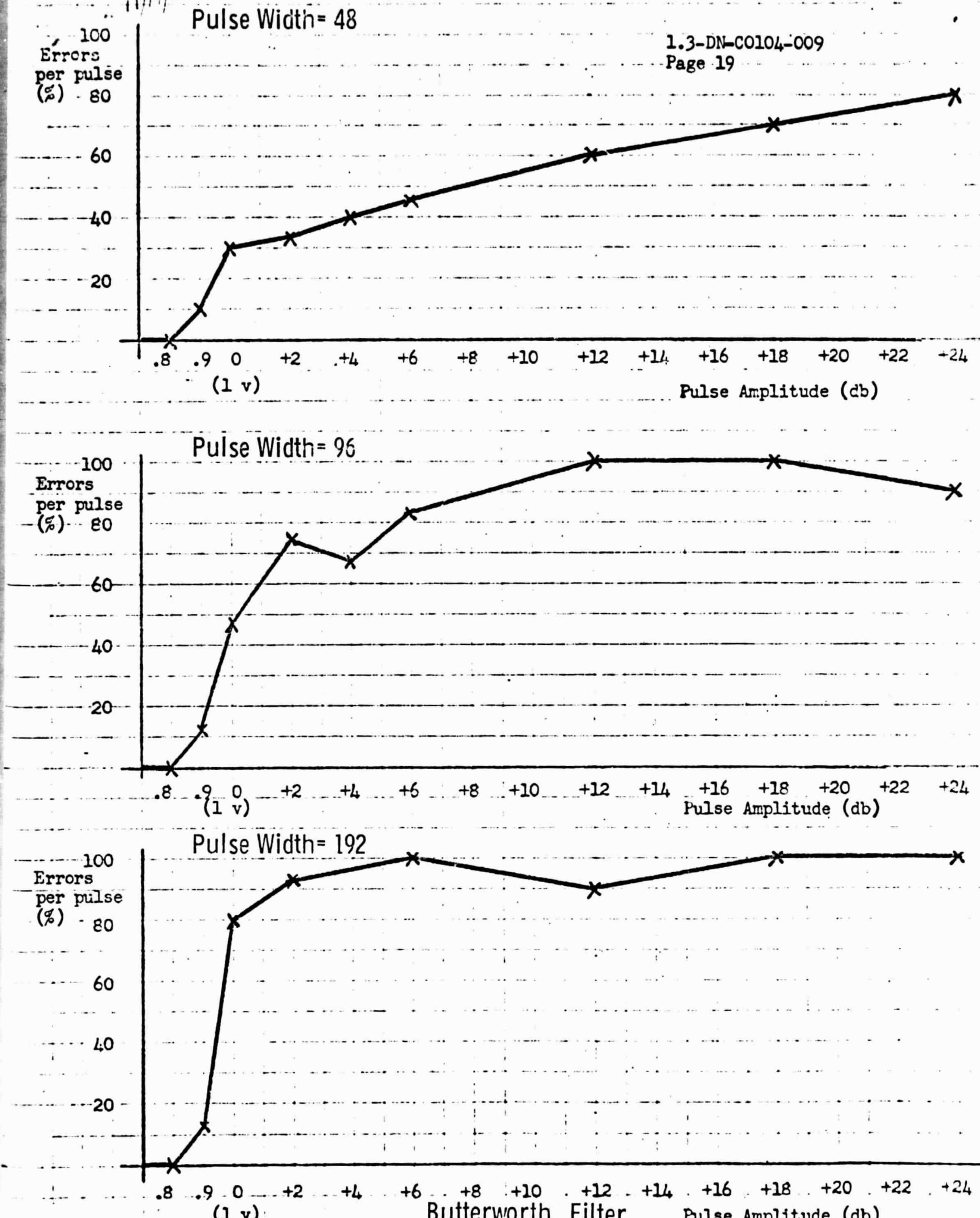



Butterworth Filter

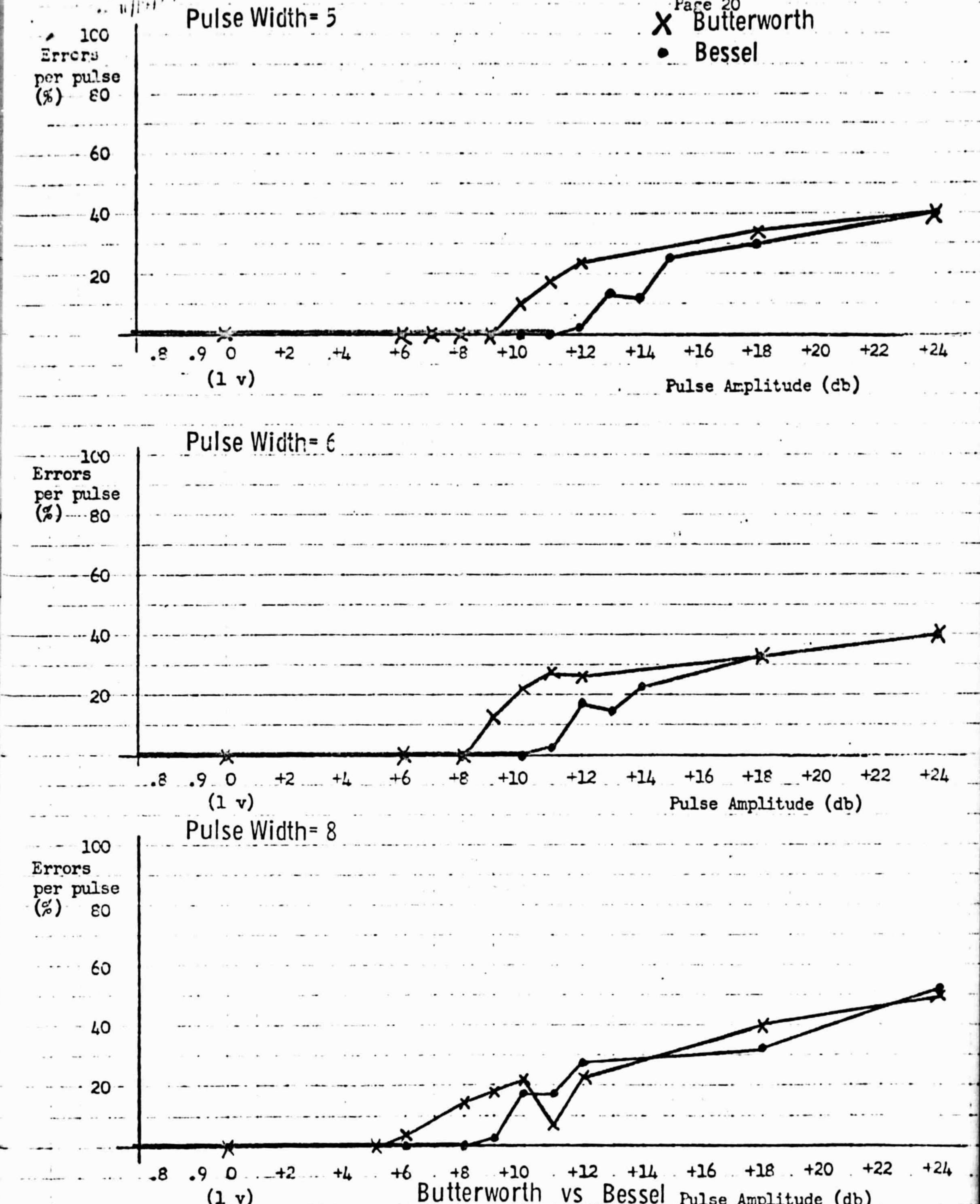
Figure 7




Butterworth Filter
Figure 7 (cont)

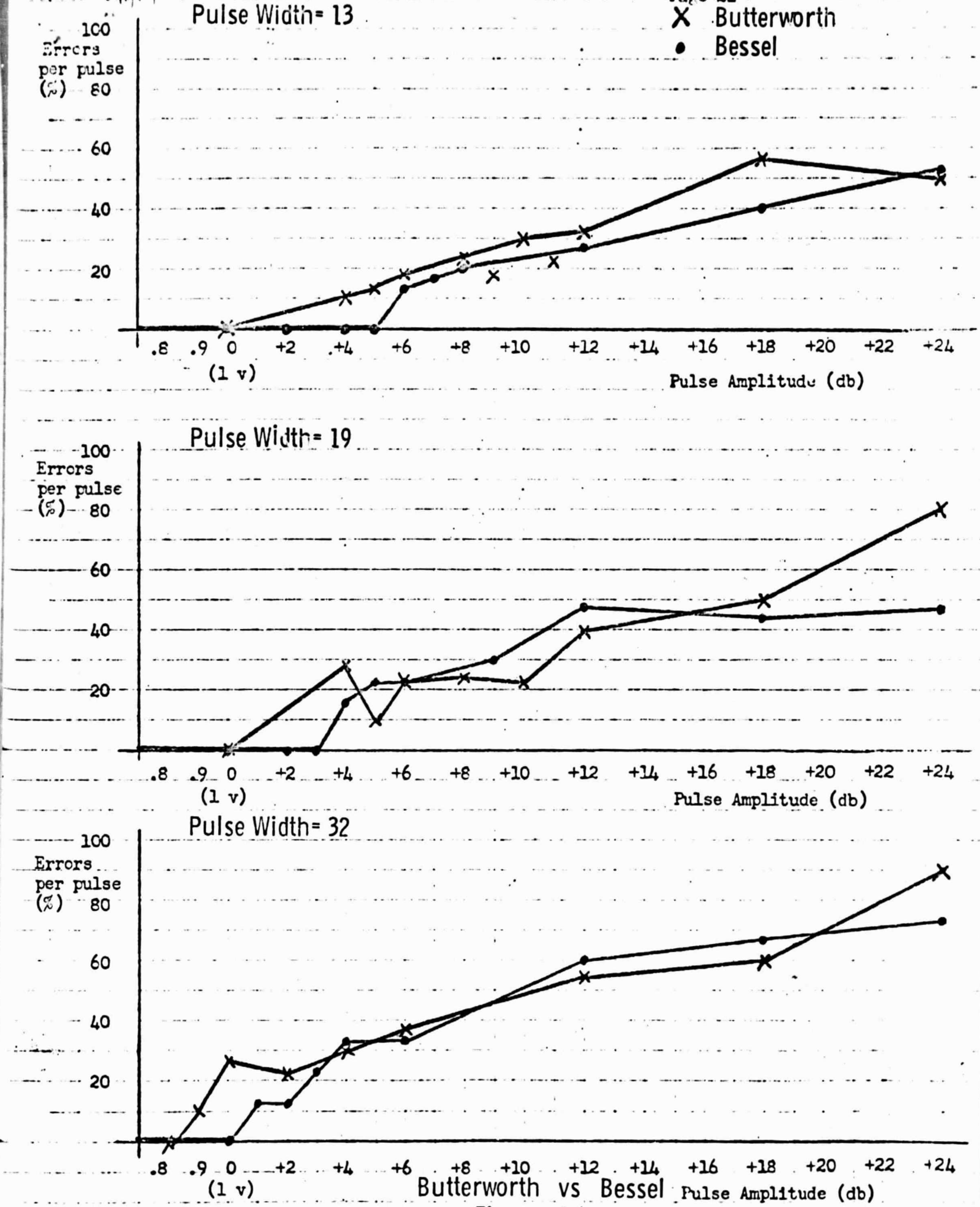



Butterworth Filter
Figure 7 (cont)



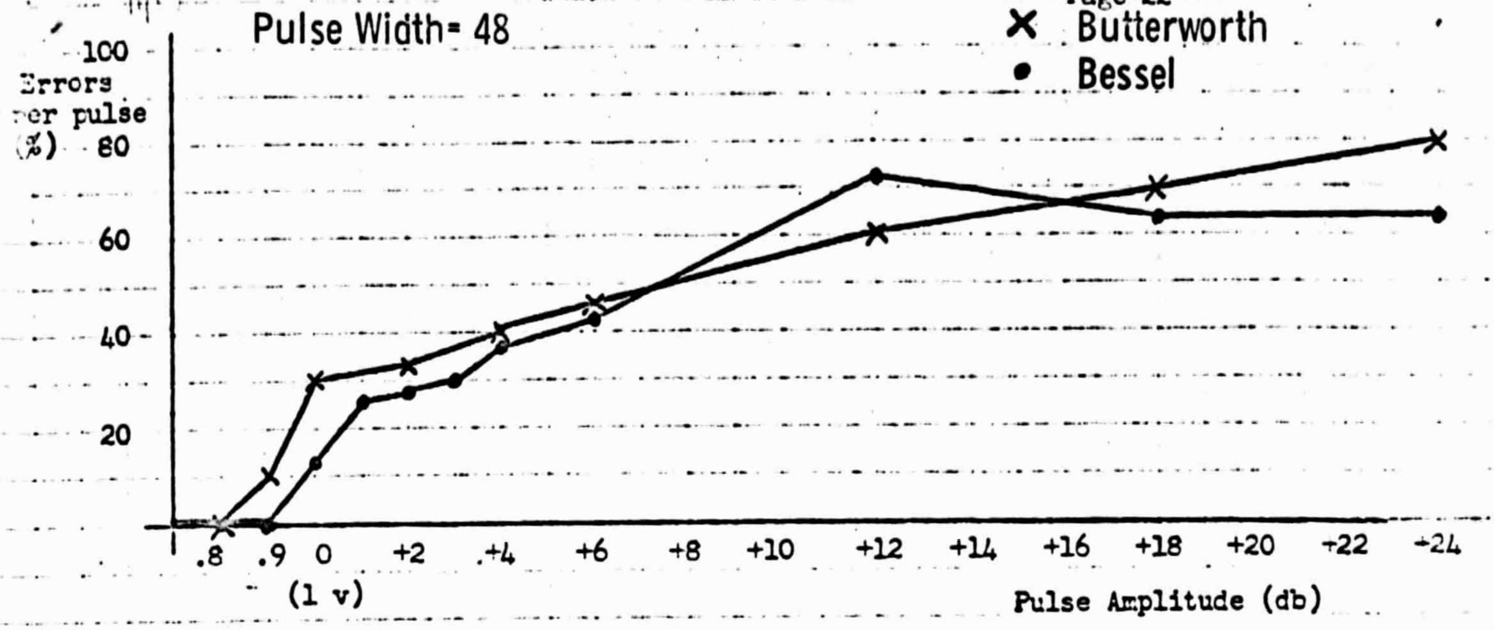

Butterworth vs Bessel

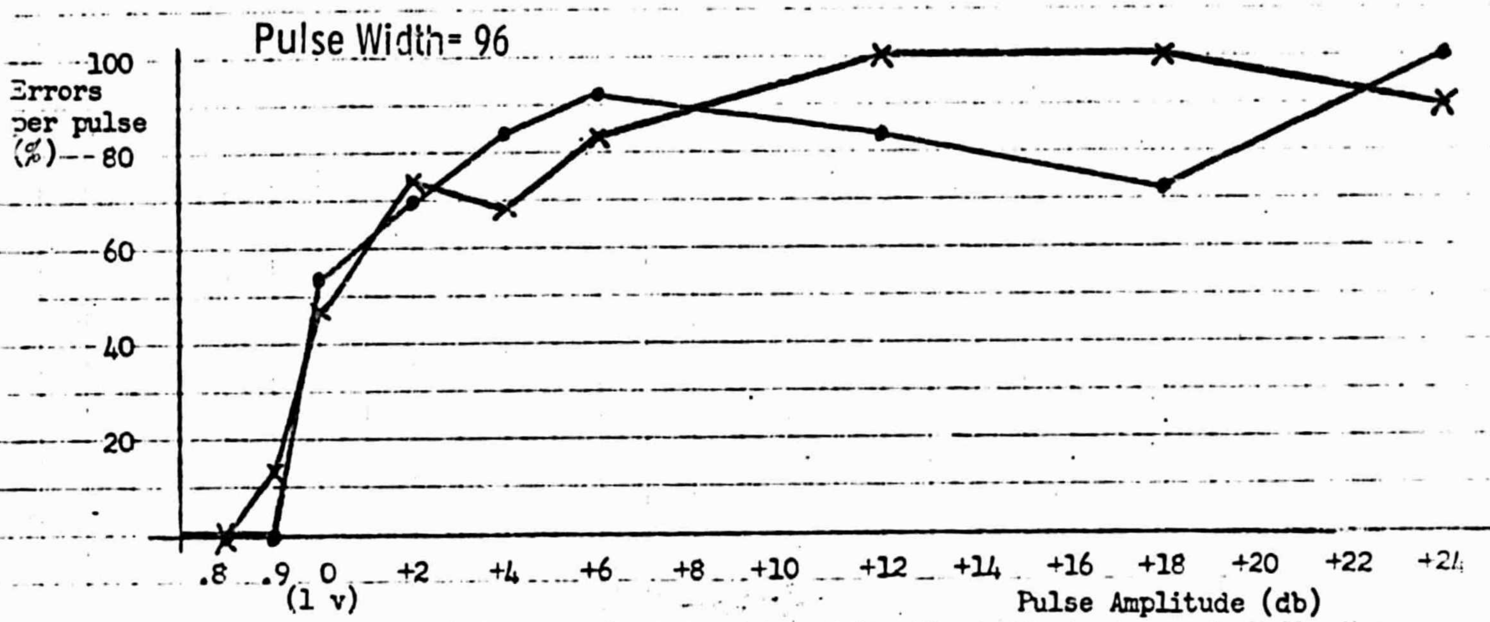
Figure 8

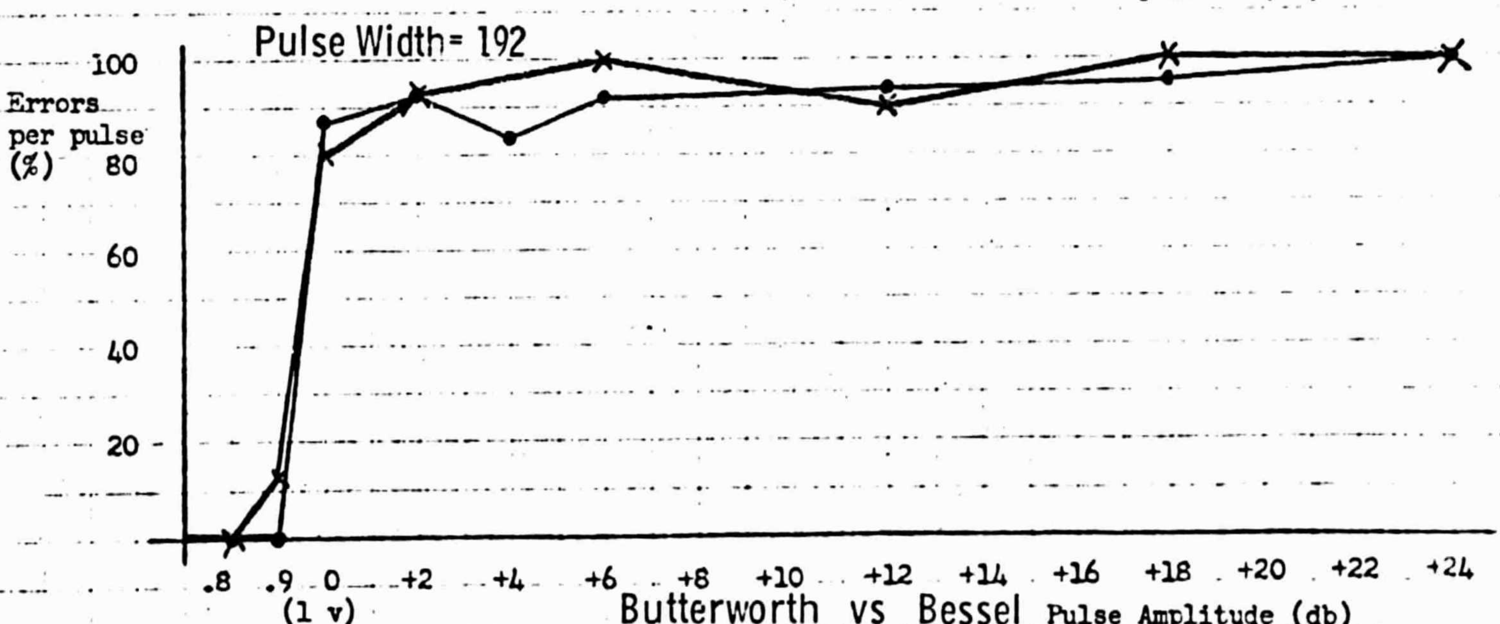



Butterworth vs Bessel

Figure 8 (cont)




Butterworth vs Bessel

Figure 8 (cont)

## Appendix A.

## Filter Equation Derivations

### 1. Bessel Filter

The transfer function for a 6-pole Bessel (maximally flat delay) filter is well-known to be:

$$G_{12}(s) = \frac{10,395}{10,395 + 10,395Ts + 4,725T^2s^2 + 1,260T^3s^3 + 210T^4s^4 + 21T^5s^5 + T^6s^6}$$

where T is the desired delay in seconds. Using Fig. 13-16, pg. 391 of Modern Network Synthesis (Ref. M. E. Van Valkenburg, <u>Modern Network Synthesis</u>. New York: Wiley & Sons, 1967), for a 6-pole Bessel filter the 3-db down point corresponds to

$$\omega_c T = 2.7$$

$$T = \frac{2.7}{\omega_c}$$

Using the bi-linear Z transform requires that we set

$$\omega_A = \tan \frac{\omega_c \cdot DT}{2}$$

to compensate for a frequency axis warping introduced by the transform, where DT is the sample interval, and $\omega_A$ acts as a dummy variable.

We now set

$$T = \frac{\omega_A}{2.7} .$$

Letting,

$$A = 10,395$$

$$B = 10,395T$$

$$C = 4,725T^2$$

$$D = 1,260T^3$$

$$E = 210T^4$$

$$F = 21T^5$$

$$G = T^6$$

and performing the substitution

$$s = \frac{z - 1}{z + 1}$$

which is the bi-linear Z transformation, we obtain

$$G_{12}(s) = \frac{A}{A + B\left(\frac{z-1}{z+1}\right) + C\left(\frac{z-1}{z+1}\right)^2 + D\left(\frac{z-1}{z+1}\right)^3 + E\left(\frac{z-1}{z+1}\right)^4 + F\left(\frac{z-1}{z+1}\right)^5 + G\left(\frac{z-1}{z+1}\right)^6}$$

Multiplying through by $(z + 1)^6$, and letting

$Q1 = A + B + C + D + E + F$

$Q2 = 6A + 4B = 2C - 2E - 4F - 6G$

$Q3 = 15A + 5B - C - 3D - E + 5F + 15G$

$Q4 = 20A - 4C + 4E - 20G$

$Q5 = 15A - 5B - C - 3D - E - 5F + 15G$

$Q6 = 6A - 4B + 2C - 2E + 4F - 6G$

$Q7 = A - B + C - D + E - F + G$

We obtain

$$G_{12}(z) = \frac{A\,(z^6 + 6z^5 + 15z^4 + 20z^3 + 15z^2 + 6z + 1)}{Q1z^6 + Q2z^5 + Q3z^4 + Q4z^3 + Q5z^2 + Q6z + Q7}$$

$$= \frac{A(1 + 6z^{-1} + 15z^{-2} + 20z^{-3} + 15z^{-4} + 6z^{-5} + z^{-6})}{Q1 + Q2z^{-1} + Q3^{-2} + Q4z^{-3} + Q5z^{-4} + Q6z^{-5} + Q7z^{-6}}$$

Since the $z^{-1}$ operator corresponds to a delay of one sample time we finally obtain

$$Y(nT) = \frac{1}{Q1}\,[A[\,X(nT) + 6\,X(nT - T) + 15\,X(nT - 2T) + 20\,X(nT - 3T)$$
$$+ 15\,X(nT - 4T) + 6\,X(nT - 5T) + X(nT - 6T)]$$
$$- [Q2\,Y(nT - T) + Q3\,Y(nT - 2T) + Q4Y(nT - 3T)$$
$$+ Q5\,Y(nT - 4T) + Q6\,Y(nT - 5T) + Q7\,Y(nT - 6T)]]$$

Where X(nT) is the sampled input signal and Y(nT) is the sampled output (filtered) signal.

2. Butterworth Filter

The transfer function for a 6-pole Butterworth (maximally flat amplitude response) filter is:

$$G_{12}(s) = \frac{\omega_c^6}{\omega_c^6 + 3.8637s\omega_c^5 + 7.4641s^2\omega_c^4 + 9.1416s^3\omega_c^3 + 7.4641s^4\omega_c^2 + 3.8637s^5\omega_c + s^6}$$

Where $\omega_c$ is the 3-db cutoff frequency.

Using the bi-linear Z transform requires (see Bessel Filter, Part 1) that we set

$$\omega_A = \tan \frac{\omega_c \cdot DT}{2}$$

Letting

$$Q1 = 3.8637\ \omega_A$$

$$Q2 = 7.4641\ \omega_A^2$$

$$Q3 = 9.1416\ \omega_A^3$$

$$Q4 = 7.4641\ \omega_A^4$$

$$Q5 = 3.8637\ \omega_A^5$$

$$Q6 = \omega_A^6$$

We have

$$G_{12}(s) = \frac{Q6}{s^6 + Q1s^5 + Q2s^4 + Q3s^3 + Q4s^2 + Q5s + Q6}$$

Taking the bi-linear Z transform, multipying by $(z + 1)^6$ and letting

$$C1 = 1 + Q1 + Q2 + Q3 + Q4 + Q5 + Q6$$

$$C2 = -6 - 4Q1 - 2Q2 + 2Q4 + 4Q5 + 6Q6$$

$$C3 = 15 + 5Q1 - Q2 - 3Q3 - Q4 + 5Q5 + 15Q6$$

$$C4 = -20 + 4Q2 - 4Q4 + 20Q6$$

$$C5 = 15 - 5Q1 - Q2 + 2Q4 - 4Q5 + 6Q6$$

$$C6 = -6 + 4Q1 - 2Q2 + 2Q4 - 4Q5 + 6Q6$$

$$C7 = 1 - Q1 + Q2 - Q3 + Q4 - Q5 + Q6$$

we obtain

$$G_{12}(z) = \frac{Q6\,(z^6 + 6z^5 + 15z^4 + 20z^3 + 15z^2 + 6z + 1)}{C1z^6 + C2z^5 + C3z^4 + C4z^3 + C5z^2 + C6z + C7}$$

$$= \frac{Q6\,(1 + 6z^{-1} + 15z^{-2} + 20z^{-3} + 15z^{-4} + 6z^{-5} + z^{-6})}{C1 + C2z^{-1} + C3z^{-2} + C4z^{-3} + C5z^{-4} + C6z^{-5} + C7z^{-6}}$$

which yields

$$Y(nT) = \frac{1}{C1} [[Q6\,(X(nT) + 6\,X(nT - T) + 15\,X(nT - 2T) + 20\,X(nT - 3T)$$
$$+ 15\,X(nT - 4T) + 6\,X(nT - 5T) + X(nT - 6T)]$$
$$- C2\,Y(nT - T) + C3\,Y(nT - 2T) + C4\,Y(nT - 3T)$$
$$+ C5\,Y(nT - 4T) + C6\,Y(nT - 5T) + C7\,Y(nT - 6T)]]$$

3. Note

The implementation of each of the above equations is of the "direct implementation" form. This is the easiest form to implement, but it does have some disadvantages. The primary problem is that the coefficients, necessarily being of finite length, begin to cause erroneous output when $\omega_c DT$ becomes too small.