TO: ROGER STROMSTA

SHUGART SA850/450

READ CHANNEL ANALYSIS

BYRON WONG
12-79

TABLE OF CONTENTS

I. OVERVIEW p. 4

- -Read Channel Block Diagram p. 5

II. READ CHANNEL FRONT END

- -D.C. Analysis p. 4
- -Equivalent Circuit p. 6
- -Transfer Function p. 7
- -Read Damping Analysis p. 8
- -Sensitivity Analysis p. 9

III. READ CHIP-- AMPLIFIER PORTION

- -Amplifier gain calculation p. 12
- -Transfer Function p. 13
- -D.C. Blocking Capacitor Analysis p. 14
- -Amplifier Saturation p. 14

IV. IBM FILTER

- -Single Pole Low Pass Filter p. 15
- -Single Pole All Pass Filter p. 16

V. LOW PASS BESSEL FILTER p. 17

VI. READ CHIP-- DIFFERENTIATOR PORTION

- -Overall Description p. 18
- -Transfer Function p. 20
- -Component Selection p. 21

VII. READ CHIP-- TIME DOMAIN FILTER AND DIGITIZER

- -Time Domain Filter and Bit Pulse Width p. 24
- -Digitizer p. 26
- -An Example of Converting 1T/2T Analog Signal into Digital Bits p. 27

VIII. CONCLUSION p. 28

IX. ACKNOWLEDGEMENTS p. 28

X. REFERENCES p. 29

XI. SUMMARY OF EQUATIONS p. 29

XII. SUMMARY OF PLOTS p. 32

XIII. SET UP OF EXPERIMENTS p. 39

XIV. APPENDIX

A. Read Channel Front End:

- A-1: Derivation of read channel front end transfer function and related parameters p. 41
- A-2: Linear phase analysis p. 46
- A-3: Simulated Bode plots of SA850 p. 49
- A-4: Simulated Bode plots of SA450 p. 54
- A-5: Experiment determining damping factor of SA850 p. 58

B. Read Amplifier:

- B-1: Derivation of read amplifier transfer function and related parameters. p. 62
- B-2: Simulated read amplifier Bode plots with various values of D.C. blocking capacitors p. 64
- B-3: Actual Bode plots of a read amplifier with various values of D.C. blocking capacitors p. 71
- B-4: Exponential decay verse RC time constant p. 78
- B-5: Amplifier saturation plot p. 79

C. IBM Filter:

- C-1: Derivation of IBM all pass filter transfer function p. 80
- C-2: Simulated Bode plots of IBM all pass filter p. 81
- C-3: Actual Bode plots of IBM all pass filter p. 95
- C-4: Derivation of IBM low pass filter transfer function p. 97
- C-5: Simulated Bode plots of IBM low pass filter p. 98
- C-6: Actual Bode plots of IBM low pass filter p. 102
- C-7: Simulated Bode plots of read amplifier and IBM all pass filter p. 104
- C-8: Actual Bode plots of read amplifier and IBM all pass filter p. 112
- C-9: Simulated Bode plots of read amplifier and IBM low pass filter p. 114
- C-10: Actual Bode plots of read amplifier and IBM low pass filter p. 124

D. Bessel Filter:

D-1: Actual Bode plots of SA 850 Bessel filter p. 127
D-2: Actual Bode plots of SA 450 Bessel filter p. 129
D-3: Actual Bode plots of SA 450 Bessel filter with ideal value (without adjustment). p. 131
D-4: Actual Bode plots of SA 850 Amplifier, IBM L.P. & Bessel L.P. p. 133
D-5: Actual Bode plots of SA 850 Amplifier, IBM A.P. & Bessel L.P. p. 135
D-6: Actual Bode plots of SA 850 Amplifier & Bessel L.P. p. 137
D-7: Actual Bode plots of SA 850 Amplifier & Bessel L.P. with differentiator connected p. 139
D-8: Actual Bode plots of SA 450 Amplifier & Bessel L.P. p. 141
D-9: Actual Bode plots of SA 450 Amplifier & Bessel L.P. with differentiator connected p. 143

E. Differentiator:

E-1: Derivation of idfferentiator with/without parallel resistor p. 146
E-2: Simulated Bode plots of differentiator with actual elements p. 153
E-3: Simulated Bode plots of differentiator with optimum elements p. 155
E-4: Simulated Bode plots of amplifier and differentiator with actual elements p. 161
E-5: Simulated Bode plots of amplifier and differentiator with optimum elements p. 164
E-6: Simulated Bode plots of amplifier and differentiator after perfect pole/zero cancellation with actual elements p. 168
E-7: Simulated Bode plots of amplifier and differentiator after perfect pole/zero cancellation with optimum elements p. 173
E-8: Derivation of time response of differentiator for pure sinewave input p. 177
E-9: Simulated time response of differentiatorfor sinewave input with actual elements p. 180
E-10: Simulated time response of differentiator for sinewave input with optimum elements p. 186
E-11: Derivation of time response of differentiator for pure sinewave input assuming perfect pole/zero cancellation p. 191
E-12: Simulated time response of differentiator for sinewave input with actual and optimum elements, no perfect pole/zero cancellation p. 194
E-13: Simulated time response of differentiator for sinewave input with actual and with optimum elements after perfect pole/zero cancellation p. 200

F. Common collector transistor equivalent circuit model. p. 205

G. Schematics.

- F-1: SA 850 Schematics p. 206
- F-2: SA 450 Schematics p. 207
- F-3: Read Amplifier Schematics p. 208

I. OVERVIEW

The purpose of this analysis is to provide a basic understanding of the Shugart SA 850/450 floppy drive read chain electronics,and to provide a record for future references.

Experiments were performed where ever possible to provide comparisons between theoretical and actual results. It probably would be helpful to study the table of contents on appendix and also section twelve--summary of plots, more closely to visualize the comparisons.

A read chain block diagram is shown on page five.

II. READ CHANNEL FRONT END

The front end of read channel consists of read/write head, read damping resistors and steering diodes.

1. D.C. ANALYSIS:

The steering diodes are there to provide D.C. bias paths during the read mode, and to provide D.C. blocking during write mode. Side select is accomplished by the write chip center taps. A summary table is provided below:

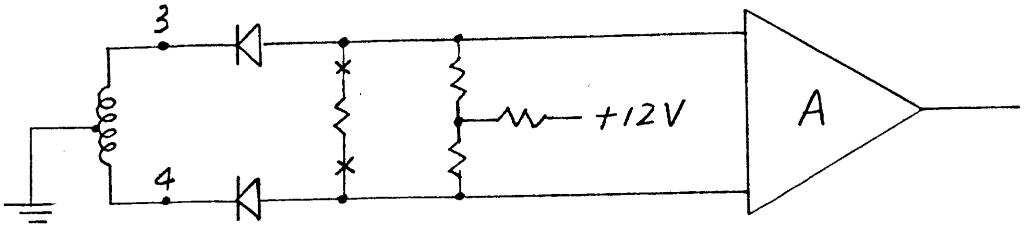
	READ MODE		WRITE MODE	
	SIDE 0	SIDE 1	SIDE 0	SIDE 1
CT 0	LOW	HIGH	HIGH	LOW
CT 1	HIGH	LOW	LOW	HIGH

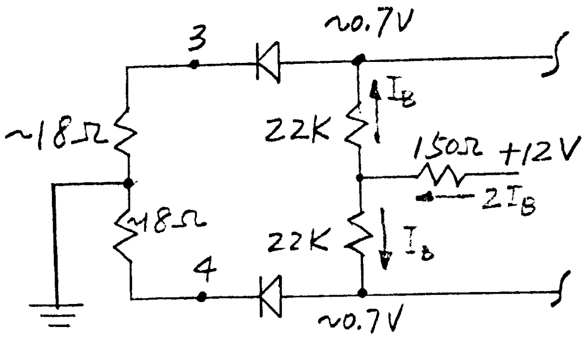
During write mode, the write chip data pins (6,7) provide high and low resistance paths, according to the input data, to accomplish the write function.

During read mode, pins (6,7) of write chip become an open circuit, hence no data would be written even if one of the center taps (the side that is not selected) is high.

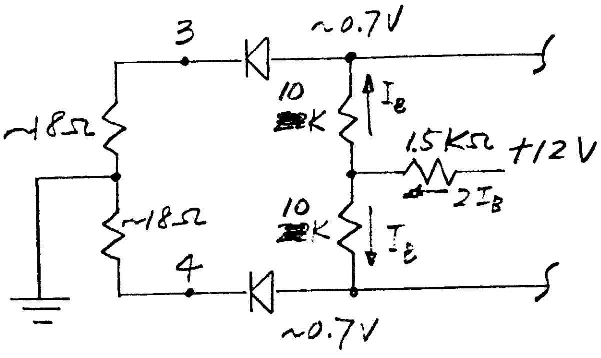
There are also two diodes in front of the read chip to provide input clamping to prevent read chip from blowing up during transient and/or static discharge.

D.C. equivalent CKT of head in read mode is





SA 850



SA 450

D.C. bias current (D.C. current through the head):

SA 850:

$$I_B = \frac{12V - 0.7V}{22K}$$

$= 0.51 mA$

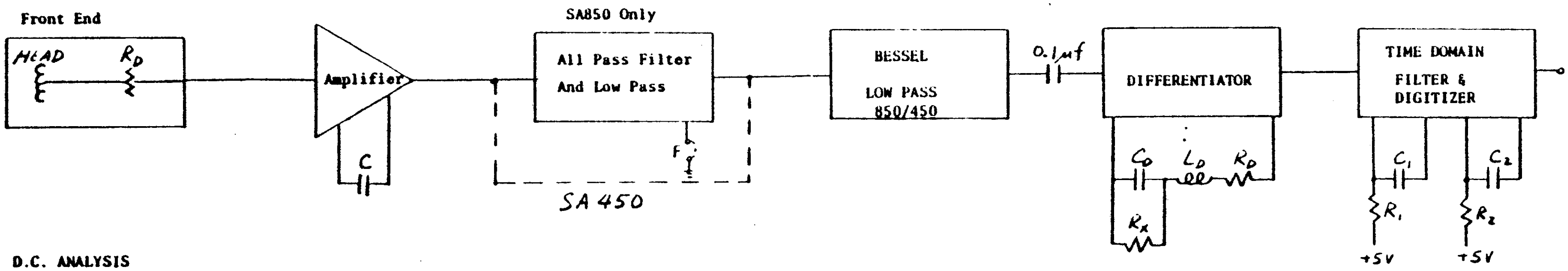
SA 450:

$$I_B = \frac{\dfrac{12V - 0.7V}{1.5K + 10K//10K}}{2}$$

$= 0.87 mA$

The D.C. voltage at points 3 & 4 is, for all practical purposes, at ground.

SA850/450 CHANNEL BLOCK DIAGRAM



D.C. ANALYSIS

- EQUIVALENT CKT
- TRANSFER FUNCTION
- SIMULATED BODE PLOTS
- DAMPING FACTOR ANALYSIS
- SENSITIVITY ANALYSIS
- LINEAR PHASE ANALYSIS
- Experimental Verification of SA850 Damping Factor

- GAIN CALCULATION
- TRANSFER FUNCTION
- SIMULATED BODE PLOTS
- ACTUAL BODE PLOTS
- D.C. BLOCKING CAP. CONSIDERATION
- READ/WRITE RECOVERY
- AMPLIFIER SATURATION PLOTS

- EQUIVALENT CKT-- A.P. & L.P.
- TRANSFER FUNCTION--A.P. & L.P.
- SIMULATED BODE PLOTS--A.P. & L.P.
- ACTUAL BODE PLOTS--A.P. & L.P.

- TRANSFER FUNCTION
- ACTUAL BODE PLOTS
- BODE PLOTS FOR OPTIMUM THEORETICAL 450 L.P.

- TRANSFER FUNCTION
- SIMULATED BODE PLOTS
- TIME RESPONSE PLOT OF 1F & 2F
- COMPONENT SELECTION CONSIDERATION
- POLE/ZERO CANCELLATION CONSIDERATION

- TIME FILTER PERIOD T_1 SELECT
- PULSE WIDTH T_2 SELECT
- TIME DOMAIN FILTER PITFALLS

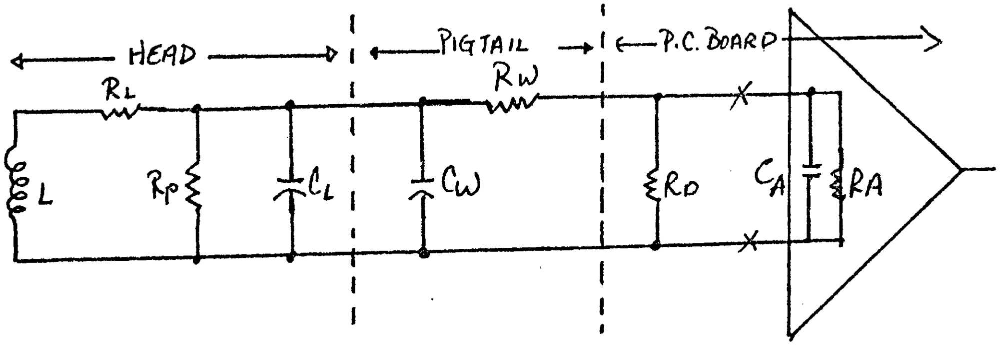
SIMULATED AND ACTUAL BODE PLOTS OF:

- Amp. + A.P. + Bessel (SA850-- with or without differentiator connected)
- Amp. + L.P. + Bessel (SA450-- with or without differentiator connected)
- Amp. + A.P. (SA850)
- Amp. + L.P. (SA850)
- Amp. + Bessel (SA450-- with or without differentiator connected)

Simulated Frequency and Time Response of Amplifier and Differentiator Together.

2. EQUIVALENT CIRCUIT:

A complete model of the A.C. equivalent circuit is shown below:



L = Equivalent head inductance (full coil)
R_L= Head internal D.C. resistance
C_L= Equivalent distributed head capacitance
R_P= Pure resistance at resonance.
R_W= Pig tail wire resistance
C_W= Pig tail wire capacitance
R_D= Equivalent read damping resistance
C_A= Amplifier input capacitance
R_A= Amplifier input resistance
F_0= Resonant frequency (Head and pigtail only)

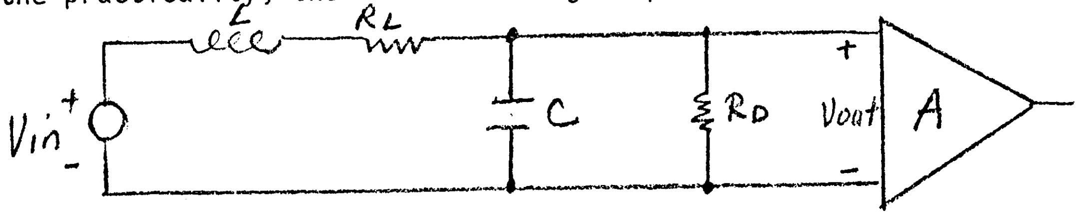
Typical readings of head and pigtail are:

	F_0	L	R_L	C_L	R_P	R_W	C_W	R_D		C_A	R_A
SIDE 0	513 Khz	1.91 mH	36ohm	48pf	76Kohm	4 ohm	1 pf	850	450	10pf	100kohm
SIDE 1	536 Khz	1.72 mH	36ohm	51pf	51Kohm	4 ohm	1 pf	5.9K ohm	4k ohm		

* The readings for both side 0 & 1 are usually identical.
The inductance is spec. for 18mH ± 2mH and the capacitance is spec. for 12 ± 3pf.

3. TRANSFER FUCTION: (Appendix A)

Due to the complexity of the above model and in consideration of the practicality, the model is being simplified as the following:



Assuming: $R_W=0$, $R_p=R_A=\infty$

$C=C_L+C_W+C_A$

The transfer function as derived in appendix A is:

$$T(s) = \frac{1}{LC} \cdot \frac{1}{s^2+s\left(\frac{R_L}{L}+\frac{1}{CR_D}\right)+\frac{R_L+R_D}{LCR_D}}$$

$2\xi = \left(\frac{R_L}{L}+\frac{1}{CR_D}\right)$; ξ = Damping factor, not normalized

$W_0{}^2 = \frac{R_L+R_D}{LCR_D} \simeq \frac{1}{LC}$; W_0 = 3 dB corner frequency

$|\xi| = \frac{\xi}{W_0} = \frac{1}{2R_D}\sqrt{\frac{L}{C}}$

From the relationship listed above, it is obvious that head performance is degraded after connected to the amplifier. That is the head band-width is reduced due to the introduction of additional capacitance. For both 850/450:

$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$ (L= 1.91 mH, C= 59 pf) (natural frequency)

$= 474$ KHz (Compare with 513 Khz)

Bode plot of various L_s and C_s are plotted at Appendix A.

	L	C	RD	$\vert\xi\vert$	OVERSHOOT %	Fo
SA 850	1.75 mH	50 pf	5.89K	0.502	15.2 %	538 KHz
		39 pf		0.462	22 %	495 KHz
	1.9 mH	50 pf				
		59 pf				
SA 450	1.75mH	50 pf	4.0 K	0.74	0 %	538 KHz
		59 pf		0.68	0 %	495 KHz
	1.9 mH	50 pf				
		59 pf				

As can be noted from the plots for SA 850, peaking does not occur at f_0. For $|\xi|<0.1$, peaking occurs at f_0. For $0.707>|\xi|>0.1$, peaking occurs at

$f = f_0\sqrt{1-2|\xi|^2}$ (peaking frequency)

Inter-Office Memo

To
DISTRIBUTION

From
BYRON WONG

Subject
UPDATES ON SA450/850 READ CHANNEL ANALYSIS

Date
FEBRUARY 4, 1980

A mistake was discoverd by Art Geffon on P. 18A of the report.

The equation for C_D is:

$$C_D = \frac{\text{Imax}}{\text{Amax Emax Wmax}}$$

where Emax should have been defined as

$$\text{Emax} = \text{Max. head output (zero to peak)}$$
$$\leq 7 \text{ mV (0-P)}$$

The error caused all subsequent calculations to be off by a factor of two. However, using the values calculated in the report would not affect the differentiator's performance in terms of frequency and linearity. The error resulted in a more conservative differentiator design. In other words, it increased the upper limit of the differentiator's input dynamic range. All other parameters were self-adjusted to compensate for the shift. Due to this conservative design, we might be sacrificing the low end sensitivity of the differentiator. Art is going to run some experiments to determine the effect.

BW:ds

4. READ DAMPING ANALYSIS:

For minimum phase distortion, group delay should equal to phase delay. Under this theoretical consideration, we would like to have a read damping factor of .866 and quality factor of .577. (See Appendix A --linear phase analysis). The damping factor indicates the amount of over shoot and it affects the amplitude and phase linearity of signal. Damping factor for SA 850:

$$|\zeta| = \frac{\zeta}{\omega_0} = \frac{1}{2R_D}\sqrt{\frac{L}{C}}$$

$R_D = 6.8K // 2(2.2K) = 5.9K$ ohm

$|\zeta| = 0.48$ (Under Damped) (if $L = 1.7mH$, $C = 59pf$)

$|\zeta| = 0.46$ ($L = 1.91mH$, $C = 59pf$)

SA 450:

$R_D = 4.87K // 2(10K) = 4K$ ohm

$|\zeta| = 0.71$

$|\zeta| = 0.68$ (if $L = 1.7mH$, $C = 59pf$)

Given ZETA, the percent of overshoot, if occurs, can be calculated by

$$\text{Overshoot \%} = \left[\frac{1}{2|\zeta|\sqrt{1-|\zeta|^2}} - 1\right]100\% \qquad |\zeta| < .707$$

This equation is true for ZETA less than 0.707. For ZETA greater than .707, the system is over damped and no overshoot can occur. For an under-damped system, overshoot will occur yet the read back signal will have a narrower pulse width.

An experiment was done by Art Geffon to determine the damping factor. The result showed that a head with L=1.7mH, C=59 pf, R_D=5.9k ohm has ZETA equal to 0.43 (see Appendix A). This is very close to the calculated value.

*** Three parameters dictate the choice of damping factors. They are 1) head bandwidth entension consideration to retain more higher harmonies which would affect the margin; 2) signal to noise ratio which would also affect margin; 3) phase linearity which would affect signal linearity and margin to see P. 46 for linear phase analysis.

5. SENSITIVITY ANALYSIS:

In order to determine how component tolerance will affect various parameters, it is necessary to do a sensitivity analysis for individual parameter with respect to different components. Damping factor sensitivity will be considered.

$$S_{q_i}^{|\xi|} \triangleq \frac{\frac{\partial|\xi|}{\xi}}{\frac{\delta q_i}{q_i}} = \frac{q_i}{|\xi|}\,\frac{d(\xi|}{d q_i}$$

(Sensitivity of $|\xi|$ with respect to variable q_i)

$$S^{|\xi|}_{q_1+q_2+q_3+\dots} \triangleq S^{|\xi|}_{q_1} + S^{|\xi|}_{q_2} + S^{|\xi|}_{q_3} + \dots$$

$$S^{|\xi|}_{R_D+L+C} = S^{|\xi|}_{RD} + S^{|\xi|}_{L} + S^{|\xi|}_{C}$$

$$\frac{\Delta\xi}{\xi} = \frac{\Delta R_D}{R_D} S^{|\xi|}_{R_0} \; ; \; \frac{\Delta\xi}{\xi} = \frac{\Delta L}{L} S^{|\xi|}_{L} \; ; \; \frac{\Delta\xi}{\xi} = \frac{\Delta C}{C} S^{|\xi|}_{C}$$

Worest case analysis:

$$\frac{\Delta|\xi|}{|\xi|} = \frac{\Delta R_D}{R_D} S^{|\xi|}_{R_D} + \frac{\Delta L}{L} S^{|\xi|}_{L} + \frac{\Delta C}{C} S^{|\xi|}_{C}$$

$$\because |\xi| = \frac{1}{2R_D}\sqrt{\frac{L}{C}}$$

$$S^{|\xi|}_{R_D} = \frac{R_D}{|\xi|}\,\frac{d|\xi|}{dR_D} = \frac{R_D}{2|\xi|}\sqrt{\frac{L}{C}}\left(-\frac{1}{R_D^2}\right) = -\frac{1}{2|\xi|R_D}\sqrt{\frac{L}{C}}$$

$$S^{|\xi|}_{L} = \frac{L}{|\xi|}\,\frac{d\xi}{dL} = \frac{L}{\xi}\,\frac{1}{4R_D\sqrt{LC}} = \frac{1}{4R_D\xi}\sqrt{\frac{L}{C}}$$

$$S^{|\xi|}_{C} = \frac{C}{|\xi|}\,\frac{d\xi}{dC} = \frac{C\sqrt{L}}{2|\xi|R_D}\left(-\frac{1}{2}\right)(C)^{-\frac{3}{2}} = \frac{1}{4\xi R_D}\sqrt{\frac{L}{C}}$$

$$\frac{\Delta|\xi|}{|\xi|} = -\frac{1}{2|\xi|R_D}\sqrt{\frac{L}{C}}\left(\frac{\Delta R_D}{R_D}\right) + \frac{1}{4R_D|\xi|}\sqrt{\frac{L}{C}}\left(\frac{\Delta L}{L}\right) - \frac{1}{4|\xi|R_D}\sqrt{\frac{L}{C}}\left(\frac{\Delta C}{C}\right)$$

$$= \left[-2\left(\frac{\Delta R}{R_D}\right) + \left(\frac{\Delta L}{L}\right) - \frac{\Delta C}{C}\right]\frac{1}{4|\xi|R_D}\sqrt{\frac{L}{C}}$$

$$\frac{\Delta|\xi|}{|\xi|} = \left[\left|\frac{\Delta R}{R_D}\right| + \frac{1}{2}\left|\frac{\Delta L}{L}\right| + \frac{1}{2}\left|\frac{\Delta C}{C}\right| \right] \frac{1}{2|\xi| R_D} \sqrt{\frac{L}{C}}$$

$$\frac{\Delta|\xi|}{|\xi|} = \left[\left|\frac{\Delta R}{R_D}\right| + \frac{1}{2}\left|\frac{\Delta L}{L}\right| + \frac{1}{2}\left|\frac{\Delta C}{C}\right| \right]$$

Percent change of $|\xi| \propto$ percent change of R_D, L, C. e.g., 5% change in components could cause a

$$\frac{\Delta|\xi|}{|\xi|} = \left[5\% + \frac{1}{2} 5\% + \frac{1}{2} 5\% \right]$$

$\frac{\Delta|\xi|}{|\xi|} = 10\%$ change in damping factor.

This also implies using 5% damping resistors could cause a worse case of 5% change in damping factor.

The following two families of curves are standard second order response with various damping factors. The one on the left is in frequency domain and the other one is in time domain.

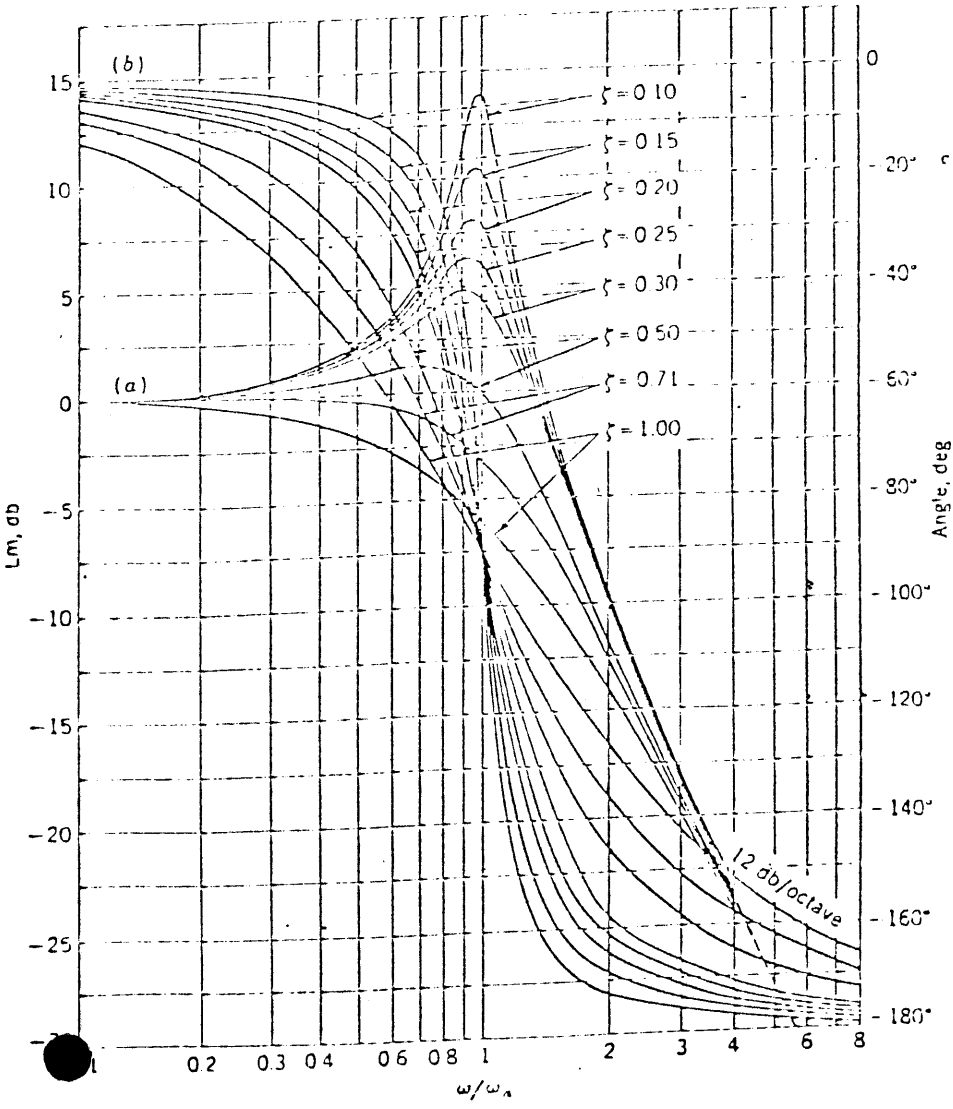
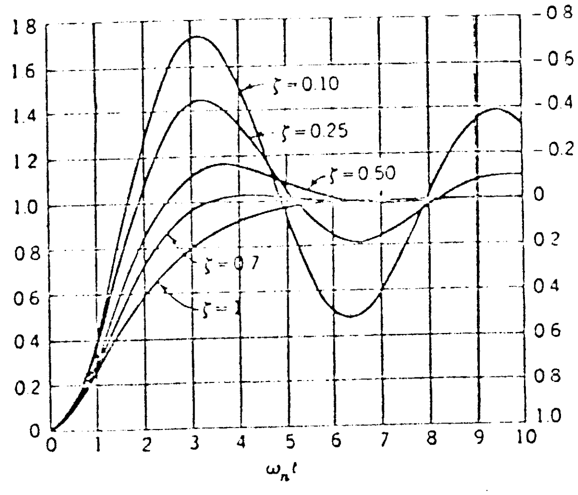


FIGURE 3-4
Log magnitude and phase diagram for

$$\left[1 + \frac{j2\zeta\omega}{\omega_n} + \left(\frac{j\omega}{\omega_n}\right)^2\right]^{-1}$$



III. READ CHIP--AMPLIFIER PORTION

The read chip is an eighteen-pins LSI chip. (See Shugart ES 30064-0 & Mot. MC3470). The chip basically consists of three separate portions--amplifier, differentiator and time-domain filter and digitizer. Each portion will be discussed separately in a logical order so as to preserve the flow of read chain signals.

1. AMPLIFLIER GAIN CALCULATION:

The amplifier is a two-stage ampliflier with gains equalled to:

$$A_o = A_1 \cdot A_2$$

$$A_1 = \frac{2 \times (2500)}{240 + 2r_e}$$

$$= 10\Omega$$

$$A_2 = \frac{2(3226)}{580 + 2r_e'} = 8.6$$

$$A_o = 86$$

$$\underline{\underline{\simeq 100}}^{**}$$

r_e = Transistor internal emitter resistance

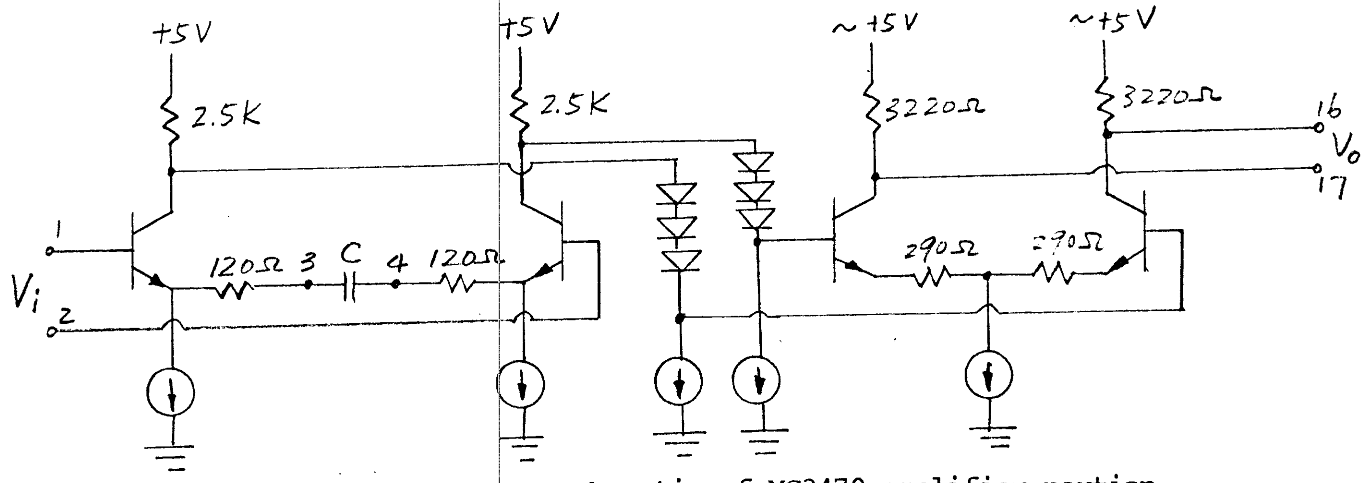
$$\simeq \frac{26mV}{200\mu A}$$

$$= 130\Omega$$

$$r_e' \simeq \frac{26mV}{300\mu A}$$

$$= 87\Omega$$

**The Motorola LSI Process Variation, according to the designer--Mike Henry, usually resulted in values of average gain higher than calculated. The average is usually around 100.



Simplified schematic of MC3470, amplifier portion.

2. TRANSFER FUNCTION:

Due to the fact that the transistor parameters are not given, the band-width of the amplifier cannot be calculated. I shall use the guaranteed minimum device band-width for analysis purposes. From actual tests (See Appendix B), the minimum band-width of the amplifier is more than 5 MHZ.

$$T(S) = \frac{A_1 \cdot A_2 \cdot W_B}{S + W_B}$$

W_B= Min. band-width
= $2\pi \times 5 \times 10^6$ Hz

$$= \frac{10 A_1 W_B}{S + W_B}$$

The gain of the first stage is affected by the D.C. blocking capacitor.

$$A_1 = \frac{2(2500)}{R + \frac{1}{SC}}$$

$$R = 2(120) + 2 \times \left(\frac{26 \times 10^{-3}}{200 \times 10^{-6}}\right) \simeq 500\,\Omega$$

$$A_1 = \frac{500SC}{500SC + 1}$$

$$T(S) = 10 \cdot \frac{\frac{500SCW_B}{500SC+1}}{S + W_B}$$

$$= \frac{100 S W_B}{(S + W_B)(S + \frac{1}{500C})}$$

From the transfer function, it is obvious that the high frequency corner of the amplifier is determained by W_B while the low frequency corner is determined by the value of the capacitor & the internal resistance. If we do not have to worry about read/write recovery, then the capacitor can be chosen such that $\frac{1}{WC} = \frac{R}{100}$ W= the lowest frequency we want to pass

e.g. W= 2π (62.5 KHz)
R= 500Ω (Fixed)
C $\simeq$ .47 uf

→ This number can be varied to suit different requirements

3. D.C. BLOCKING CAPACITOR:

The capacitor is necessary at gain-stage #1 of the read amplifier to prevent gain-stage #2 from saturating due to D.C. offset from stage #1. A problem arises after insertion of the capacitor. That is, during write mode, the capacitor will be AC charged to a worse case of 5V P-P which will affect the read/write recovery time. It was determined empirically (visually) that read/write recovery time equals to 100μs for SA 450 and 50μS for SA 850. This amounted to two time constants for SA 450 and four time constants for SA 850.

$$C = \frac{\text{R/W Recovery time}}{XR} \qquad X = \text{Number of time constants}$$

$$= \frac{50 \mu s}{4 \times 500}$$

$$= 0.025 \mu f \qquad \text{(SA850)}$$

$$C = \frac{100 \ \mu s}{2 \times 500}$$

$$= 0.1 \mu f \qquad \text{(SA 450)}$$

See Appendix B for the exponential decaying of amplitude verse time contant plot.

4. AMPLIFIER SATURATION:

The read amplifier begins to show distortion if the input exceeded 28mV (P-P). With a nominal gain of 100, the output would be 2.8 V (P-P). when input reaches 35 mV, the amplifier breaks down completely. We are currently operating at an input voltage of less than 15 mV (P-P) which is in the linear region. (See Appendix B for the saturation plot).

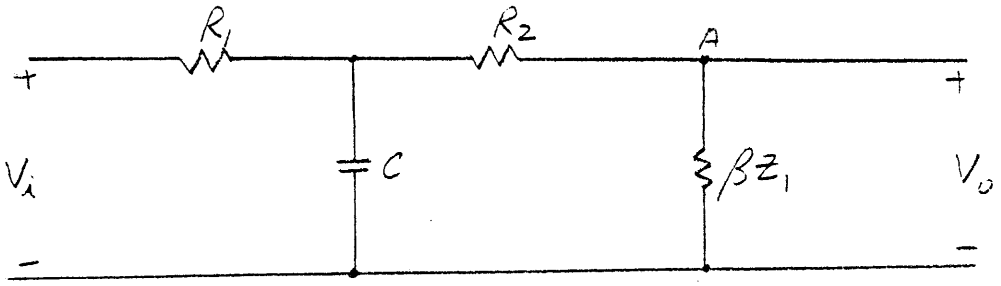
A rough extimation from the read circuit shows that the read output pins are sitting at +3V. This tells us that the output cannot exceed 2V (O-P). This agrees with what was observed.

IV. IBM FILTER (SA 850 ONLY)

The so-called IBM filter is actually a jumper selectible "all pass" filter or "low pass" filter. When the "F" jumper is "IN", a ground is provided to the circuit, the filter becomes a single pole low pass filter. When "F" jumper is "OUT", the filter becomes a single pole all pass filter.

1. SINGLE POLE LOW PASS FILTER

The equivalent circuit of the single pole low pass is:

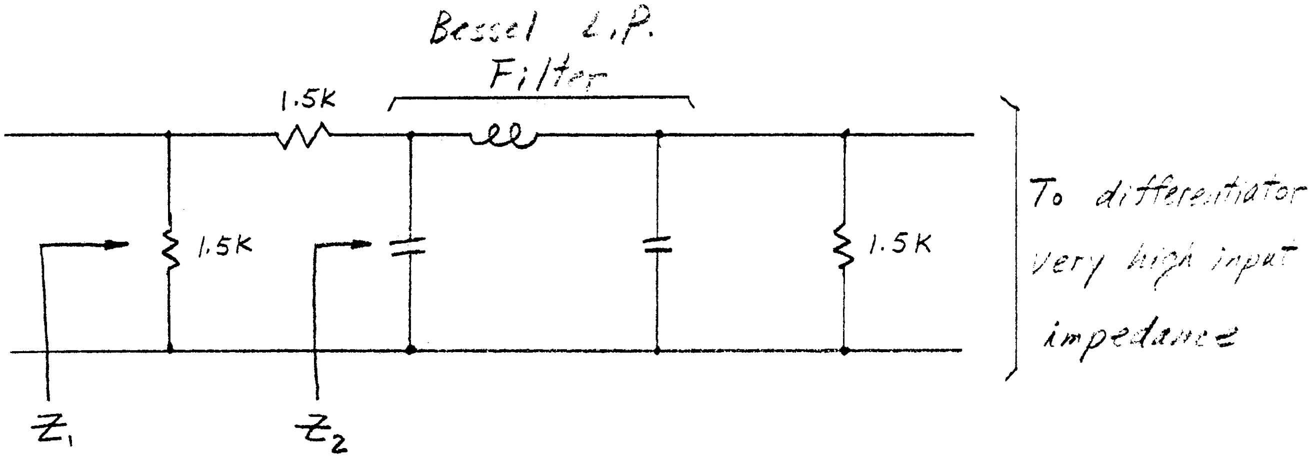


Point A is the emitter of either transistors (8B, pin 10 or 8) on the schematic of SA 850.

Z_1 is the parallel impedance of 1.5K ohm and 1.5k ohm + Z_2.

Z_2 is the input impedance of Bessed filter.

Beta is the forward current gain of the transistors.



To evaluate the change of impedance Z_1 to the response of the L.P. network and for simplicity without losing accuracy, I am using piece wise linear approach by assuming:

Z_2= 1.5K (in passband)
Z_2= 0 (in stopband)
Z_1= 1.5k (1.5K+1.5K)=1K (pass band)
Z_1= 1.5k 1.5K =.75K (stop band)
$\beta \geq 100$
R_1=1k ohm
R_2=1k ohm
$\beta(1K\Omega)$ or $\beta(.75K\Omega) >> 1K$

This means that the impedance changes will not have a drastic effect on the network under study. This is an important point to note when we are trying to calculate the transfer function and response of the network in Appendix C. It simplifies the matter a lot.

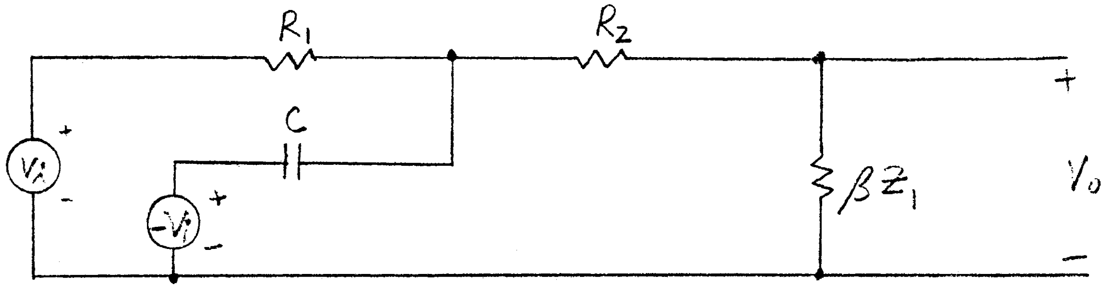
The transfer function of the original network as calculated in Appendix C is:

$$T(S) = \frac{1}{CR_1}\left(\frac{1}{S+\frac{1}{CR_1}}\right) \qquad (\beta Z_1 >> R_1, R_2)$$

This is a typical single pole low pass network. Its responses are plotted in Appendix C with various C's and R_1's.

2. SINGLE POLE ALL PASS FILTER:

The equivalent circuit is:



The transfer function of this network (see Appendix C) is:

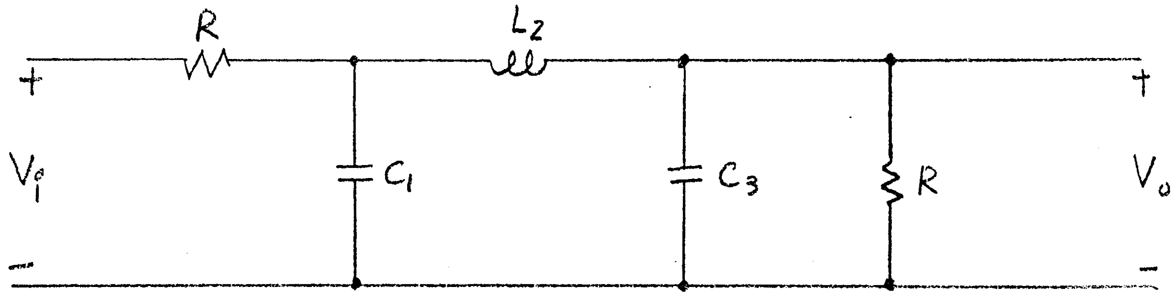
$$T(s) = \frac{1-sCR_1}{1+sCR_1} \quad ; \quad T(j2\pi f) = \angle -2\tan^{-1} 2\pi f CR_1$$

It is obvious that the network is used for phase compensation. The amplititude is unity. The responses of this network are plotted in appendix C with various values of C and R.

V. LOW PASS BESSEL FILER

The filter was used for its superior linear phase characteristics. See memo to Roger Stromsta on 8-7-79 on the filter.

The transfer function of the third order filter is:



$$T(s) = \frac{1}{S^3 R C_1 L_2 C_3 + S^2 L_2 (C_1 + C_3) + S\left(R(C_1 + C_3) + \frac{L_2}{R}\right) + 2}$$

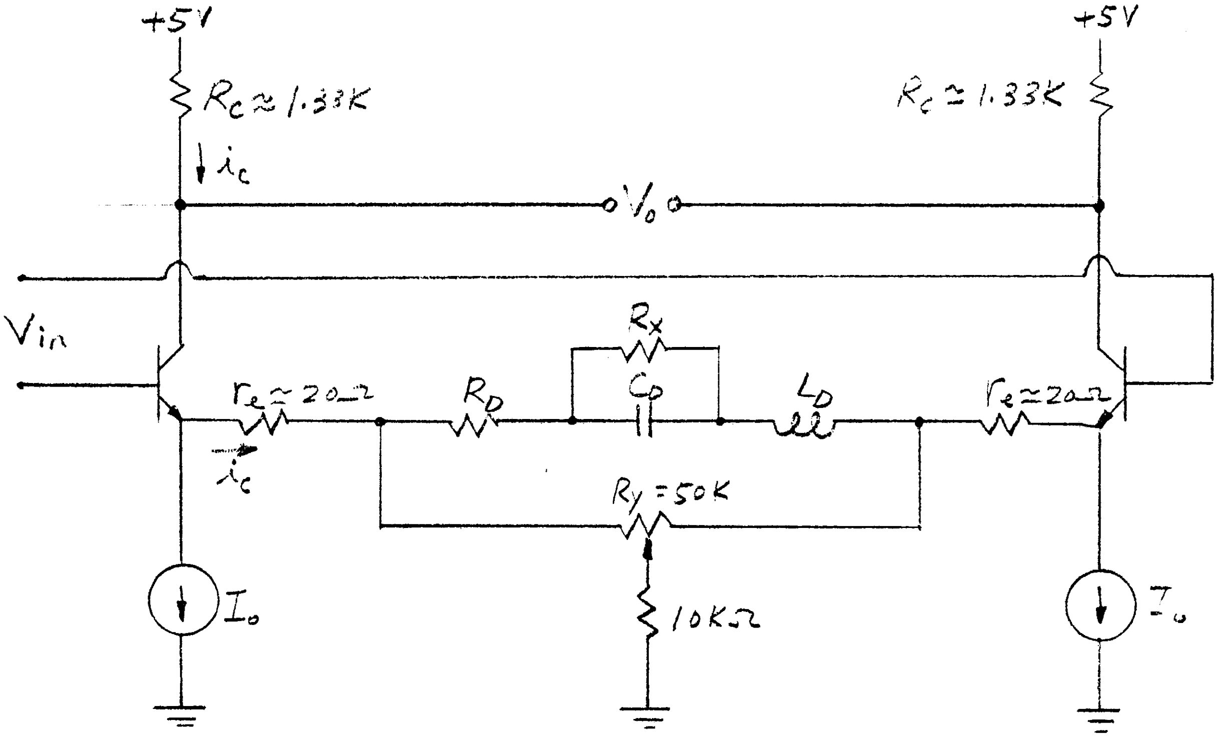
The filter being used for the current SA 850 is a standard 3 pole L.P. Bessel filter with proper scaling. The one being used for the SA 450 is a modified 3 pole L.P. Bessel with C_3 changed from standard 47 pf to 100 pf for high frequency compensation.

The actual frequency response plots of the SA450 do indicate that the standard elements LP filter has a more linear phase characteristics than the adjusted one.

VI. READ CHIP--DIFFERENTIATOR PORTION

1. OVERALL DESCRIPTION:

For a complete description of the differentiator, please read Motorola's ML3470 specification and application note. The following is a brief description of the differentiator. There are two 0.1 micro-farad capacitors at the input of differentiator. They are there to prevent any D.C. level imbalance on the line which would upset (saturate) the input stage of the differentiator.



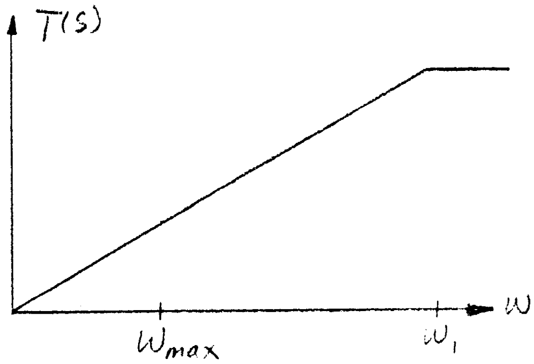
$$V_o = 2R_c i_c$$

For a simple differentiator

$R_D = 0$, $R_X = \infty$, $L_D = 0$, $R_y = \infty$

$$\because \quad i_c = C\frac{dv_i}{dt}$$

$$\therefore \quad \boxed{V_o = 2R_cC_D\frac{dV_i}{dt}}$$



Simple ideal differentiator

ω_{max} = Max. operating freq.

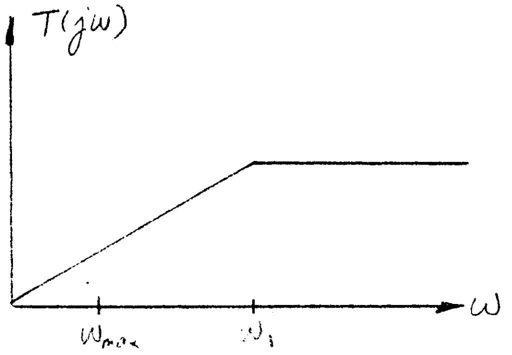
$\omega_1 = \text{Pole} = \frac{1}{2r_eC_D}$

R_D is introduced to ensure the phase linearity of the differentiator and to limit the noise band-width where

$$10\,W_{max} = \frac{1}{C_D(2r_e + R_D)}$$

$$W_1 = 10\,W_{max}$$

$$\boxed{R_D = \frac{1}{10\,W_{max}\,C_D} - 2r_e} \text{ ——— } ①$$



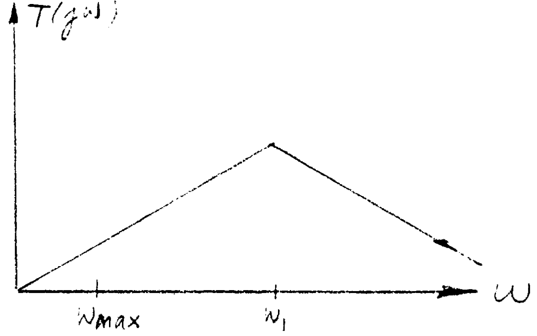
Differentiator whose pole is affected by R_D.

L_D is introduced to create another pole to further reduce the noise band-width:

$$W_1 = 10\,W_{max}$$

$$= \frac{1}{\sqrt{L_D C_D}}$$

$$L_D = \frac{1}{100(W_{max})^2\,C_D} \text{ ——— } ②$$



Differentiator where another pole is added

C_D is determined such that under maximum input voltage, the current source will not be saturated. That is,

$$C_D = \frac{I_{max}}{A_{max}\,E_{max}\,W_{max}} \text{ ——— } ③$$

$I_{max} \simeq 1mA$

A_{max} = Max. amplifier gain

$= 120$

E_{max} = Max. head output

$\leq 15mV\ (p-p)$

W_{max} = Max. frequency $= 2\pi \times 250KHz$ (2A 2D)

$= 2\pi \times 125KHz$ (2A 4D)

R_Y is there to null the current imbalance in the differentiator and to compensate for offset voltage in the digitizer portion. By varying R_Y, the internal asymmetry of the device can be eliminated.* Under A.C. analysis, the resistor R_Y can be ignored.

R_X is added to control the location of zero of the transfer function. This zero is adjusted so as to cancell out the pole created by the D.C. blocking capacitor in the amplifier portion as discussed earlier. In other words, we want to adjust R_X to improve the overall system low frequency linearity.

∵ Pole create by D.C. capacitor = $\frac{1}{RC}$

$$\frac{1}{RC} = \frac{1}{\underbrace{C_D R_x}_{\text{Zero of differentiator}}}$$

$$\therefore \quad R_X = \frac{500C}{C_D} \qquad \text{———} \quad ④$$

There are two capacitors at each of the read chip's D.C. power inputs. The power inputs are +24 V and +5 V for SA850 and +12 V and +5 V for SA450. The capacitors are there for power line noise filtering. For SA850, there is an additional +12 V zener diode CR11 which is for generating +12 V on board.

* Assumption was made here that the supply voltages and input voltage remain constant. Otherwise, asymmetry can still occur.

2. TRANSFER FUNCTION:

The transfer function without R_x is : (See Appendix E)

$$T(s) = \frac{R_c}{L_D} \cdot \frac{s}{s^2 + s\frac{(2r_e + R_D)}{L_D} + \frac{1}{L_D C_D}}$$

With R_x:

$$T'(s) = \frac{R_c}{L_D} \cdot \frac{\left(s + \frac{1}{C_D R_x}\right)}{s^2 + s\left(\frac{1}{C_D R_x} + \frac{R_D + 2r_e}{L_D}\right) + \frac{1}{L_D C_D}}$$

Note the zero location has changed

Transfer function for the amplifier:

$$T''(s) = \frac{100 s \omega_B}{(s + \omega_B)(s + \frac{1}{RC})}$$

Since this is a linear system, the total transfer function is:

$$T(s) = T'(s) \cdot T''(s)$$

$$= \frac{R_c}{L_D} \cdot \frac{\cancel{\left(S + \frac{1}{C_D R_x}\right)}}{S^2 + S\left(\frac{1}{C_D R_x} + \frac{R_D + 2r_e}{L_D}\right) + \frac{1}{L_D C_D}} \cdot \frac{100 S \omega_B}{(S + \omega_B)(S + \frac{1}{RC})}$$

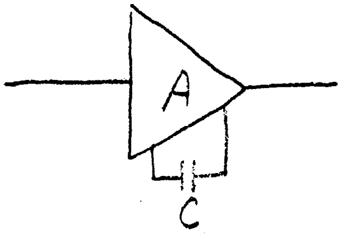
With perfect pole/zero cancellation:

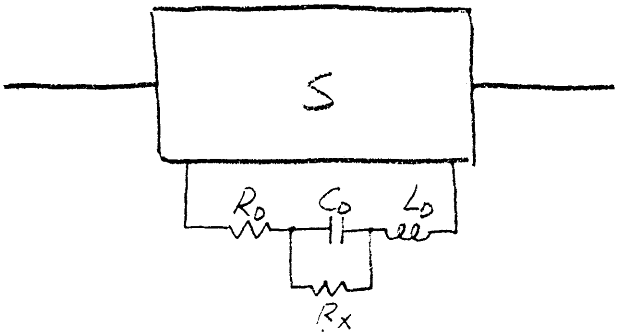
$$T(S) = \frac{100 R_C S \omega_B}{L_D} \cdot \frac{1}{\left(S^2 + S\left(\frac{1}{C_D R_x} + \frac{R_D + 2r_e}{L_D}\right) + \frac{1}{L_D C_D}\right)(S + \omega_B)}$$

The responses of the differentiator before and after pole/zero cancellation are plotted in Appendix E.

3. COMPONENT SELECTION:

The following components are selected under ideal and theoretical conditions. They are selected and their responses are plotted for the purpose of comparison with the actual values used on the devices.





$C = 0.025 \mu f$ (SA 850)

$C = 0.1 \mu f$ (SA 450)

} Calculated earlier.

$$C_D = \frac{i_{c(max)}}{A_{max} E_{max} W_{max}}$$ (From eqn #3)

$$= \frac{1 \times 10^{-3}}{(120)(15 \times 10^{-3})(250 \times 10^{3})}$$

$$\boxed{C_D = 353\ pf}$$ (SA850)

$$C_D = \frac{1 \times 10^{-3}}{(120)(15 \times 10^{-3})(125 \times 10^{3})}$$

$$\boxed{C_D = 707\ pf}$$ (SA450)

$$R_D = \frac{1}{10 W_{max} C_D} - 2r_e$$ (From eqn. #1)

$$= \frac{}{10\,(2\pi\, 250 \times 10^{3})(330 \times 10^{-12})} - 40\Omega$$

standard value used

$$\boxed{\begin{matrix} R_D = 153\Omega \\ (150\Omega) \end{matrix}}$$

(SA 850)
standard value

$$R_D = \frac{1}{(10)(2\pi \times 125 \times 10^{3})(680 \times 10^{-12})} - 40\Omega$$

Standard value used

$$\boxed{\begin{array}{l} R_D = 147\Omega \\ \quad (150\Omega) \end{array}}$$

(SA 450)
Standard value

$$R_x = \frac{RC}{C_D}$$

(From eqn. #4)

$$= \frac{500 \times 0.027 \times 10^{-6}}{330 pf}$$

$$\boxed{R_x = 40.1 K\Omega}$$

(SA 850)

$$R_x = \frac{500 \times 0.1 \times 10^{-6}}{680 \times 10^{-12}}$$

$$\boxed{R_x = 73.5 K\Omega}$$

(SA 450)

$$L_D = \frac{1}{100(\omega_{max})^2 C_D}$$

(From eqn. #2)

$$= \frac{1}{100(2\pi \times 250 \times 10^{3})^2 \times 330 \times 10^{-12}}$$

$$\boxed{\begin{array}{l} L_D = 12.3 \mu H \\ \quad (12 \mu H) \end{array}}$$

(SA 850)
(Standard value)

$$L_D = \frac{1}{100(2\pi \times 125 \times 10^{3})^2 \times 680 \times 10^{-12}}$$

$$\boxed{\begin{array}{l} L_D = 23.8 \mu H \\ \quad (22 \mu H) \end{array}}$$

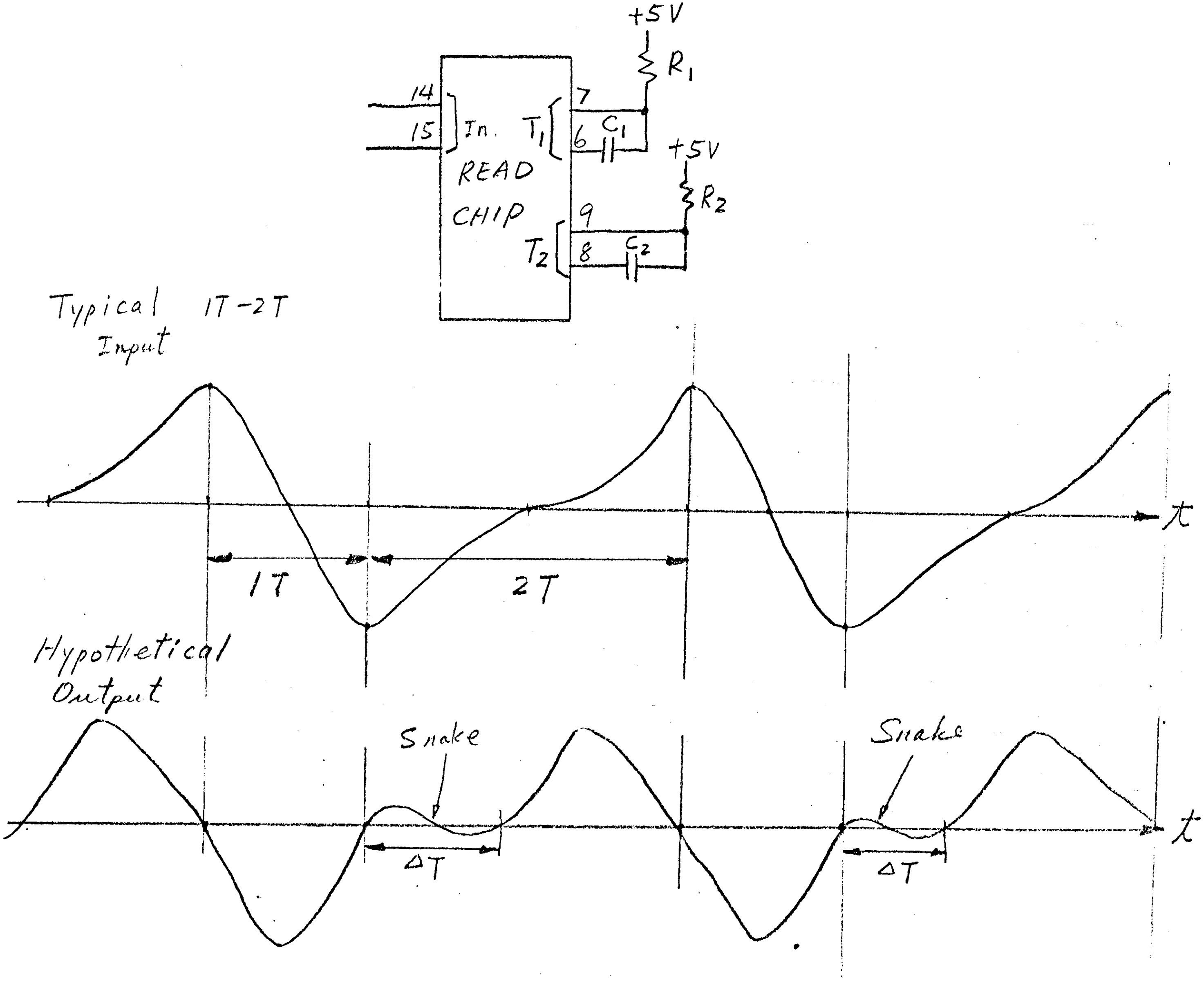
(SA 450)
(standard value)

Frequency response and time response plot of the actual values and the ideal (optimum) values are shown in Appendix E. As revealed from the plots, the frequency response curves (no perfect pole/zero cancellation) with optimum elements do look better than the response curves with actual values--currently in use on our drives. Furthermore, by assuming a perfect pole/zero cancellation, the frequency response of the actual value curves improved substantially at low frequency while the optimum value curves did not show much of a difference. The time domain response plots do indicate less phase delay in the optimum case than the actual. These time domain plots are assuming a steady state conditions. One thing that is interesting to note is that in the case of perfect pole/zero cancellation, the steady-state phase delay remains the same--no improvement.

VII. READ CHIP-- TIME DOMAIN FILTER AND DIGITIZER

1. TIME DOMAIN FILTER AND BIT PULSE WIDTH:

The filter is necessary because the actual signal from our read/write head is not a sinewave. It is more like Guassian curves superimposed on each other and plus the system noise. The differentiated signal would not be a pure cosine wave. It would have "snakes" on the differentiated signal. This would mean that extra bit would be generated if these "snakes" were not being filtered. The time domain filter behaves like a window where it opens up at some instances and closed at other instances to block out the "snakes".



If the time domain filter had effectively blocked out the snakes, then the differentiator and the zero-crossing comparator in the chip would behave like a peak detector and data bit would be regenerated. Period T_1 determines effectively how much we want to block and period T_2 determines the pulse width of the regenerated bits. The periods are determined

$$T_1 > \Delta T$$

$$T_1 < \frac{1}{3}(2T)$$

2T is assured to be the longest period in MFM encoding.

Under the worst case situation:

$$\Delta T \leq \frac{4\mu s}{3} \quad (SA\,850)$$

$$\leq \frac{8\mu s}{3} \quad (SA\,450)$$

$$2T = 4\mu s \quad (SA\,850)$$

$$= 8\mu s \quad (SA\,450)$$

If ΔT ever gets greater than 1/3 (2T), the time domain filter would not be effective. Bit error would occur!

Without going into any further details, it is obvious that the optimum T_1 (assuming symmetrical signal) should be:

Device time variance.

$$T_1 \simeq \frac{1}{3}(2T)(1-15\%)$$

$$= 1133\,ns \quad (SA850)$$

$$= 2267\,ns \quad (SA450)$$

Optimum theoretical values

$$T_1 = (R_1 C_1 \times 0.625) + 200\,ns \quad \text{(See Spec.)}$$

$$= 969\,ns \quad (SA850)$$

$$= 1250\,ns \quad (SA450)$$

Actual values used on Shugart drives.

There are three constraints which have to be met for the time domain filter to work:

(1) $\Delta T < \frac{1}{3}(2T)$ (snake cannot be big)

(2) ΔT pulse is near center

(3) $T_1 > \Delta T$

The aforementioned criteria is not critical for our current SA 850/450 operations. We have a lot of margin to play with at this point. However, in the future, if we intend to increase bit density with the same chip, problems may arise.

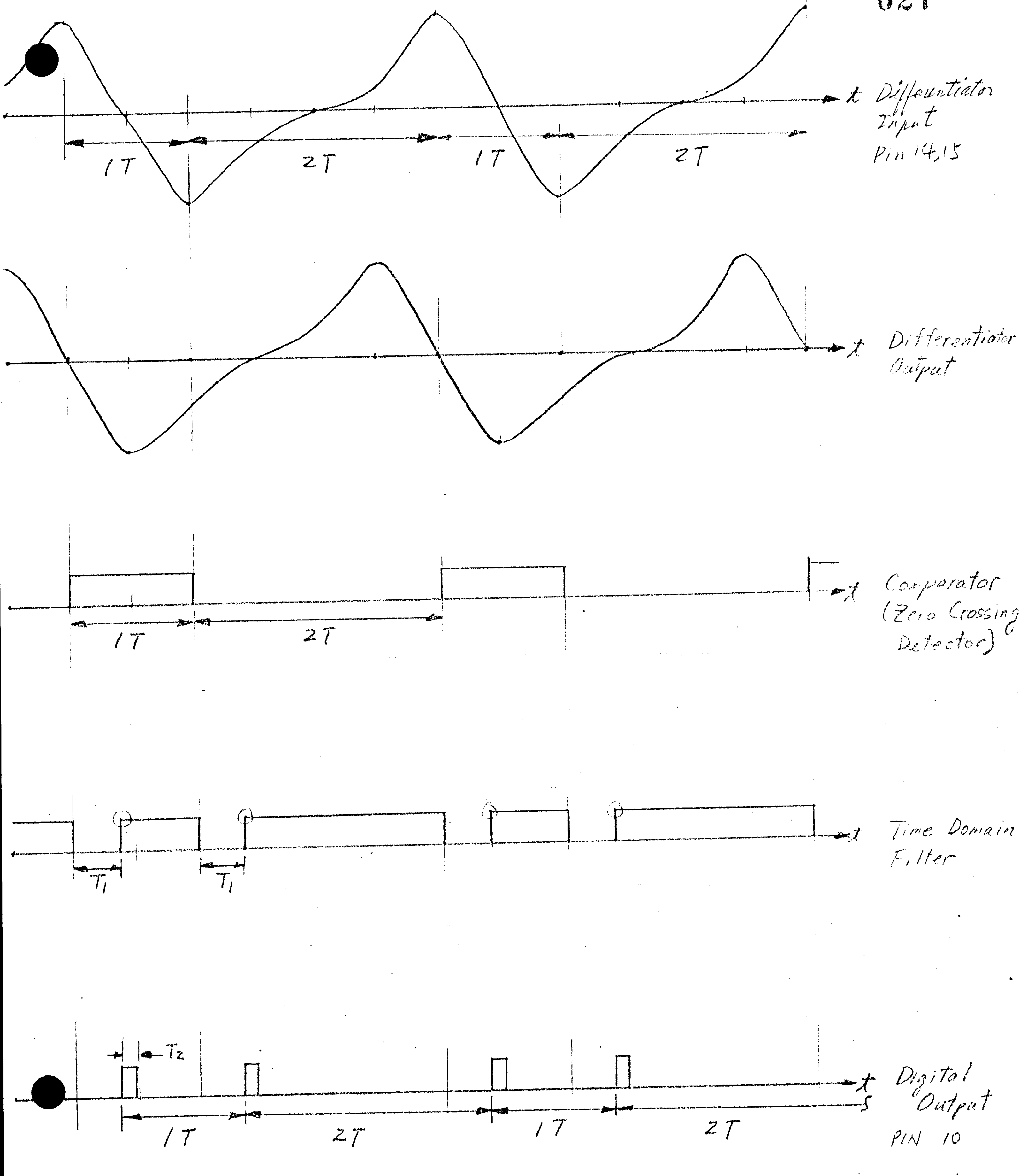
T_2 (Pulse width) = $R_2 C_2 \times 0.625$ (see Spec.)

T_2 is not critical as long as it is wide enough to provide enough hold time for TTL circuit. Minimum of 100 nano seconds is sufficient. Current value of $T_2$for SA 850 is 200 nS , for SA 450 is 1.05μS .

2. DIGITIZER:

It consists of basically a comparator, one shot and a D-flip flop. Together they convert the analog input signal which contains the data into a series of digital pulse train. Then the digitized information (bits) can be processed by the host system (computer). The digital output is being time delayed by an amount T_1, which is the time domain filter window width.

The following sketch show a hypothetical and ideal case of how an analog signal is being converted into digital information.


t
Differentiator Input
Pin 14,15
1T
2T
1T
2T
t
Differentiator Output
t
Comparator (Zero Crossing Detector)
1T
2T
t
Time Domain Filter
T_1
T_1
T_2
t
Digital Output
PIN 10
1T
2T
1T
2T

IIX. CONCLUSION:

This read chain analysis by no means is "the analysis" to to determine the system parameters. It is extremely unlikely for anyone to come up with a perfect working system from paper work calculation and modeling. A lot of changes have to be made by an experienced system designer judging from overall system performance to perfect the design. However, this analysis does provide a complete explantion of individual functions of the read chain and also provides a quantitative way (guideline) of selectingcomponents. Any major deviation from the calculation should probably be backed up with logical explantions from the original designer.

In general, the experiments agreed very well with simulated plots in the pass band. The original goal of this assignment was to put in writing how each individual blocks of the read chain functioned. The time expection and the original goal of this assignment making it not feasible at this point to delve into other related questions. They are as follows:

1. Actual impacts of IBM filter on phase performance.
2. Is the low pass Bessel filter necessary at all and how does is affect our phase margin?
3. What is the amount of phase jitter introduced by the read chip?
4. The noise level of the read chain.
5. Electromagnetic interference susceptibility of our drives.

Some of these questions can be answered quite easily, with time availability, by taking the analysis done here one step further. Others require a completely different approach to get to the answer.

A similar analysis on write chain, which is supposedly to be completed at the same time, will most likely ready in about a week.

IX. ACKNOWLEDGEMENTS:

I am grateful to both Art Geffon and Dick Freytag for their kind advise and suggestions. Also, it would have been impossible to complete this analysis in the given amount of time without the help of Steve Downey in turning out those computer plots.

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8. Motorola MC3470 Specifications and Applications Information.
9. Shugart Engineering Specifications on Read Amplifier, ES 30064-0, Rev. 780.
10. Memorandum to Roger Stromsta on "Analysis of SA450 LP Filter and Synthesis of Two LP Bessel Filters", by Byron Wong on 8-7-79.

XI. SUMMARY OF EQUATIONS

1. Read channel front end :

$$T(s) = \frac{1}{Ls} \cdot \frac{1}{s^2 + s\left(\frac{R_L}{L} + \frac{1}{CR_D}\right) + \frac{R_L + R_D}{LCR_D}}$$

$$\omega_0 \simeq \frac{1}{\sqrt{LC}}$$

$$|\xi| = \frac{\xi}{\omega_0} = \frac{1}{2R_D}\sqrt{\frac{L}{C}}$$

$$\text{Overshoot \%} = \left[\frac{1}{2|\xi|\sqrt{1-|\xi|^2}} - 1\right] 100\% \qquad |\xi| < .707$$

$$= 0\% \qquad |\xi| \geq .707$$

$$|\xi| = \frac{[illegible]}{\sqrt{1+\left(\frac{[illegible]}{[illegible]}\right)^2}}$$

$$\frac{[illegible]}{\text{Main lobe [illegible]}}$$

$$[illegible] = \frac{N_o}{[illegible]}$$ 0.707 > [illegible] > 0.030

$$= N_o$$ [illegible] < 0.1

$$= \text{No } [illegible]$$ [illegible] > 0.707

2. Amplifier

$$A_1 \simeq \frac{50000}{[illegible] R_{in}}$$

[illegible] External [illegible] if [illegible] = 0 ([illegible])

$$T(s) = \frac{5000 S [illegible]}{[illegible]}$$

$$C = \frac{\text{Recovery Time}}{500\chi}$$

χ = No. of [illegible] [illegible]

3. Differentiator

$$R_D \simeq \frac{[illegible]}{10\omega_{max} C_D} [illegible]$$ $r_s \simeq 22\Omega$

$$C_D = \frac{1mA}{(120)(15mV)\omega_{max}}$$

$$L_D = \frac{1}{100(\omega_{max})^2 C_D}$$

$$Z_i = \frac{500C}{C_D}$$

4. Time domain filter and digitizer

$$T_1 = (R_1 C_1 \times 0.625) + \text{[illegible]}$$

$$\Delta T < T_1 < \frac{1}{5}(2T)$$

$$T_2 = (R_2 C_2 \times 0.625)$$

XII. SUMMARY OF VARIOUS CURVES

1. Simulated Frequency Response of Read Channel Front End With Various L's and C's:

	L	C	R_D	R_L	Freq.	Page No.
SA 850	1.9mH	50pf	5.89KΩ	36 Ω	0-1 MHz	50
	1.9mH	59pf	↓	↓	↓	51
	1.7mH	50pf	↓	↓	↓	52
	1.7mH	59pf	↓	↓	↓	53
SA 450	1.9mH	50pf	4K Ω	↓	↓	54
	1.9mH	59pf	↓	↓	↓	55
	1.7mH	50pf	↓	↓	↓	56
	1.7mH	59pf	↓	↓	↓	57

2. Simulated Frequency Response of Read Amplifier With Various Values of D.C. Blocking Capacitor and Frenquency:

	C	Freq.	Page No.
SA850/450	0.01uf	0 - 500 KHz	64
	0.1uf	↓	65
	1uf	↓	66
	10uf	↓	67
	100uf	↓	68
	0.01uf	0 - 10 MHz	69
	10uf	↓	70
	100uf	↓	70A

3. Actual Frequency Response of Read Amplifier With Various Values of D.C. Blocking Capacitors and Frequency:

	C	Freq.	Page No.
SA 850/450	0.01uf	0-500 KHz	71
	0.027uf	0-500 KHz	72
	↓	0-10 MHz	73
	0.1uf	0-500 KHz	74
	↓	0-10 MHz	75
	1uf	0-500 KHz	76
	↓	0-10 MHz	77

4. Exponential Decaying verse RC Time Constant for Read/Write Recovery. p. 78

5. Amplifier Saturation Plot p. 79

6. Simulated All Pass Filter Response With Various R's, C's and Frequency:

	R	C	Freq.	Page No.
SA 850	500 Ω	220pf	0-500 KHz	83
	↓	390pf	↓	84
		↓	0-10 MHz	85
		680pf	0-500 KHz	86
	1000 Ω	220pf	↓	87
	↓	390pf		88
		↓	0-10 MHz	89
		680pf	0-500 KHz	90
	3000 Ω	220pf	↓	91
	↓	390pf		92
		390pf	0-10 MHz	93
		680pf	0-500 KHz	94

7. Actual Plot of IBM All Pass Filter:

R= 1000 ohm, C= 390 pf, 0 - 500 Khz P. 95
R= 1000 ohm, C= 390 pf, 0 - 10 Mhz P. 96

8. Simulated Plot of IBM Low Pass Filter With Various Capacitors and Frequency:

	R	C	Freq.	Page No.
SA 850	1000 Ω	220pf	0-1 MHz	98
	↓	390pf	0-500 KHz	99
		↓	0-10 MHz	100
		680pf	0-1 MHz	101

9. Actual Plot of IBM Low Pass with:

R= 1000 ohm, C= 390 pf, 0 - 500 Khz, P. 102
R= 1000 ohm, C= 390 pf, 0 - 10 Mhz, P. 103

10. Simulated Response of Read Amplifier and IBM All Pass Filter with Various Values of C's and Frequency:

	R	C_2 (Filter)	C_1 (D.C.)	Freq.	Page No.
SA 850	1000 Ω	220pf	0.027uf	0-500 KHz	104
	↓	390pf	↓	↓	105
		↓		0-10 MHz	106
			0.01uf	0-500 KHz	107
			↓	0-10 MHz	108
			0.1uf	0-500 KHz	109
			0.1uf	0-10 MHz	110
		680pf	0.027uf	0-500 KHz	111

11. Actual Plot of Read Amplifier and IBM All Pass Filter with (C_1= D.C. blocking, C_2= Filter)

R= 1000Ω , C_1= 0.027uf , C_2= 390pf , 0-500 KHz P.112

R= 1000Ω , C_1= 0.027uf , C_2= 390pf , 0-10 MHz P.112

12. Simulated response of Read Amplifier and IBM Low Pass Filter with Various Values of C's and Frequency:

	R	C_2 (Filter)	C_1 (D.C.)	Freq.	Page No.
SA 850	1000Ω	220pf	0.01uf	0-1 MHz	114
	↓	390pf	↓	↓	115
	↓	680pf	↓	↓	116
	↓	220pf	0.027uf	↓	117
	↓	390pf	↓	0-500 KHz	118
	↓	↓	↓	0-10 MHz	119
	↓	680pf	0.027uf	0-1 MHz	120
	↓	220pf	0.1uf	0-1 MHz	121
	↓	390pf	↓	↓	122
	↓	680pf	↓	↓	123

13. Actual Response of Read Amplifier and IBM Low Pass Filter with (C_1= D.C. Blocking, C_2= Filter)

R= 1000 ohm, C_1=0.027uf , C_2= 390 pf, 0 - 500Khz	P.124
R= 1000 ohm, C_1=0.027uf , C_2= 390 pf, 0 - 10 Mhz	P.125

14. Actual Response of Bessel Filter:

	C_1	C_3	L_2	Freq.	Page No.
SA 850	150pf	27pf	330uH	0-500KHz 0-10 MHz	127 128
SA 450 Actual	300pf	100pf	680uH	0-500KHz 0-10 MHz	129 130
SA 450 Ideal	↓	47pf	↓	0-500KHz 0-10 MHz	131 132

15. Actual Response of Amplifier, IBM Filter L.P. and Bessel Filter:

0 - 500 Khz	P.133
0 - 10 Mhz	P.134

16. Actual Response of Amplifier, IBM Filter A.P. and Bessel Filter:

Bessel Filter	0 - 500 Khz	P.135
	0 - 10 Mhz	P.136

17. Actual Response of Amplifier and Bessel Filter (SA850)

Differentiator disconnected	0 - 500 Khz	P. 137
	0 - 10 Mhz	P. 138
With Differentiator connected	0 - 500 Khz	P. 139
	0 - 10 Mhz	P. 140

18. Actual Response of Amplifier and Bessel Filter (SA 450)

Differentiator disconnected	0 - 500 Khz	P. 141
	0 - 10 Mhz	P. 142
Differentiator connected	0 - 500 Khz	P. 143
	0 - 10 Mhz	P. 144

19. Simulated Frequency Response of Differentiator with Actual and with Optimum elements:

	R_D	R_X	C_D	L_D	Freq.	Page No.
SA 850 Actual	270	15K	680pf	62uH	0-500 KHz	151
	↓	↓	↓	↓	0-10 MHz	152
Optimum	150	40.2K	330pf	12uH	0-500 KHz	155
	↓	↓	↓	↓	0-10 MHz	156
SA 450 Actual	200	47K	1800pf	100uH	0-500 KHz	153
	↓	↓	↓	↓	0-10 MHz	154
Optimum	150	68K	680pf	22uH	0-500 KHz	157
	↓	↓	↓	↓	0-10 MHz	158

20. Simulated Frequency Response of Differentiator and Amplifier with actual and with optimum elements (No perfect pole/zero cancellation assumed)

	C	R_D	R_X	C_D	L_D	Freq.	Page no.
SA 850 Actual	0.027	270	15K	680pf	62uH	0-500KHz	160
	↓	↓	↓	↓	↓	0-10 MHz	161
Optimum		150	40.2K	330pf	12uH	0-500KHz	164
		↓	↓	↓	↓	0-10 MKz	165
SA 450 Actual	0.1uf	200	47K	1800pf	100uH	0-500KHz	162
	↓	↓	↓	↓	↓	0-10 MHz	163
Optimum		150	68K	680pf	22uH	0-500KHz	166
		↓	↓	↓	↓	0-10 MHz	167

21. Simulated Frequency Response of Differentiator and Amplifier with actual and with Optimum Elements. Perfect pole/zero cancellation assumed! (Ideal differentiator response)

	R_D	R_X	C_D	L_D	Freq.	Page No.
SA 850 Actual	270	15K	680pf	62uH	0-1 MHz	169
	↓	↓	↓	↓	0-10 MHz	170
Optimum	150	40.1K	330pf	12uH	0-1 MHz	173
	↓	↓	↓	↓	0-10 MHz	174
SA 450 Actual	200	47K	1800pf	100uH	0-1 MHz	171
	↓	↓	↓	↓	0-10 MHz	172
Optimum	150	68K	680pf	22uH	0-1 MHz	175
	↓	↓	↓	↓	0-10 MHz	176

22. Simulated Time Response Plots of Differentiator to Sinewave input with Actual and with Optimum Elements:

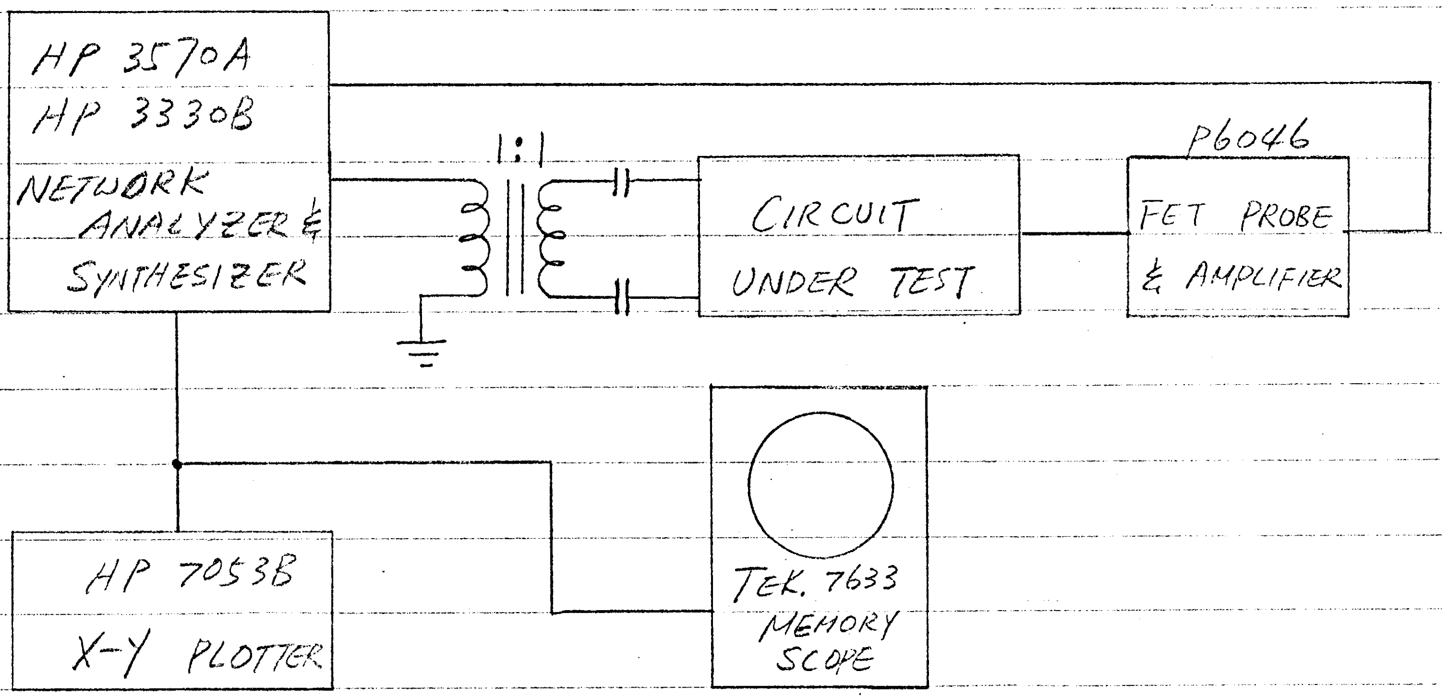
Same variation on elements as in #19, P.180- P.190

23. Simulated Time Response Plots of Amplifier and differentiator to sinewave input, assuming perfect pole/zero cancellation, with actual and with optimum elements:

Same variations on elements as in #21, P.194- P.204

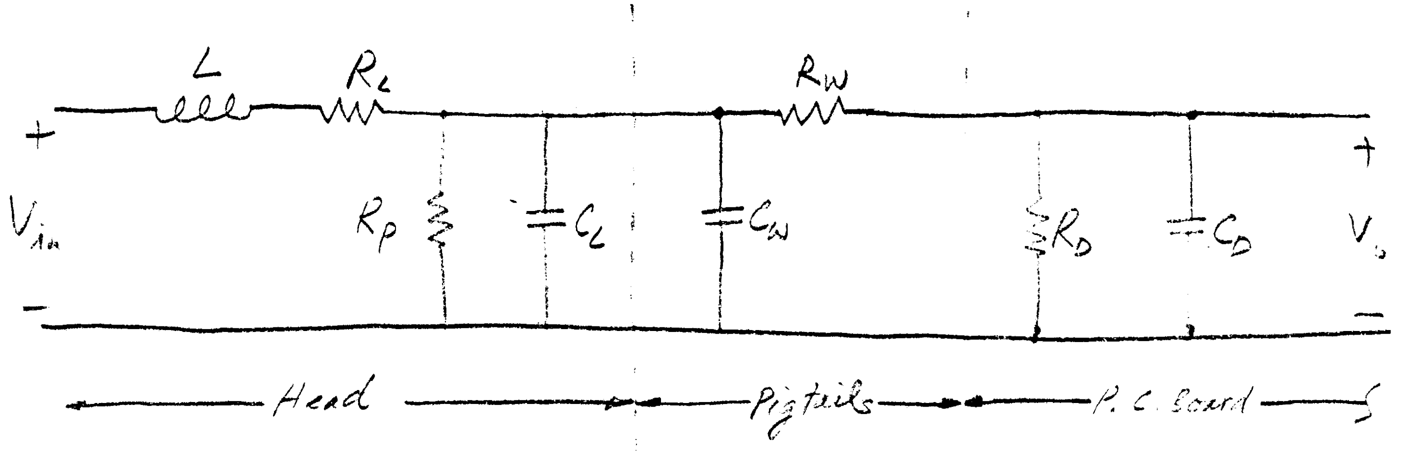
△III. SET UP OF EXPERIMENTS:

The frequency response experiment was set up as following.



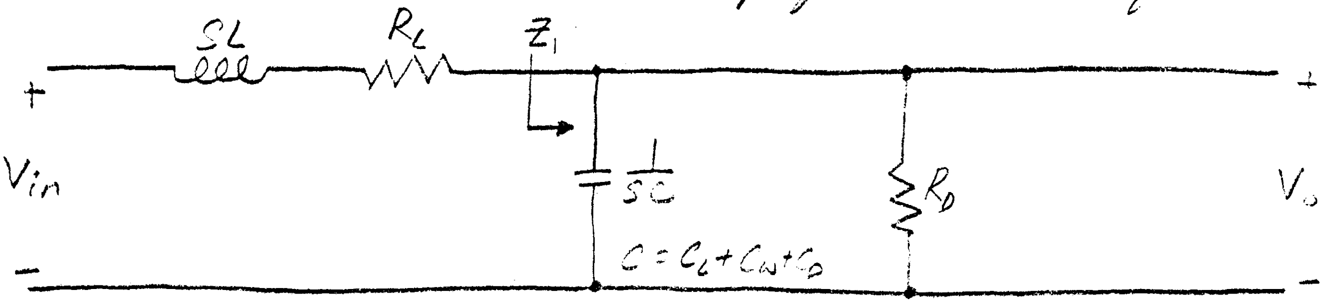
For the response of transformer and FET probe, please see reference #10. Their total responses are very linear. The experiment set up is not ideal because of number of jumpers and length of wires. For frequency beyond 5MHZ, the results may not be accurate. The experiments were done to provide comparisons to the theoretical predications. Accuracy is not the real object here. Accuracy here means ±5% – ±10%. However, within the pass band 50KHz - 300KHZ, the responses are generally very accurate.

A-1. Derivation of read channel front end transfer function and related parameters



L = Head inductance
C_L = Head distributed capacitance
R_L = Head D.C. resistance
R_p = Head resistance at resonant
C_W = Pigtail equivalent capacitance
R_W = Pigtail D.C. resistance
R_D = Input damping resistance
C_D = Input capacitance of amplifier

∵ $R_W \approx 0$; $R_p >> R_D$
∴ The circuit can be simplified and transformed to



$$Z_1 = \frac{1}{SC} // R_D = \frac{\frac{1}{SC} \cdot R_D}{\frac{1}{SC} + R_D}$$

$$= \frac{R_D}{SCR_D + 1}$$

$$\frac{V_o}{V_{in}} = \frac{\frac{R_D}{SCR_D+1}}{SL + R_L + \frac{R_D}{SCR_D+1}}$$

$$= \frac{R_D}{S^2 LCR_D + SL + SR_L CR_D + R_L + R_D}$$

$$T(S) = \frac{V_o}{V_{in}} = \frac{1}{LC\left[S^2 + S\left(\frac{R_L}{L} + \frac{1}{CR_D}\right) + \frac{R_L + R_D}{LCR_D}\right]}$$

$$W_o^2 = \frac{R_L + R_D}{LCR_D} \simeq \frac{1}{LC} \qquad (R_D >> R_L)$$

$$f_o = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

$$2\xi = \left(\frac{R_L}{L} + \frac{1}{CR_D}\right) \simeq \frac{1}{CR_D} \qquad \left(\text{For current load } \frac{R_L}{L} << \frac{1}{CR_D}\right)$$

$$|\xi| \triangleq \frac{\xi}{W_o} = \frac{1}{2R_D}\sqrt{\frac{L}{C}}$$

For current drives:

$C_L + C_W \simeq 50pf$; $C_D < 10pf$

$R_D = 6.8K\Omega // 22K\Omega = 5.89K\Omega$ (SA 850)

$= 4.87K\Omega // 20K\Omega = 4K\Omega$ (SA 450)

To find the amplitude and phase response

$$T(j\omega) = \frac{1}{LC} \cdot \frac{1}{-\omega^2 + j\omega\left(\frac{R_L}{L} + \frac{1}{CR_D}\right) + \frac{1}{LC}}$$

$$= \omega_0^2 \; \frac{1}{-\omega^2 + j\omega 2\zeta + \omega_0^2}$$

$$= A(\omega) \angle \theta(\omega)$$

$$A(\omega) = \omega_0^2 \sqrt{\frac{1}{(-\omega^2 + \omega_0^2)^2 + (2\zeta\omega)^2}}$$

$$A(\omega) = \sqrt{\frac{1}{\left(1 - \frac{\omega^2}{\omega_0^2}\right)^2 + \left(\frac{2\zeta\omega}{\omega_0}\right)^2}}$$

$$\boxed{A(2\pi f) = \sqrt{\frac{1}{\left(1 - \frac{f^2}{f_0^2}\right)^2 + \left(\frac{2\zeta f}{f_0}\right)^2}}}$$

Amplitude response

$$\theta(\omega) = \angle - \tan^{-1} \frac{2\omega\zeta}{\omega_0^2 - \omega^2}$$

The solution to the phase is a valid solution yet it is not in the form we like, e.g. the angle is bounded by $\pm\frac{\pi}{2}$. We would prefer a solution in another form which would produce a more familiar curve. (90°/decade-pole)

From the original transfer function

$$T(s) = \frac{1}{LC} \cdot \frac{1}{s^2 + 2\zeta s + \omega_0^2}$$

$\omega_0^2 = \frac{1}{LC}$

ζ = damping factor

$$T(S) = \frac{1}{LC}\,\frac{1}{\left(S - \xi + \sqrt{\xi^2 - \omega_0^2}\right)\left(S - \xi - \sqrt{\xi^2 - \omega_0^2}\right)}$$

Since we are interested in underdamped systems, $\xi < \omega_0$

$$\therefore \quad T(S) = \frac{1}{LC}\,\frac{1}{\left(S + \xi + j\sqrt{\omega_0^2 - \xi^2}\right)\left(S + \xi - j\sqrt{\omega_0^2 - \xi^2}\right)}$$

$$T(j\omega) = \frac{1}{LC}\,\frac{1}{\left[j\left(\omega + \sqrt{\omega_0^2 - \xi^2}\right) + \xi\right]\left[j\left(\omega - \sqrt{\omega_0^2 - \xi^2}\right) + \xi\right]}$$

$$\theta(\omega) = -\tan^{-1}\frac{\omega + \sqrt{\omega_0^2 - \xi^2}}{\xi} - \tan^{-1}\frac{\omega + \sqrt{\omega_0^2 - \xi^2}}{\xi}$$

$$= -\tan^{-1}\frac{\frac{\omega}{\omega_0} + \sqrt{1 - |\xi|^2}}{|\xi|} - \tan^{-1}\frac{\frac{\omega}{\omega_0} - \sqrt{1 - |\xi|^2}}{|\xi|}$$

$$\boxed{\theta(2\pi f) = -\tan^{-1}\frac{\frac{f}{f_0} + \sqrt{1 - |\xi|^2}}{|\xi|} - \tan^{-1}\frac{\frac{f}{f_0} - \sqrt{1 - |\xi|^2}}{|\xi|}}$$

Phase response

Percentage of overshoot for a second order system is (See ref. # 1, chapter 9)

$$\text{Overshoot } \% = \left[\frac{1}{2|\xi|\sqrt{1-|\xi|^2}} - 1\right] 100\% \qquad |\xi| < .707$$

$$= 0\% \qquad |\xi| > .707$$

The signal doesn't peak at ω_0 for $|\xi| > 0.1$

The signal peaks at

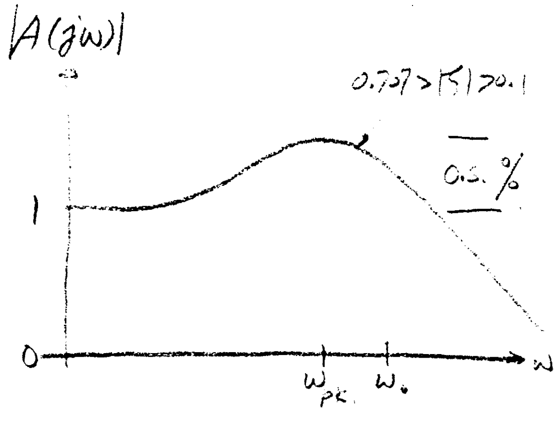
$$\omega_{peak} = \frac{\omega_0}{\sqrt{1-2|\xi|^2}} \qquad 0.707 > |\xi| > 0.1$$

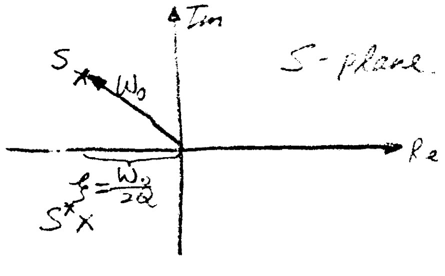
$$\simeq \omega_0 \qquad |\xi| < 0.1$$

$$= \text{zero} \qquad |\xi| > 0.707$$

$$2\xi \triangleq \frac{\omega_0}{Q}$$

$$|\xi| = \frac{1}{2Q}$$





A-2. Linear phase analysis:

It is important to know what is the real meaning of linear phase and what criteria to use to achieve linear phase for a second order system. Second order system is important to most of network analysis because of all the relatively simple yet importa characteristics exhibit by it. For a first order system, there is no self-resonant and hence no peaking can occur. This means that a first order system has to be overdamped and that there is not such thing we can do to a first order system to alter its normalized phase and amplitude characteristics. Any higher order of linear system can thus be broken down into a combination of first and second order system. Interestingly enough, a lot of real life engineering circuits can be modelled as a second order system.

By definition, in order to achieve linear phase:

T_{ph} (phase delay) $=$ $T_{gr.}$ (Group delay).

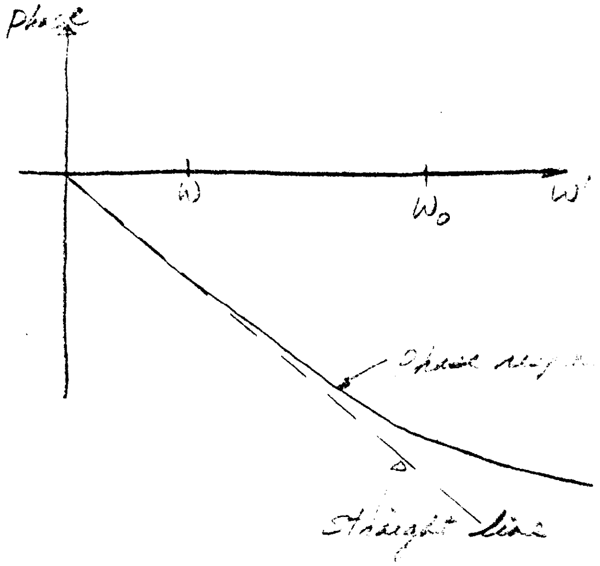
In general: $T(j\omega) = |A(\omega)| \angle \theta(\omega)$

$$T_{ph} \triangleq -\frac{\theta(\omega)}{\omega} \quad ; \quad T_{gr} \triangleq -\frac{d\theta(\omega)}{d\omega}$$

For the case of read channel front end (See ref. #2 - Chapter 16)

$$\theta(\omega) = -\tan^{-1}\frac{2\omega\omega_0|\xi|}{\omega_0^2-\omega^2}$$

Let us assume that we want the phase response to be linear within a certain reasonable region where $\omega \ll \omega_0$. (It is not possible to have a second order phase response to be linear over the whole frequency spectrum)



Using the Maclaurin-series expansion of the inverse-tangent function:

$$\tan^{-1}x \simeq x - \frac{x^3}{3} + \cdots \qquad (x^2<1)$$

$$T_{ph} = \frac{1}{\omega}\left(\tan^{-1}\frac{2\omega\omega_0|\xi|}{\omega_0^2-\omega^2}\right)$$ (the argument can be proven to be <1; $\omega \ll \omega_0$)

$$= \frac{1}{\omega}\left\{\frac{2|\xi|}{\omega_0^2-\omega^2} - \frac{1}{3}\left(\frac{2|\xi|\omega_0\omega}{\omega_0^2-\omega^2}\right)^3\right\}$$

$$= \frac{1}{\omega}\left\{\frac{2|\xi|\frac{\omega}{\omega_0}}{1-\left(\frac{\omega}{\omega_0}\right)^2} - \frac{1}{3}\left(\frac{2|\xi|\frac{\omega}{\omega_0}}{1-\left(\frac{\omega}{\omega_0}\right)^2}\right)^3\right\}$$

$$T_{ph} = \frac{1}{\omega}\left\{[2|\xi|\frac{\omega}{\omega_0})(1+(\frac{\omega}{\omega_0})^2] - \frac{1}{3}[2|\xi|\frac{\omega}{\omega_0}(1+(\frac{\omega}{\omega_0}^2))]^3\right\}$$

Binominal series expansion for the denominator, $(1-x)^{-n} = 1+nx+\cdots$

$$T_{ph} = \frac{2|\xi|}{\omega_0}\left[1+(\frac{\omega}{\omega_0})^2 - \frac{4|\xi|^2}{3}(\frac{\omega}{\omega_0})^2\right]$$

$$T_{gr} = \frac{d}{d\omega}\tan^{-1}\frac{2\omega\omega_0|\xi|}{\omega_0^2-\omega^2}$$

$$= \frac{1}{1+(\frac{2\omega\omega_0|\xi|}{\omega_0^2-\omega^2})^2}\frac{d}{d\omega}\left(\frac{2\omega\omega_0|\xi|}{\omega_0^2-\omega^2}\right)$$

$$= \frac{2|\xi|}{\omega_0}\left[\frac{1+(\frac{\omega}{\omega_0})^2}{1-(\frac{\omega}{\omega_0})^2(2-4|\xi|^2)+(\frac{\omega}{\omega_0})^4}\right]$$

$$= \frac{2|\xi|}{\omega_0}\left[\frac{1+(\frac{\omega}{\omega_0})^2}{1-[2(\frac{\omega}{\omega_0})^2-4|\xi|^2(\frac{\omega}{\omega_0})^2]}\right]$$

(Higher order term ignored $\frac{\omega}{\omega_0} \ll 1$)

$$= \frac{2|\xi|}{\omega_0}\left[1+(\frac{\omega}{\omega_0})^2\right]\left[1+(2-4|\xi|^2)(\frac{\omega}{\omega_0})^2\right]$$

$(1-x)^{-n} = 1+nx+\cdots$

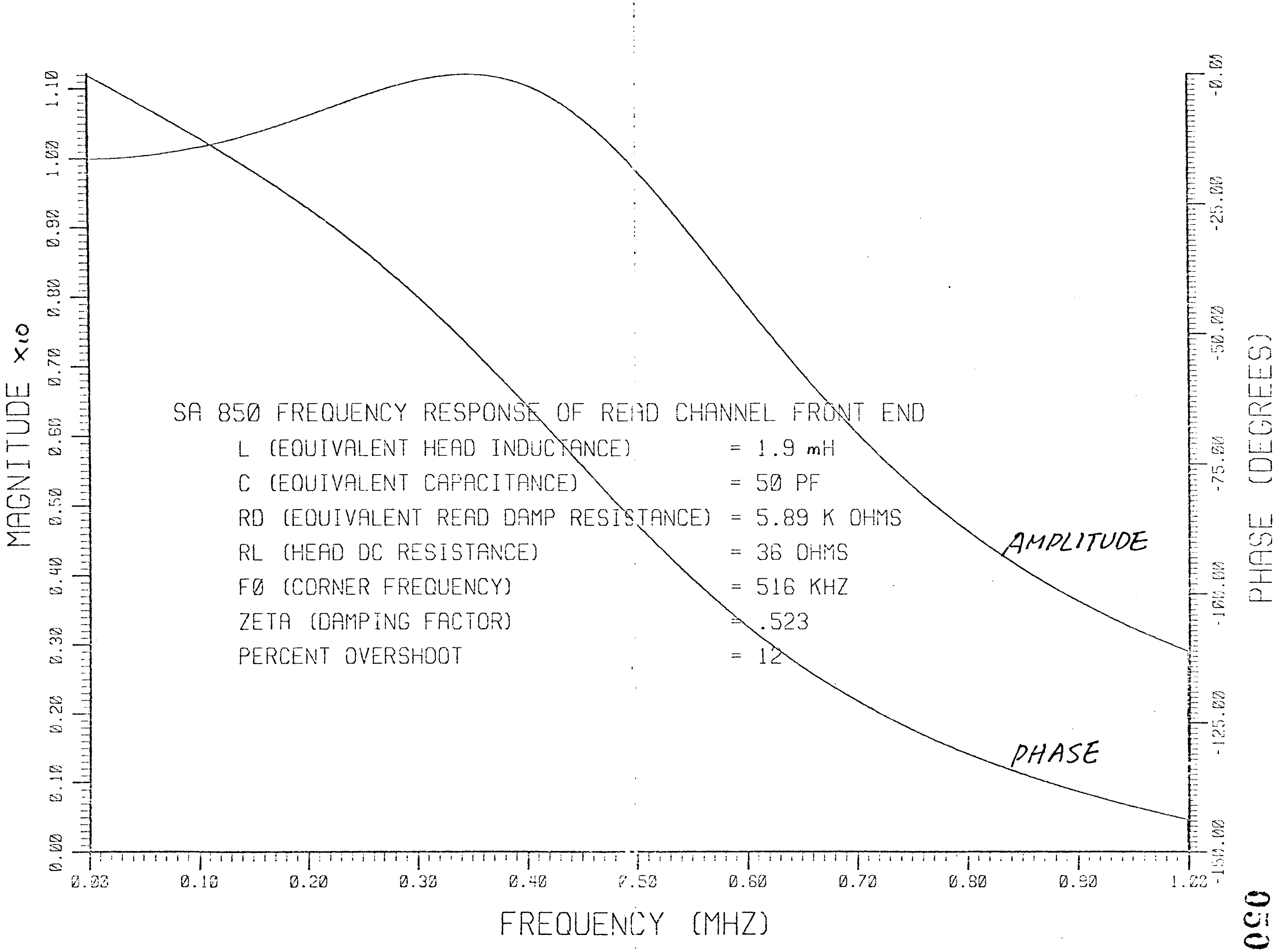
$$= \frac{2|\xi|}{\omega_0}\left[1+(3-4|\xi|^2)(\frac{\omega}{\omega_0})^2\right]$$

(Fourth-order term ignored $\omega \ll \omega_0$)

If $T_{ph} = T_{gr}$; then $1-\frac{4}{3}|\xi|^2 = 3-4|\xi|^2$

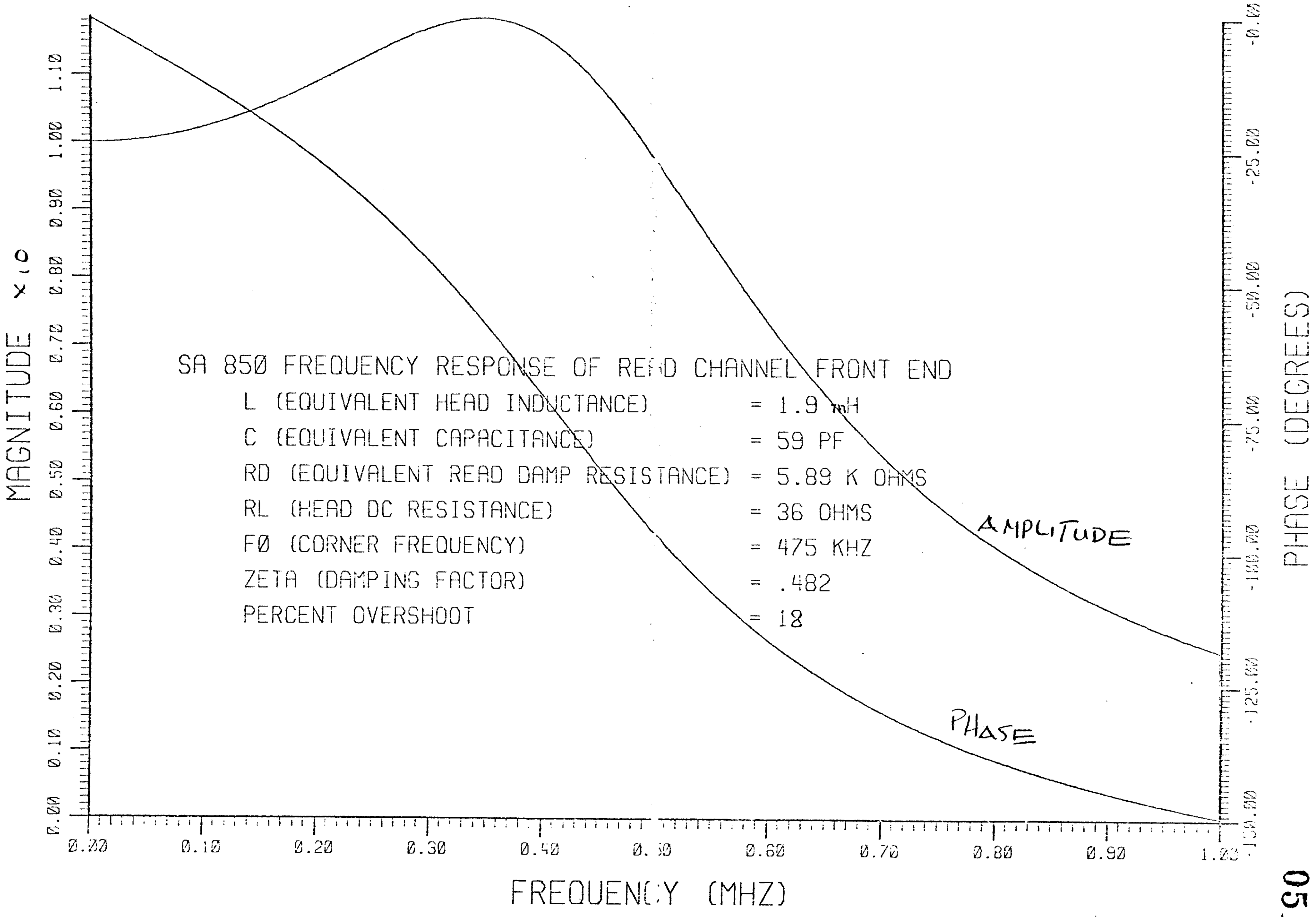
$$\boxed{|\xi| = 0.866 \;;\; Q = \frac{1}{2|\xi|} = 0.577} \Rightarrow \text{Ideal condition for linear phase}$$

```
$INSERT SYSCOM>KEYS.F
$INSERT SYSCOM>ASKEYS

      DIMENSION Y(1001),X(1001),FAZE(1001)
      REAL L

      CALL SRCH$$(KSWRIT,'FURT4',5,1,0,CODE)

      RD=4.E3
      L=1.75E-3
      C=59.E-12

      ZETA=(SQRT(L/C))/(2.*RD)
      F0=495301.

      DO 10 I=1,1001
      F=FLOAT(I-1)*1.E3
      X(I)=F
      RAT=F/F0
      Y(I)=SQRT(1./((1.-RAT**2)**2+(2.*ZETA*RAT)**2))
   10 FAZE(I)=-ATAN((RAT+SQRT(1-ZETA**2))/ZETA)
     1          -ATAN((RAT-SQRT(1-ZETA**2))/ZETA)
   30 FORMAT(I5,5E12.5)

      WRITE(5,20)(X(I),Y(I),FAZE(I),I=1,1001)
   20 FORMAT(3E12.5)

      CALL SRCH$$(KSCLOS,0,0,1,0,CODE)
      CALL EXIT
      END
```



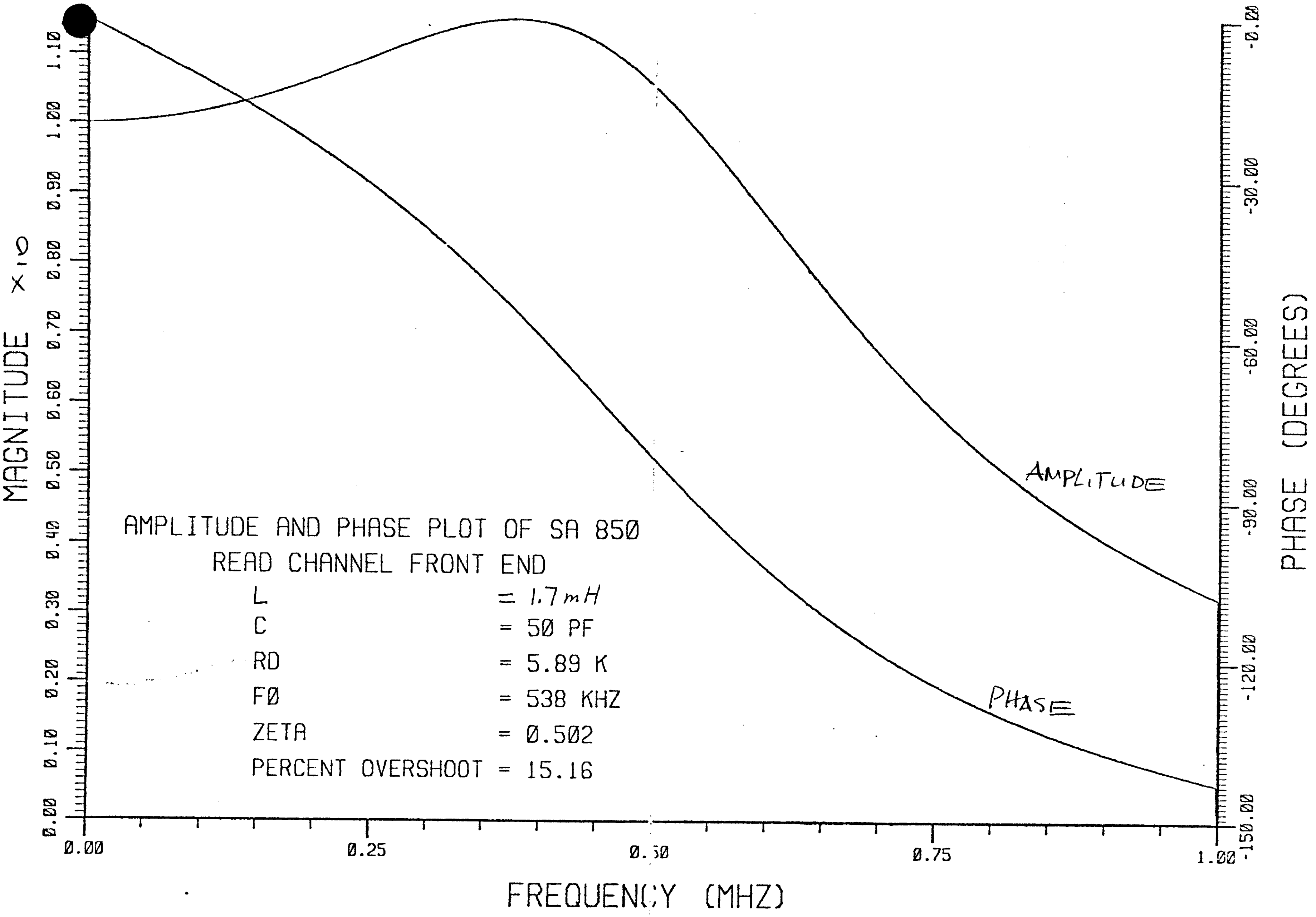
SA 850 FREQUENCY RESPONSE OF READ CHANNEL FRONT END

L (EQUIVALENT HEAD INDUCTANCE) = 1.9 mH
C (EQUIVALENT CAPACITANCE) = 50 PF
RD (EQUIVALENT READ DAMP RESISTANCE) = 5.89 K OHMS
RL (HEAD DC RESISTANCE) = 36 OHMS
F0 (CORNER FREQUENCY) = 516 KHZ
ZETA (DAMPING FACTOR) = .523
PERCENT OVERSHOOT = 12



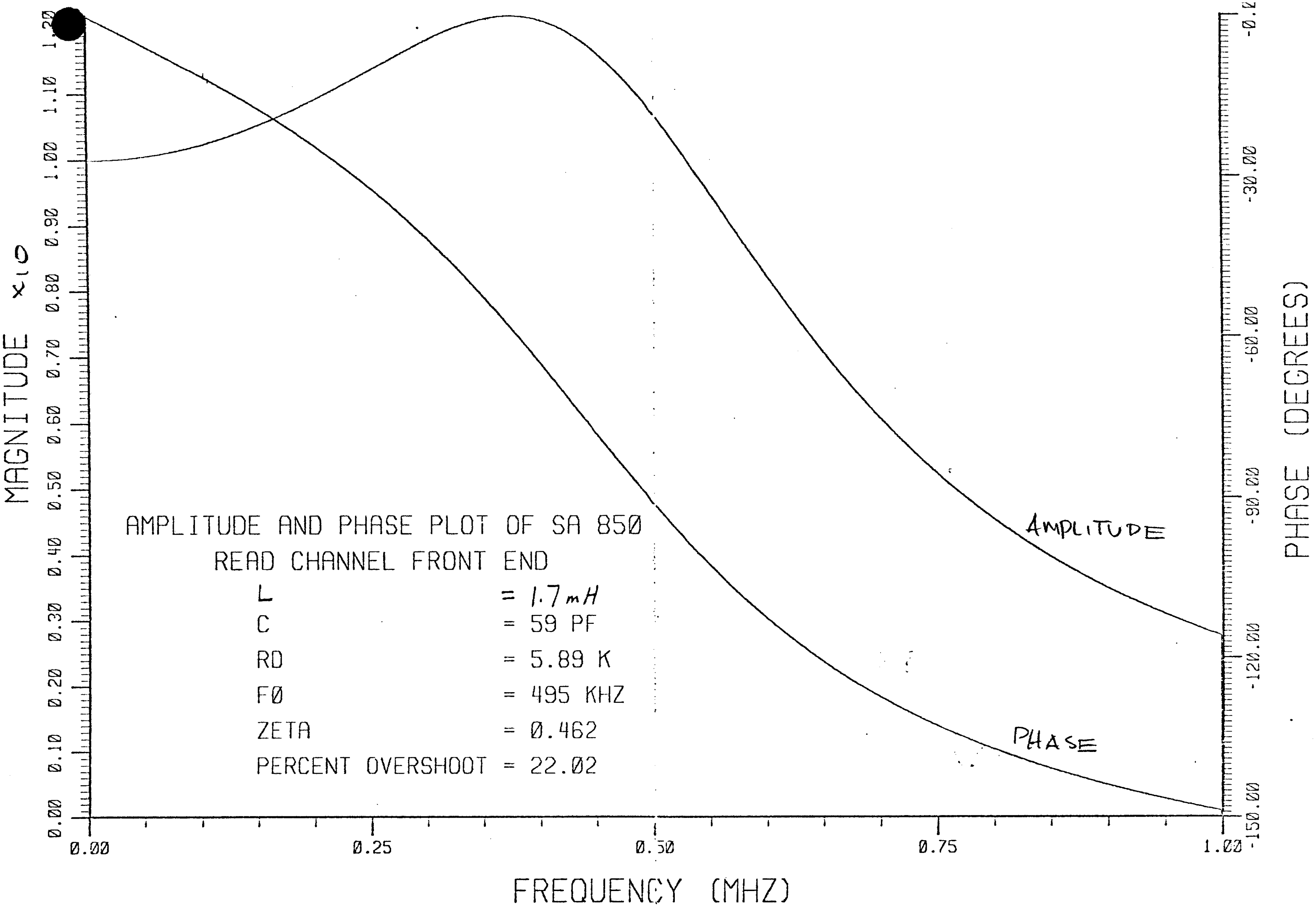
SA 850 FREQUENCY RESPONSE OF READ CHANNEL FRONT END

L (EQUIVALENT HEAD INDUCTANCE) = 1.9 mH
C (EQUIVALENT CAPACITANCE) = 59 PF
RD (EQUIVALENT READ DAMP RESISTANCE) = 5.89 K OHMS
RL (HEAD DC RESISTANCE) = 36 OHMS
F0 (CORNER FREQUENCY) = 475 KHZ
ZETA (DAMPING FACTOR) = .482
PERCENT OVERSHOOT = 18



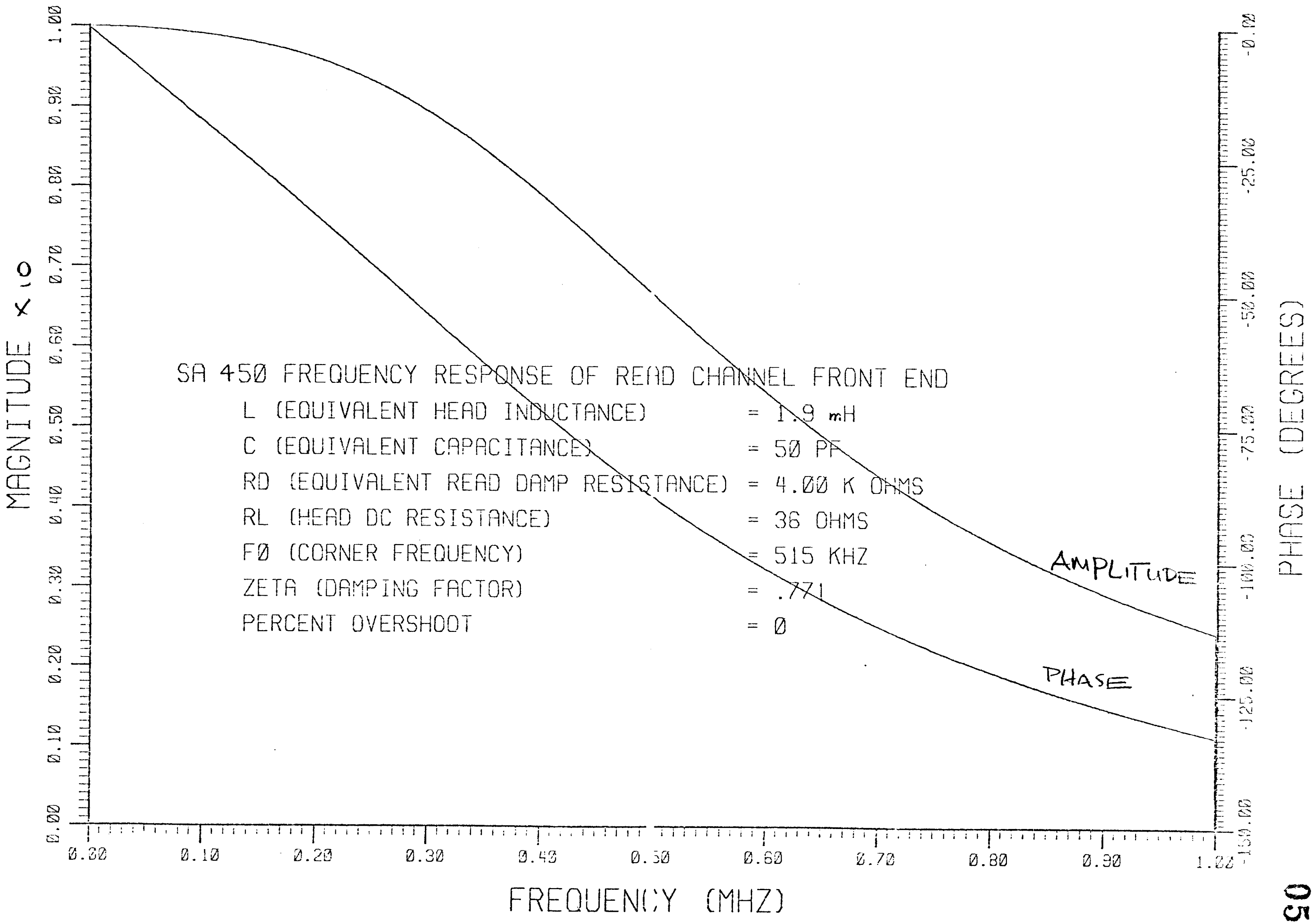
AMPLITUDE AND PHASE PLOT OF SA 850
READ CHANNEL FRONT END

L = 1.7 mH
C = 50 PF
RD = 5.89 K
F0 = 538 KHZ
ZETA = 0.502
PERCENT OVERSHOOT = 15.16



AMPLITUDE AND PHASE PLOT OF SA 850
READ CHANNEL FRONT END

L = 1.7 mH
C = 59 PF
RD = 5.89 K
F0 = 495 KHZ
ZETA = 0.462
PERCENT OVERSHOOT = 22.02



SA 450 FREQUENCY RESPONSE OF READ CHANNEL FRONT END

L (EQUIVALENT HEAD INDUCTANCE) = 1.9 mH

C (EQUIVALENT CAPACITANCE) = 50 PF

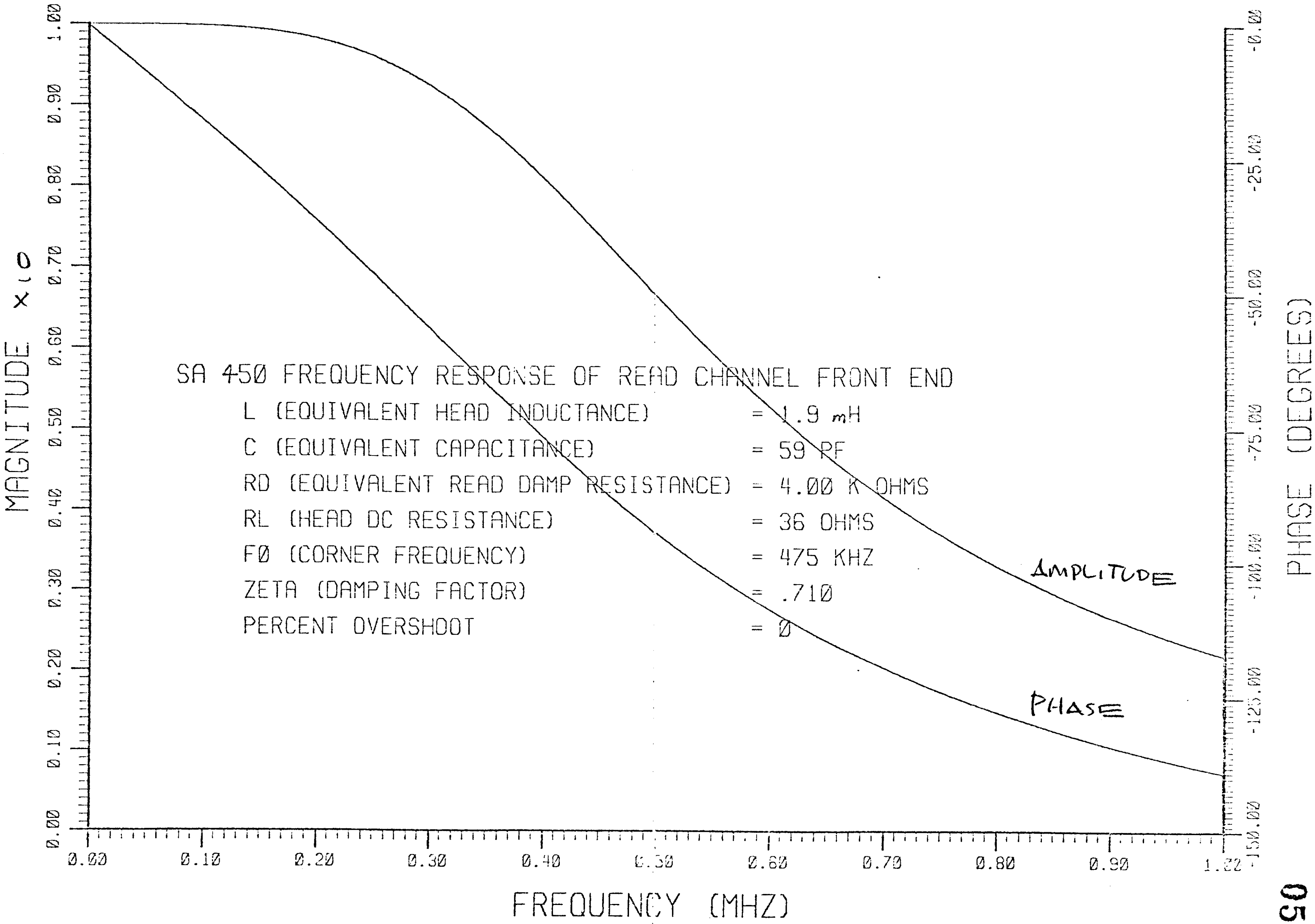
RD (EQUIVALENT READ DAMP RESISTANCE) = 4.00 K OHMS

RL (HEAD DC RESISTANCE) = 36 OHMS

F0 (CORNER FREQUENCY) = 515 KHZ

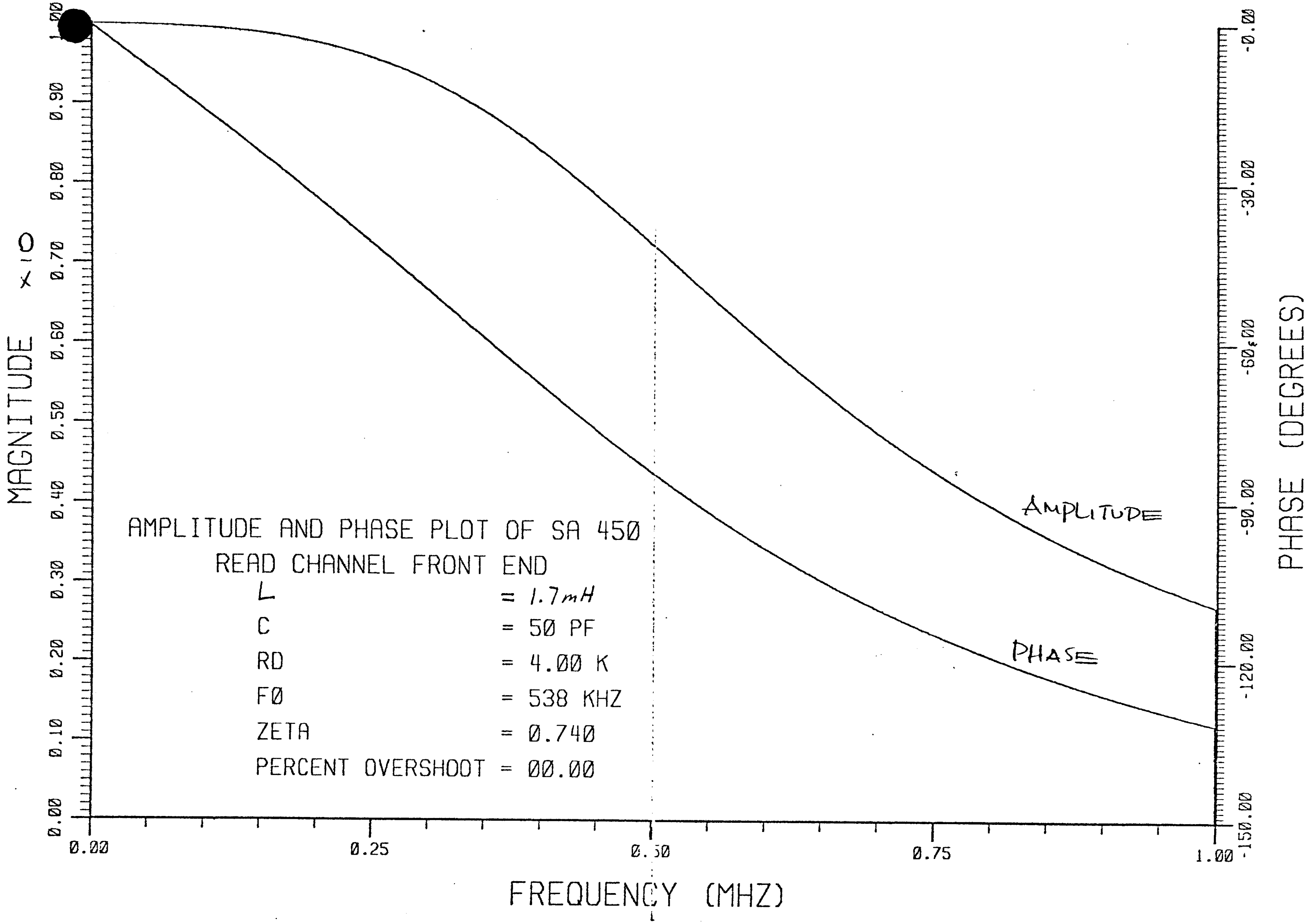
ZETA (DAMPING FACTOR) = .771

PERCENT OVERSHOOT = 0



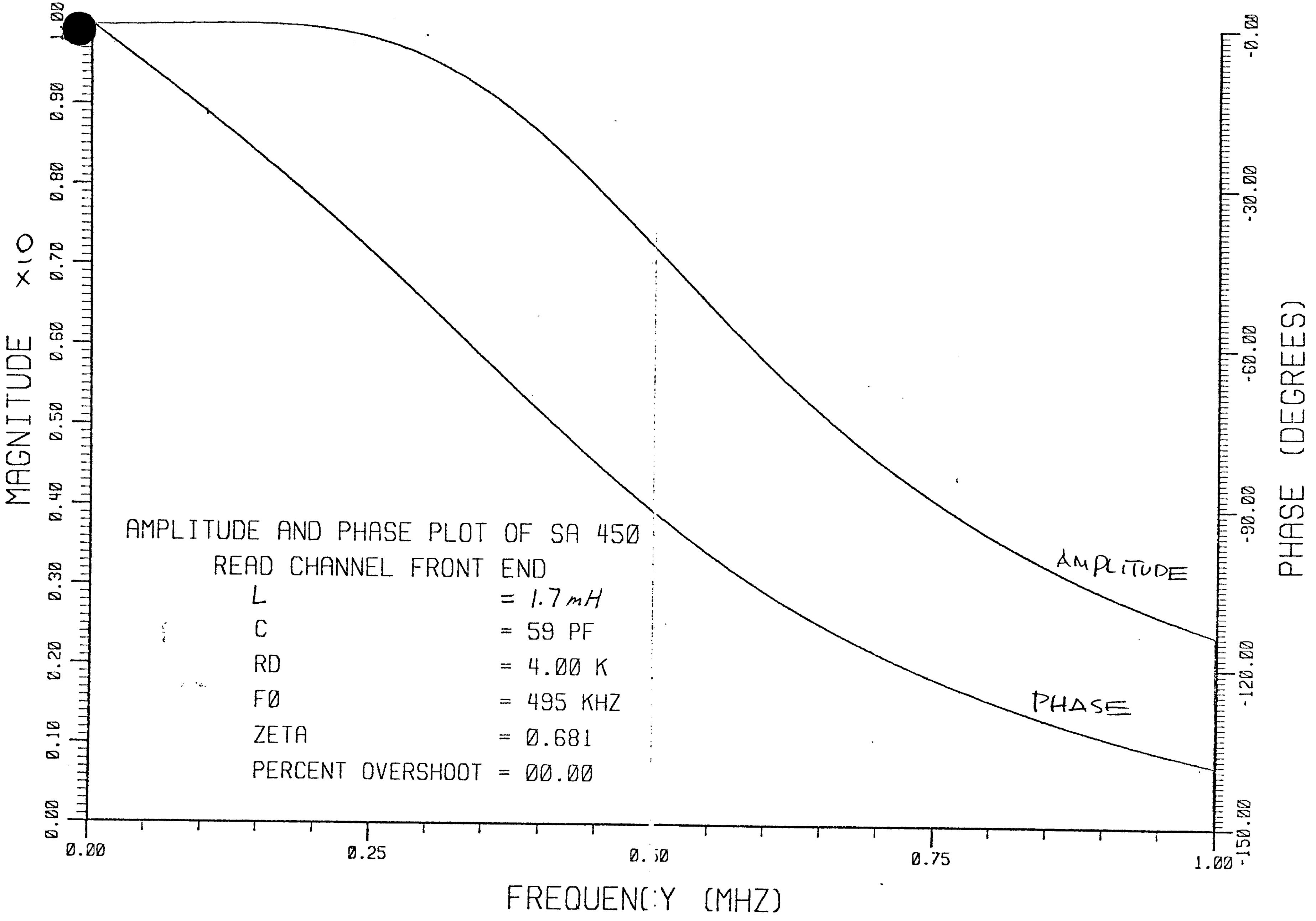
SA 450 FREQUENCY RESPONSE OF READ CHANNEL FRONT END

L (EQUIVALENT HEAD INDUCTANCE) = 1.9 mH
C (EQUIVALENT CAPACITANCE) = 59 PF
RD (EQUIVALENT READ DAMP RESISTANCE) = 4.00 K OHMS
RL (HEAD DC RESISTANCE) = 36 OHMS
F0 (CORNER FREQUENCY) = 475 KHZ
ZETA (DAMPING FACTOR) = .710
PERCENT OVERSHOOT = 0



AMPLITUDE AND PHASE PLOT OF SA 450
READ CHANNEL FRONT END

L = 1.7mH
C = 50 PF
RD = 4.00 K
F0 = 538 KHZ
ZETA = 0.740
PERCENT OVERSHOOT = 00.00

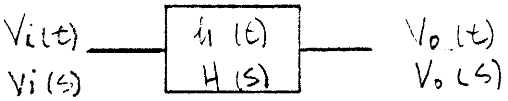


AMPLITUDE AND PHASE PLOT OF SA 450
READ CHANNEL FRONT END

L = 1.7 mH
C = 59 PF
RD = 4.00 K
F0 = 495 KHZ
ZETA = 0.681
PERCENT OVERSHOOT = 00.00

A-5 Experimental Determination of Damping Factor:

THEORY



$$V_o(t) = V_i(t) * h(t)$$

$$(\text{OUTPUT}) = (\text{INPUT}) \underset{\uparrow\text{CONVOLUTION}}{*} (\text{ZERO INPUT RESPONSE})$$

$$\mathcal{L}[V_o(t)] = \mathcal{L}[V_i(t) * h(t)]$$

$$V_o(s) = \mathcal{L}[V_i(t)] \underset{\text{MULTIPLICATION}}{\cdot} \mathcal{L}[h(t)]$$

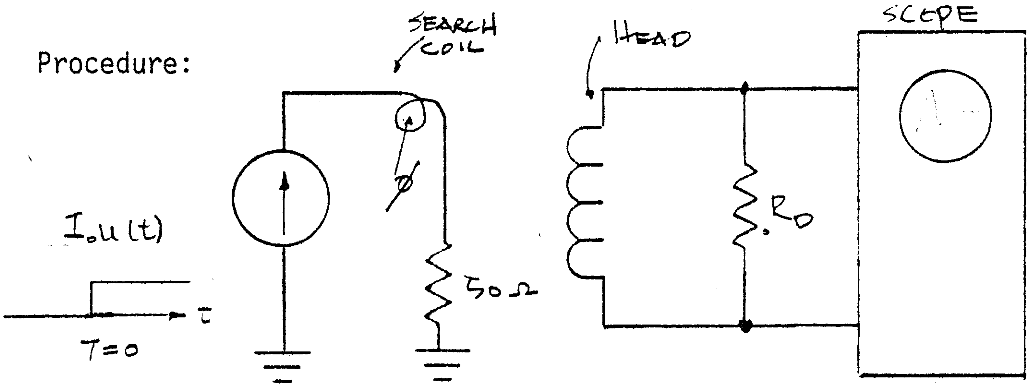
$$= V_i(s) \underset{\uparrow\text{TRANSFER FUNCTION}}{H(s)}$$

$$\because \mathcal{L}[\delta(t)] = 1$$

$$\begin{cases} V_o(t) = \underset{\text{IMPULSE}}{\delta(t)} * h(t) \\ V_o(s) = H(s) \end{cases}$$

The last two equations described that response of a system (network) to an impulse equalled to the system transfer function H(S) in frequency domain and equalled to zero input response in time domain.

Procedure:



A step current is applied to the search coil. The flux generated equals to ;

n_o = turns of search coil; I_o = Amplitude of current

R_m = reluctance of the set up (consider to be constant)

$$= \frac{l}{\mu_o A}$$

μ_o =Permeability of air

A =Cross-section of head

l =Length of magnetic linkage surrounding search coil and head coil

Voltage induced at the head equals:

$$V_i = -n\frac{d\phi}{dt}$$

n = Number of turns of head coil

$$= \frac{-n \, d\, n_o I_o u(t)}{dt}$$

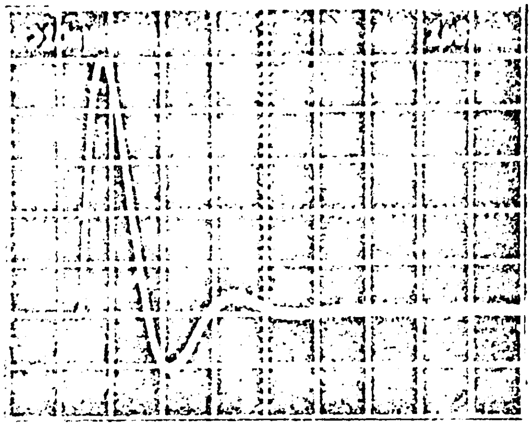
$$= -n n_o I_o \delta(t)$$

$$\frac{du(t)}{dt} \triangleq \delta(t)$$

This implied that by applying a step current to the search coil, we are really applying an impulse to the head. The response we see on a memory scope is the zero response of the head.

Result of experiment:

By finding the ratio between the main lobe and the second lobe from the scope, we can find ZETA of the system by using the following relationship:



$$S = \frac{\text{2nd lobe amplitude}}{\text{Main lobe amplitude}}$$

$$S = \frac{1.1}{5} = .22$$

$$|\xi| = \frac{\left|\frac{\ln S}{\pi}\right|}{\sqrt{1+\left(\frac{\ln S}{\pi}\right)^2}}$$

$$|\xi| = \underline{0.434}$$

DAMPING RESISTOR = 6.8KΩ

*L= 1.7mH

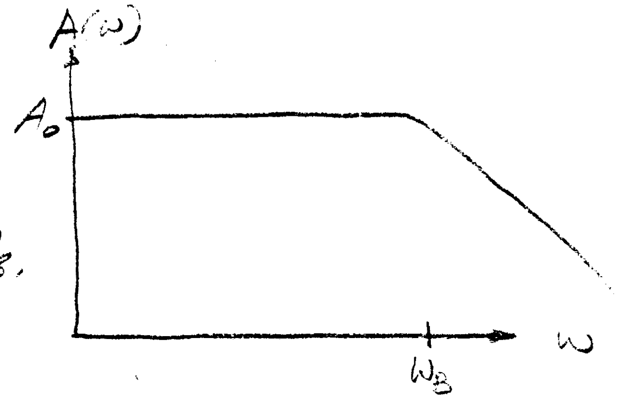
C= 5.9pf

R_D = 6.8K // 44KΩ = 5.89KΩ

This experimental result agreed very closely to the calculated value. $|\xi| = \underline{0.48}$

* Inductance value could be in error due to improper range selected when measurement was taken. The value probably should have been 1.9 mH. In this case, the calculated damping factor agrees better with the experiment. $|\xi| = 0.46$

B-1. Derivation of read amplifier transfer function and related parameters.



Typical linear amplifier respo

For a typical linear amplifier with bandwidth of W_B, its transfer function is

$$T(S) = \frac{A_o W_B}{S+W_B} \quad ; A_o = A_1 \cdot A_2 \simeq 100$$

With introduction of D.C. blocking capacitor, A_o becomes

$$\because \quad A_o = A_1 \cdot A_2$$

$$A_1 = \frac{2 \times 2.5K\Omega}{R+\frac{1}{SC}}$$ (Standard gain of differential amplifier)

R = Total internal & external resistance

C = External D.C. blocking capacitors

$A_2 \simeq 10$ $\qquad$ $W_B = 2\pi \times 5MHz$ (from spec.)

$$\therefore \quad A_o = \frac{5000SC}{5000SC+1} \times 10$$

$$T(S) = \frac{\frac{5000SCW_B}{5000SC+1}}{S+W_B} \times 10$$

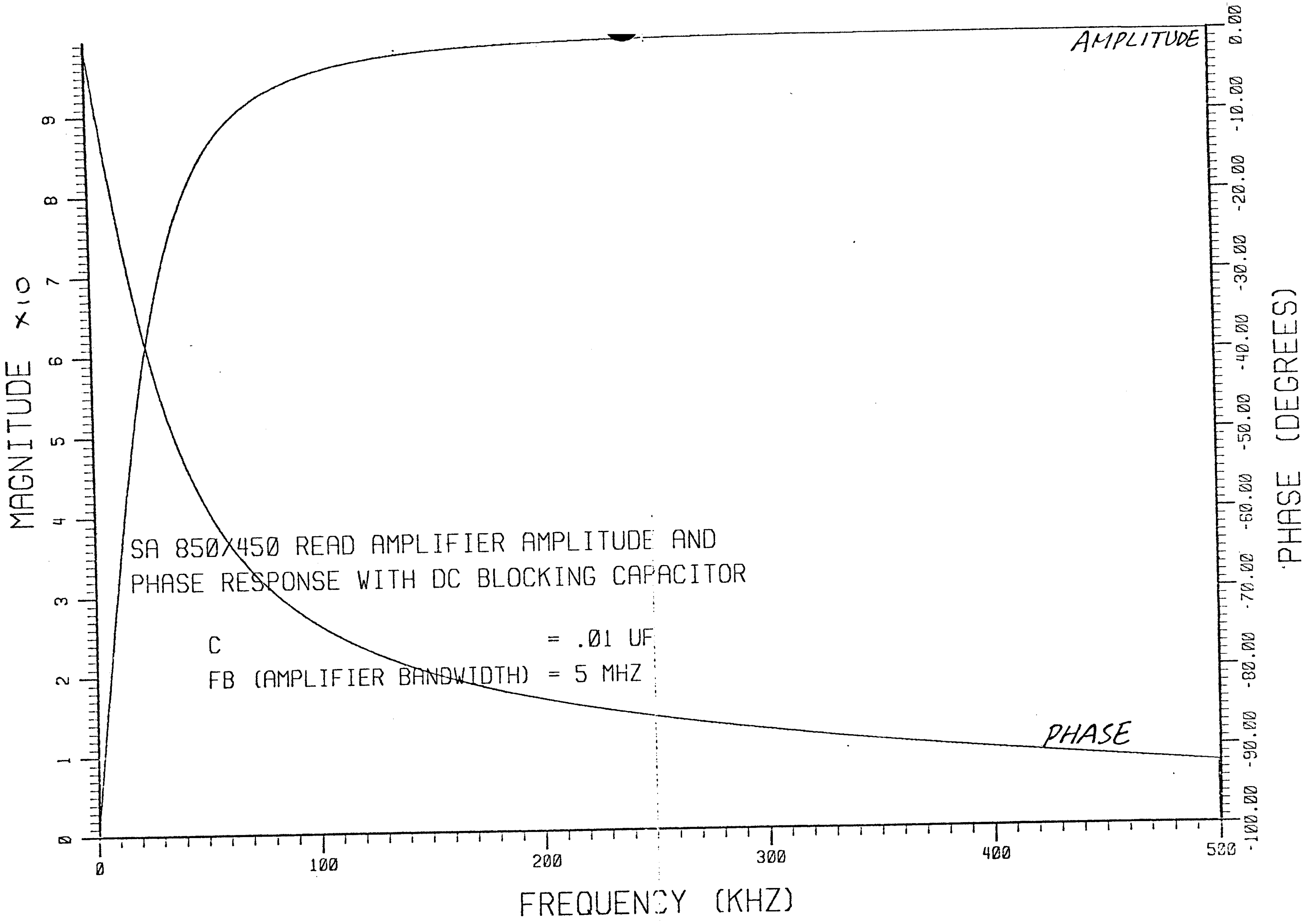
$$T(S) = \frac{5000SC\,\omega_B}{(S+\omega_B)(500SC+1)} \times 10$$

$$= \frac{10S\omega_B}{(S+\omega_B)\left(S+\frac{1}{500C}\right)} \times 10$$

$$T(j\omega) = \frac{100j\omega\omega_B}{(j\omega+\omega_B)\left(j\omega+\frac{1}{500C}\right)}$$

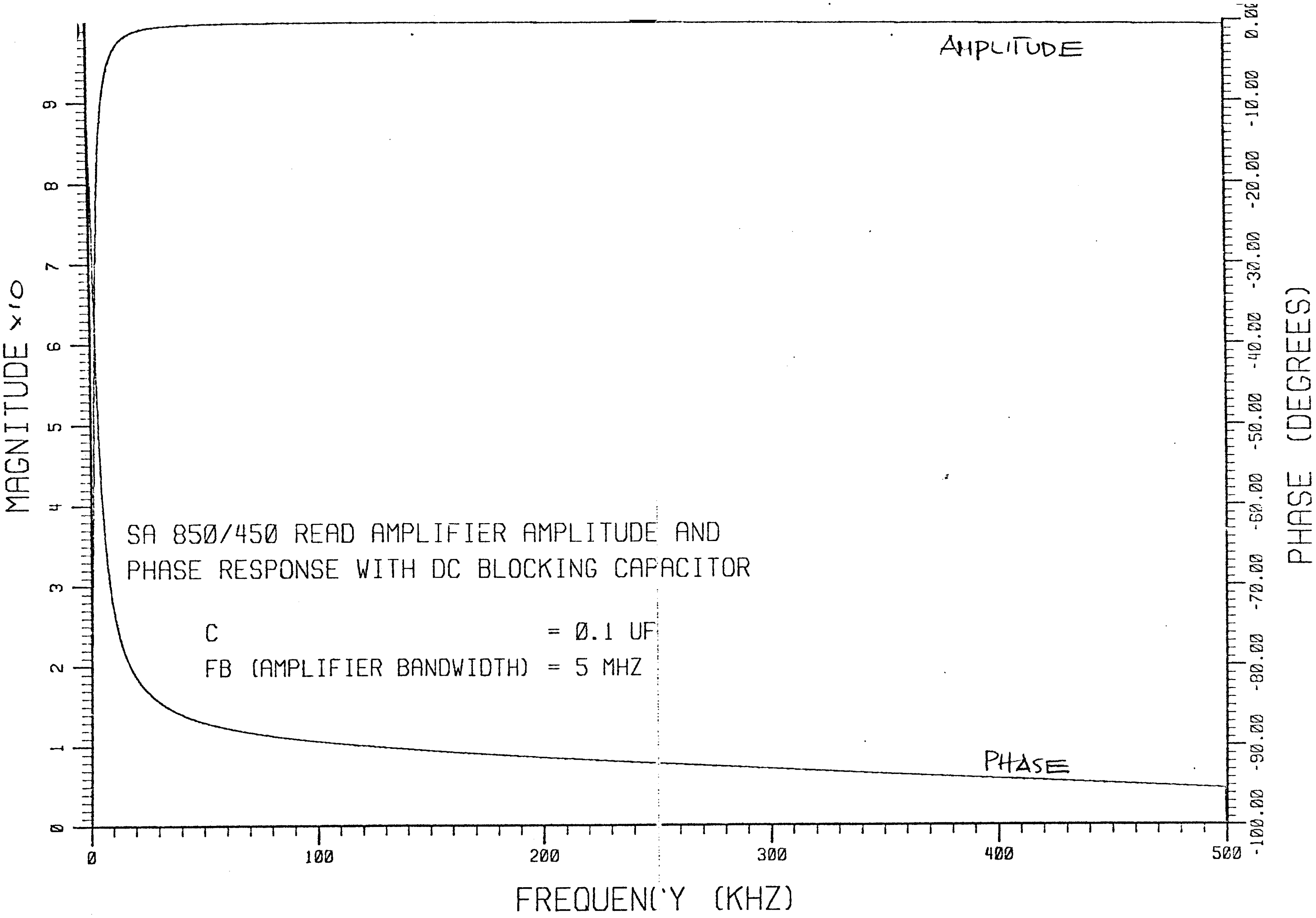
$$= \frac{100\omega\omega_B}{\sqrt{\omega^2+\omega_B^2}\cdot\sqrt{\omega^2+\left(\frac{1}{500C}\right)^2}} \angle 90^\circ - \tan^{-1}\frac{\omega}{\omega_B} - \tan^{-1}500C\omega$$

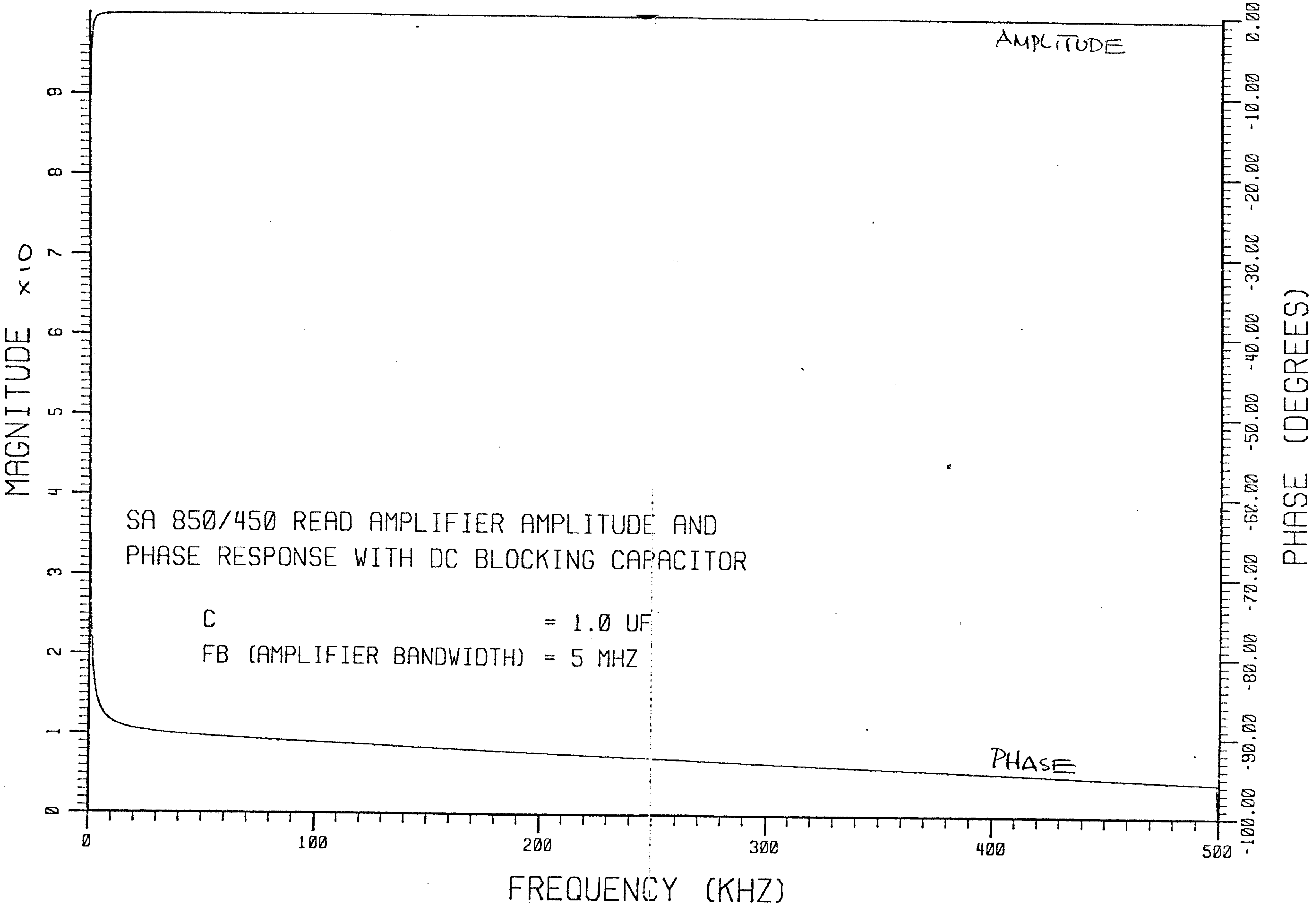
$$\boxed{T(j2\pi f) = \frac{100\,f f_B}{\sqrt{f^2+f_B^2}\cdot\sqrt{f^2+\left(\frac{1}{500\times2\pi\times C}\right)^2}} \angle 90^\circ - \tan^{-1}\frac{f}{f_B} - \tan^{-1}2\pi\times500Cf}$$



SA 850X450 READ AMPLIFIER AMPLITUDE AND
PHASE RESPONSE WITH DC BLOCKING CAPACITOR

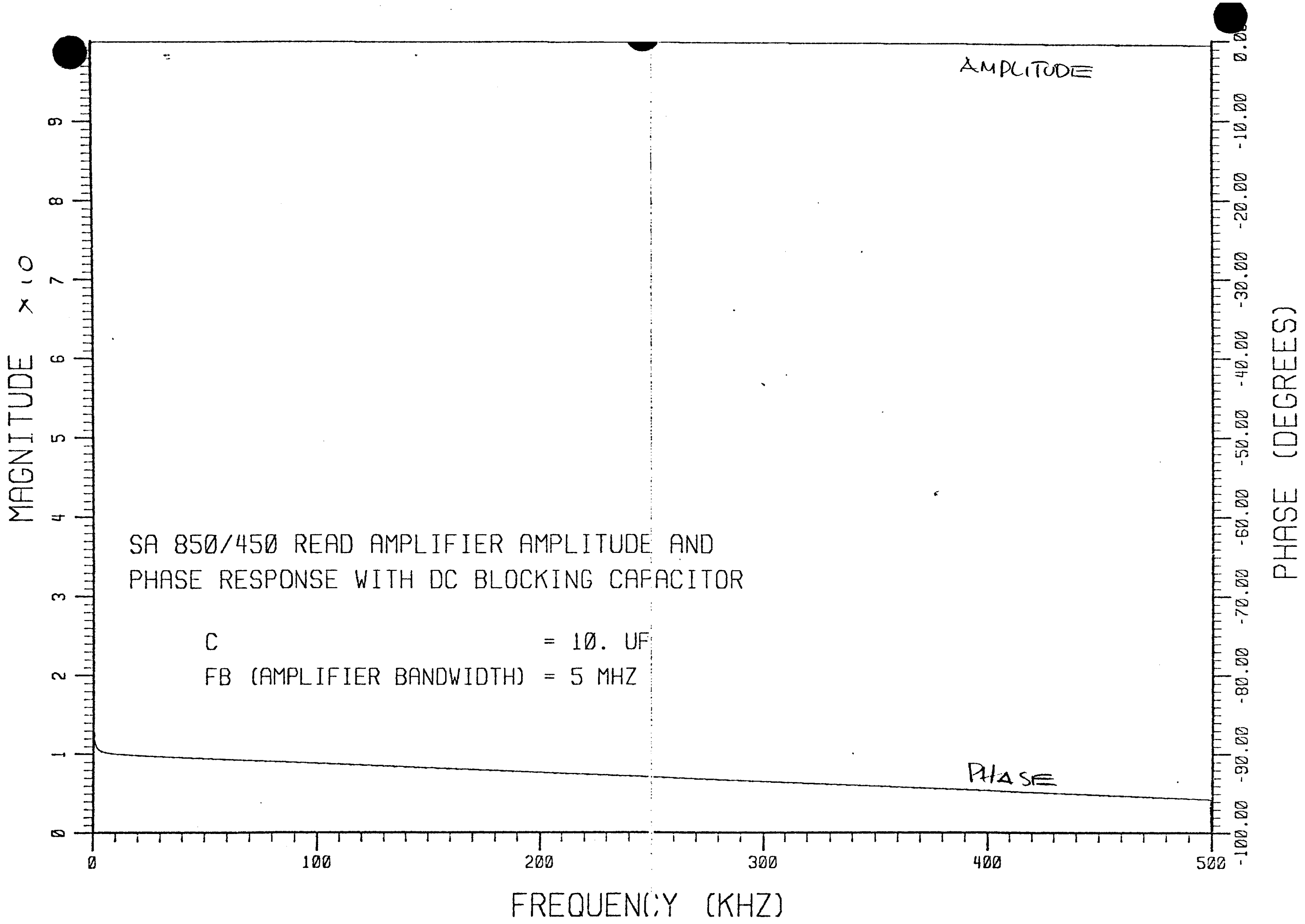
C = .01 UF
FB (AMPLIFIER BANDWIDTH) = 5 MHZ


AMPLITUDE
PHASE
SA 850/450 READ AMPLIFIER AMPLITUDE AND
PHASE RESPONSE WITH DC BLOCKING CAPACITOR
C = 0.1 UF
FB (AMPLIFIER BANDWIDTH) = 5 MHZ
MAGNITUDE x10
0
1
2
3
4
5
6
7
8
9
PHASE (DEGREES)
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
-90.00
-100.00
FREQUENCY (KHZ)
0
100
200
300
400
500



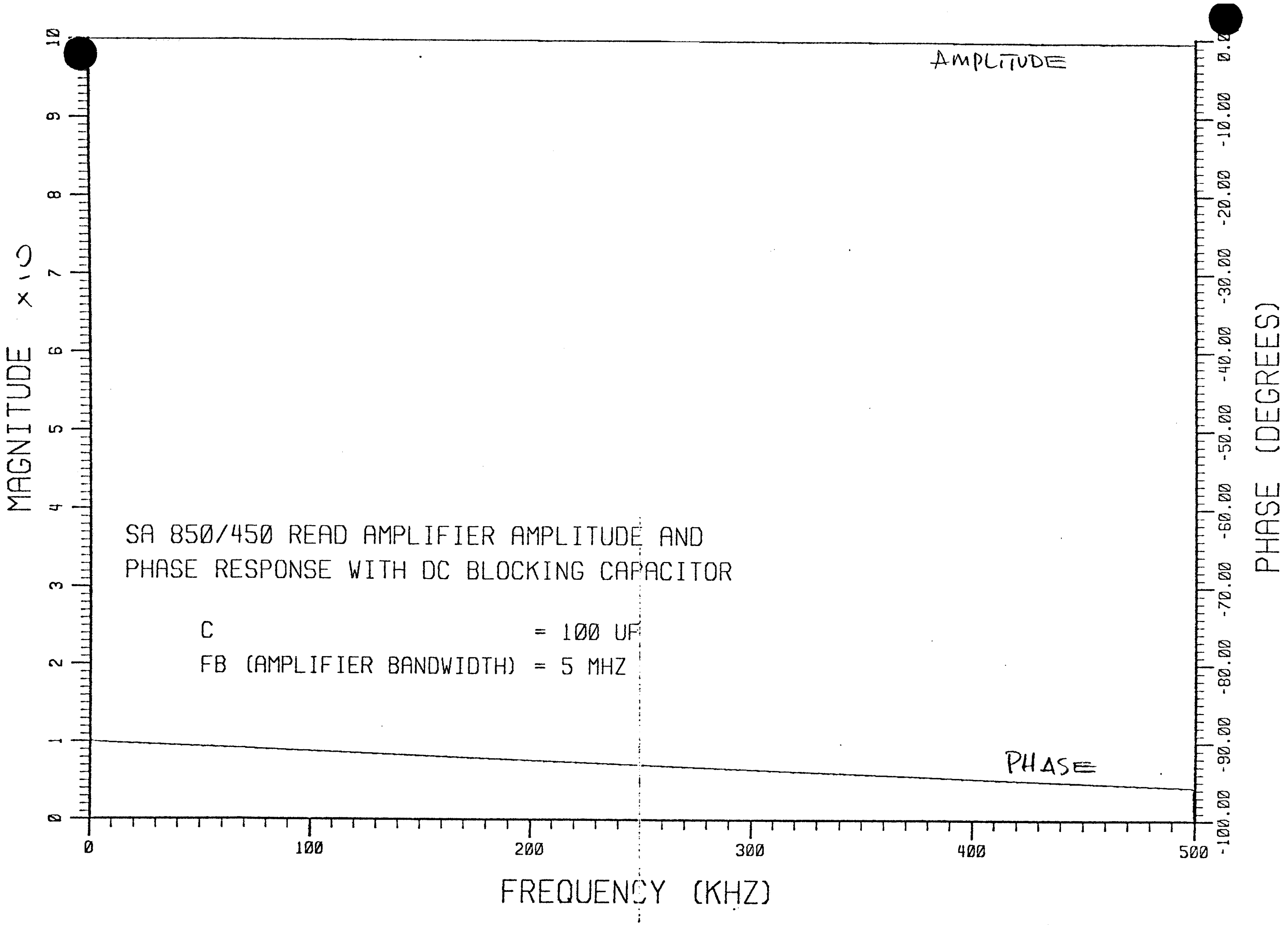
SA 850/450 READ AMPLIFIER AMPLITUDE AND PHASE RESPONSE WITH DC BLOCKING CAPACITOR

C = 1.0 UF
FB (AMPLIFIER BANDWIDTH) = 5 MHZ



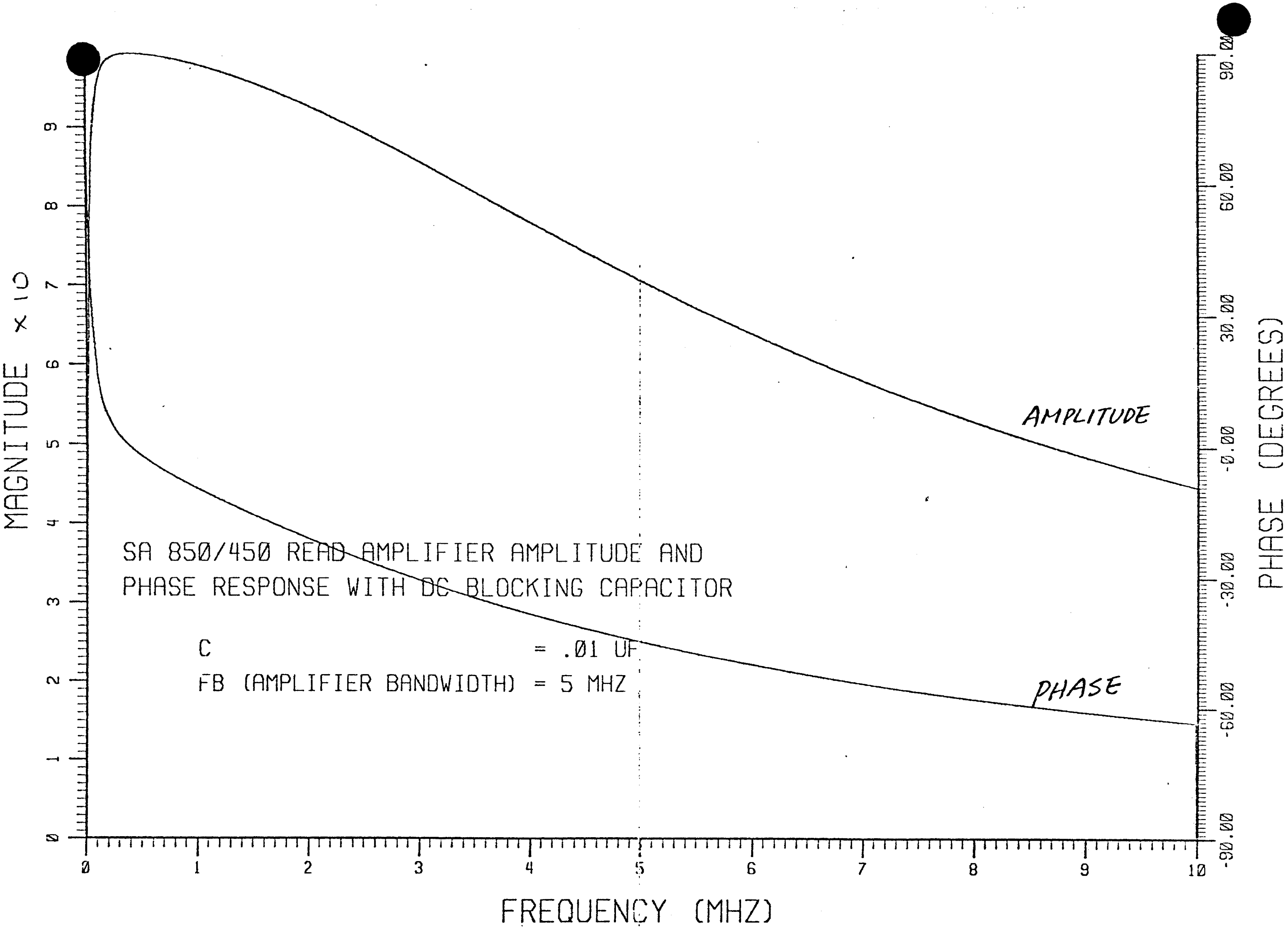
SA 850/450 READ AMPLIFIER AMPLITUDE AND
PHASE RESPONSE WITH DC BLOCKING CAFACITOR

C = 10. UF
FB (AMPLIFIER BANDWIDTH) = 5 MHZ



SA 850/450 READ AMPLIFIER AMPLITUDE AND
PHASE RESPONSE WITH DC BLOCKING CAPACITOR

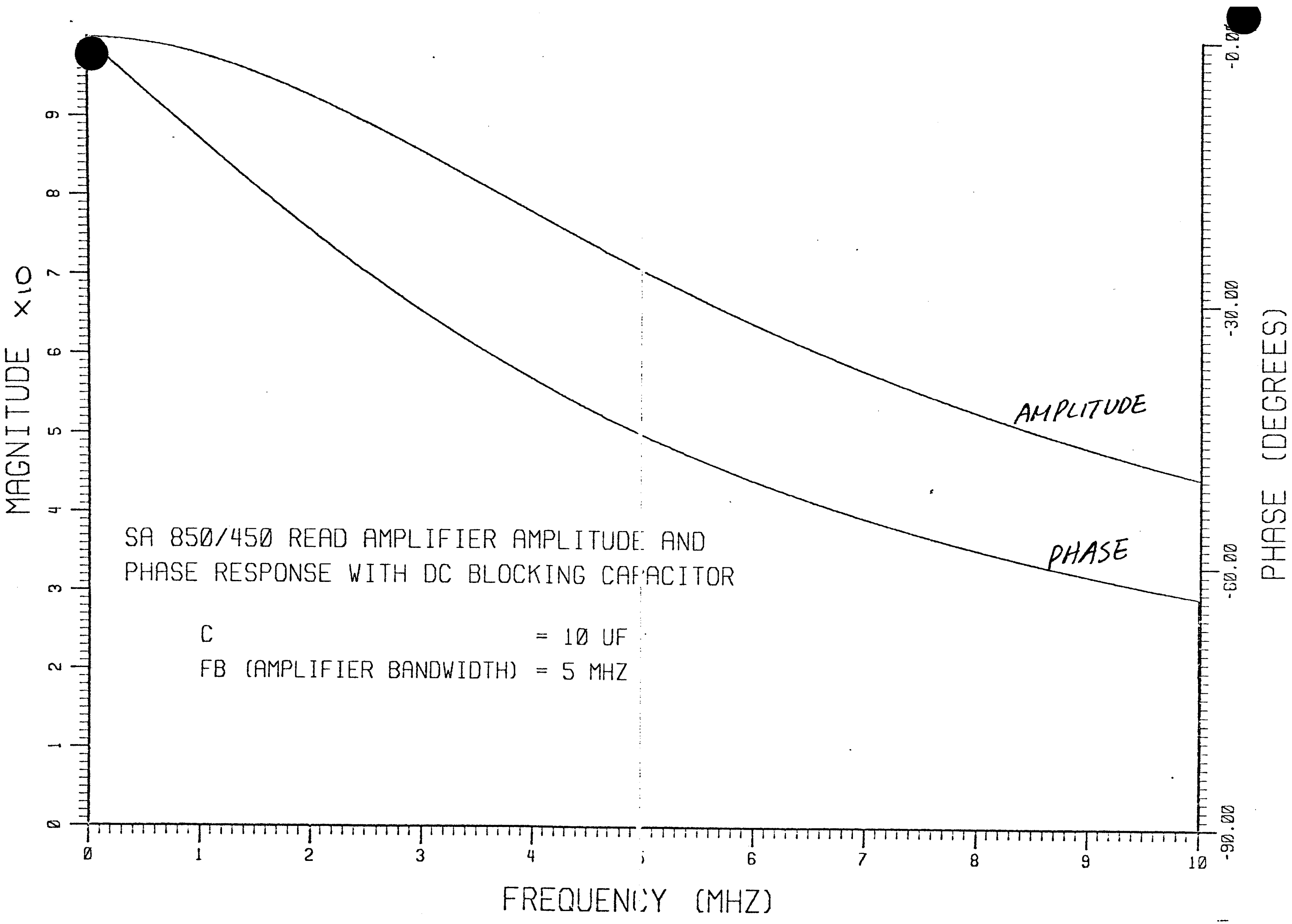
C = 100 UF
FB (AMPLIFIER BANDWIDTH) = 5 MHZ



SA 850/450 READ AMPLIFIER AMPLITUDE AND PHASE RESPONSE WITH DC BLOCKING CAPACITOR

C = .01 UF

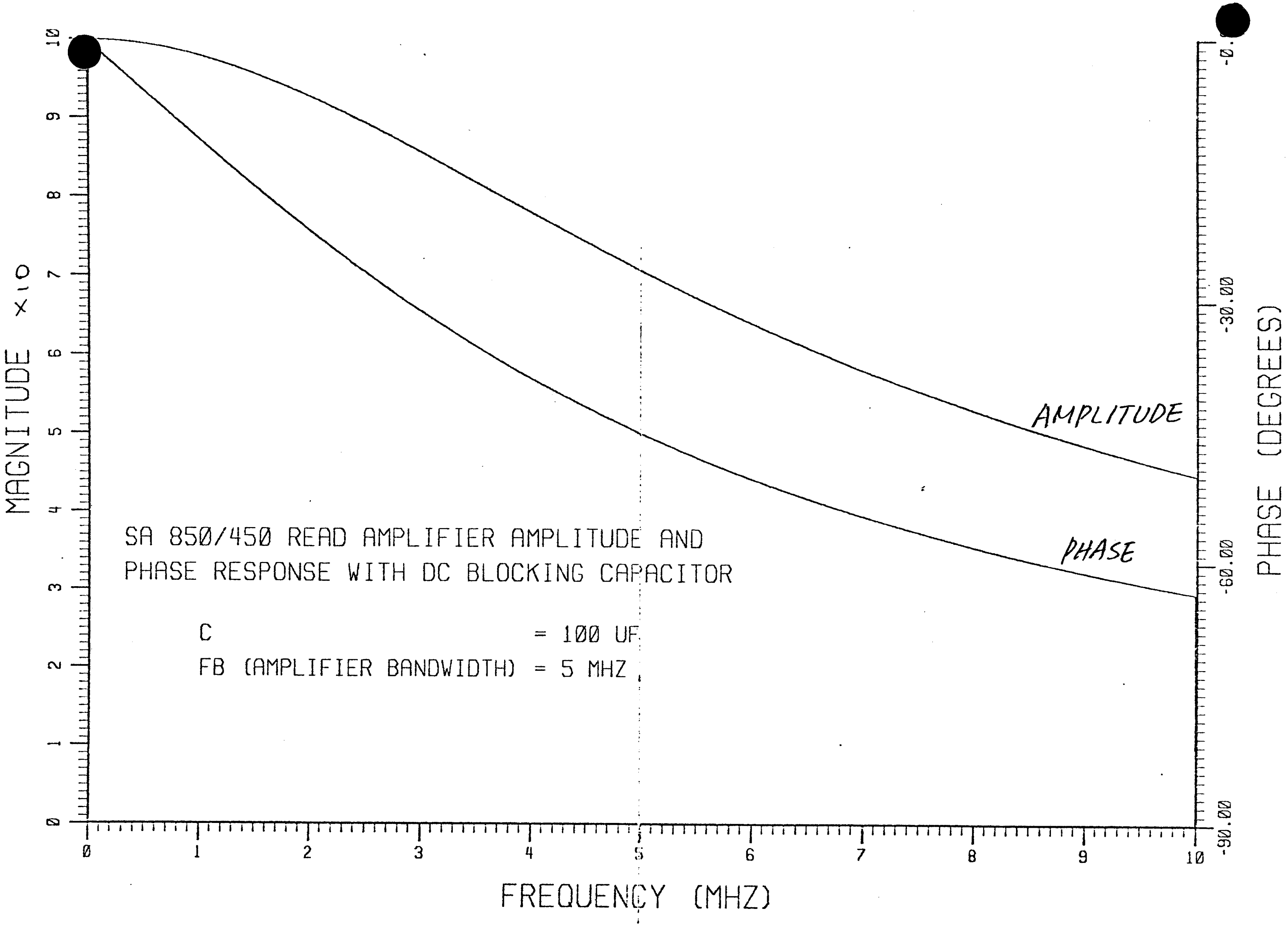
FB (AMPLIFIER BANDWIDTH) = 5 MHZ



SA 850/450 READ AMPLIFIER AMPLITUDE AND PHASE RESPONSE WITH DC BLOCKING CAPACITOR

C = 10 UF

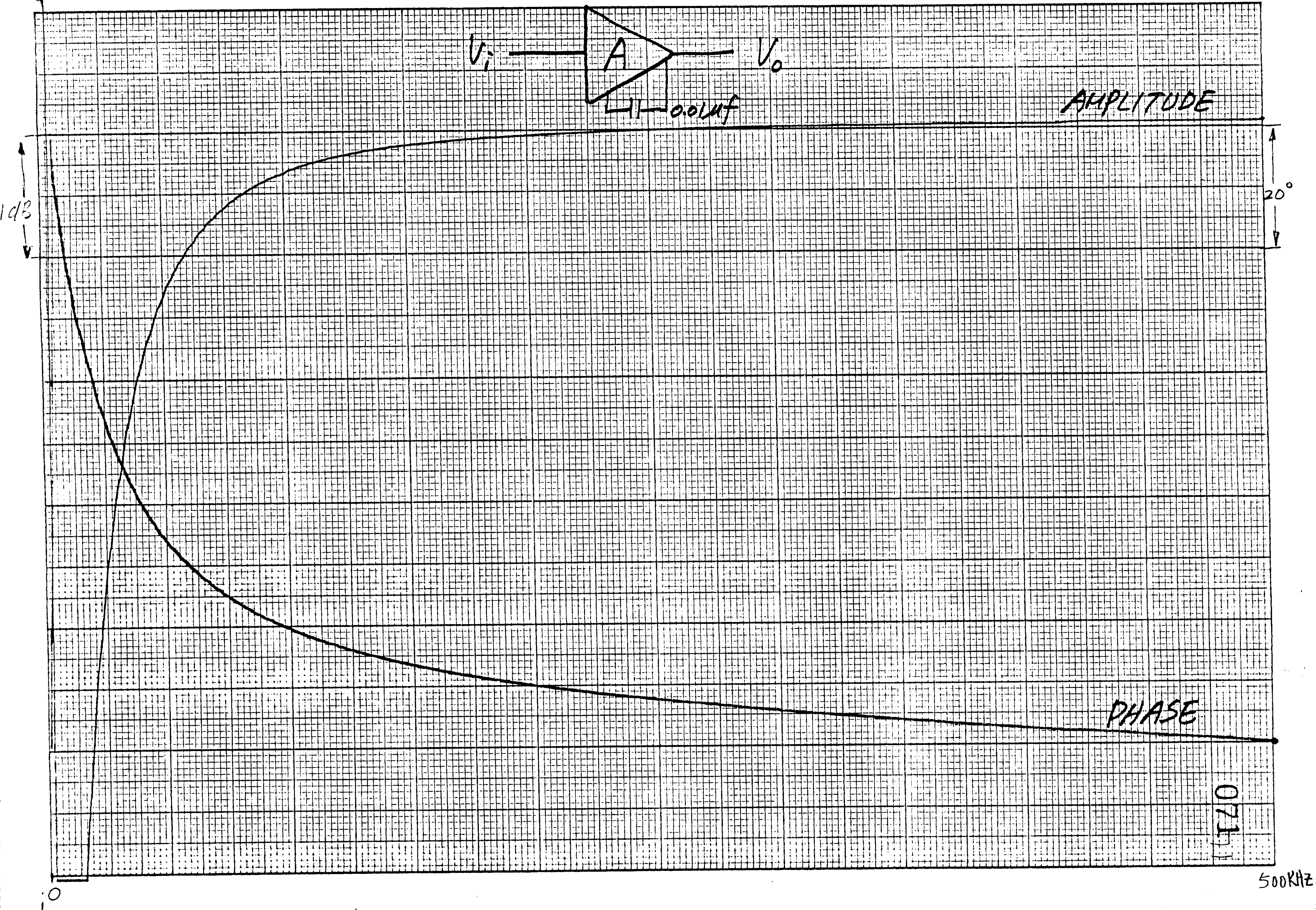
FB (AMPLIFIER BANDWIDTH) = 5 MHZ



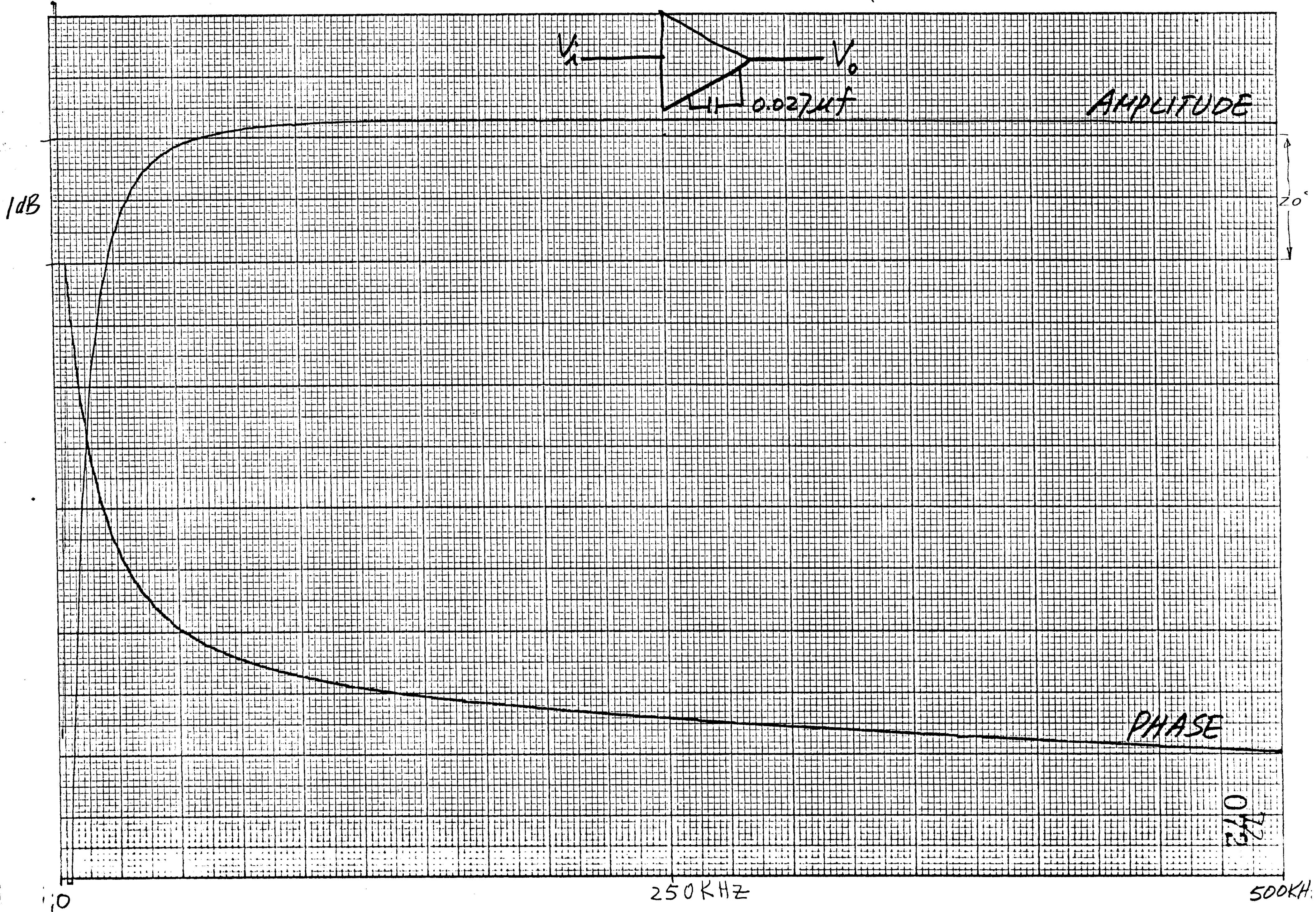
SA 850/450 READ AMPLIFIER AMPLITUDE AND PHASE RESPONSE WITH DC BLOCKING CAPACITOR

C = 100 UF
FB (AMPLIFIER BANDWIDTH) = 5 MHZ

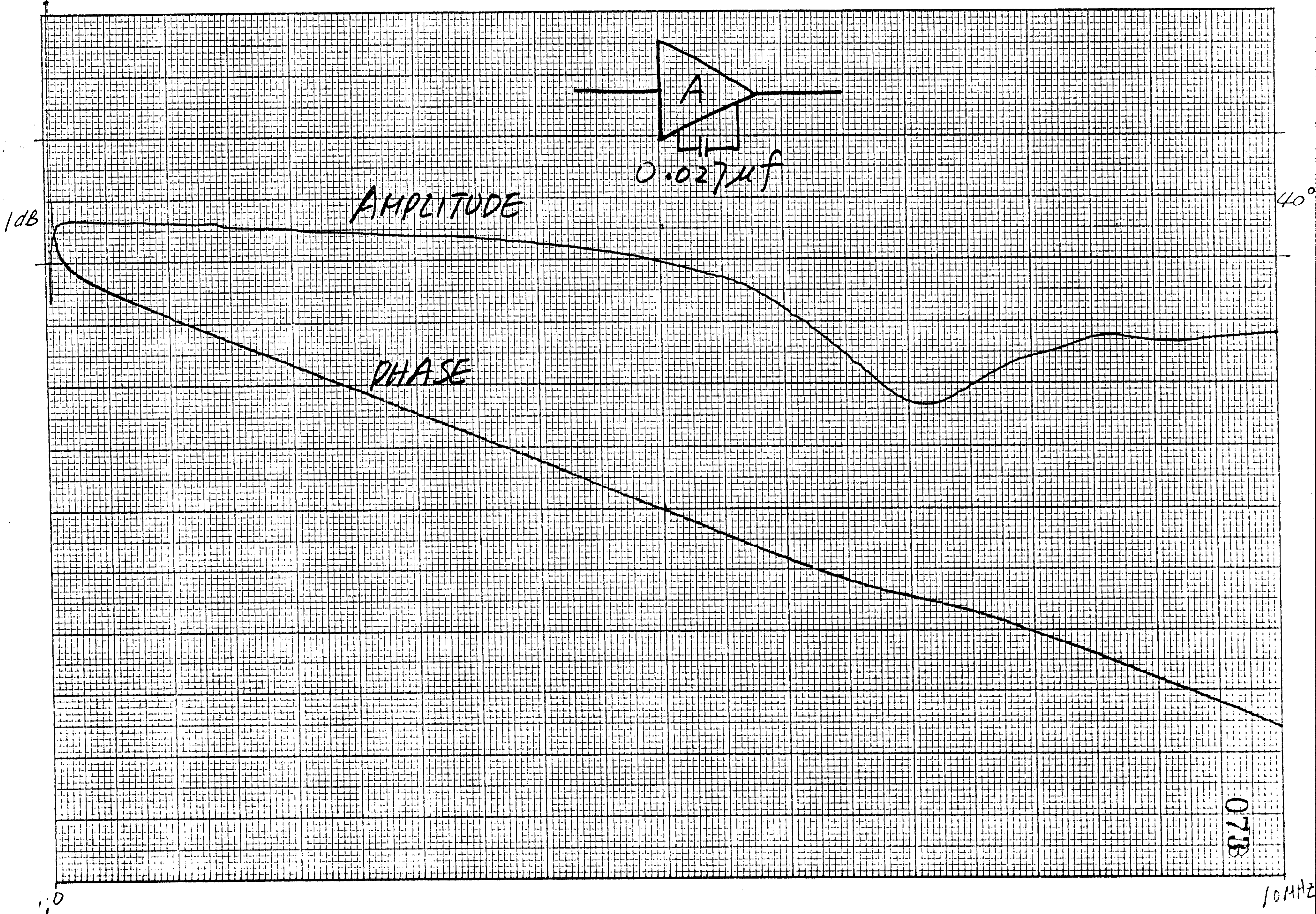
C = 0.01 μf

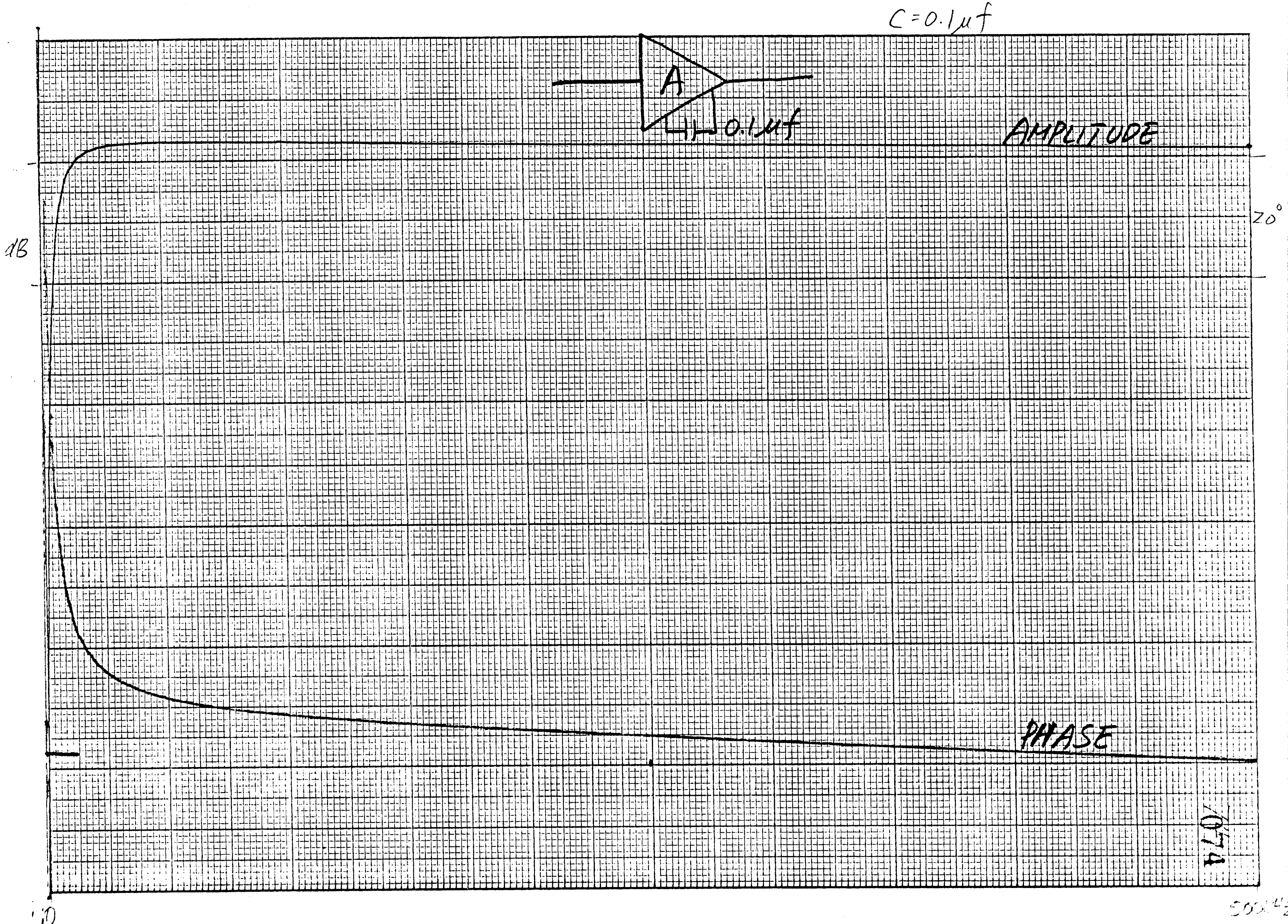


C=0.027



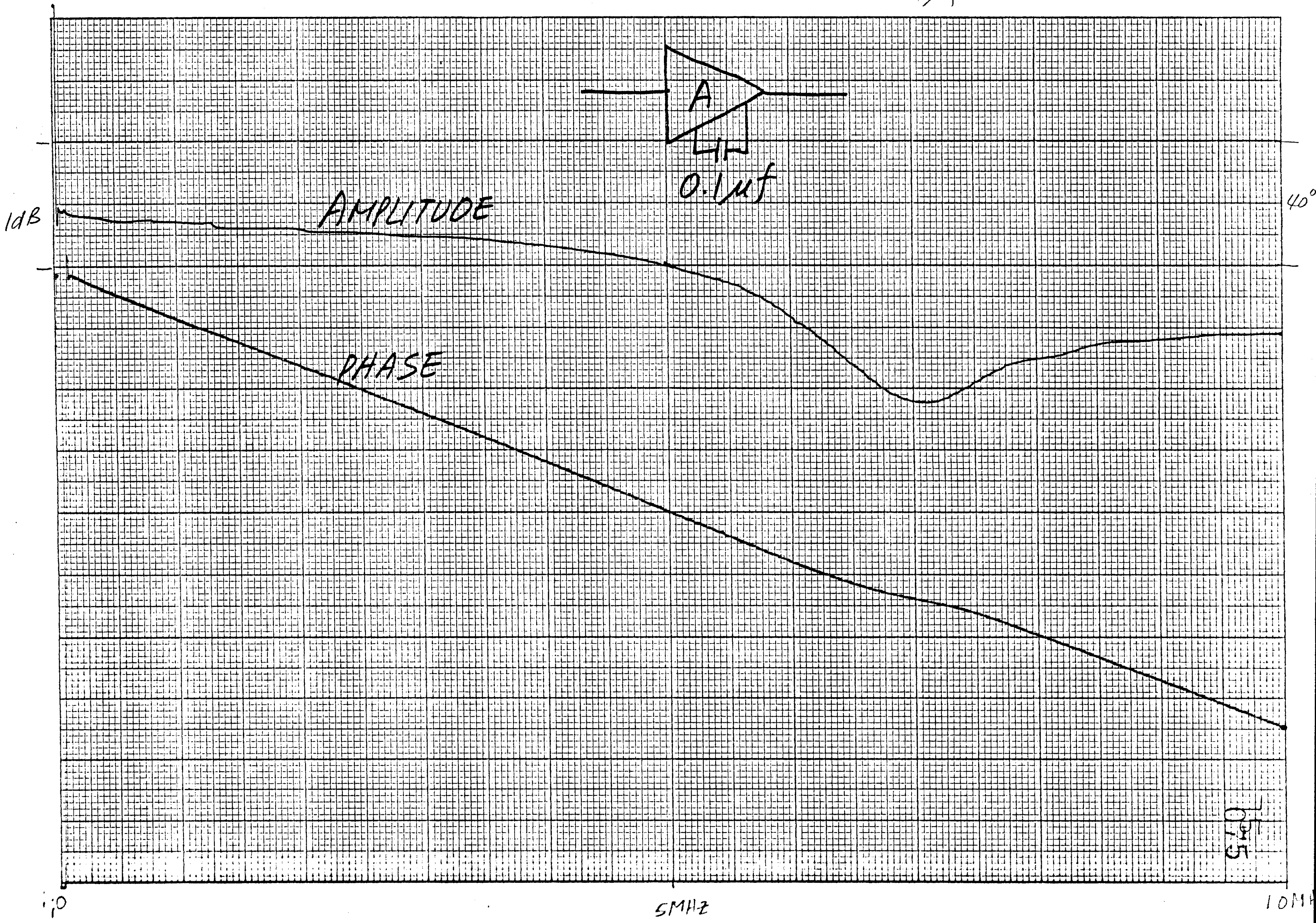
c =0.027µf

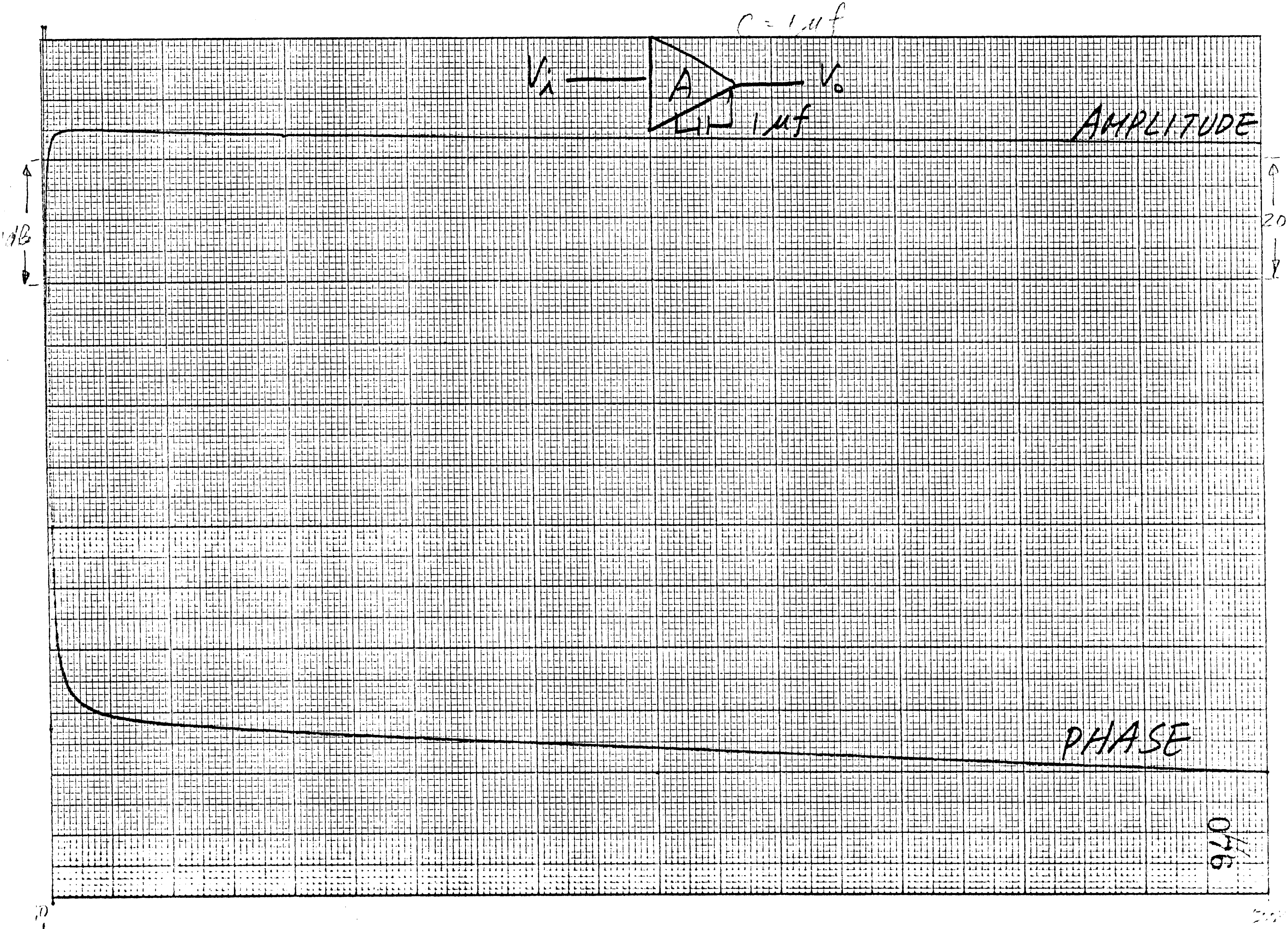



C=0.1µf
A
0.1µf
AMPLITUDE
dB
20°
PHASE
10
500Hz

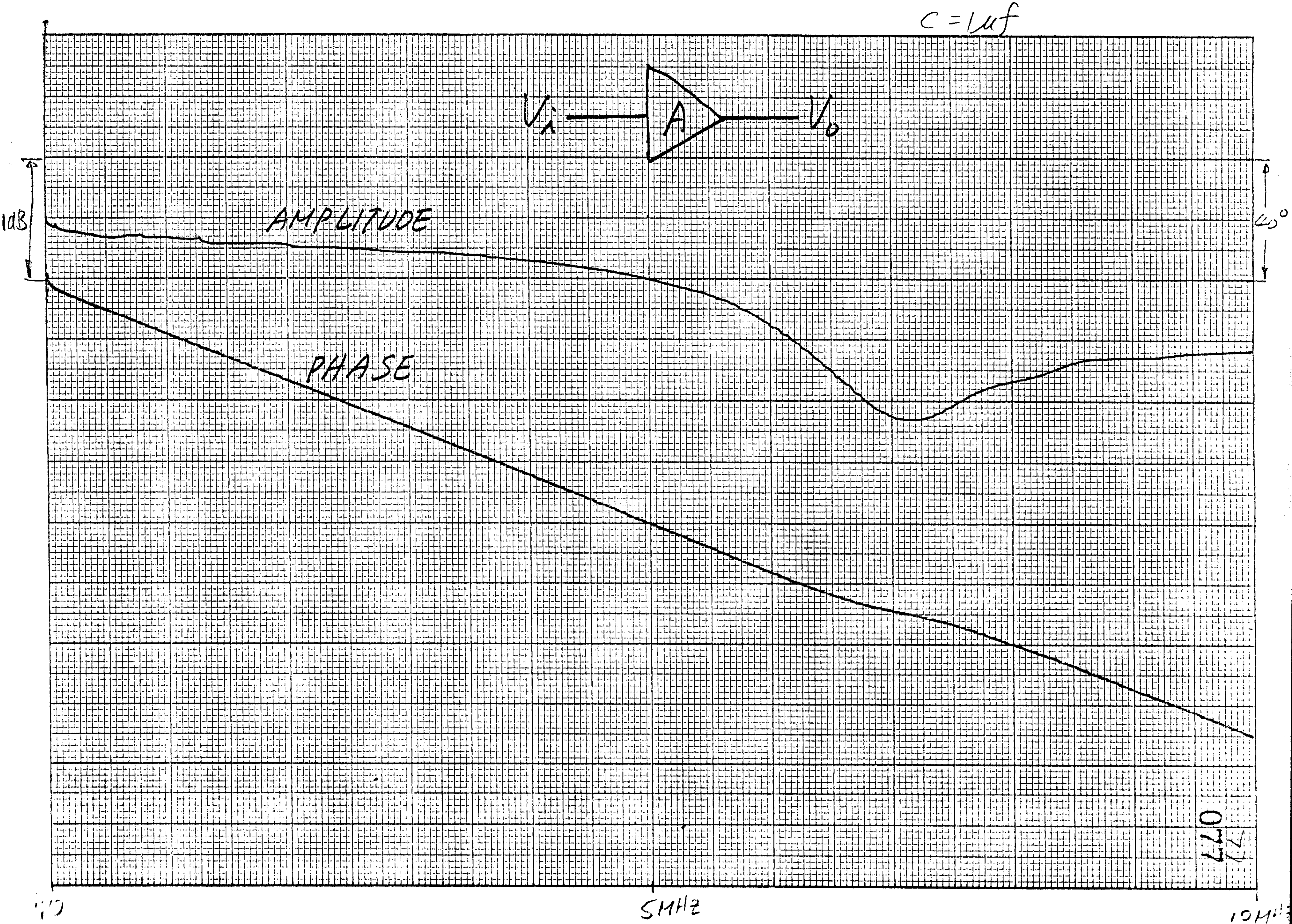
K+E 20 X 20 TO THE INCH 46 1240
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

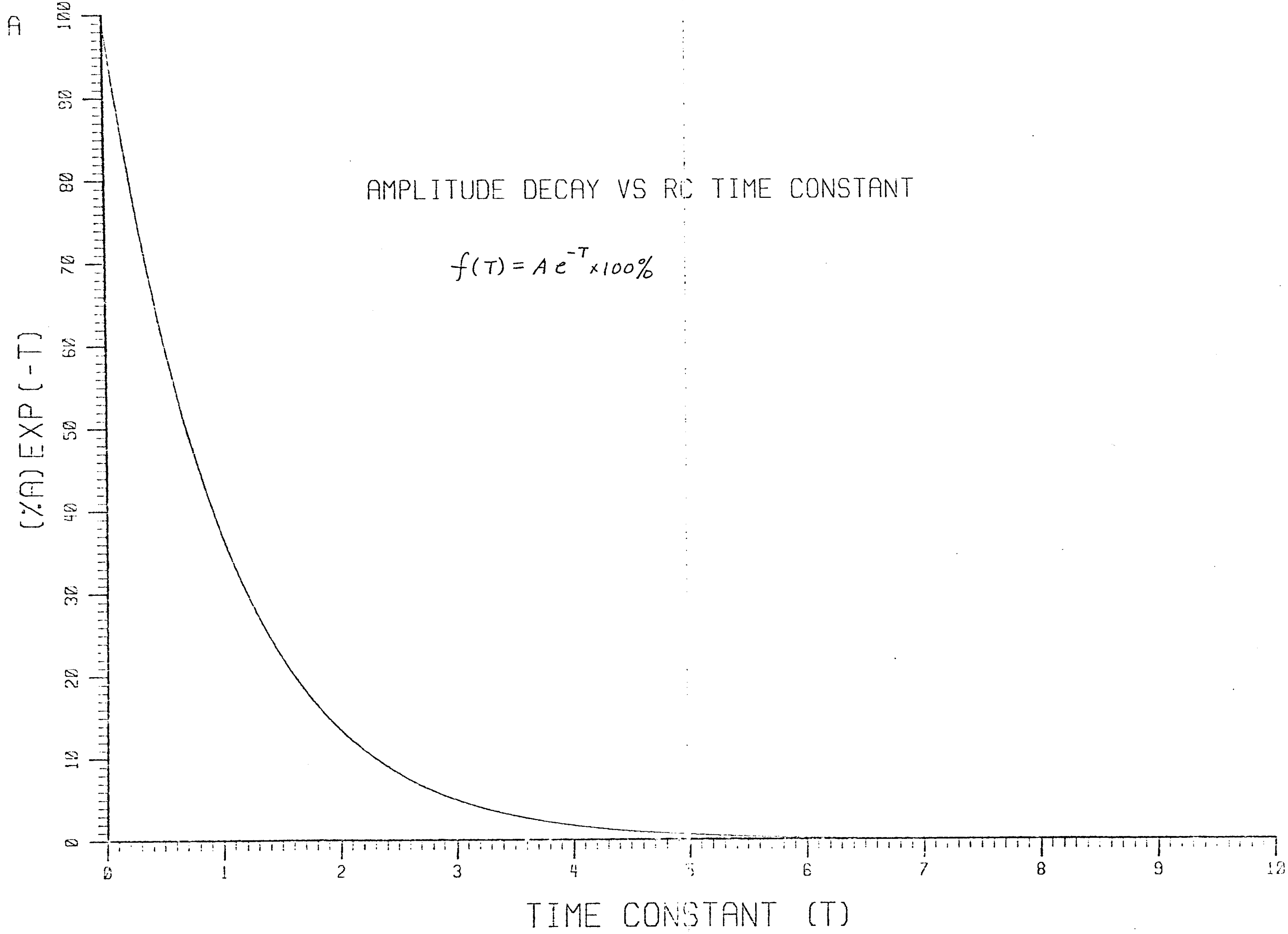
C = .1μf




C = 1uf
Vi
A
Vo
1uf
AMPLITUDE
dB
20°
PHASE
970

C = 1uf

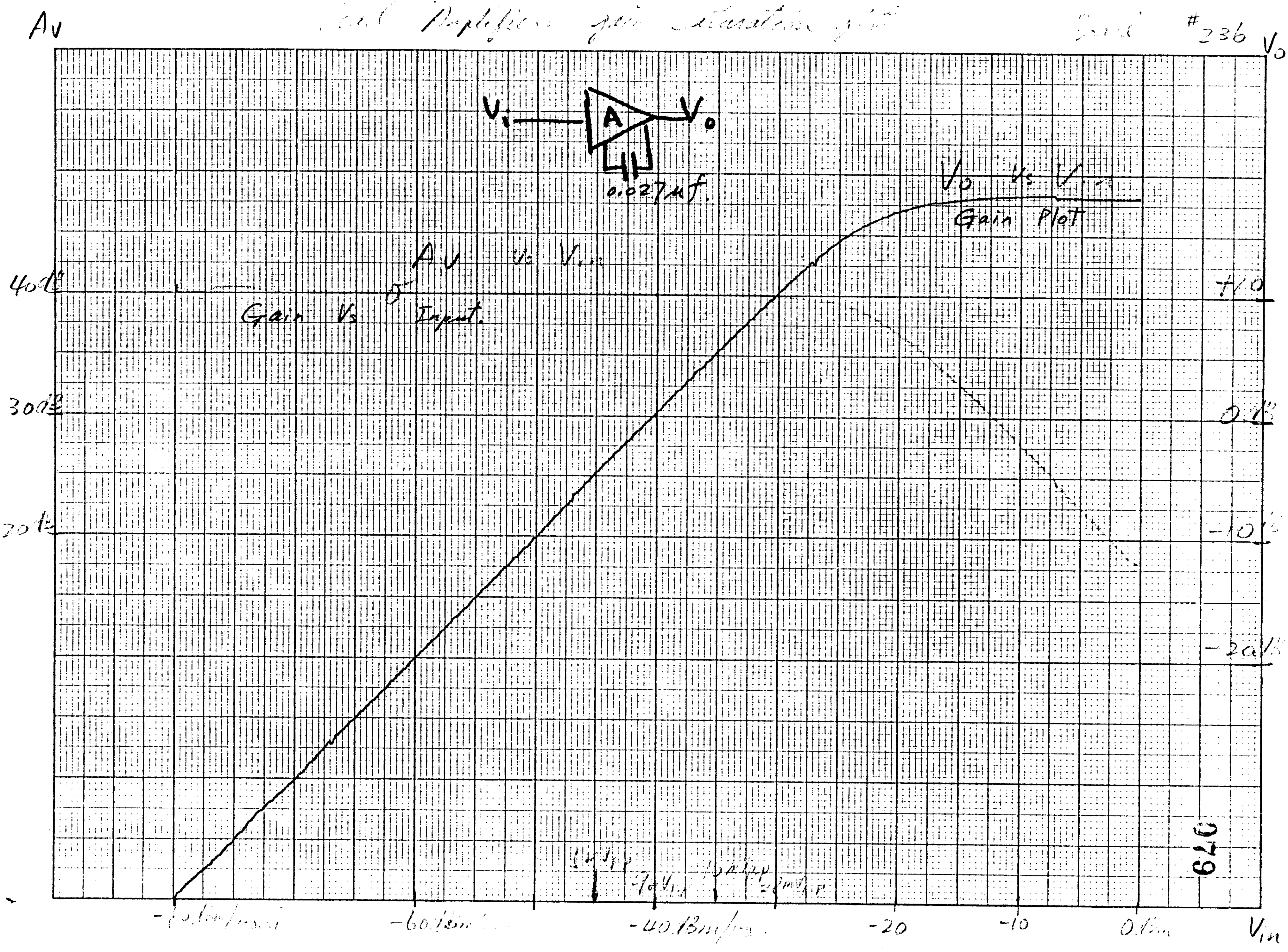




AMPLITUDE DECAY VS RC TIME CONSTANT

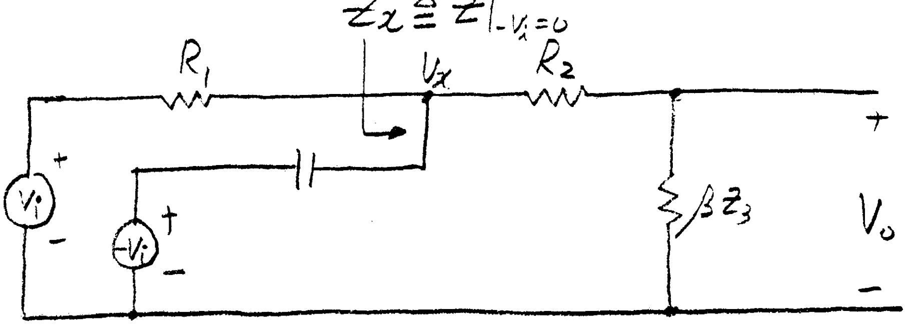
$f(T) = A e^{-T} \times 100\%$

[illegible] Amplifier gain saturation plot [illegible] #236



C-1. Derivation of ICM all pass filter transfer function:

Equivalent CKT:



$Z_3 \triangleq$ Input Impedance of Bessel filter

β = Forward current gain of transistor

Superposition:

$$Z_x = \frac{(\beta Z_3 + R_2)\frac{1}{SC}}{R_2 + \beta Z_3 + \frac{1}{SC}} = \frac{(\beta Z_3 + R_2)}{SC(\beta Z_3 + R_2) + 1}$$

$$V_x = V_i \frac{Z_x}{R_1 + Z_x} = \frac{\frac{\beta Z_3 + R_2}{(\beta Z_3 + R_2)SC + 1}}{R_1 + \frac{\beta Z_3 + R_2}{(\beta Z_3 + R_2)SC + 1}}$$

$$= \left(\frac{\beta Z_3 + R_2}{SCR_1(\beta Z_3 + R_2) + \beta Z_3 + R_1 + R_2}\right) V_i$$

$$V_o'\Big|_{-V_i=0} = V_x\left(\frac{\beta Z_3}{R_2 + \beta Z_3}\right) = V_i\left(\frac{\beta Z_3 + R_2}{SCR_1(\beta Z_3 + R_2) + \beta Z_3 + R_1 + R_2}\right)\left(\frac{\beta Z_3}{R_2 + \beta Z_3}\right)$$

$$= V_i\left(\frac{\beta Z_3}{SCR_1(\beta Z_3 + R_2) + \beta Z_3 + R_1 + R_2}\right)$$

$$V_o''\Big|_{V_i=0} = (-V_i)\left[\frac{\frac{(\beta Z_3 + R_2)R_1}{\beta Z_3 + R_1 + R_2}}{\frac{1}{SC} + \frac{(\beta Z_3 + R_2)R_1}{\beta Z_3 + R_1 + R_2}}\right]\left(\frac{\beta Z_3}{\beta Z_3 + R_2}\right)$$

$$= -V_i\left[\frac{SC(\beta Z_3 + R_2)R_1\beta Z_3}{\beta Z_3 + R_1 + R_2 + SCR_1(\beta Z_3 + R_2)(\beta Z_3 + R_2)}\right]$$

$$= -V_i\frac{SCR_1\beta Z_3}{SCR_1(\beta Z_3 + R_2) + \beta Z_3 + R_1 + R_2}$$

$$V_o = V_o' + V_o''$$

$$= V_i \left(\frac{\beta Z_3 - SCR_1 \beta Z_3}{SCR_1(\beta Z_3 + R_2) + \beta Z_3 + R_1 + R_2} \right)$$

$$= V_i \left(\frac{1 - SCR_1}{SCR\left(1 + \frac{R_2}{\beta Z_3}\right) + \frac{R_1 + R_2}{\beta Z_3} + 1} \right)$$

For SA 850 : $\beta \geqslant 100$, $R_1 = R_2 = 1000\,\Omega$

$Z_3 \simeq 1.5K // (1.5K + 1.5K)$ (In Passband of Bessel filter)

$= 1\,K\Omega$

$Z_3 \simeq 1.5K // 1.5K$ (In Stopband of Bessel filter)

$= 750\,\Omega$

The above transfer function can be simplified to

$$T(S) = \frac{V_o}{V_i} = \left(\frac{1 - SCR_1}{1 + SCR_1} \right)$$

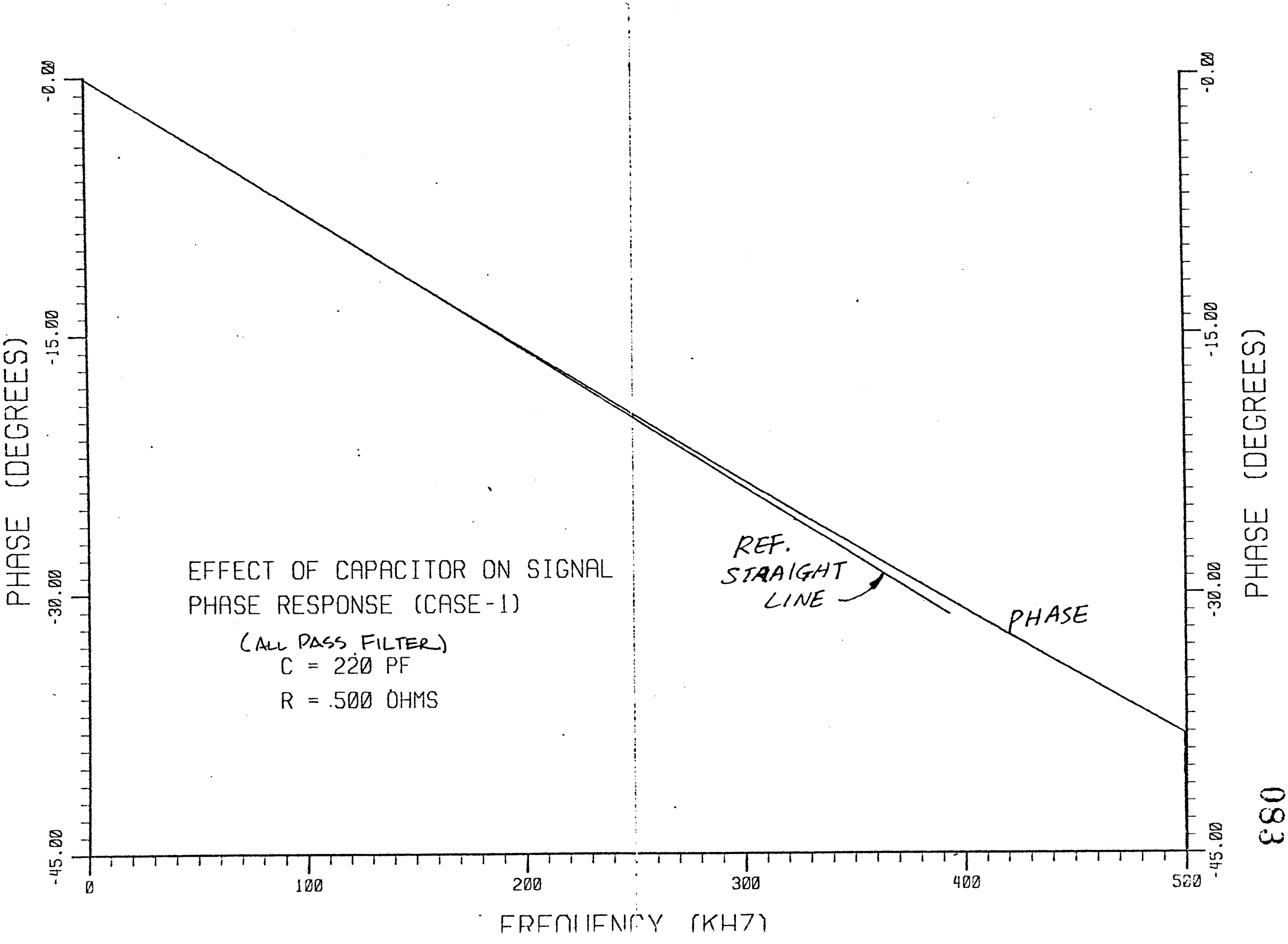
$$T(jw) = \frac{1 - jwCR_1}{1 + jwCR_1}$$

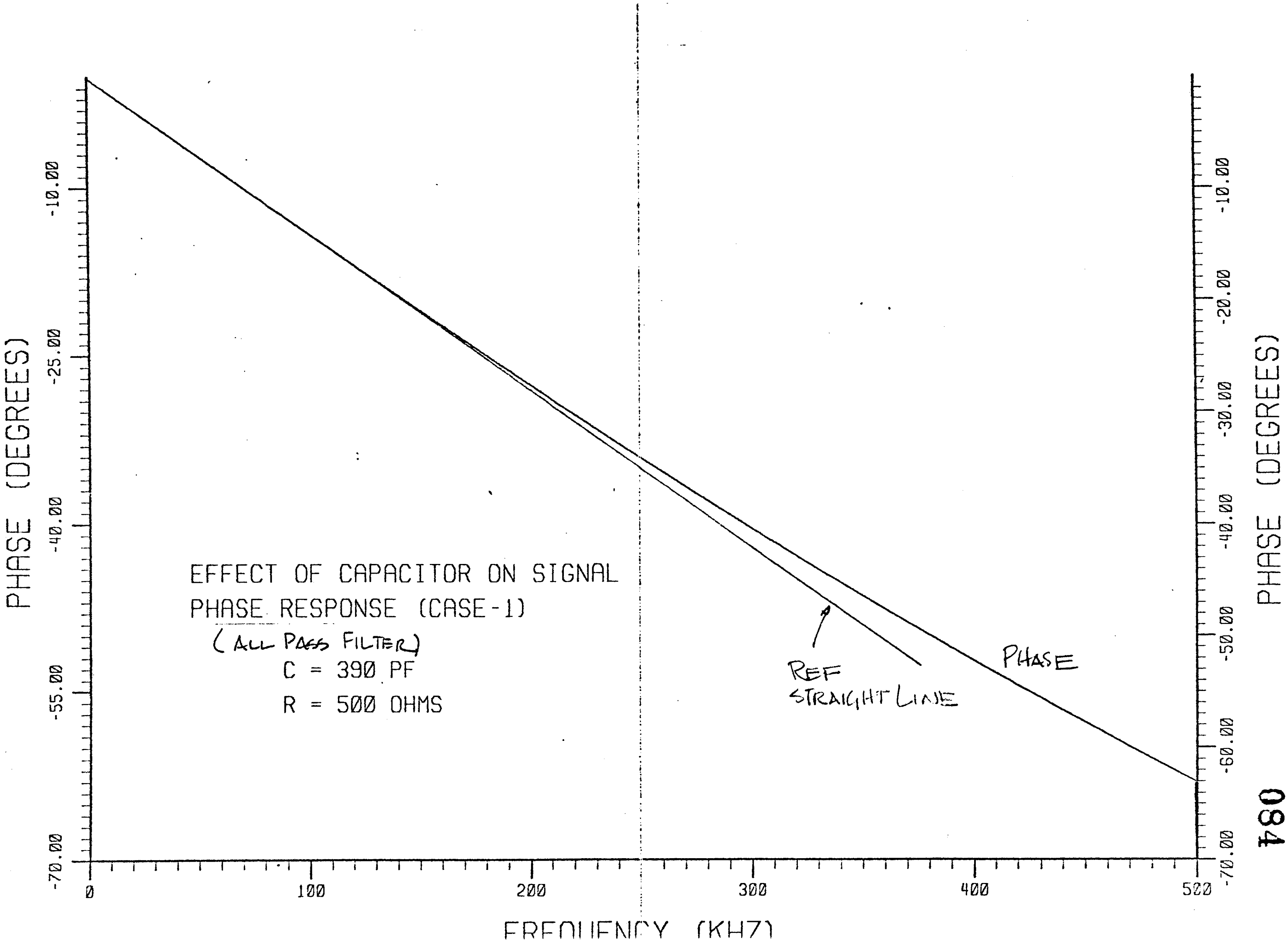
$$= \frac{\sqrt{1 + (wCR_1)^2} \angle -\tan^{-1} wCR_1}{\sqrt{(1 + wCR_1)^2} \angle \tan^{-1} wCR_1}$$

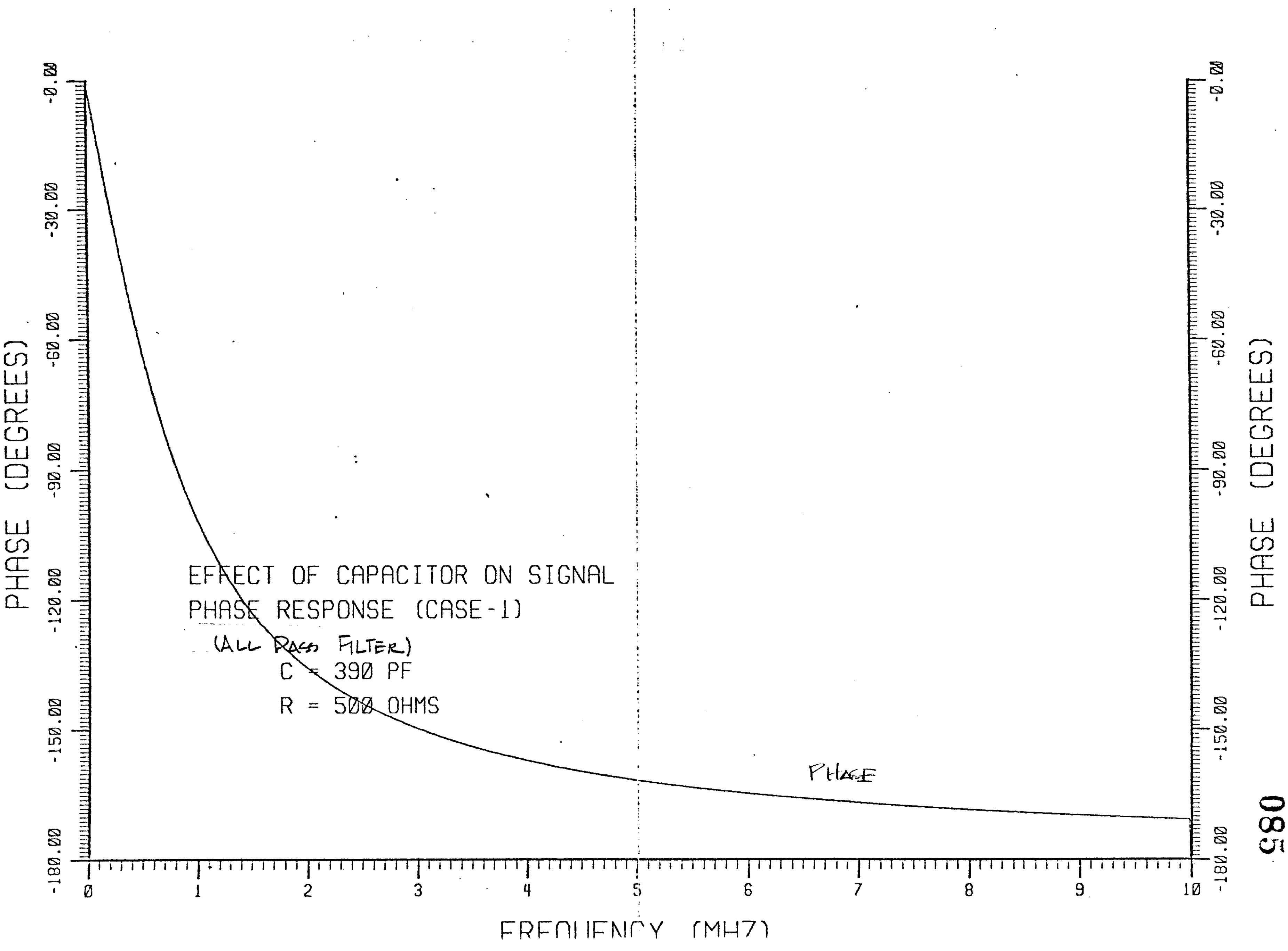
$$= -2 \tan^{-1} wCR_1$$

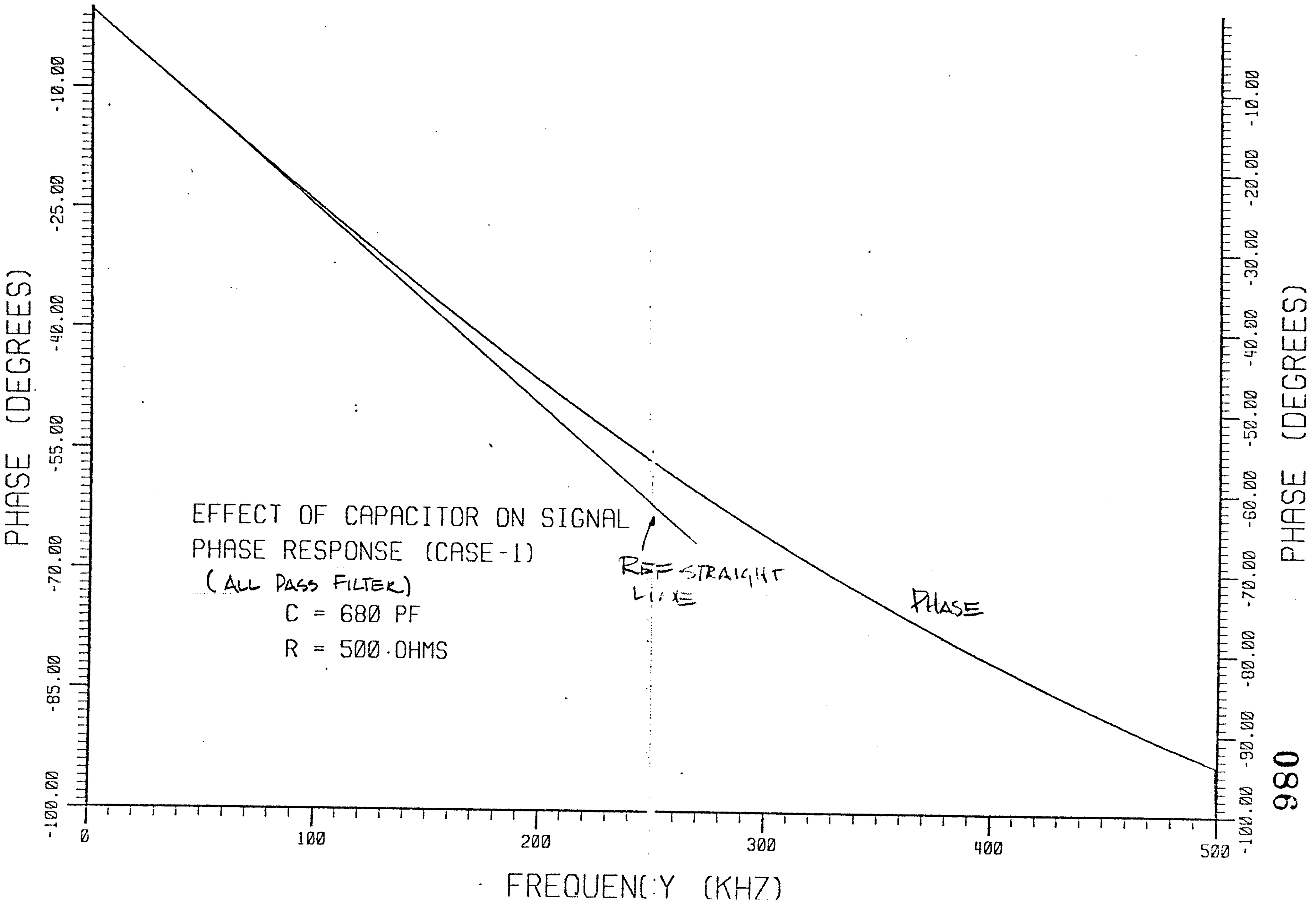
$$\boxed{T(j2\pi f) = \angle -2 \tan^{-1} 2\pi f CR_1}$$

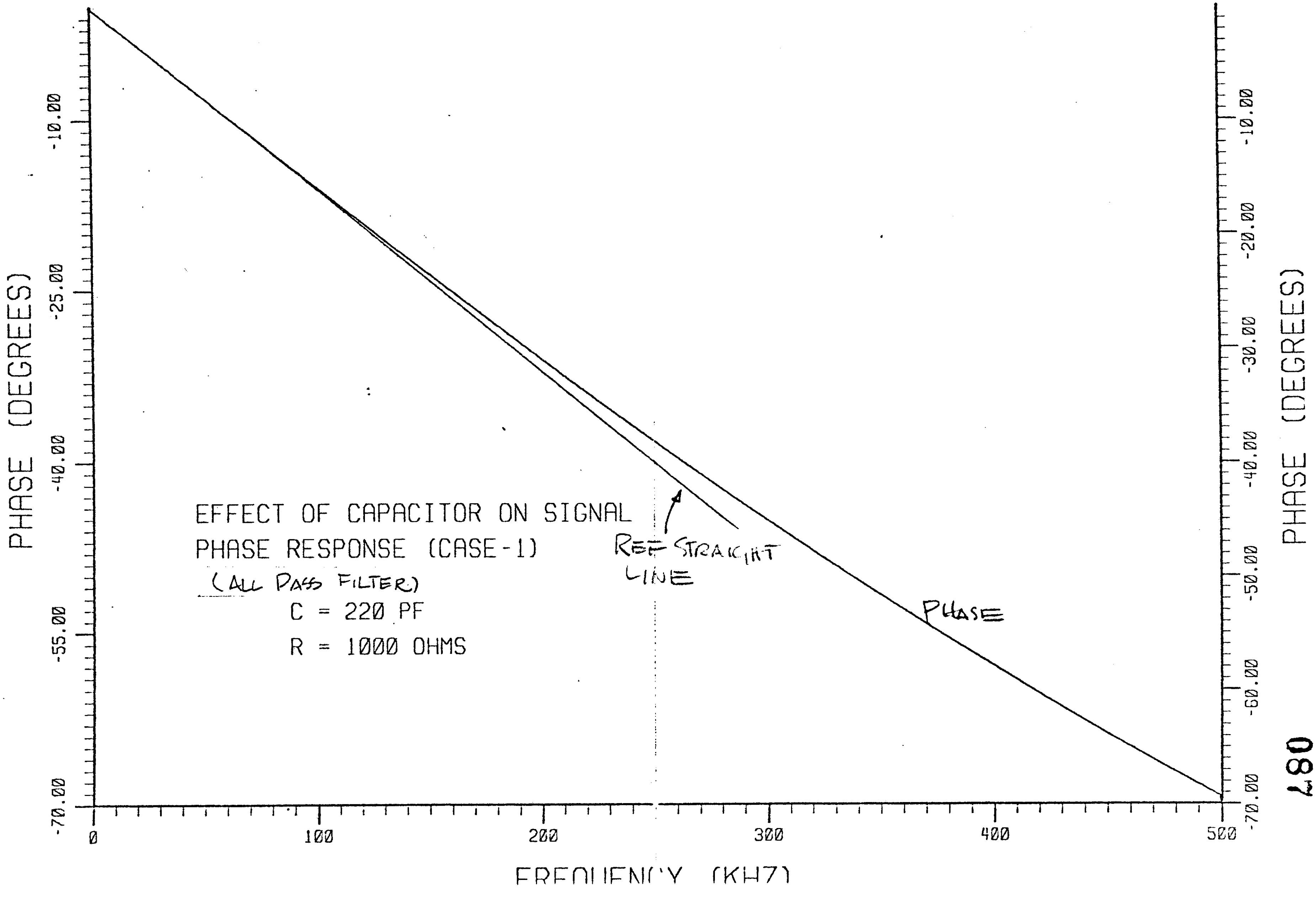
This is obvious an all pass function with magnitude of 1.

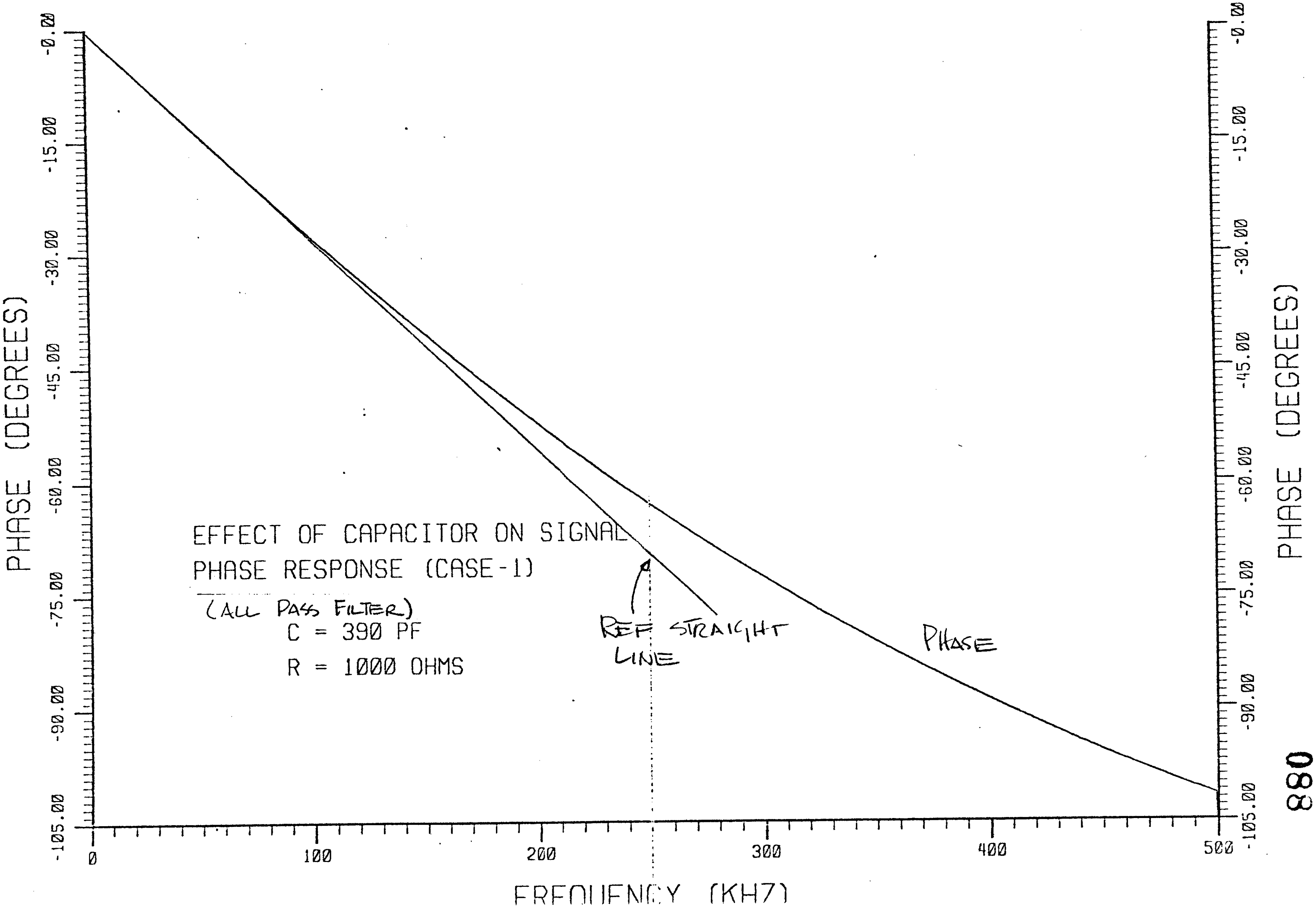

EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 220 PF
R = .500 OHMS
REF. STRAIGHT LINE
PHASE
PHASE (DEGREES)
-0.00
-15.00
-30.00
-45.00
0
100
200
300
400
500
FREQUENCY (KHZ)


EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 390 PF
R = 500 OHMS
REF
STRAIGHT LINE
PHASE
PHASE (DEGREES)
-10.00
-25.00
-40.00
-55.00
-70.00
PHASE (DEGREES)
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
0
100
200
300
400
500
FREQUENCY (KHZ)

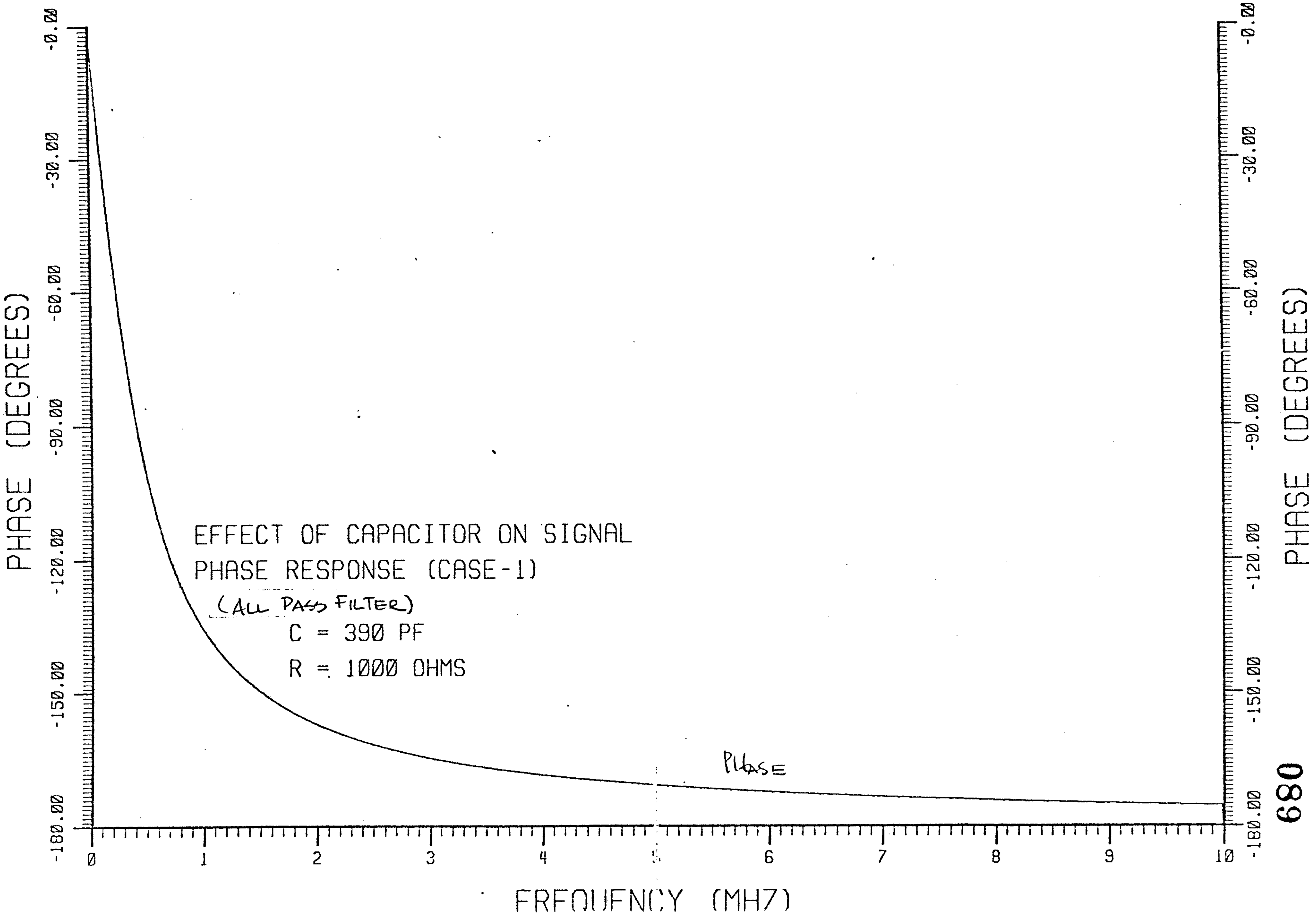

EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 390 PF
R = 500 OHMS
PHASE
PHASE (DEGREES)
-0.00
-30.00
-60.00
-90.00
-120.00
-150.00
-180.00
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY (MHZ)

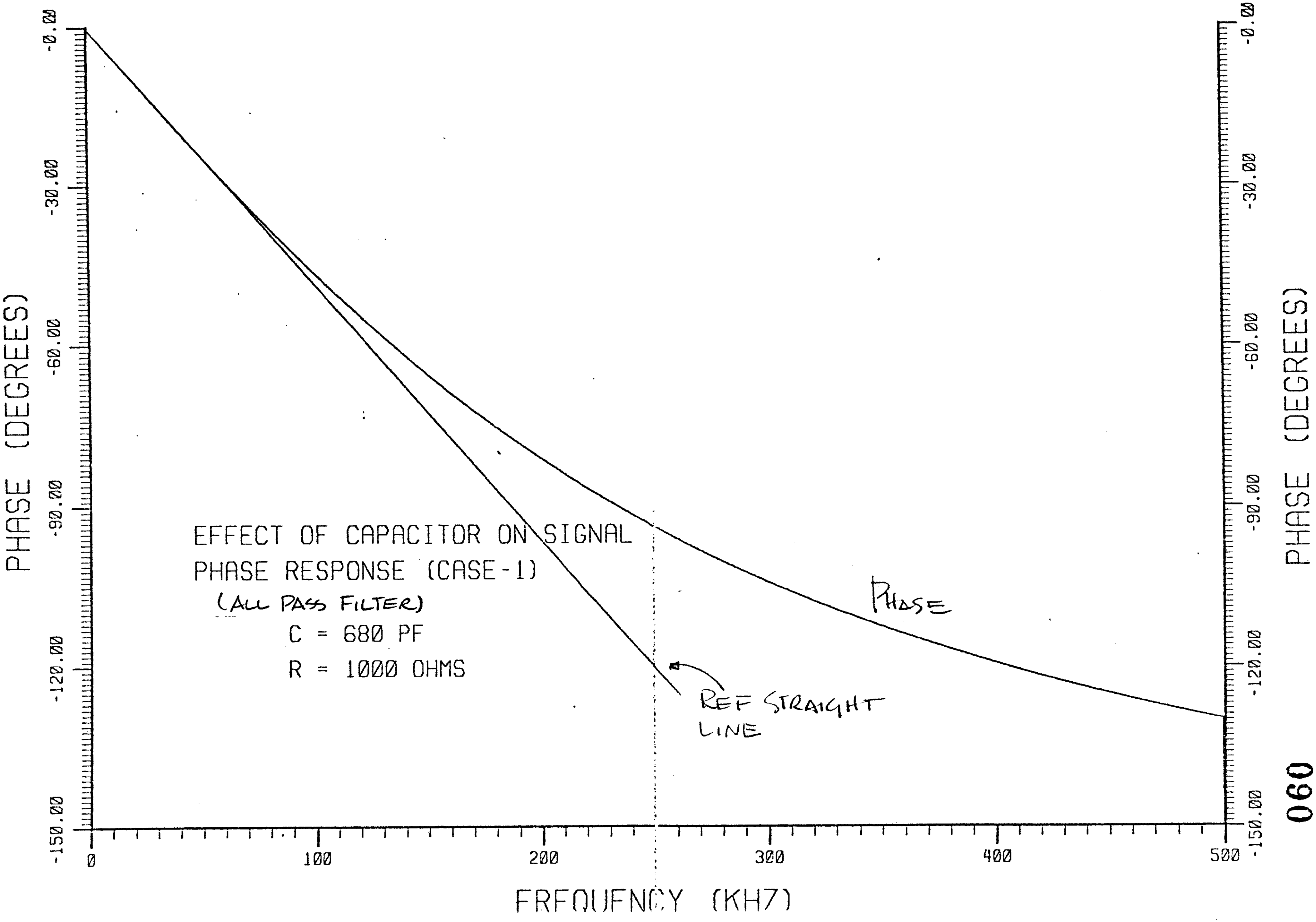

EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 680 PF
R = 500 OHMS
REF STRAIGHT LINE
PHASE
PHASE (DEGREES)
-10.00
-25.00
-40.00
-55.00
-70.00
-85.00
-100.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
-90.00
-100.00
0
100
200
300
400
500
FREQUENCY (KHZ)

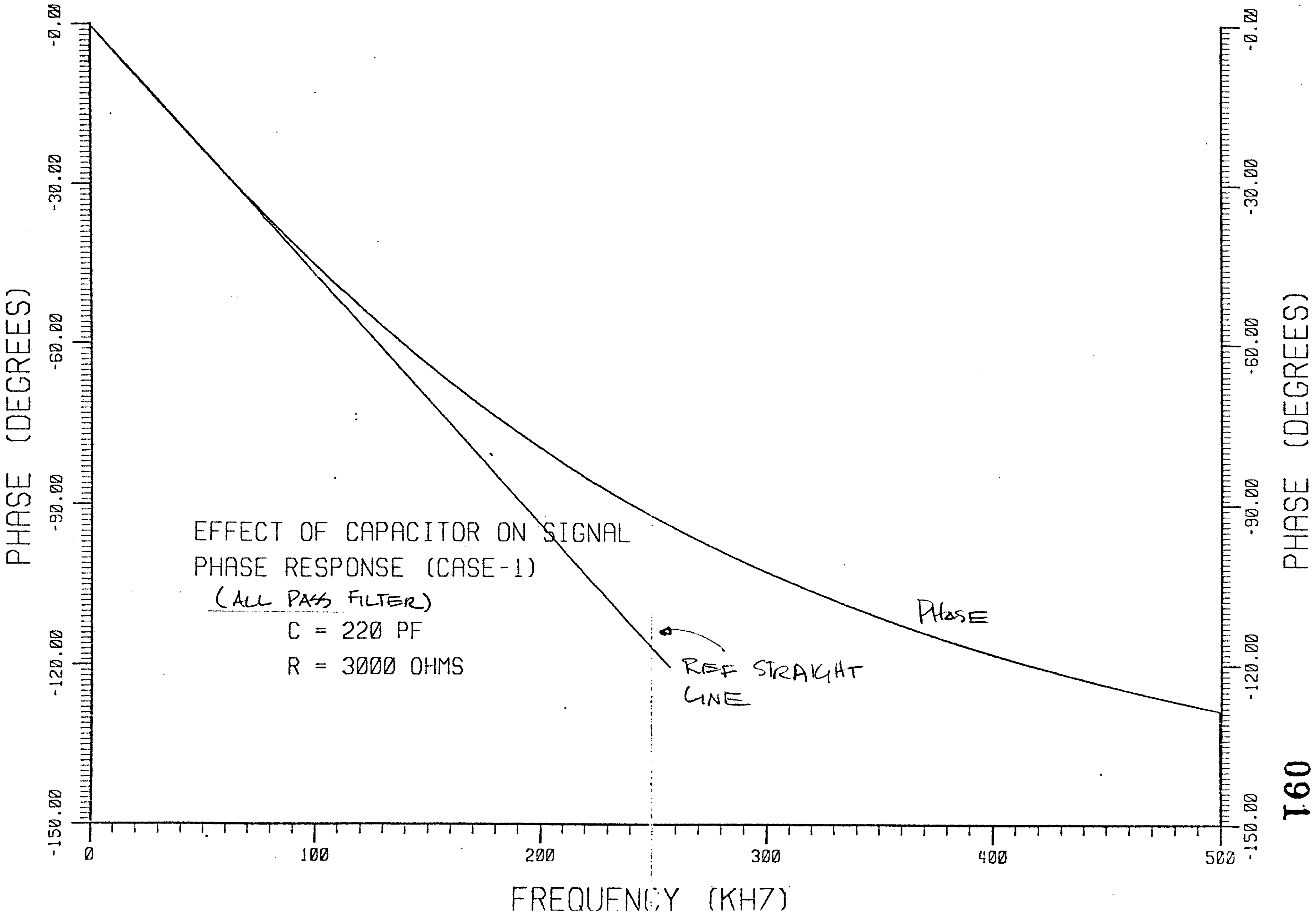

EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 220 PF
R = 1000 OHMS
REF STRAIGHT LINE
PHASE
PHASE (DEGREES)
-10.00
-25.00
-40.00
-55.00
-70.00
PHASE (DEGREES)
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
0
100
200
300
400
500
FREQUENCY (KHZ)

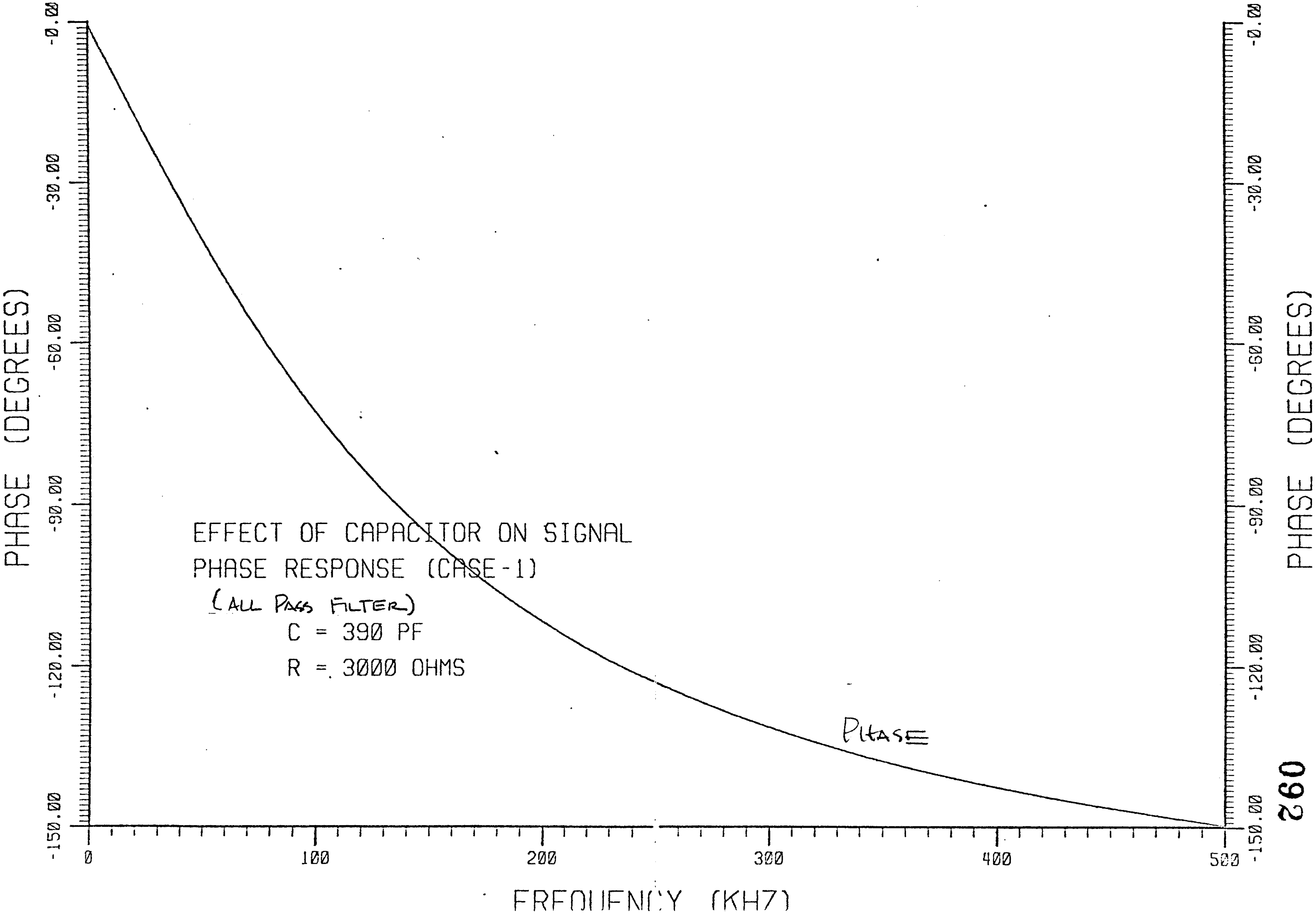


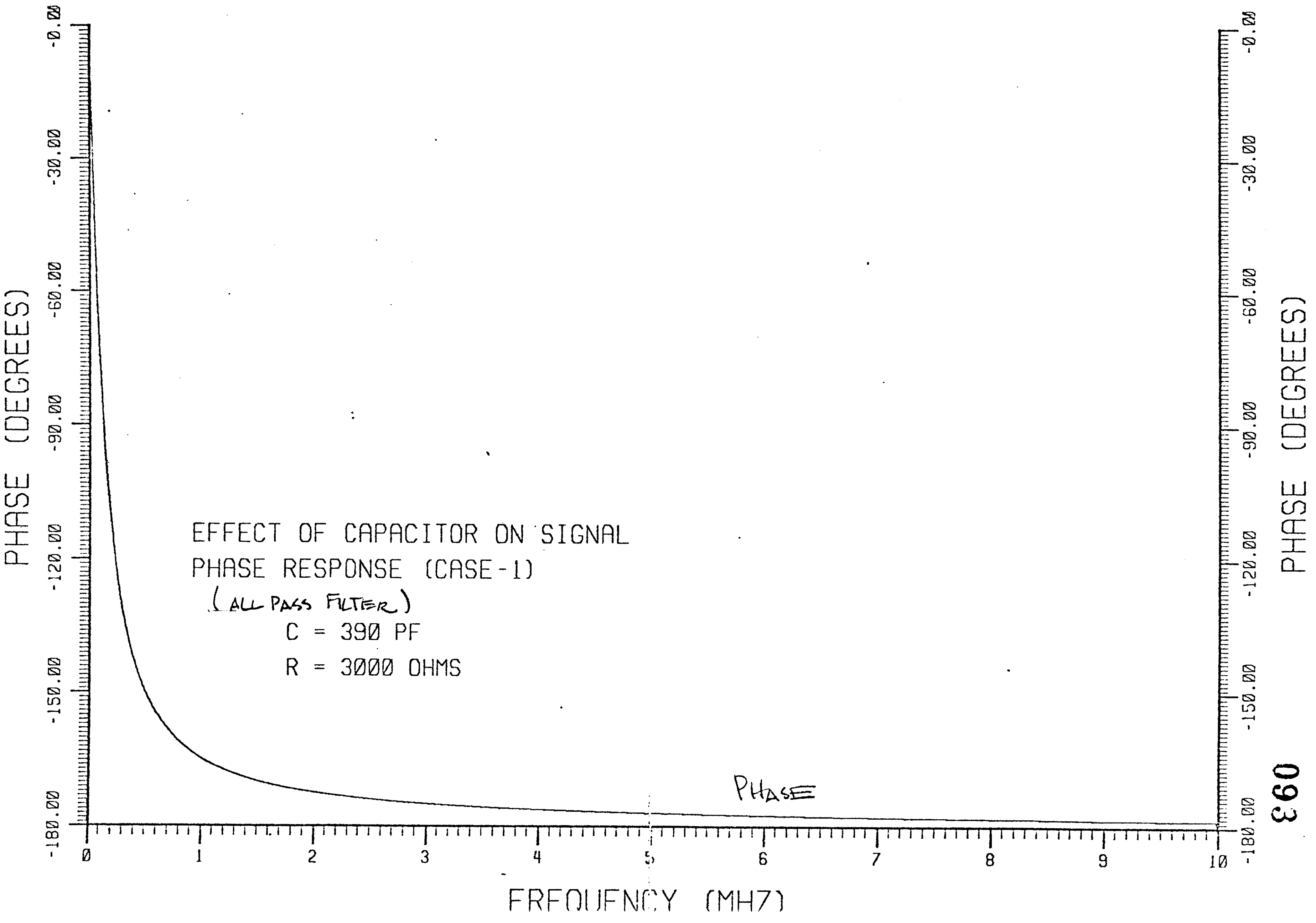
EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 390 PF
R = 1000 OHMS


EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 390 PF
R = 1000 OHMS
PHASE
PHASE (DEGREES)
-0.00
-30.00
-60.00
-90.00
-120.00
-150.00
-180.00
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY (MHZ)

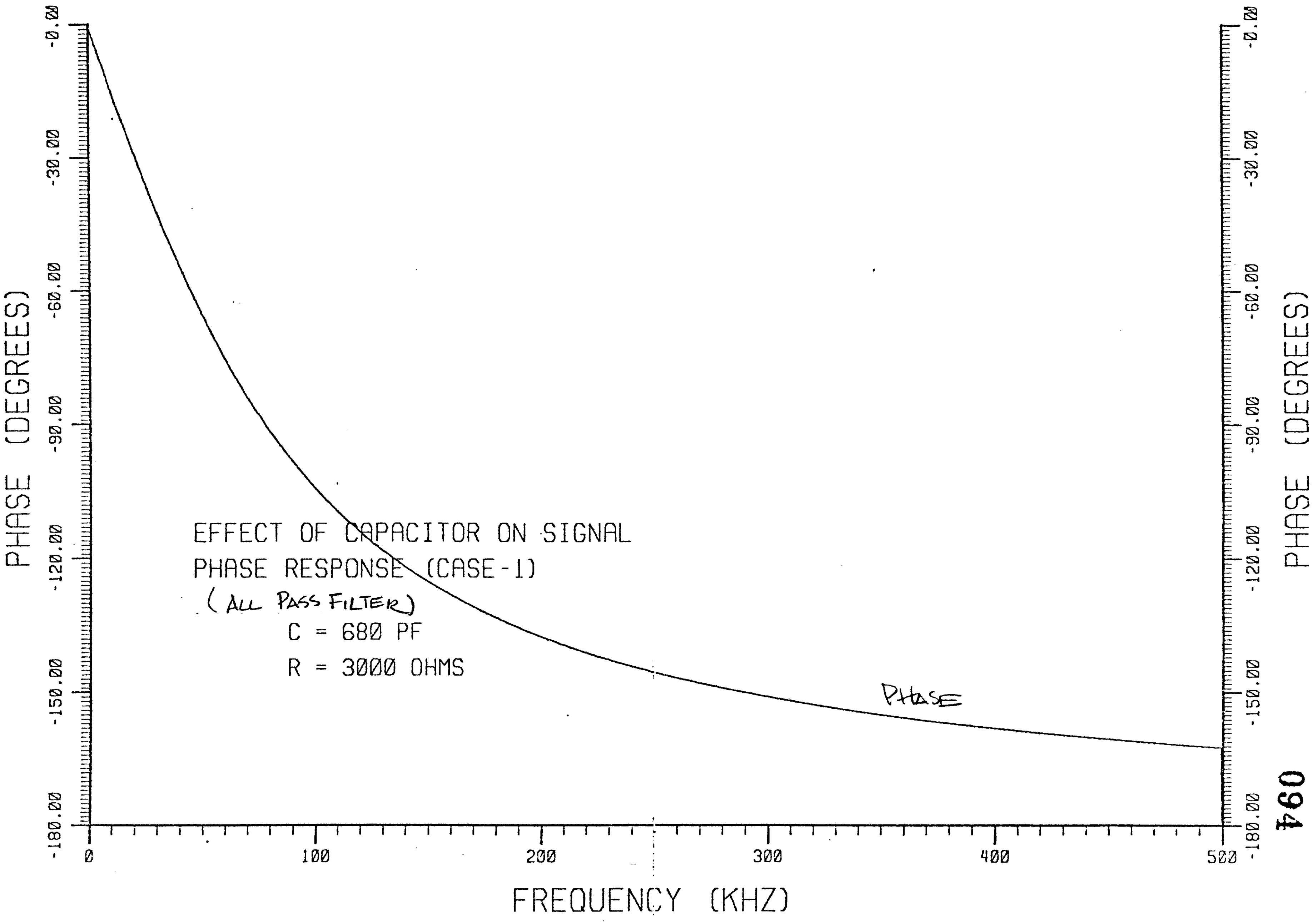

EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 680 PF
R = 1000 OHMS
PHASE
REF STRAIGHT LINE
PHASE (DEGREES)
-0.00
-30.00
-60.00
-90.00
-120.00
-150.00
FREQUENCY (KHZ)
0
100
200
300
400
500


EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 220 PF
R = 3000 OHMS
REF STRAIGHT LINE
PHASE
PHASE (DEGREES)
-0.00
-30.00
-60.00
-90.00
-120.00
-150.00
0
100
200
300
400
500
FREQUENCY (KHZ)

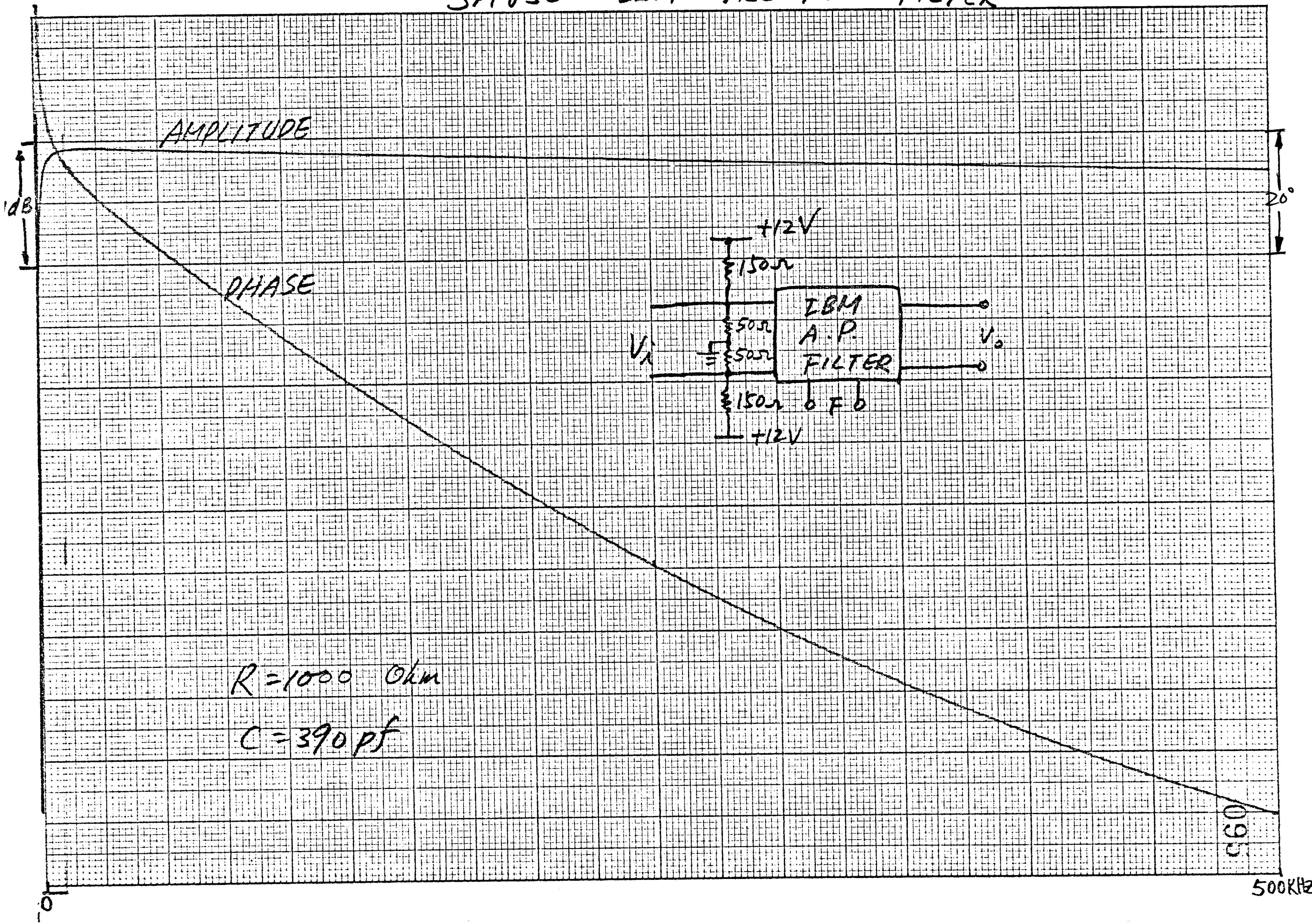

EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 390 PF
R = 3000 OHMS
PHASE
PHASE (DEGREES)
PHASE (DEGREES)
-0.00
-30.00
-60.00
-90.00
-120.00
-150.00
0
100
200
300
400
500
FREQUENCY (KHZ)



EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 390 PF
R = 3000 OHMS


EFFECT OF CAPACITOR ON SIGNAL
PHASE RESPONSE (CASE-1)
(ALL PASS FILTER)
C = 680 PF
R = 3000 OHMS
PHASE
PHASE (DEGREES)
-0.00
-30.00
-60.00
-90.00
-120.00
-150.00
-180.00
0
100
200
300
400
500
FREQUENCY (KHZ)

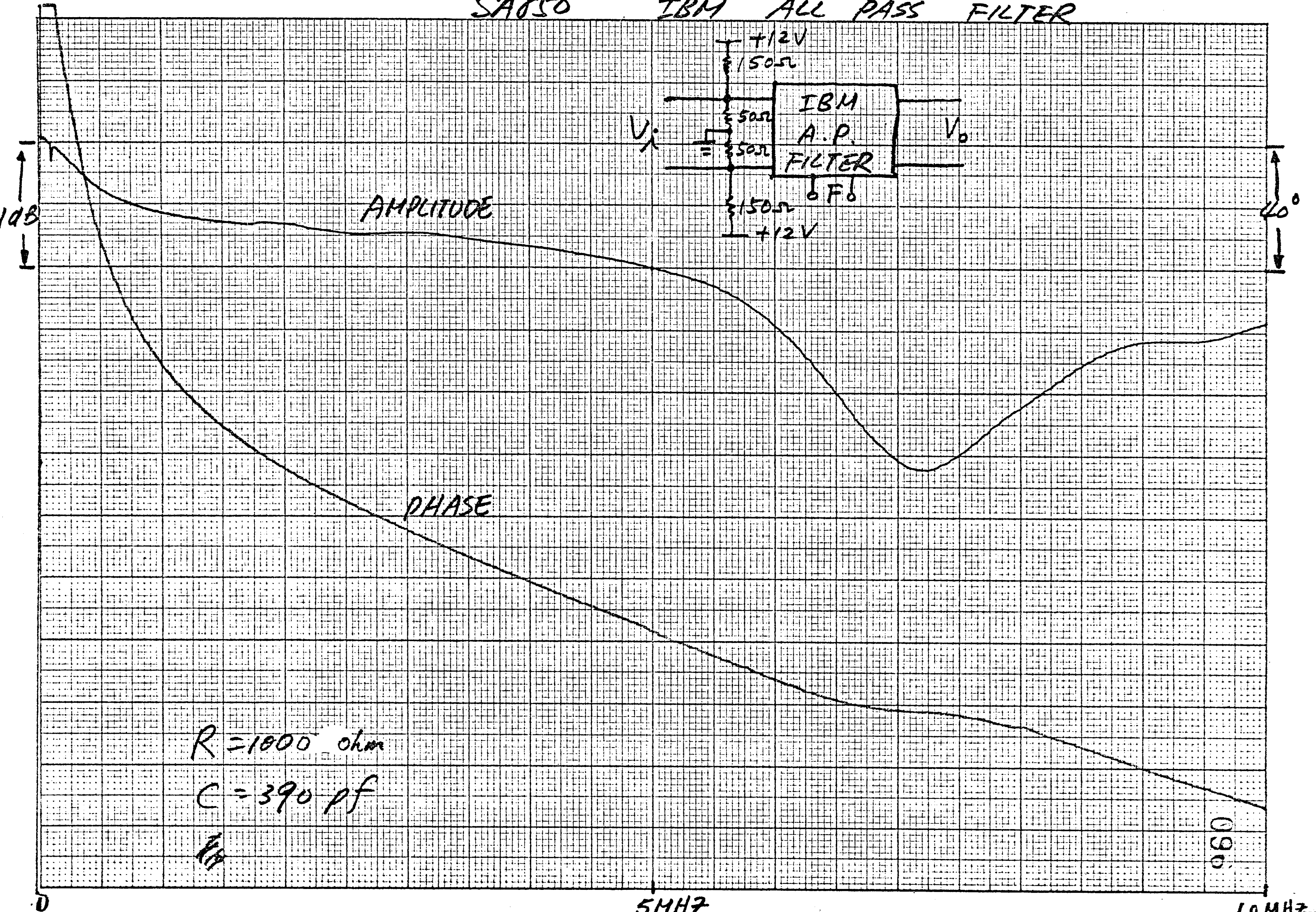
SA850 IBM ALL PASS FILTER



R=1000 Ohm

C=390pf

SA850 IBM ALL PASS FILTER

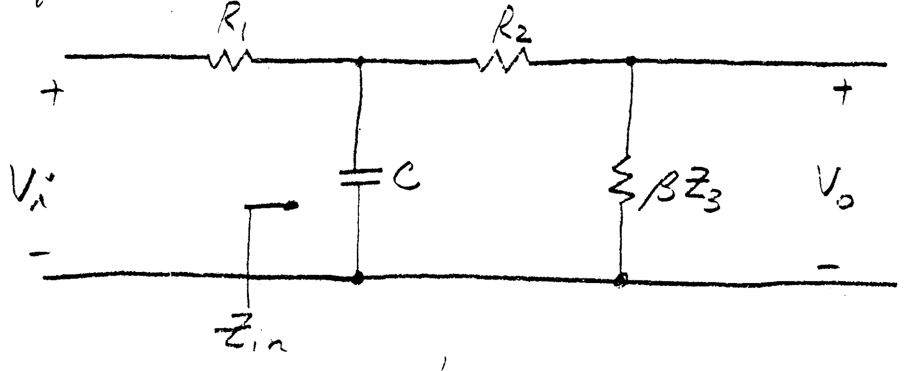


R = 1000 ohm

C = 390 pf

C-4. Derivation of IBM low pass filter transfer function:

Equivalent CKT:



$\beta \geq 100$

Z_3 = Bessel filter input impedance

$$Z_{in} = R_1 + \frac{\frac{1}{SC}\beta Z_3}{\frac{1}{SC} + \beta Z_3}$$

$$= R_1 + \frac{\beta Z_3}{1+\beta Z_3 SC}$$

$$= \frac{R_1(1+\beta Z_3 SC)+\beta Z_3}{1+\beta Z_3 SC}$$

$$T(s) = \frac{V_o}{V_{in}} = \frac{\frac{\beta Z_3}{1+\beta Z_3 SC}}{Z_{in}}$$

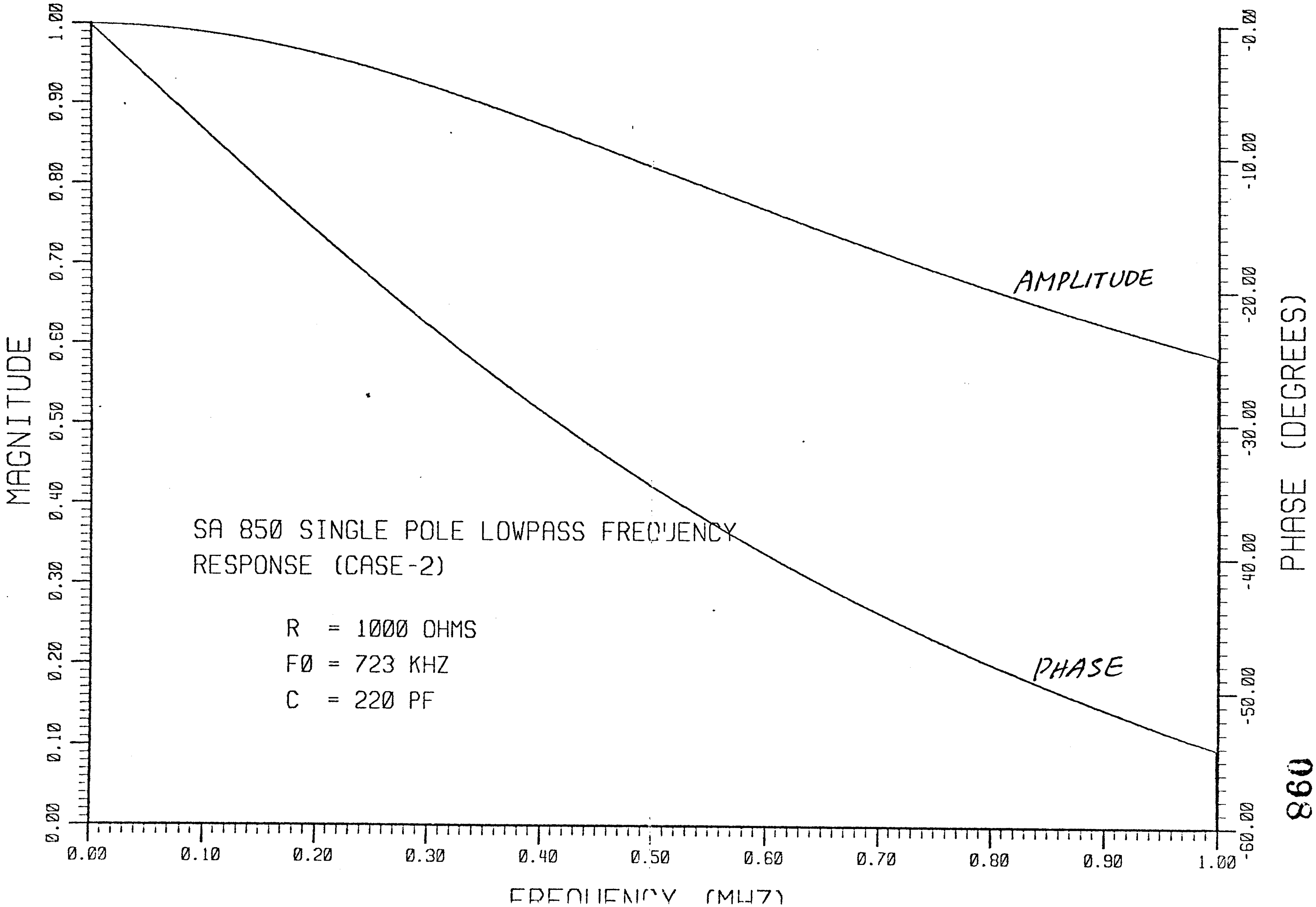
$$T(S) = \frac{\beta Z_3}{R_1(1+\beta Z_3 SC)+\beta Z_3}$$

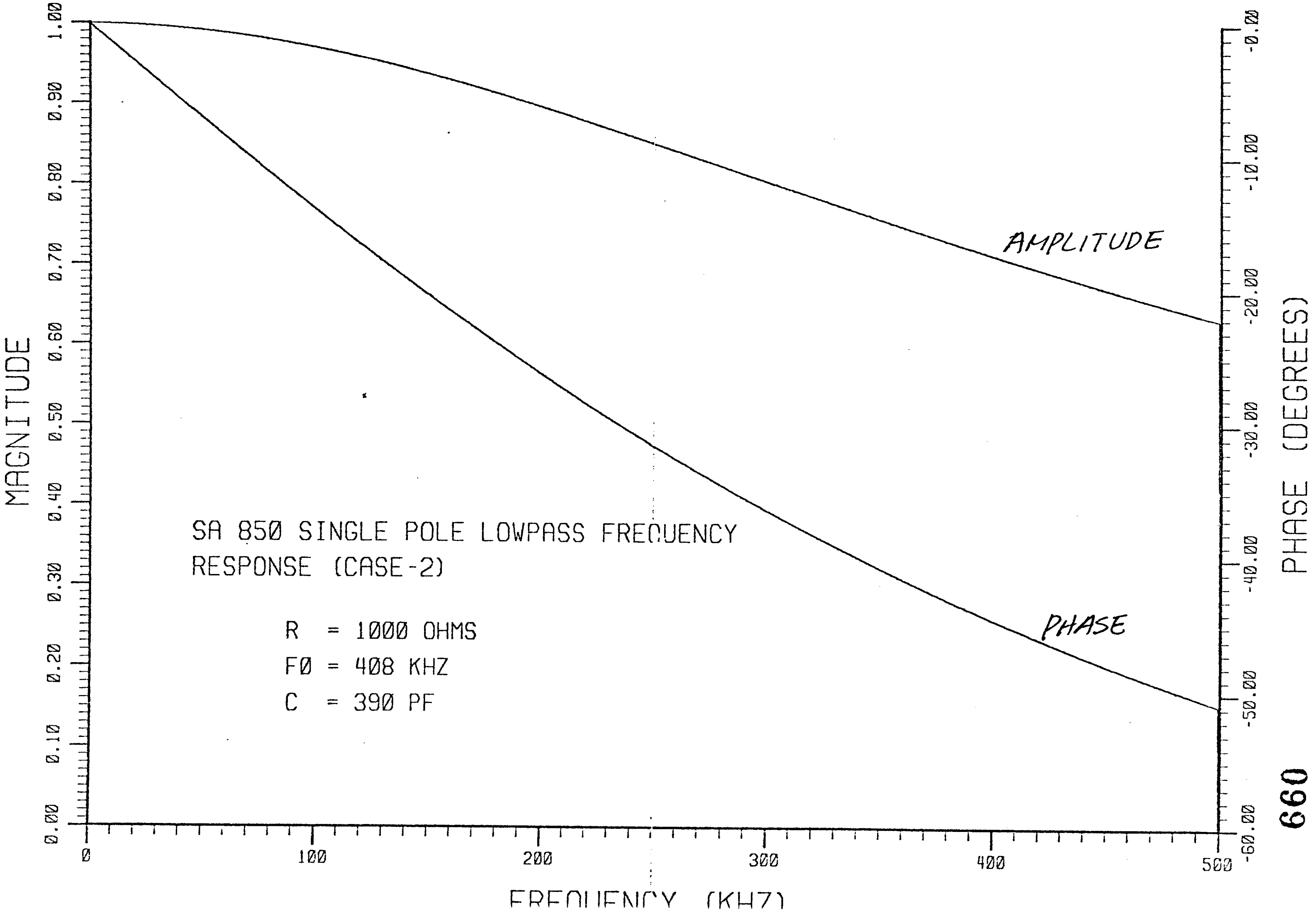
$$= \frac{\beta Z_3}{SC\beta Z_3 R_1 + R_1 + \beta Z_3}$$

$$= \frac{1}{SCR_1 + 1} \qquad (\beta Z_1 >> R_1)$$

$$T(j\omega) = \frac{1}{CR_1}\,\frac{1}{\sqrt{W^2+(\frac{1}{CR_1})^2}} \angle -\tan^{-1} 2\pi f C R_1$$

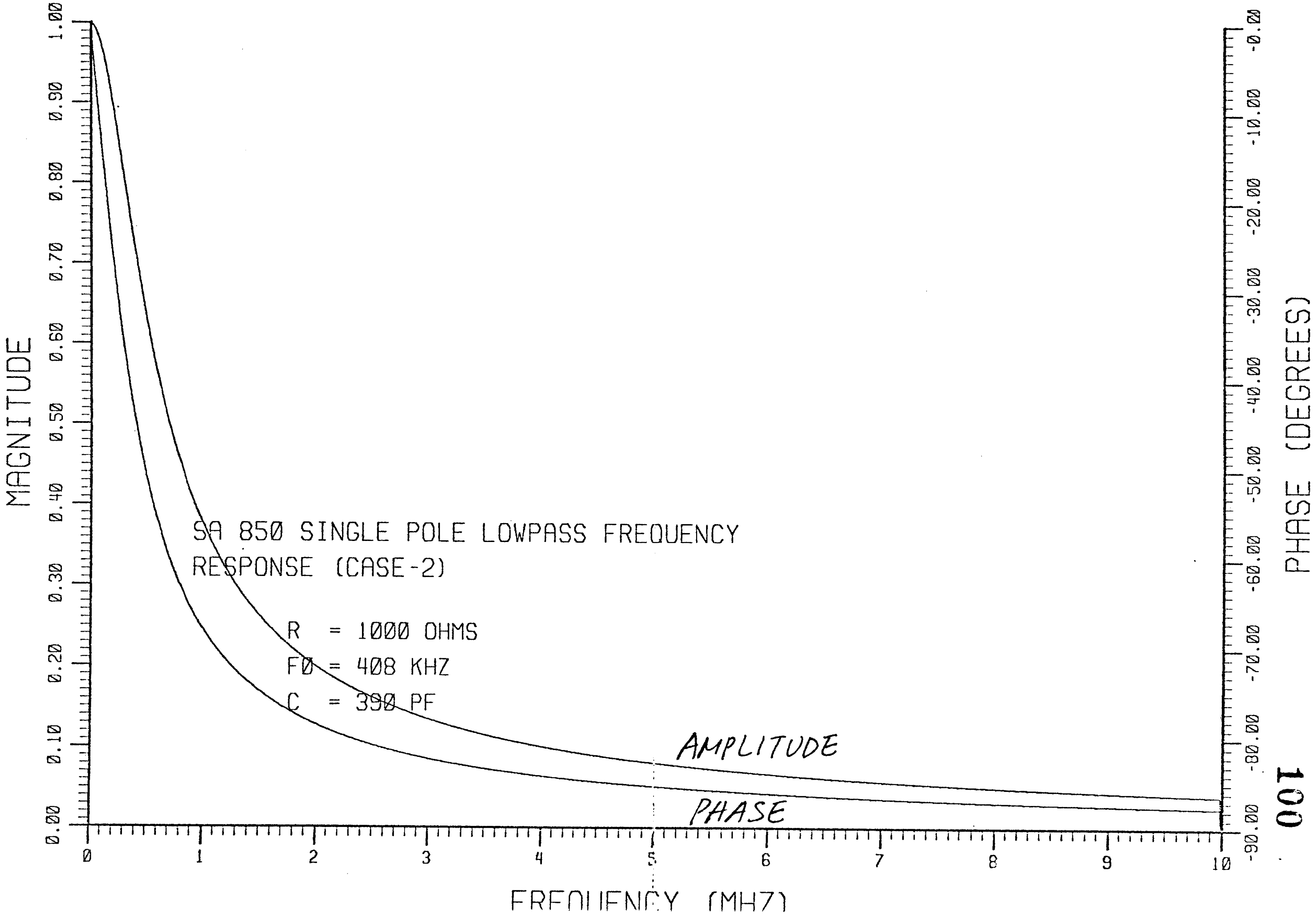
$$\boxed{T(j2\pi f) = \frac{1}{CR_1}\,\frac{1}{\sqrt{(2\pi f)^2+(\frac{1}{CR_1})^2}} \angle -\tan^{-1} 2\pi f C R_1} \qquad \text{(L.P. function}$$

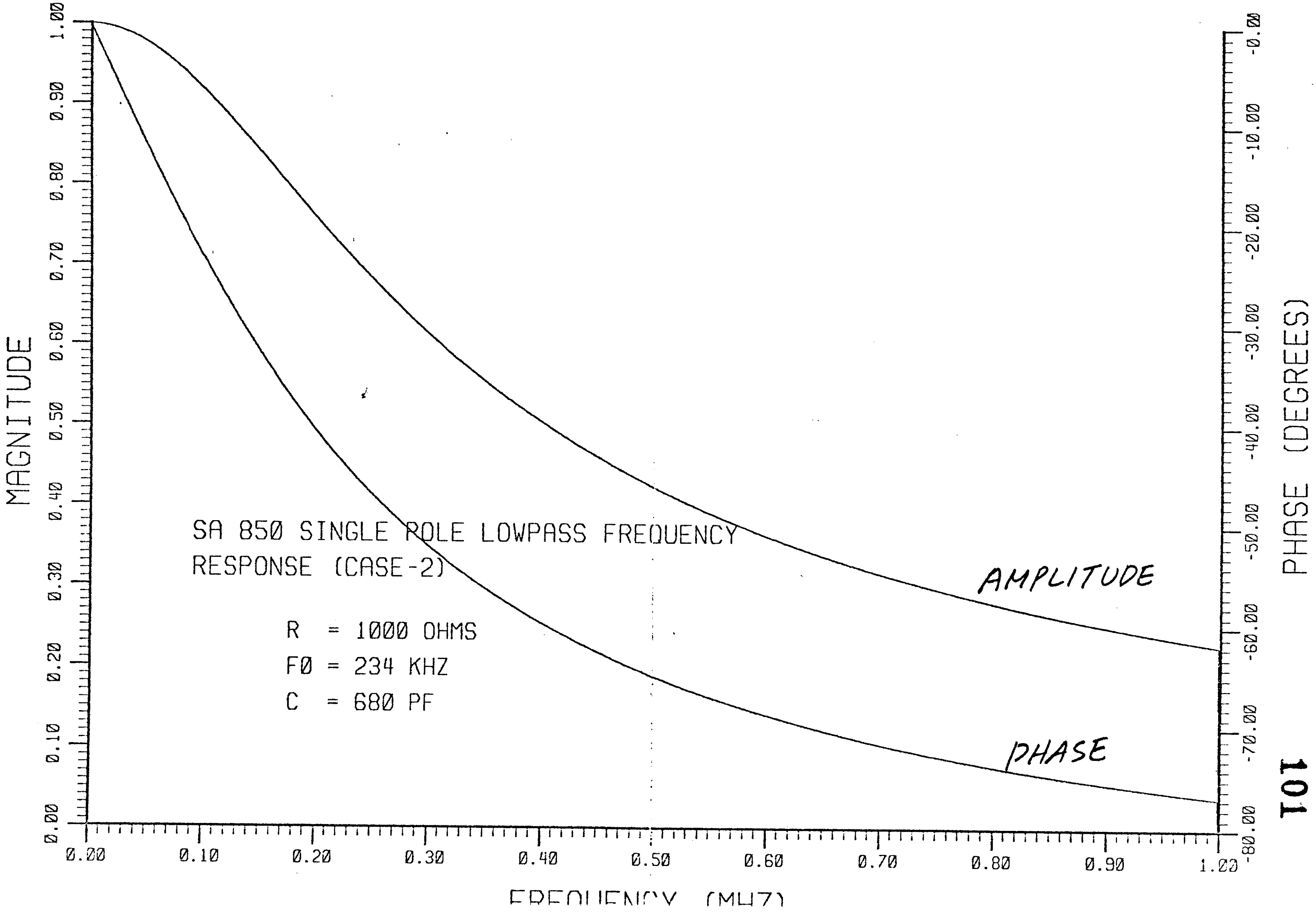

SA 850 SINGLE POLE LOWPASS FREQUENCY
RESPONSE (CASE-2)
R = 1000 OHMS
F0 = 723 KHZ
C = 220 PF
AMPLITUDE
PHASE
MAGNITUDE
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
PHASE (DEGREES)
-0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
FREQUENCY (MHZ)



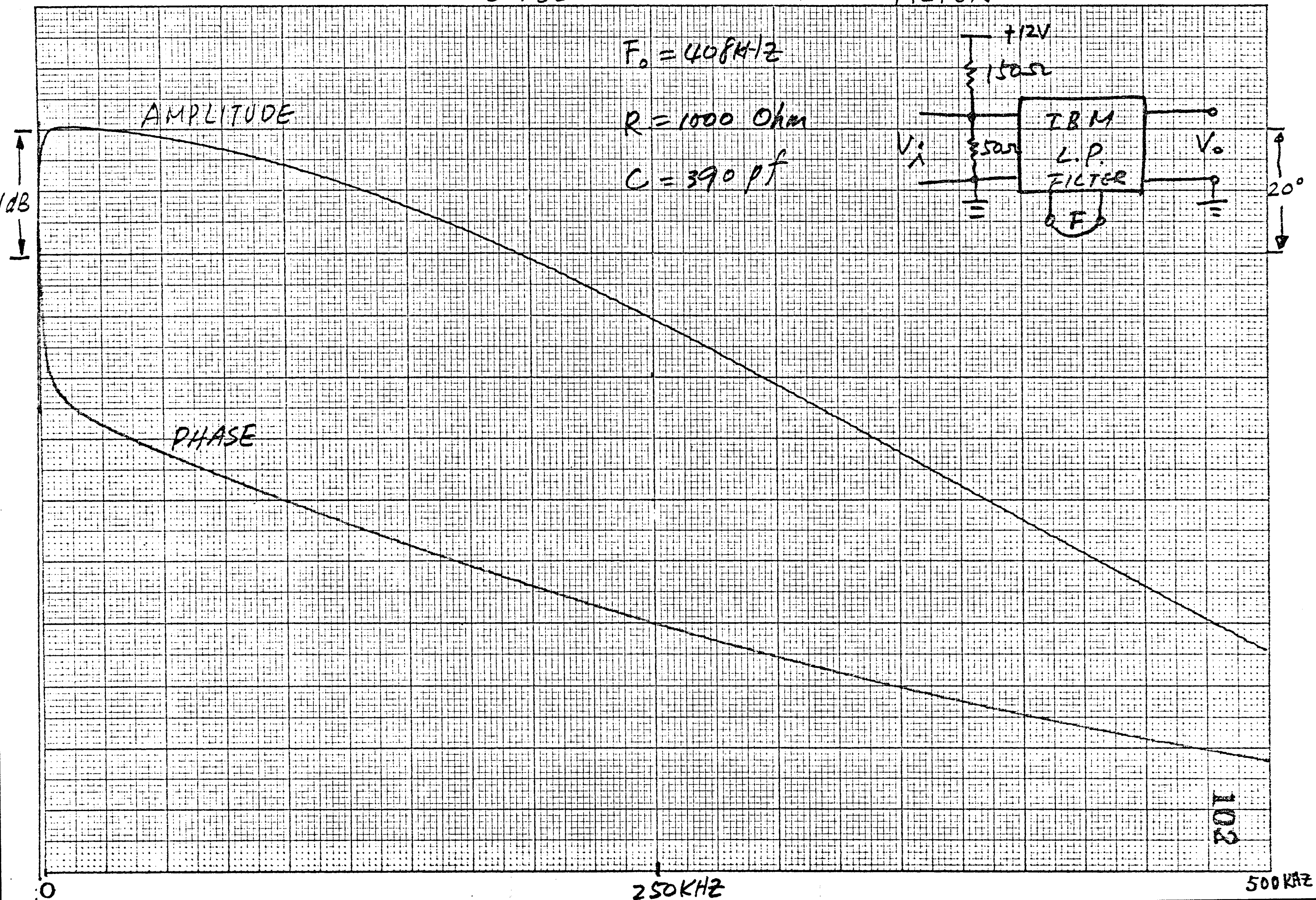
SA 850 SINGLE POLE LOWPASS FREQUENCY RESPONSE (CASE-2)

R = 1000 OHMS
F0 = 408 KHZ
C = 390 PF

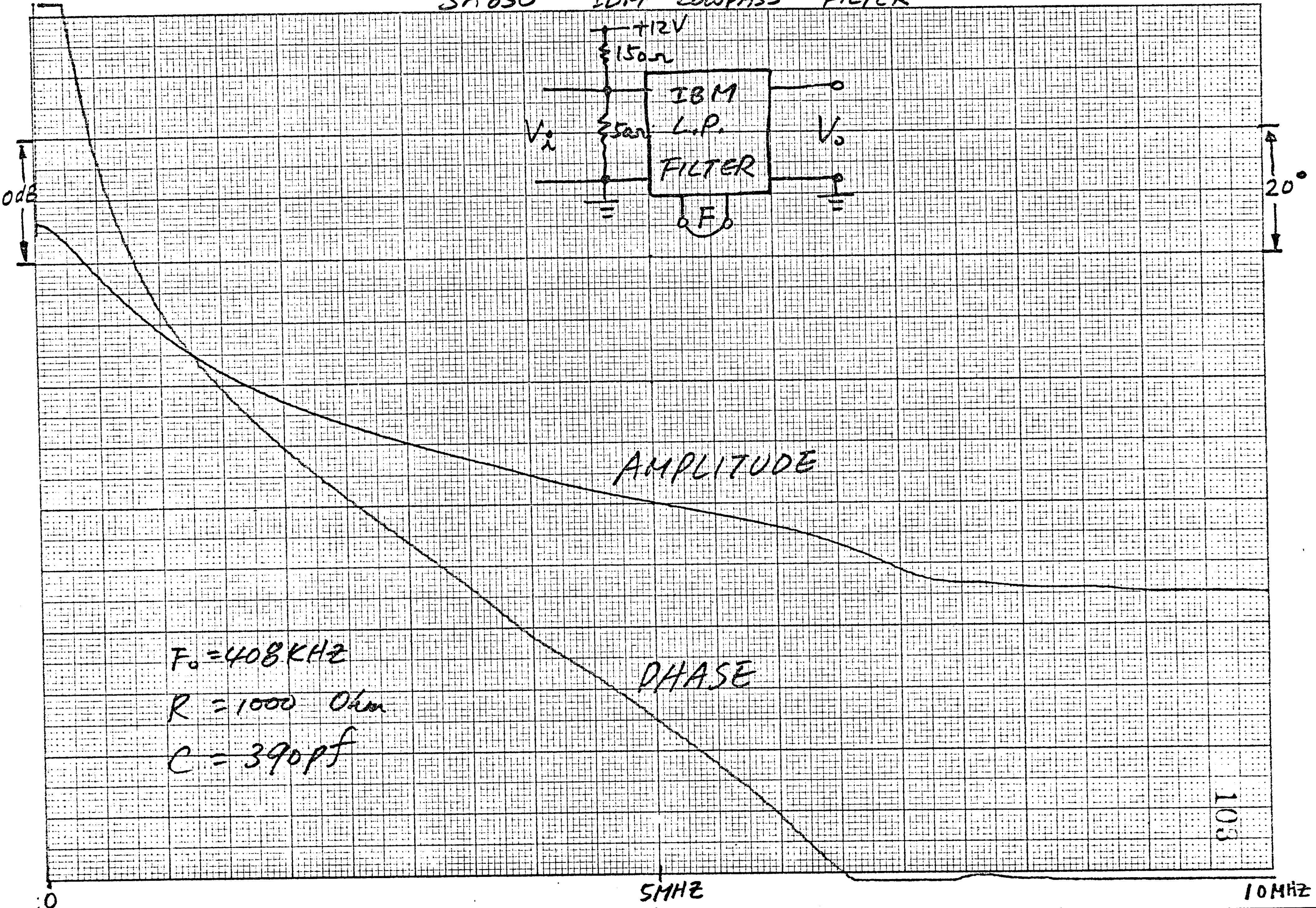

SA 850 SINGLE POLE LOWPASS FREQUENCY
RESPONSE (CASE-2)
R = 1000 OHMS
F0 = 408 KHZ
C = 390 PF
AMPLITUDE
PHASE
MAGNITUDE
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
PHASE (DEGREES)
-0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
-90.00
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY (MHZ)


SA 850 SINGLE POLE LOWPASS FREQUENCY
RESPONSE (CASE-2)
R = 1000 OHMS
F0 = 234 KHZ
C = 680 PF
AMPLITUDE
PHASE
MAGNITUDE
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
PHASE (DEGREES)
-0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
FREQUENCY (MHZ)

SA 850 IBM LOWPASS FILTER



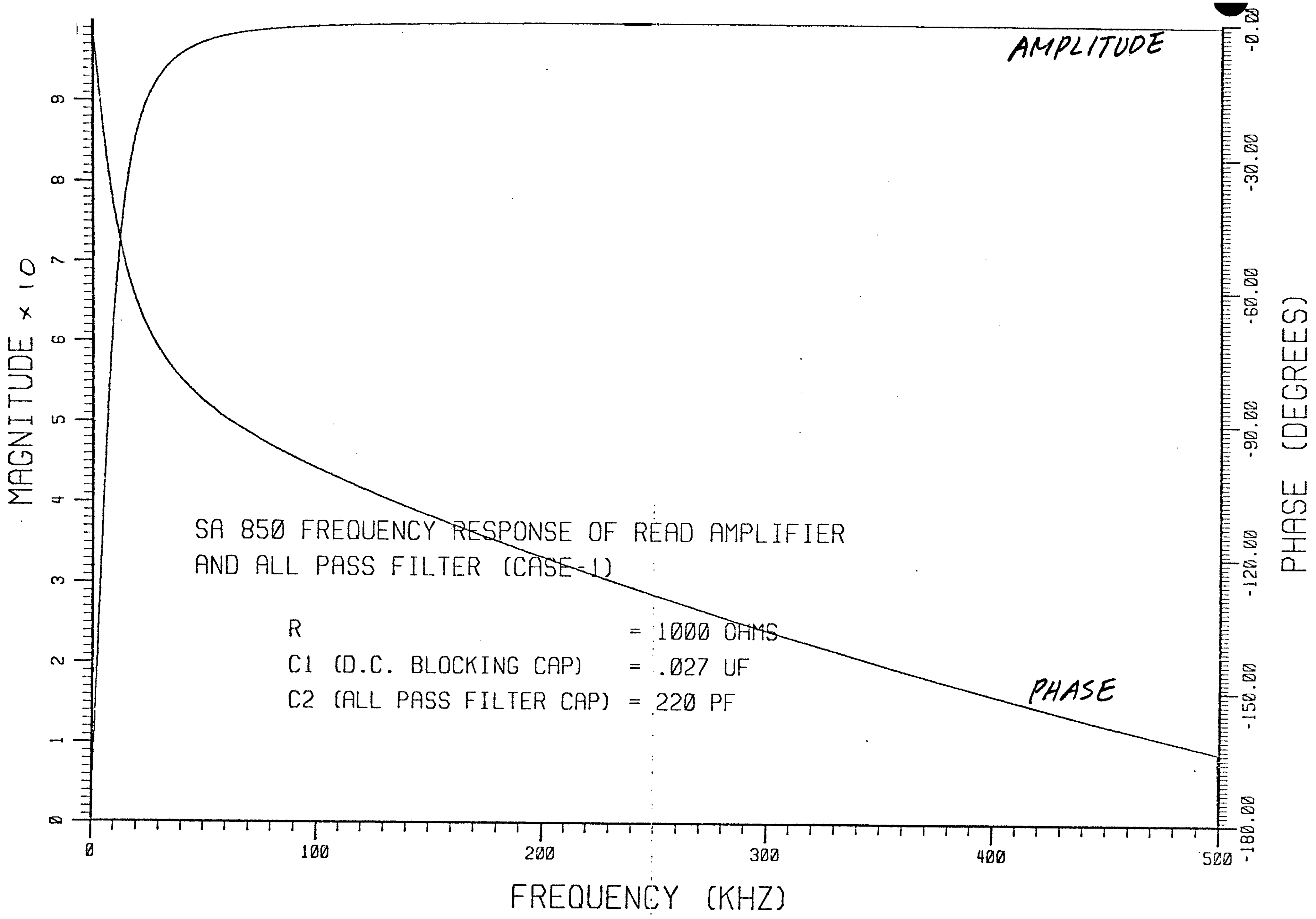
SA850 IBM LOWPASS FILTER



F₀ = 408 KHZ

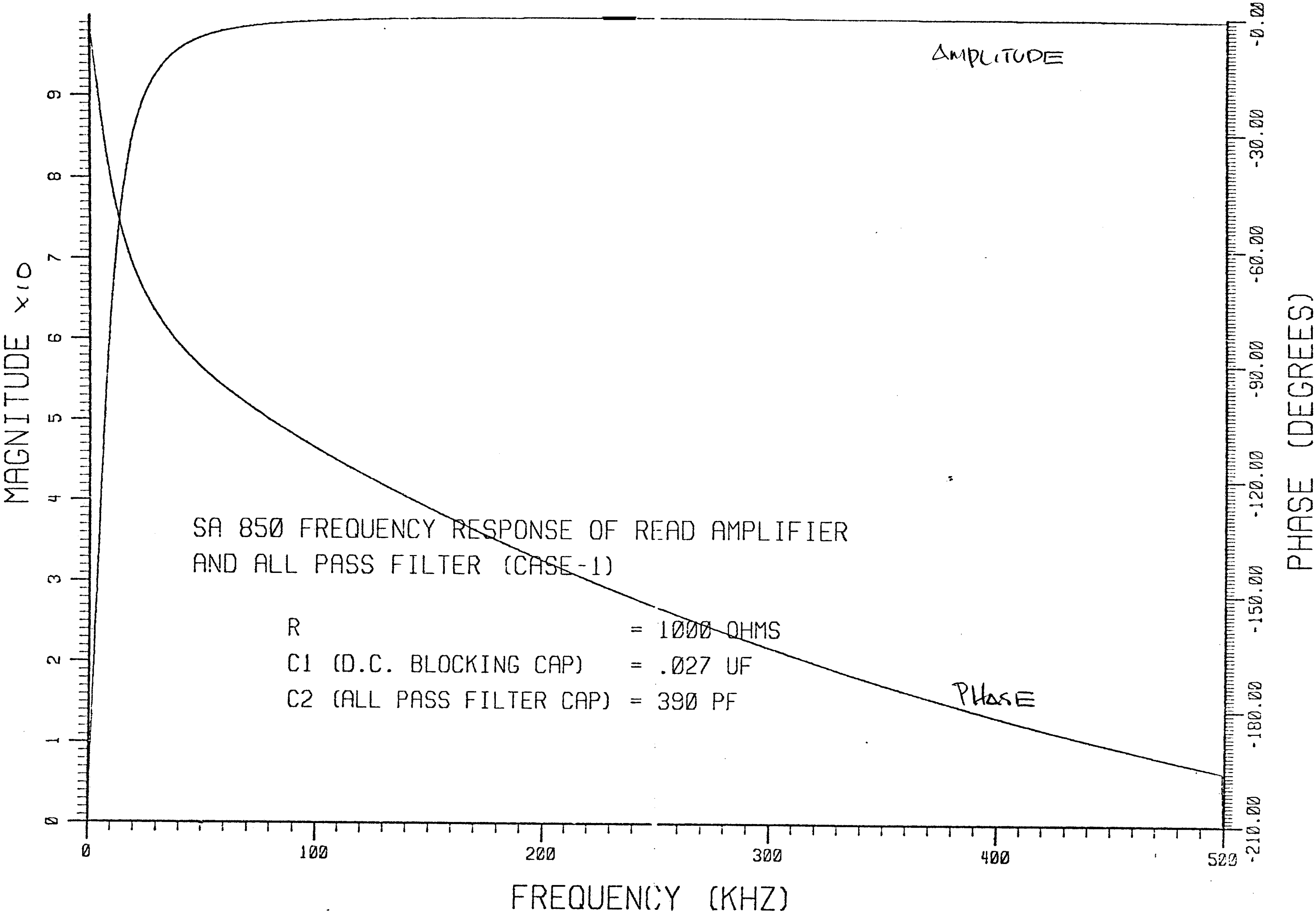
R = 1000 Ohm

C = 390 pf



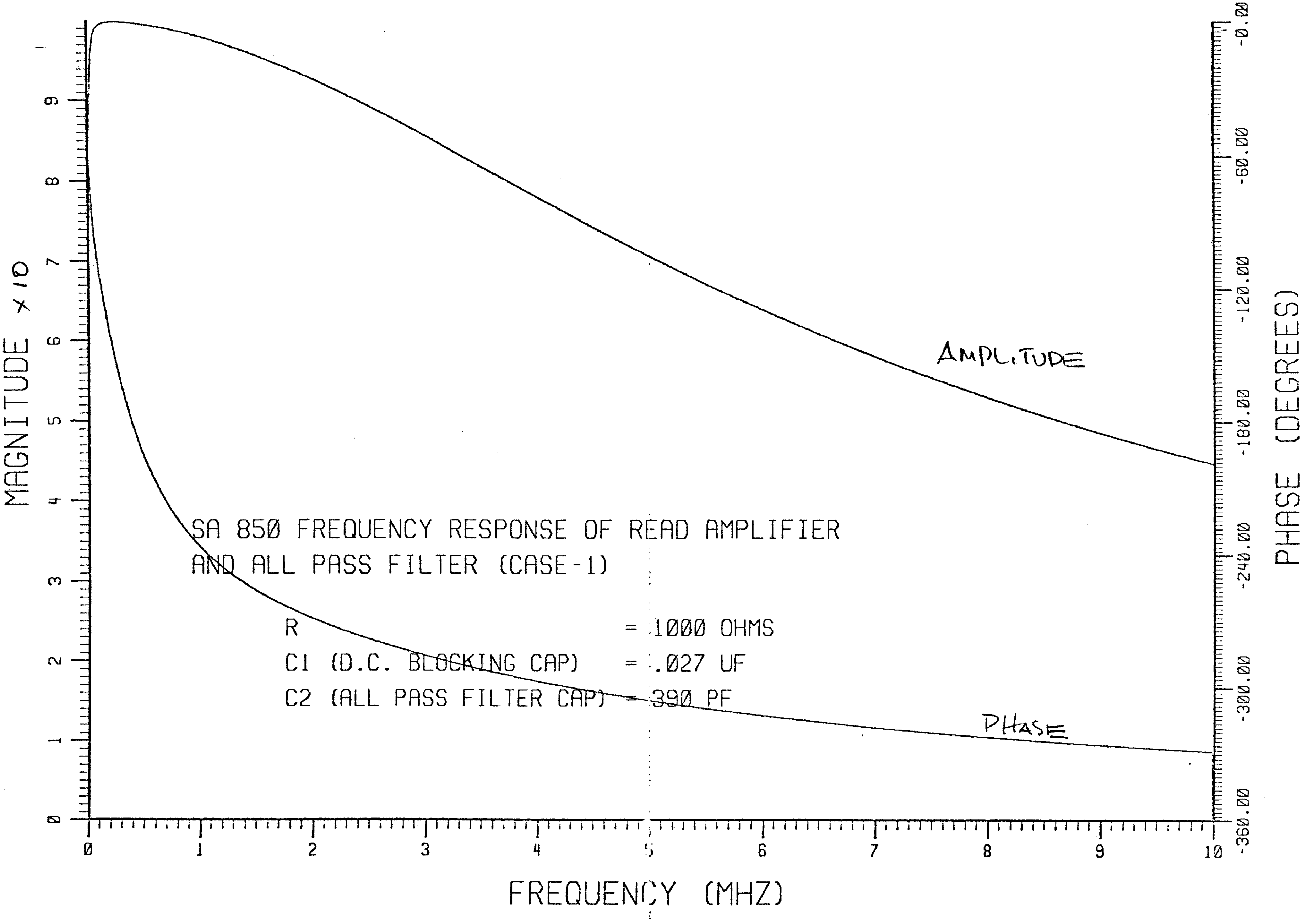
SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER
AND ALL PASS FILTER (CASE-1)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .027 UF
C2 (ALL PASS FILTER CAP) = 220 PF



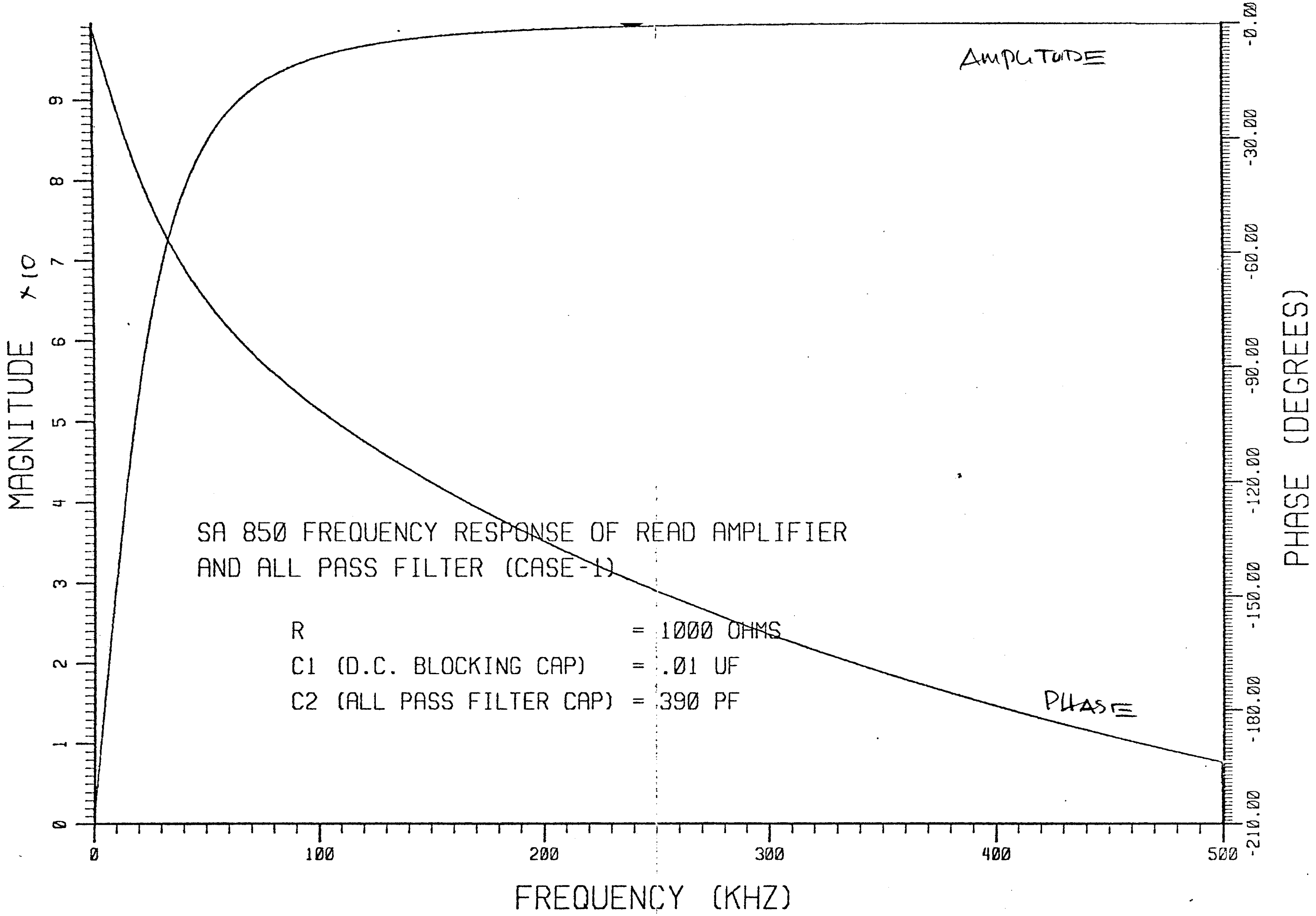
SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER AND ALL PASS FILTER (CASE-1)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .027 UF
C2 (ALL PASS FILTER CAP) = 390 PF



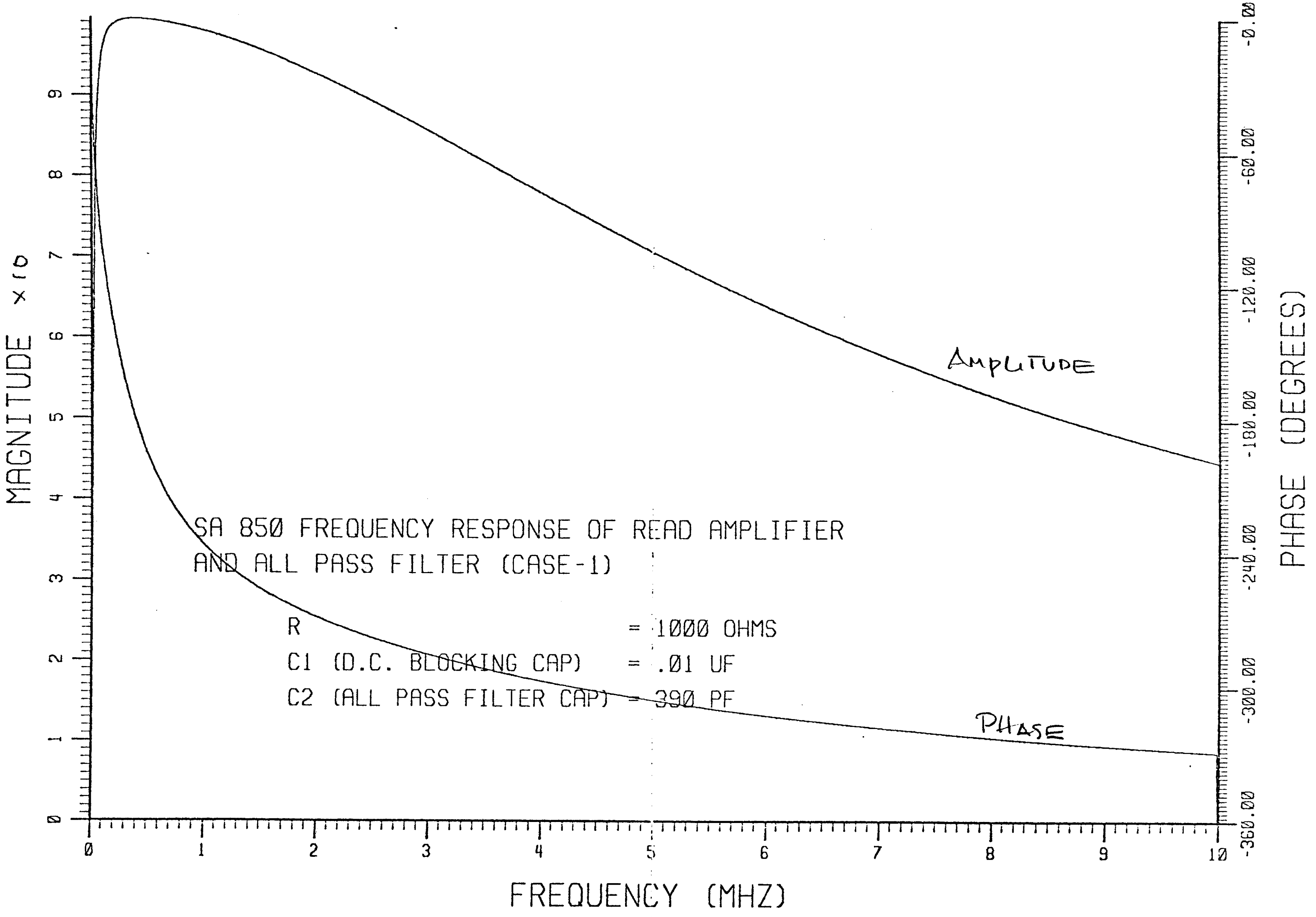
SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER
AND ALL PASS FILTER (CASE-1)

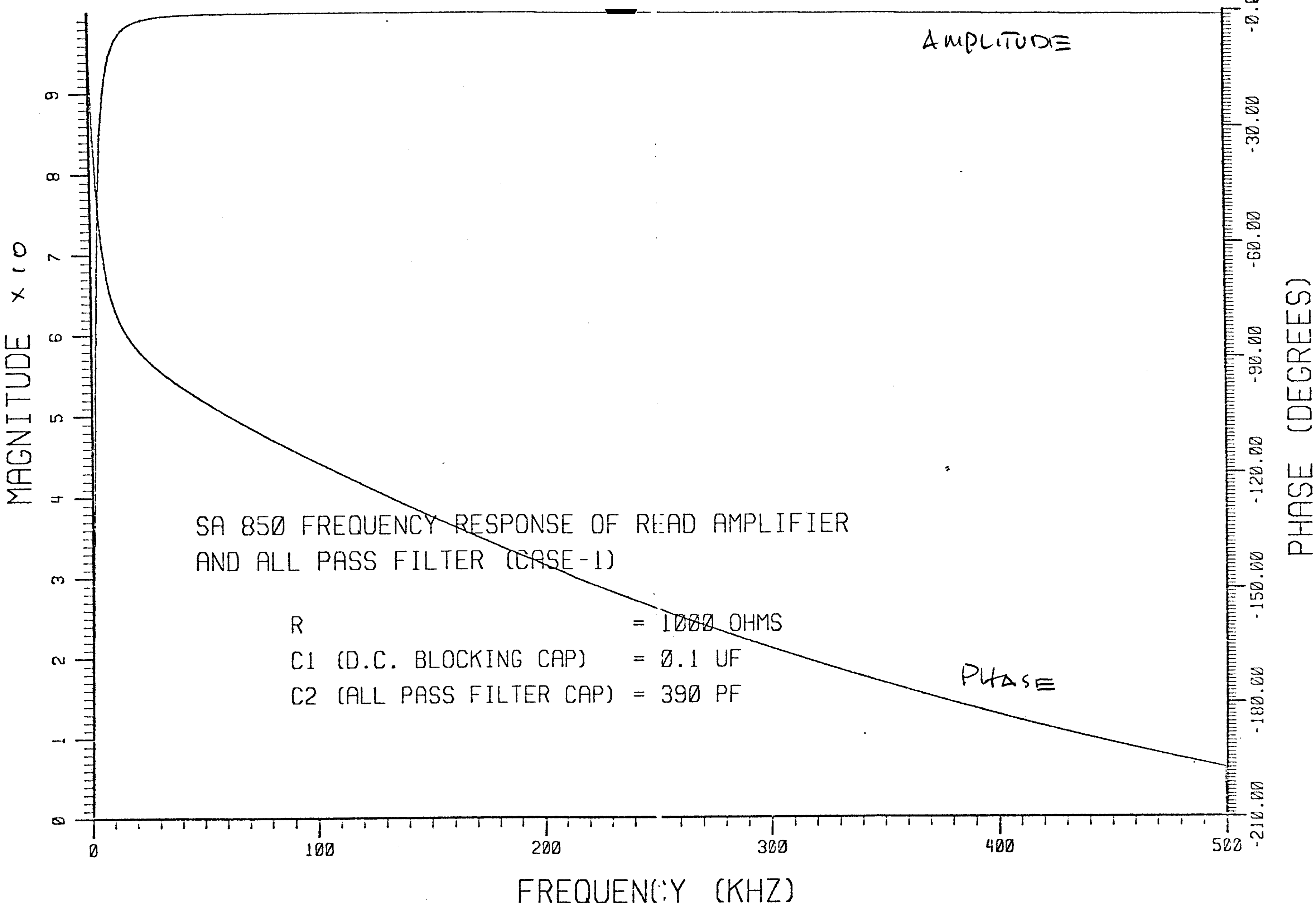
R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .027 UF
C2 (ALL PASS FILTER CAP) = 390 PF



SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER
AND ALL PASS FILTER (CASE-1)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .01 UF
C2 (ALL PASS FILTER CAP) = 390 PF

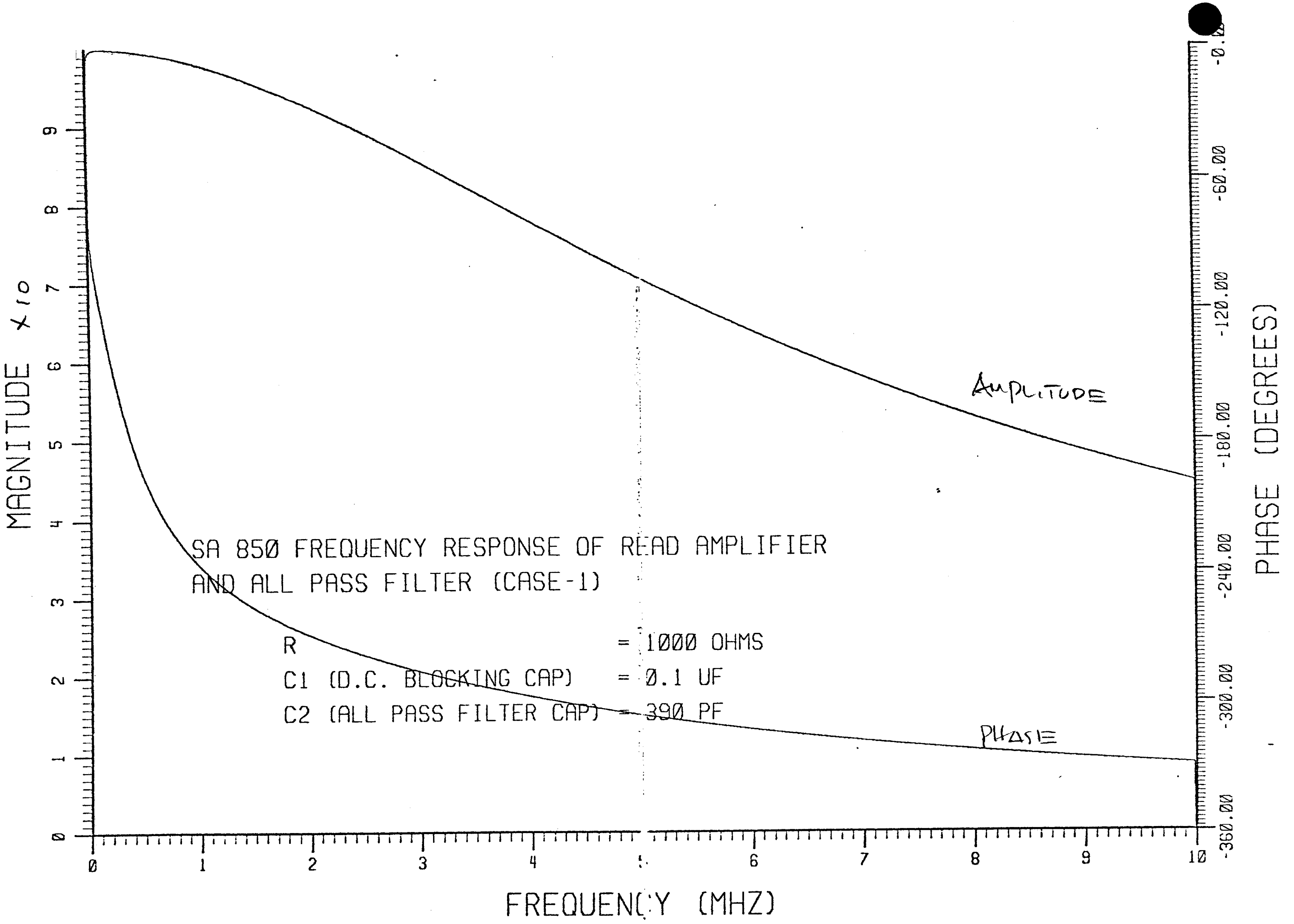

SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER
AND ALL PASS FILTER (CASE-1)
R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .01 UF
C2 (ALL PASS FILTER CAP) = 390 PF
AMPLITUDE
PHASE
MAGNITUDE ×10
0
1
2
3
4
5
6
7
8
9
PHASE (DEGREES)
-0.00
-60.00
-120.00
-180.00
-240.00
-300.00
-360.00
FREQUENCY (MHZ)
0
1
2
3
4
5
6
7
8
9
10

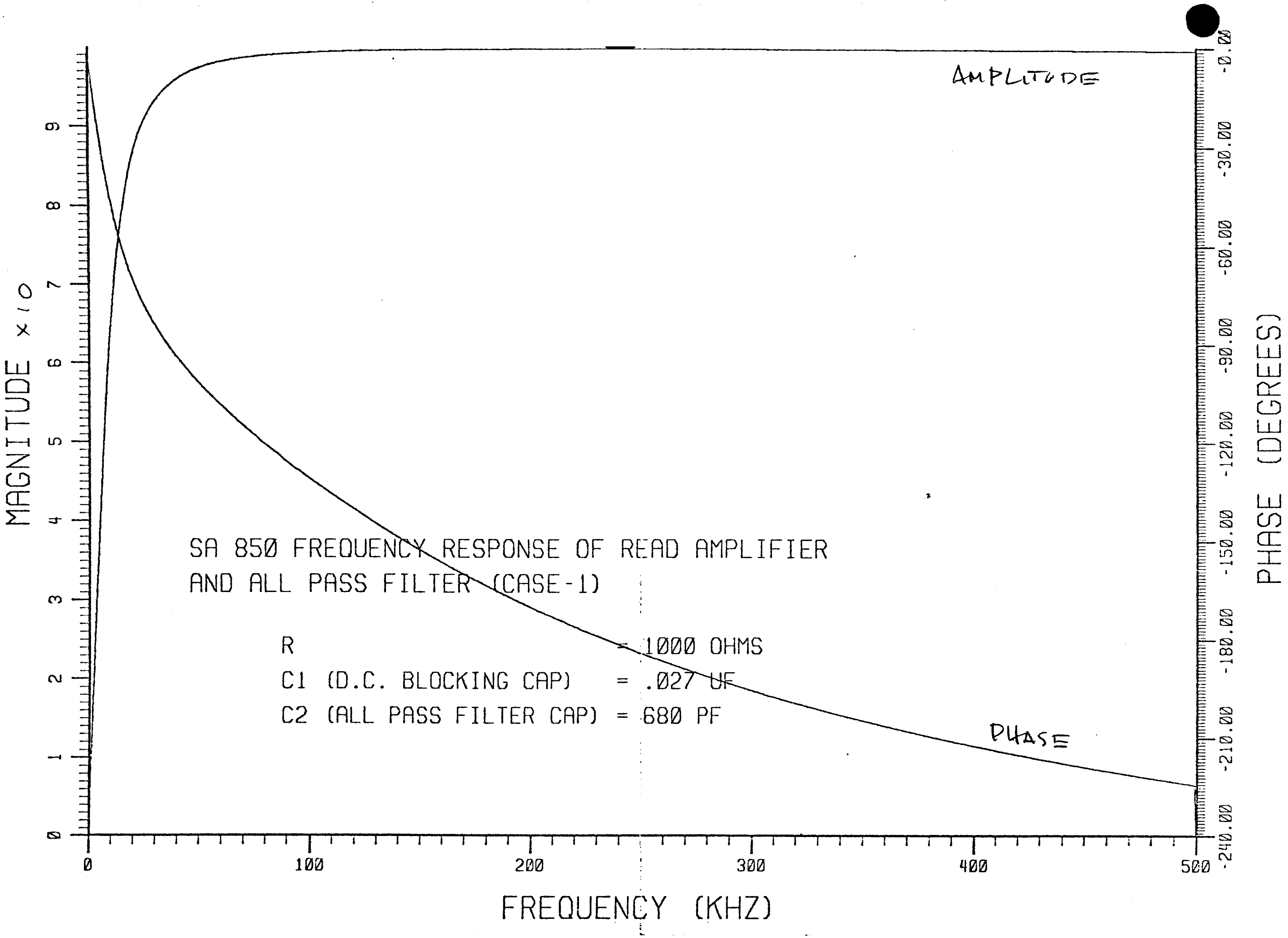

SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER AND ALL PASS FILTER (CASE-1)

R = 1000 OHMS

C1 (D.C. BLOCKING CAP) = 0.1 UF

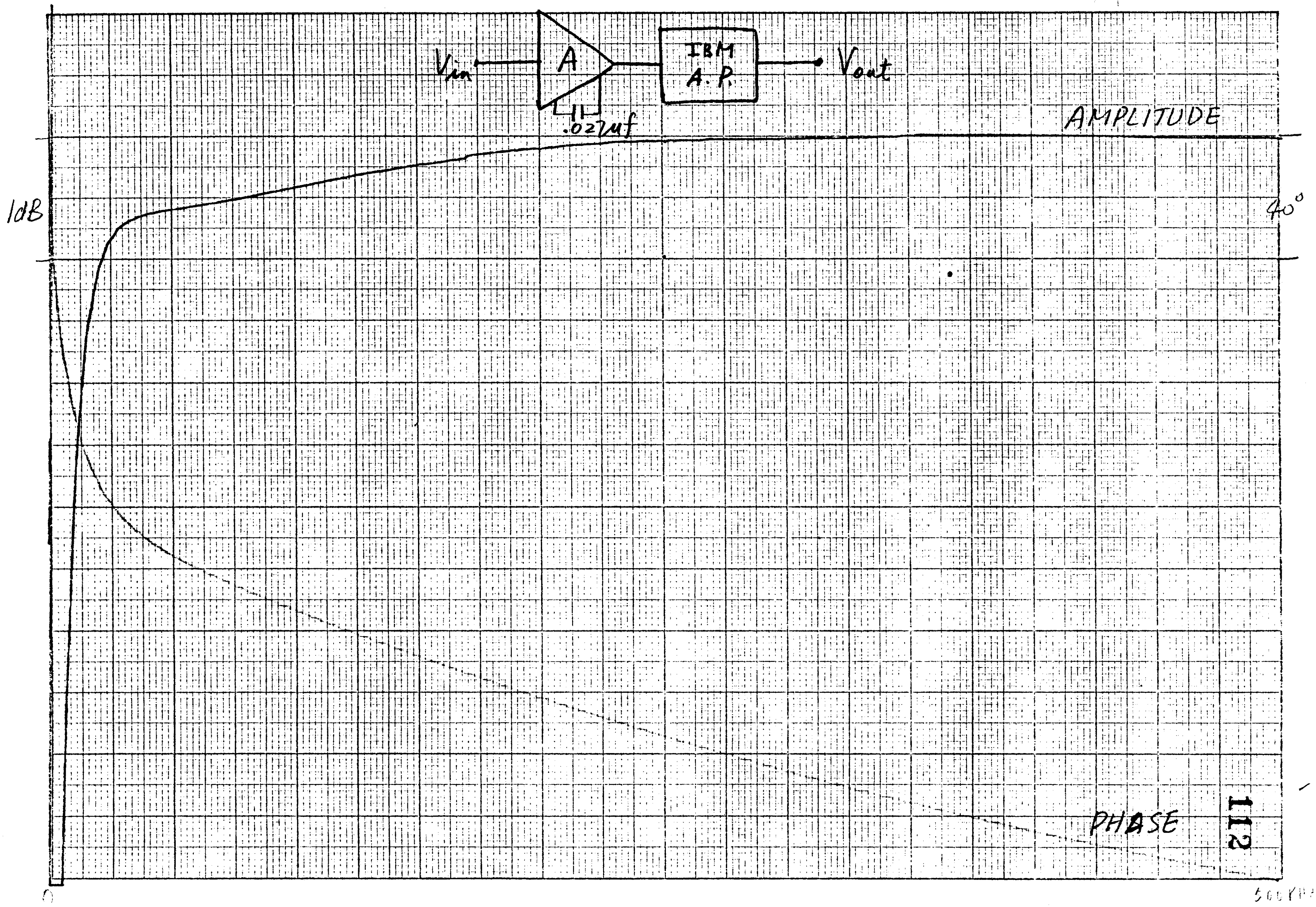
C2 (ALL PASS FILTER CAP) = 390 PF

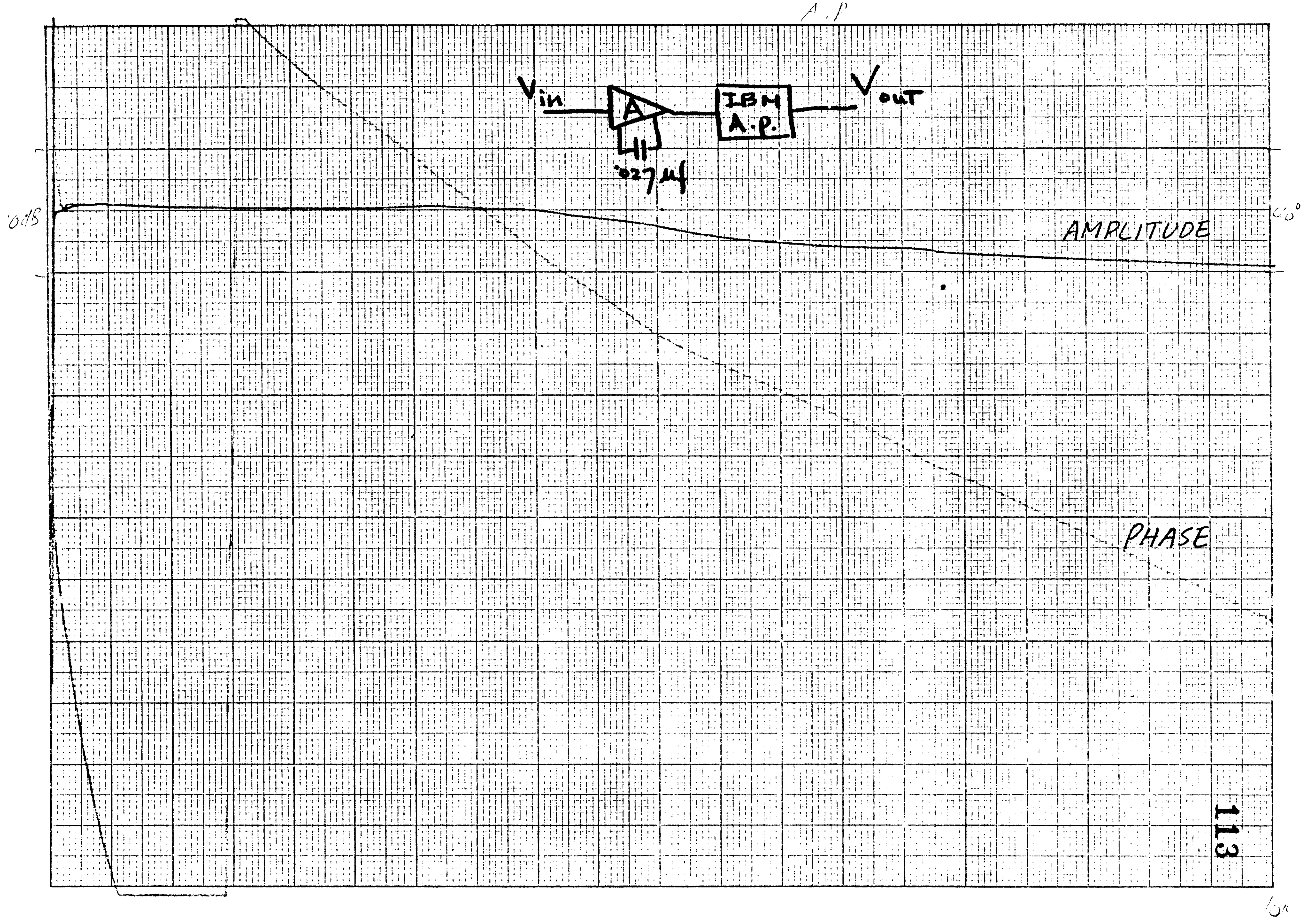

SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER
AND ALL PASS FILTER (CASE-1)
R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = 0.1 UF
C2 (ALL PASS FILTER CAP) = 390 PF
AMPLITUDE
PHASE
MAGNITUDE x10
0
1
2
3
4
5
6
7
8
9
PHASE (DEGREES)
-0.00
-60.00
-120.00
-180.00
-240.00
-300.00
-360.00
FREQUENCY (MHZ)
0
1
2
3
4
5
6
7
8
9
10

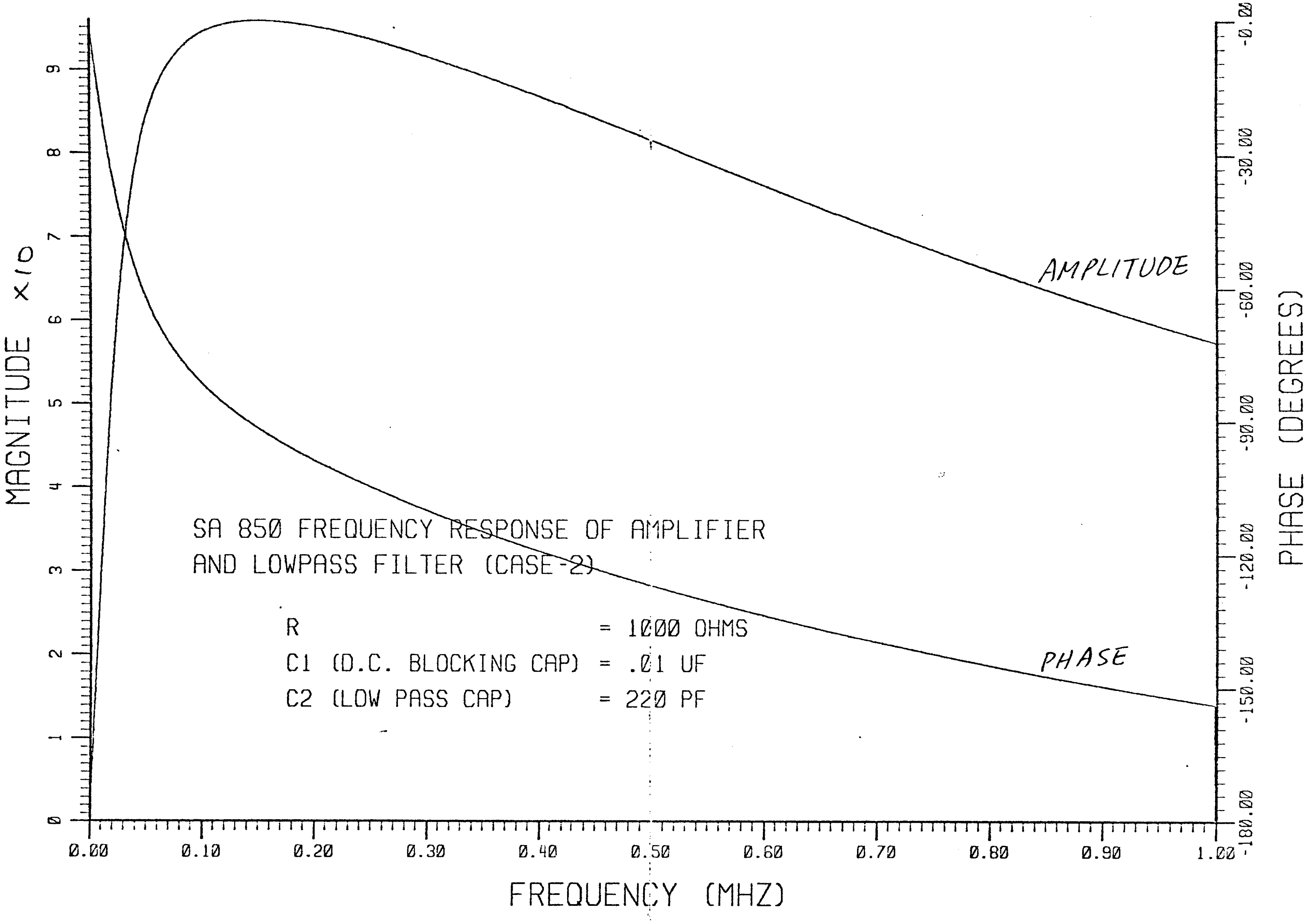


SA 850 FREQUENCY RESPONSE OF READ AMPLIFIER
AND ALL PASS FILTER (CASE-1)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .027 UF
C2 (ALL PASS FILTER CAP) = 680 PF

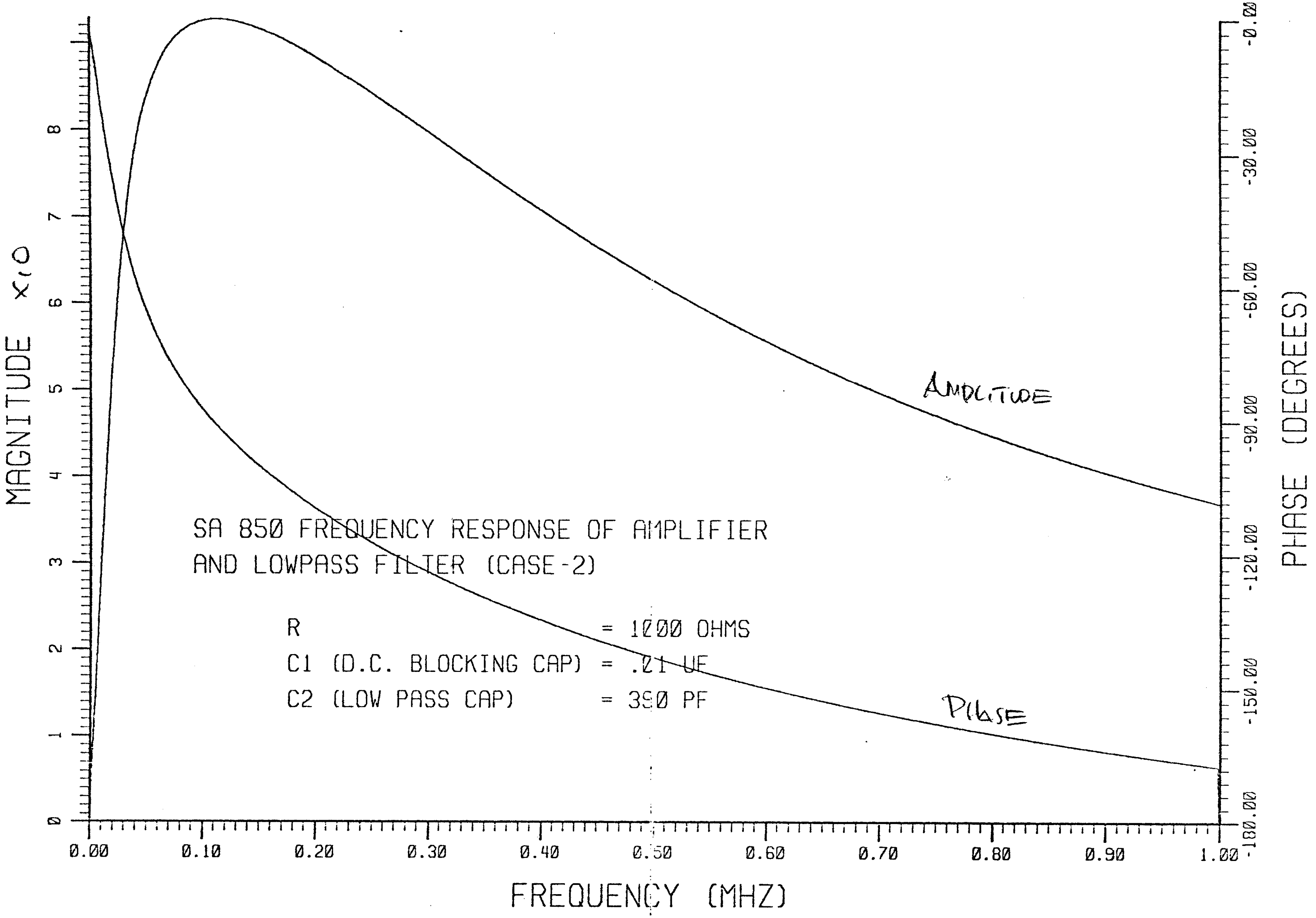

V_{in}
A
IBM
A.P.
V_{out}
.027uf
AMPLITUDE
1dB
40°
PHASE
0
500KHz


A.P
V_{in}
A
IBM A.P.
V_{out}
.027 μf
0dB
60°
AMPLITUDE
PHASE



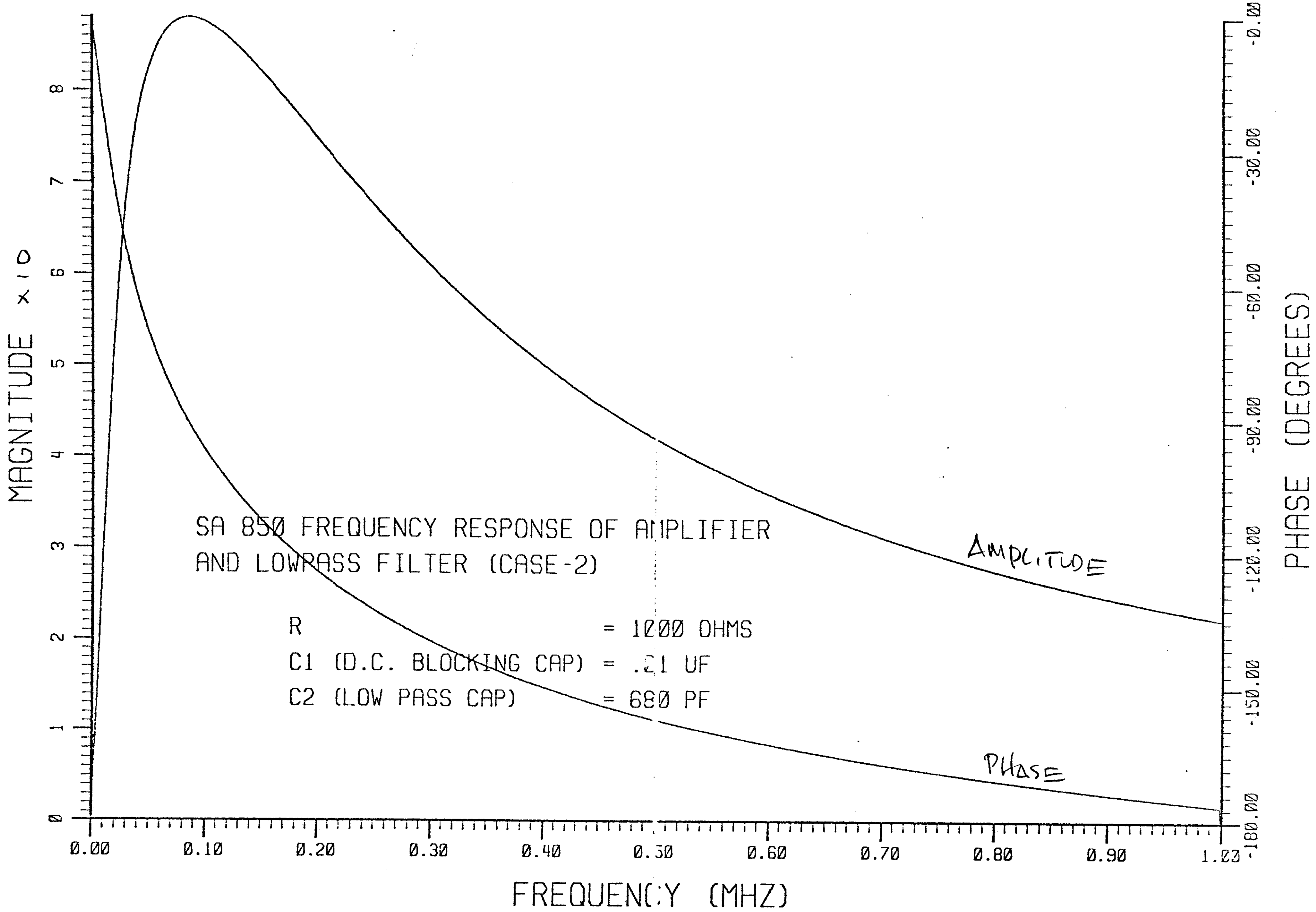
SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .01 UF
C2 (LOW PASS CAP) = 220 PF



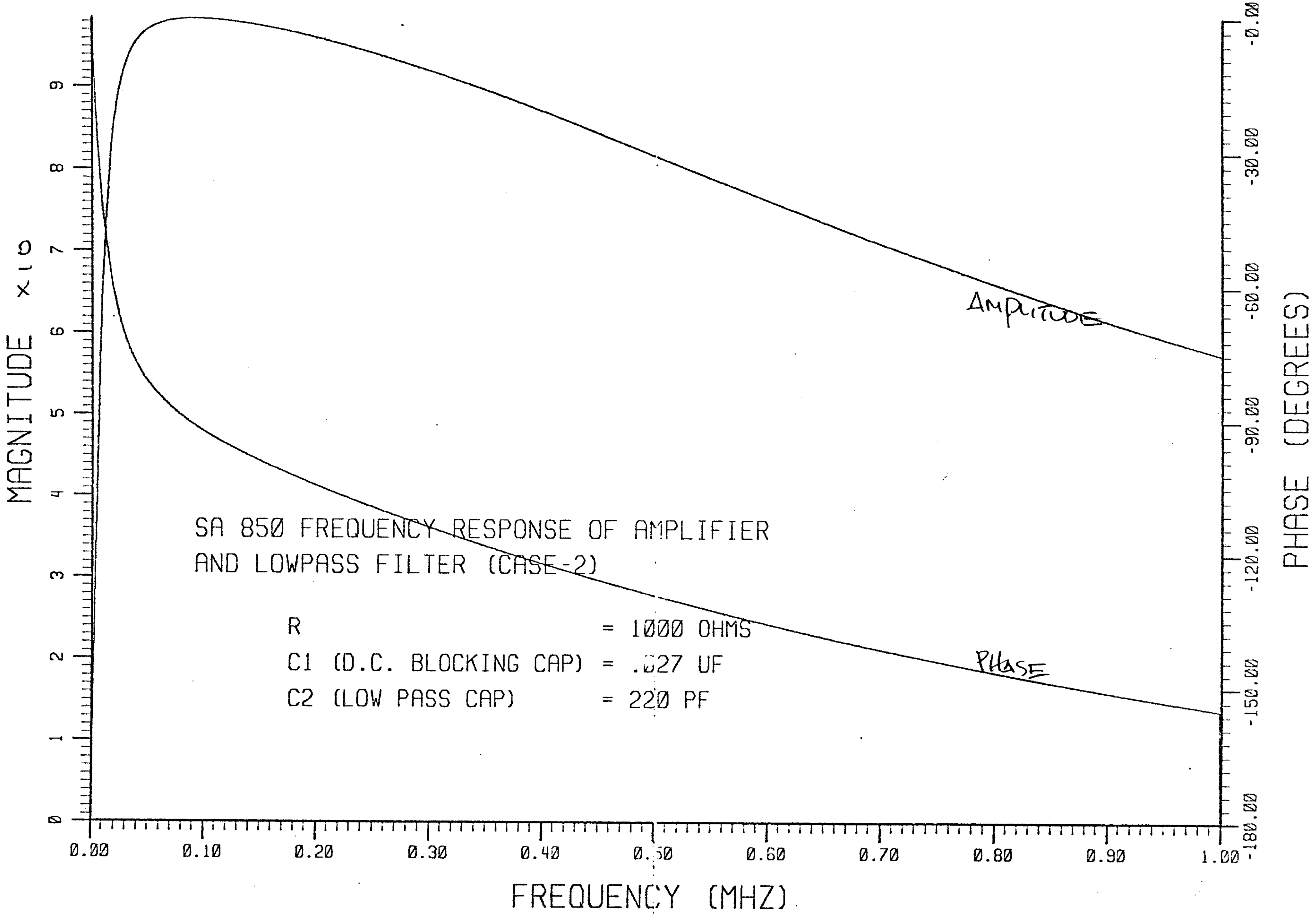
SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .01 UF
C2 (LOW PASS CAP) = 390 PF

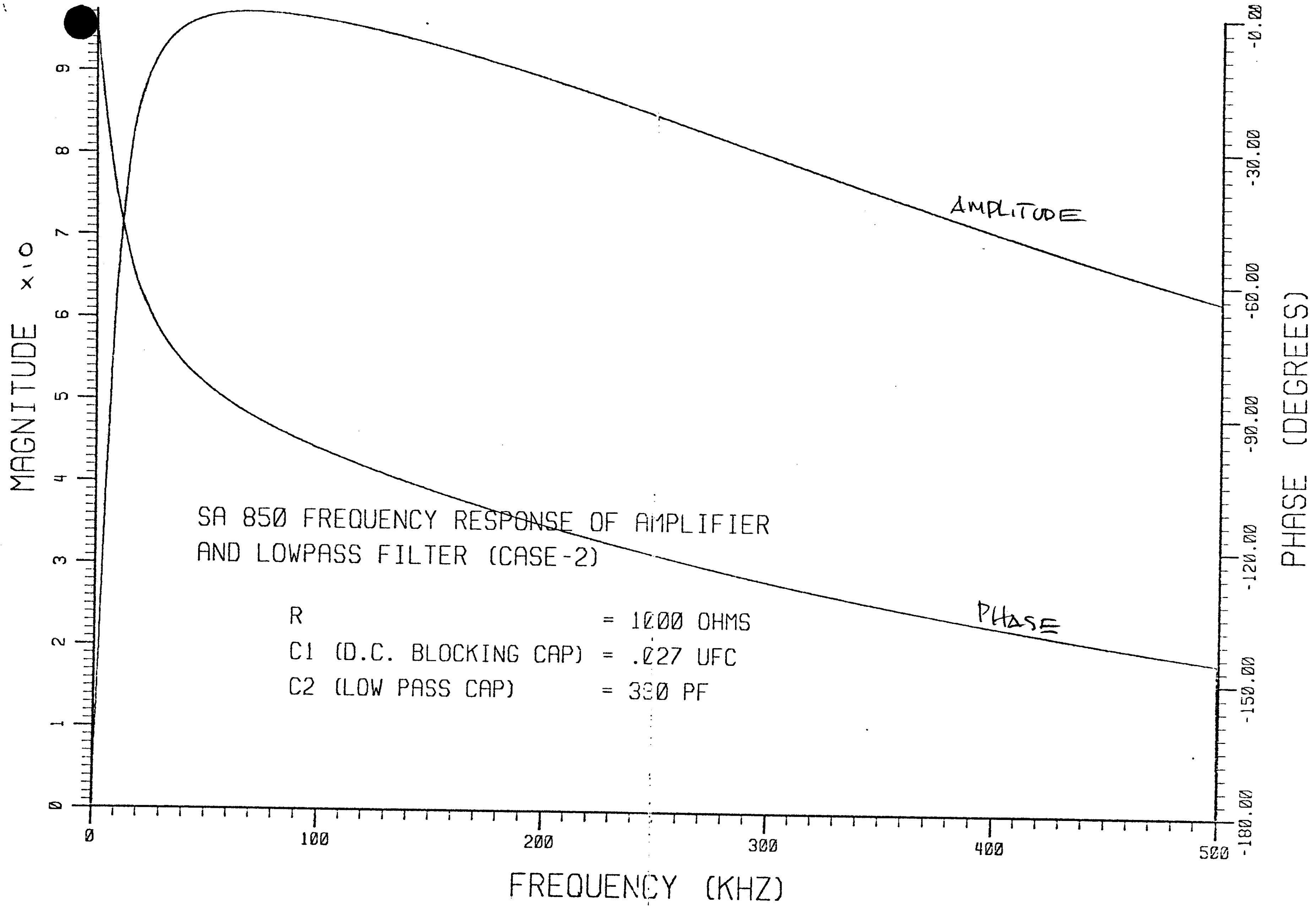


SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .01 UF
C2 (LOW PASS CAP) = 680 PF


SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .027 UF
C2 (LOW PASS CAP) = 220 PF

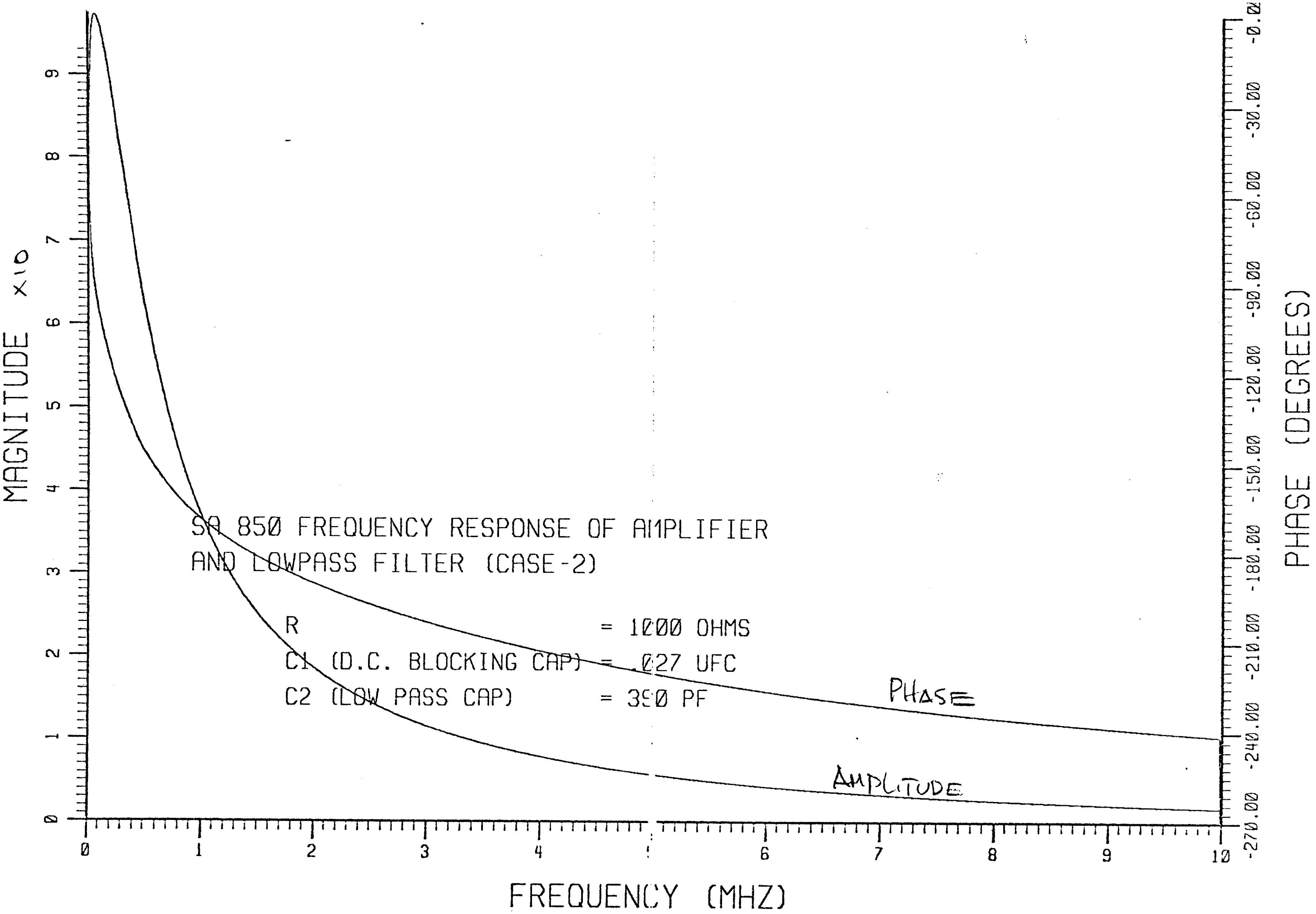


SA 850 FREQUENCY RESPONSE OF AMPLIFIER AND LOWPASS FILTER (CASE-2)

R = 1000 OHMS

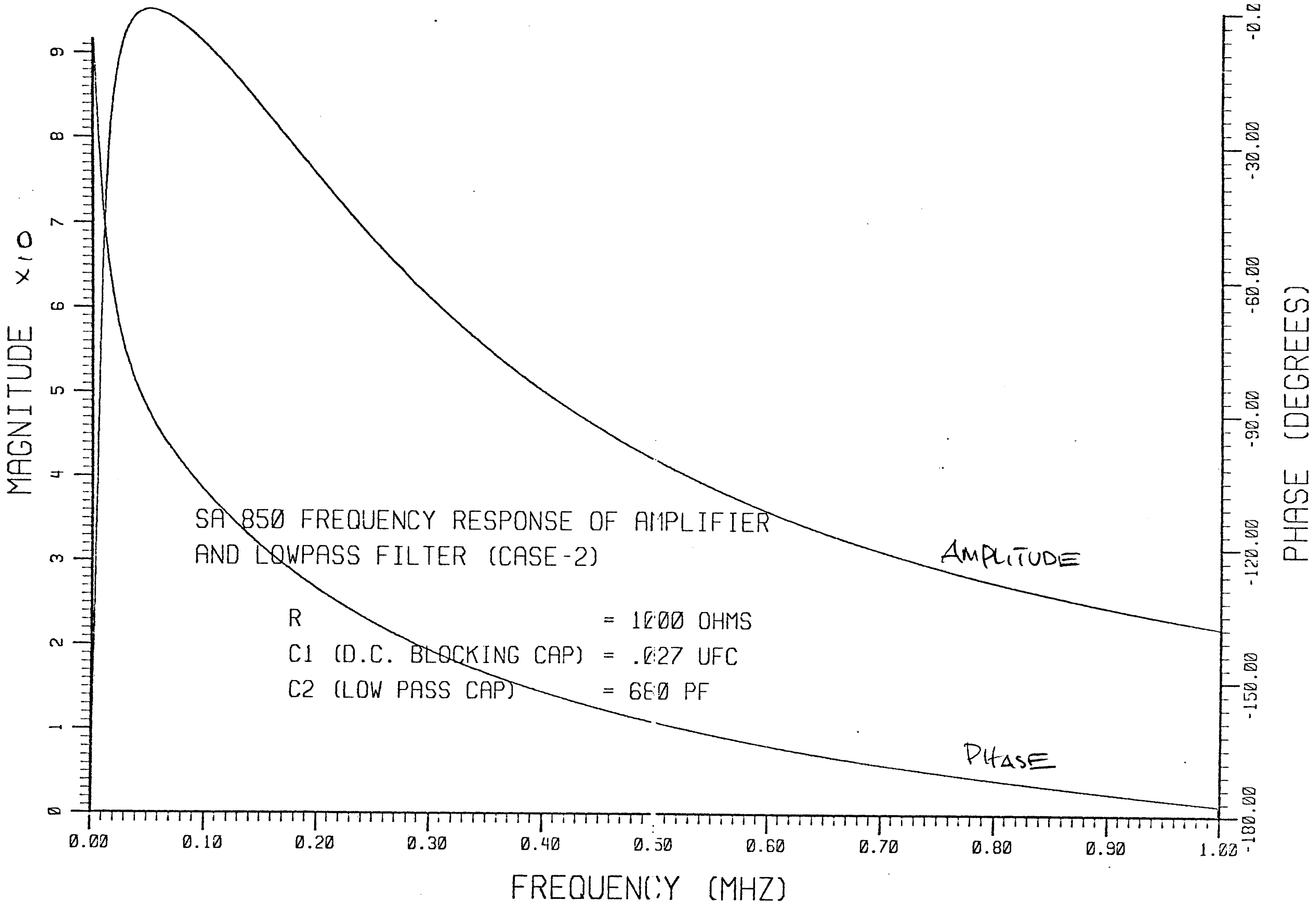
C1 (D.C. BLOCKING CAP) = .027 UFC

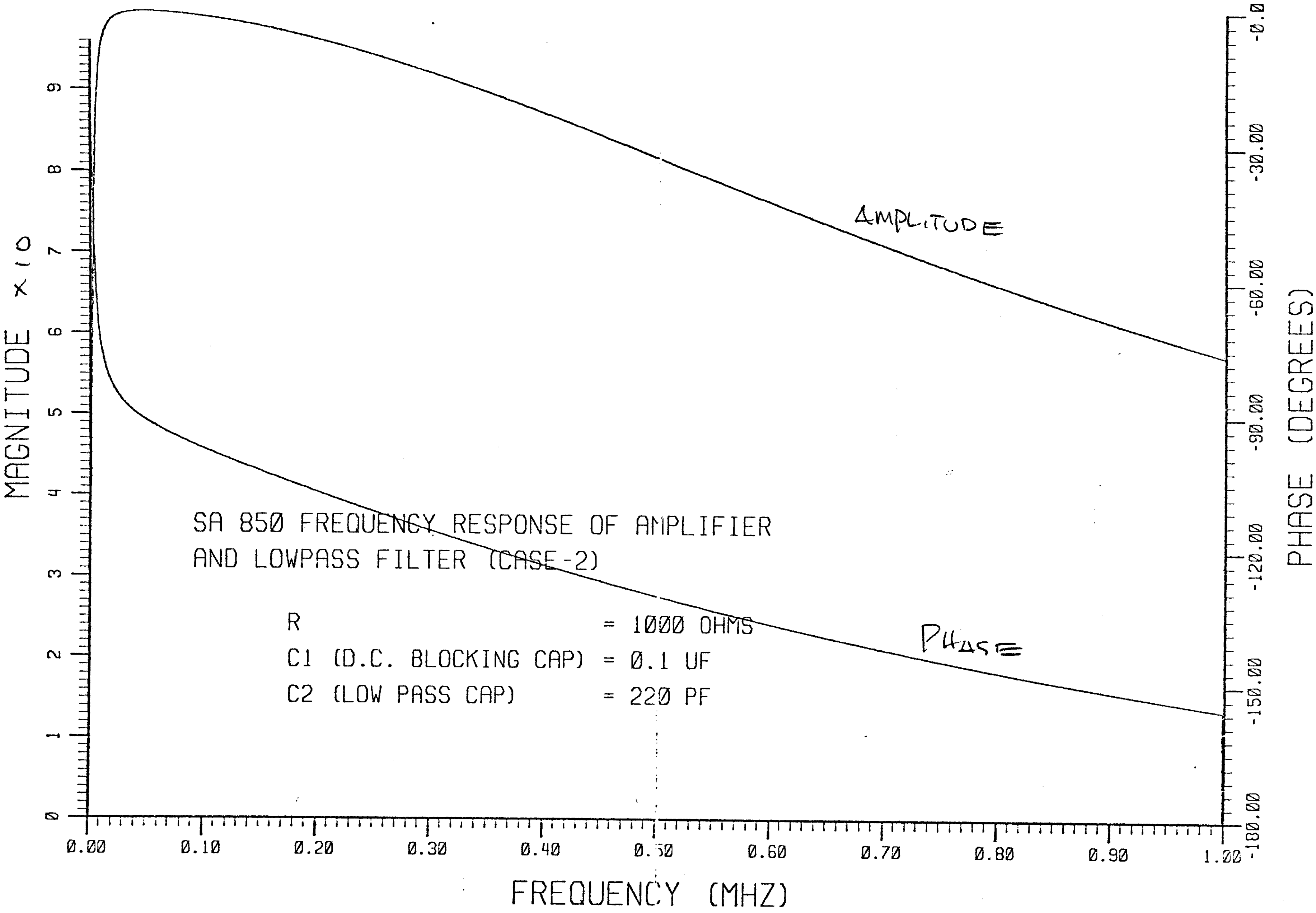
C2 (LOW PASS CAP) = 330 PF

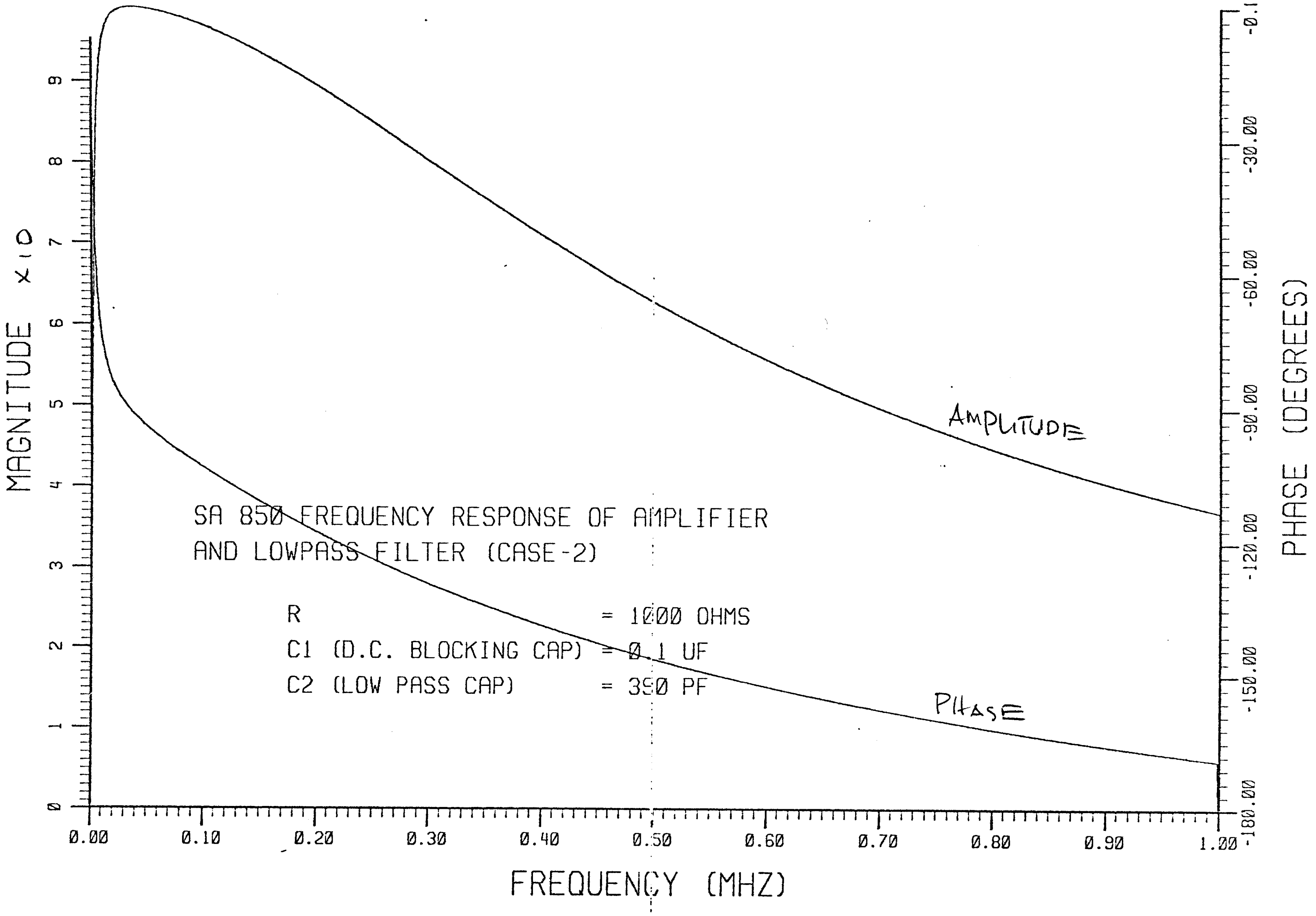


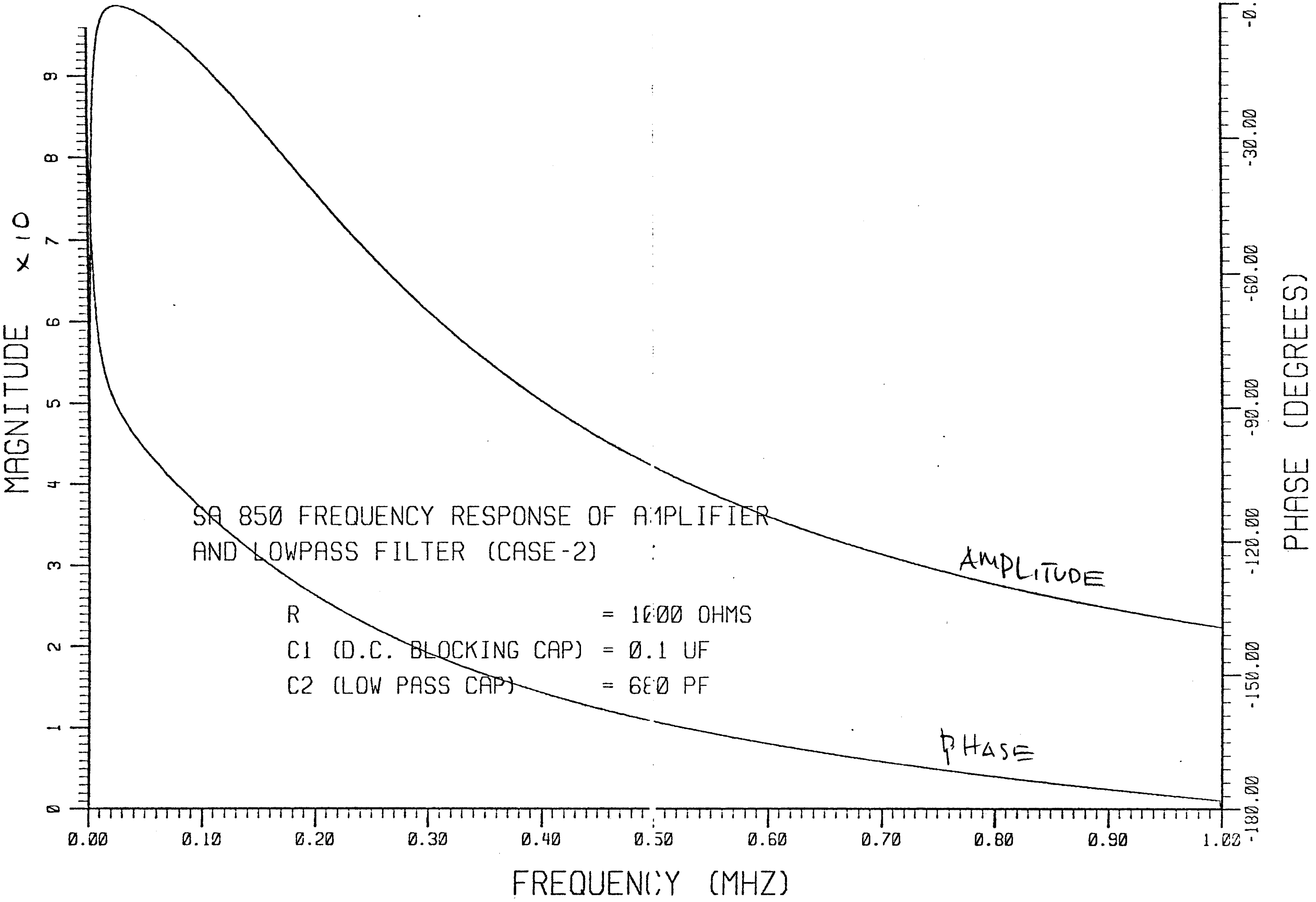
SA 850 FREQUENCY RESPONSE OF AMPLIFIER AND LOWPASS FILTER (CASE-2)

R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .027 UFC
C2 (LOW PASS CAP) = 390 PF


SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)
R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = .027 UFC
C2 (LOW PASS CAP) = 680 PF
AMPLITUDE
PHASE
MAGNITUDE x10
0
1
2
3
4
5
6
7
8
9
PHASE (DEGREES)
-0.0
-30.00
-60.00
-90.00
-120.00
-150.00
-180.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
FREQUENCY (MHZ)

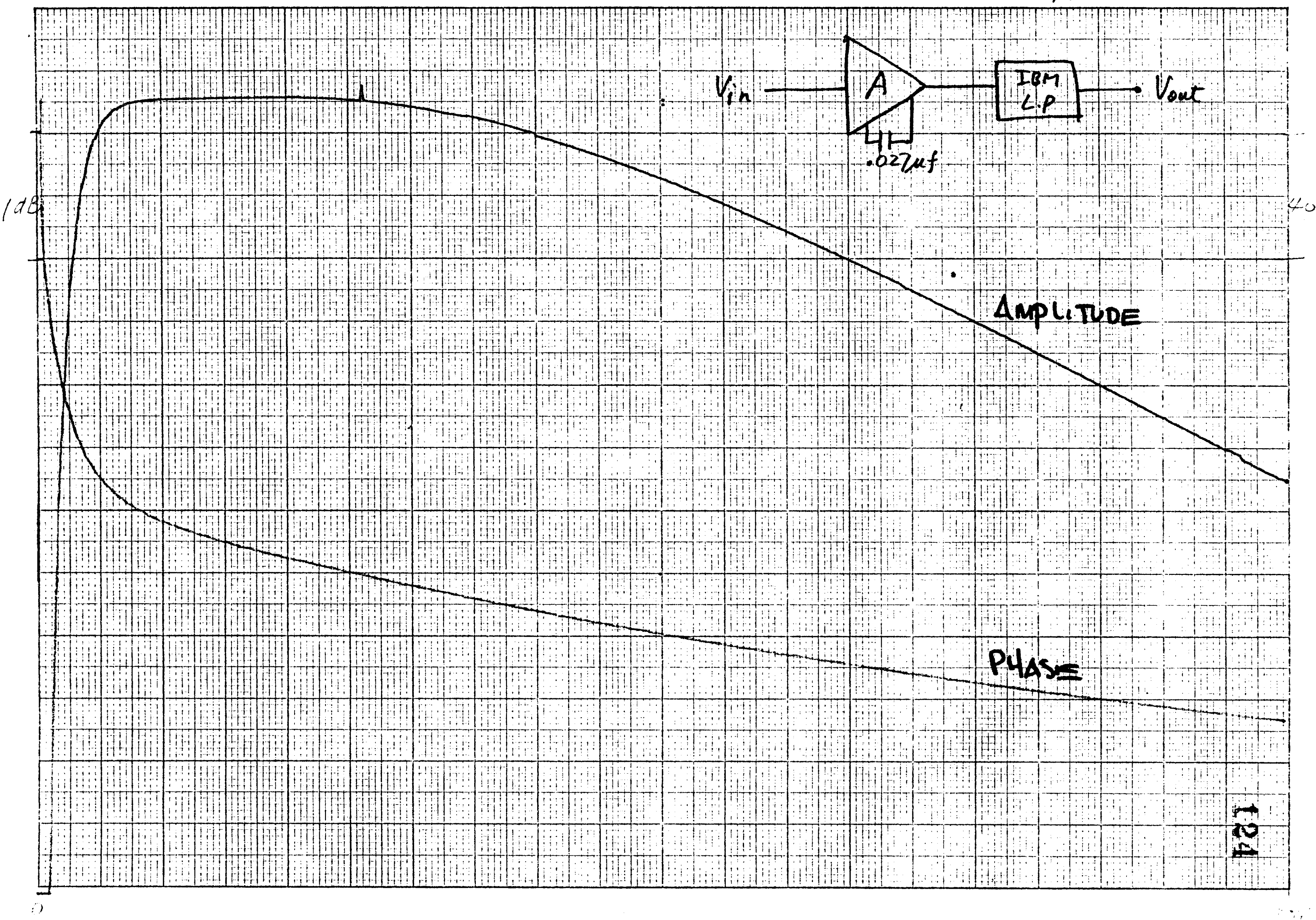

SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)
R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = 0.1 UF
C2 (LOW PASS CAP) = 220 PF
AMPLITUDE
PHASE
MAGNITUDE x 10
0
1
2
3
4
5
6
7
8
9
PHASE (DEGREES)
-0.0
-30.00
-60.00
-90.00
-120.00
-150.00
-180.00
FREQUENCY (MHZ)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00


SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)
R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = 0.1 UF
C2 (LOW PASS CAP) = 390 PF
AMPLITUDE
PHASE
MAGNITUDE x10
0
1
2
3
4
5
6
7
8
9
PHASE (DEGREES)
-0.1
-30.00
-60.00
-90.00
-120.00
-150.00
-180.00
-180.
FREQUENCY (MHZ)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

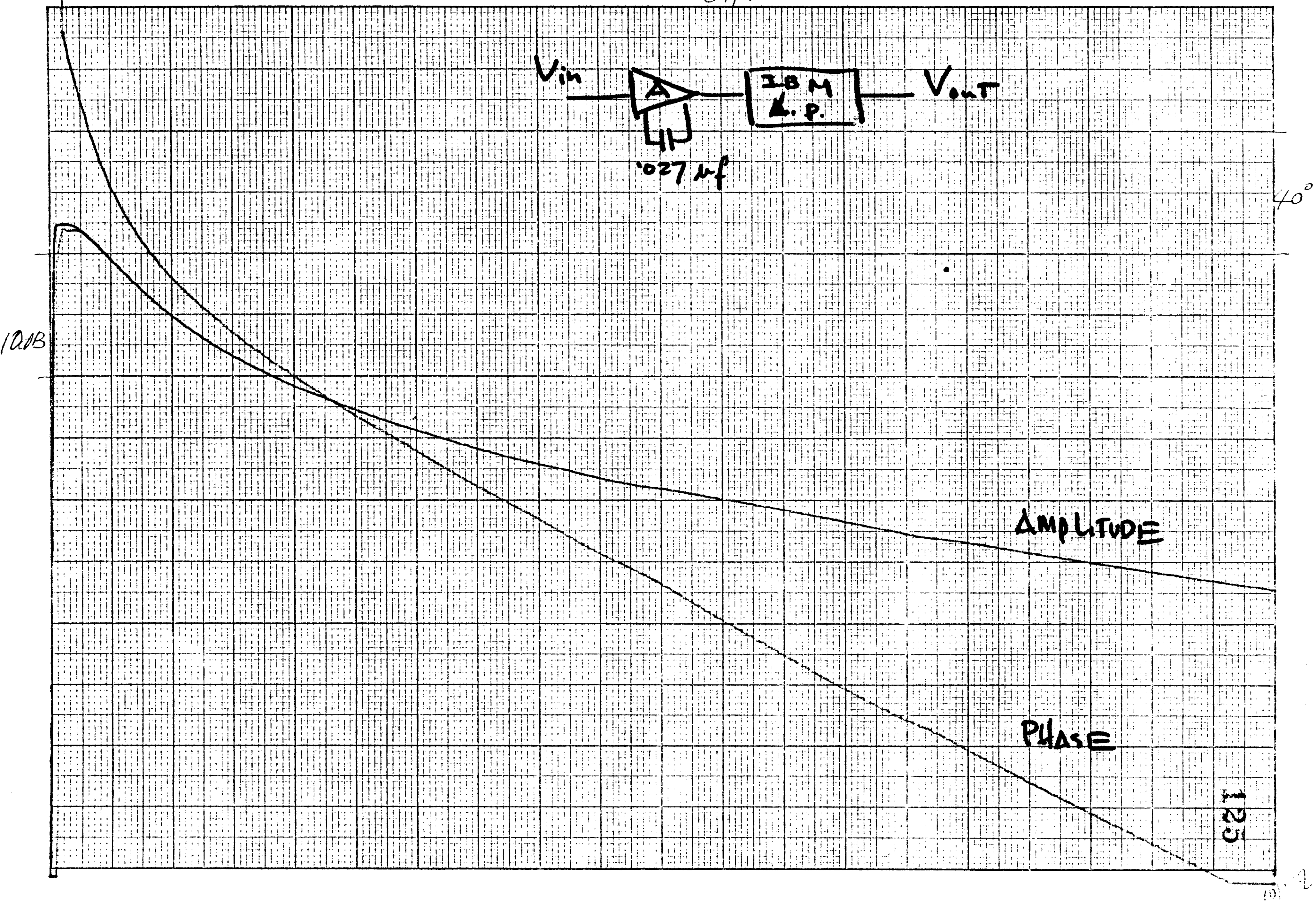

SA 850 FREQUENCY RESPONSE OF AMPLIFIER
AND LOWPASS FILTER (CASE-2)
R = 1000 OHMS
C1 (D.C. BLOCKING CAP) = 0.1 UF
C2 (LOW PASS CAP) = 680 PF
AMPLITUDE
PHASE
MAGNITUDE x10
0
1
2
3
4
5
6
7
8
9
PHASE (DEGREES)
-0.
-30.00
-60.00
-90.00
-120.00
-150.00
-180.00
FREQUENCY (MHZ)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

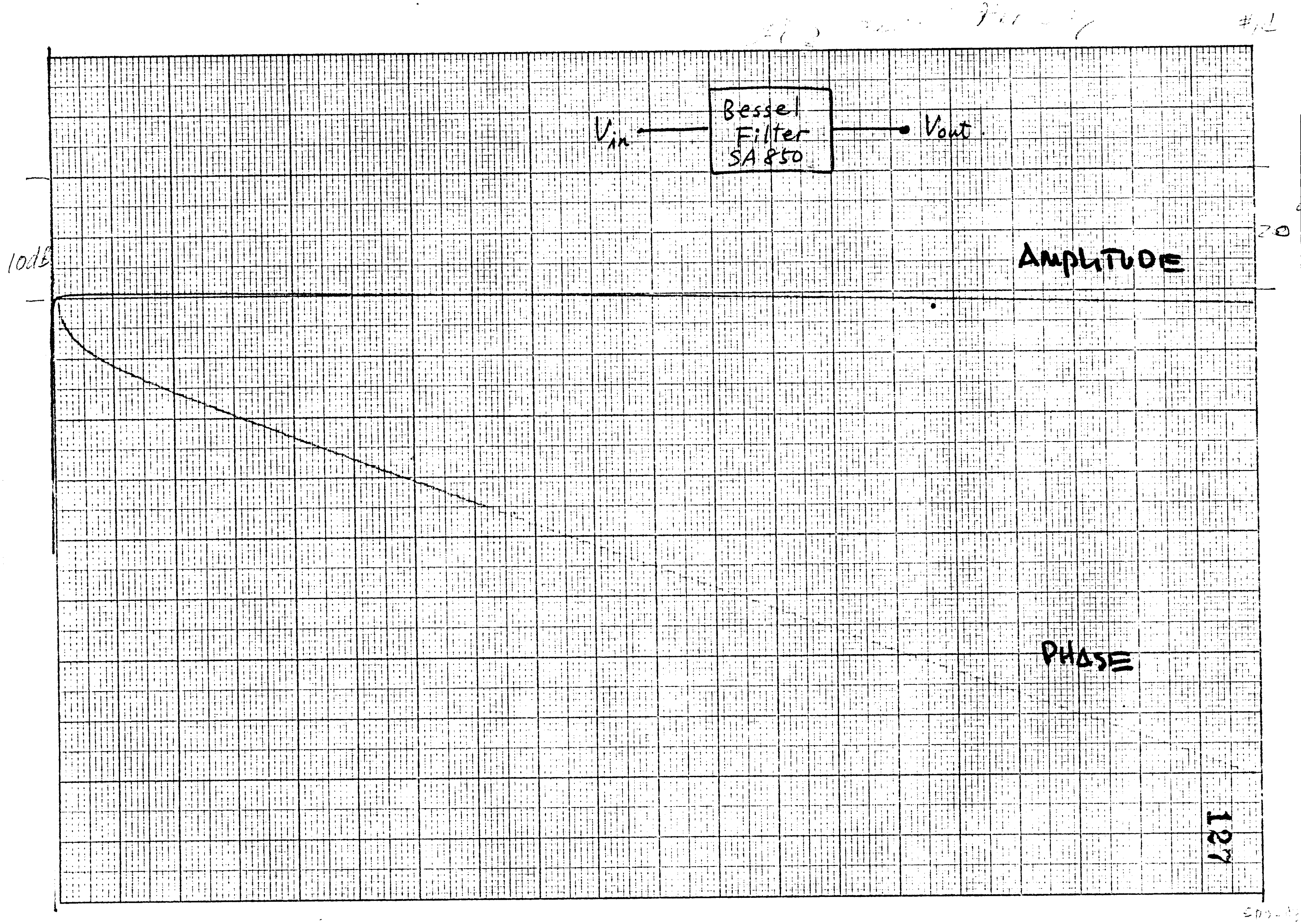
\# 13

L.P.



L.P.

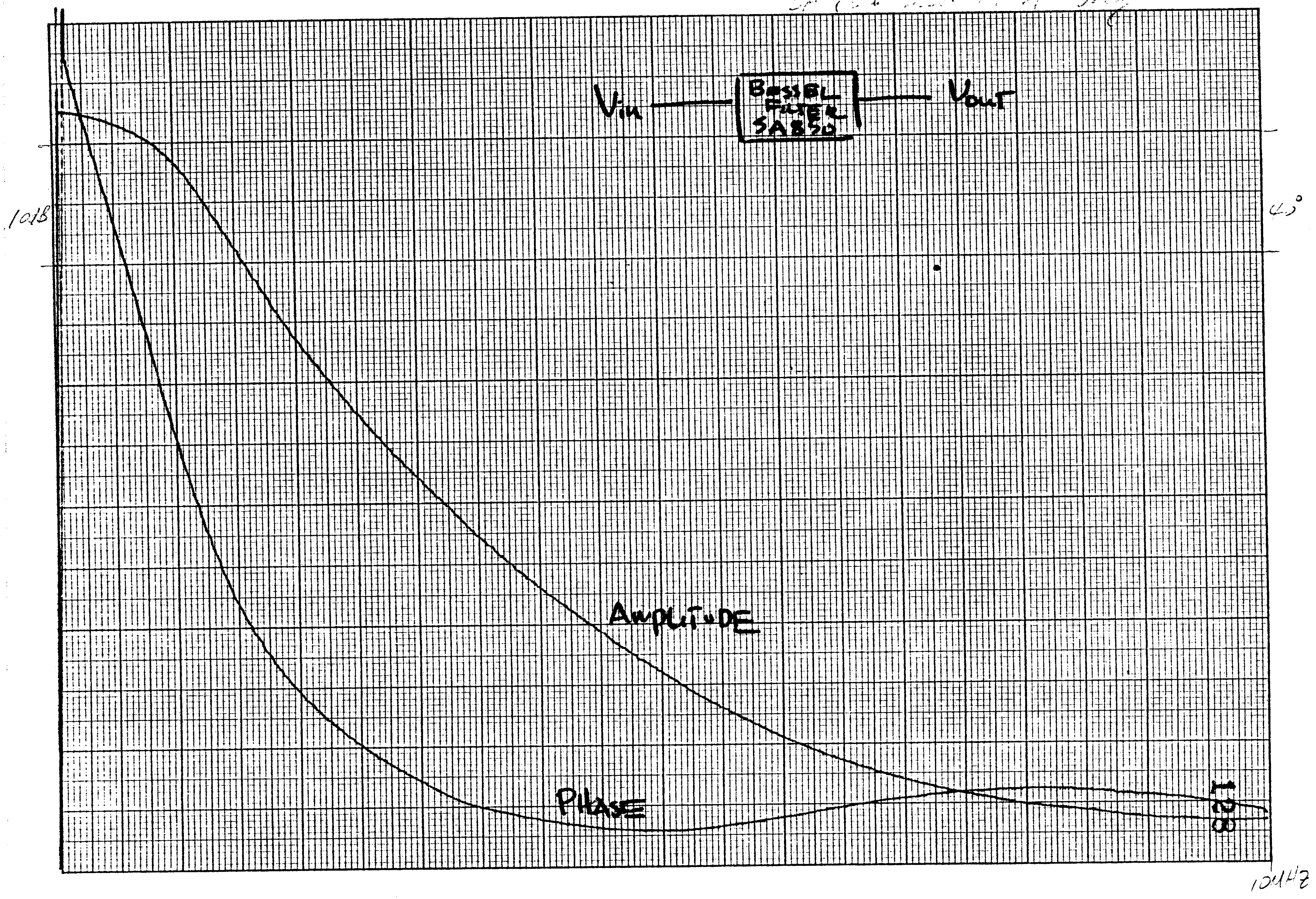


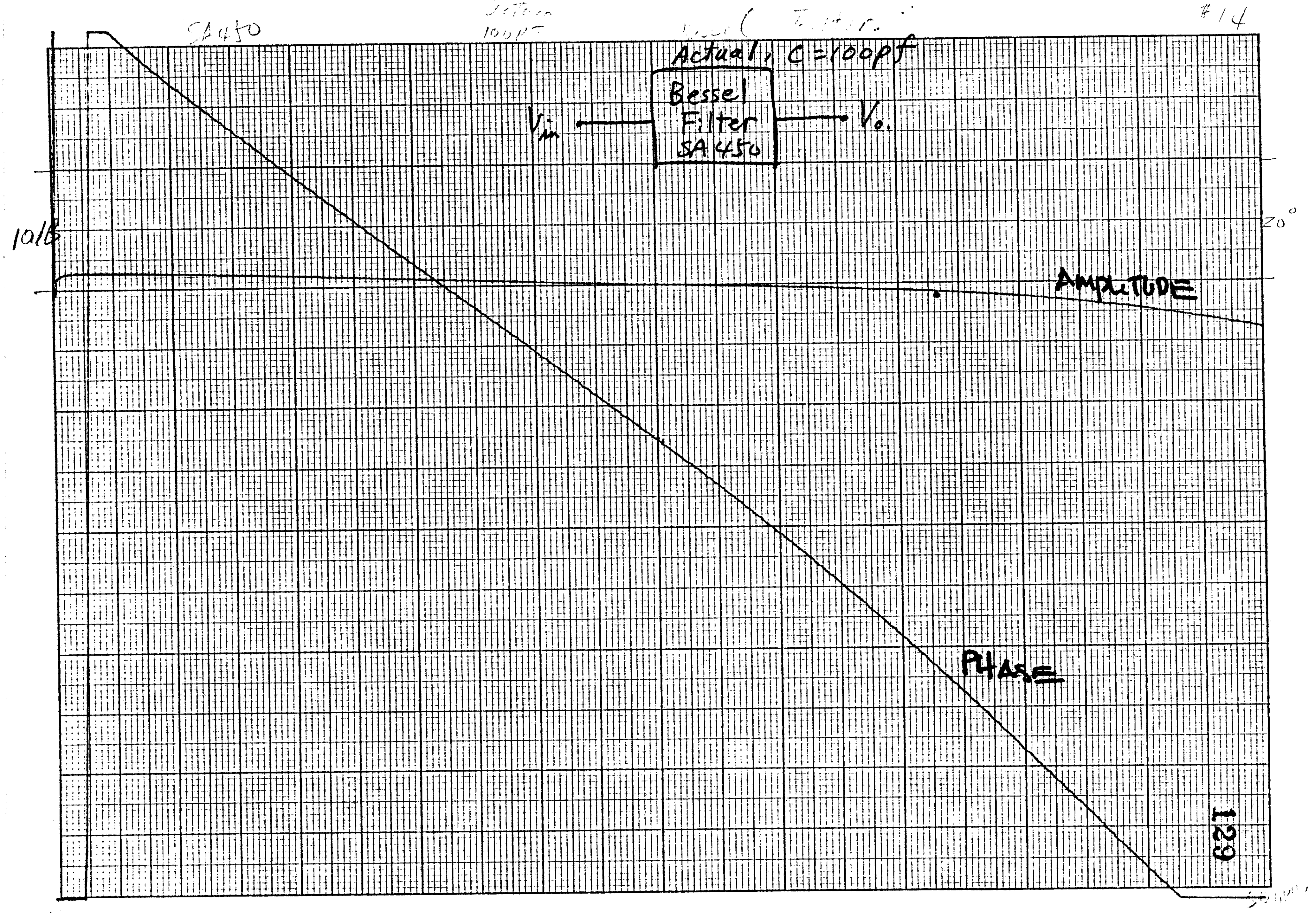

Vin
Bessel Filter SA 850
Vout
10dB
20
AMPLITUDE
PHASE

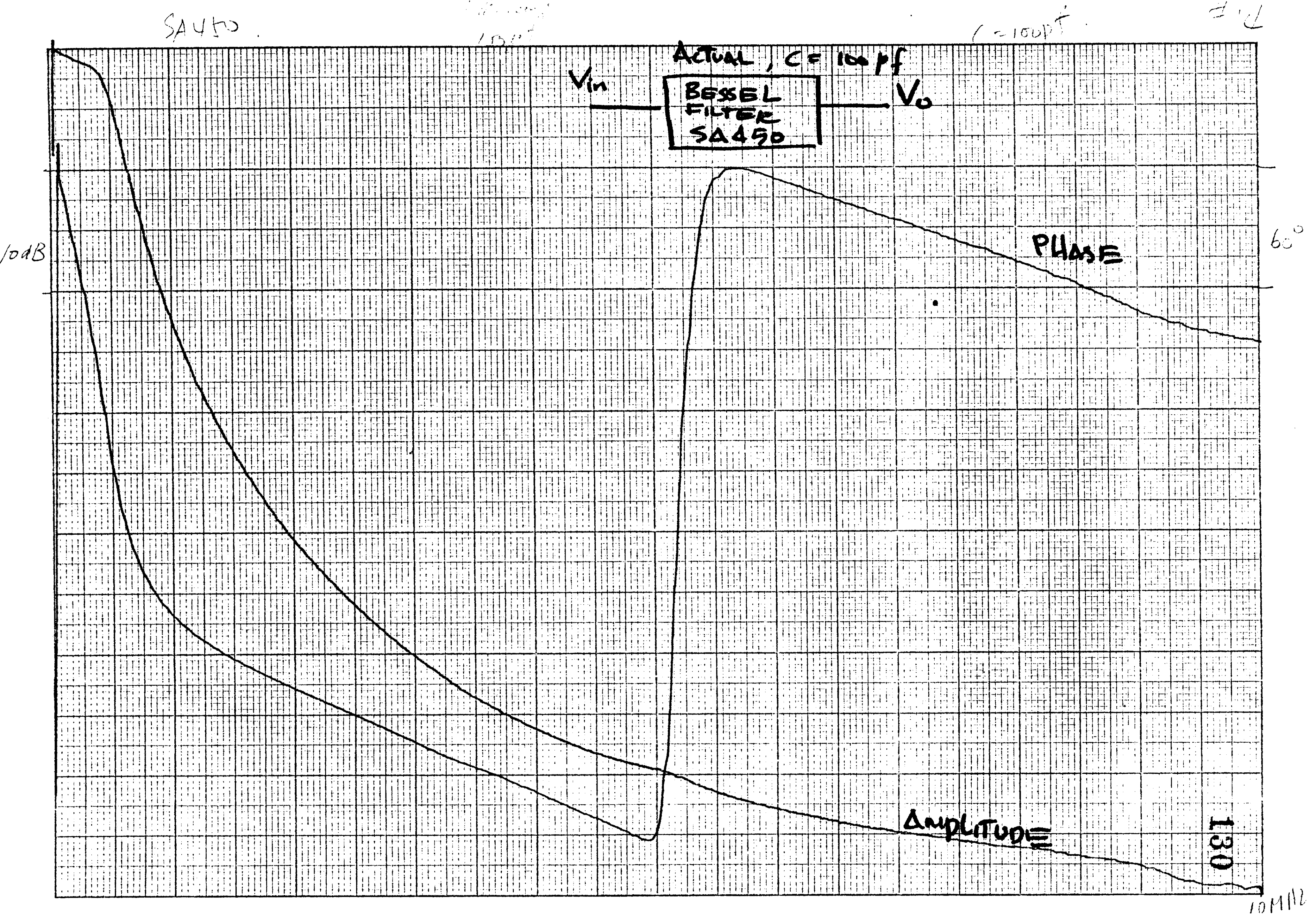
K+E 20 X 20 TO THE INCH 46 1240
7 X 10 INCHES MADE IN U. S. A.
KEUFFEL & ESSER CO.

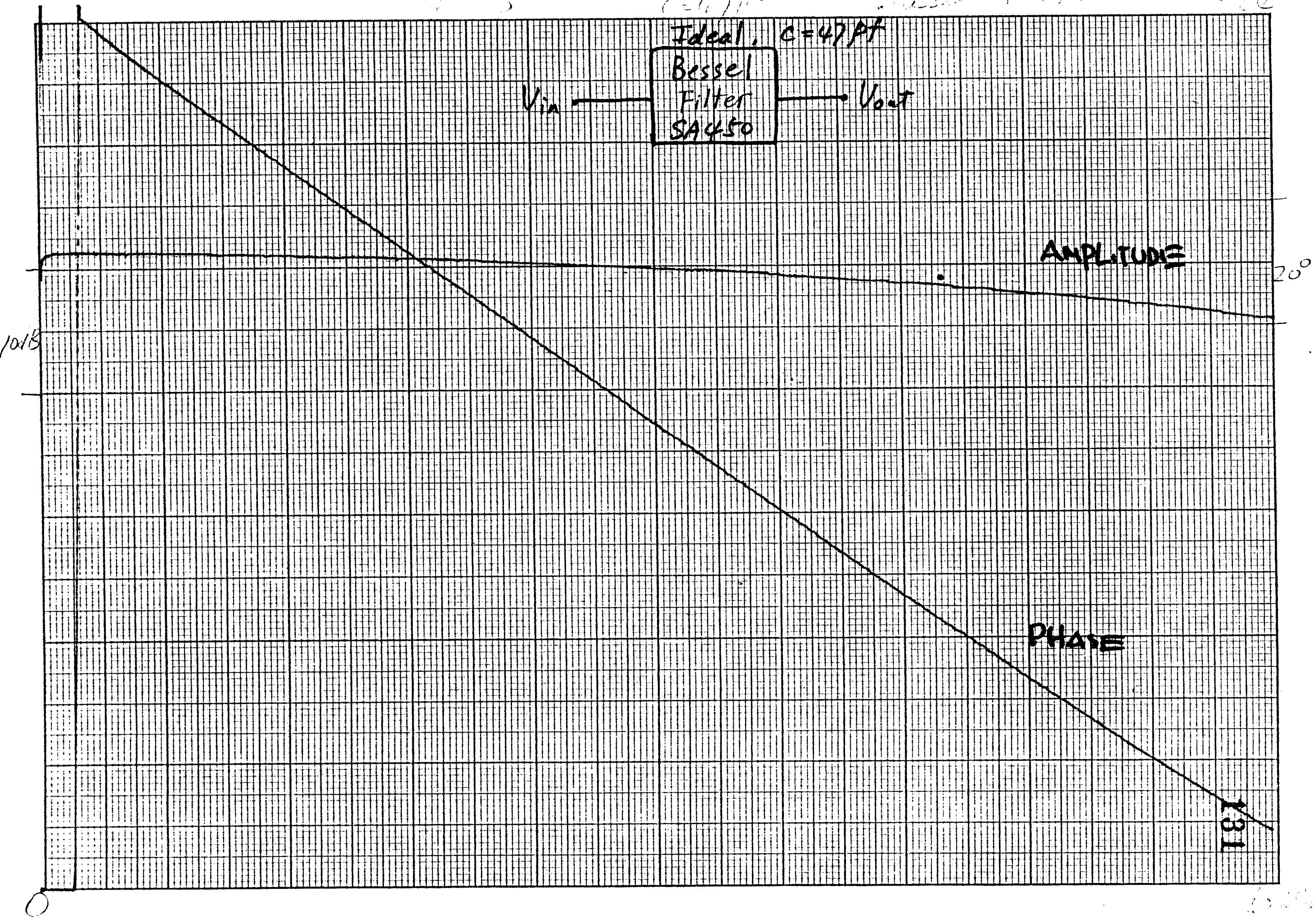
#12

SA [illegible] only

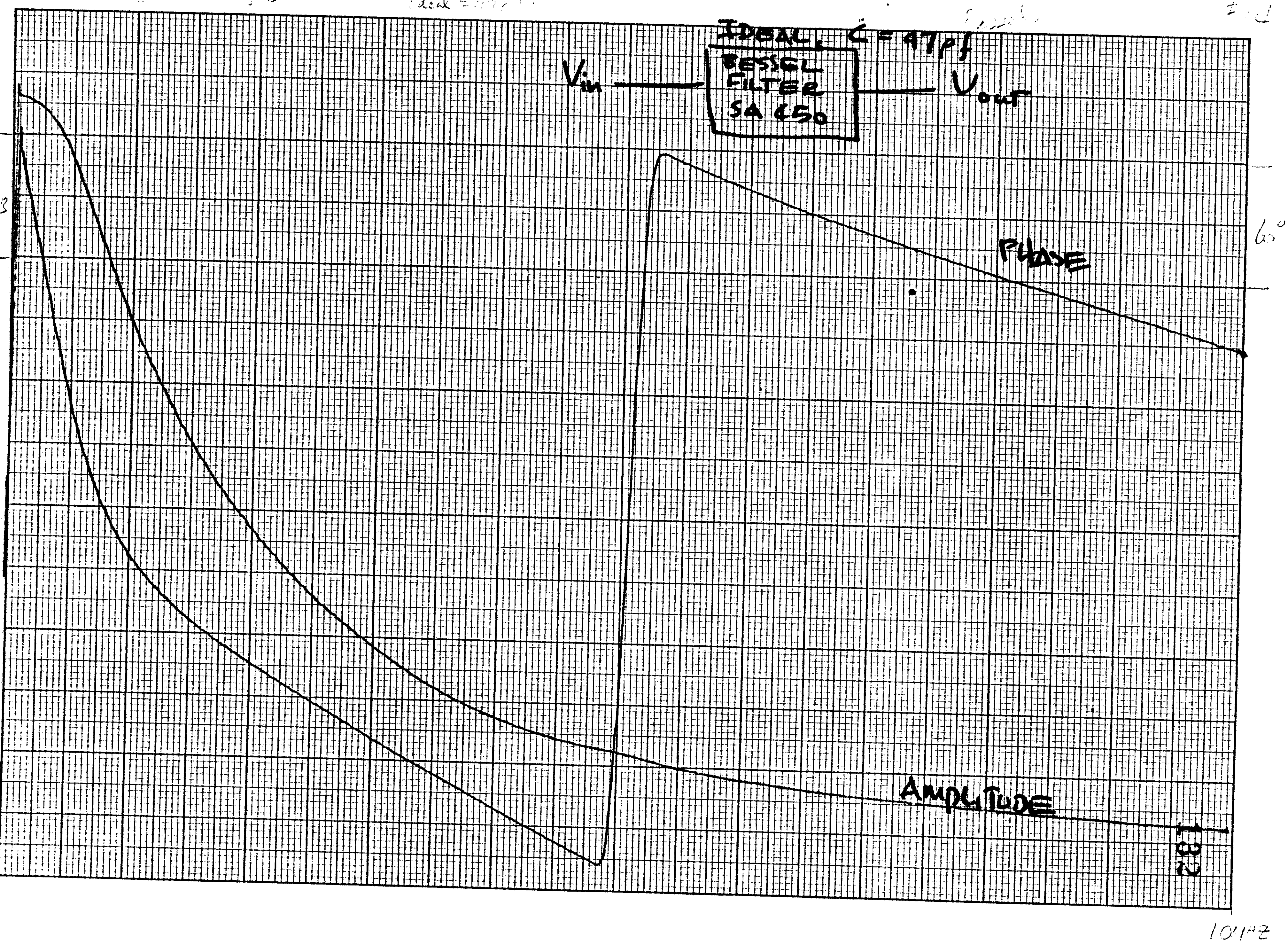



SA450
Actual 100pF
Bessel Filter
#14
Actual, C=100pf
Bessel Filter SA450
V_{in}
V_o
1dB
20°
AMPLITUDE
PHASE


SA450
C=100pF
ACTUAL, C= 100 pf
Vin
BESSEL FILTER SA450
Vo
10dB
60°
PHASE
AMPLITUDE
10MHz

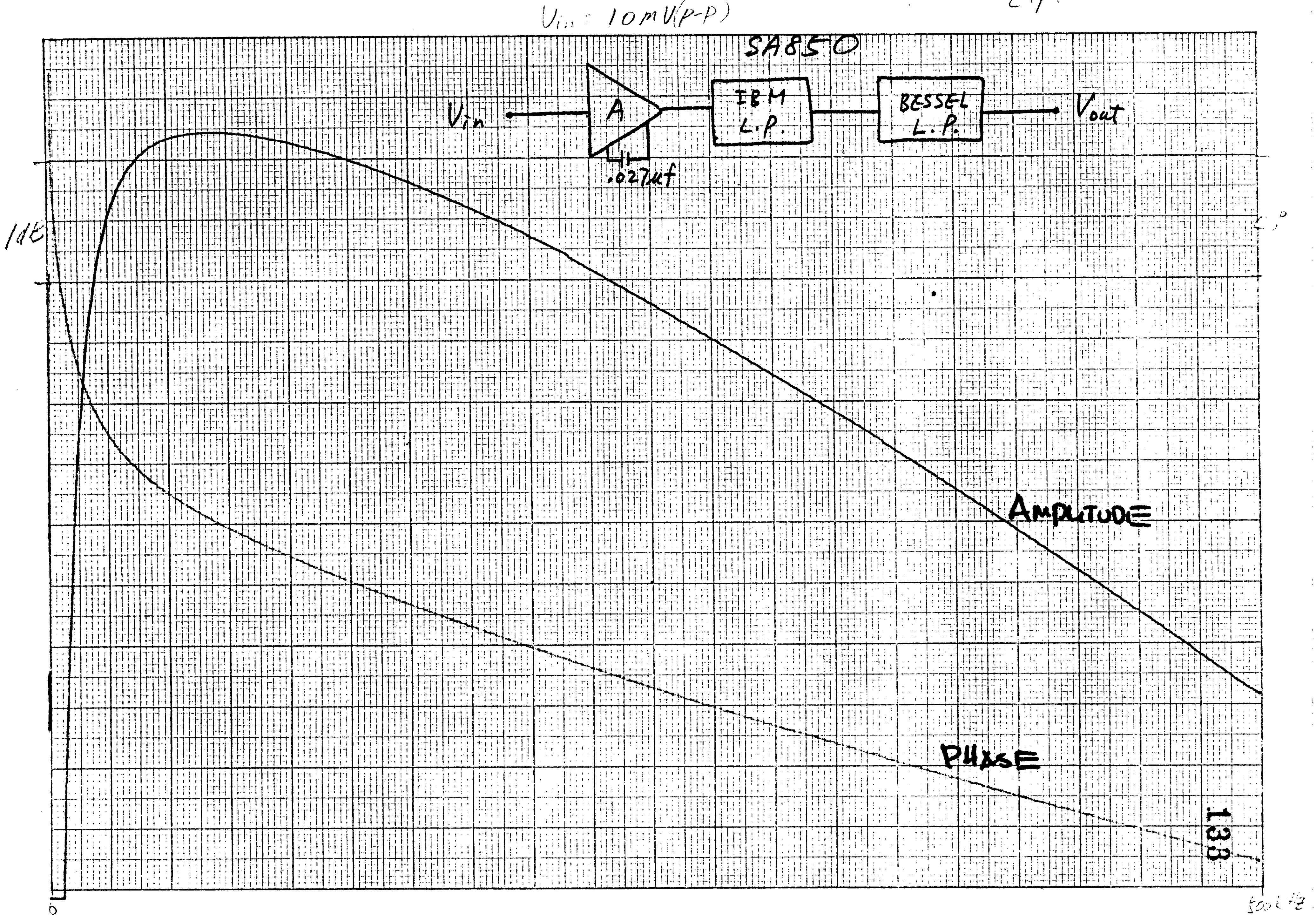

Ideal, C=47pf
Bessel
Filter
SA450
Vin
Vout
AMPLITUDE
20°
1dB
PHASE
0

SA450 Ideal C=47pf.

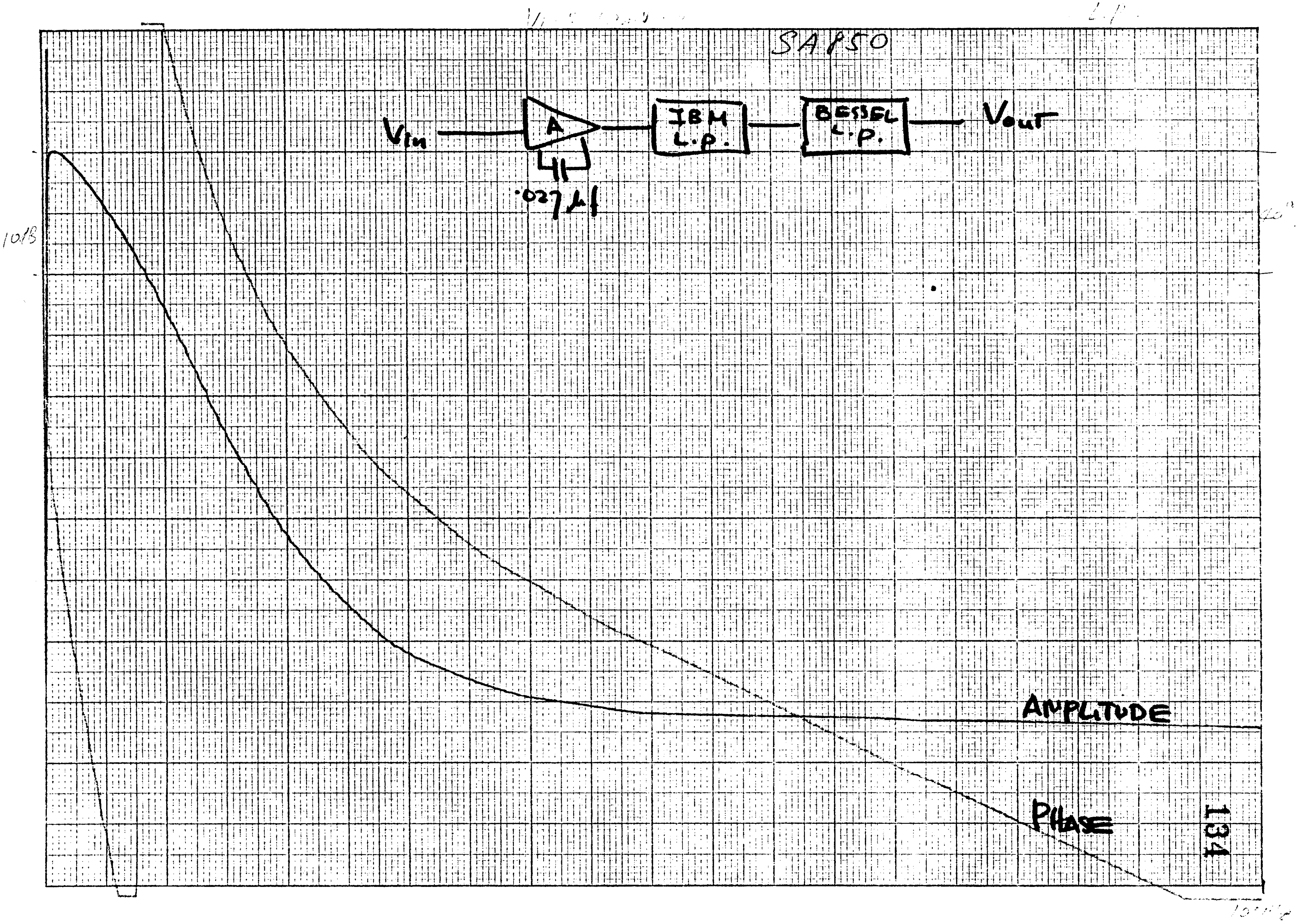


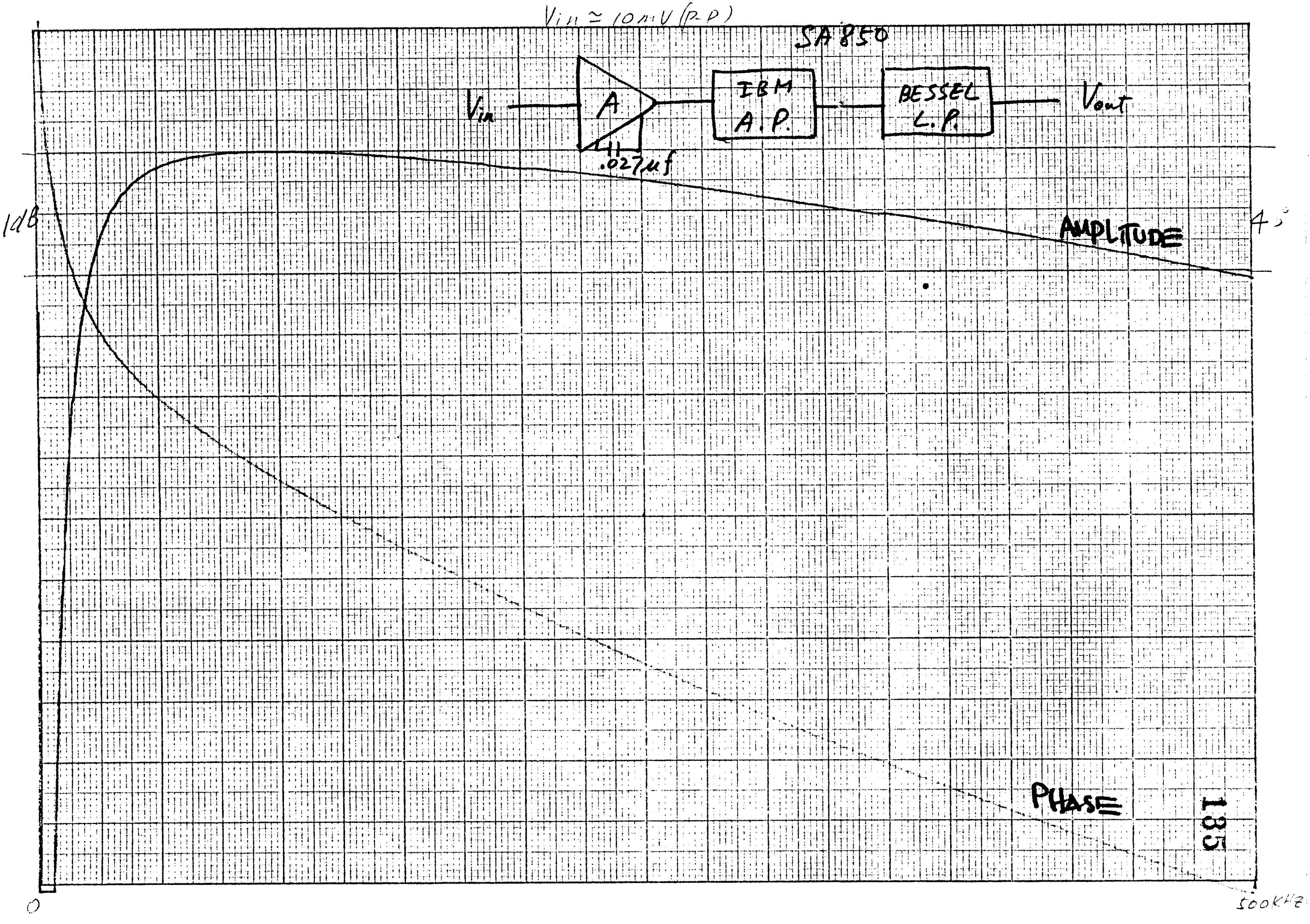
15

L.P.


Vin: 10mV(p-p)
SA850
Vin
A
.027μf
IBM L.P.
BESSEL L.P.
Vout
1dB
AMPLITUDE
PHASE
0
500kHz

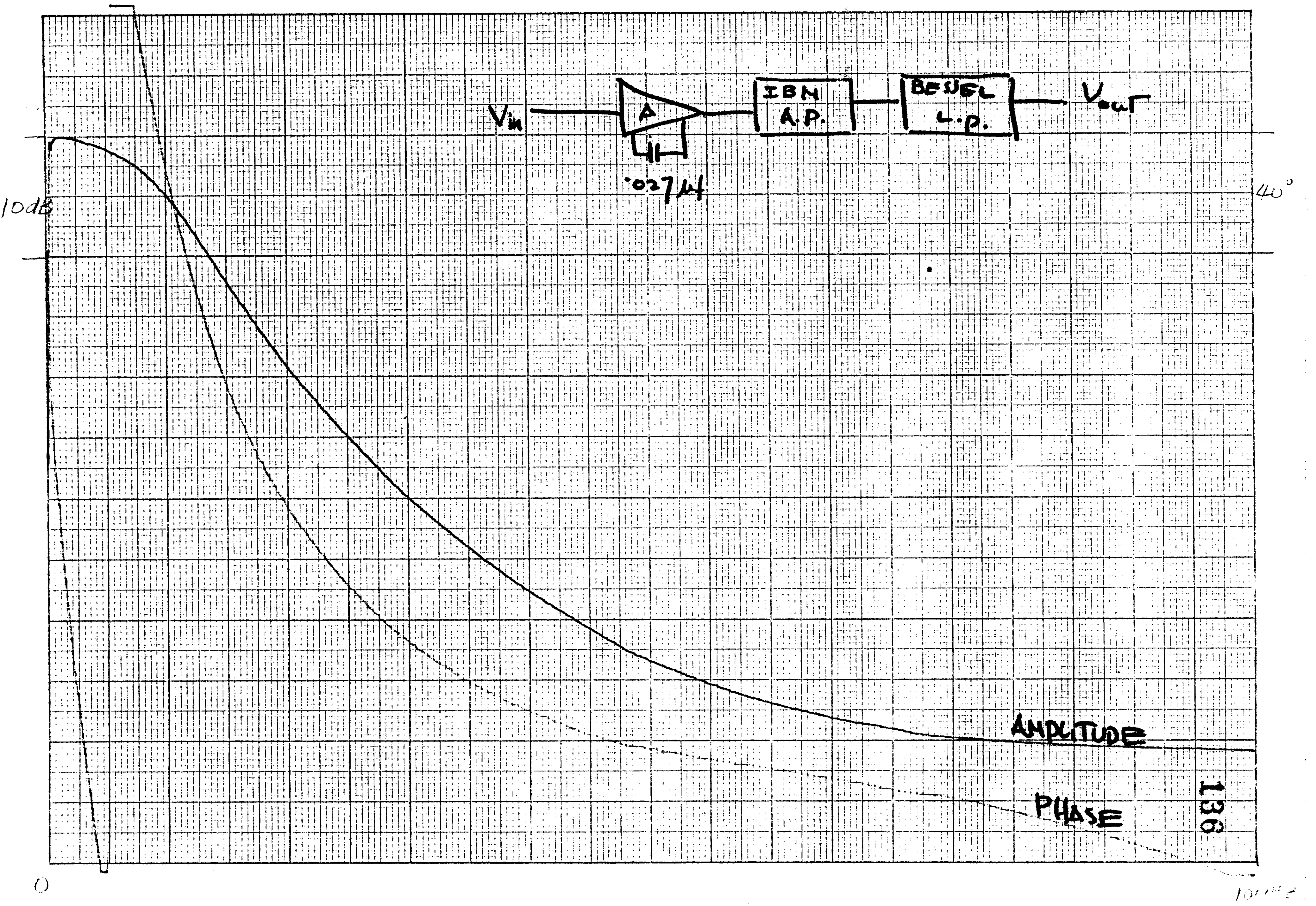
#15


SA850
Vin
A
.027 μf
IBM L.P.
BESSEL L.P.
Vout
1dB
40°
AMPLITUDE
PHASE
L.P.
10 Hz

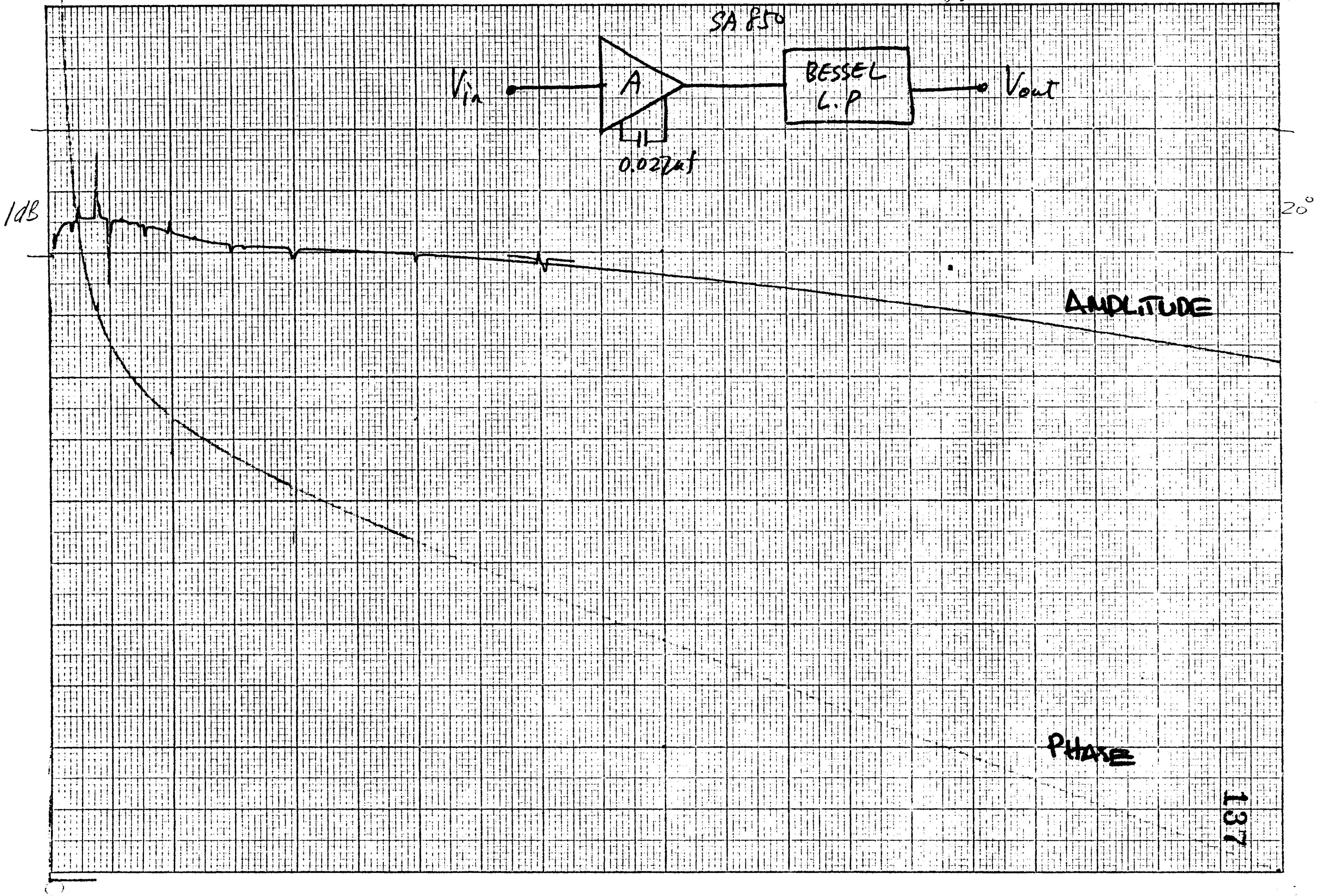

Vin ≈ 10mV (p-p)
SA850
Vin
A
IBM A.P.
BESSEL L.P.
Vout
.027uf
1dB
4°
AMPLITUDE
PHASE
185
0
500KHz

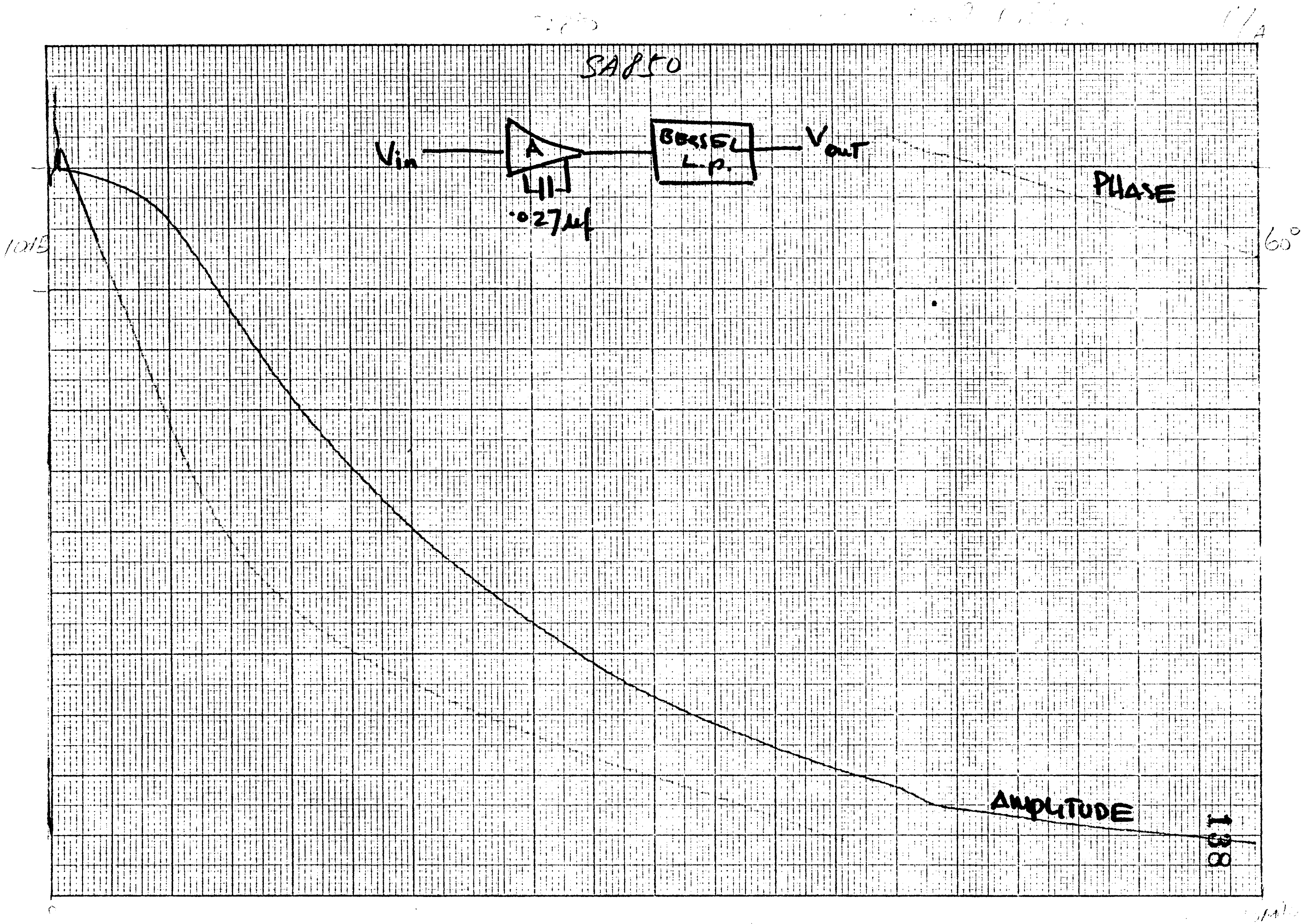
A.P

#6


Vin
A
.027μf
IBM
A.P.
BESSEL
L.p.
Vout
10dB
40°
AMPLITUDE
PHASE
0
10KHz

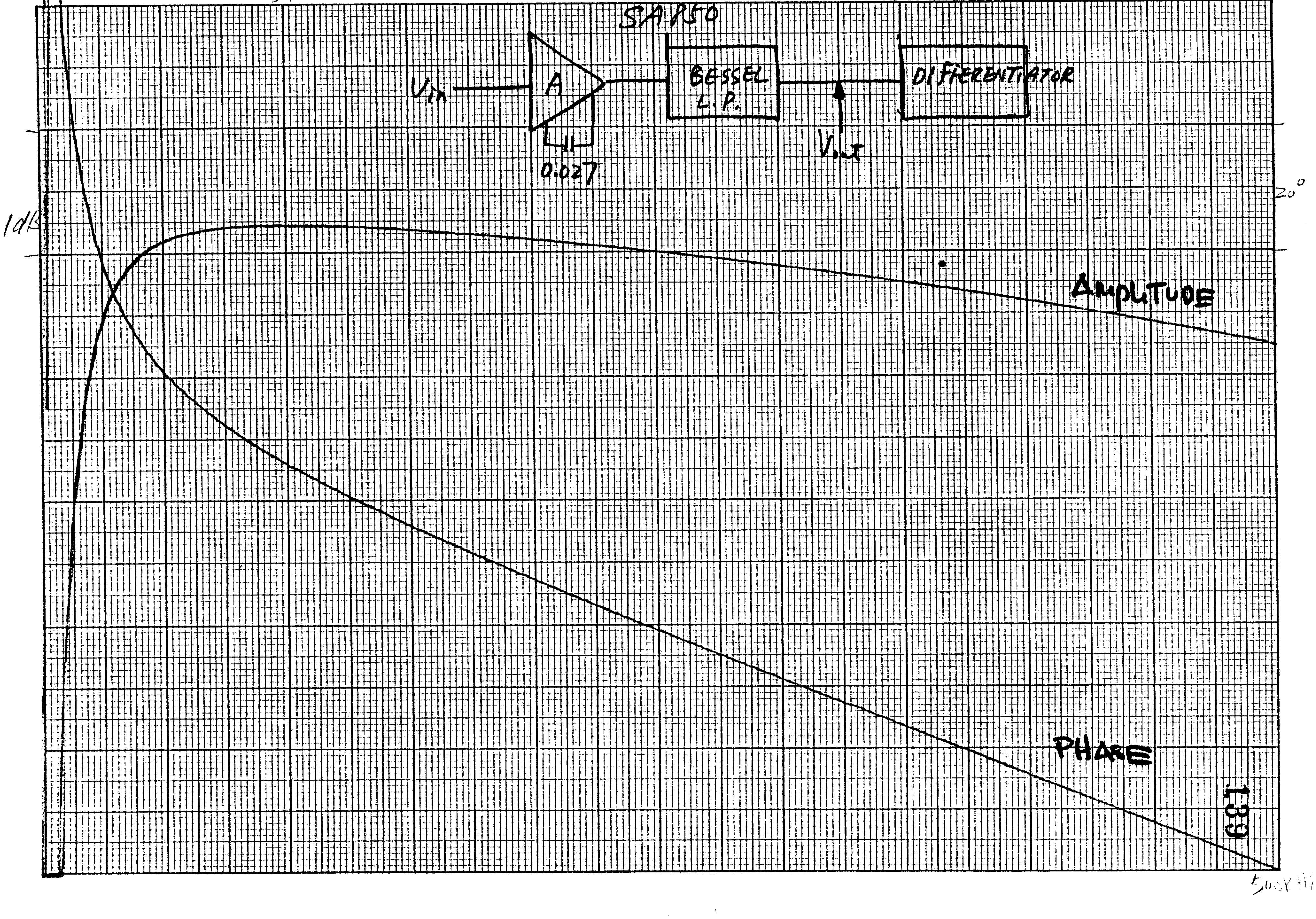
Bessel Filter




SA850
Vin
A
.027µf
BESSEL L.P.
Vout
PHASE
1015
60°
AMPLITUDE
180

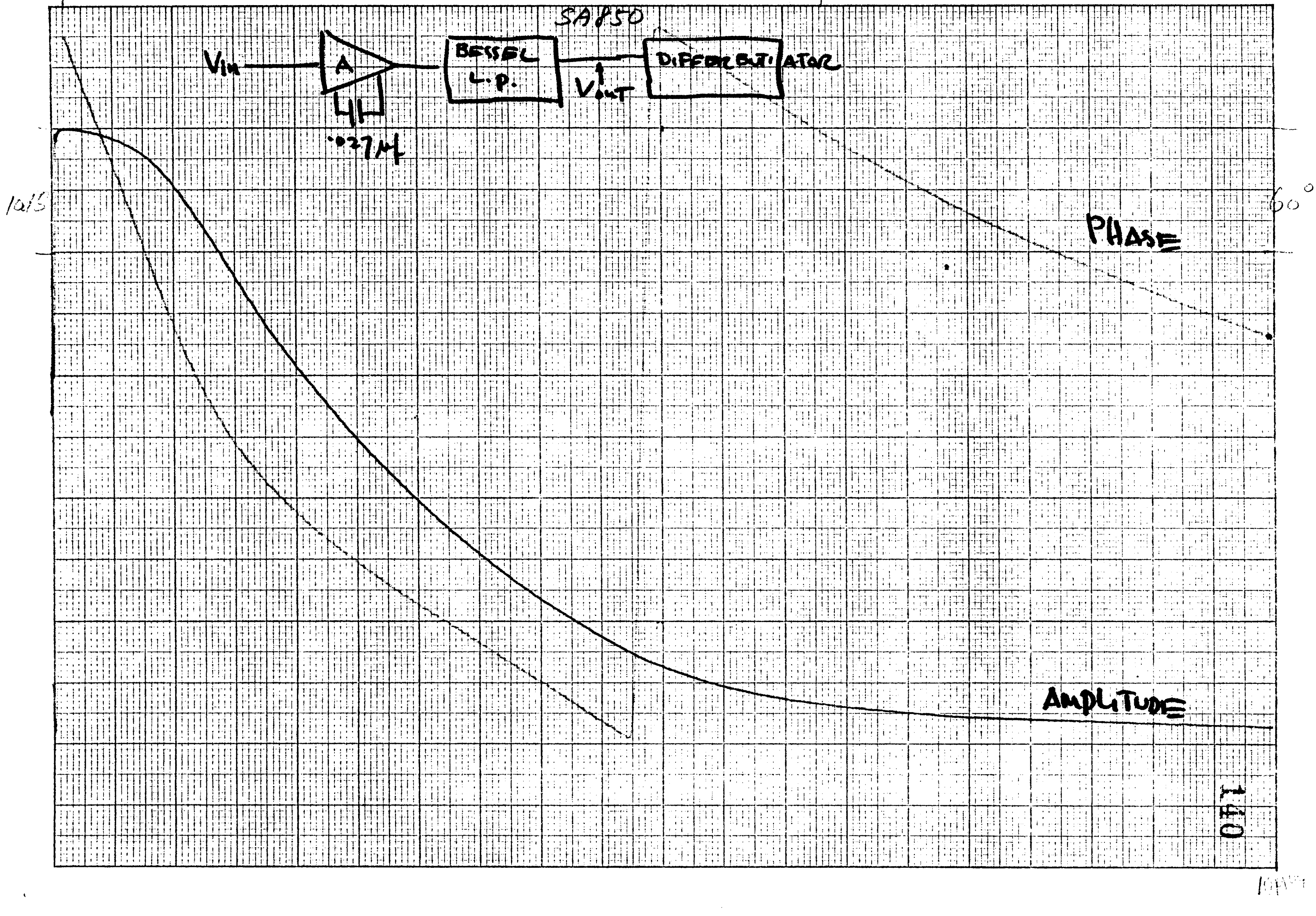
SA850

Amp, Filter & differentiator #11B



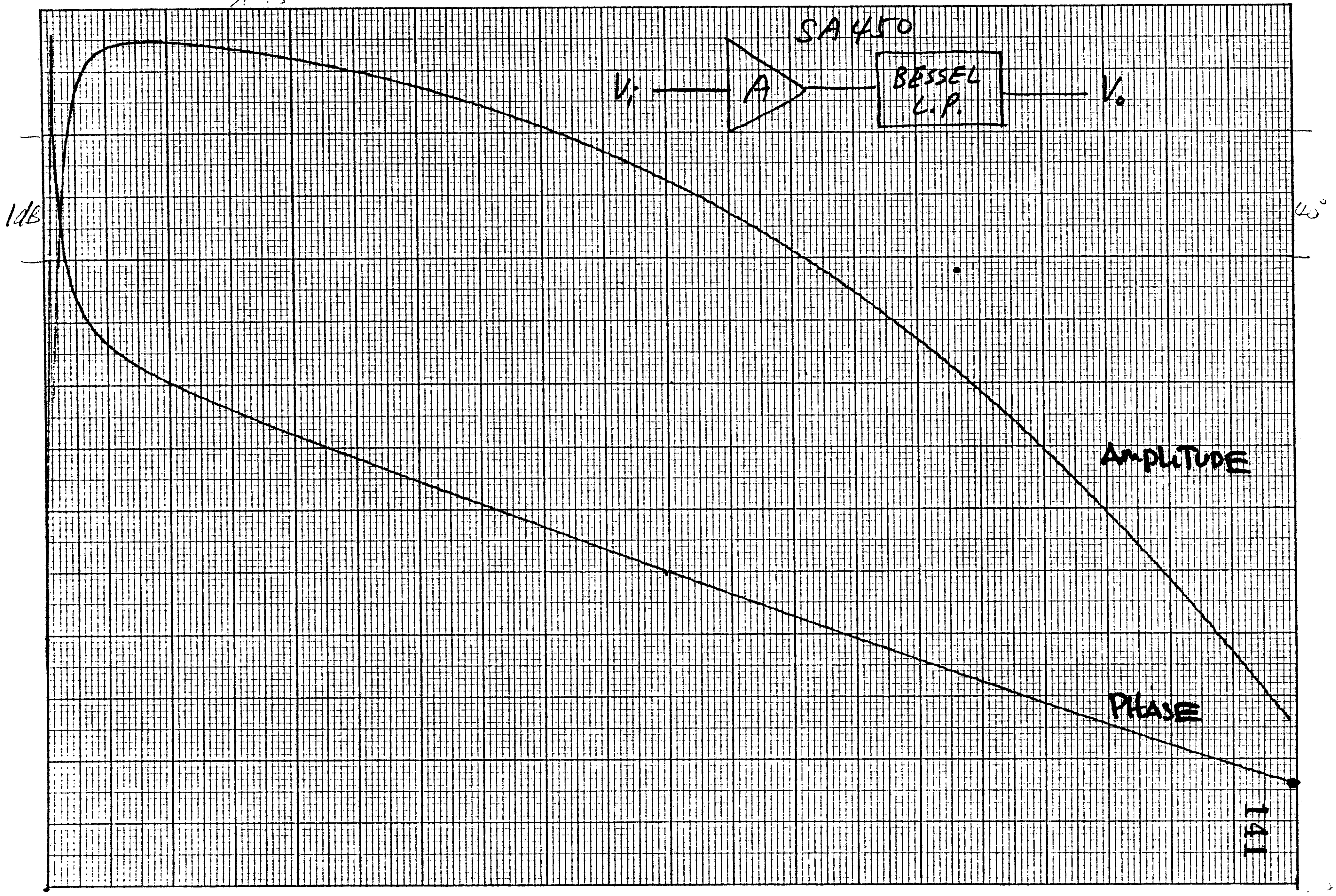
SA850

[illegible] #17B


SA850
Vin
A
.027M
BESSEL
L.P.
Vout
DIFFERENTIATOR
10dB
60°
PHASE
AMPLITUDE
0Hz
10MHz

SA450

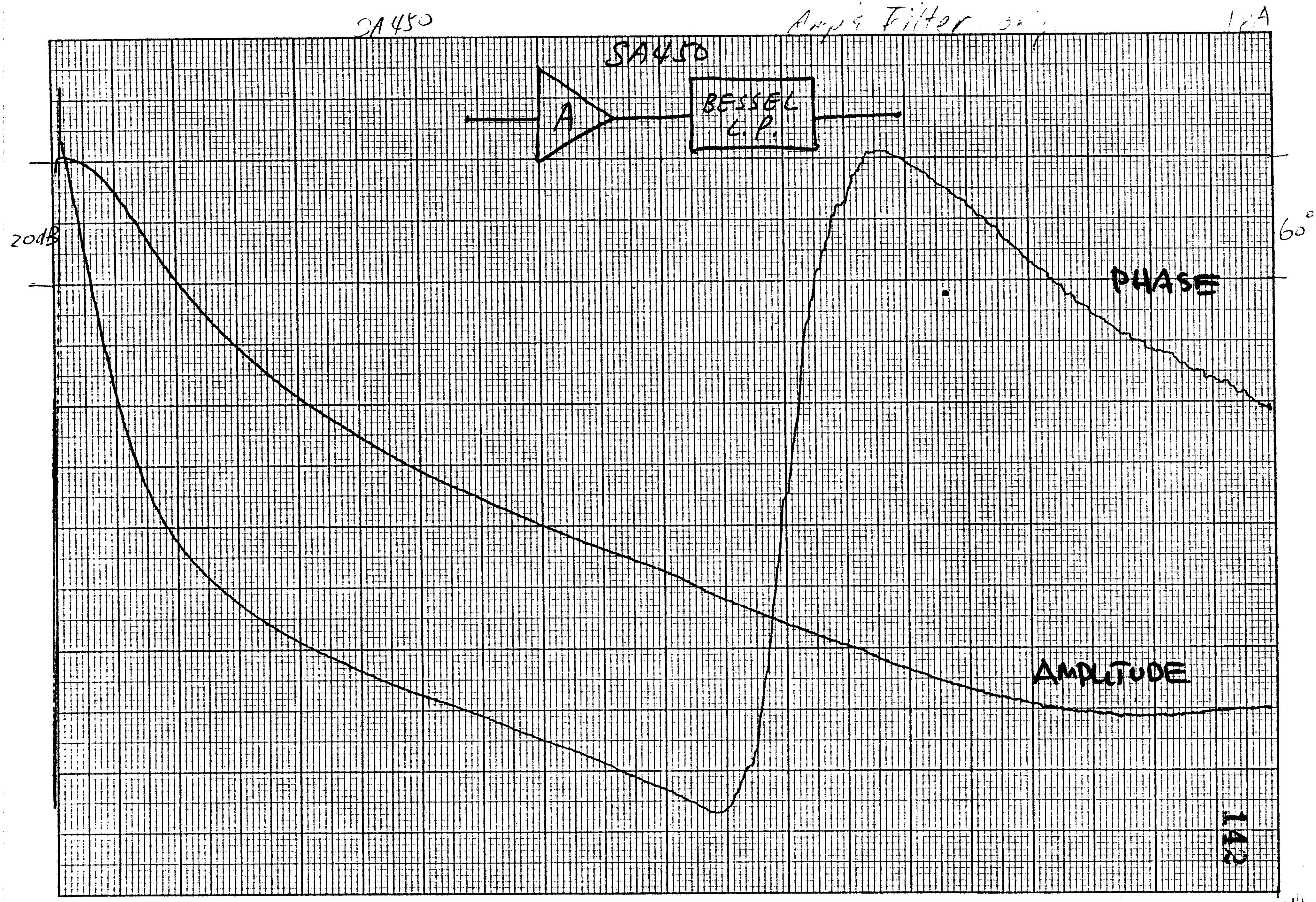
#18A



SA450

Amp & Filter only

12A

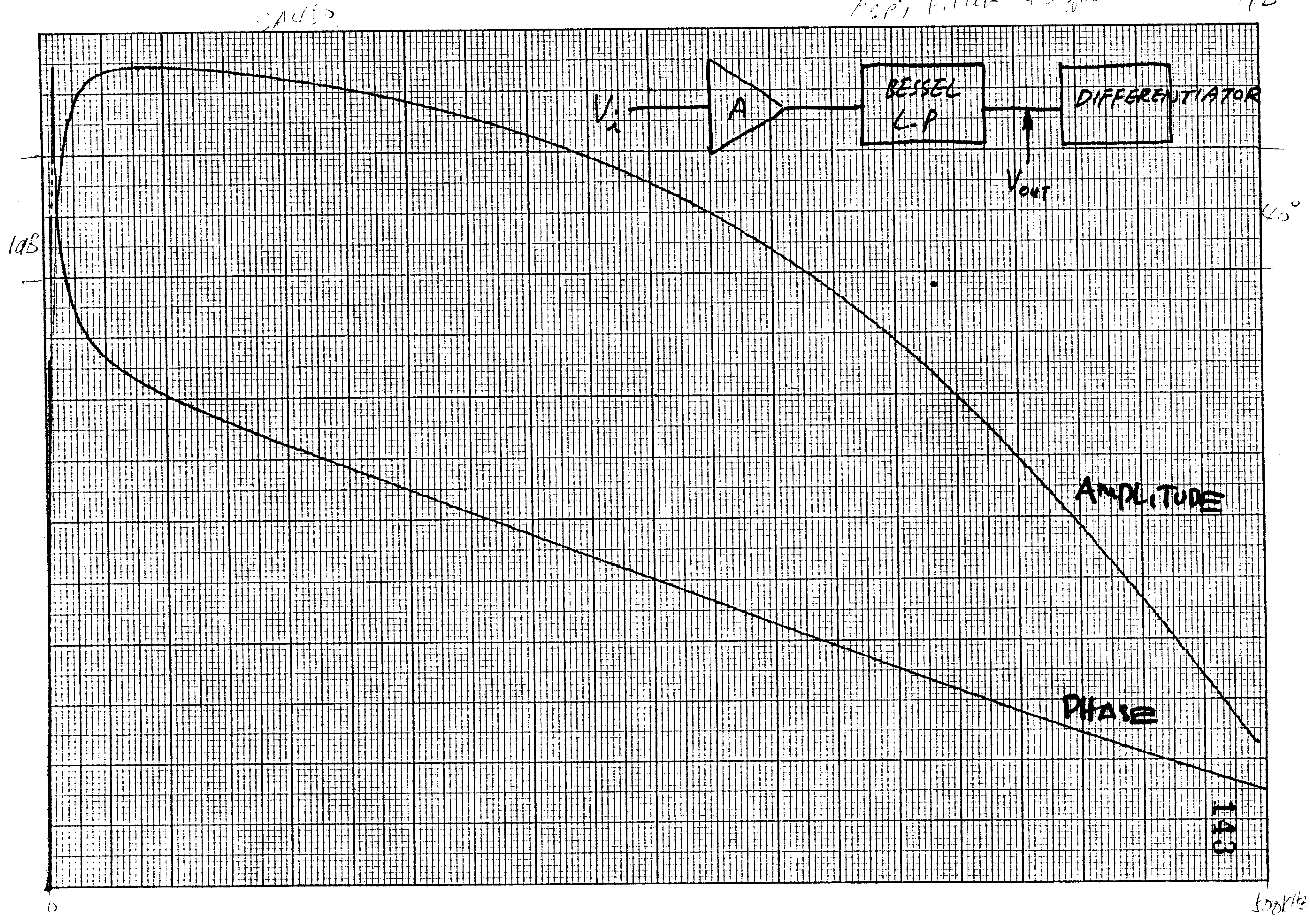


10MHz

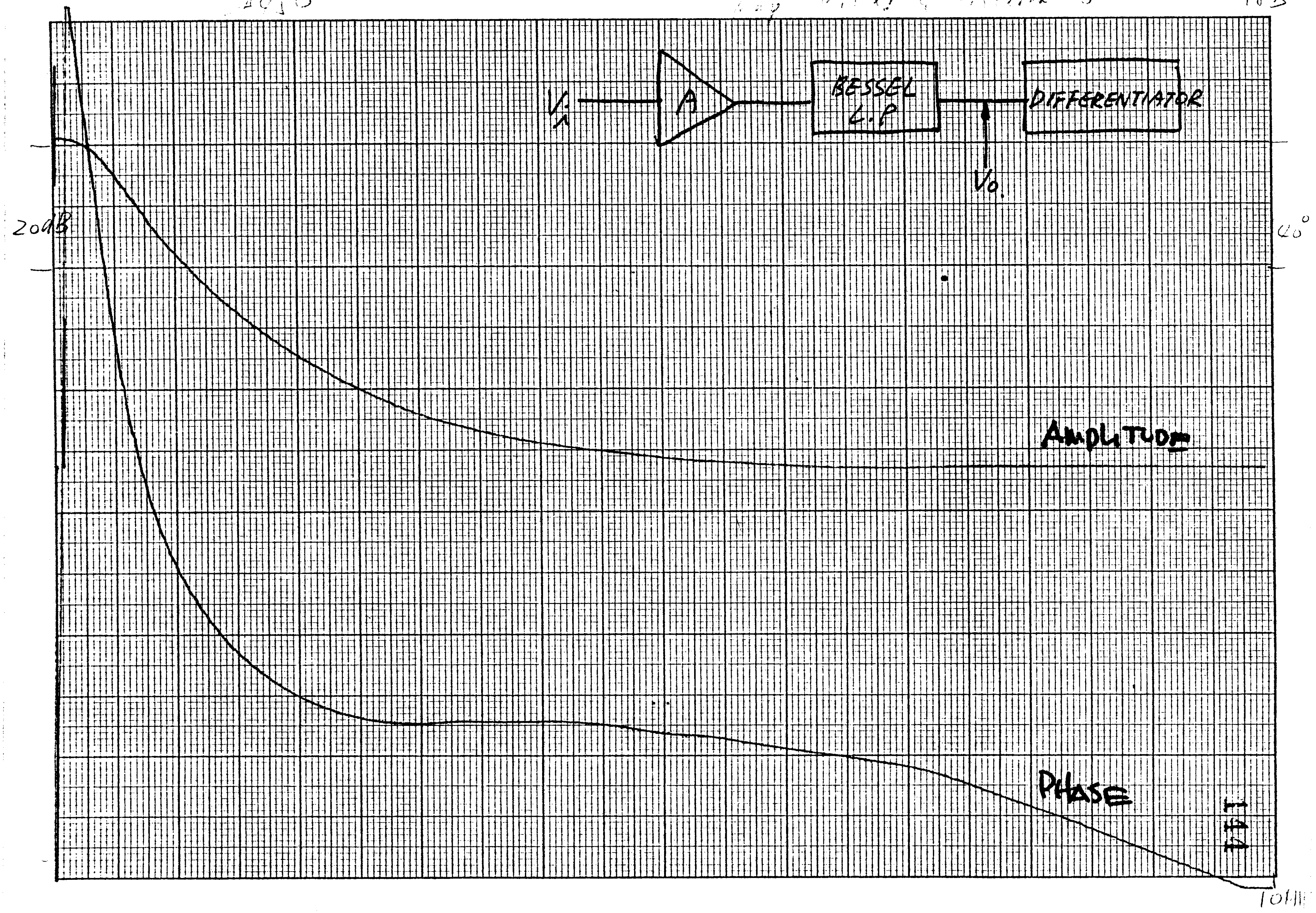
142

K+E 20 X 20 TO THE INCH 46 1240
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

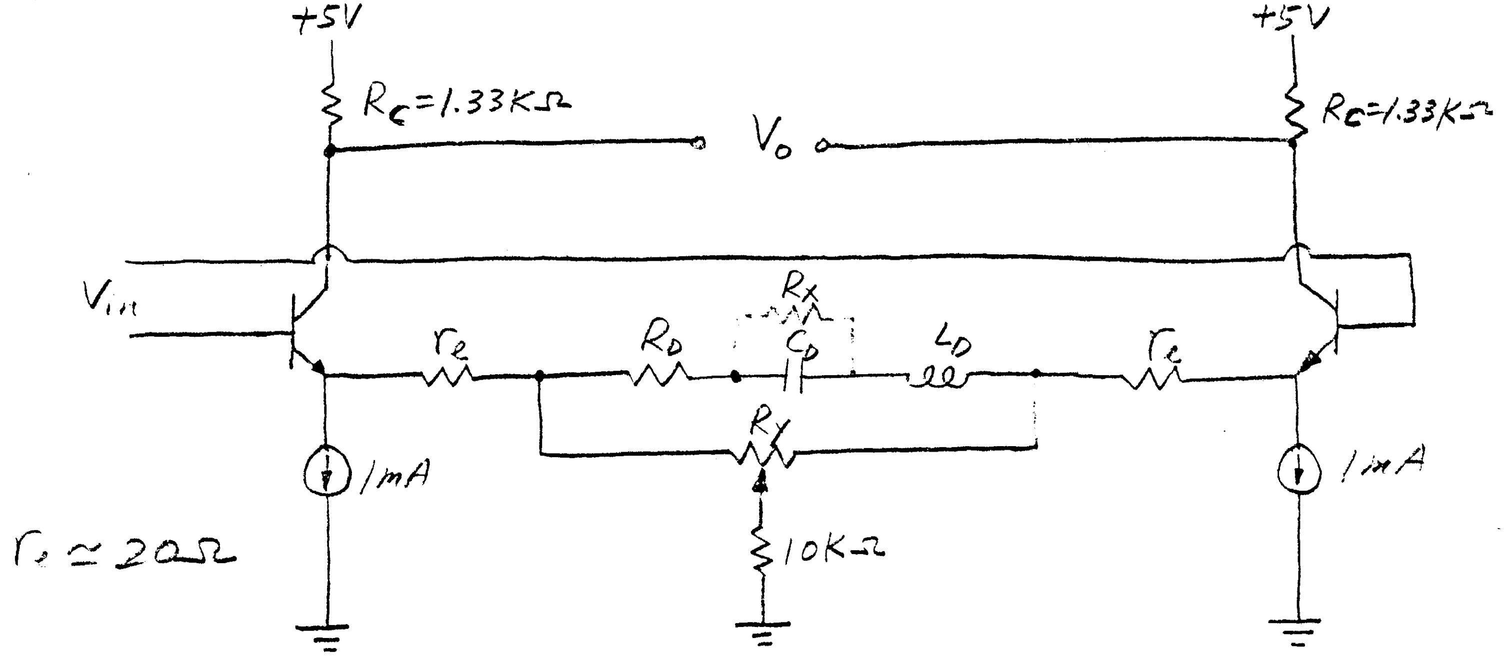
Ampl Filter & differentiator 11B



[illegible] [illegible] 18B


V_i
A
BESSEL L.P
DIFFERENTIATOR
V_o
20dB
40°
AMPLITUDE
PHASE
10MHz

E-1 Derivation of differentiator transfer function with/without parallel resistor:



The current source according to calculation is 1.8mA. For conservative reason, 1mA is being used for the following analysis. For A.C. analysis purpose, resistors R_Y & 10KΩ are ignored. They are there to adjust D.C. offset (asymmetry).

Case I — R_x does not exist :

$$\frac{V_o}{V_i} = \frac{R_C}{2r_e + Z}$$

$$Z = R_D + SL_D + \frac{1}{SC_D}$$

$$= \frac{SC_DR_D + S^2L_DC_D + 1}{SC_D}$$

$$\frac{V_o}{V_{in}} = \frac{R_c}{2r_e + \frac{SC_DR_D + S^2L_DC_D + 1}{SC_D}}$$

$$= \frac{R_c}{\frac{2SC_Dr_e + SC_DR_D + S^2L_DC_D + 1}{SC_D}}$$

$$= \frac{SC_DR_c}{S^2L_DC_D + S(2C_Dr_e + C_DR_D) + 1}$$

$$\boxed{T(S) = \frac{R_c}{L_D} \cdot \frac{S}{S^2 + S\left(\frac{2r_e + R_D}{L_D}\right) + \frac{1}{L_DC_D}}}$$

$$|\zeta| = \left(\frac{2r_e + R_D}{2}\right)\sqrt{\frac{C_D}{L_D}}$$

$$\omega_o = \sqrt{\frac{1}{L_DC_D}}$$

Case II — $R_x \parallel C_D$:

$$R_x \parallel C_D = \frac{R_x \cdot \frac{1}{SC_D}}{R_x + \frac{1}{SC_D}}$$

$$= \frac{R_x}{SC_DR_x + 1}$$

$$Z = R_D + SL_D + \frac{R_x}{SC_DR_x + 1}$$

$$= \frac{SC_DR_DR_x + S^2L_DC_DR_x + SL_D + R_D + R_x}{SC_DR_x + 1}$$

$$Z = \frac{S^2 L_D C_D R_x + S(L_D + C_D R_D R_x) + R_D + R_x}{S C_D R_x + 1}$$

$$T(S) = \frac{V_o}{V_i} = \frac{R_D}{2r_e + \frac{S^2 L_D C_D R_x + S(L_D + C_D R_D R_x) + R_D + R_x}{S C_D R_x + 1}}$$

$$= \frac{S C_D R_x R_D + R_D}{S^2 L_D C_D R_x + S(L_D + C_D R_D R_x - 2r_e C_D R_x) + R_D + R_x + 2r_e}$$

$$= \frac{R_D\left(S + \frac{1}{C_D R_x}\right)}{L_D\left(S^2 + S\left(\frac{L_D + C_D R_D R_x - 2r_e C_D R_x}{L_D C_D R_x}\right) + \frac{R_D + R_x + 2r_e}{L_D C_D R_x}\right.}$$

$$\boxed{T(S) = \frac{R_D}{L_D} \cdot \frac{\left(S + \frac{1}{C_D R_x}\right)}{\left(S^2 + S\left(\frac{1}{C_D R_x} + \frac{R_D + 2r_e}{L_D}\right) + \frac{1}{L_D C_D}\right)}} \qquad (R_x \gg 2r_e + R_D)$$

$$|\zeta| = \frac{\sqrt{L_D C_D}}{2}\left(\frac{1}{C_D R_x} + \frac{R_D + 2r_e}{L_D}\right)$$

$$\omega_o = \frac{1}{\sqrt{L_D C_D}}$$

We can see how a zero is being moved from infinity to $-\frac{1}{C_D R_x}$ by comparing both cases. The self-resonant frequency is not effected and the damping factor is only effected by a negligible amount.

To carry case II further, since this is the circuit that is being used on our SA850/450 drives,

$$T(s) = \frac{R_c \quad s+\frac{1}{C_0 R_x}}{L_D\,(s^2+2\zeta s+\omega_0^2)}$$

$$= \frac{R_c}{L_D}\,\frac{s+\frac{1}{C_0 R_x}}{\left(s+\zeta+\sqrt{\zeta^2-\omega_0^2}\right)\left(s+\zeta-\sqrt{\zeta^2-\omega_0^2}\right)}$$

$$T(j\omega) = \frac{R_c}{L_D}\,\frac{\sqrt{\omega^2+\left(\frac{1}{C_0 R_x}\right)^2}\ \angle \tan^{-1} C_0 R_x \omega}{\left(j\omega+\zeta+j\sqrt{\omega^2-\zeta^2}\right)\left(j\omega+\zeta-j\sqrt{\omega_0^2-\zeta^2}\right)}$$

$$= \frac{R_c}{L_D}\cdot\frac{\sqrt{\omega^2+\left(\frac{1}{C_0 R_x}\right)^2}}{\sqrt{\left[\left(\omega+\sqrt{\omega^2-\zeta^2}\right)^2+\zeta^2\right]\left[\left(\omega-\sqrt{\omega_0^2-\zeta^2}\right)^2+\zeta^2\right]}}\ \angle\theta(\omega)$$

$$A(\omega) = \frac{R_c}{L_D}\,\frac{\sqrt{\omega^2+\left(\frac{1}{C_0 R_x}\right)^2}}{\sqrt{\left[(\omega^2+\omega_0^2)+2\omega\sqrt{\omega_0^2-\zeta^2}\right]\left[(\omega^2+\omega_0^2)-2\omega\sqrt{\omega^2-\zeta^2}\right]}}$$

$$= \frac{R_c}{L_D}\,\frac{\sqrt{\omega^2+\left(\frac{1}{C_0 R_x}\right)^2}}{\sqrt{(\omega^2+\omega_0^2)^2-\left(2\omega\sqrt{\omega_0^2-\zeta^2}\right)^2}}$$

$$\boxed{A(2\pi f) = \frac{R_c}{L_D}\,\frac{\sqrt{(2\pi f)^2+\left(\frac{1}{C_D R_x}\right)^2}}{\sqrt{\left[(2\pi f^2+2\pi f_0)^2\right]^2-\left[4\pi f\sqrt{(2\pi f_0)^2+\zeta^2}\right]^2}}} \qquad |\zeta| \leqslant 1$$

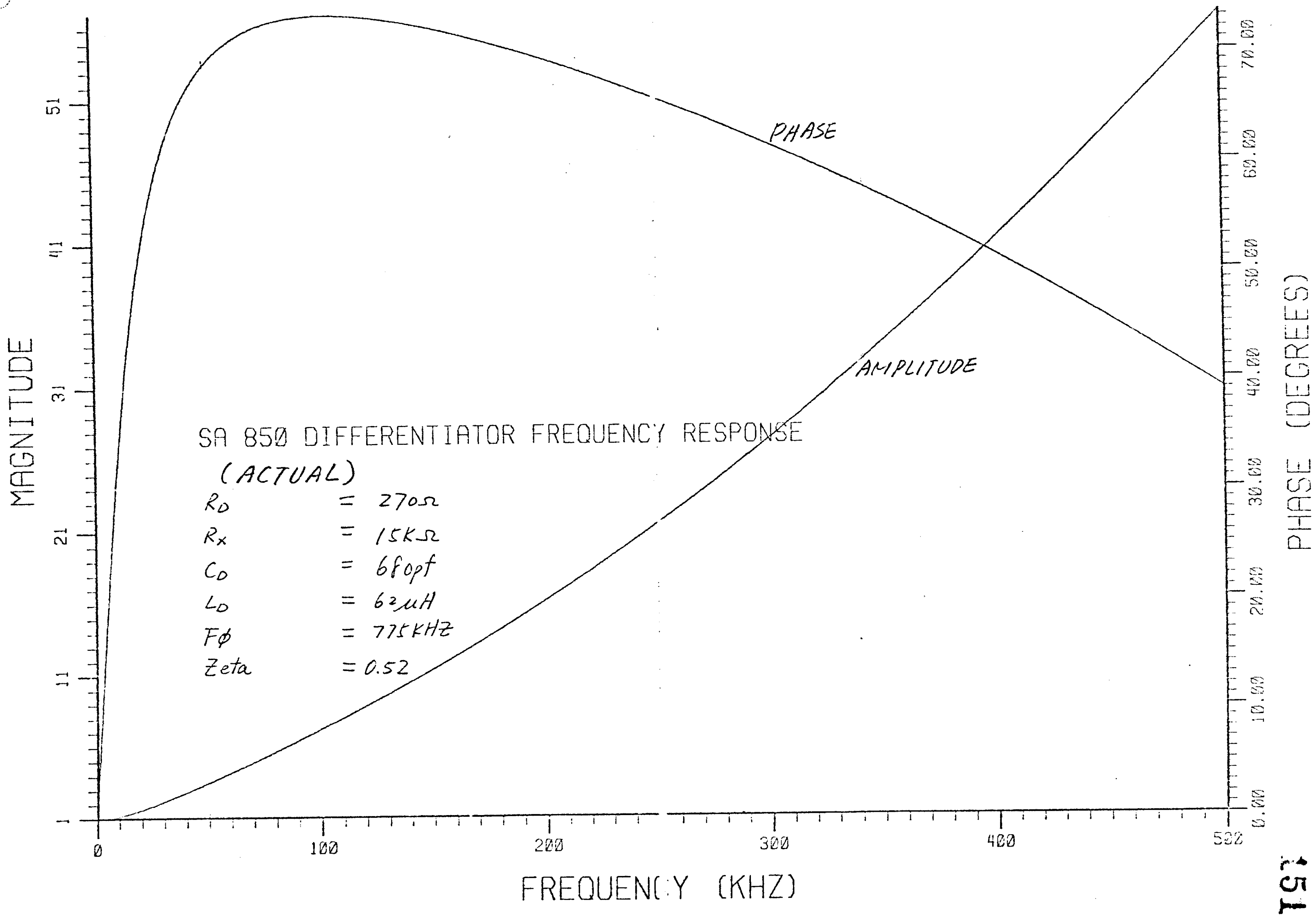
$$\theta(\omega) = \angle \tan^{-1} C_0 R_x \omega - \tan^{-1}\frac{\omega+\sqrt{\omega_0^2-\zeta^2}}{\zeta} - \tan^{-1}\frac{\omega-\sqrt{\omega_0^2-\zeta^2}}{\zeta}$$

$$\boxed{\theta(2\pi f) = \angle \tan^{-1} C_D R_x 2\pi f - \tan^{-1}\frac{\frac{f}{f_0}+\sqrt{1-|\zeta|^2}}{|\zeta|} - \tan^{-1}\frac{\frac{f}{f_0}-\sqrt{1-|\zeta|^2}}{|\zeta|}}$$

```
SINSERT SYSCOM>KEYS.F
SINSERT SYSCOM>A$KEYS

       DIMENSION X(1001),Y(1001),FAZ(1001)
       REAL LD

       CALL SRCH$$(K$WRIT,'LOT7',4,1,0,CODE)

       TOPI=6.2832
       RE=20.
       RC=1330.
       RD=150.
       RX=68000.
       CD=680.E-12
       LD=22.E-6
       F0=1./(TOPI*SQRT(LD*CD))
       AZETA=(SQRT(LD*CD)/2.)*(1./(CD*RX)+(RD+2.*RE)/LD)
       ZETA=.5*(1./(CD*RX)+(RD+2.*RE)/LD)

       DO 10 I=1,1001
       F=FLOAT(I-1)*500.
       X(I)=F
       A=RC/LD
       B=SQRT((TOPI*F)**2+(1./(CD*RX))**2)
       C=2.*TOPI*F*SQRT((TOPI*F0)**2-ZETA**2)
       D=SQRT(((TOPI*F)**2+(TOPI*F0)**2)-C)
       Y(I)=(A*B)/D
       FAZ(I)=ATAN(TOPI*CD*RX*F)-ATAN((F/F0+SQRT(1.-AZETA**2))/AZETA)
    10 FAZ(I)=FAZ(I)-ATAN((F/F0-SQRT(1.-AZETA**2))/AZETA)

       Z=Y(1)
       DO 30 I=1,1001
    30 Y(I)=Y(I)/Z
       WRITE(5,20)(X(I),Y(I),FAZ(I),I=1,1001)
    20 FORMAT(3E12.5)

       CALL SRCHSS(KSCLOS,0,0,1,0,CODE)
       CALL EXIT
       END
```

E2 & E3

①



SA 850 DIFFERENTIATOR FREQUENCY RESPONSE

(ACTUAL)

R_D = 270Ω

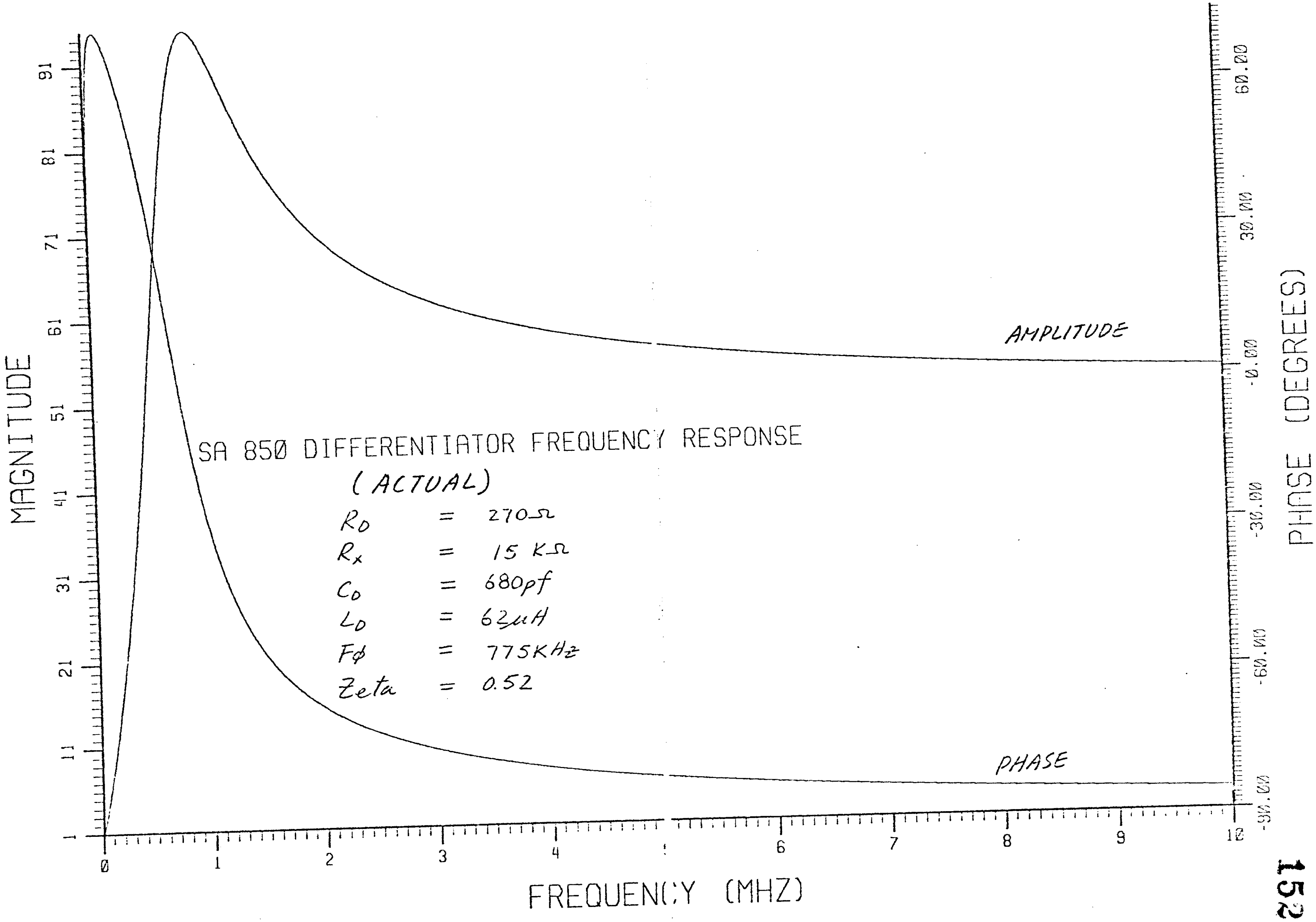
R_x = 15KΩ

C_D = 680pf

L_D = 62µH

Fφ = 775KHZ

Zeta = 0.52



SA 850 DIFFERENTIATOR FREQUENCY RESPONSE

(ACTUAL)

R_D = 270Ω

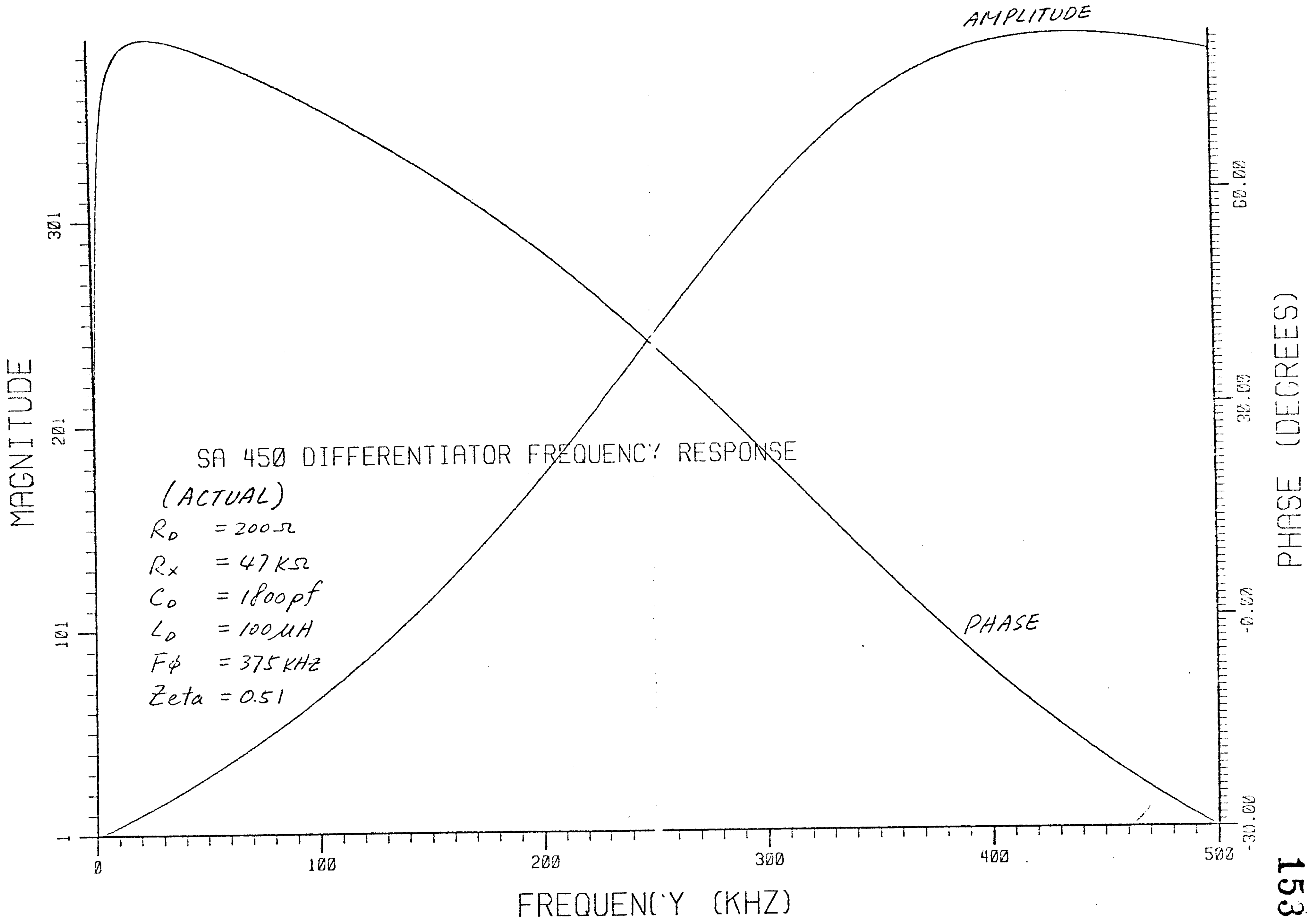
R_x = 15 KΩ

C_D = 680pf

L_D = 62μH

$F\phi$ = 775KHz

Zeta = 0.52



SA 450 DIFFERENTIATOR FREQUENCY RESPONSE

(ACTUAL)

R_o = 200Ω

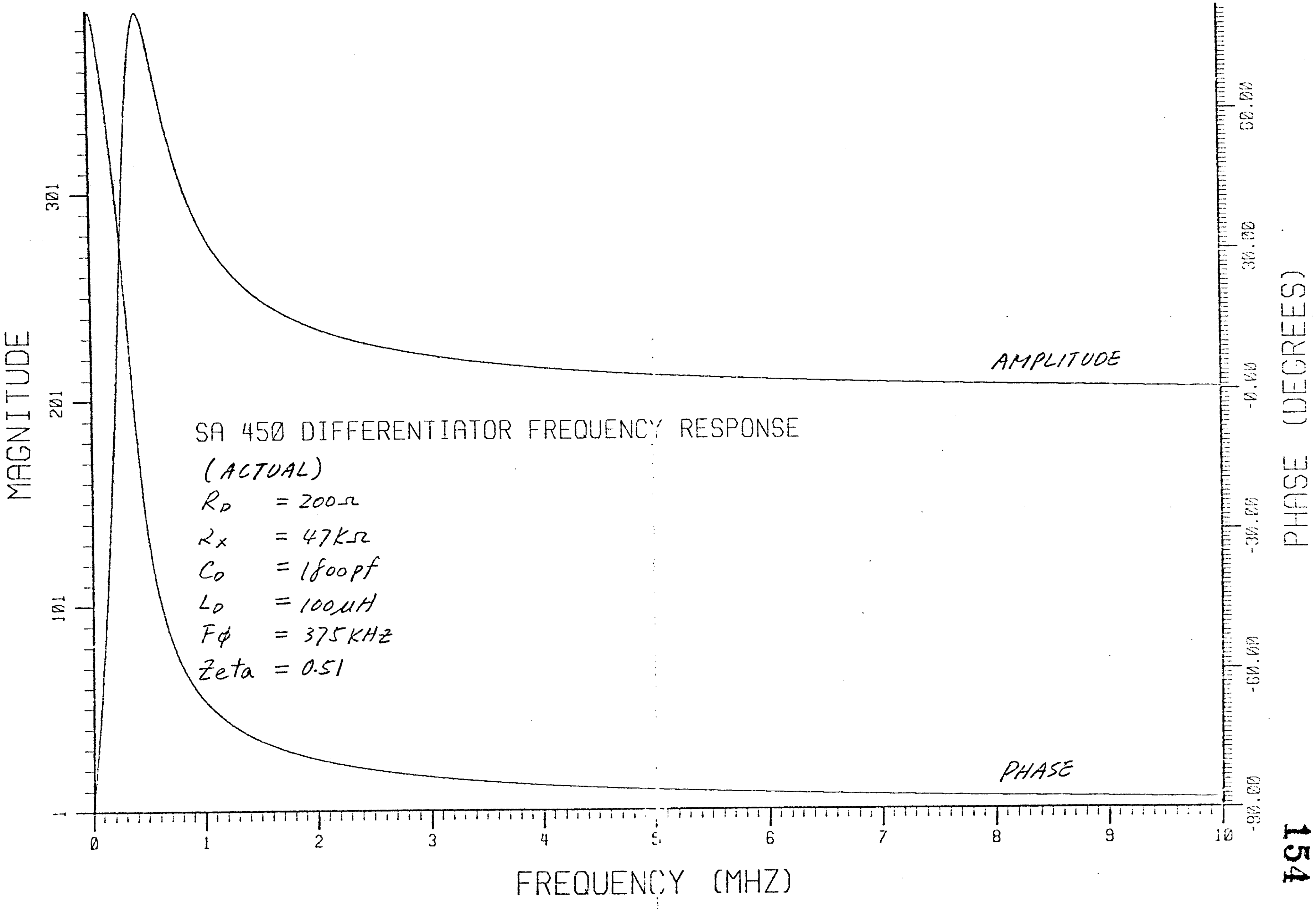
R_x = 47KΩ

C_o = 1800pf

L_o = 100μH

$F\phi$ = 375KHz

Zeta = 0.51



SA 450 DIFFERENTIATOR FREQUENCY RESPONSE

(ACTUAL)

R_D = 200Ω

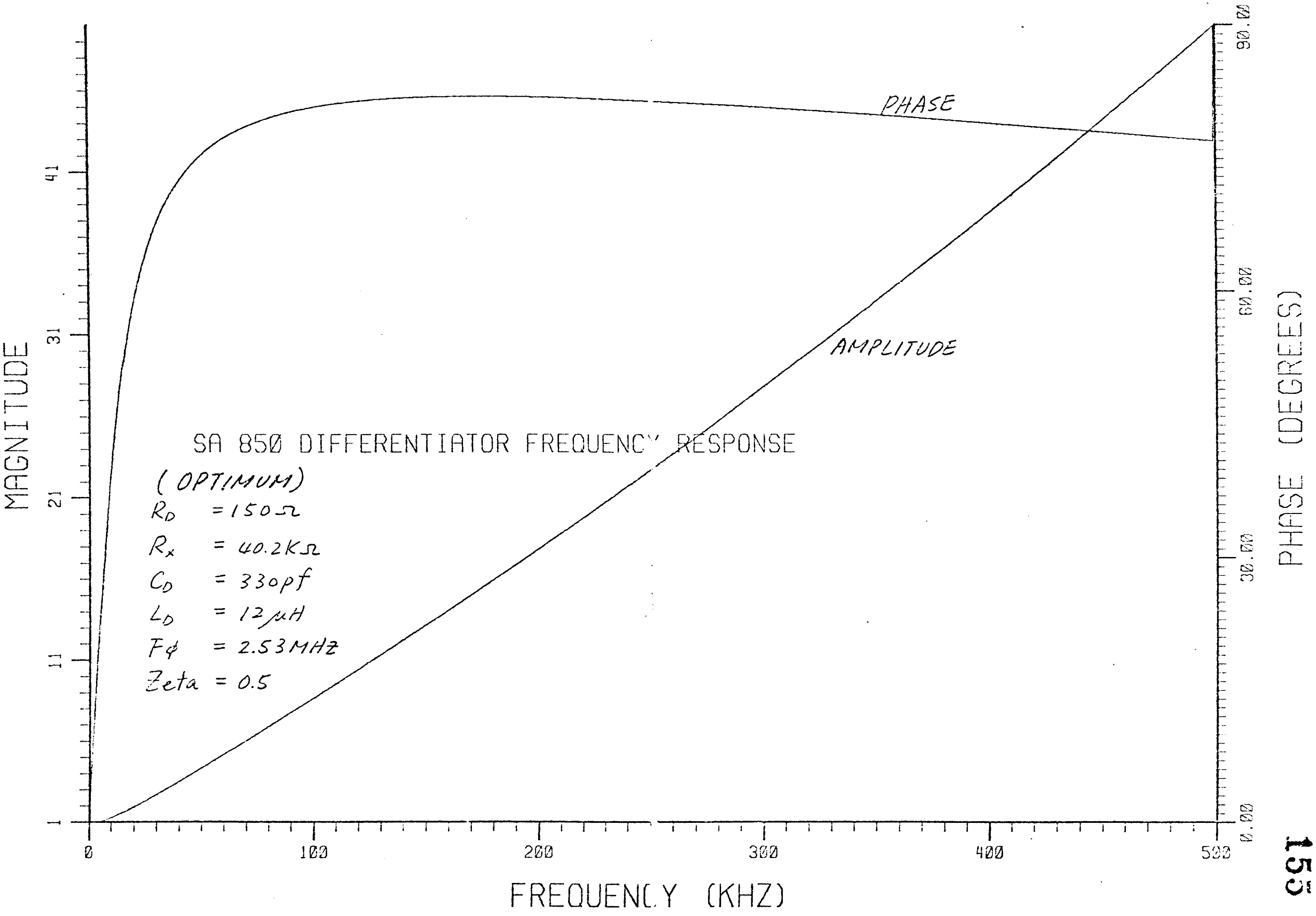
R_x = 47KΩ

C_0 = 1800pf

L_0 = 100μH

F_ϕ = 375KHz

Zeta = 0.51



SA 850 DIFFERENTIATOR FREQUENCY RESPONSE

(OPTIMUM)

R_D = 150Ω

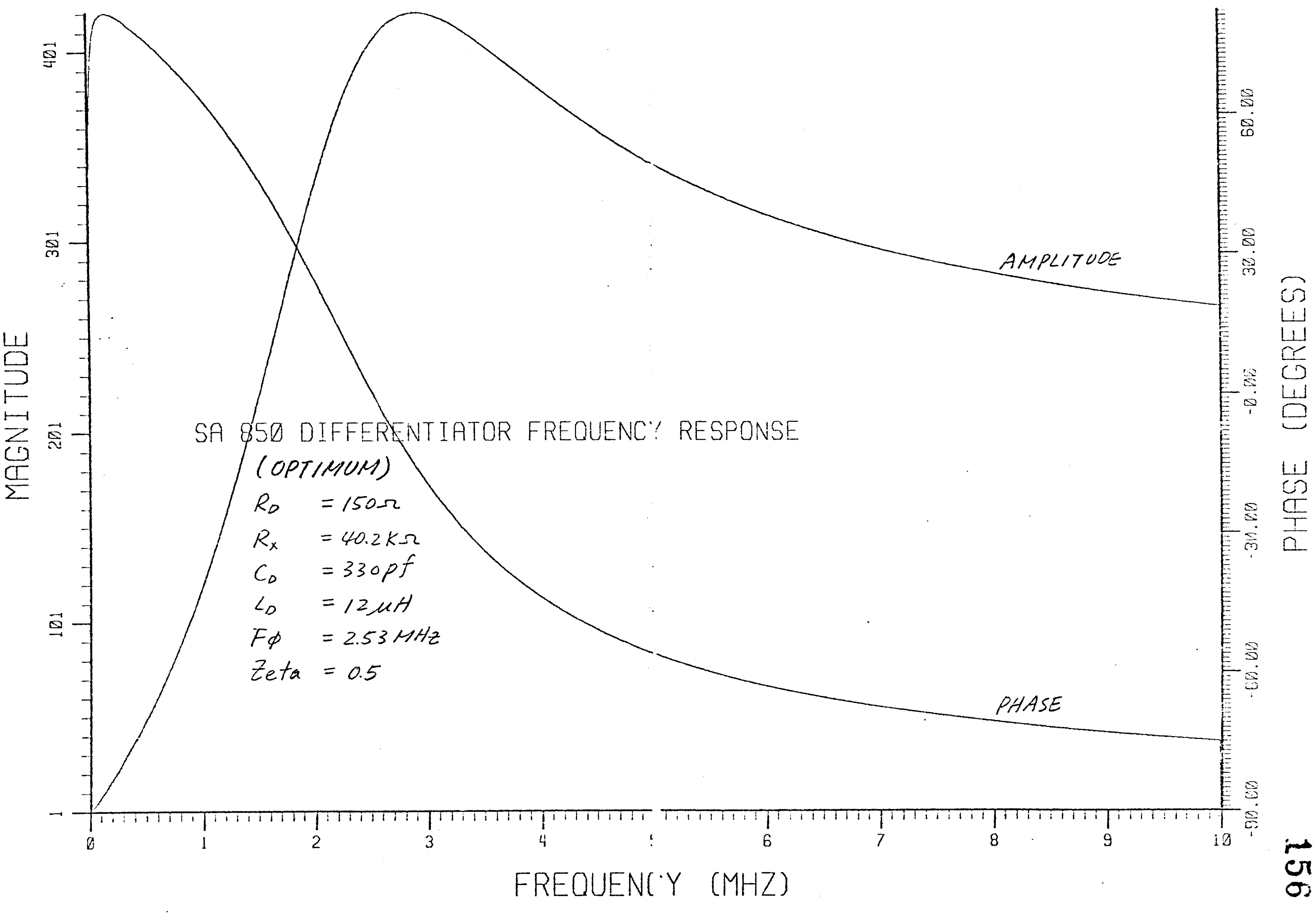
R_x = 40.2KΩ

C_D = 330pf

L_D = 12μH

$F\phi$ = 2.53MHz

Zeta = 0.5



SA 850 DIFFERENTIATOR FREQUENCY RESPONSE

(OPTIMUM)

R_D = 150Ω

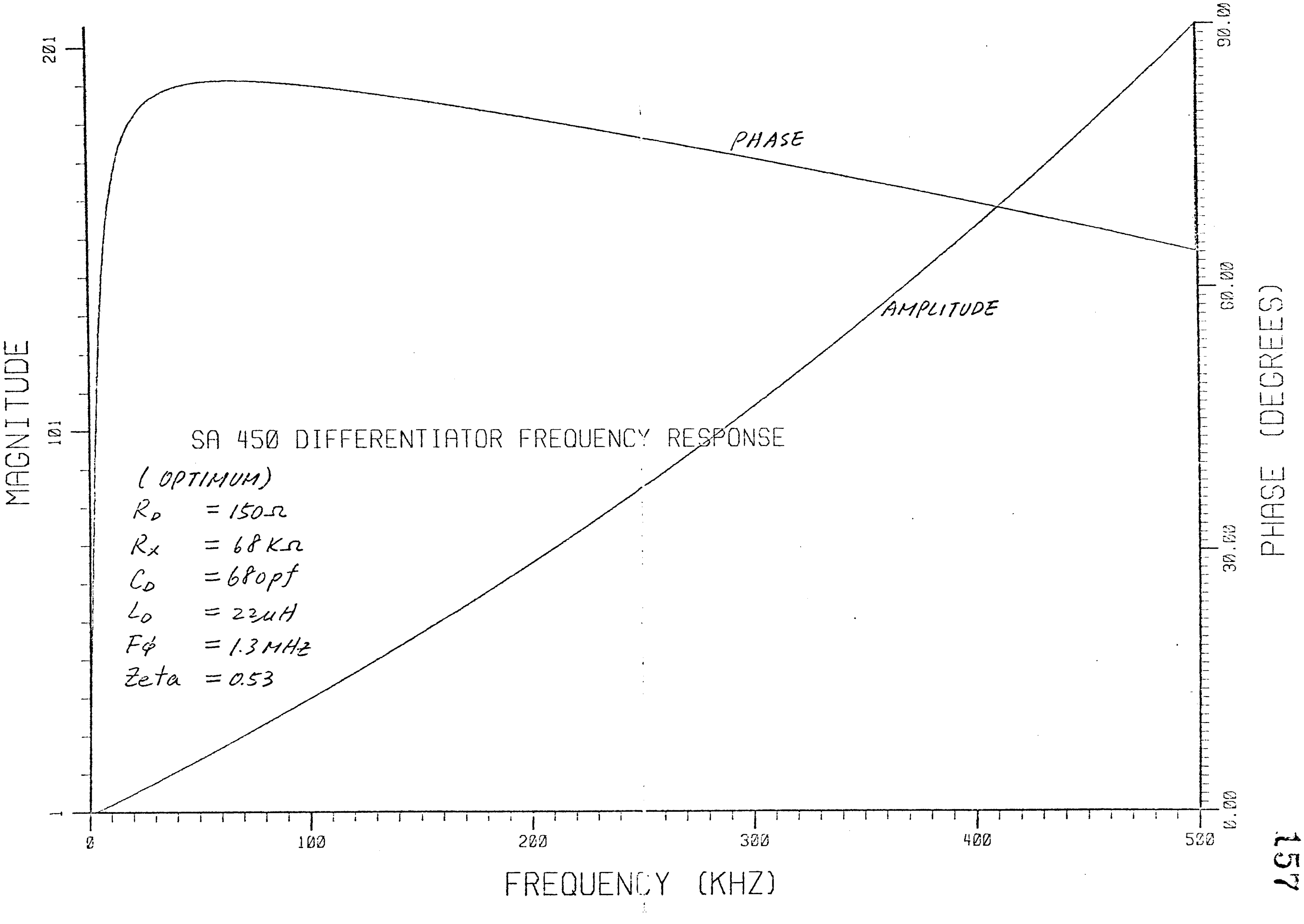
R_x = 40.2KΩ

C_D = 330pf

L_D = 12μH

Fφ = 2.53 MHz

Zeta = 0.5



SA 450 DIFFERENTIATOR FREQUENCY RESPONSE

(OPTIMUM)

R_D = 150Ω

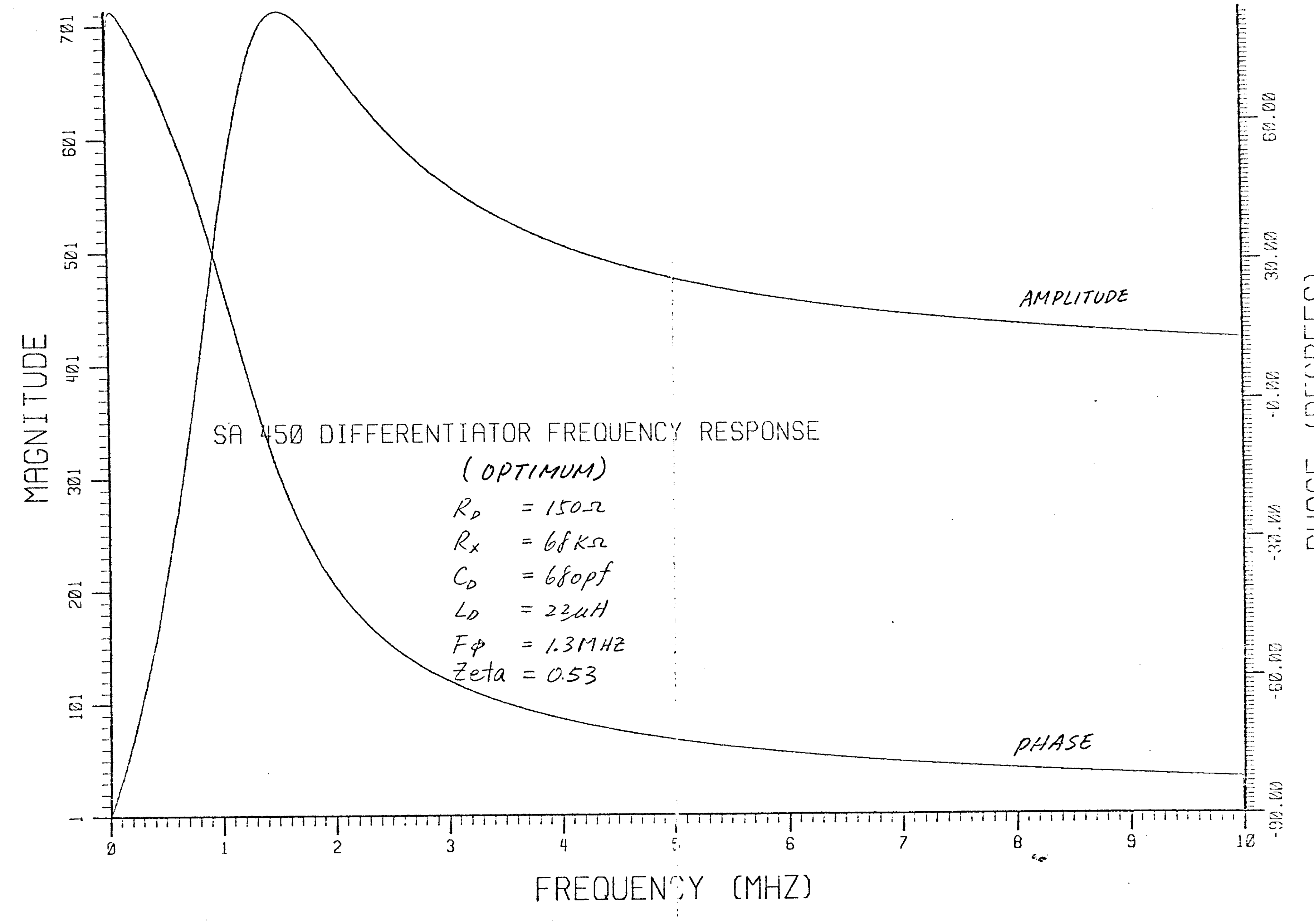
R_X = 68 KΩ

C_D = 680pf

L_0 = 22uH

Fφ = 1.3 MHz

Zeta = 0.53



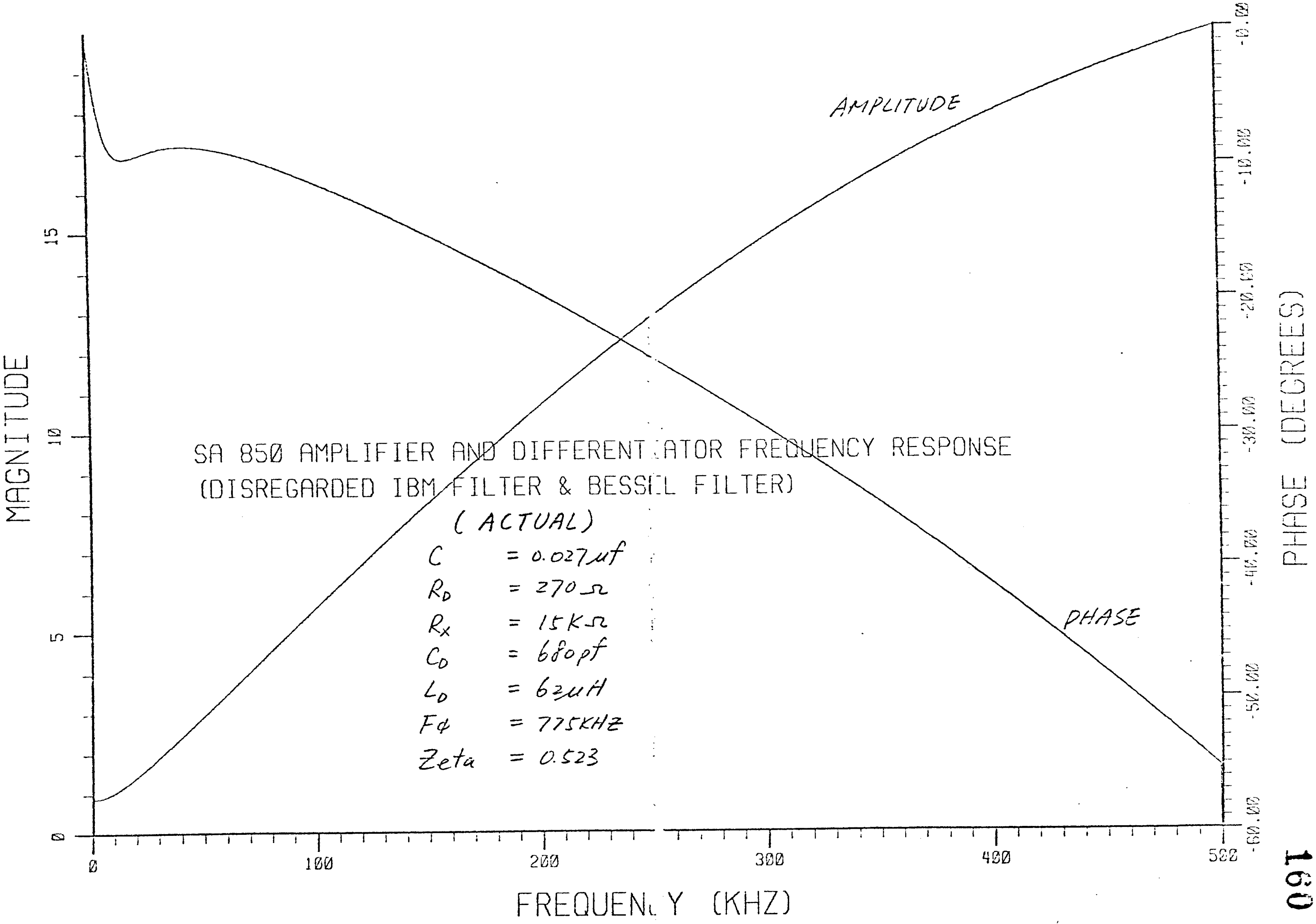
SA 450 DIFFERENTIATOR FREQUENCY RESPONSE

(OPTIMUM)

R_D = 150Ω
R_x = 68KΩ
C_D = 680pf
L_D = 22μH
Fφ = 1.3MHZ
Zeta = 0.53

```
SINSERT SYSCOM>KEYS.F
SINSERT SYSCOM>A$KEYS

      DIMENSION X(1001),Y(1001),FAZ(1001)
      REAL LD

      CALL SRCH$$(KSWRIT,'LOD7',4,1,0,CODE)

      TOPI=6.2832
      FB=5.E6
      RE=20.
      RC=1000.
      C=.1E-6
      RD=150.
      RX=65000
      CD=600.E-12
      LD=22.E-6

      F0=1./(TOPI*SQRT(LD*CD))
      ZETA=.5*(1./(CD*RX)+(RD+2.*RE)/LD)
      AZETA=.5*SQRT(LD*CD)*(1./(CD*RX)+(RD+2.*RE)/LD)
      POSHT=50./(AZETA*SQRT(1.-AZETA**2))

      DO 10 I=1,1001
      F=FLOAT(I-1)*500.
      X(I)=F
      A=10.*F*FB/SQRT(F*F+FB*FB)
      B=1./SQRT(F*F+(1./3141.6*C)**2)
      D=(TOPI*RC/LD)*SQRT(F*F+(1./(TOPI*CD*RX))**2)
      E=2.*TOPI*F*SQRT((TOPI*F0)**2-ZETA**2)
      G=SQRT(((TOPI*F)**2+(TOPI*F0)**2)**2-E)
      Y(I)=(A*B*D)/G
 10   FAZ(I)=ATAN(TOPI*CD*RX*F)-ATAN((F/F0+SQRT(1.-AZETA**2))/AZETA)-
     1        ATAN((F/F0-SQRT(1.-AZETA**2))/AZETA)-ATAN(F/FB)
     2       -ATAN(3141.6*F*C)

      WRITE(5,20)(X(I),Y(I),FAZ(I),I=1,1001)
 20   FORMAT(3E12.5)

      WRITE(5,30)F0,ZETA,AZETA,POSHT
 30   FORMAT(E12.5)
      CALL SRCH$$(KSCLOS,0,0,1,0,CODE)
      CALL EXIT
      END
```

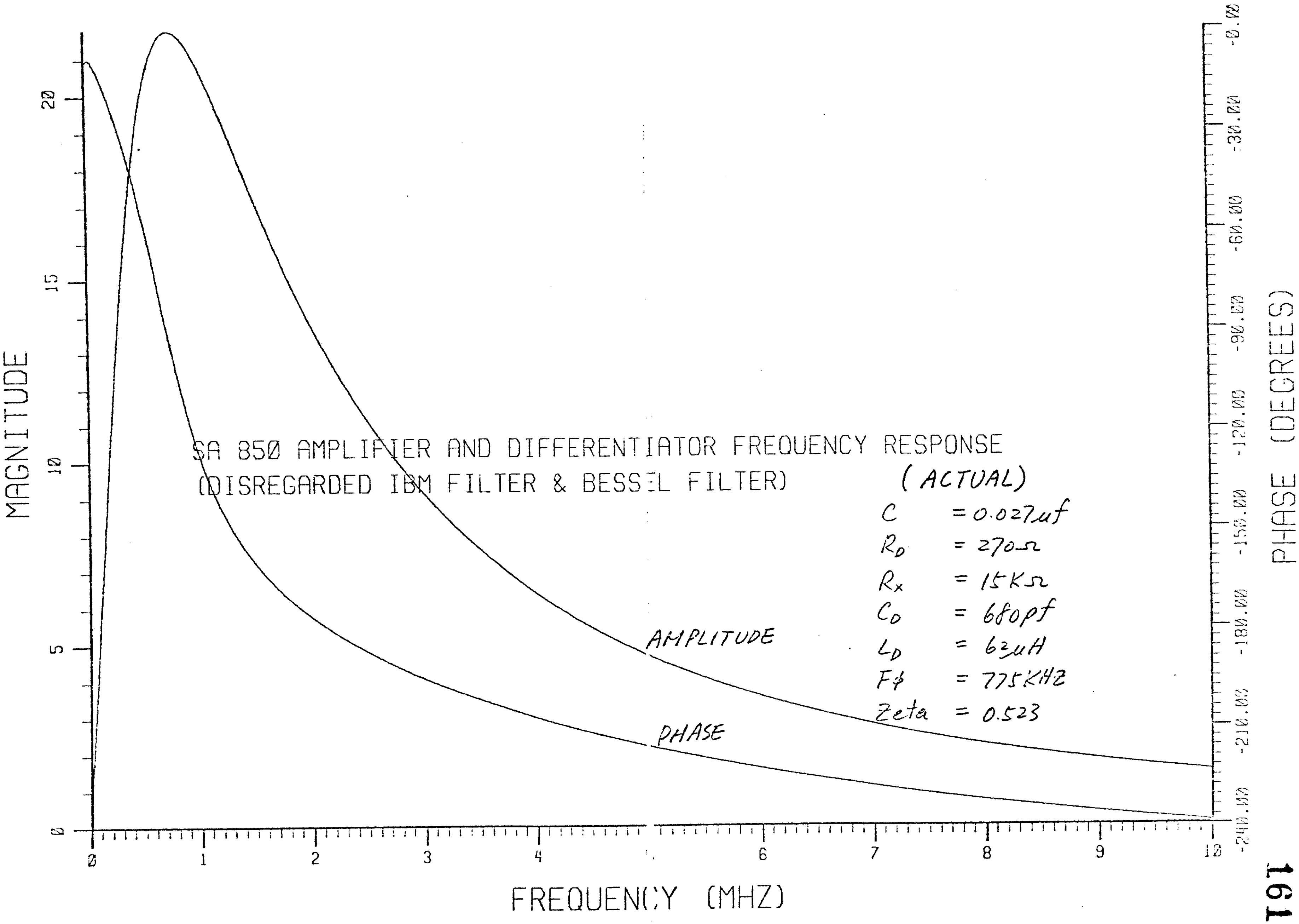
E4 & E5



SA 850 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)

(ACTUAL)

C = 0.027 µf
R_D = 270 Ω
R_x = 15KΩ
C_D = 680pf
L_D = 62µH
$F\phi$ = 775KHZ
Zeta = 0.523

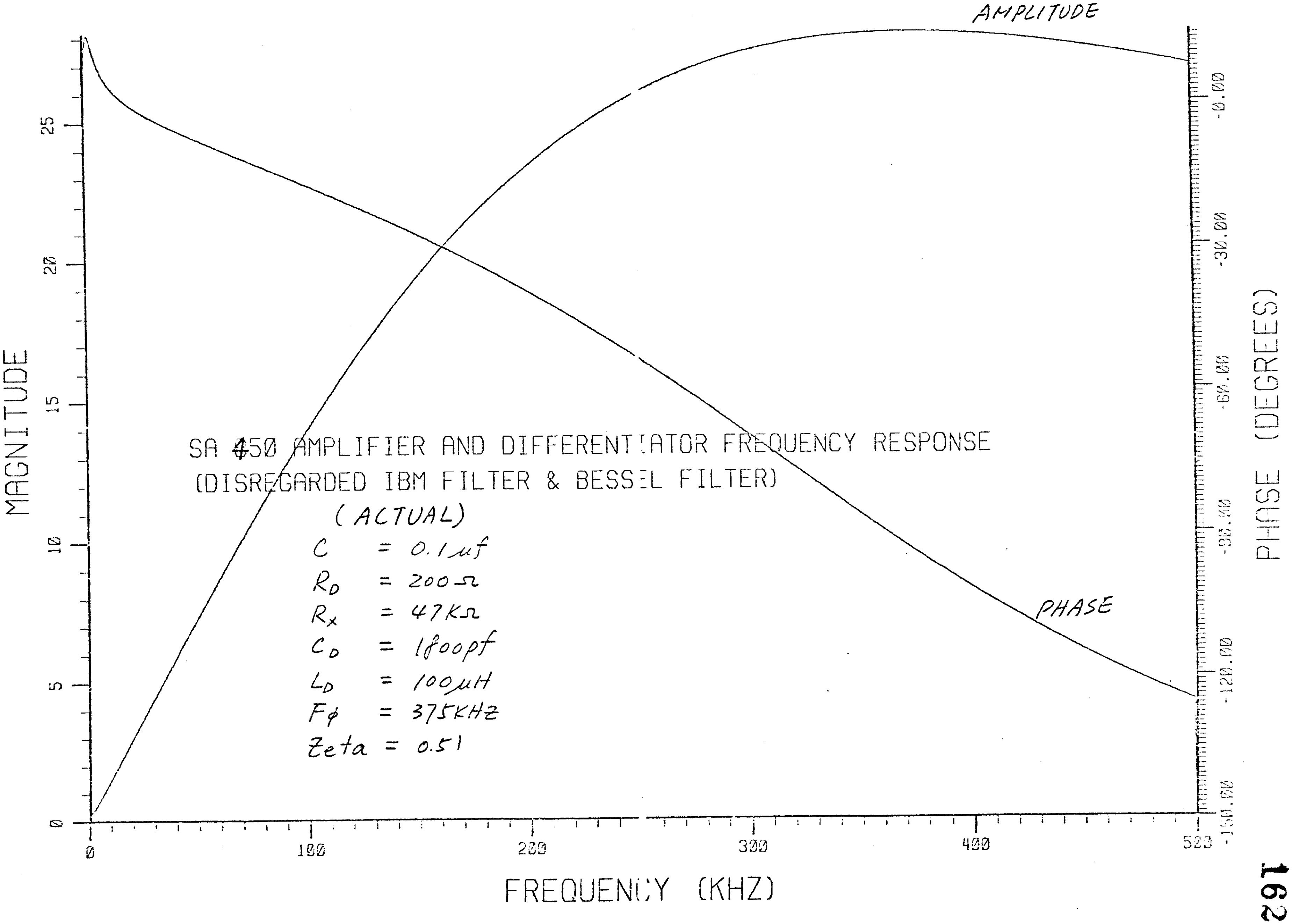


SA 850 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)

(ACTUAL)

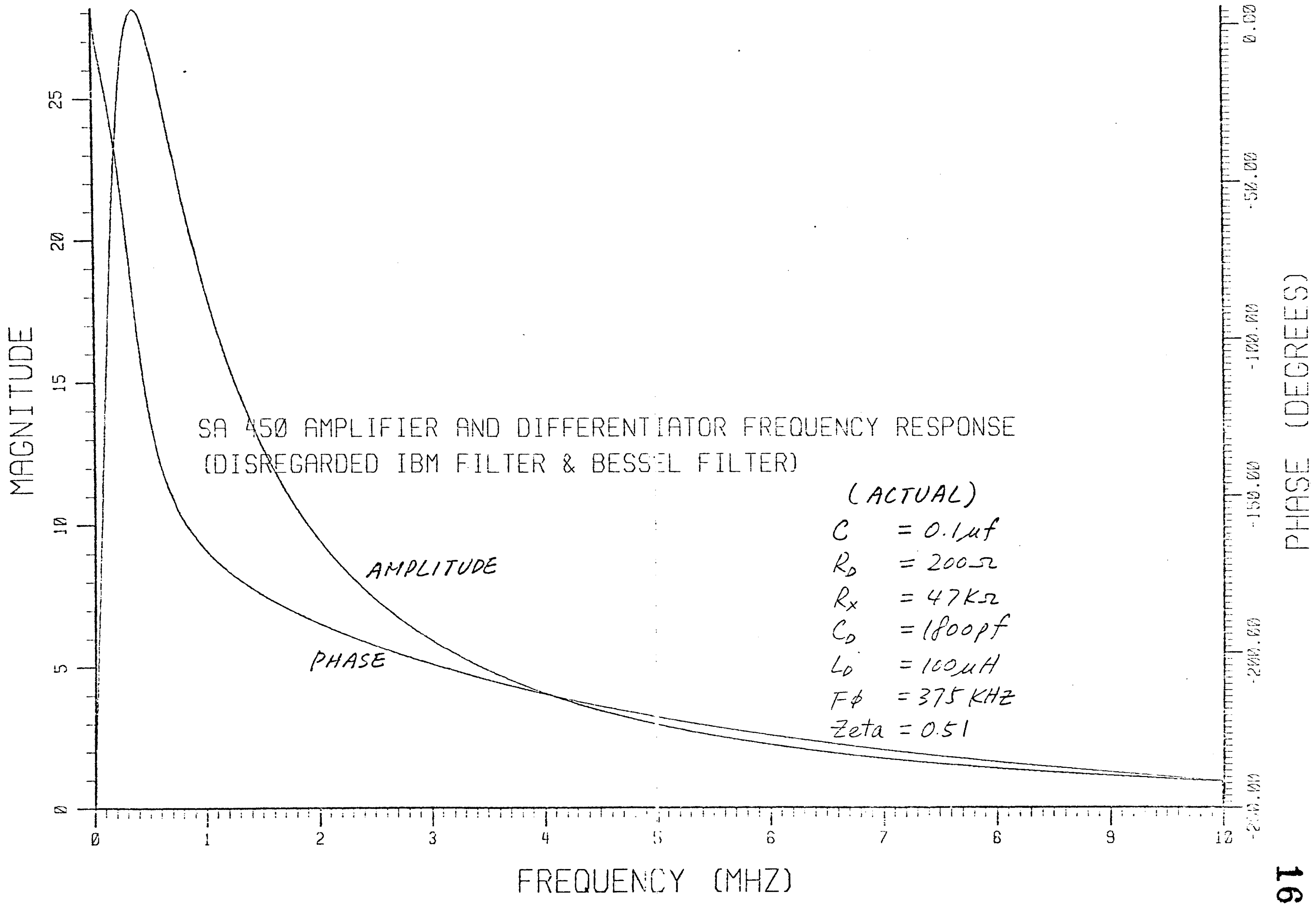
C = 0.027uf
R_D = 270Ω
R_x = 15KΩ
C_D = 680pf
L_D = 62uH
F∅ = 775KHZ
Zeta = 0.523

5



SA ~~4~~50 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)
(ACTUAL)

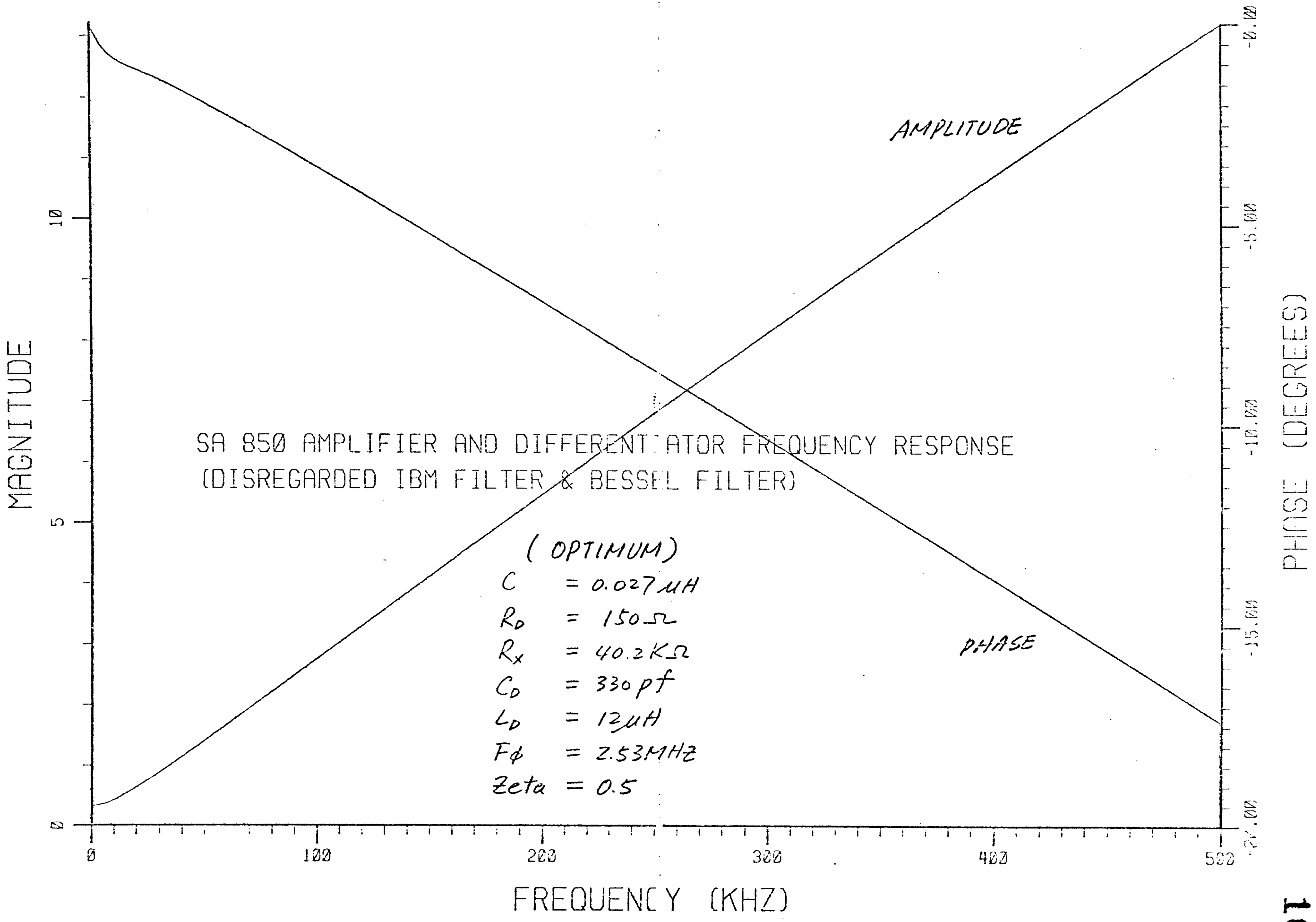
C = 0.1 µf
R_D = 200 Ω
R_x = 47 KΩ
C_D = 1800 pf
L_D = 100 µH
F_ϕ = 375 KHz
Zeta = 0.51



SA 450 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)

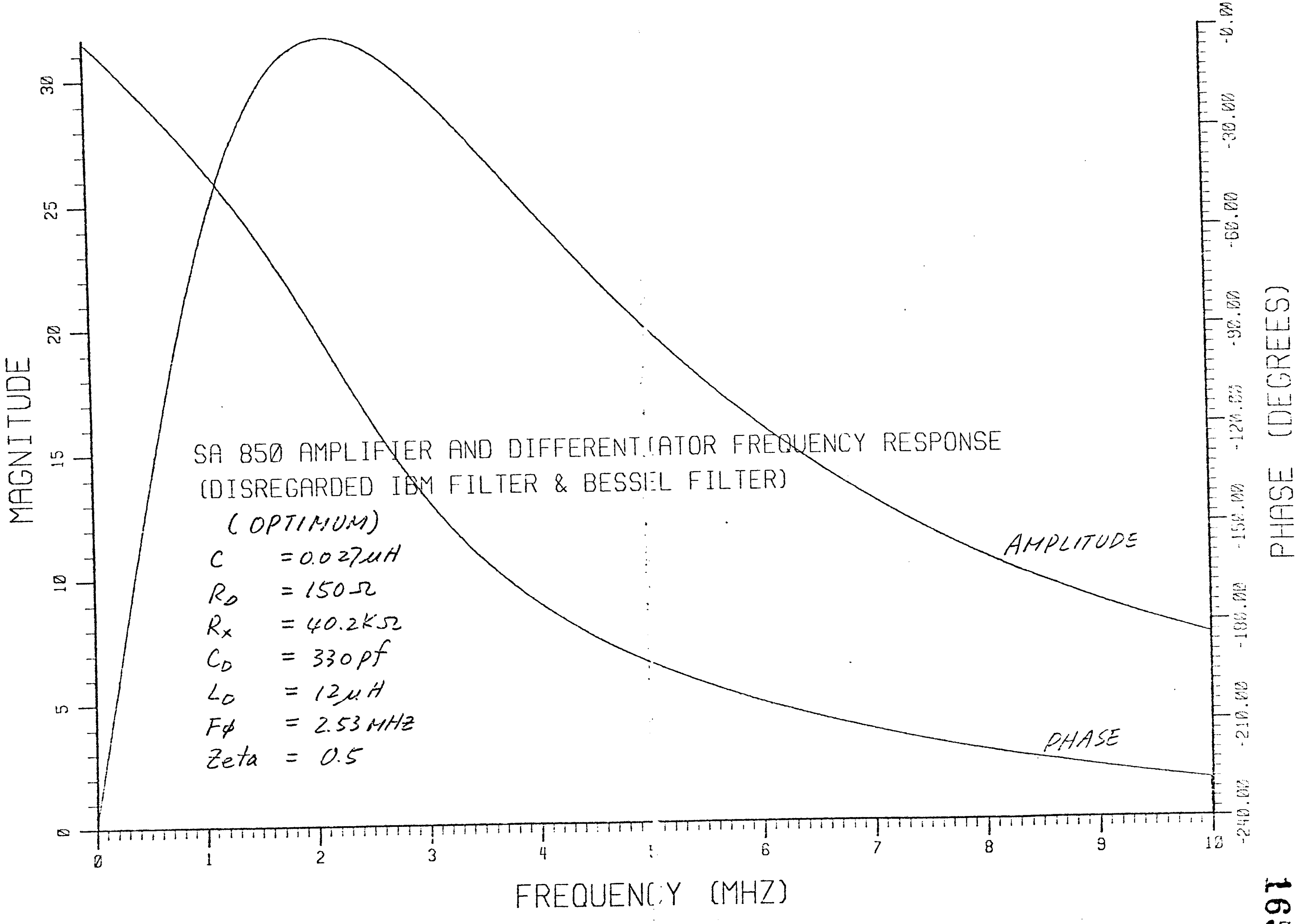
(ACTUAL)

C = 0.1μf
R_D = 200Ω
R_x = 47KΩ
C_D = 1800pf
L_D = 100μH
$F\phi$ = 375 KHz
Zeta = 0.51



SA 850 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)

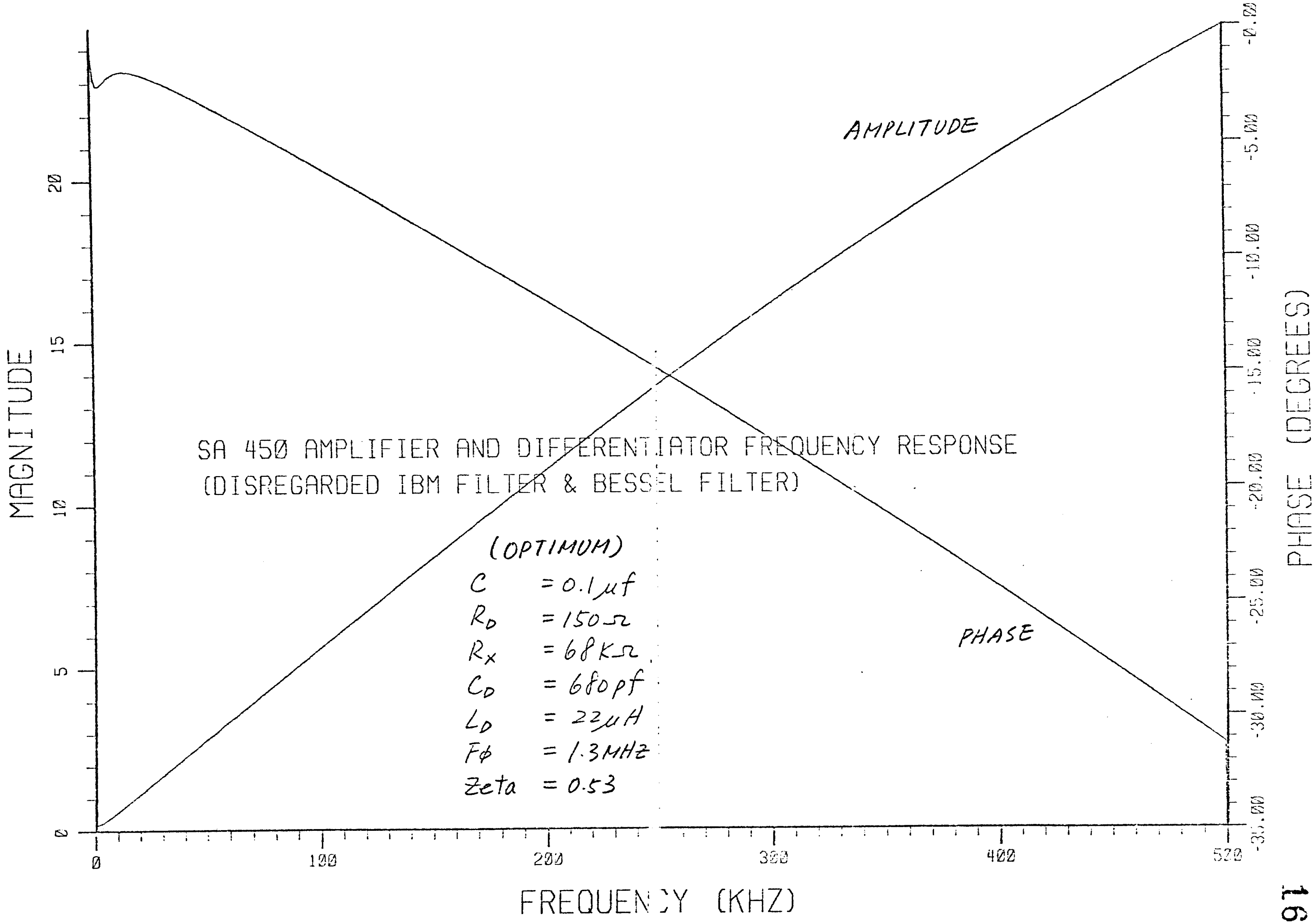
(OPTIMUM)
C = 0.027 µH
R_D = 150 Ω
R_x = 40.2 KΩ
C_D = 330 pf
L_D = 12 µH
F_ϕ = 2.53 MHz
Zeta = 0.5



SA 850 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)

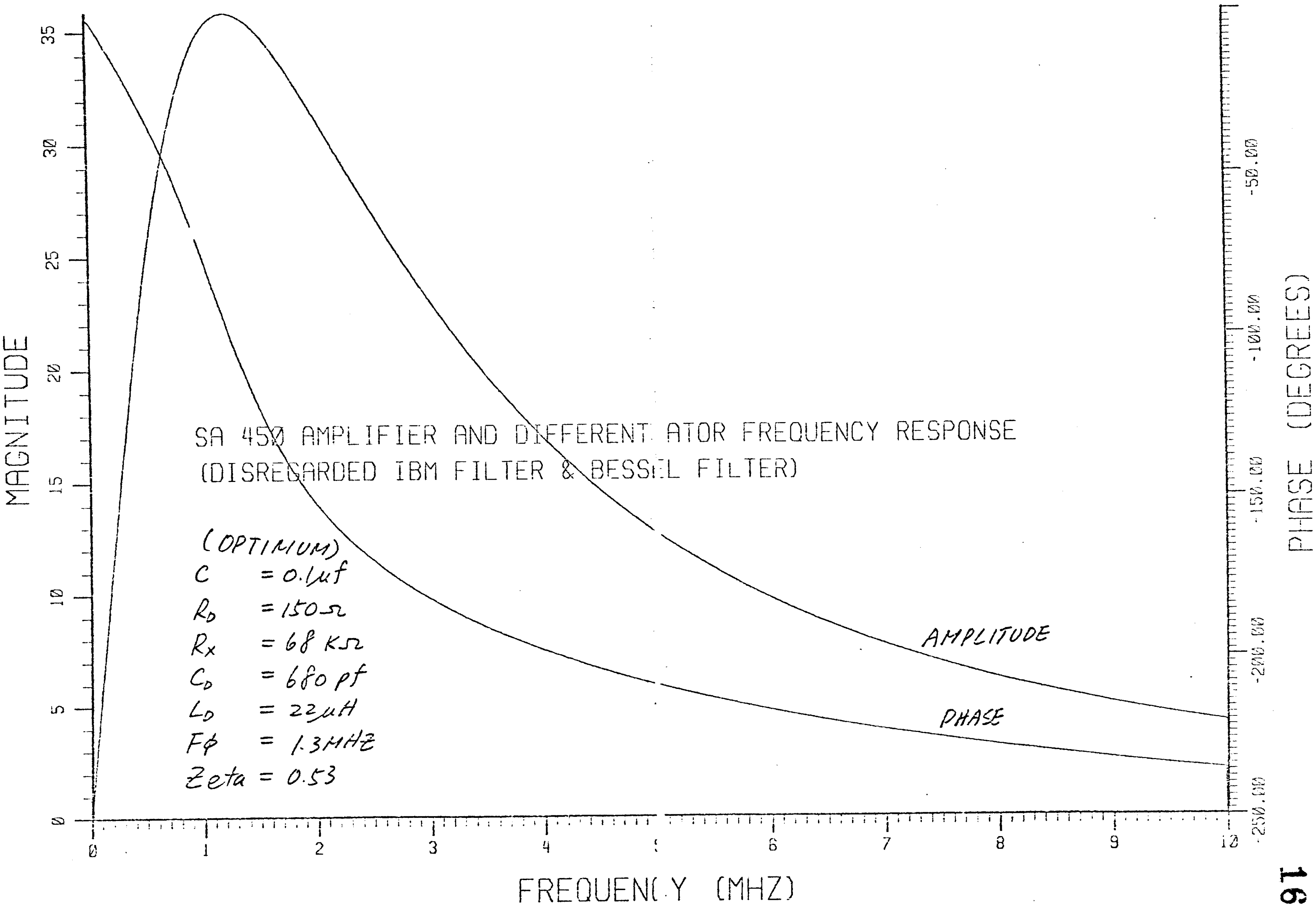
(OPTIMUM)

$C = 0.027 \mu H$
$R_D = 150 \Omega$
$R_x = 40.2 K\Omega$
$C_D = 330 pf$
$L_D = 12 \mu H$
$F\phi = 2.53 MHz$
$Zeta = 0.5$



SA 450 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)

(OPTIMUM)
C = 0.1 µf
R_D = 150 Ω
R_X = 68 KΩ
C_D = 680 pf
L_D = 22 µH
Fφ = 1.3 MHz
Zeta = 0.53

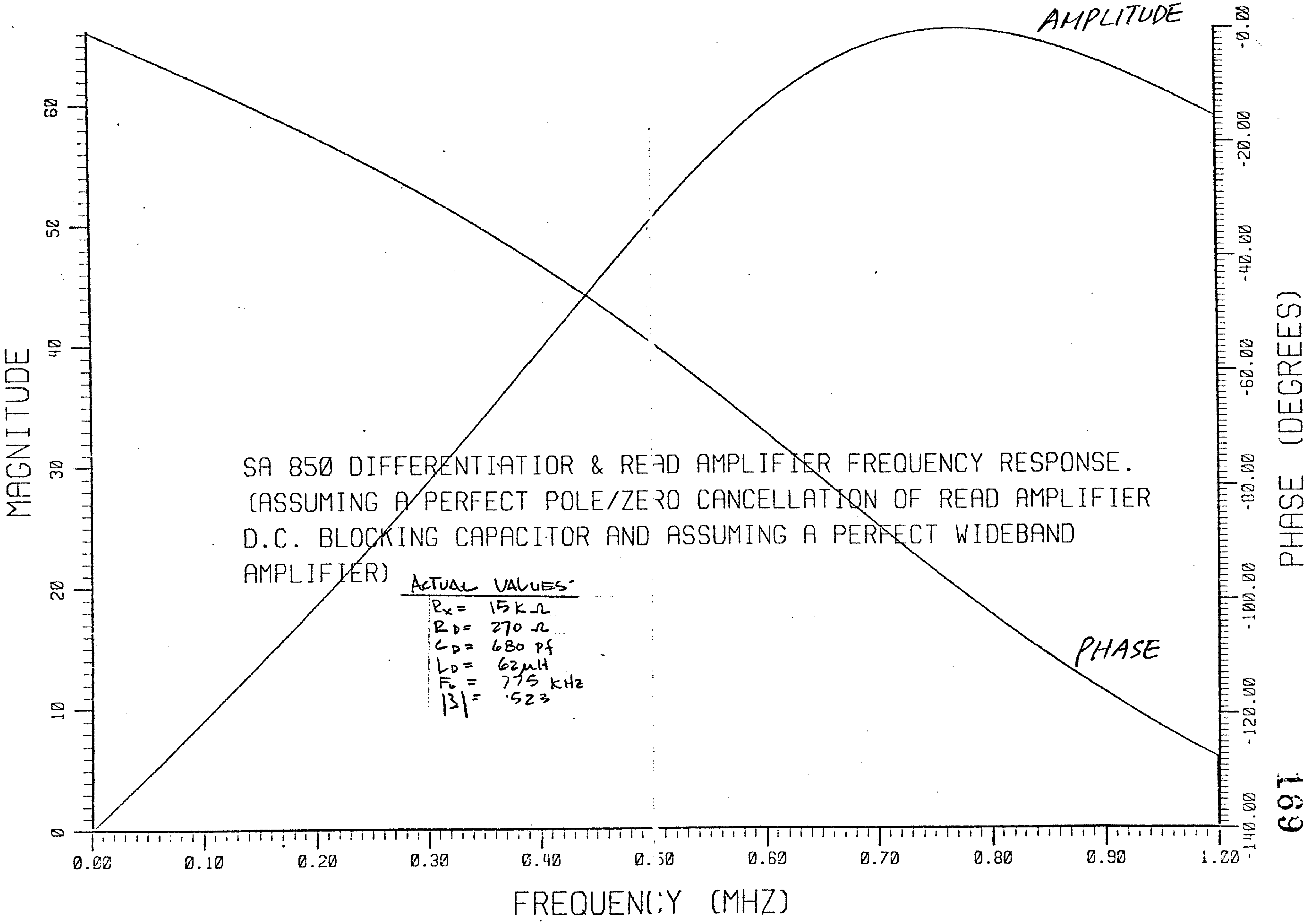


SA 450 AMPLIFIER AND DIFFERENTIATOR FREQUENCY RESPONSE
(DISREGARDED IBM FILTER & BESSEL FILTER)

(OPTIMUM)
C = 0.1µf
R_D = 150Ω
R_X = 68 KΩ
C_D = 680 pf
L_D = 22µH
Fφ = 1.3MHZ
Zeta = 0.53

```
$INSERT SYSCOM>KEYS.F
$INSERT SYSCOM>ASKEYS

      DIMENSION X(1001),Y(1001),FAZ(1001)
      REAL LD

      CALL SRCH$$(K$WRIT,'LUD5',4,1,0,CODE)

      TOPI=6.28318
      RE=20.
      RC=1330.
      RX=15000.
      RD=270.
      CD=680.E-12
      LD=62.E-6

      F0=1./(TOPI*SQRT(LD*CD))
      ZETA=.5*SQRT(LD*CD)*(1./(CD*RX)+(RD+2.*RE)/LD)
      D=SQRT(1.-ZETA**2)
      FB=5.E6

      DO 10 I=1,1001
      F=FLOAT(I-1)*1.E4
      X(I)=F
      A=(100.*RC)/(LD*TOPI*TOPI)
      B=SQRT((F*F+F0*F0)**2-((2.*F*F0)**2)*(1-ZETA**2))
      G=(F*FB)/SQRT(F*F+FB*FB)
      Y(I)=A*G/B
   10 FAZ(I)=-ATAN((F/F0+D)/ZETA)-ATAN((F/F0-D)/ZETA)-ATAN(F/FB)

      WRITE(5,20)(X(I),Y(I),FAZ(I),I=1,1001)
   20 FORMAT(3E12.5)

      WRITE(5,20)F0
      WRITE(5,20)ZETA

      CALL SRCH$$(K$CLOS,0,0,1,0,CODE)
      CALL EXIT
      END
```

E6 & E7

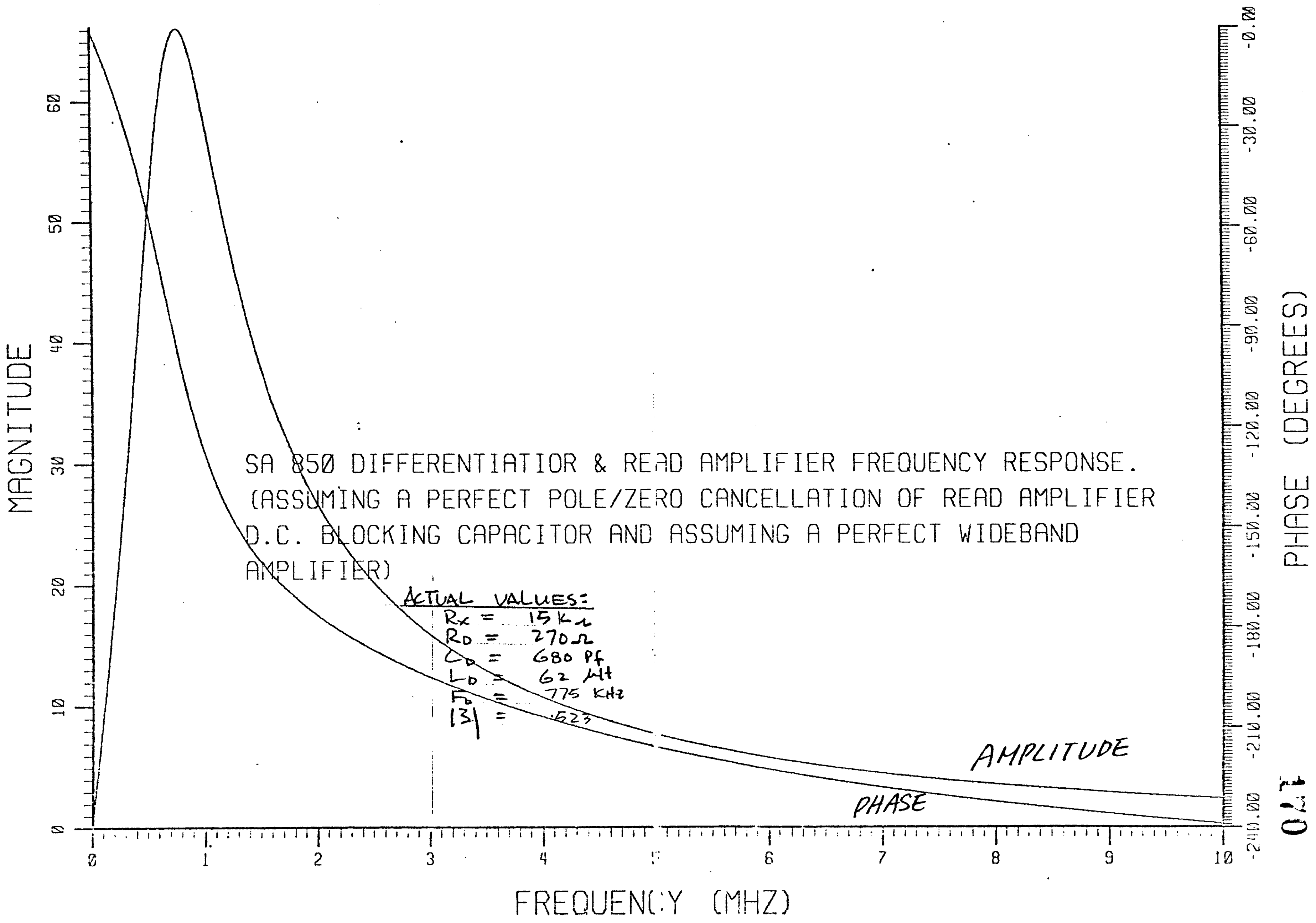


SA 850 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE.
(ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER
D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND
AMPLIFIER)

ACTUAL VALUES:

R_x = 15 kΩ
R_D = 270 Ω
C_D = 680 pf
L_D = 62 µH
F_0 = 775 kHz
$|\beta|$ = ·523

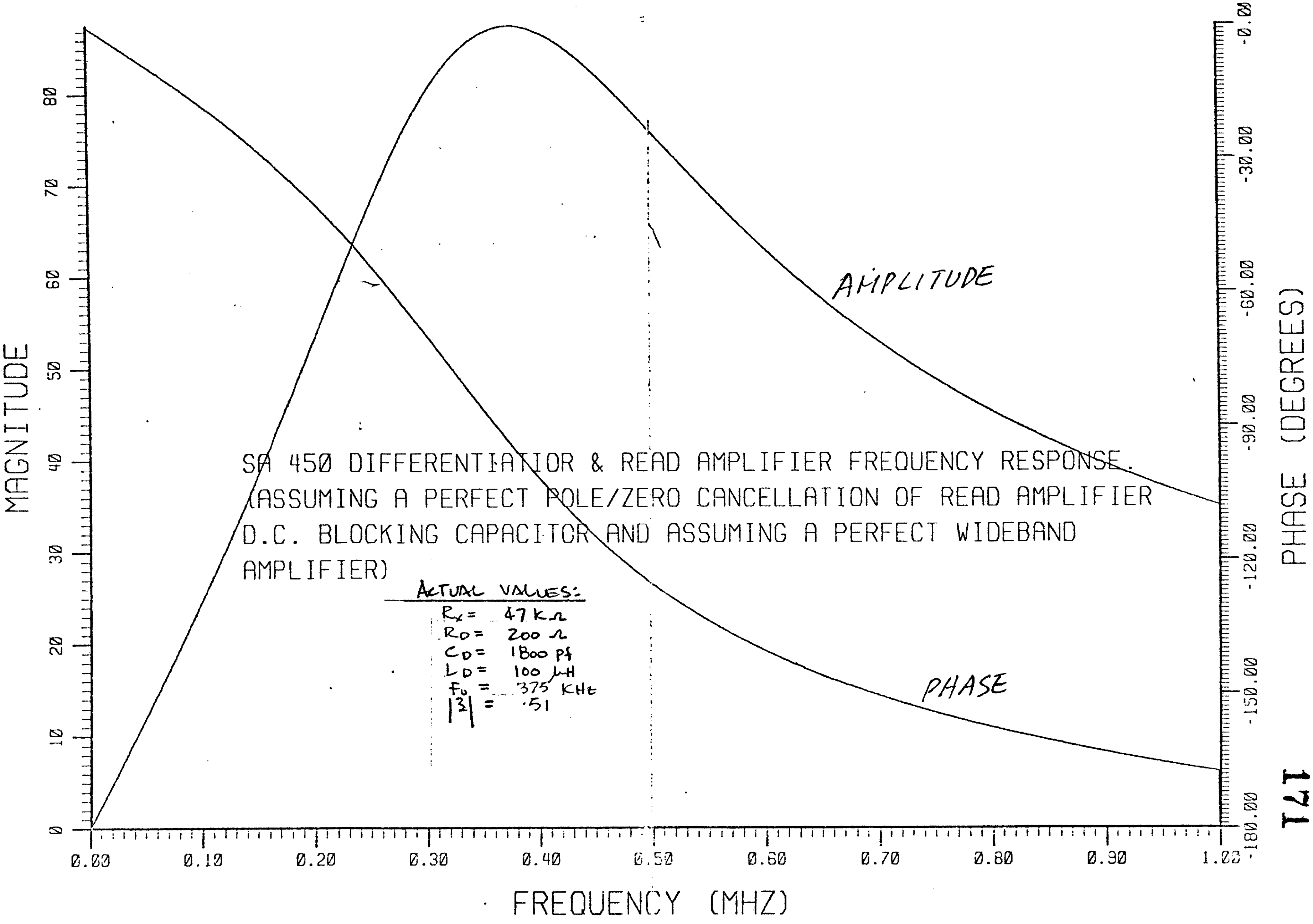
5



SA 850 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE.
(ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND AMPLIFIER)

ACTUAL VALUES:
R_x = 15 kΩ
R_D = 270Ω
C_D = 680 pf
L_D = 62 μH
F_D = 775 KHz
|3| = .523

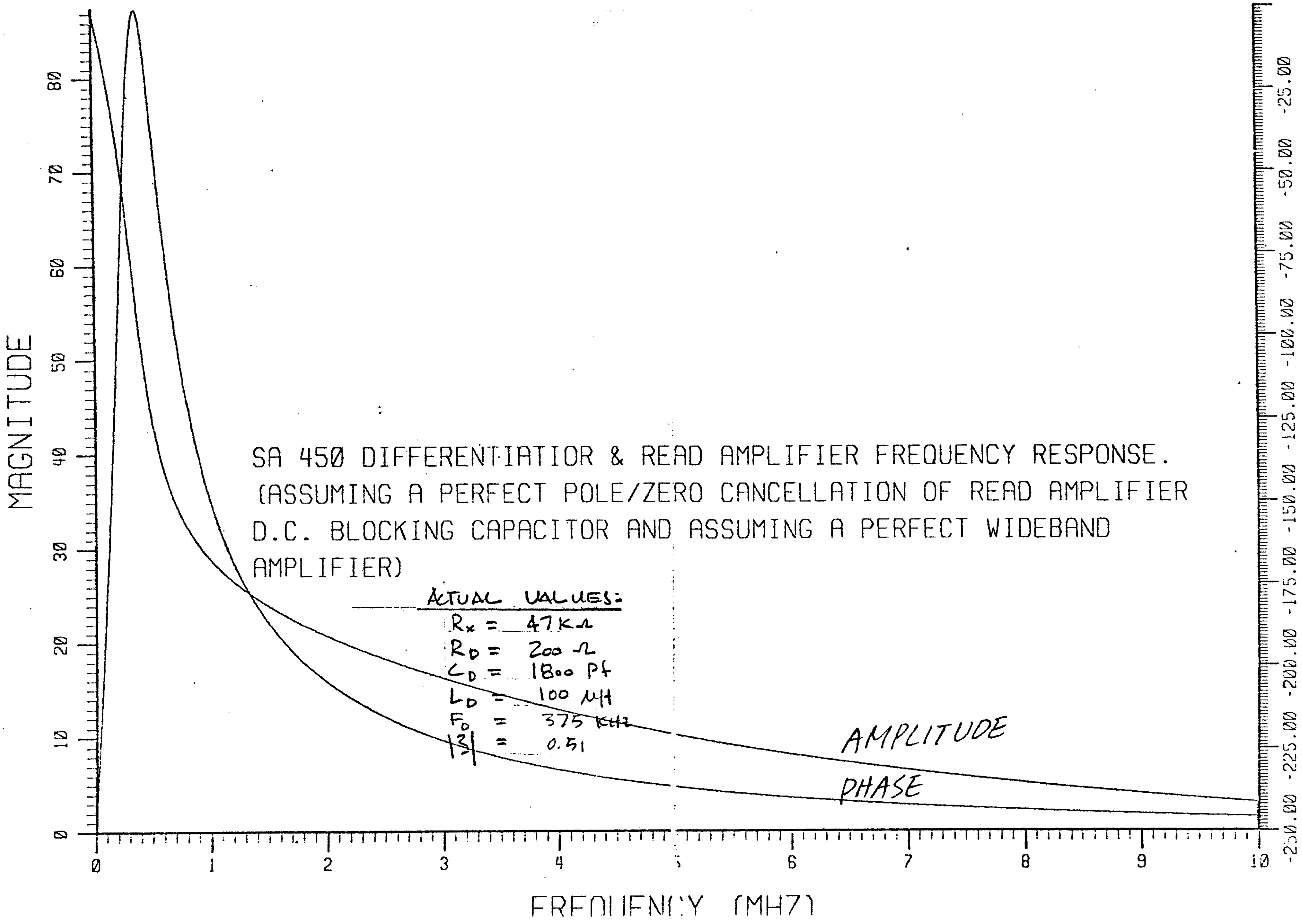
③



SA 450 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE.
(ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER
D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND
AMPLIFIER)

ACTUAL VALUES:

R_x = 47 kΩ
R_D = 200 Ω
C_D = 1800 pf
L_D = 100 µH
F_0 = 375 KHz
|3| = ·51



SA 450 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE.
(ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND AMPLIFIER)

ACTUAL VALUES:

R_x = 47KΩ

R_D = 200 Ω

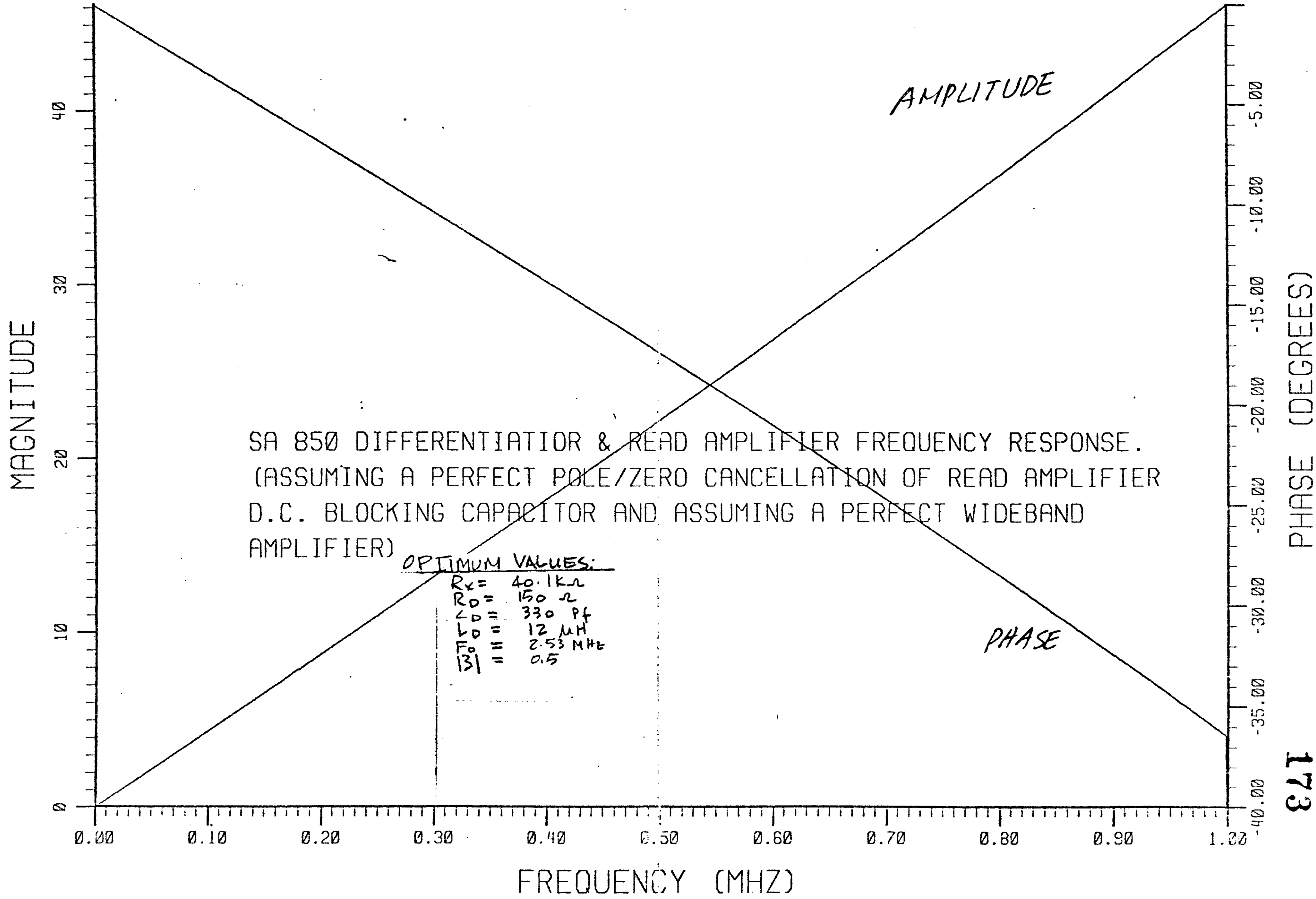
C_D = 1800 Pf

L_D = 100 μH

F_D = 375 KHz

$|\zeta|$ = 0.51

(2)



SA 850 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE. (ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND AMPLIFIER)

OPTIMUM VALUES:

R_x = 40.1kΩ

R_D = 150 Ω

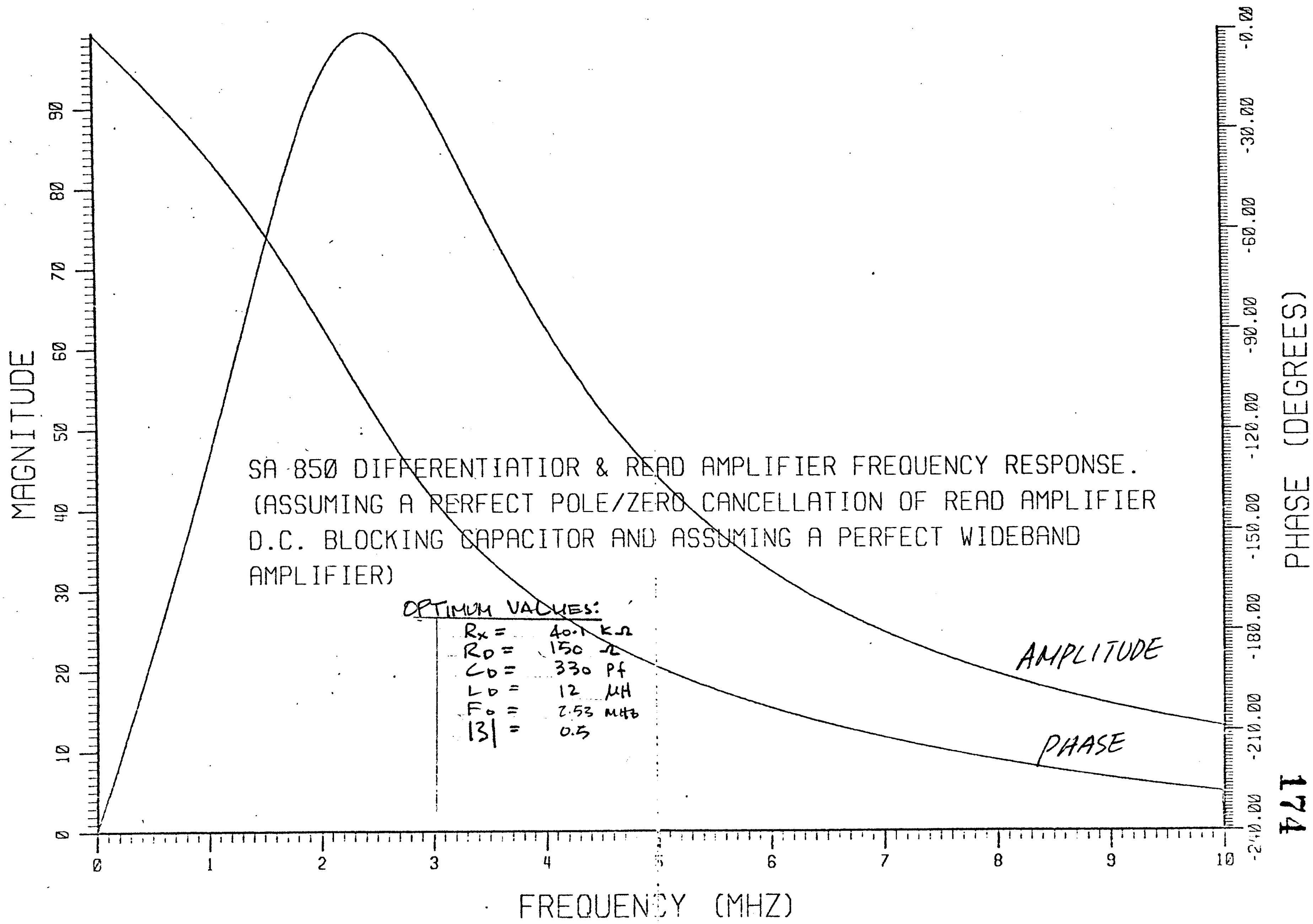
C_D = 330 pf

L_D = 12 μH

F_o = 2.53 MHz

$|\beta|$ = 0.5

6

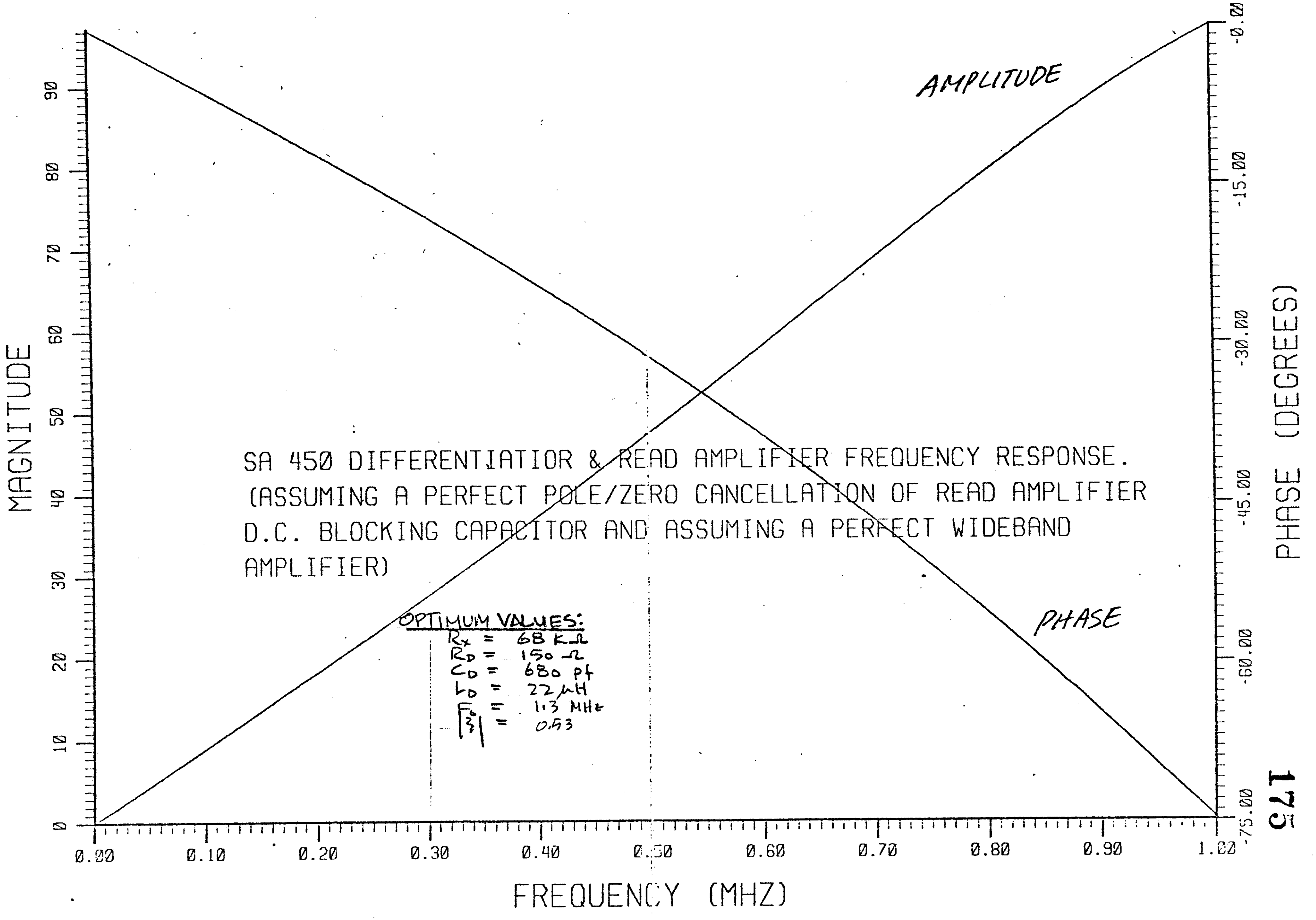


SA 850 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE. (ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND AMPLIFIER)

<u>OPTIMUM VALUES:</u>

R_x = 40.1 kΩ
R_D = 150 Ω
C_D = 330 pf
L_D = 12 μH
F_o = 2.53 MHz
$|\beta|$ = 0.5

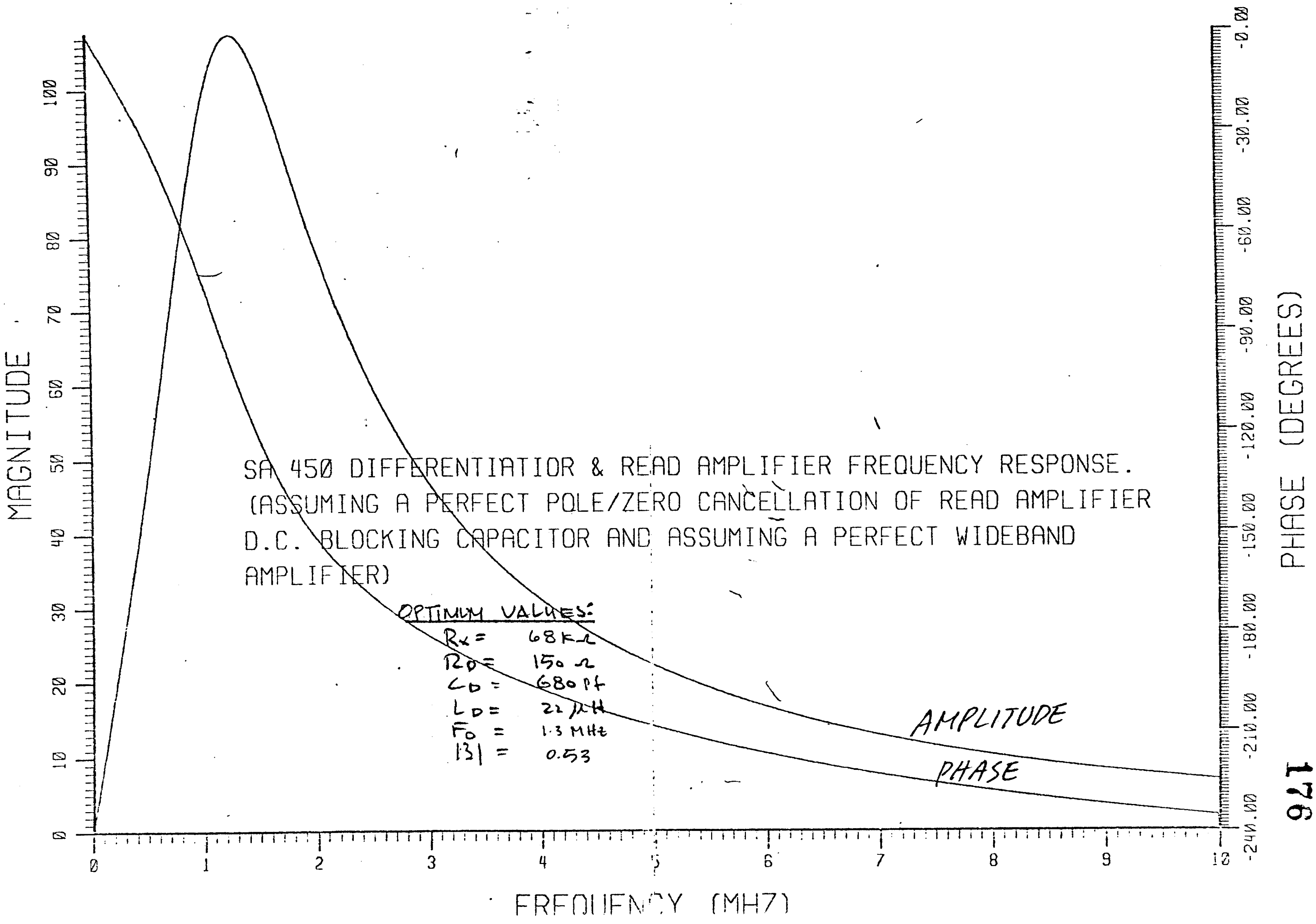
(4)



SA 450 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE. (ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND AMPLIFIER)

<u>OPTIMUM VALUES:</u>

R_x = 68 KΩ
R_D = 150 Ω
C_D = 680 pf
L_D = 22 μH
F_0 = 1.3 MHz
$|\zeta|$ = 0.53



SA 450 DIFFERENTIATIOR & READ AMPLIFIER FREQUENCY RESPONSE. (ASSUMING A PERFECT POLE/ZERO CANCELLATION OF READ AMPLIFIER D.C. BLOCKING CAPACITOR AND ASSUMING A PERFECT WIDEBAND AMPLIFIER)

<u>OPTIMUM VALUES:</u>

R_x = 68KΩ
R_D = 150 Ω
C_D = 680 pf
L_D = 22 μH
F_0 = 1.3 MHz
|β| = 0.53

E-8. Derivation of time response of differentiator for pure sinewave input.

Sinewave was chosen for its relatively simple Laplace transform form. Also, it is quite close to the head output signal for time delay evaluation purposes. The transfer function for Case I in Appendix E-1 shows that:

$$T(S) = \frac{R_c}{L_D} \frac{S + \frac{1}{C_D R_x}}{\left((S+\xi)^2 - \xi^2 + W_0^2\right)}$$

IF $V_{in} = \sin Wt \cdot u(t)$

$$V_i(S) = \mathcal{L}(V_{in}) = \frac{W}{S^2 + W^2}$$

$$V_0(t) = V_i(t) \overset{\text{Convolution}}{*} \underset{\text{Zero input response}}{h(t)}$$

$$V_o(S) = V_i(S) \cdot \underset{\text{Transfer function}}{H(S)}$$

$$V_o(S) = \left(\frac{W}{S^2 + W^2}\right) \cdot \left(\frac{R_c}{L_D} \frac{S + \frac{1}{C_D R_x}}{\left[(S+\xi)^2 - \xi^2 + W_0^2\right]}\right)$$

$$= \frac{AS+B}{S^2 + W^2} + \frac{CS+D}{(S+\xi)^2 - (\xi^2 - W_0^2)}$$ Partial fraction expansion

$$(AS+B)(S^2 + 2\xi S + W_0^2) + (CS+D)(S^2 + W^2) = \frac{R_c}{L_D} W S + \frac{R_c W}{L_D C_D R_x}$$

$$AS^3 + (B + 2\xi A)S^2 + (2\xi B + AW_0^2)S + BW_0^2 + CS^3 + DS^2 + CW^2S + DW^2 =$$

$$\frac{R_c}{L_D} WS + \frac{R_c W}{L_D C_D R_x}$$

Equating equal power terms:

$$\begin{cases} A + C = 0 \\ 2\xi A + B + D = 0 \\ \omega_0^2 A + 2\xi B + \omega^2 C = \frac{R_c\omega}{L_D} \\ \omega_0^2 B + \omega^2 D = \frac{R_c\omega}{L_D C_D R_x} \end{cases}$$

To solve for A, B, C & D, a determinant approach is deemed necessary

$$\triangle = \begin{vmatrix} 1 & 0 & 1 \\ 2\xi & \omega^2 & 0 \\ \omega_0^2 & 0 & \omega^2 \end{vmatrix} + \begin{vmatrix} 2\xi & 1 & 1 \\ \omega_0^2 & 2\xi & 0 \\ 0 & \omega_0^2 & \omega^2 \end{vmatrix}$$

$$= \omega^4 - \omega_0^2\omega^2 + 4\xi^2\omega^2 + \omega_0^4 - \omega_0^2\omega^2$$

$$\triangle = \omega^4 + \omega_0^4 - 2\omega_0^2\omega^2 + 4\xi^2\omega^2 = (\omega^2 - \omega_0^2)^2 + (2\xi\omega)^2$$

$$A = \frac{\begin{vmatrix} 0 & 1 & 1 \\ \frac{R_c\omega}{L_D} & 2\xi & 0 \\ \frac{R_c\omega}{L_D C_D R_x} & \omega_0^2 & \omega^2 \end{vmatrix}}{\triangle} = \frac{\frac{R_c\omega\omega_0^2}{L_D} - \frac{2\xi R_c\omega}{L_D C_D R_x} - \frac{R_c\omega^3}{L_D}}{\triangle}$$

$$B = \frac{\begin{vmatrix} 2\xi & 0 & 1 \\ \omega_0^2 & \frac{R_c\omega}{L_D} & 0 \\ 0 & \frac{R_c\omega}{L_D C_D R_x} & \omega^2 \end{vmatrix} + \begin{vmatrix} 0 & 0 & 1 \\ \frac{R_c\omega}{L_D} & \omega^2 & 0 \\ \frac{R_c\omega}{L_D C_D R_x} & 0 & \omega^2 \end{vmatrix}}{\triangle}$$

$$= \frac{\frac{2\xi R_c\omega^2}{L_D} + \frac{R_c\omega\omega_0^2}{L_D C_D R_x} - \frac{R_c\omega^3}{L_D C_D R_x}}{\triangle}$$

$$C = \frac{\begin{vmatrix} 1 & 0 & 1 \\ 2\xi & \frac{R_c W}{L_D} & 0 \\ W_0^2 & \frac{R_c W}{L_D C_D R_x} & W^2 \end{vmatrix}}{\Delta} = \frac{\frac{R_c W^3}{L_D} + \frac{2 R_c W \xi}{L_D C_D R_x} - \frac{R_c W W_0^2}{L_D}}{\Delta}$$

$$D = \frac{\begin{vmatrix} 1 & 0 & 0 \\ 2\xi & W^2 & \frac{R_c W}{L_D} \\ W_0^2 & 0 & \frac{R_c W}{L_D C_D R_x} \end{vmatrix} + \begin{vmatrix} 2\xi & 1 & 0 \\ W_0^2 & 2\xi & \frac{R_c W}{L_D} \\ 0 & W_0^2 & \frac{R_c W}{L_D C_D R_x} \end{vmatrix}}{\Delta}$$

$$= \frac{\frac{R_c W^3}{L_D C_D R_x} + \frac{4\xi^2 R_c W}{L_D C_D R_x} - \frac{2\xi W_0^2 R_c W}{L_D} - \frac{R_c W W_0^2}{L_D C_D R_x}}{\Delta}$$

$$V_0(S) = \frac{AS}{(S^2+W^2)} + \frac{B}{(S^2+W^2)} + \frac{CS}{(S+\xi)^2 + (\sqrt{W_0^2-\xi^2})^2} + \frac{D}{(S+\xi)^2 + (\sqrt{W_0^2-\xi^2})^2}$$

$$\underline{\underline{\xi < W_0}}$$

(Causal System!)

$$V_0(t) = \mathcal{L}^{-1}[V_0(S)]$$

$$= A\cos Wt + \frac{B}{W}\sin Wt + \frac{Ce^{-\xi t}}{W_0^2-\xi^2}\left\{\frac{d}{dt}\left[\xi\cos\sqrt{W_0^2-\xi^2}\,t + \sqrt{W_0^2-\xi^2}\sin\sqrt{W_0^2-\xi^2}\,t\right]\right.$$

$$\left. - 2\sqrt{W_0^2-\xi^2}\frac{d}{dt}\sin\sqrt{W_0^2-\xi^2}\,t\right\} - \frac{De^{-\xi t}}{W_0^2-\xi^2}\frac{d}{dt}\cos(\sqrt{W_0^2-\xi^2}\,t)$$

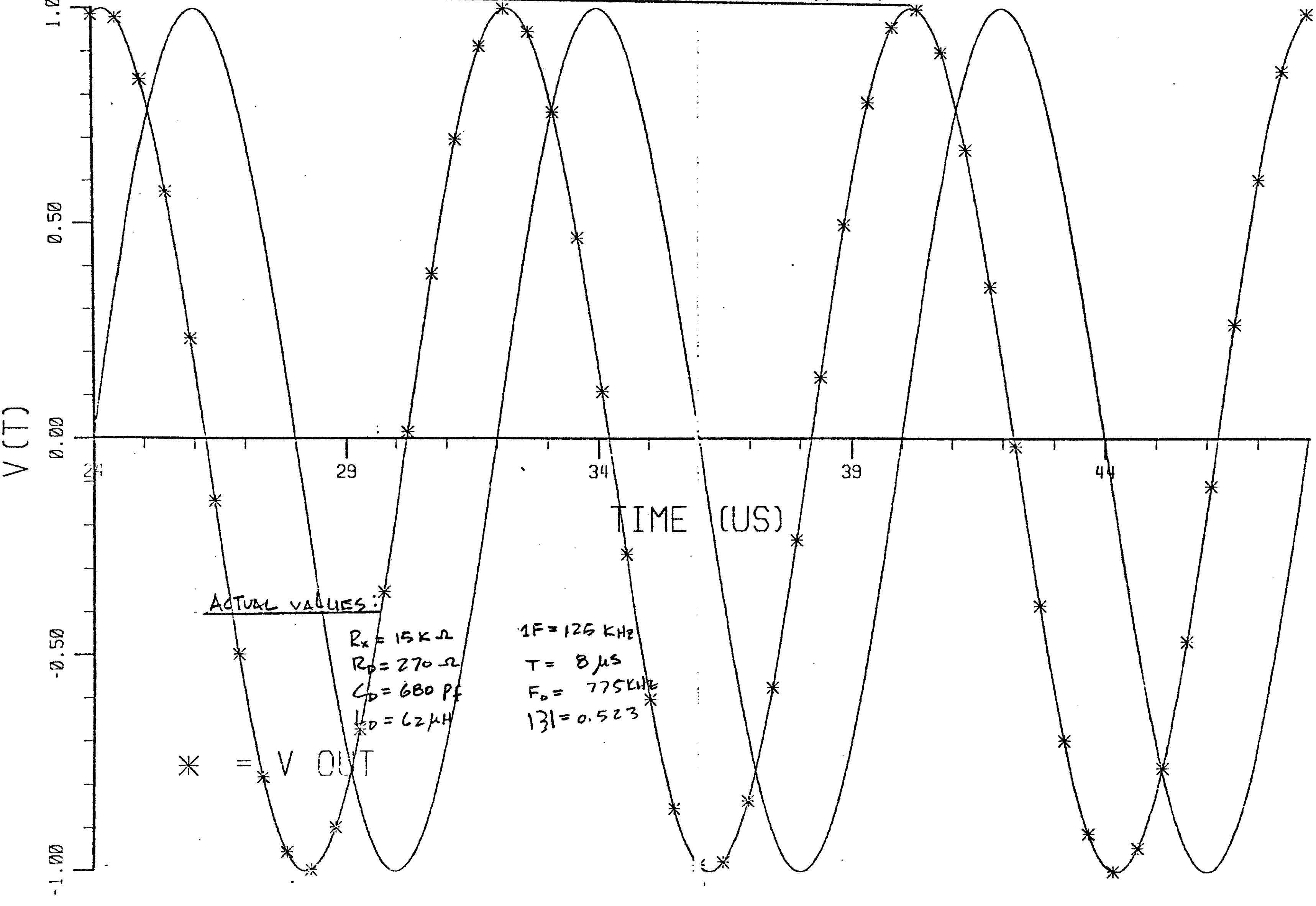
$$\boxed{\begin{aligned} V_0(t) = {} & A\cos Wt + \frac{B}{W}\sin Wt + \frac{Ce^{-\xi t}}{W_0^2-\xi^2}\left[-\xi\sqrt{W_0^2-\xi^2}\sin\sqrt{W_0^2-\xi^2}\,t - (W_0^2-\xi^2)\cos\sqrt{W_0^2-\xi^2}\,t\right] \\ & + \frac{De^{-\xi t}\sqrt{W_0^2-\xi^2}}{W_0^2-\xi^2}\sin\sqrt{W_0^2-\xi^2}\,t \end{aligned}}$$

Before Cancellation

```
$INSERT SYSCOM>KEYS.F
$INSERT SYSCOM>A$KEYS
      DIMENSION X(1001),Y(1001),Y2(1001)
      REAL LD

      CALL SRCH$$(K$WRIT,'LAD8',4,1,0,CODE)

      RX=68000.
      RD=150.
      CD=680.E-12
      LD=22.E-6
      RE=20.
      RC=1330.

      W0=1./SQRT(LD*CD)
      ZETA=.5*(1./(CD*RX)+(RD+2.*RE)/LD)
      AZETA=ZETA/W0

      F=125000.
      W=6.2832*F
      DELTA=(W*W-W0*W0)**2+(2.*ZETA*W)**2

      A=(RC*W*W0*W0/LD-2.*ZETA*RC*W/(LD*CD*RX)-RC*W**3/LD)/DELTA
      B=(2.*ZETA*RC*W**3/LD+RC+W+W0*W0/(LD*CD*RX)-RC*W**3/(LD*CD*RX))/DE
     1LTA
      C=(RC*W**3/LD+2.*RC*W*ZETA/(LD*CD*RX)-RC*W*W0*W0/LD)/DELTA
      D=(RC*W**3/(LD*CD*RX)+4.*ZETA**2*RC*W/(LD*CD*RX)-2.*ZETA*W0*W0*RC*
     1W/LD-RC*W*W0*W0/(LD*CD*RX))/DELTA

      DO 10 I=1,1001
      T=FLOAT(I-1)*2.4E-8+24.E-6
      X(I)=T
      Y(I)=A*COS(W*T)+(B/W)*SIN(W*T)+(C*EXP(-ZETA*T)/(W0*W0-ZETA**2))*(-
     1ZETA*SQRT(W0*W0-ZETA**2)*SIN(SQRT(W0*W0-ZETA**2)*T)-(W0*W0-ZETA**2
     2)*COS(SQRT(W0*W0-ZETA**2)*T))+D*EXP(-ZETA*T)*SIN(SQRT(W0*W0-ZETA**
     32)*T)/SQRT(W0*W0-ZETA**2)
   10 Y2(I)=SIN(6.2832*F*T)

      WRITE(5,20)(X(I),Y(I),Y2(I),I=1,1001)
   20 FORMAT(3E12.5)

      WRITE(5,20)A,B,C,D,DELTA,W,W0,ZETA,AZETA
      CALL SRCH$$(K$CLOS,0,0,1,0,CODE)
      CALL EXIT
      END
```

E9 & E-10

SA 850 DIFFERENTIATOR TIME RESPONSE TO 1F SINWAVE INPUT

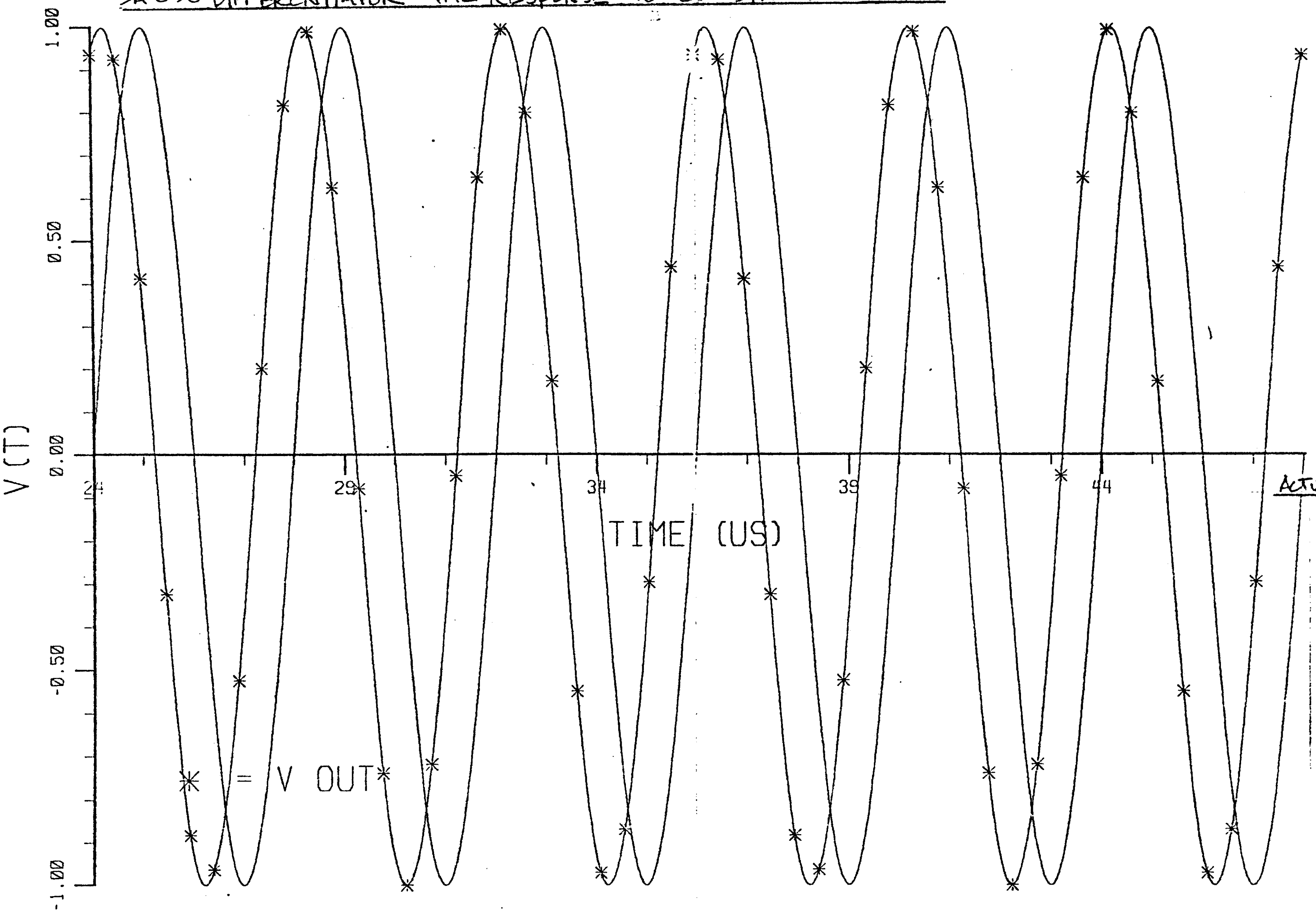


ACTUAL VALUES:

$R_x = 15 K\Omega$
$R_D = 270\,\Omega$
$C_D = 680$ pf
$L_D = 62\,\mu H$

1F = 125 KHz
T = 8 μs
$F_o = 775$ KHz
$|\beta| = 0.523$

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT

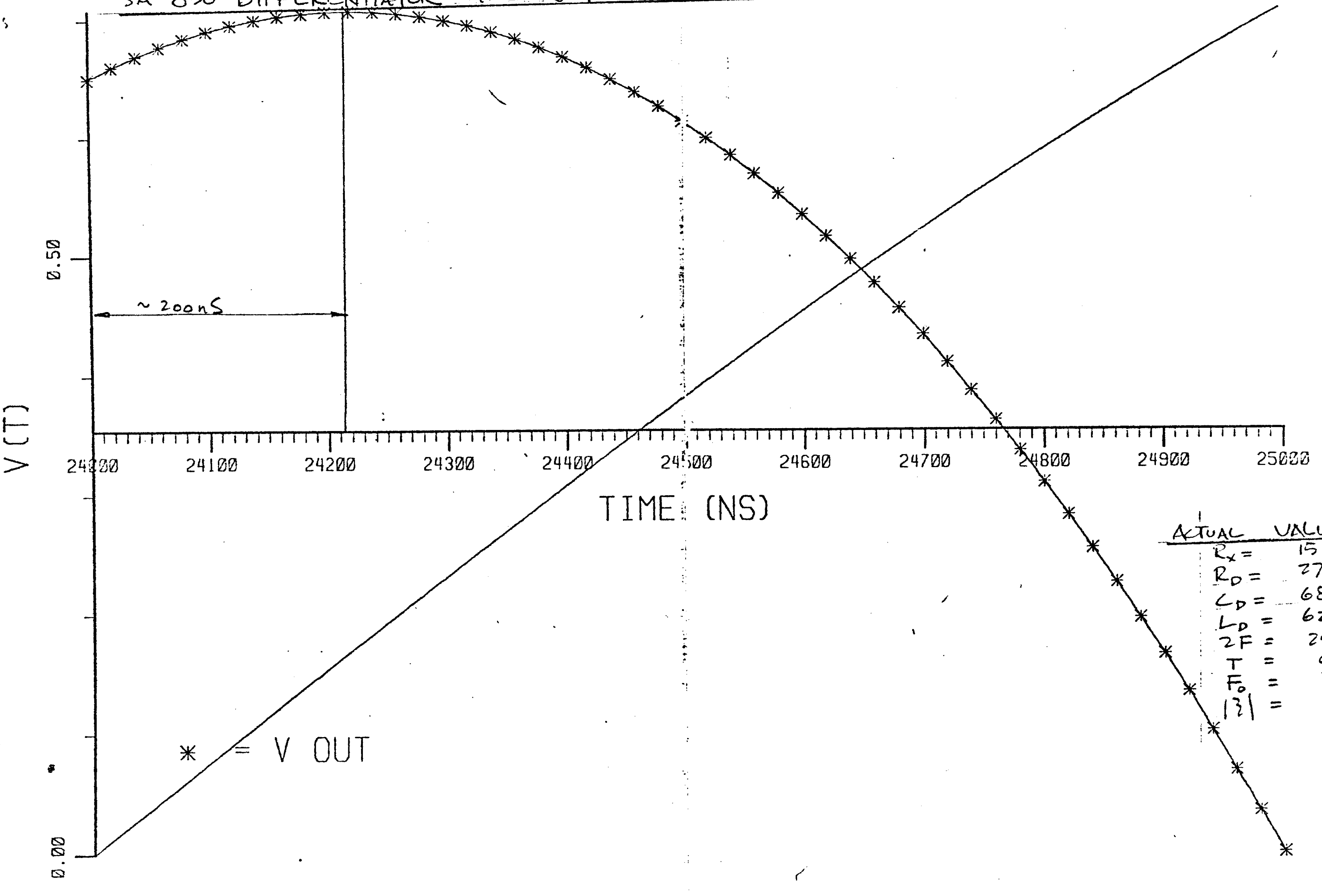


ACTUAL VALUES:

$R_x = 15 K \Omega$
$R_D = 270 \Omega$
$C_D = 680 pf$
$L_D = 62 \mu H$
$2F = 250 KHz$
$T = 4 \mu S$
$F_0 = 775 KHz$
$|B| = 0.523$

3

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



ACTUAL VALUES:

R_x = 15K Ω

R_D = 270 Ω

C_D = 680 Pf

L_D = 62 μH

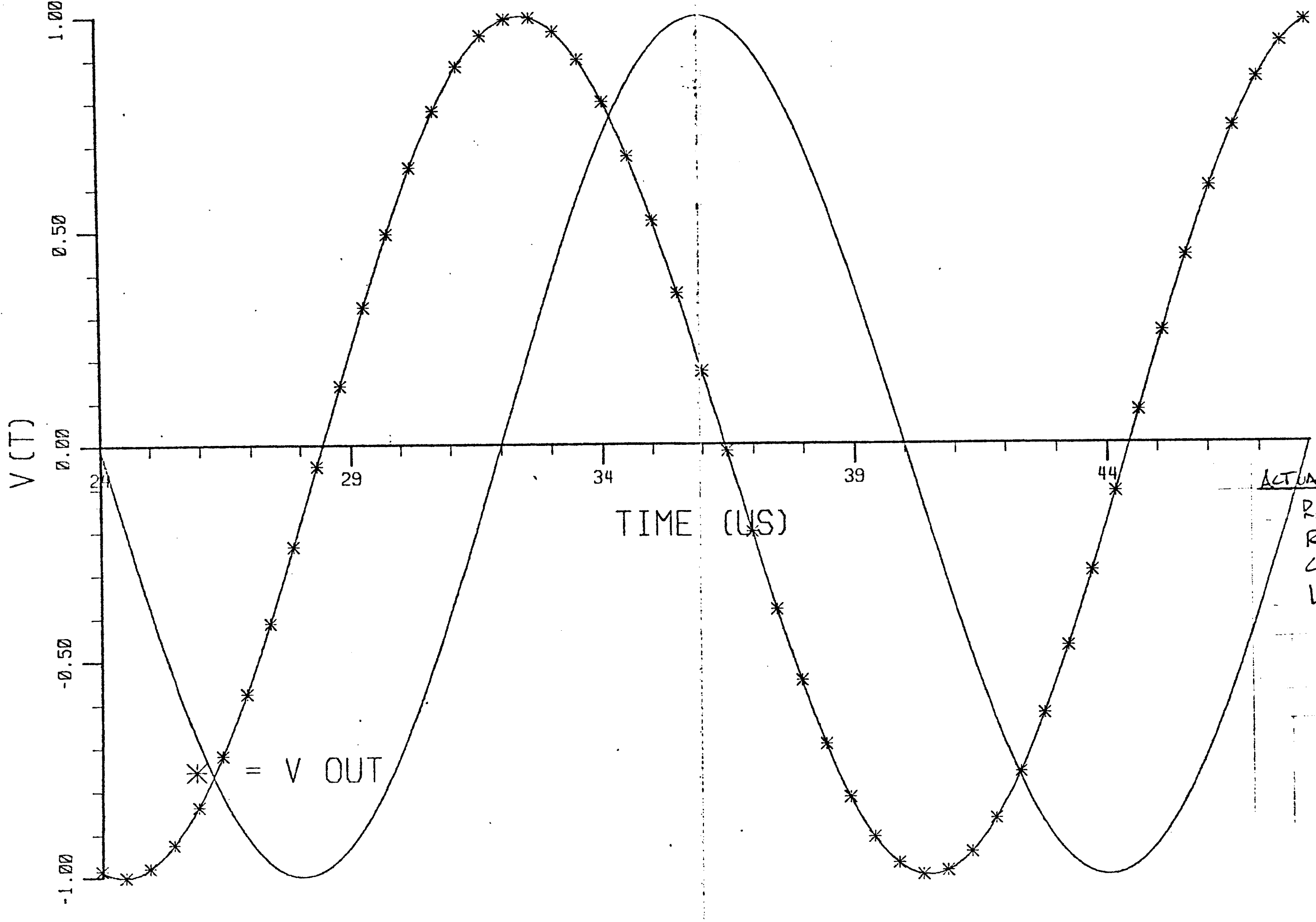
2F = 250 KHZ

T = 4 μS

F_0 = 775 KHz

$|\zeta|$ = 0.523

SA 450 DIFFERENTIATOR TIME RESPONSE TO 1F SINWAVE INPUT



ACTUAL VALUES:

$R_X = 47\ k\Omega$

$R_D = 200\ \Omega$

$C_D = 1800\ pF$

$L_D = 100\ \mu H$

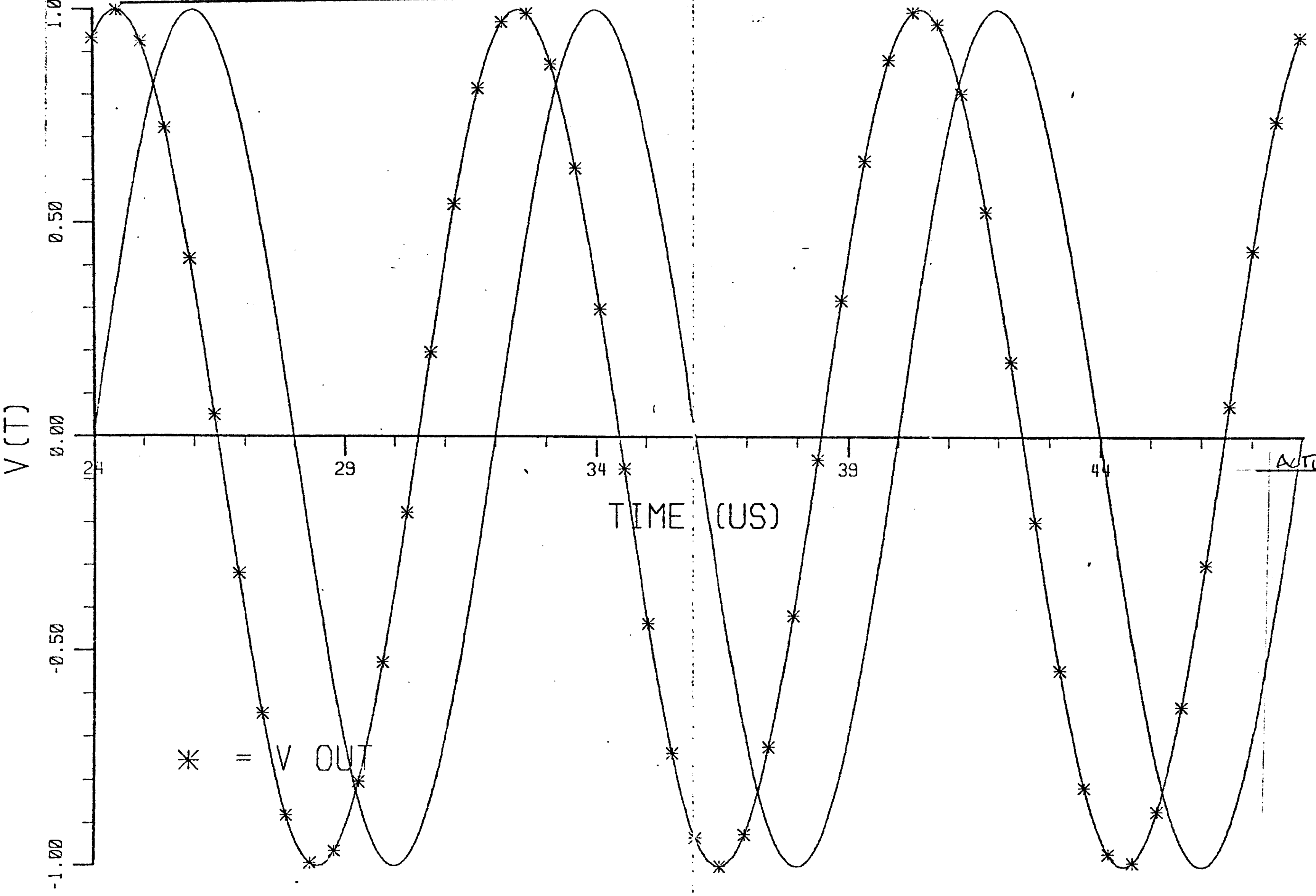
$IF = 62.5\ kHz$

$T = 16\ \mu S$

$F_o = 375\ kHz$

$|\beta| = 0.51$

SA 450 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



ACTUAL VALUES:

R_x = 47 kΩ

R_D = 200 Ω

C_D = 1500 pf

L_D = 100 μH

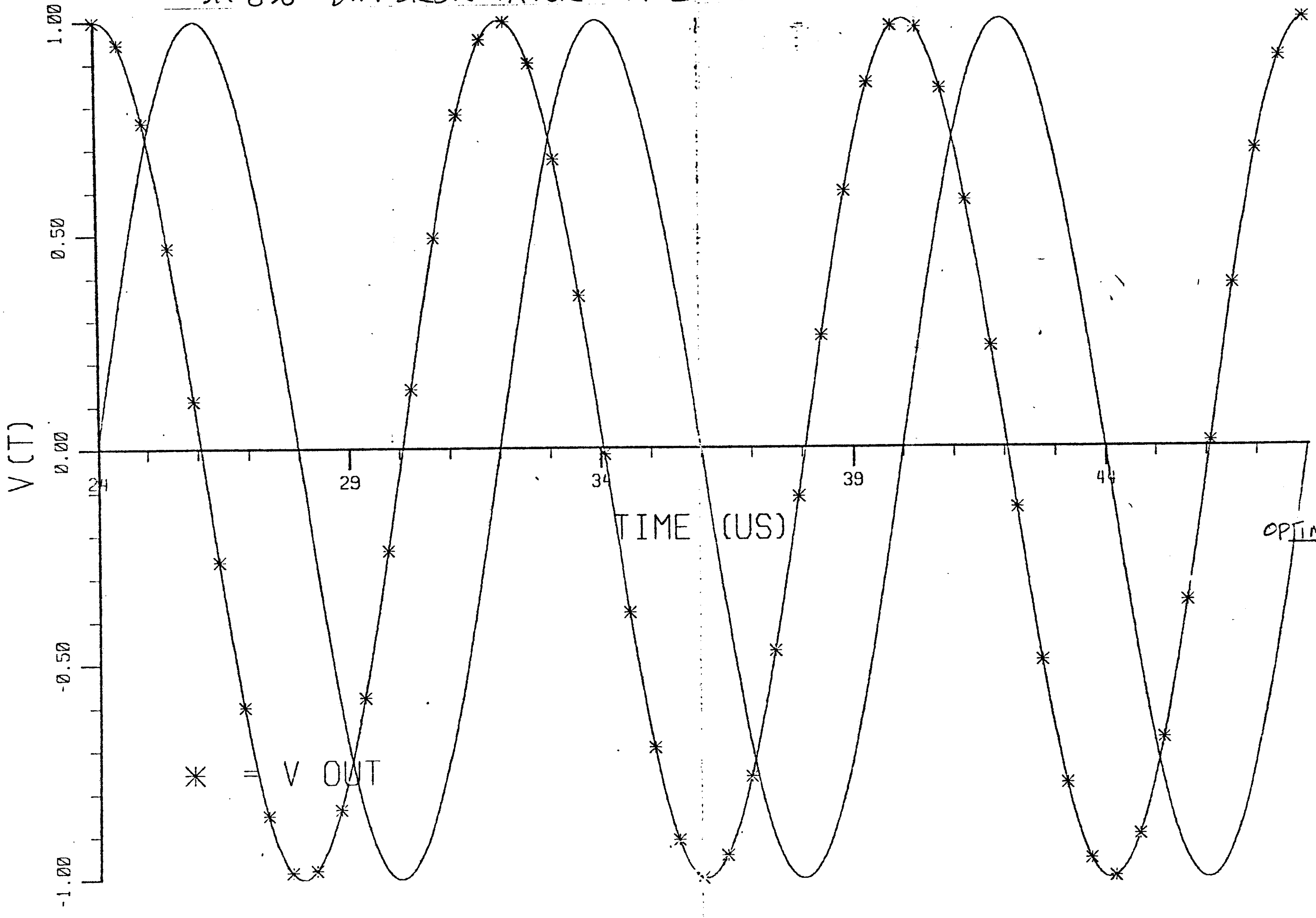
2F = 125 kHz

T = 8 μs

F_o = 375 kHz

|β| = 0.51

SA 850 DIFFERENTIATOR TIME RESPONSE TO IF SINWAVE INPUT



OPTIMUM VALUES:

$R_x = 40.1\ K\Omega$

$R_D = 150\ \Omega$

$C_D = 330\ pf$

$L_D = 12\ \mu H$

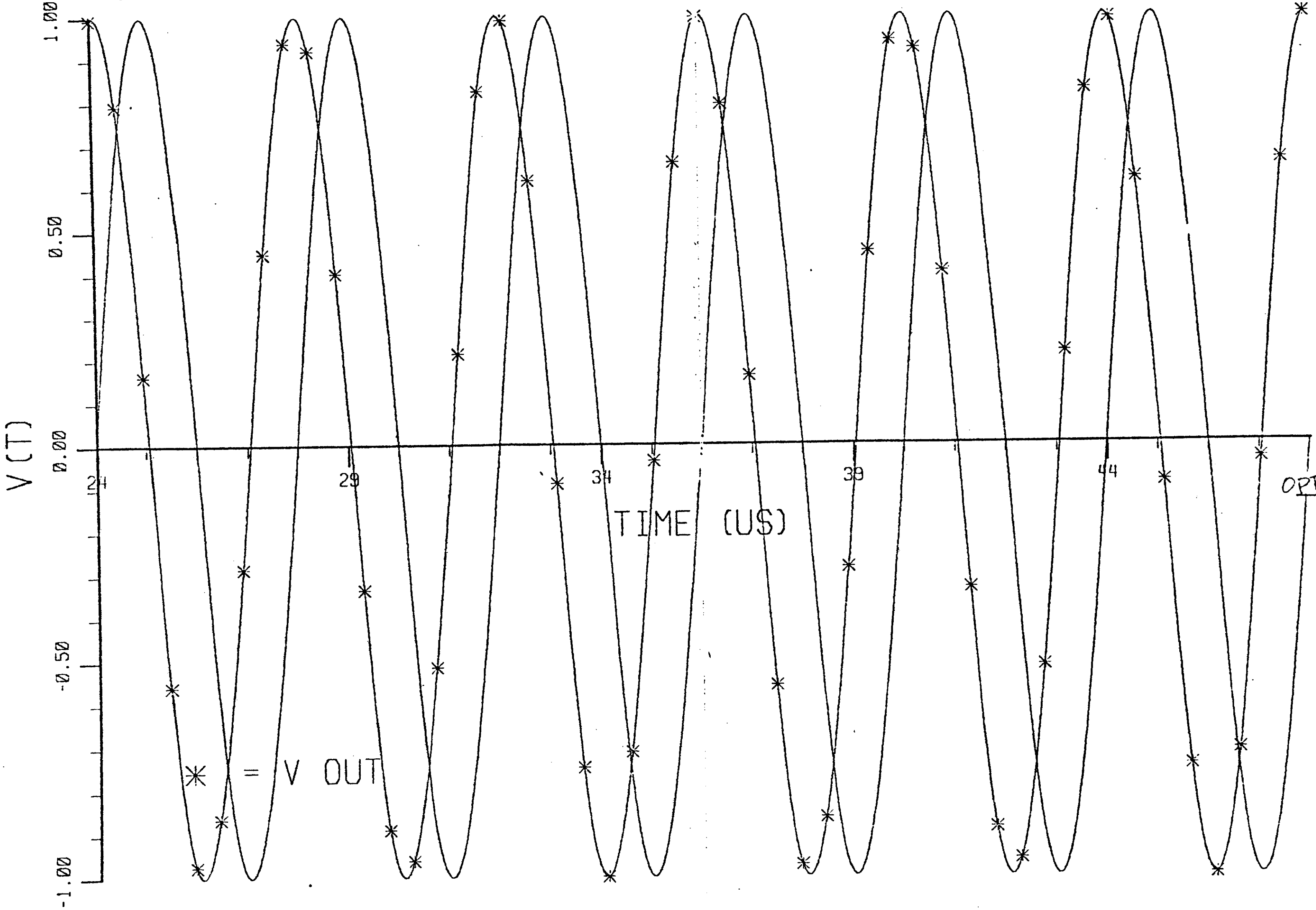
$IF = 125\ KHz$

$T = 8\ \mu S$

$F_D = 253\ MHz$

$|\zeta| = 0.5$

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



OPTIMUM VALUES:

$R_x = 40.1\ K\Omega$

$R_D = 150\ \Omega$

$C_D = 330\ pf$

$L_D = 12\ \mu H$

$2F = 250\ KHz$

$T = 4\ \mu S$

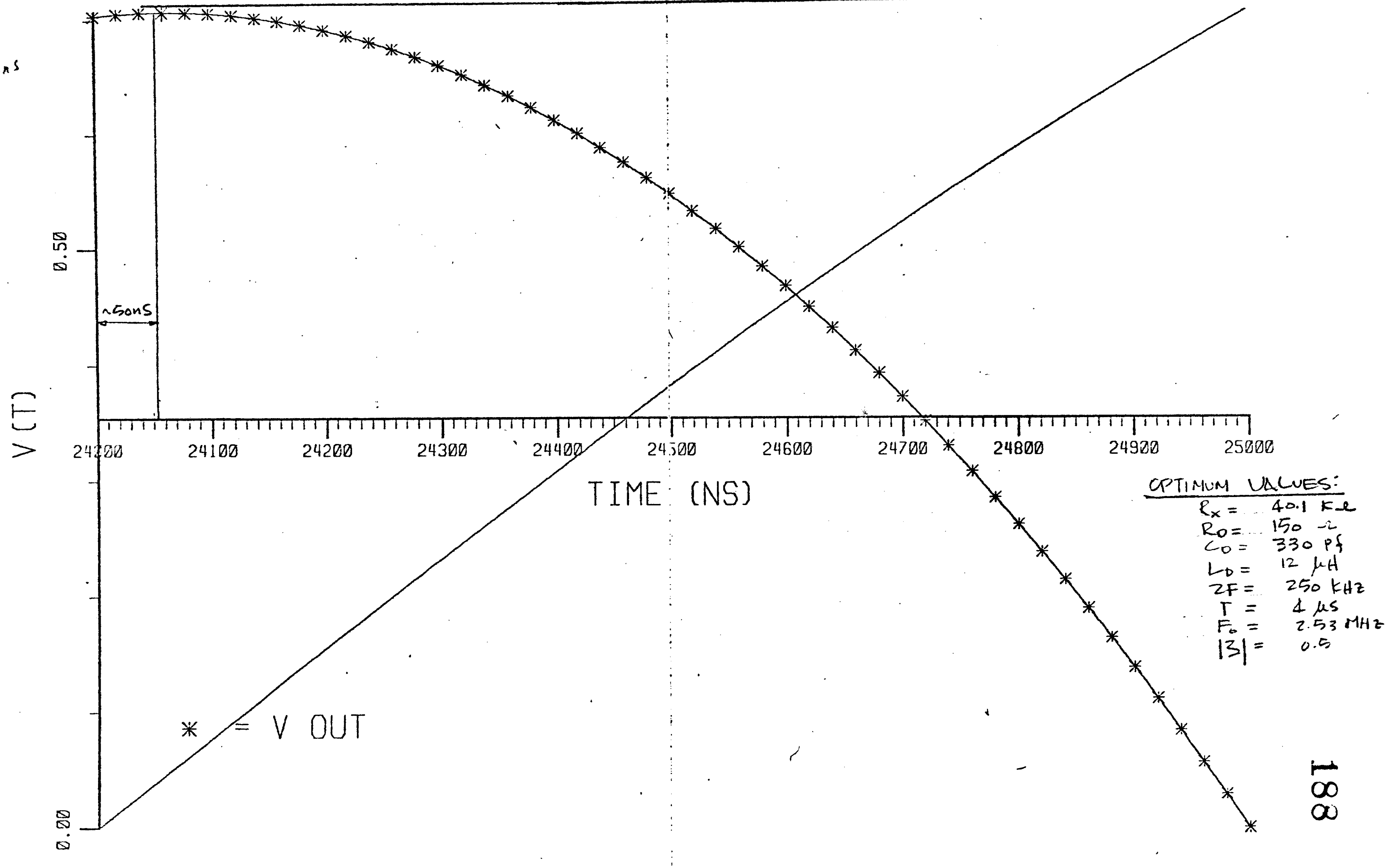
$F_0 = 2.53\ MHz$

$|\beta| = 0.5$

4

~50ns

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



OPTIMUM VALUES:

R_x = 40.1 KΩ

R_O = 150 Ω

C_O = 330 pf

L_O = 12 μH

2F = 250 KHz

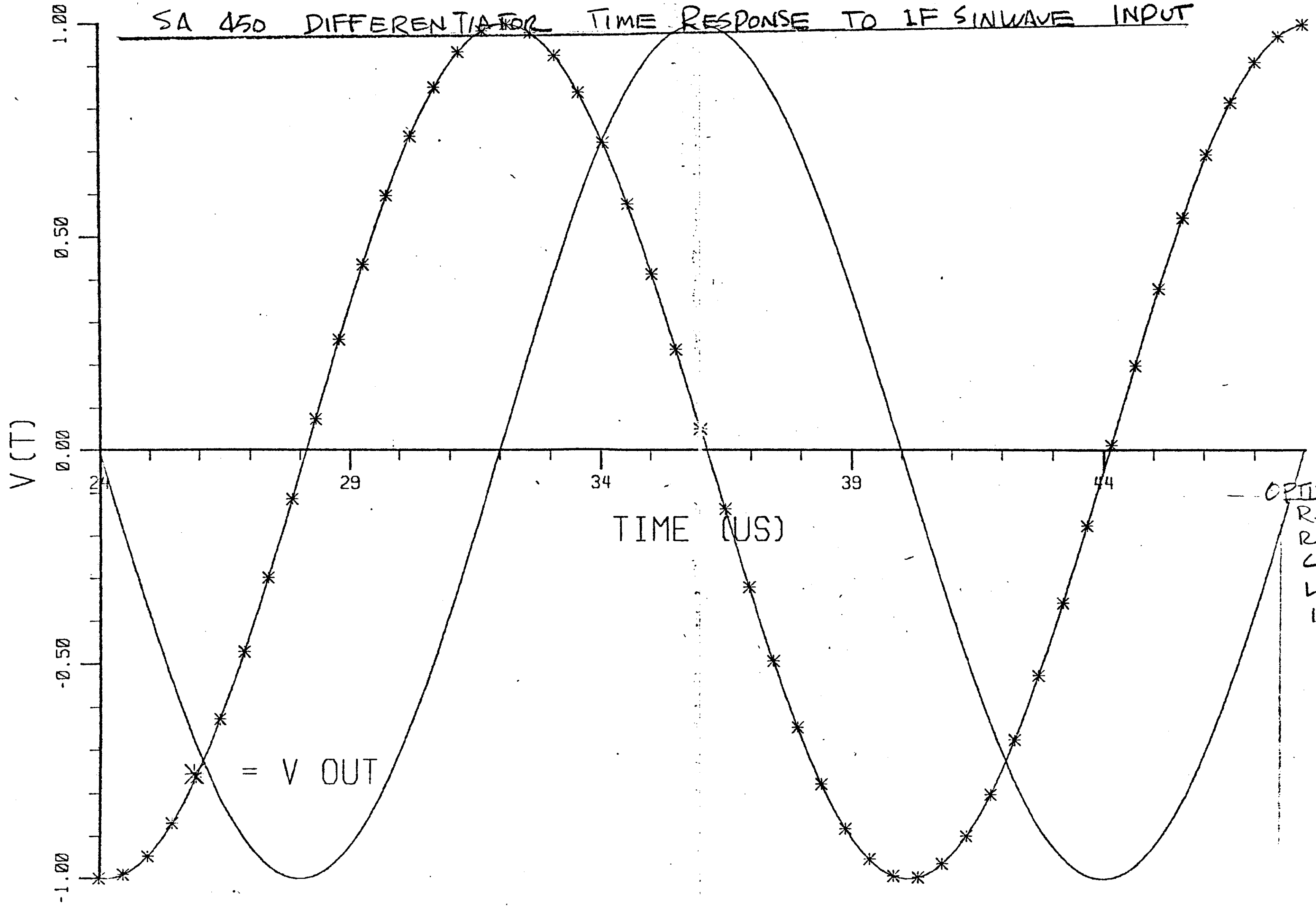
T = 4 μs

F_o = 2.53 MHz

$|\beta|$ = 0.5

6

SA 450 DIFFERENTIATOR TIME RESPONSE TO IF SINWAVE INPUT



OPTIMUM VALUES:

$R_x = 68$ kΩ

$R_D = 150$ Ω

$C_D = 680$ pf

$L_D = 22$ μH

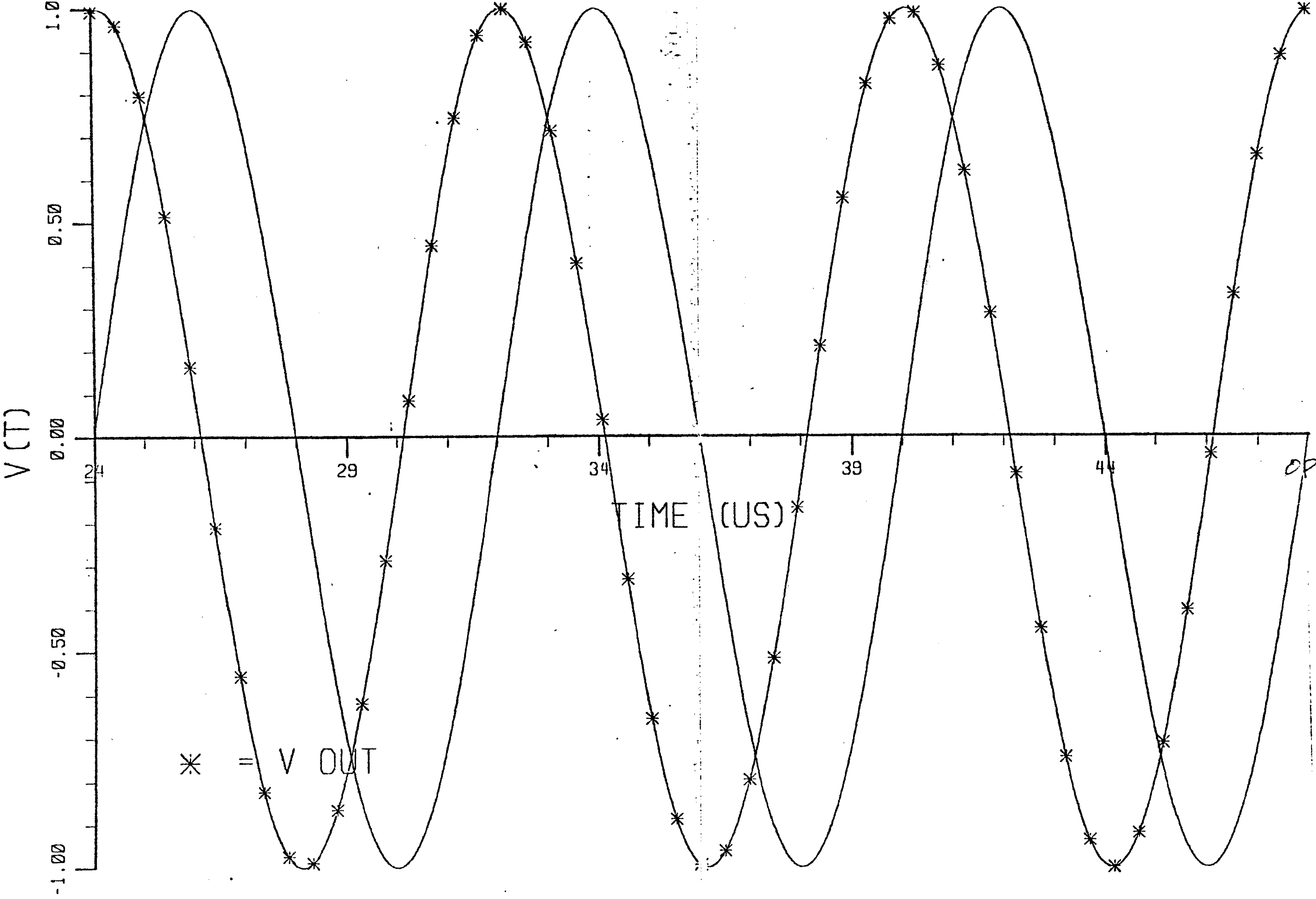
IF = 62.5 kHz

T = 16 μs

$F_0 = 1.3$ MHz

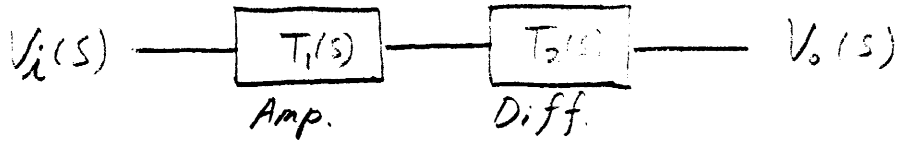
$|B| = 0.53$

SA 450 DIFFERENTIATOR TIME RESPONSE TO ZF SINWAVE INPUT



OPTIMUM VALUES:
R_x = 68 KΩ
R_D = 150 Ω
C_D = 680 pf
L_D = 22 µH
ZF = 125 KHz
T = 8 µs
F_o = 1.3 MHz
|B| = 0.53

E-11. Derivation of time response of differentiator for Sinewave input assuming perfect pole/zero cancellation.



$$V_o(S) = V_i(S) \cdot T_1(S) \cdot T_2(S)$$ Linear System

$$T_1(S) = \frac{100 S \omega_B}{(S+\omega_B)(S+\frac{1}{500C})}$$ (Appendix B-1)

$$T_2(S) = \frac{R_C}{L_D} \frac{S+\frac{1}{C_DR_x}}{\left(S^2+S\left(\frac{1}{C_DR_x}+\frac{R_D+2r_e}{L_D}\right)+\frac{1}{L_DC_D}\right)}$$

$$V_i(S) = \frac{\omega}{S^2+\omega^2}$$

$$V_o(S) = \frac{\omega}{S^2+\omega^2} \cdot \frac{100 S \omega_B}{\cancel{(S+\omega_B)(S+\frac{1}{500C})}} \cdot \frac{R_C}{L_D} \frac{\cancel{(S+\frac{1}{C_DR_x})}}{\left[S^2+S\left(\frac{1}{C_DR_x}+\frac{R_D+2r_e}{L_D}\right)+\frac{1}{L_DC_D}\right]}$$

Assuming perfect pole/zero cancellation and, to make life easier, a perfect wideband amplifier ($\omega_B \sim \infty$). The $V_o(S)$ expression can be simplified as

$$V_o(S) = \frac{100 R_C}{L_D} \left(\frac{\omega}{S^2+\omega^2}\right)(S)\left(\frac{1}{S^2+S\left(\frac{1}{C_DR_x}+\frac{R_D+2r_e}{L_D}\right)+\frac{1}{L_DC_D}}\right)$$

Partial fraction expansion

$$V_o(S) = \frac{100 R_C}{L_D}\left[\frac{AS+B}{S^2+\omega^2}+\frac{CS+D}{S^2+2\zeta S+\omega_o^2}\right]$$

$$(As+B)(s^2+2\xi s+\omega_0^2)+(Cs+D)(s^2+\omega^2)=\omega =$$

$$As^3+(B+2A\xi)s^2+(2B\xi+A\omega_0^2)s+B\omega_0^2+Cs^3+Ds^2+C\omega^2 s+D\omega^2=\omega s$$

$$\left[\begin{array}{lllll} A & & +C & & =0 \\ 2\xi A & +B & & +D & =0 \\ \omega_0^2 A & +2\xi B & +\omega^2 C & & =\omega s \\ & \omega_0^2 B & & +\omega^2 D & =0 \end{array}\right.$$

$$\Delta=\begin{vmatrix} 1 & 0 & 1 \\ 2\xi & \omega^2 & 0 \\ \omega_0^2 & 0 & \omega^2 \end{vmatrix}+\begin{vmatrix} 2\xi & 1 & 1 \\ \omega_0^2 & 2\xi & 0 \\ 0 & \omega_0^2 & \omega^2 \end{vmatrix}=(\omega^2-\omega_0^2)^2+(2\xi\omega)^2$$

$$A=\frac{\begin{vmatrix} 0 & 1 & 1 \\ \omega & 2\xi & 0 \\ 0 & \omega_0^2 & \omega^2 \end{vmatrix}}{\Delta}=\frac{\omega\omega_0^2-\omega^3}{\Delta}$$

$$B=\frac{\begin{vmatrix} 2\xi & 0 & 1 \\ \omega_0^2 & \omega & 0 \\ 0 & 0 & \omega^2 \end{vmatrix}+\begin{vmatrix} 0 & 0 & 1 \\ \omega & \omega^2 & 0 \\ 0 & 0 & \omega \end{vmatrix}}{\Delta}=\frac{\omega^3 2\xi}{\Delta}$$

$$C=\frac{\begin{vmatrix} 1 & 0 & 1 \\ 2\xi & \omega & 0 \\ \omega_0^2 & 0 & \omega^2 \end{vmatrix}}{\Delta}=\frac{\omega^3-\omega\omega_0^2}{\Delta}$$

$$D = \frac{\begin{vmatrix} 2\xi & 1 & 0 \\ \omega_0^2 & 2\xi & \omega \\ 0 & \omega_0^2 & 0 \end{vmatrix} + \begin{vmatrix} 1 & 0 & 0 \\ 2\xi & \omega^2 & \omega \\ \omega_0^2 & 0 & 0 \end{vmatrix}}{\Delta} = \frac{-2\xi\omega_0^2\omega}{\Delta}$$

$$\mathcal{L}^{-1}\left[V_0(S)\right] = \frac{100R_c}{L_0}\left[\frac{AS}{S^2+\omega^2} + \frac{B}{S^2+\omega^2} + \frac{CS}{(S+\xi)^2+(\sqrt{\omega^2-\xi^2})^2} + \frac{D}{(S+\xi)^2+(\sqrt{\omega^2-\xi^2})^2}\right.$$

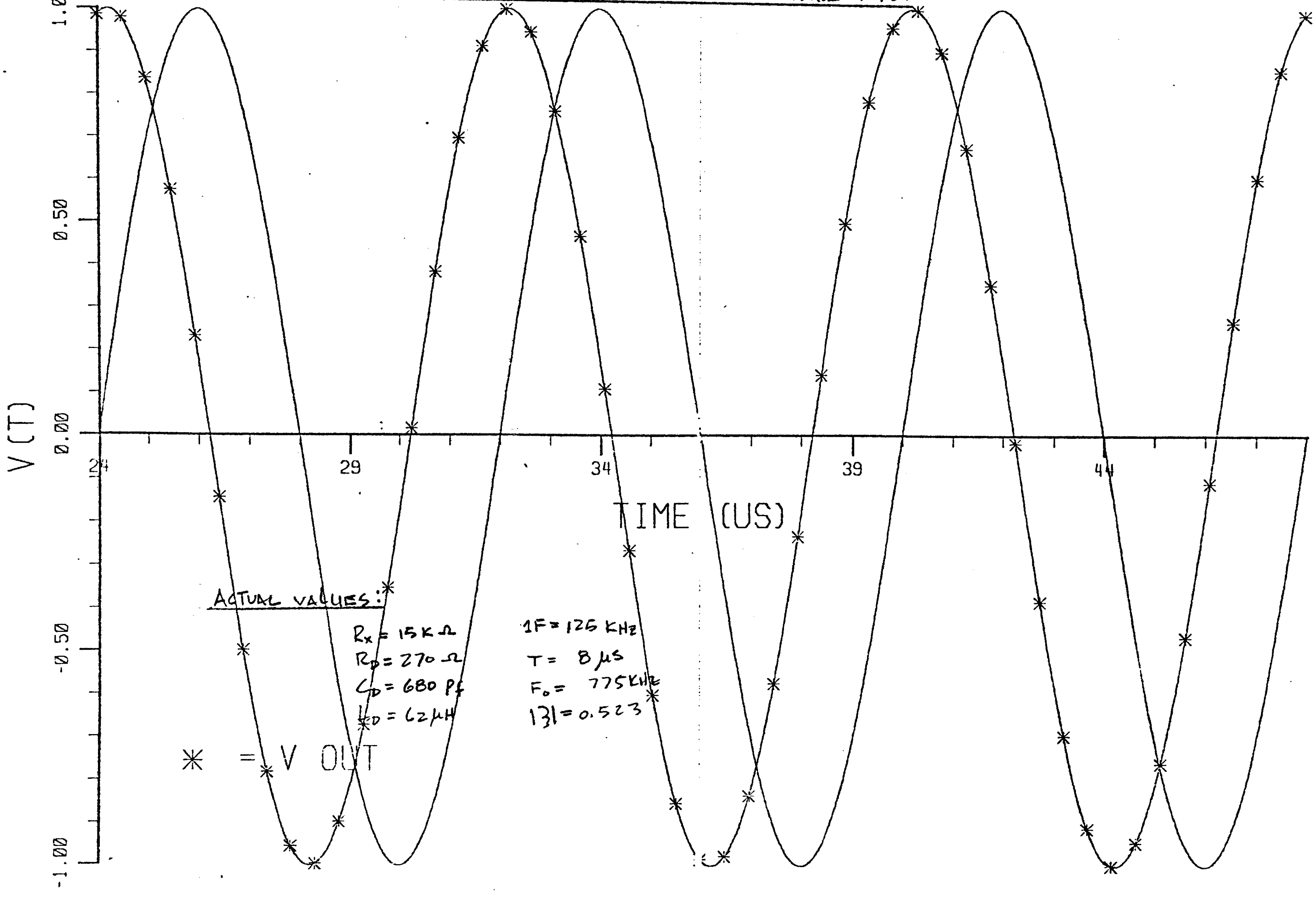
$$\boxed{\begin{aligned} V_0(t) = \frac{100R_c}{L_0}\Bigg\{ & A\cos\omega t + \frac{B}{\omega}\sin\omega t + \frac{Ce^{-\xi t}}{\omega_0^2-\xi^2}\left[-\xi\sqrt{\omega_0^2-\xi^2}\sin(\sqrt{\omega_0^2-\xi^2})t - (\omega_0^2-\xi^2)\cos\sqrt{\omega_0^2-\xi^2}\,t\right] \\ & + \frac{De^{-\xi t}\sqrt{\omega_0^2-\xi^2}}{\omega_0^2-\xi^2}\sin\left(\sqrt{\omega_0^2-\xi^2}\right)t\Bigg\} \end{aligned}}$$

After cancellation

```
$INSERT SYSCOM>KEYS.F
$INSERT SYSCOM>A$KEYS

      DIMENSION X(1001),Y(1001),Y2(1001)
      REAL LD

      CALL SRCH$$(K$WRIT,'LUB2',4,1,0,CODE)

      RX=40100.
      RD=150.
      CD=330.E-12
      LD=12.E-6
      RE=20.
      RC=1330.

      W0=1./SQRT(LD*CD)
      ZETA=.5*(1./(CD*RX)+(RD+2.*RE)/LD)
      AZETA=ZETA/W0

      F=125000.
      W=6.2832*F
      DELTA=(W*W-W0*W0)**2+(2.*ZETA*W)**2

      A=(W*W0*W0-W**3)/DELTA
      B=W**3*2.*ZETA/DELTA
      C=(W**3-W*W0*W0)/DELTA
      D=-2.*ZETA*W0*W0*W/DELTA

      DO 10 I=1,1001
      T=FLOAT(I-1)*2.4E-8+24.E-6
      X(I)=T
      Y(I)=A*COS(W*T)+(B/W)*SIN(W*T)+(C*EXP(-ZETA*T)/(W0*W0-ZETA**2))*(-
     1ZETA*SQRT(W0*W0-ZETA**2)*SIN(SQRT(W0*W0-ZETA**2)*T)-(W0*W0-ZETA**2
     2)*COS(SQRT(W0*W0-ZETA**2)*T))+D*EXP(-ZETA*T)*SIN(SQRT(W0*W0-ZETA**
     32)*T)/SQRT(W0*W0-ZETA**2)
   10 Y2(I)=SIN(6.2832*F*T)

      WRITE(5.20)(X(I),Y(I),Y2(I),I=1,1001)
   20 FORMAT(3E12.5)

      WRITE(5,20)A,B.C,D,DELTA,W,W0,ZETA,AZETA
      CALL SRCH$$(K$CLOS,0,0,1,0,CODE)
      CALL EXIT
      END
```

E12 & E-13

SA 850 DIFFERENTIATOR TIME RESPONSE TO 1F SINWAVE INPUT



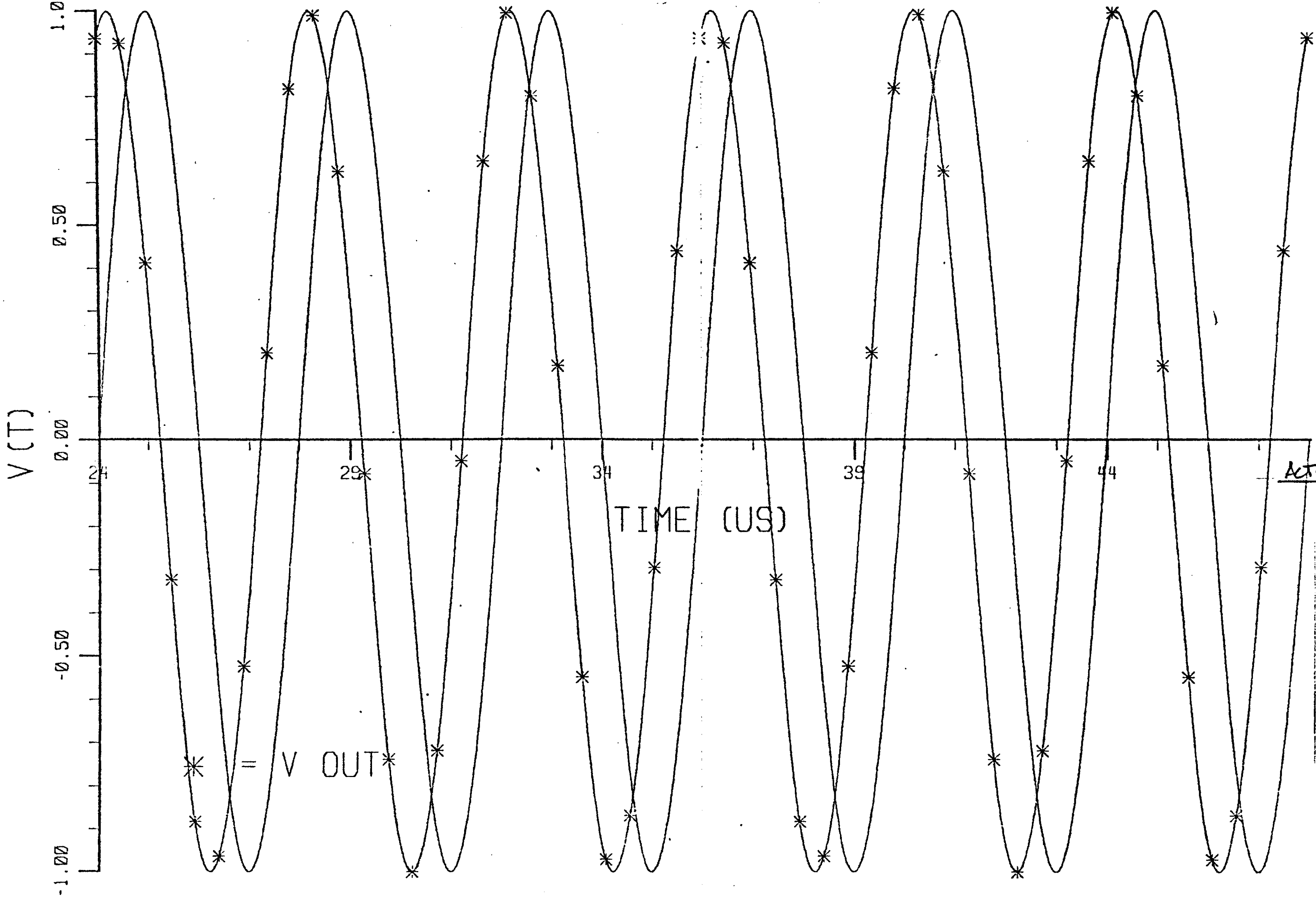
ACTUAL VALUES:

$R_x = 15 K\Omega$
$R_D = 270 \Omega$
$C_D = 680 pf$
$L_D = 62 \mu H$

1F = 125 KHz
T = 8 μs
$F_o =$ 775 KHz
|3| = 0.523

3

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



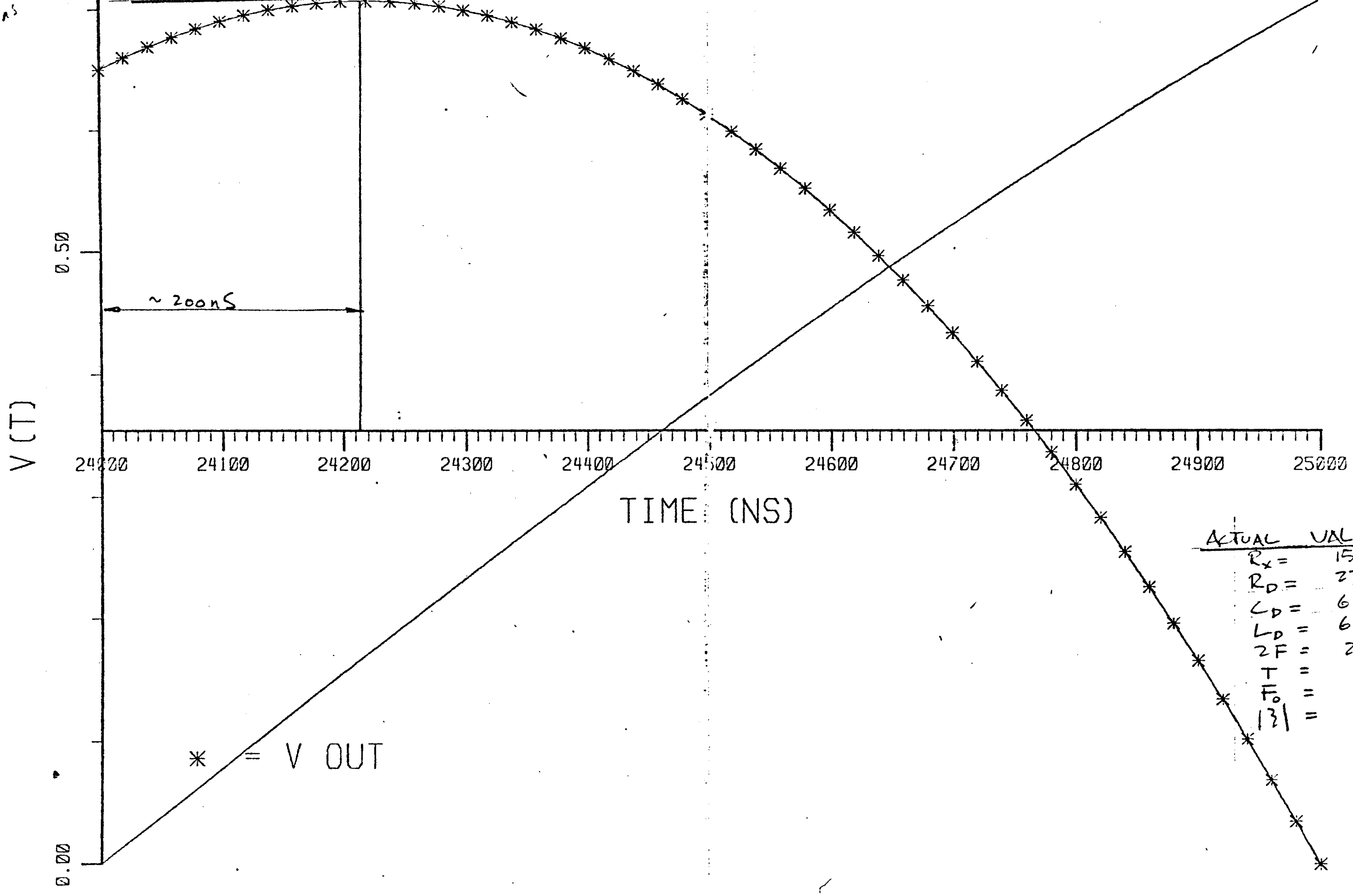
ACTUAL VALUES:

R_x = 15 K Ω
R_D = 270 Ω
C_D = 680 pf
L_D = 62 μH
2F = 250 KHz
T = 4 μS
F_0 = 775 KHz
$|\beta_3|$ = 0.523

24213
200nS

3

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



ACTUAL VALUES:

R_x = 15K-Ω

R_D = 270 Ω

C_D = 680 PF

L_D = 62 μH

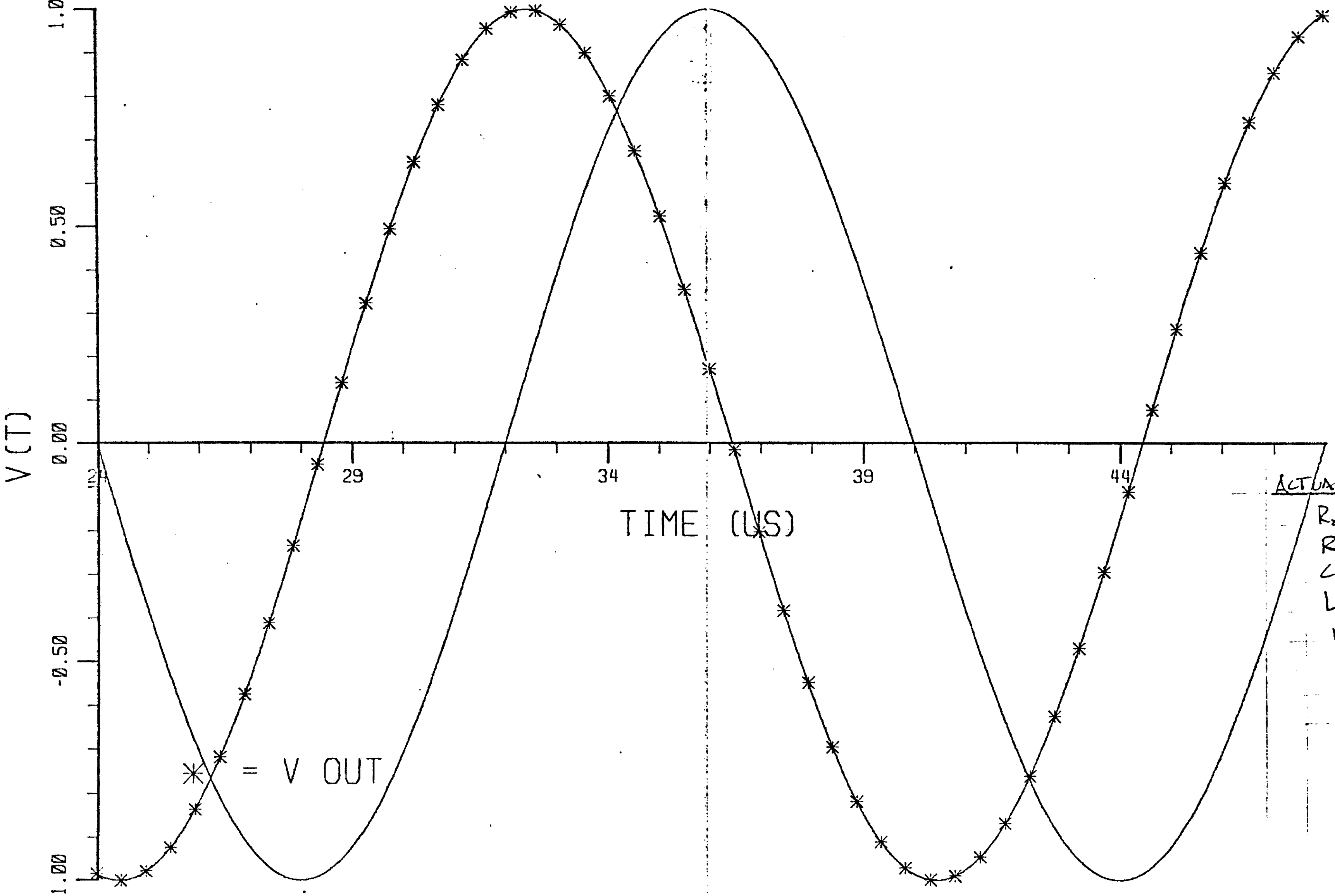
2F = 250 KHZ

T = 4 μS

F_o = 775 KHZ

|ζ| = 0.523

SA 450 DIFFERENTIATOR TIME RESPONSE TO 1F SINWAVE INPUT



ACTUAL VALUES:

$R_x = 47$ kΩ

$R_D = 200$ Ω

$C_D = 1800$ pf

$L_D = 100$ µH

1F = 62.5 KHz

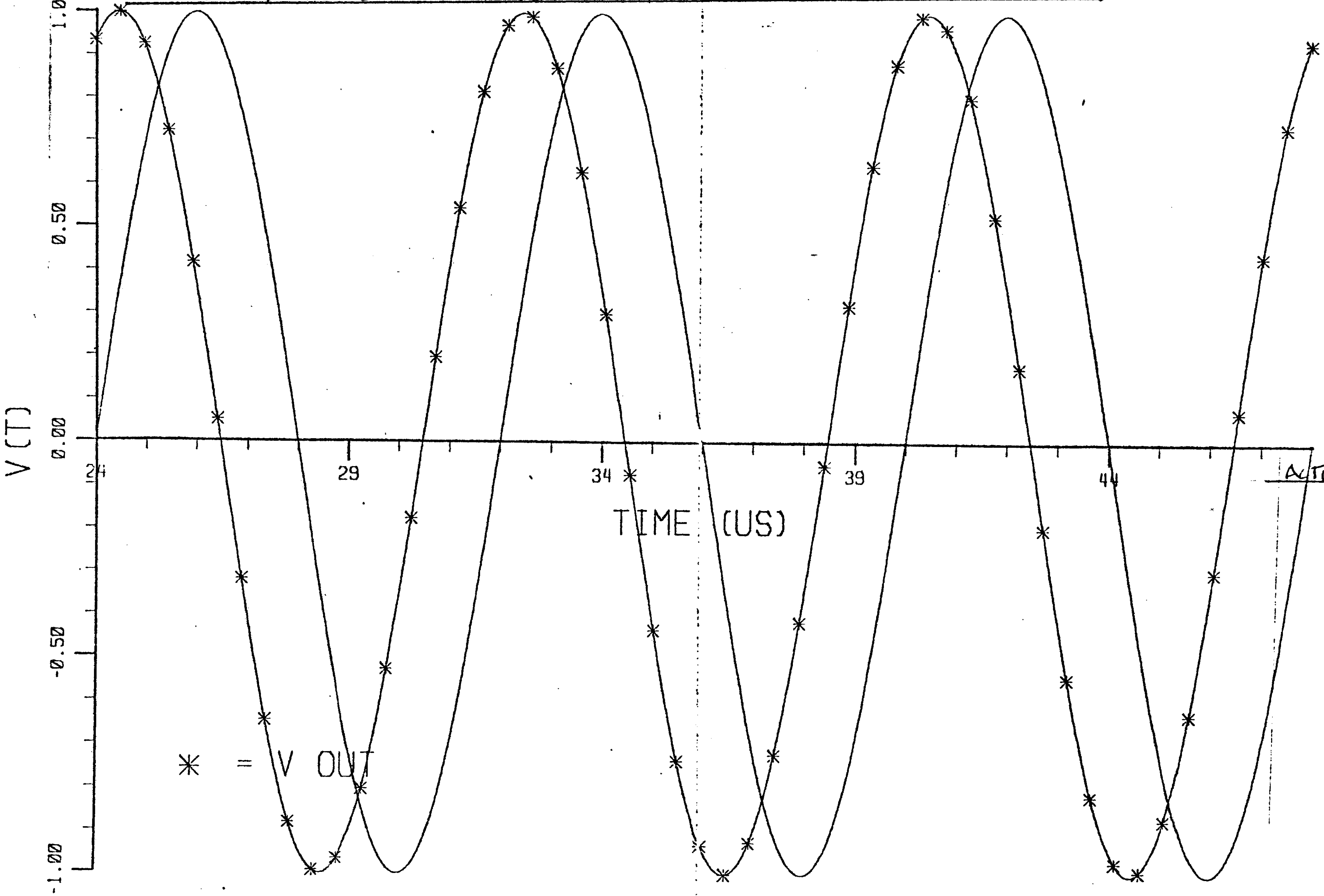
T = 16 µs

$F_o = 375$ kHz

$|\beta| = 0.51$

7

SA 450 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



ACTUAL VALUES:

$R_x = 47\ k\Omega$

$R_D = 200\ \Omega$

$C_D = 1500\ pf$

$L_D = 100\ \mu H$

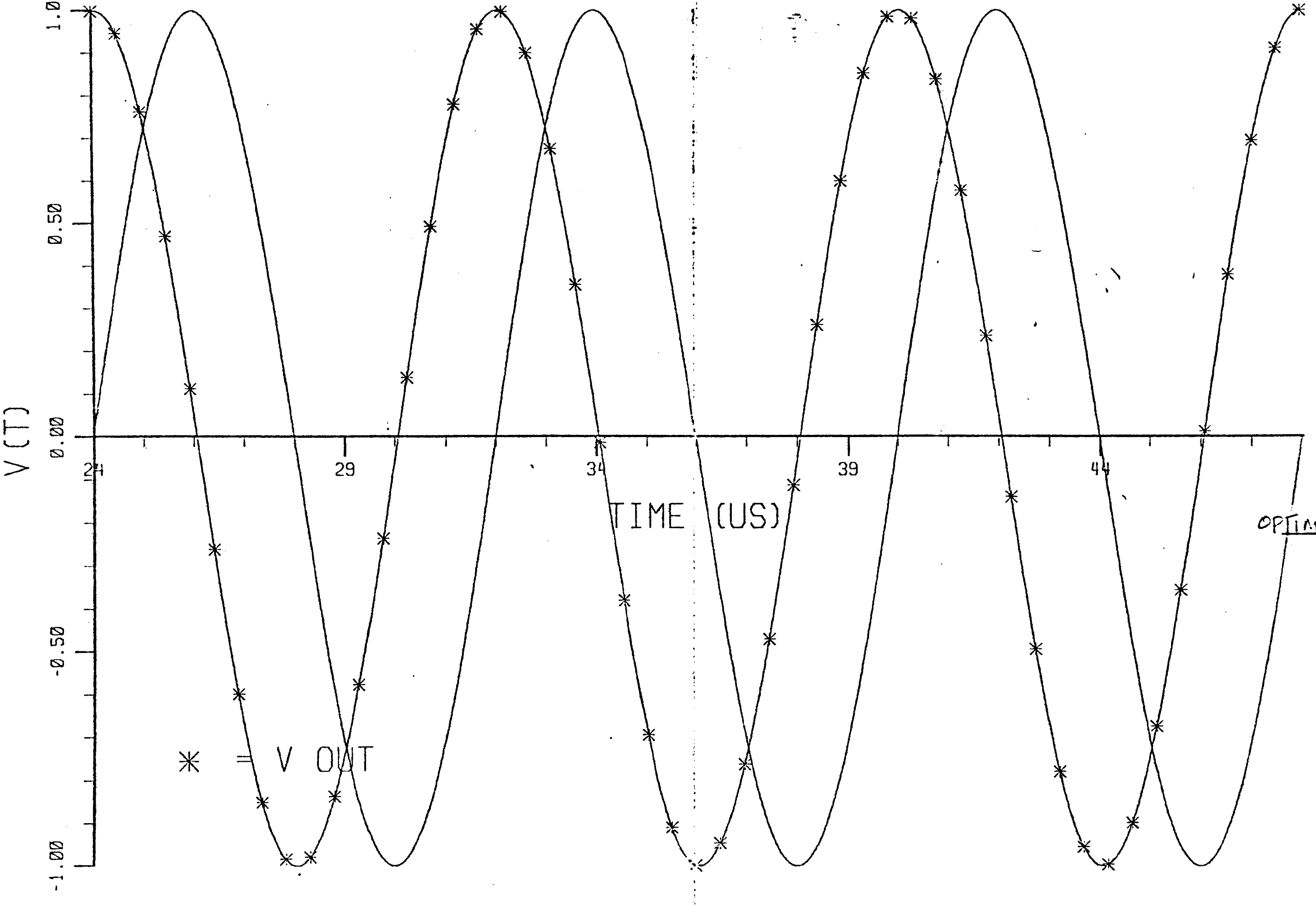
$2F = 125\ kHz$

$T = 8\ \mu s$

$F_o = 375\ kHz$

$|\beta| = 0.51$

SA 850 DIFFERENTIATOR TIME RESPONSE TO IF SINWAVE INPUT



OPTIMUM VALUES:

R_x = 40.1 KΩ

R_D = 150 Ω

C_D = 330 pf

L_D = 12 μH

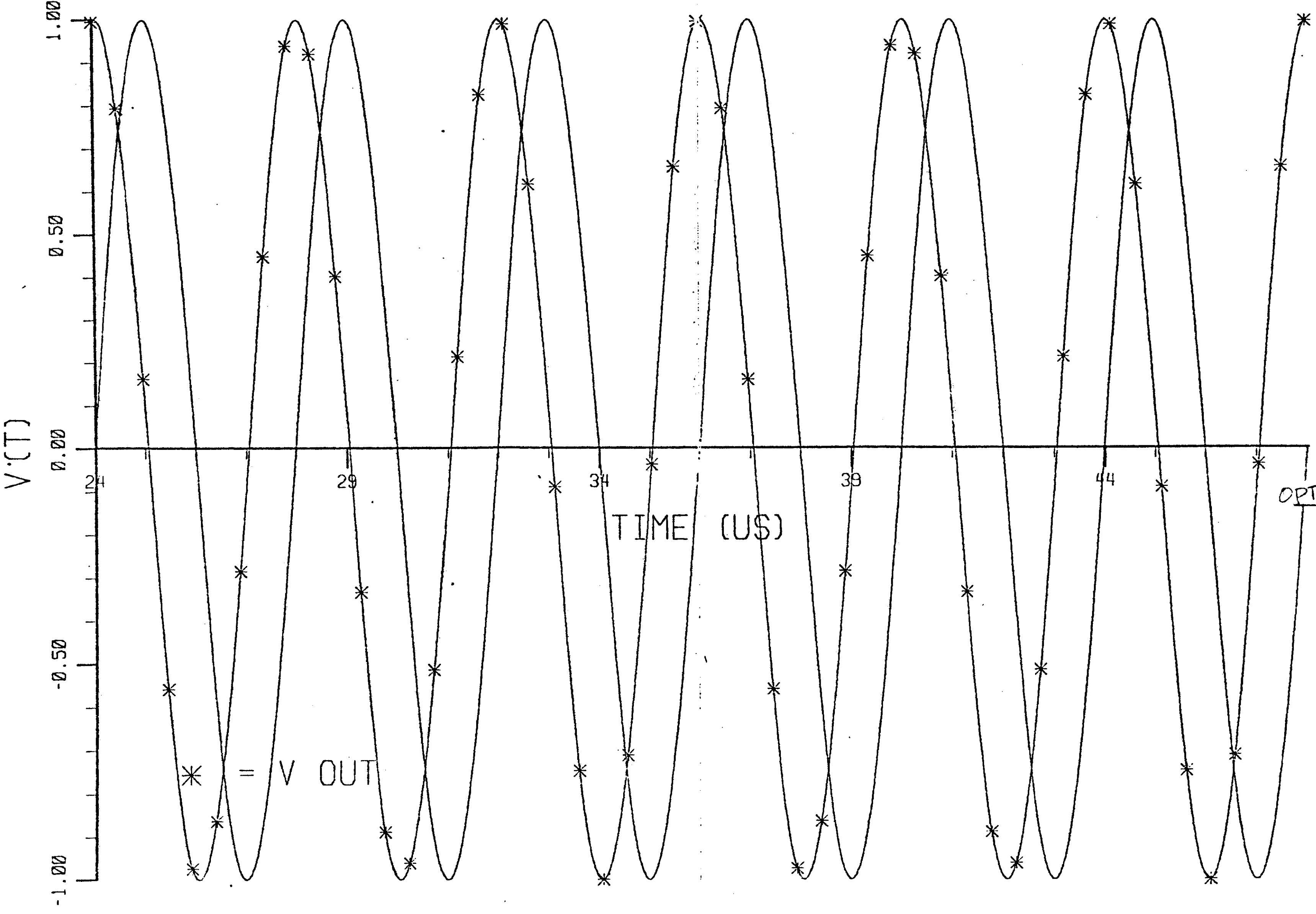
IF = 125 KHz

T = 8 μS

F_D = 253 MHZ

$|\beta|$ = 0.5

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT



OPTIMUM VALUES:

$R_x = 40.1$ KΩ

$R_D = 150$ Ω

$C_D = 330$ pf

$L_D = 12$ μH

2F = 250 KHz

T = 4 μS

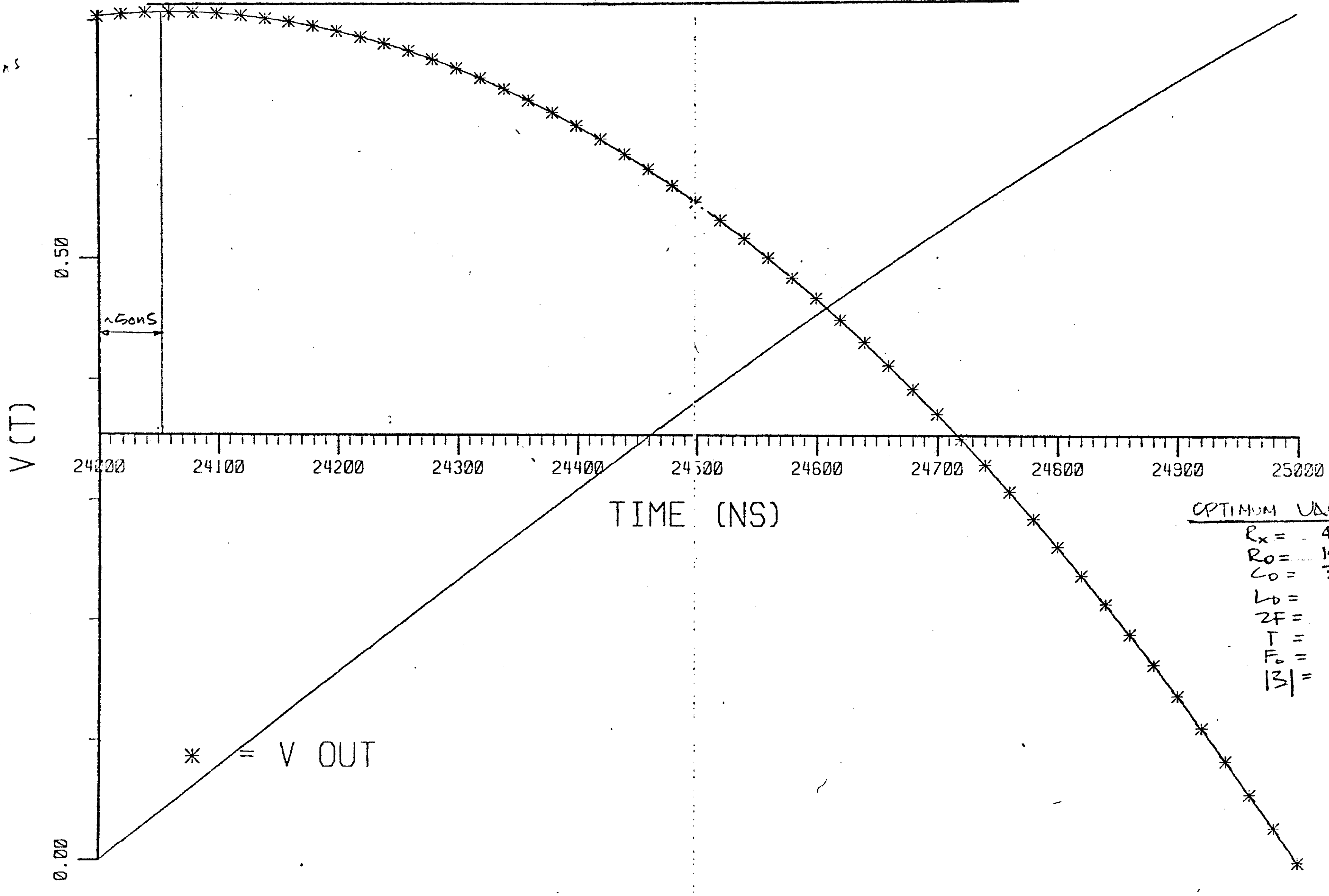
$F_0 = 2.53$ mHz

$|\beta| = 0.5$

4

~50ns

SA 850 DIFFERENTIATOR TIME RESPONSE TO 2F SINWAVE INPUT

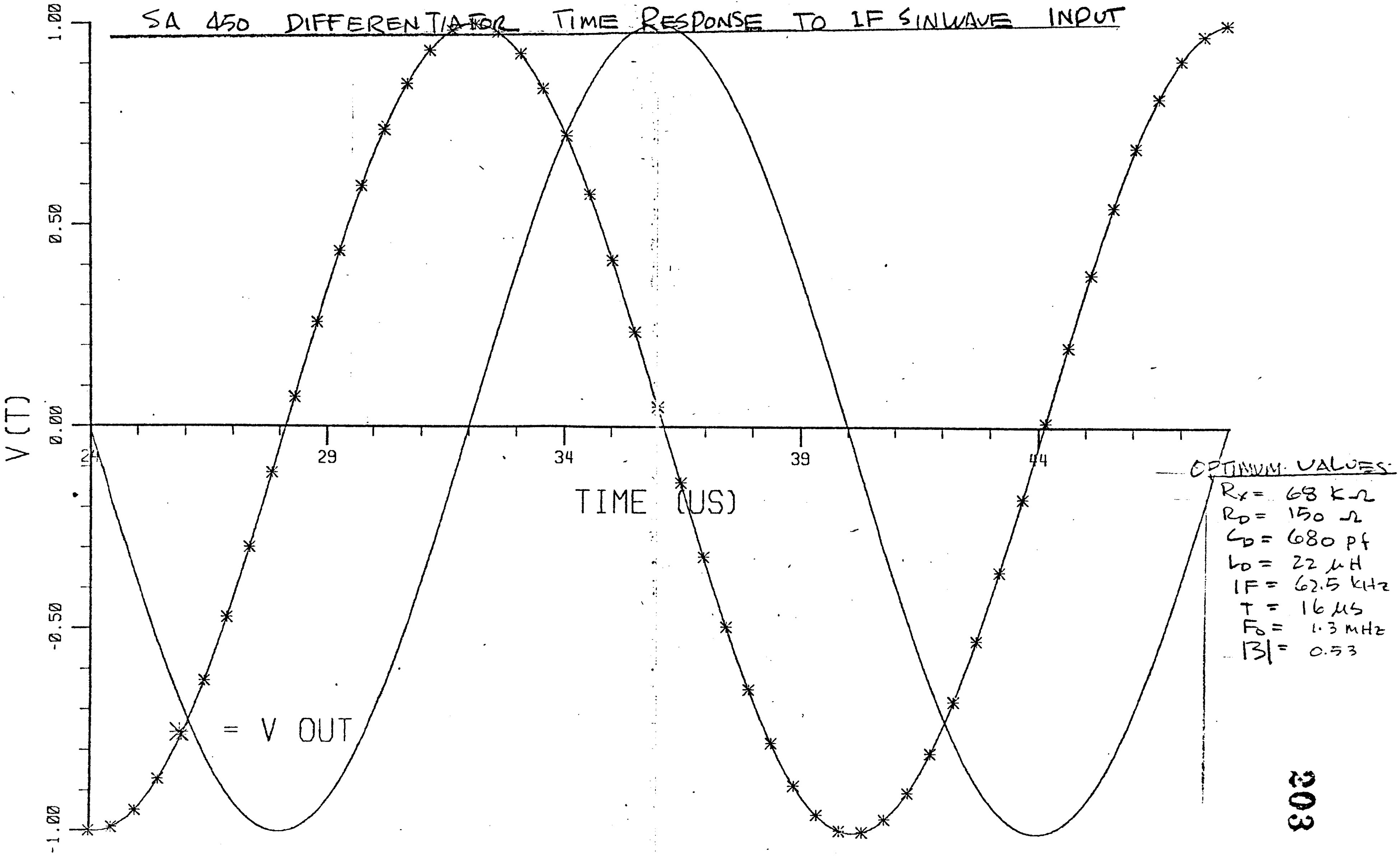


OPTIMUM VALUES:

R_x = 40.1 KΩ
R_O = 150 Ω
C_O = 330 pf
L_O = 12 μH
2F = 250 KHz
T = 4 μs
F_o = 2.53 MHz
|B| = 0.5

6

SA 450 DIFFERENTIATOR TIME RESPONSE TO IF SINWAVE INPUT

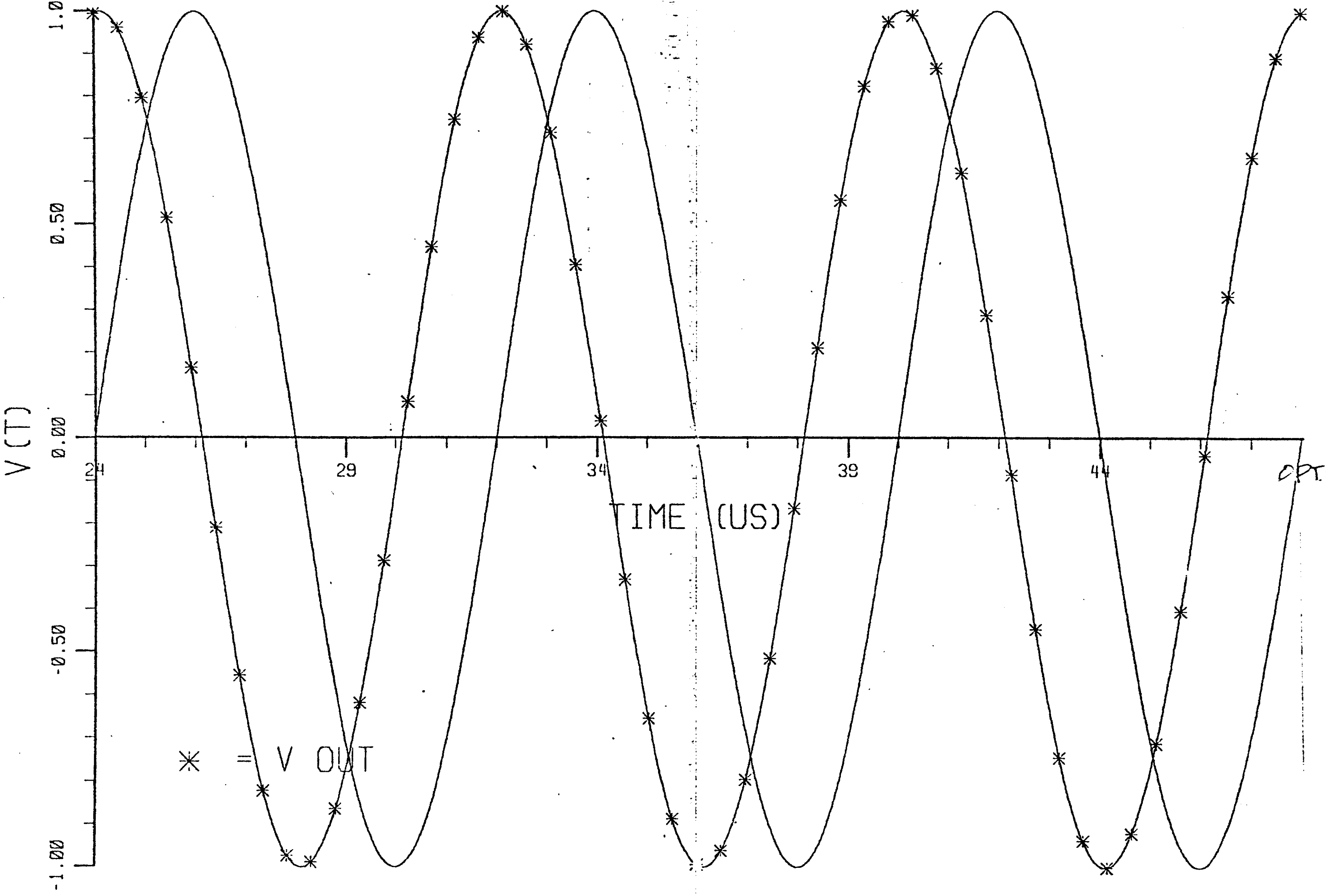


OPTIMUM VALUES:

R_x = 68 KΩ
R_D = 150 Ω
C_D = 680 pf
L_D = 22 μH
IF = 62.5 kHz
T = 16 μs
F_0 = 1.3 MHz
|B| = 0.53

8

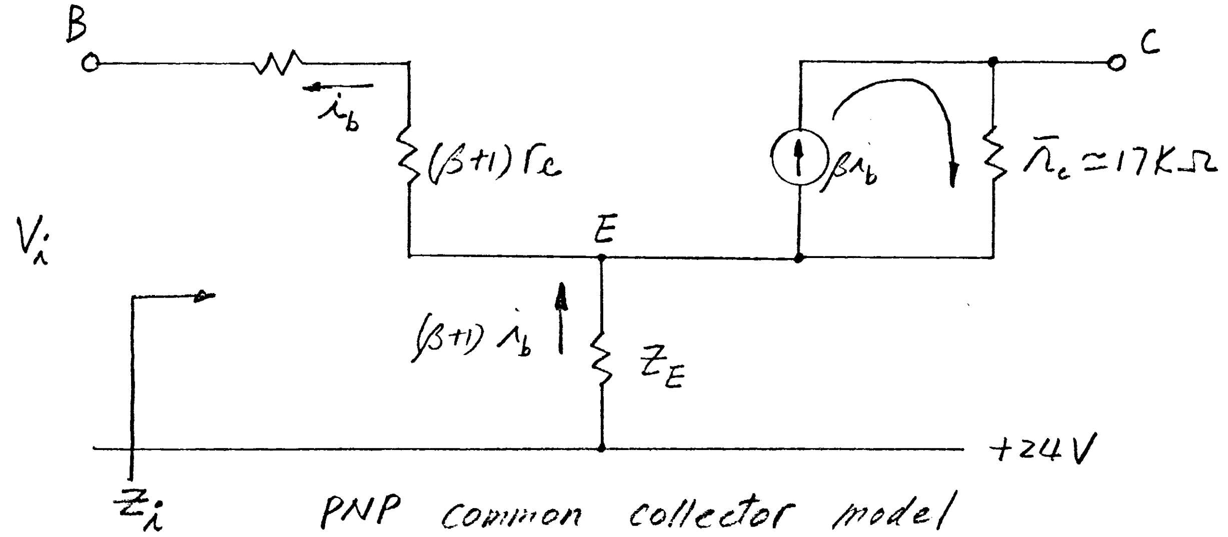
SA 450 DIFFERENTIATOR TIME RESPONSE TO ZF SINWAVE INPUT



OPTIMUM VALUES:
R_x = 68 KΩ
R_D = 150 Ω
C_D = 680 pf
L_D = 22 μH
ZF = 125 KHz
T = 8 μS
F_o = 1.3 MHz
|B| = 0.53

F. Common collector transistor equivalent circuit model:

Common collector transistor circuit is commonly used as buffer to isolate (reduce) the effect of output circuit effect (loading) on the input circuit. There are many ways of modelling a transistor circuit. The most common ones are Tee equivalent circuit, hybrid, hybrid II, charge control model and other variations. The model I am going to use is a variation of hybrid II model for small signal and low frequency applications. Small signal means the transistor is in linear regim. Low frequency means singal below 10 MHz.



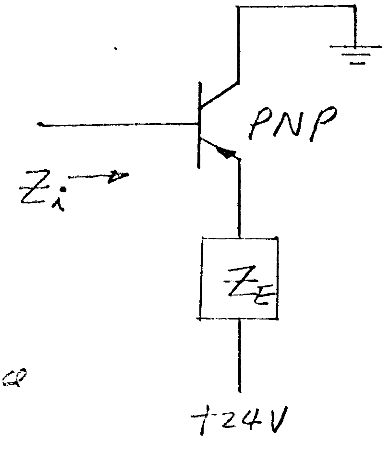
PNP common collector model

$$V_i = (\beta+1) i_b Z_E + i_b (h_{ie})$$

$$h_{ie} = r_b + (\beta+1) r_e$$

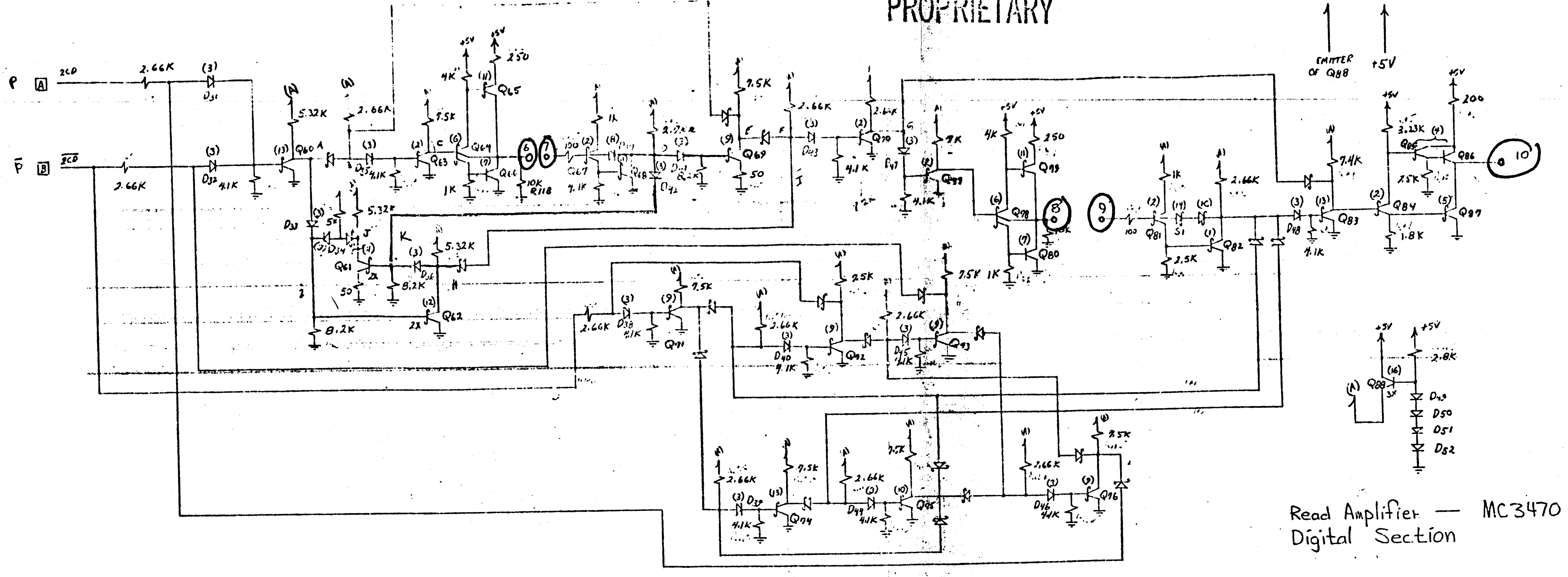
$$Z_i = \frac{V_i}{i_b} = (\beta+1) Z_E + h_{ie}$$

$$\simeq \beta Z_E$$



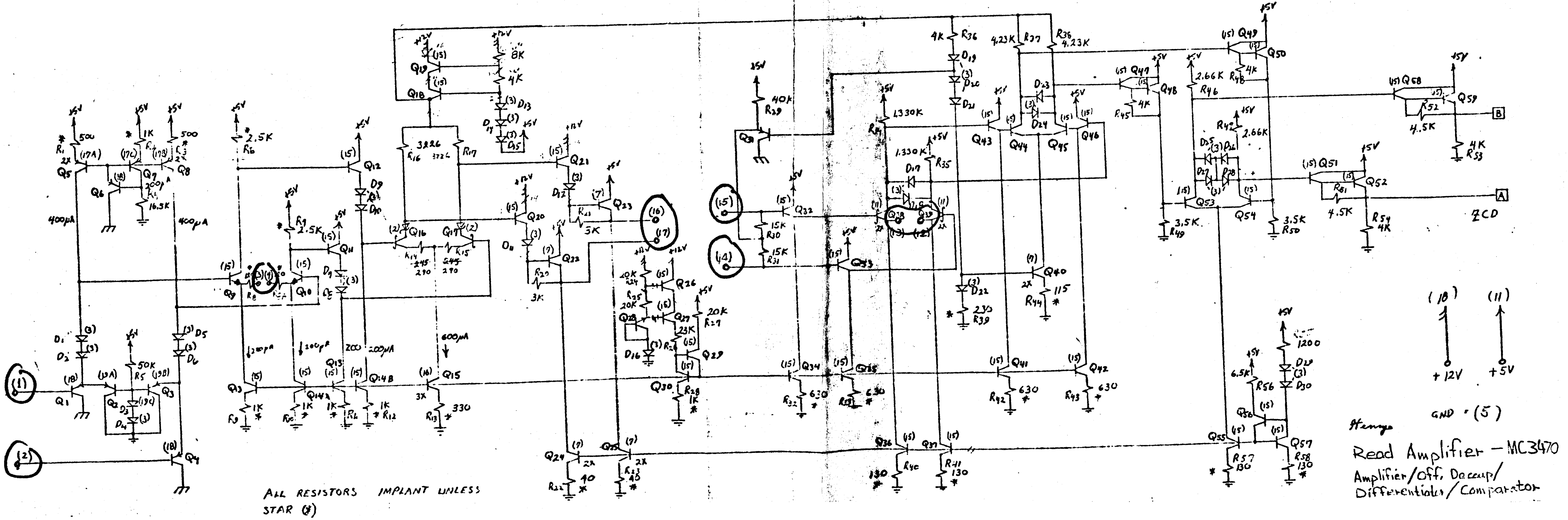
From the derivation, the input impedance of a common collector amplifier is βZ_E, where Z_E is the total effective impedance at the emitter leg.

MOTOROLA
PROPRIETARY



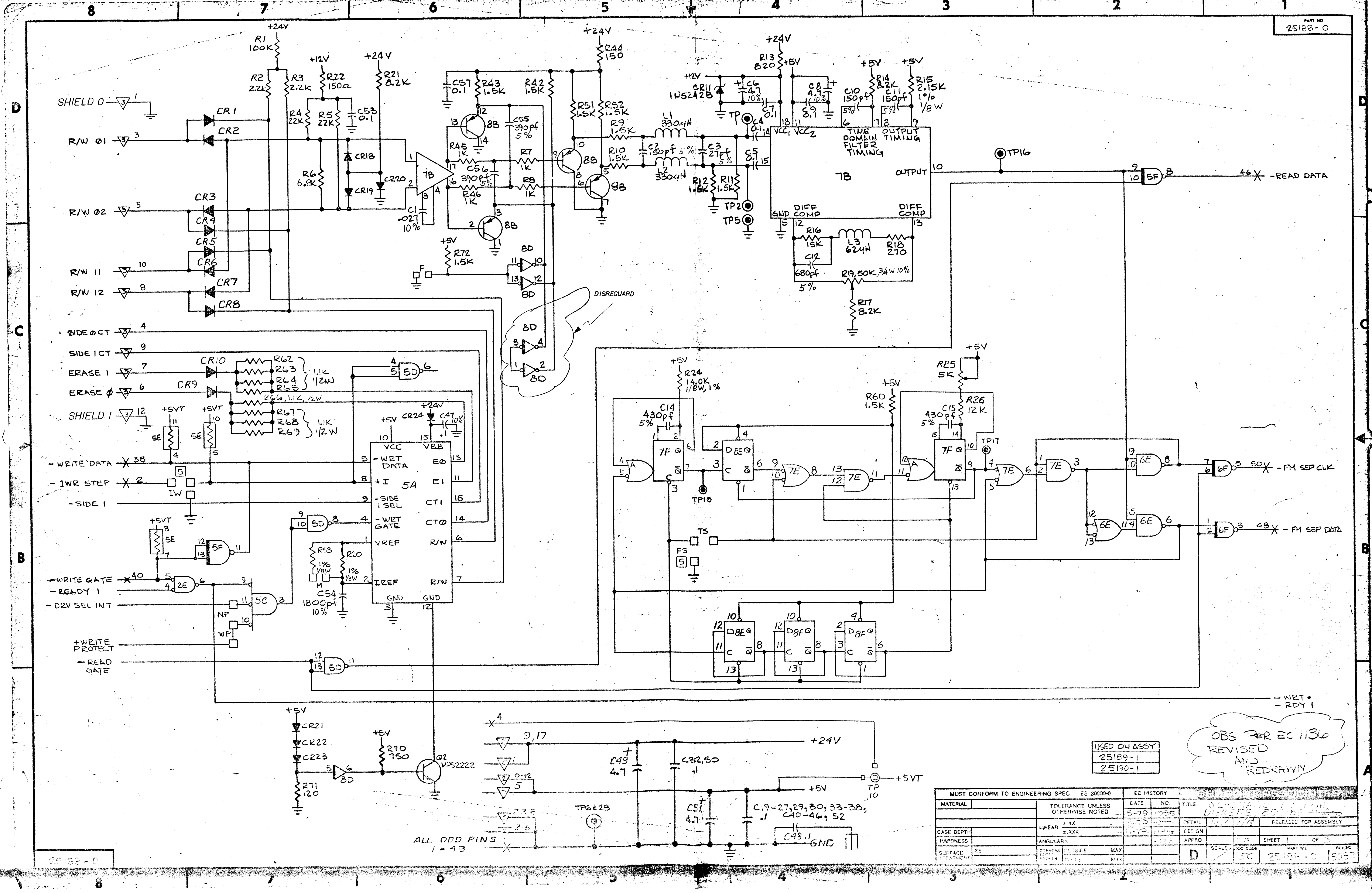
Read Amplifier — MC3470
Digital Section

MOTOROLA
PROPRIETARY



ALL RESISTORS IMPLANT UNLESS STAR (*)

Read Amplifier – MC3470
Amplifier/Off. Decoup/
Differentiator/Comparator

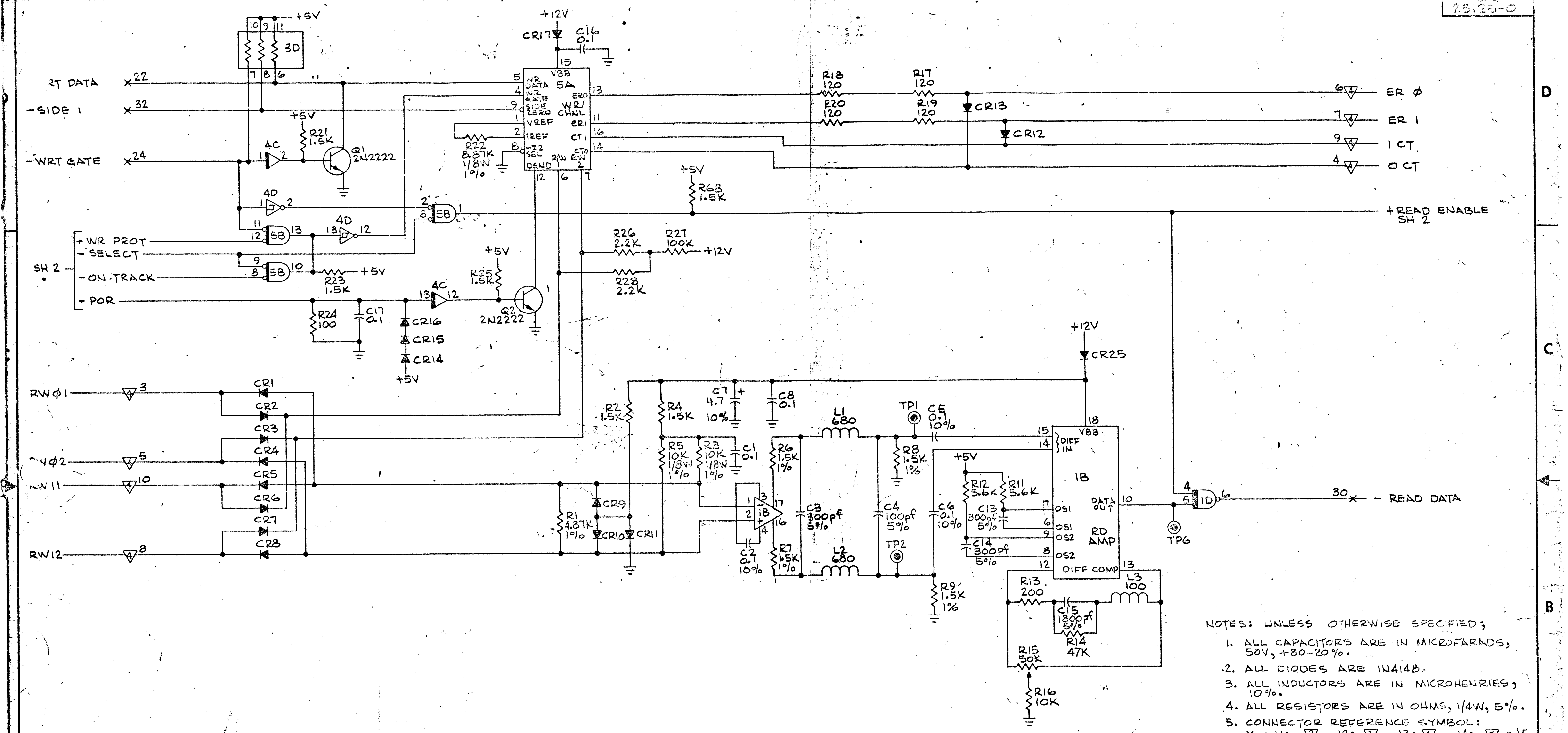


USED ON ASSY
25189-1
25190-1

MUST CONFORM TO ENGINEERING SPEC. ES 30000-0

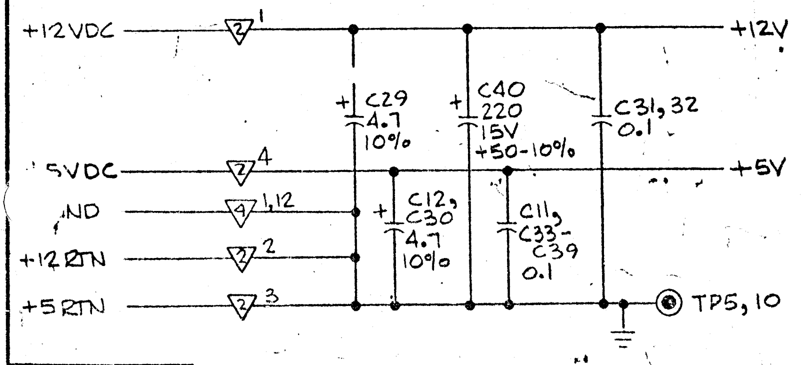
				EC HISTORY					
MATERIAL		TOLERANCE UNLESS OTHERWISE NOTED		DATE	NO.	TITLE	SCHEMATIC DIAGRAM DISKETTE 850/85		
		LINEAR	±.XX			DETAIL			RELEASED FOR ASSEMBLY
CASE DEPTH			±.XXX			DESIGN			
HARDNESS		ANGULAR±				APPRO			SHEET 1 OF 3
SURFACE TREATMENT	ES	CORNERS EDGES BROKEN	OUTSIDE MAX INSIDE MAX			D	SCALE	DOC CODE 5C	PART NO. 25188-0 REV EC 5093

25125-0



NOTES: UNLESS OTHERWISE SPECIFIED;

1. ALL CAPACITORS ARE IN MICROFARADS, 50V, +80-20%.
2. ALL DIODES ARE IN4148.
3. ALL INDUCTORS ARE IN MICROHENRIES, 10%.
4. ALL RESISTORS ARE IN OHMS, 1/4W, 5%.
5. CONNECTOR REFERENCE SYMBOL: ✕ = J1; ▽1 = J2; ▽2 = J3; ▽3 = J4; ▽4 = J5.
6. ─□─□─ INDICATES CUT TRACE OPTION.
7. ─□ □─ INDICATES SHUNT BLOCK OPTION



TYPE	POSITION	UNUSED ELEMENTS	+5V (PIN)	GND (PIN)
7407	4C		14	7
74LS14	4D		14	7
7433	5B		14	7
7438	1D		14	7
74136	6B		14	7
74LS139	5D		16	8
74LS191	5C		16	8
74LS221	6C		16	8
75326	6D		12	1,8
LM2917N	7C		—	12
16270-0	5A		10	3
16278-0	1B		11	5
R.PK, 150Ω	3D		—	—
OPTION	2D		—	—

REFERENCE DESIGNATIONS

LAST USED	NOT USED
C40	C9, C10
CR25	
L3	
Q4	
R69	
TP13	TP3, TP4

DEC 21 1979

MUST CONFORM TO ENGINEERING SPEC. ES 30000-0			EC HISTORY		SHUGART ASSOCIATES
MATERIAL		TOLERANCE UNLESS OTHERWISE NOTED	DATE	NO.	TITLE SCHEMATIC DIAGRAM-450
			10-79	5074	
		LINEAR ±.XX	10-79	5087	DETAIL Jude 9/79 RELEASED FOR ASSEMBLY
CASE DEPTH		±.XXX	11-79	5105	DESIGN
HARDNESS		ANGULAR±			APPRO SHEET 1 OF 2
SURFACE TREATMENT	ES	CORNERS EDGES BROKEN OUTSIDE MAX			D SCALE DOC CODE SC PART NO. 25125-0 REV/EC 5105
		INSIDE MAX			

Inter-Office Memo

To Distribution

From Byron Wong
735-7192 Econics

TD257:mw

Subject SA850/450 Read Channel Analysis Report Corrections

Date September 23, 1980

Please correct the following typographical errors in subject report, dated December 1979:

Page #	Was	Should Be
04A (SA450 CKT)	22K, 22K	10K, 10K
012, line 10	$= 10\Omega$	$= 10$
013, line 12	$A_1 = \frac{500SC}{500SC+1}$	$A_1 = \frac{5000SC}{500SC+1}$
045, Line 7	$W_{peak} = \frac{W_0}{\sqrt{1-2\lvert\zeta\rvert^2}}$	$W_{peak} = W_0\sqrt{1-2\lvert\zeta\rvert^2}$
047, second line from the bottom	$= \frac{1}{W} \frac{2\lvert\zeta\rvert}{W_0^2-W^2} \ldots \}$	$= \frac{1}{W} \frac{2\lvert\zeta\rvert WW_0}{W_0^2 - W_2} \ldots \}$
048, line 1	$\ldots(1+(\frac{W}{W_0})^2]$	$\ldots(1+(\frac{W}{W_0})^2)]$

Thanks to Dr. M. K. Tsai of the Head/Media Group for spotting these errors.

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