NATIONAL ACOUSTIC LABORATORIES

COMMONWEALTH DEPARTMENT OF HEALTH

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INVESTIGATION OF THE STABILITY FACTORS OF THE TFA 1069 THICK FILM AMPLIFIER

BY

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HEARING AID DEVELOPMENT

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Contents

Abstract

An investigation was initiated by the H.A.D. section on an apparent H.F. instability of the TFA 1069, which also give rise to increased quiescent current being drawn. However, as the examination proceeded, several extra problems were uncovered, the more serious of these being a "flicker" distortion evident at low frequency and almost full drive of the amplifier. Associated with this problem was quite severe 2nd harmonic distortion at the output, seemingly indicating lack of current drive to charge the coupling capacitor, and finally, current spike superimposed on the supply line with an apparent "resonance" type maximum at 2kHz when supplied from a zero ohm voltage supply.

1. <u>The Thick Film Amplifier Jig</u>

As the amplifier chip has a high gain-bandwidth product (7×10^6), it is critical that the surrounding circuitry's performance is carefully defined. For example, a track resistance of about 100mΩ produces a signal level comparable to that of the input level if it is driven from the output of the amplifier.

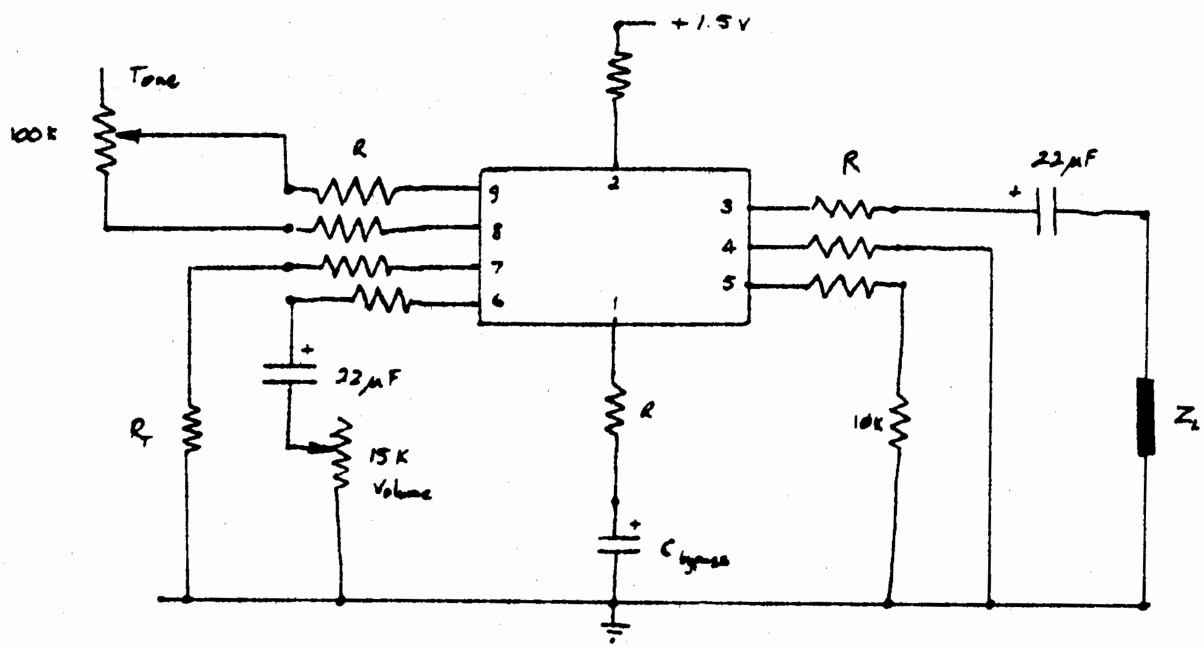
There were 3 jigs made, with only the final one being successful in obtaining at least a stable output by using RF techniques to reduce the effects of mutual coupling between various tracks. Since I was investigating (at least initially) a high frequency instability that manifest itself as a "cocks comb" superimposed on top of the basic sine wave, there was good justification for using RF techniques. The circuit is etched into a double sided board, with the unetched side acting as a ground plane. Coupling between input and output circuitry is minimized by use of earth leads separating the two, and supply resistance is minimized by the use of heavy earth and positive supply rails, as well as keeping track lengths to a minimum.

Despite all the precautions, some TFA displayed the H.F. instability at maximum output with the tone control set to flat.

2. <u>Measurements</u>

a) <u>Track Resistance</u>

The track resistance on the thick film and the p.c. board were measured using a HP 3455A digital voltmeter set up on the 4 wire resistance testing mode.



R = contact resistance + wire resistance

R_T = track resistance

Z_L = load impedance of earphone

Most critical are the values of R (= contact resistance + wire resistance) of pins 7, 2, 1 and 4 as in other parts, they are swamped by the external resistors.

Measurements made on the value of R indicated a typical value of a 10m ohms(3m ohms minimum and 20m ohms maximum).

R_T was the track resistance of the longest path track and was found to lie in the range 20-27m ohms.

Measurements made on the resistances associated with the tracks internal to the TFA showed that they came within specifications of the conductive paints used.

b) Output Impedance

In this I used a Standard test method - no load voltage vs on load voltage. The load in this case was series combination of the coupling capacitor and a resistor (15ohm). The graph attached shows a negative resistance anomaly at very low frequencies despite the effect of taking several readings and obtaining average values. This seemed to point to possible instability problems, which, as will be shown later in this report, was verified.

The output resistance varies from 0.3ohms minimum to 1.25ohms maximum at 3kHz, with typical value being about 1ohm.

Measurements were carried using a fluke 8000A DMM with an input impedance of 10M, and frequency response from 40Hz - 20KHz at the -3dB points.

Calculations were done on a Texas Instruments T158 using the following programme:

```
lbl A   :  STO Ind 0 Op20 INV SBR
lbl B   :  STO Ind 1 Op21 INV SBR
lbl C   :  STO 27 (SBR SUM X (RCL IND 0 + RCL Ind 1 -1))
           Op 20 Op 21 INVSBR
lbl E   :  2 STO 0
           15 STO 1
lbl SUM:  (15.1x^2 + (2x X RCL 27 X 15 EE-6) x^2 1/x) INVSBR
```

Registers	Contents
0, 1	Counters
2-12	V_{NL} (open circuit voltages) vector
15-26	V_{LOAD} Vector
27	Frequency, Hz

Description of the Programme

A, B - used to store ($V_{o/c}$), (V_{LOAD}) arrays.

C - Input a frequency, press C, result is the output impedance (magnitude) at that frequency.

E - is used to initialize counter registers.

sum - calculates the magnitude of load impedance at particular frequency

c) Gain Check

The AWM 1460 chip uses a series of transconductance amplifier stages that drive the final class B output stage.

The following measurements were taken, and are tabulated on graphs 2, 3, and 4.

(i) gain from input of i.c. to volume control pin
(ii) gain from volume control to power output
(iii) overall gain from input to output.

It must be pointed out that the amplifiers checked were stabilized for r.f. instability by introducing a h.f. rolloff at the input stage of the thick film amplifier.

The overall gain was found to be within specification if allowance for the h.f. rolloff is considered.

The gain from input to volume control and the gain from volume control pin to power output also performed according to the simple model of the transconductance stages given by AWA microelectronics division.

d) Noise performance versus supply voltage and loud variations

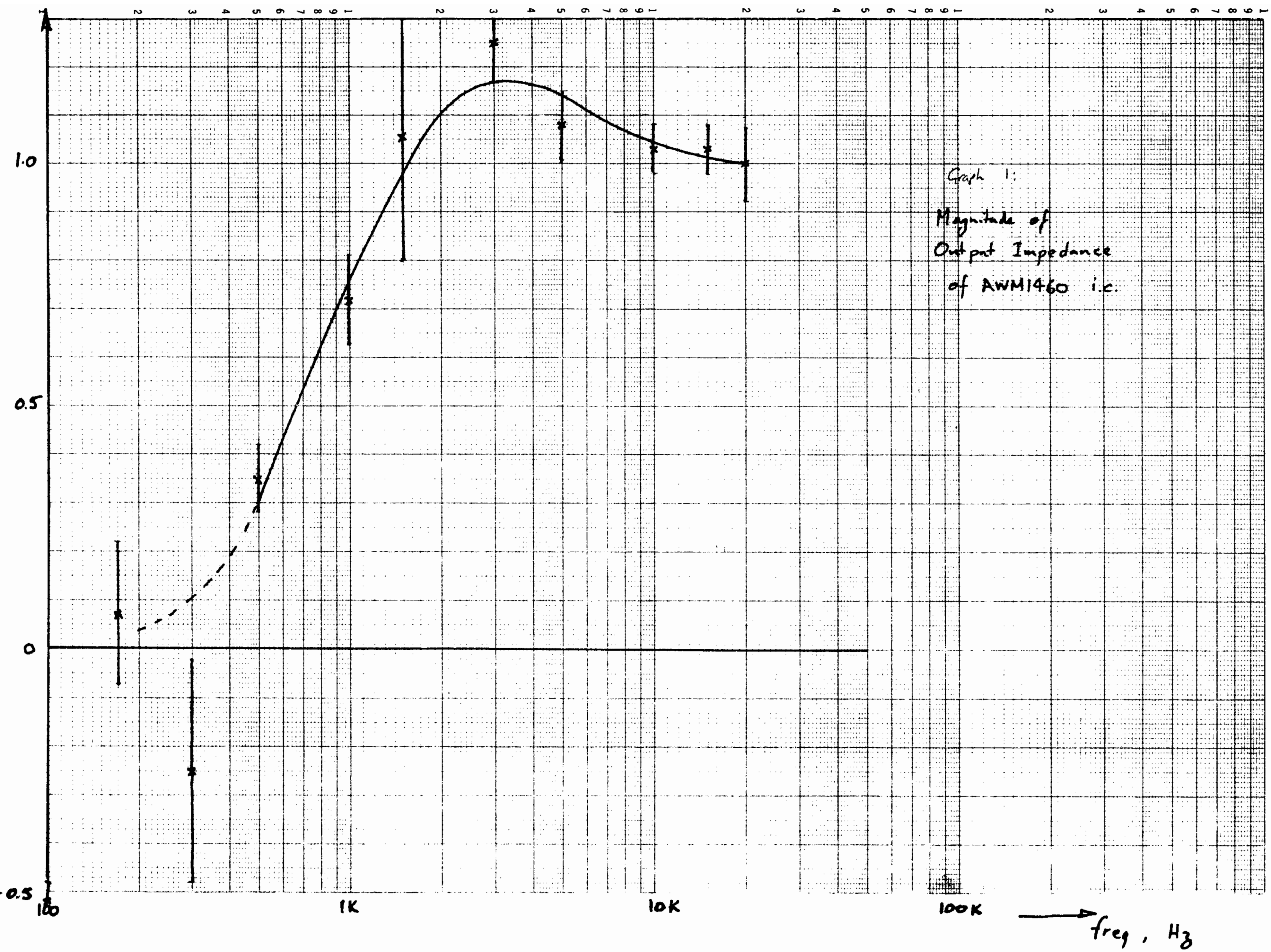
Again, using the basic test jig, and a Fluke 8000A DMM, the noise performance was readily measured. The input was terminated by a 3K3 resistor, and output loads were 15.1ohm, 41ohms (purely resistive) and a Tibbetts 8212X924 earphone. The noise voltage was measured across these using the 8000A DMM.

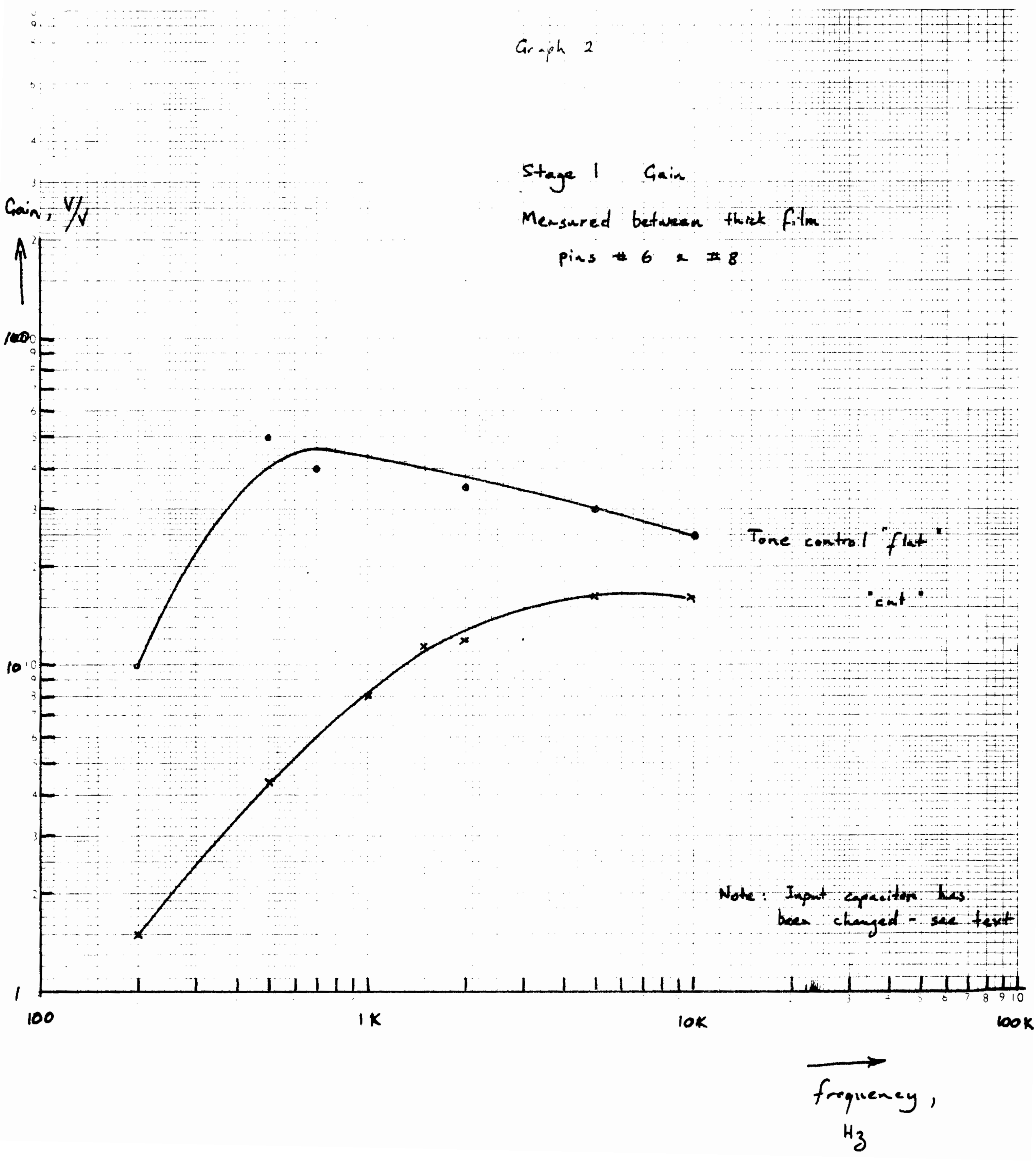
It was found that minimum noise occurs when the supply voltage is between 2 and 2.5V, and the 15 resistor at the output. This is hardly surprising as the noise voltage produced across a low valued resistor will be less assuming constant noise power output from the amplifier.

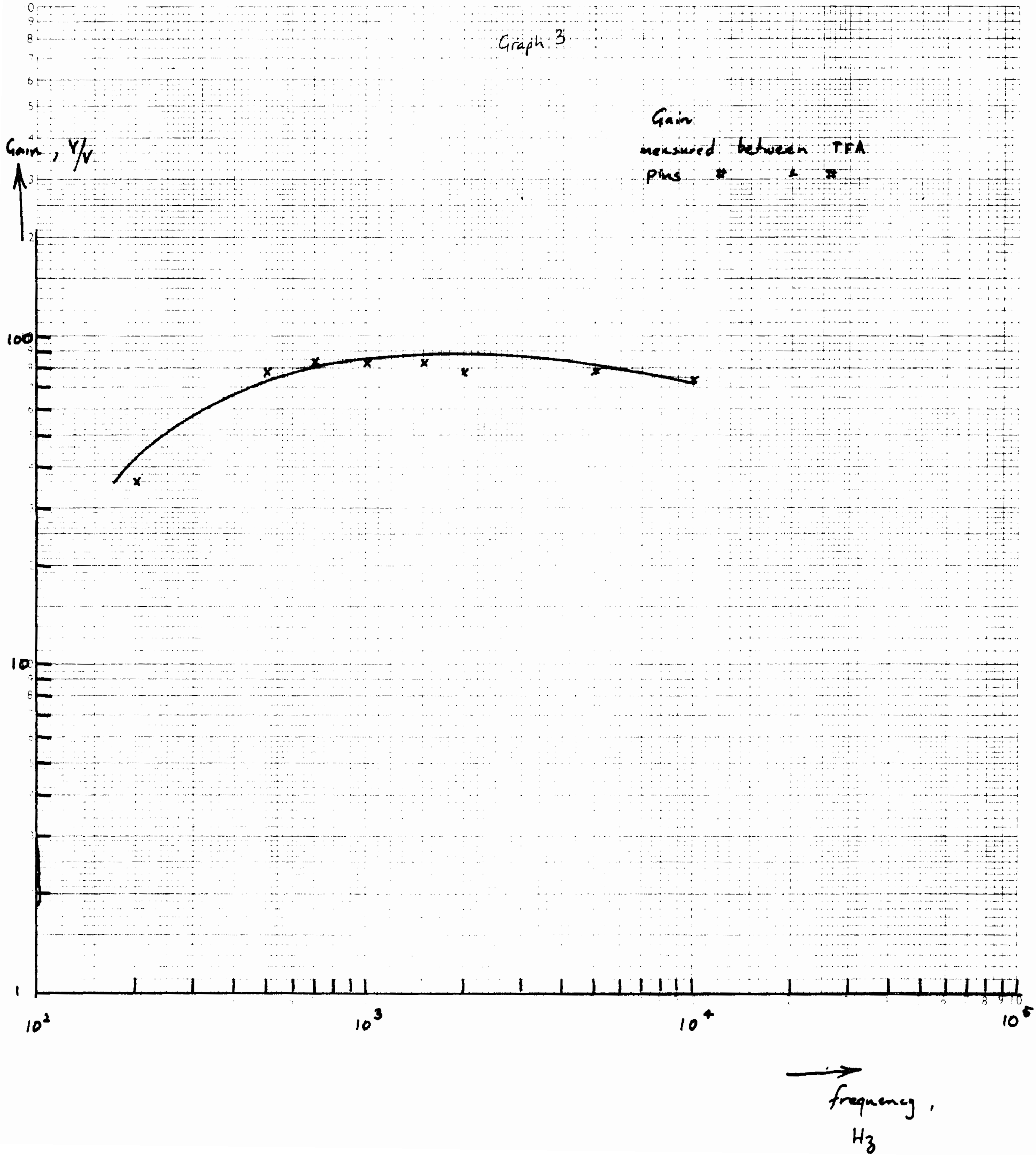
Taking the supply voltage below 1.1V resulted in oscillation at approximately 5kHz, no matter what load is applied. On the other extreme, when the supply voltage exceeds 4.2V, breakdown occurs within the semiconductor material in the I.C. and heavy currents are drawn (> 20mA).

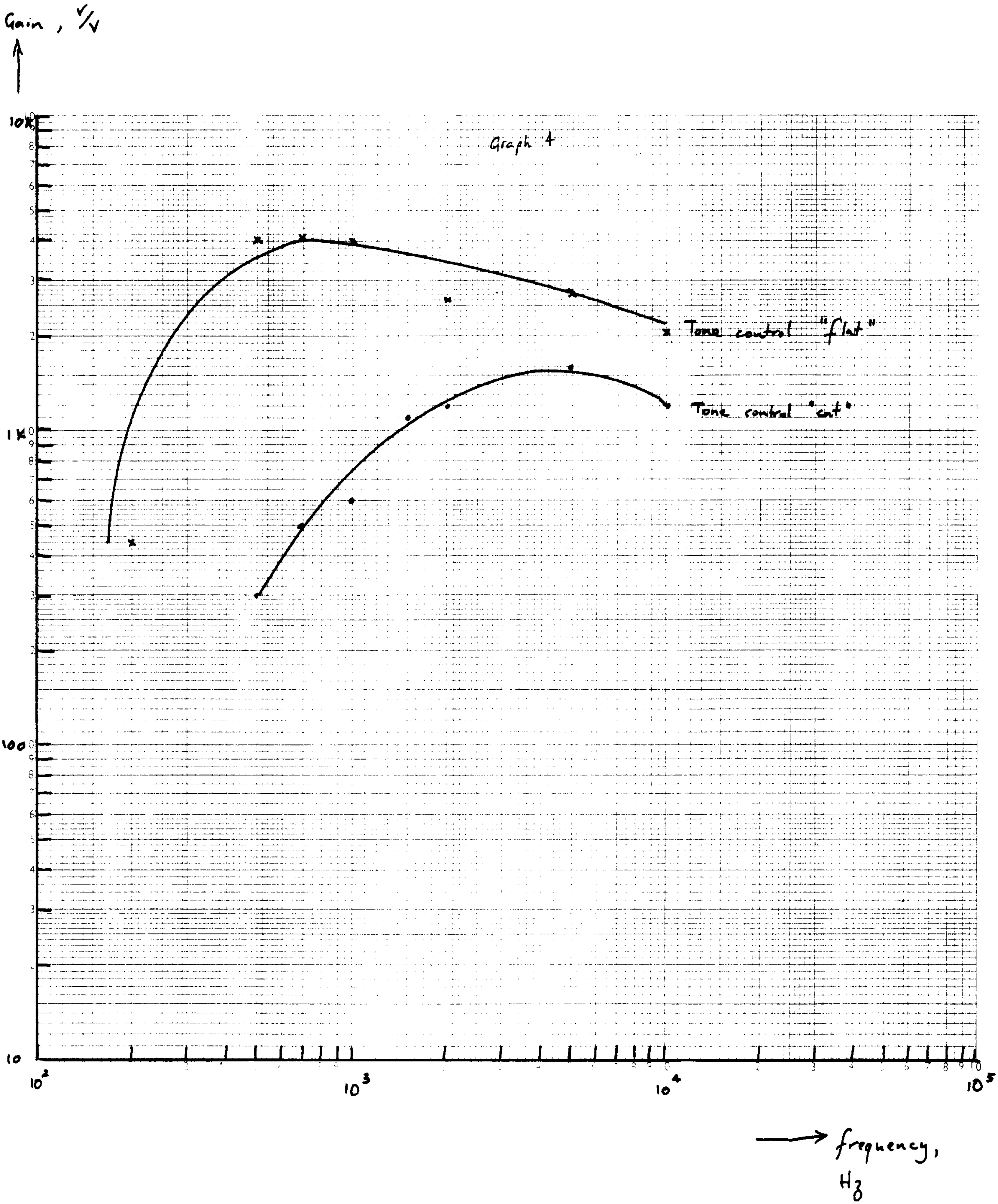
Since the test equipment was different to that used by AWM, corrections had to be allowed for comparing the two noise figures.

Define:	source resistance R_s	=	3.3K
	signal gain (voltage) G_v	=	4000
	B, bandwidth of measurement	=	19955 Hz
	input voltage	=	V_i
	output voltage	=	V_o
	load resistance	=	R_2
	power gain of device	=	A_p
	noise power at input	=	P_{ui}
	noise power at output	=	P_{no}
	noise voltage at output	=	V_{no}


Graph 1:
Magnitude of
Output Impedance
of AWM1460 i.c.
1.0
0.5
0
-0.5
100
1K
10K
100K
freq, Hz


Graph 2
Stage 1 Gain
Measured between thick film pins # 6 & # 8
Gain, V/V
100
10
1
Tone control "flat"
"cut"
Note: Input capacitor has been changed - see text
100
1K
10K
100K
frequency, Hz


Graph 3
Gain
measured between TFA
pins
Gain, V/V
100
10
1
10^2
10^3
10^4
10^5
frequency,
Hz



Gain, V/V
Graph 4
10K
1K
100
10
Tone control "flat"
Tone control "cut"
10^2
10^3
10^4
10^5
frequency, Hz

Then it follows that:

$$\text{Signal power in} = P_{si} = \frac{V^2}{R_s}$$

$$\text{Signal power out} = P_{so} = \frac{Vo^2}{R_2}$$

$$\text{Power gain} = Ap = \frac{Pso}{Psi} = \frac{(Vo)^2}{(Vi)^2} \times \frac{Rs}{R_2}$$

Noise input power due to resistor - P_{ui} = 4kTB, and Noise output power is $Pno = \frac{Vno^2}{R_L}$

$$\text{Noise factor, NF} = 10 \log_{10} \left(\frac{Pno}{Ap \ \ Pni}\right)$$

$$\text{i.e.} \qquad NF = 10 \log_{10} \left(\frac{Vno}{4kTBR_s G_v}\right)$$

Typical noise voltage out V_{no} - 5mV rms (measured) and so

$$\underline{NF = 12dB} \text{ for } B = 19955 \text{ Hz}$$

Now, since $NF_1 = 10 \log_{10} \frac{B1}{B2} \frac{Rs1}{Rs2} \left[10 \uparrow (NF_{2/10}) \right]$

and $B_1 = 19955 \quad B_2 = 707 \quad R_{s1} = 3K3 \quad R_{s2} = 51 \quad NF_2 = 6dB$

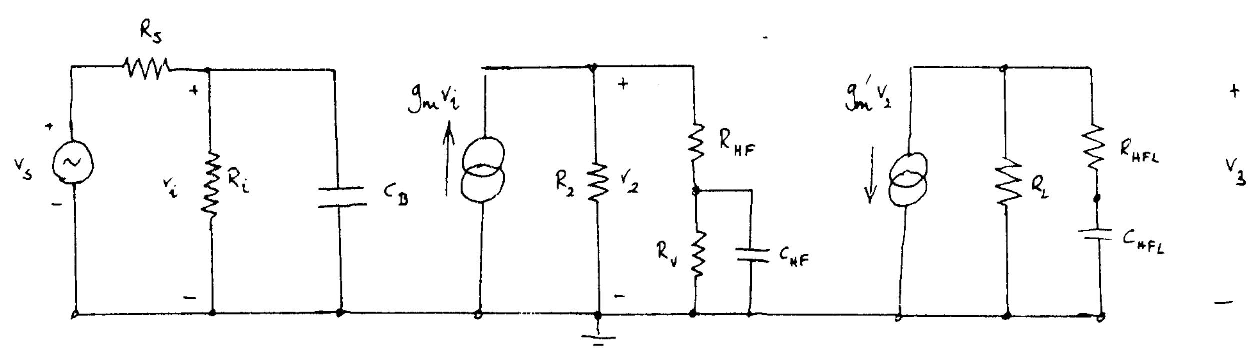
then $\underline{NF_1} = \underline{18.7dB}$ corrected for difference in bandwidth and source resistance. This shows that the measured noise figure is within specification.

3. <u>Modelling the AC performance of the TFA.</u>

Modelling was done in two separate stages, a simple minded approach and a more detailed analysis using the WANG computer to perform a node analysis on a model that included feedback loops.

a) Simple minded approach.

By using the block diagram given by AWM alone, and neglecting the effects of internal feedback paths within these blocks, the following simple equivalent circuit is obtained for mid to HF analysis.



$$v_i(s) = T_1(s) \cdot v_s(s) \qquad v_2(s) = T_2(s) \cdot g_m v_i(s) \qquad v_3(s) = T_3(s) \cdot v_2(s)$$

Transfer functions are:

$$T_1(s) = \frac{V2}{Vs} = \frac{Ri}{SC_V RiRs + (Rs + R_s)}$$

$$T_2(s) = \frac{R2}{R_2 + Rv + R} \cdot \frac{SC_1 R_v + 1}{SC(Rv \,//\, (R_2 + R_1)) + 1}$$

$$T_3(s) = \frac{(SC_{HFL} R_{HFL} + 1) R_2}{SC_{HFL} (RL_{HFL} + R_L) + 1}$$

These are graphed on the following Bode plots.

(b) More complete analysis (see appendix A4) was then done using the Wang. Included in this model were expressions yielding both DC and AC feedback loops around the complete amplifier. Parameters were adjusted until they had an overall gain of 60dB (for convenience), and the amplifier analyzed at both LF and HF ends. Since the computer analysis was done on closed loop response, and no peaking of amplitude was evident anywhere that would indicate potential instabilities, the amplifier model was judged not accurate enough.

(c) The reasons for this inaccuracy are:

1) The oversimplifications made on the circuit due to lack of space on the machine. If an analysis programme such as SPICE was used, then the entire circuit could be modelled down to device level, thereby enabling one to see exactly what was happening.

2) The bias circuitry was totally ignored in the model.

3) The supply resistance was left out.

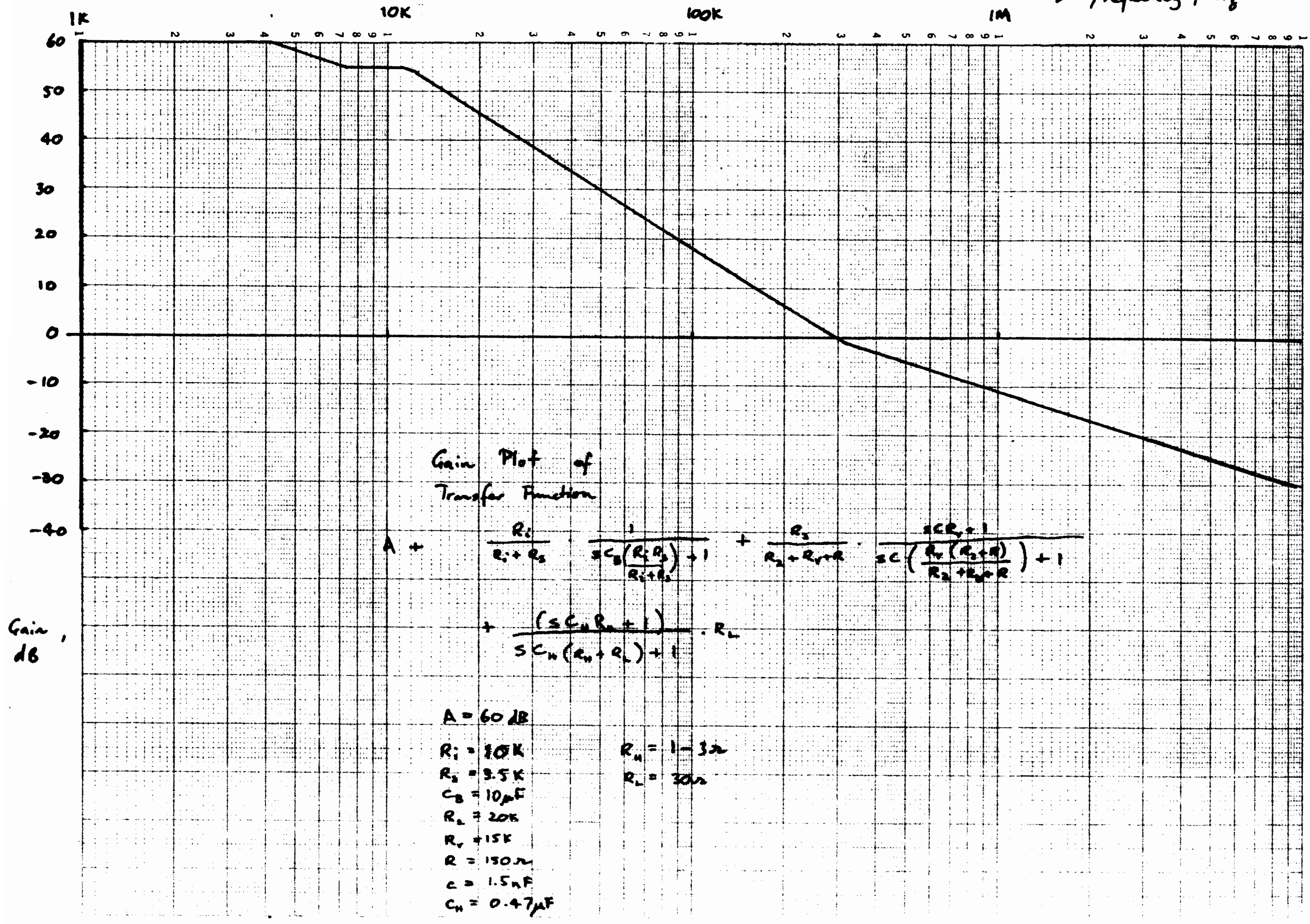
The approach therefore was abandoned, and bench measurements made.

4. A Proposed solution to the HF instability

a) AWM , on request from my section, made up some canned versions of the AWM 1460 using a ten pin TO-5 package. An extra lead was bonded onto the collector of the predriver transistor Q25 that would enable us to put in a dominant pole on the output stage and roll off much before 80kHz break point of the power stage. We aimed for a corner frequency of 10kHz. However, it was found that introducing any type of capacitor lead to the amplifier not operating at all!

A large capacitor (1uF chip type) was then introduced by accident onto the bias bypass point, and, sure enough, this killed the HF oscillations; it also increased the noise output from the amplifier, going up from 5mV to 12.6mV rms.

b) A compromise had to be made on the stability/noise tradeoff. Several types of chip capacitors were used in the place of the 1uF, and the following results were obtained.



Gain Plot of Transfer Function

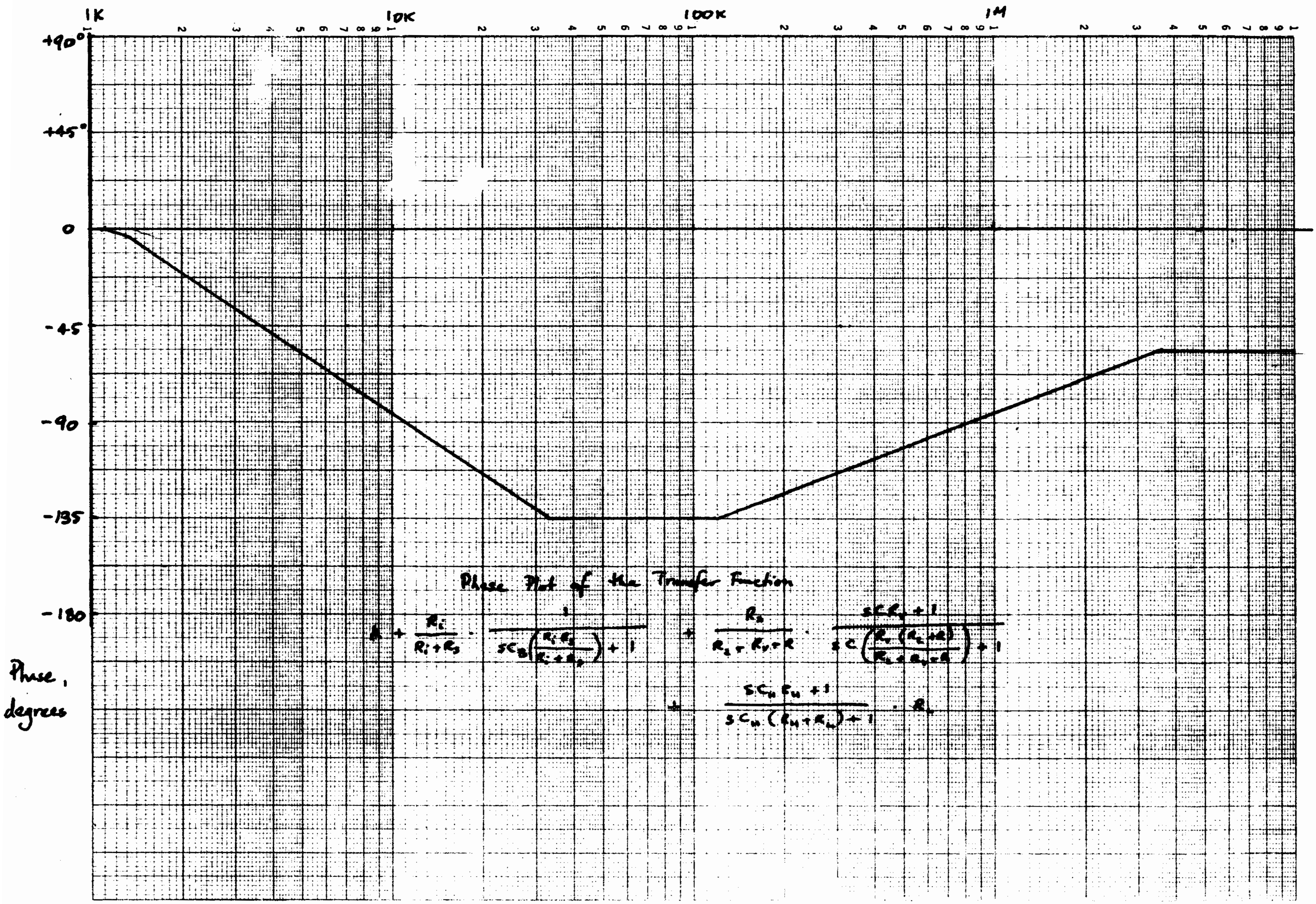
$$A + \frac{R_i}{R_i + R_s} \cdot \frac{1}{sC_B\left(\frac{R_i R_s}{R_i + R_s}\right) + 1} + \frac{R_s}{R_2 + R_v + R} \cdot \frac{sCR_v + 1}{sC\left(\frac{R_v (R_2 + R)}{R_2 + R_v + R}\right) + 1}$$

$$+ \frac{(sC_H R_H + 1)}{sC_H (R_H + R_L) + 1} \cdot R_L$$

$A = 60$ dB

$R_i = 10K$
$R_s = 3.5K$
$C_B = 10\mu F$
$R_2 = 20K$
$R_v = 15K$
$R = 150\Omega$
$c = 1.5nF$
$C_H = 0.47\mu F$

$R_H = 1-3\Omega$
$R_L = 30\Omega$


1K
10K
100K
1M
+90°
+45°
0
-45
-90
-135
-180
Phase, degrees
Phase Plot of the Transfer Function

Capacitor Value (microfarads)	Noise out (Bandwidth = 20kHz, voltage in RMS millivolts)
0.47	9.3
0.0985	6.5
0.046	6.0
0.0418	5.9
0.0232	6.4
0.0170	5.9
less than 0.015	oscillations - not noise

It was decided to use a minimum value of 0.022 as the bias bypass capacitor in all future aids.

5. L.F. Instability

The LF instability detected (at near clipping of the device) is quite closely tied in with the d.c. loop and value of battery resistance used. If a zero-ohm (true voltage) supply is used, this effect is minimal, with amplifiers showing very few impulsive bursts. However, increasing the resistance measured to simulate the typical battery values (6 ohms at d.c.) results in the impulsive bursts occuring at approx. 10-20Hz into a load of 30ohms (purely resistive).

By varying the d.c. battery bypass capacitor from 15 to 47 to 100uF resulted in a change in the frequency of the tone bursts. For example, using 47uF bypass and a 90ohms load forces the impulsive burst frequency (IBF) to be 166Hz, while using a 100uF bypass and same load forces the IBF = 26Hz.

Using a load of 30ohms and 47uF bypass results in IBF = 10-20Hz varying from i.c. to i.c.

Unfortunately, this particular problem is the most serious, as no easy solutions can be found. There is a need to bypass the supply with very high value, low e.s.r. electrolytic cap, which there is no room for.

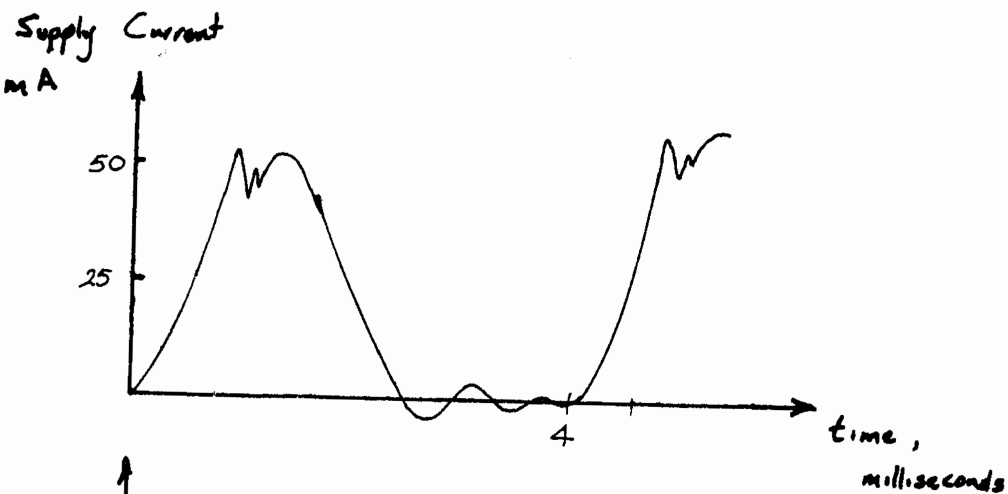
Another problem that is evident is the lack of sufficient drive capability at the low frequency and after the breakpoint of the load and output capacitor. The distortion here is quite bad, with output waveforms (voltage) across the loading looking like half-wave rectified sine waves. This particular problem is evident in the TFA that display the "flicker" distortion the most, whereas ones not displaying it all, also don't have so much LF distortion. This one again points to the D.C. loop, with which there is very little control.

In order to ensure the film amps used in the production section were quite good (i.e. not displaying the impulsive burst instability) a test set up was made up for the Quality Assurance Department. It is described in the note "Flicker" Distortion Testing, but a brief description is warranted here.

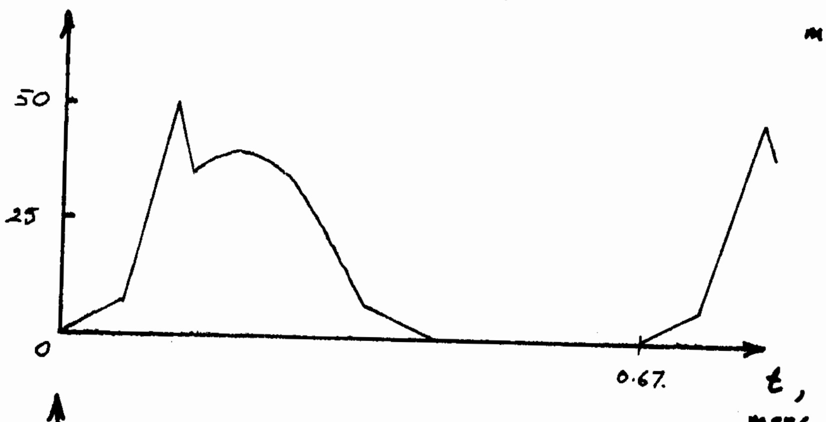
Assuming an input frequency of 250Hz, and input level to the TFA such that it is below that of level of clipping, then the f flicker component comes in, it produces a very wide bandwidth of frequencies being largely impulsive. Now, if the resulting signal is bandpass filtered about 1.09kHz, a tone burst of 1.09kHz results.

This enables the operator to pick up any "flicker" distortion quite easily, as the good amplifiers have no audible output. Once in clipping, naturally the 1.09kHz tone is heard quite clearly.

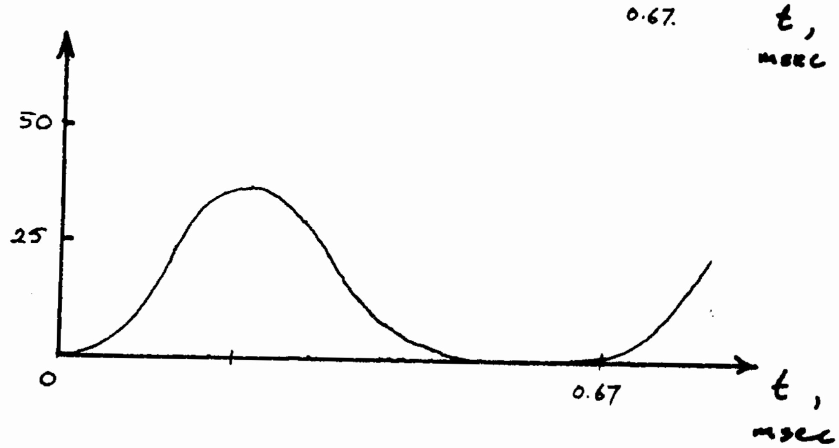
Yet another interesting problem was noticed when a zero ohm supply was used. Now, although the flicker is non-existent to a large extent, a very large current spike occurs in the supply leads when operating at about 2kHz. It seems to be a resonance effect of some type - it is present right down to 200Hz although much smaller value. This problem was considered to be largely insignificant as the presence of supply resistance causes the current spike to be lost altogether.



Supply current displaying 'spike' at 250 Hz



At 1.5 KHz



With supply resistance of 6.8 Ω added

Conclusion

Although the AWM1460 chip is capable of delivering very clean, high power outputs, the neglect (or underestimation) of the battery impedance lead to a rejection rate of 90% due to the "flicker" distortion. The evaluation of battery impedance is a very controversial one, and will be subject to investigation by the H.A.D. section in the future. Problems also could arise from the present lack of dynamic testing of devices - the "flicker" distortion is only in evidence when near full power output (~at clipping) and this will also be reduced in magnitude hopefully by a series of dynamic tests that are also being proposed by the H.A.D. section.

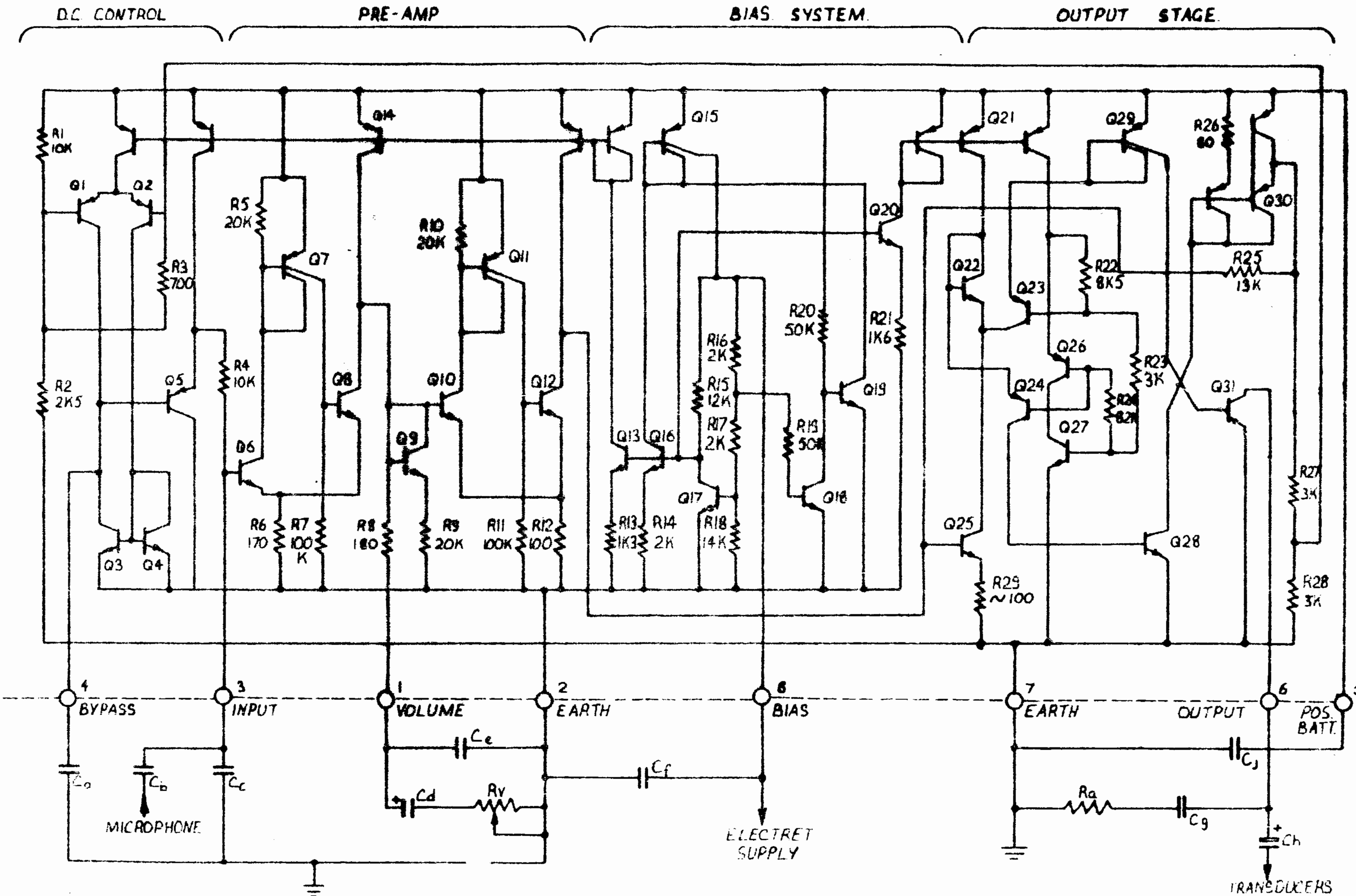
Appendices

A1: AWM 1460 Hearing Aid Amplifier Circuit

A 2: TFA 1069 Hybrid Circuit

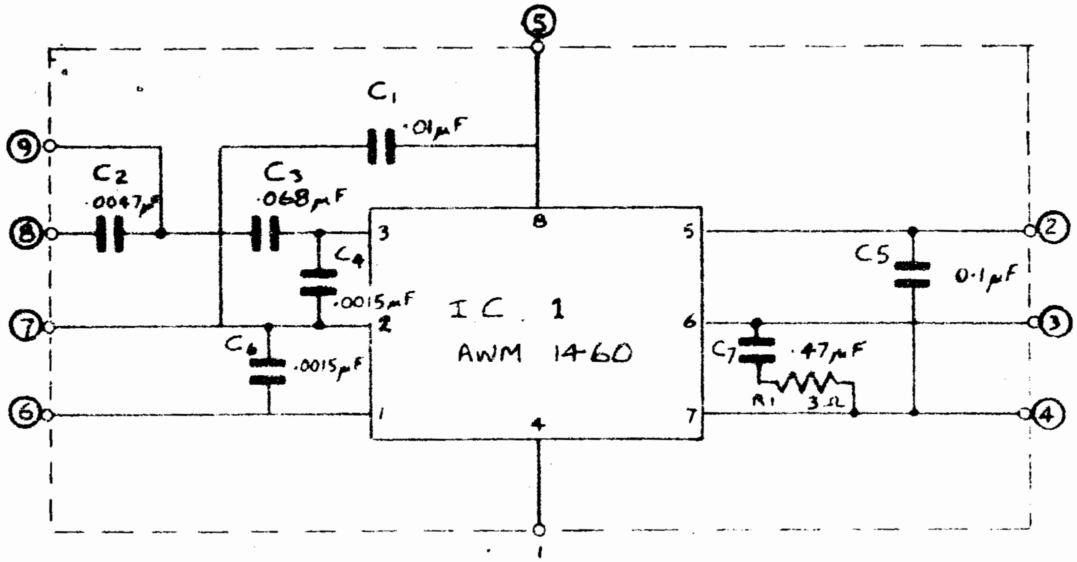
A 3: Battery Resistance of E576 Silver Oxide Cell

A 4: Wang Computer Analysis of TFA 1069 Model



AWM 1460 HEARING AID AMPLIFIER

THIRD ANGLE PROJECTION | ALL DIMENSIONS IN MILLIMETRES



NOTE - NUMBERS MARKED (1) INDICATES PIN NUMBERS OF THICK FILM BOARD.

IDENT	DESCRIPTION	TOL.	SUPPLIER
C8	CAPACITOR CERAMIC ·1 μF JOHANSON TYPE 6R0 R15 Y104ZP	+80 -20	RIFA
R1	RESISTOR SCREEN PRINTED 3 Ω	± 20	-
C7	CAPACITOR CERAMIC ·47 μF JOHANSON TYPE 120R25Y474 ZP	+80 -20	RIFA
C4, C6	CAPACITOR CERAMIC ·0015 μF VICLAN TYPE 0504 X7R 152K100PS	± 10	PEROT
C3	CAPACITOR CERAMIC ·068 μF JOHANSON TYPE 6R0R11Y683ZP	+80 -20	RIFA
C2	CAPACITOR CERAMIC ·0047 μF VICLAN TYPE 0504 X7R 472 K050PS	± 10	F PEROT
C1	CAPACITOR CERAMIC ·01 μF VICLAN TYPE 0504 X7R 103K050 PS	± 10	F. PEROT
IC	INTEGRATED CIRCUIT TYPE AWM 1460	-	AWA

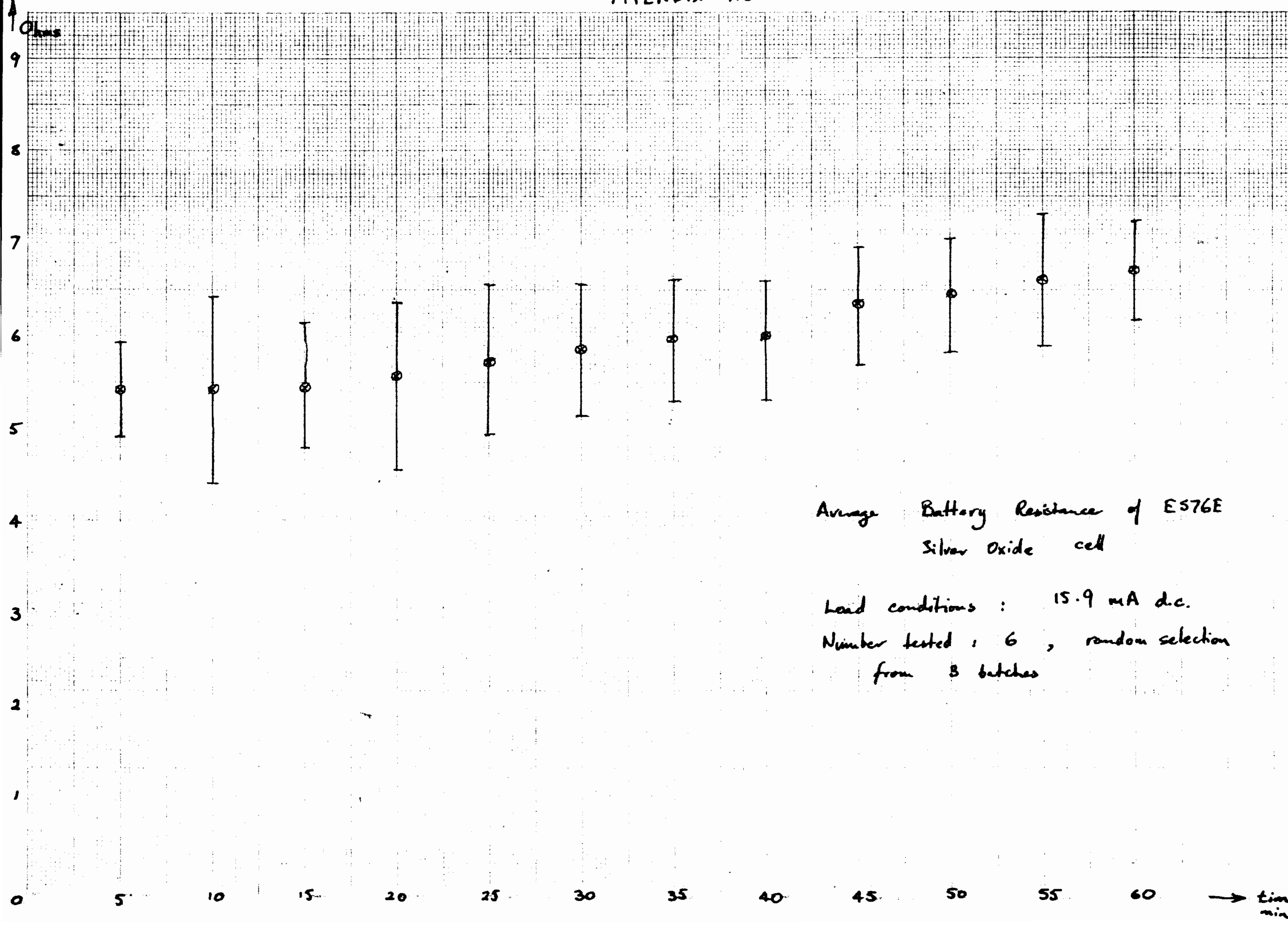
COMPONENTS

No	DATE	CHANGE	
3		DRG No WAS A3/2287; 21.1.78 C3 WAS ·068 μF, NOTE ADD	
2	13/6/78	REDRAWN	RL

TITLE: HYBRID NAL TYPE 8000
CIRCUIT DIAGRAM

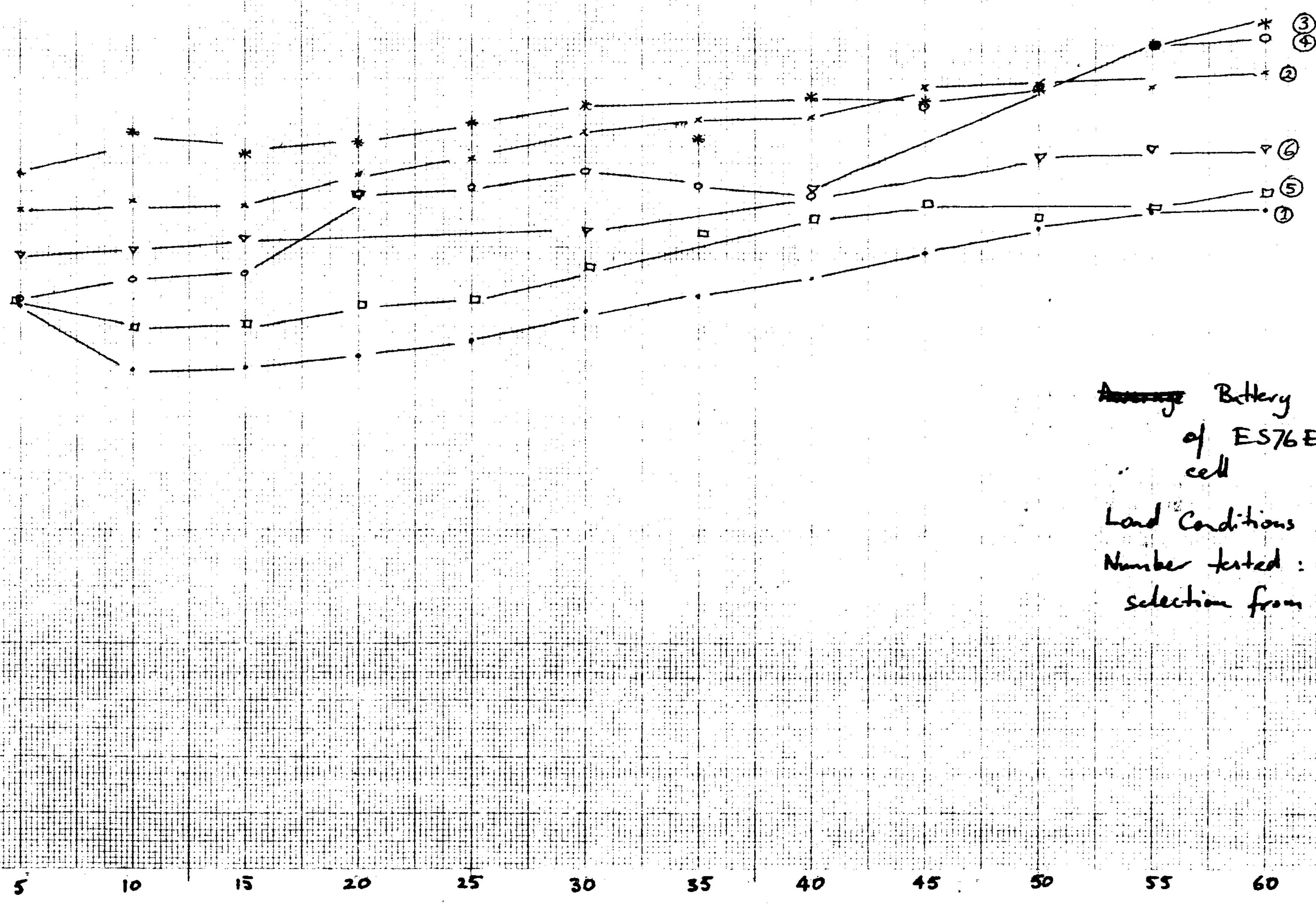
A3 8000 5

APPENDIX A3



Ohms
9
8
7
6
5
4
3
2
1
0
5
10
15
20
25
30
35
40
45
50
55
60
time min
Average Battery Resistance of ES76E
Silver Oxide cell
Load conditions : 15.9 mA d.c.
Number tested : 6 , random selection
from 8 batches

APPENDIX A3



~~Average~~ Battery Resistance of ES76E Silver Oxide cell

Load Conditions : 15.9 mA dc

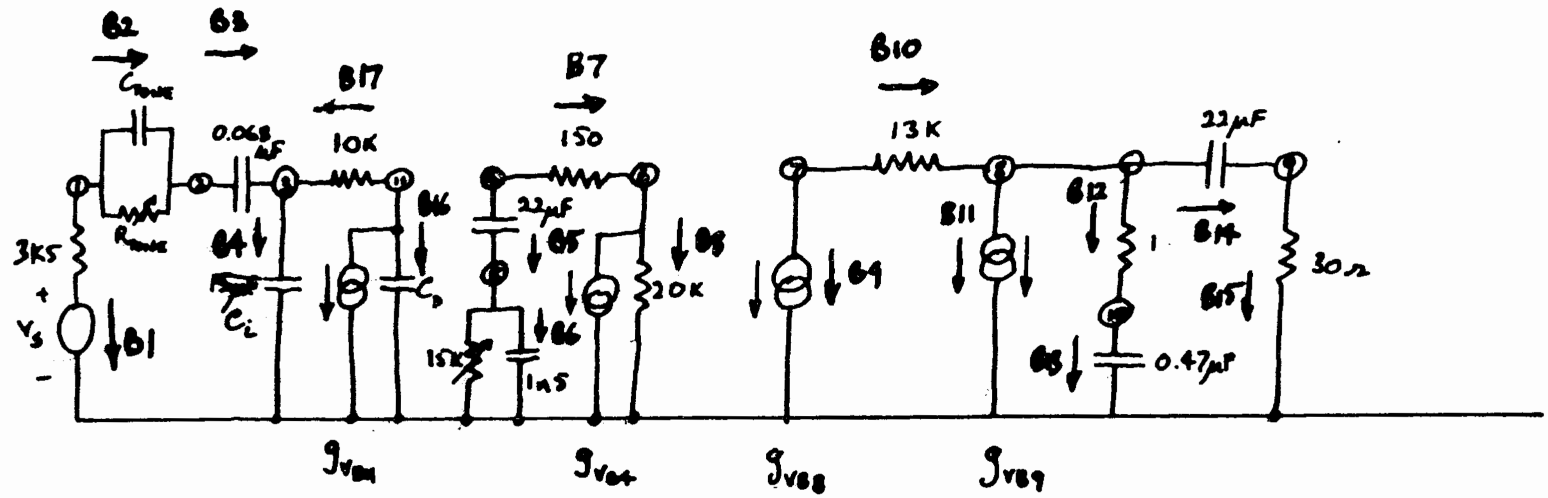
Number tested : 6 , random selection from 3 batches

THIRD ANGLE PROJECTION

ALL DIMENSIONS IN MILLIMETRES

Appendix A4

OVERALL AMPLIFIER MODEL



C_{TONE}, R_{TONE}, C_i varied as per PRE2D

$C_D = C_{BYPASS} \times \beta$

$g_{VBn} = \frac{7.5 \times 10^{-5}}{12} \beta$

NOTE 1: DUMMY RESISTOR & CAPS. HAD TO BE INTRODUCED TO ENABLE WANG COMP. TO INVERT IMPEDANCE MATRIX. SEE { CMPA1.1 / CMPA1.2 } DATA FILES.

ITEM	PART No.	DESCRIPTION	QTY.

NATIONAL ACOUSTIC LABORATORIES
5 HICKSON RD. SYDNEY, N.S.W. 2000

NODE
ANALYSIS
PROGRAMME

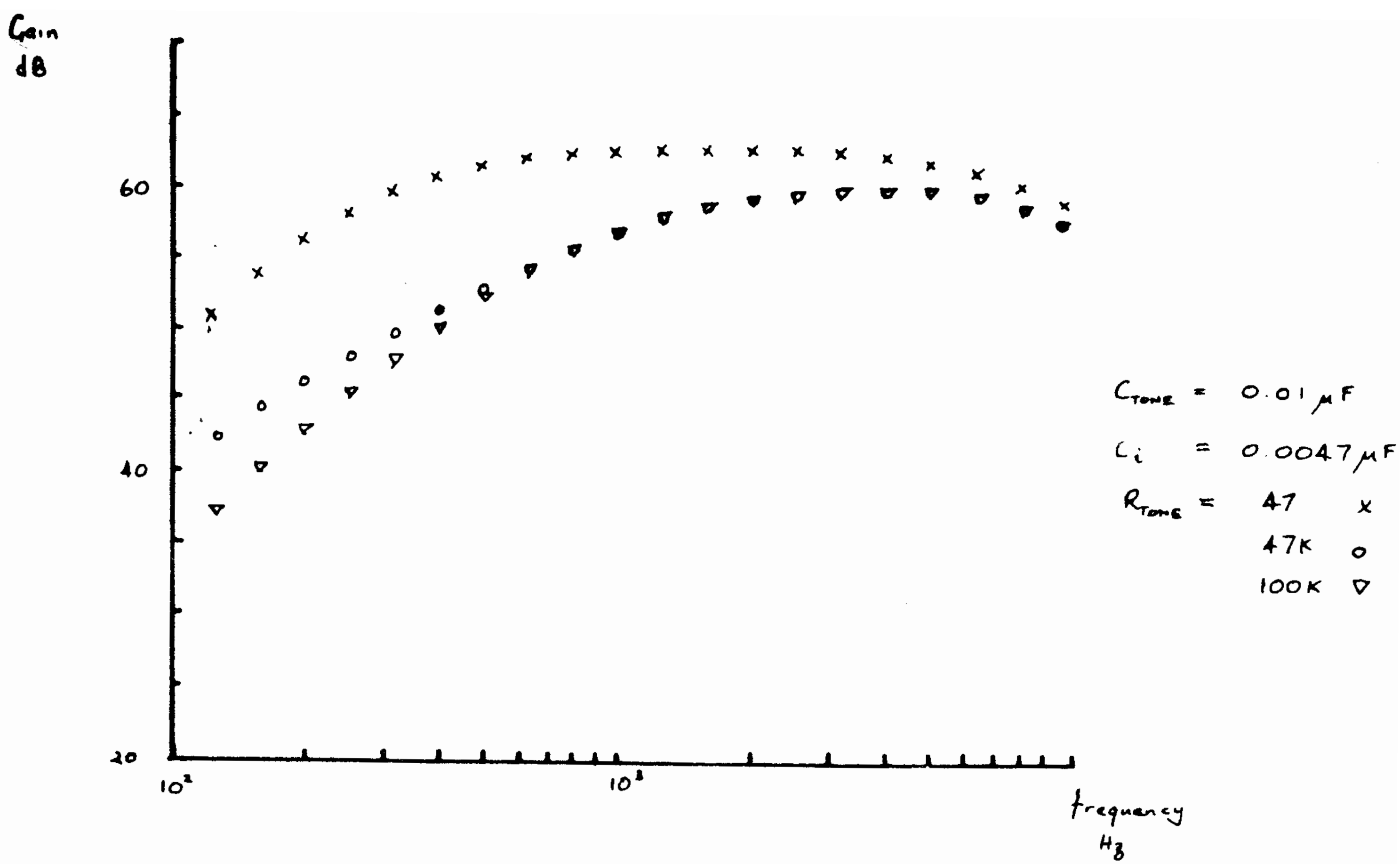
```
8999 REM     DATA FILE= CMPA1.2
9000 DATA 11,17
9010 REM
9020 REM
9030 DATA 1,    1,0,     1,0,1,1,0,0,   3.5E3,  1E-12,1
9040 DATA 2,    1,2,     1,0,1,0,0,0,   47E3,   0.022E-6
9050 DATA 3,    2,3,     1,0,1,0,0,0,   1E7,0.068E-6
9060 DATA 4,    3,0,     1,0,1,0,0,0,   1E7,0.0047E-6
9070 DATA 5,    4,5,     0,0,1,0,0,0,   22E-6
9080 DATA 6,    5,0,     1,0,1,0,0,0,   15E3,  1.5E-9
9090 DATA 7,    4,6,     1,0,1,0,0,0,   150,  1E-10
9100 DATA 8,    6,0,     1,0,1,0,0,1,   20E3,  1E-12,   0.0030,4
9110 DATA 9,    7,0,     1,0,1,0,0,1,   1E6,1E-12,  0.0060,8
9120 DATA 10,   7,8,     1,0,1,0,0,0,   13E3,1E-12
9130 DATA 11,   8,0,     1,0,1,0,0,1,   1E6,  1E-12,  1,9
9140 DATA 12,   8,10,    1,0,1,0,0,0,   1,  1E-15
9150 DATA 13,   10,0,    0,0,1,0,0,0,  0.47E-6
9160 DATA 14,   8,9,     0,0,1,0,0,0,   22E-6
9170 DATA 15,   9,0,     1,0,0,0,0,0,   30
9180 DATA 16,   11,0,    1,0,1,0,0,1,   1E6,  200E-6,6.25E-5,11
9190 DATA 17,   11,3,    1,0,0,0,0,0,   10E3,1E-12
```

Branch Number

Nodes that branch is between

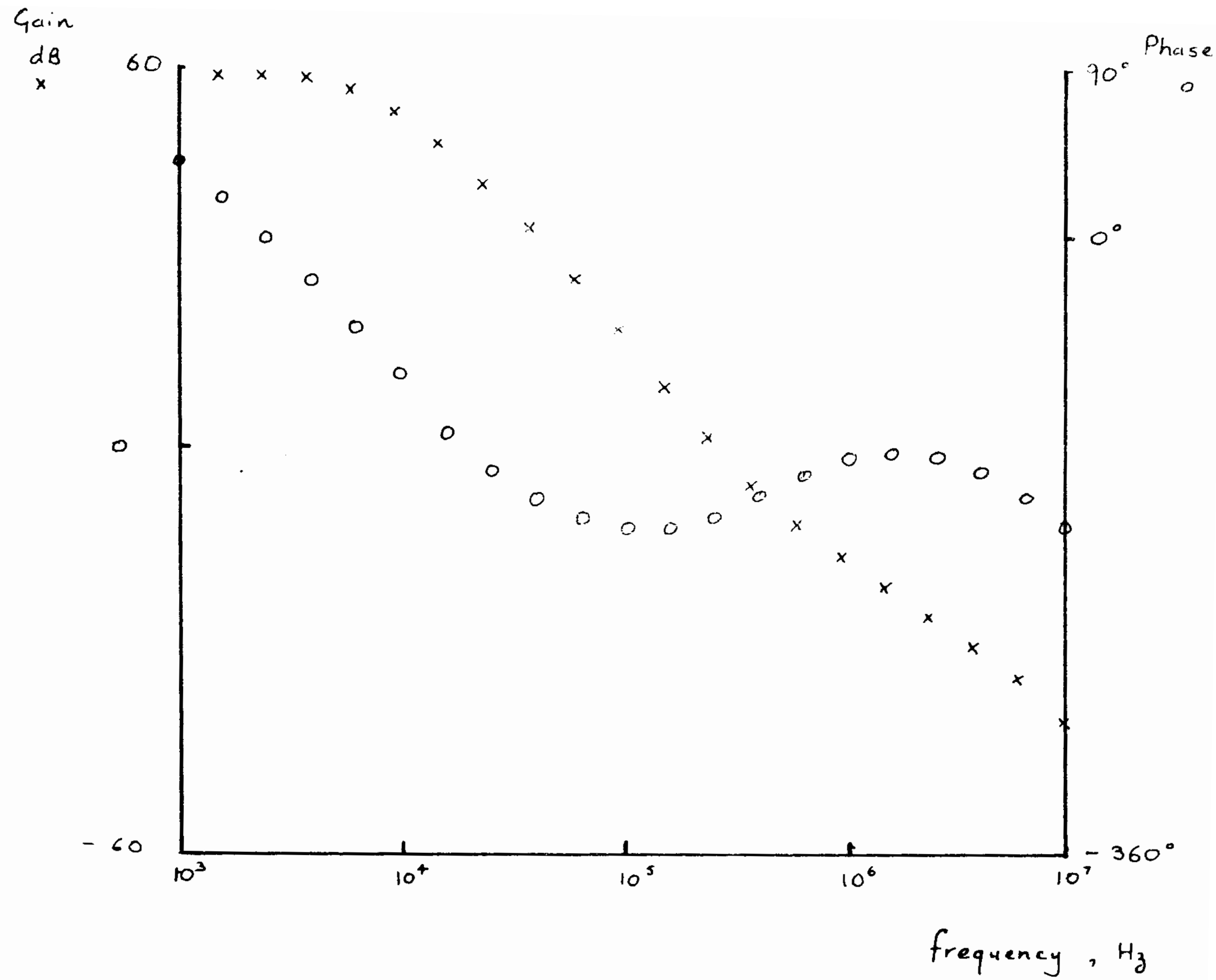
R, L, C, V, I, G_m matrix for element identification

Values of elements in branch



Bass Cut & Boost Variation
with tone pot value

```
8999 REM     DATA FILE= CMPA1.2
9000 DATA 11,17
9010 REM
9020 REM
9030 DATA 1,    1,0,     1,0,1,1,0,0,    3.5E3, 1E-12,1
9040 DATA 2,    1,2,     1,0,1,0,0,0,    47,  0.022E-6
9050 DATA 3,    2,3,     1,0,1,0,0,0,    1E7,0.068E-6
9060 DATA 4,    3,0,     1,0,1,0,0,0,    1E7,0.0047E-6
9070 DATA 5,    4,5,     0,0,1,0,0,0,    22E-6
9080 DATA [illegible]    5,0,     1,0,1,0,0,0,    15E3, 1.5E-9
9090 DATA [illegible]    [illegible],6,     1,0,1,0,0,0,    150, 1E-10
9100 DATA 8,    6,0,     1,0,1,0,0,1,    20E3, 1E-12,  0.0030,4
9110 DATA 9,    7,0,     1,0,1,0,0,1,    1E6,1E-12, 0.0060,8
9120 DATA 10,   7,8,     1,0,1,0,0,0,    13E3,1E-12
9130 DATA 11,   8,0,     1,0,1,0,0,1,    1E6, 1E-12, 1,9
9140 DATA 12,   8,10,    1,0,1,0,0,0,    1, 1E-15
9150 DATA 13,   10,0,    0,0,1,0,0,0,  0.47E-6
9160 DATA 14,   [illegible]    0,0,1,0,0,0,    22E-6
9170 DATA 15,   [illegible]    1,0,0,0,0,0,    30
9180 DATA 16,   11,[illegible]   1,0,1,0,0,1,    1E6, 200E-6,6.25E-5,11
9190 DATA 17,   11,3,    1,0,0,0,0,0,    10E3,1E-12
```



Closed Loop H.F. Response