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110 DB ANALOGUE RATIO (Δ/Σ) PROCESSOR FOR CLOSED ORBIT MEASUREMENTS

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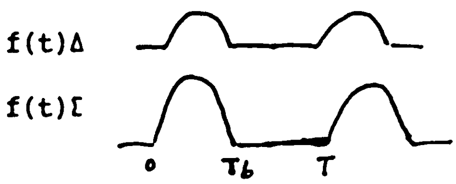
OPERATING PRINCIPLES

a) Position measurement

The position of the center of charge of a bunch-formed beam is defined by

$$P \equiv \frac{\int_0^{T_1} f(t)\Delta \, dt}{\int_0^{T} f(t)\Sigma \, dt}$$



where f(t)Δ and f(t)Σ are the periodic signals appearing at the output of a difference and a summing amplifier, respectively, connected to the plates of an electrostatic pick-up.

For constant intensity, the Σ signal will be constant and the Δ signal proportional to position. For a centered beam, Δ is zero ; the area being proportional to distance from center for non-centered beams.

If a Fourier series is used to represent the two signals

$$f(t) = Ao + \Sigma A_n \cos nwt$$

it can be shown that position is also proportional to

$$\frac{A_{n\Delta}}{A_{n\Sigma}}$$

since both signals have the same waveform.

A bunch factor can be defined

as $\frac{Ao}{Vp}$

which, for a triangular bunch, becomes

$$BF = \frac{Ao}{Vp} = \frac{Tb}{2T} = \frac{lb}{2lc}$$

A 5m bunch in a 25π circumference machine gives

BF = 30 dβ $l_b = 5m$ $l_c = 25\pi\, m$

whereas a 40 m bunch gives

BF = 12 dβ $l_b = 40m$

The system used to measure the position must have a very wide linear range in order to give an output proportional to position P.

If 30 dβ of intensity variation ΔI are expected and a resolution in position measurement of ± 0,3% is desired, then the total dynamic range becomes

$$R = (BF)^{-1} + \Delta I + \Delta P$$

$$R = 30\ d\beta + 30\ d\beta + 50\ d\beta = 110\ d\beta$$

b) <u>Measurement technique</u>

A synchronous detector is a convenient means for measuring the average value of the signals but the extremely wide dynamic range exceeds the linear operating range of available detectors.

If :

- both Σ and Δ signals are compressed by the same amount, the ratio

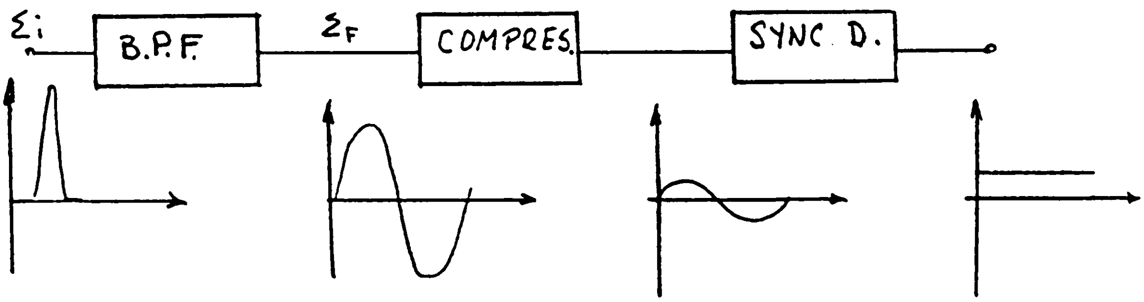
  $p = \frac{\Delta}{\Sigma}$ remains constant independently of the amount of compression.

- both signals are filtered by identical filters, then the ratio will also remain constant.

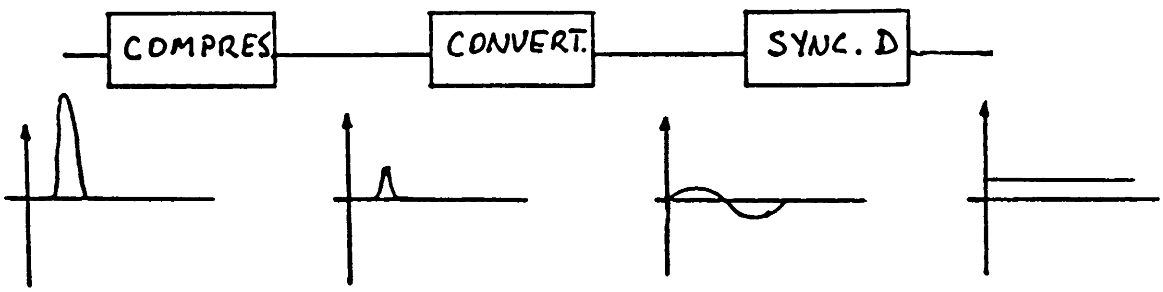
- the frequency of the signals is constant, then a bandpass filter can be used to reduce the bunch factor considerably.

- The frequency of the signals is variable, then a frequency convertor translating the signal to a constant intermediate frequency, followed by a bandpass filter, will make the same reduction as in the constant frequency case.

The basis of the measuring system is shown in the figure for a <u>constant frequency</u> signal



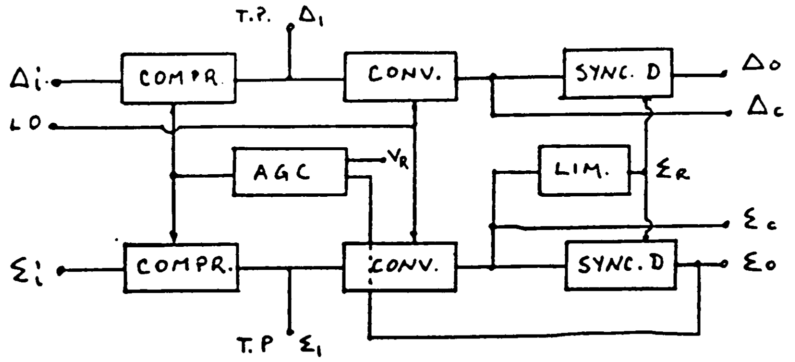
for a <u>variable frequency</u> signal the block diagram becomes



~~The Σ synchronous detectors~~ with this technique the required dynamic range ~~has been~~ can be reduced considerably. If a compression equal to the intensity variation is implemented, a constant Σo signal results.

If an identical process is applied to the Δ signal, then the Δo signal will show a dynamic range equal to the position range ΔP, i.e. 50 dB for the present case.

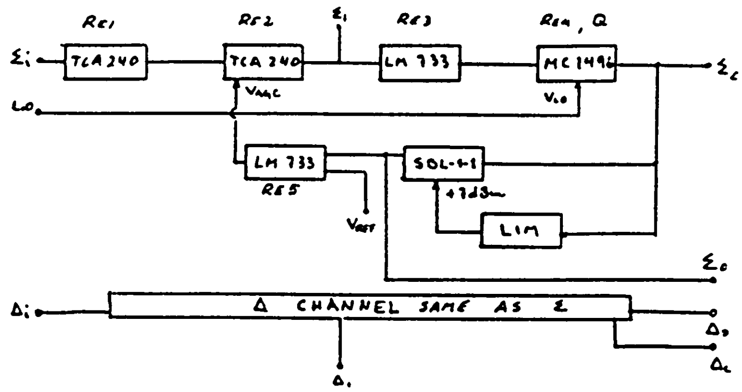
System block diagram (variable freq. signal)



A module as shown in the figure has been developed as a basic building block for different situations. Both constant and variable frequency systems can be designed, based on this module.

THE DESIGN VARIABLES

The system block diagram is shown below with the main design variables.



Linearity

The input stages determine the maximum input signal which can be processed linearly.

As shown in Appendix A, the maximum peak input signal which can be linearly amplified is determined by

$\Sigma imax = k\ Io\ RE$ where k has to be less than 1
Taking k = 1/3
a fairly linear behaviour is achieved

for $\Sigma ipeak\ mx = 1500$ mV

$Io\ RE = 4500$ mV ($Io = 8$ mA
($RE = 562\ \Omega$

Compression region

The gain at the compressor stage is controlled by V_{AGC}

In the figure is shown the frequency response of the compressor with V_{AGC} as a parameter. As much as 80 dB of gain can be controlled varying V_{AGC} from - 0.092 V to + 0.25 V.

The compression threshold is given by

$$\Sigma_{i\,min} = \frac{\Sigma_o}{G_{max}}$$

where Σo is the detected output level.

For a given value of Σo

$$Gmax = \frac{\Sigma o}{\Sigma imin}$$

Gmax is the total gain from the input to the detected output. It is dependent of the "gain resistors" RE1 ....RE4, the Q of the bandpass filter at the converter output, and the detectors efficiency. The local oscillator signal level determines the conversion gain. The synchronous detector attains its maximum efficiency when the reference signal is + 7 dBm (SBL -1-1).

If Gmax is defined as the ratio of desired output level Σo, and minimum average input signal $\Sigma AVmin$, then

$$Gmax = \frac{\Sigma o}{\Sigma iAVmin} = \frac{150\ mV}{2\ mV} = 75$$

If the maximum average input signal is 370 mV, then

$$Gmin = \frac{\Sigma o}{\Sigma imax} = \frac{150\ mV}{370\ mV} = 0.4 \quad \text{and}$$

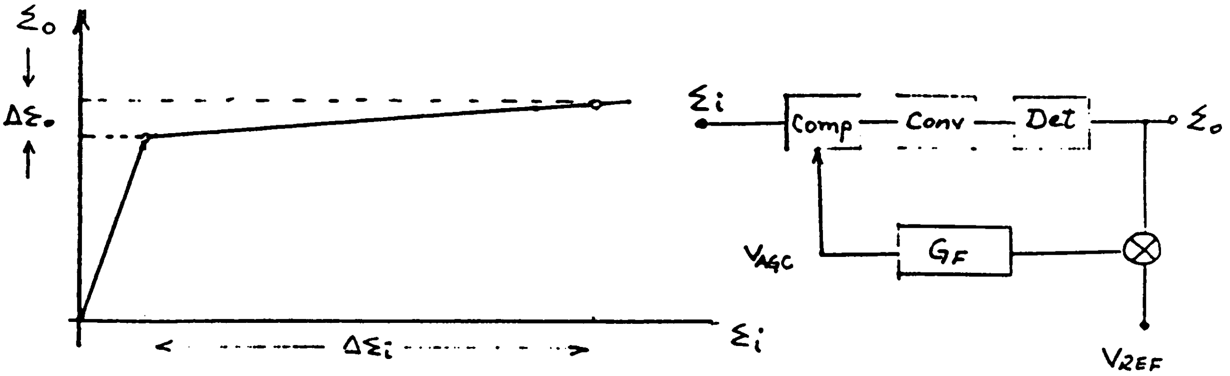
a compression range of 75/0.4 = 45 dB is required.

From the figure, it can be seen that a ΔV_{AGC} = 180 mV is necessary.

Compression ratio

The compression ratio Rc is defined as shown in the figure by :

$$Rc = \frac{\Delta\Sigma i\ (dB)}{\Delta\Sigma_0\ (dB)} = \frac{45\ dB}{1\ dB} = 45\ dB/dB$$



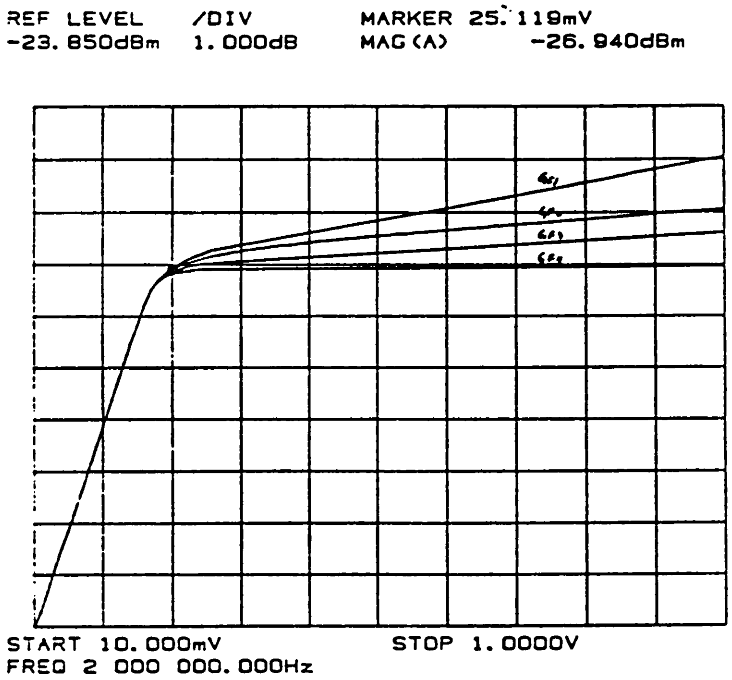
The compression ratio is dependent on the "feedback gain" from Σ_0 to V_{AGC}, determined by P6 on IC 10.

$$G_F = \frac{\Delta V_{AGC}}{\Delta\Sigma_0}$$

If Σ_0 = 150 mV, then a 1 dB change becomes $\Delta\Sigma_0$ = 18 mV.
For ΔV_{AGC} = 180 mV

$$G_F = \frac{180\ \mathrm{mV}}{18\ \mathrm{mV}} = 10$$

A higher value of G_F would give a better compression ratio but the stability and transient behaviour of the compression loop set a limit on the maximum G_F.



<u>Intermediate frequency</u>

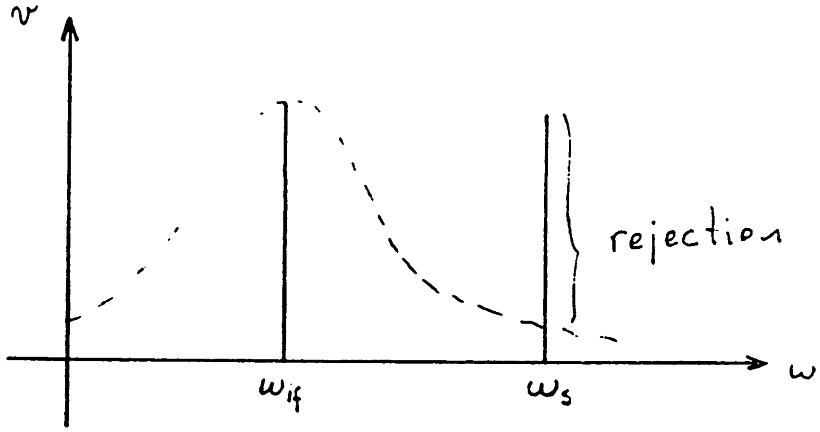
The choice of a convenient I.F. relies on the convertor behaviour and the nature of the input signal.

As shown in the Appendix, the bandpass filter at the output of the convertor has to select the difference frequency.

$w_{if} = w_{lo} - w_1$ where w_1 = input signal frequency
w_{lo} = local oscilator frequency.

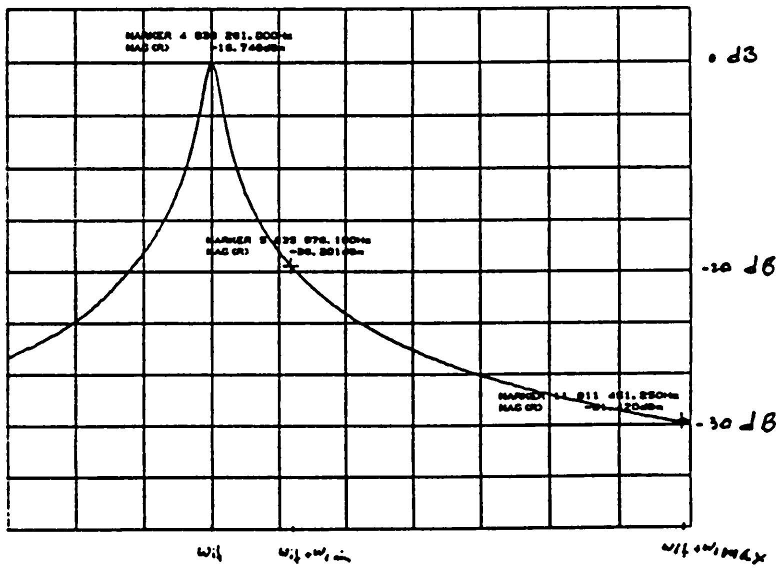
and reject the sum

$w_s = w_{lo} + w_1$



Converter spectrum for sinusoïdal inputs

For a given Q and a given w_s rejection, the IF can be determined, since w_1 is also known.



since

$$ws - w_{if} = 2\ w_1$$

then

$$\frac{ws}{w_{if}} - 1 = \frac{2\ w_1}{w_{if}}$$

For N dB of rejection, ws/wif is known from the filter characteristics the most critical situation being for $w_1 = w_1 min$

$$W_{if} \leq \frac{2\ W_1\ min}{\frac{Ws}{W_{if}} - 1} = \frac{2 \times 0.4\ MHz}{1.166 - 1} = 4.8\ MH_z$$

Besides, in order to avoid the unconvenient image frequencies, appearing when non sinusoïdal input signals are applied, an even lower limit for w_{if} is imposed

$$w_{if} \leq \frac{w_1 \min}{2} = 0.2 \text{ MHz}$$

The available L.O., based on a VCO in a PLL loop, has a tuning ratio

$$Tr = \frac{w_{max}}{w_{min}} \leq 3$$

so an IF has to be chosen such that

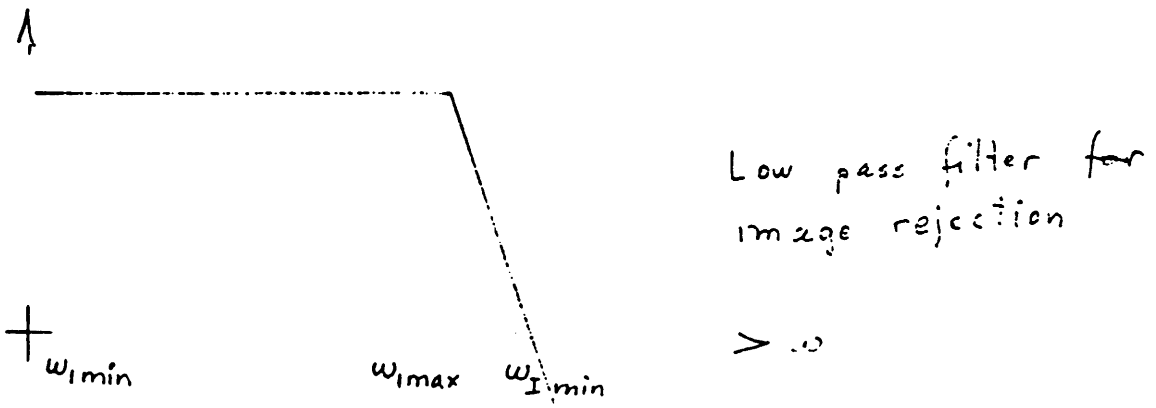
$$\frac{w_{max}}{w_{min}} = \frac{w_{if} + w_{1max}}{w_{if} + w_{1min}} \leq 3$$

from which $w_{if} \geq 1.6$ MHz

This frequency falls within the signal frequency range, so the condition

$$w_{if} \leq \frac{w_{1min}}{2}$$

is not fulfilled and image frequency problems will arise. A low pass filter can be used to exclude the image frequencies but a new condition will restrict the choice of the IF. Since the image frequencies are harmonics of the input signal, the cutoff frequency of the filter has to be higher than the highest input frequency and be able to reject the lowest image frequency.



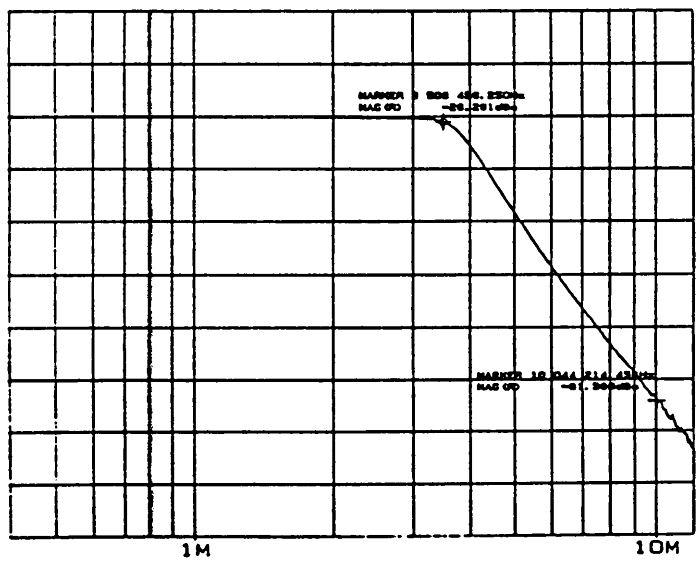
It can be shown that

$$w_{I\,min} = 2\,w_{if}$$

A reasonable 5th order low pass Chebyshev filter with a cutoff frequency of 4 MHz shows a rejection of more than 50 dB at a frequency of 9.6 MHz. Then

$$w_i = \frac{w_{Imin}}{2} = \frac{9.6\text{ MHz}}{2} = 4.8\text{ MHz}$$

seems to be our only choice.



5th order Chebyshev filter

ADJUSTMENT PROCEDURE and PERFORMANCE TESTS

Note : The procedure is based on the use of a network analyzer HP 3577 A.

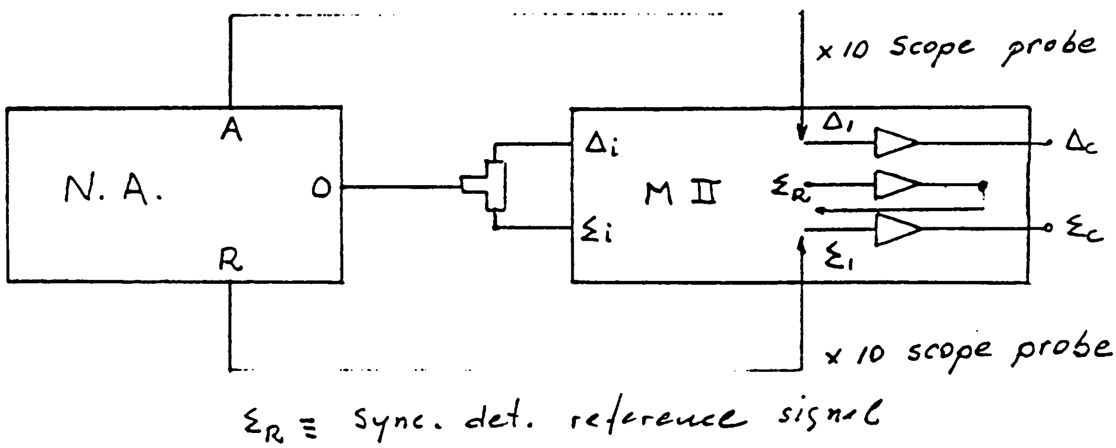
- OUTPUT LEVEL

- COMPRESSION RANGE

- COMPRESSION RATIO

MODULE II

Arrange the set-up shown in the figure



N.A. Operating conditions :

SWEEP TYPE	:	CW
FREQ	:	4.8 MHz (I.F.)
AMPL	:	360 mVrms

1. Adjust output level to Σ_1 = 600mVp (P 5) (use the scope)

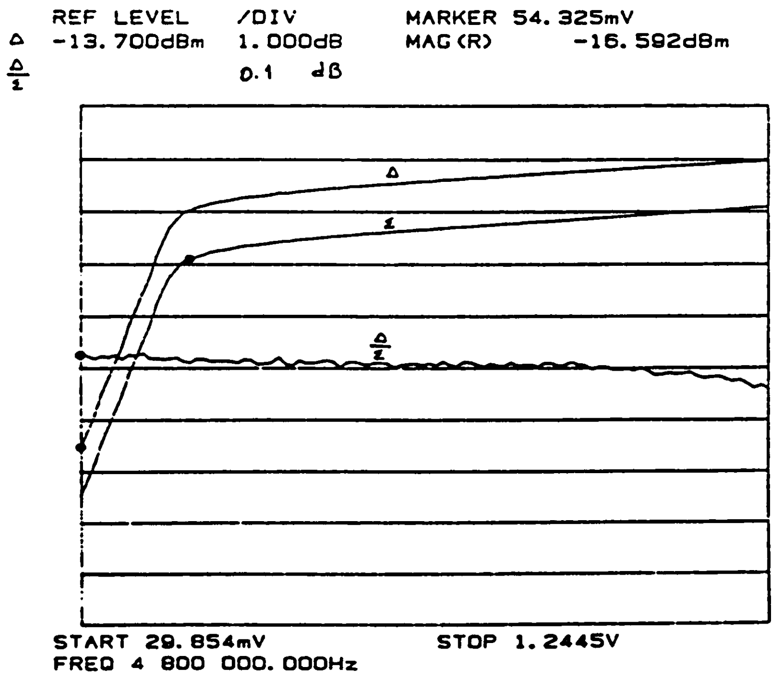
2. Adjust the synchronous detectors reference level to + 7 dBm. (Σ_r = 1400 mVp) (P 8)

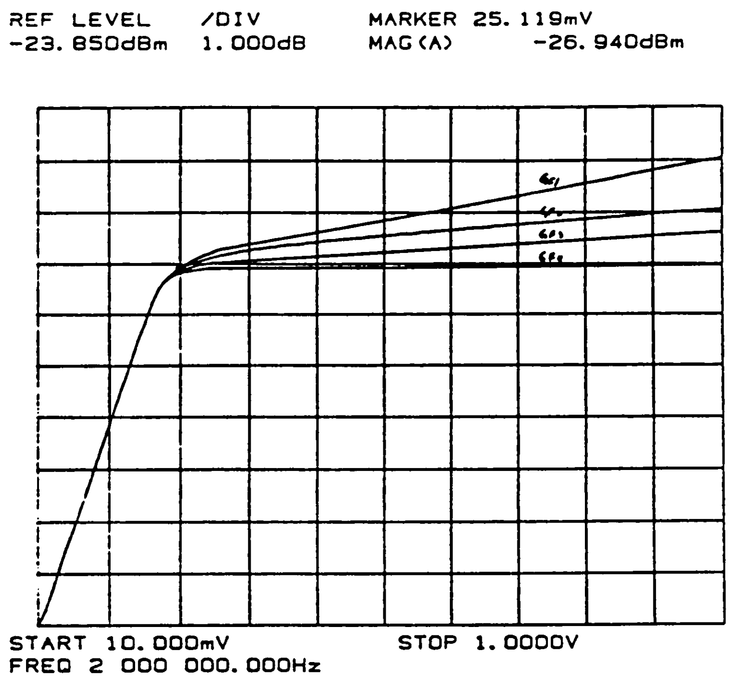
3. Repeat 1. and 2.

Change N.A. operating conditions to :

SWEEP TYPE	:	AMP. SWEEP
SWEEP MODE	:	SINGLE
FREQ	:	4.8 MHz (I.F.)
AMP, START	:	30 mVrms
STOP	:	1.25 Vrms
INPUT	:	R; A; A/R

4. Adjust loop gain (P 6) and output level (P 5) on MOD II until the conditions indicated in the figure are attained (Δ and Σ will in general be different).

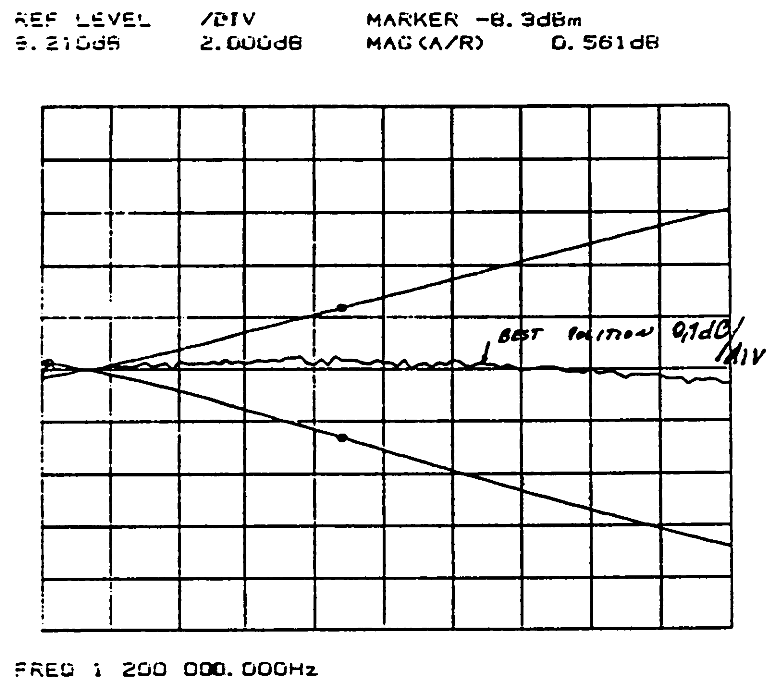




GAIN ADJUSTMENT WITH P 6

Note : The slope is controlled by P 6 and the level by P 5.

5. Adjust tracking pot (P 4) until the least variation on Δ/Σ is obtained over the full amplitude range of the compressor (A/R at the N.A.).



Note : when P4 is misadjusted, the extreme traces indicated in the figure are obtained.

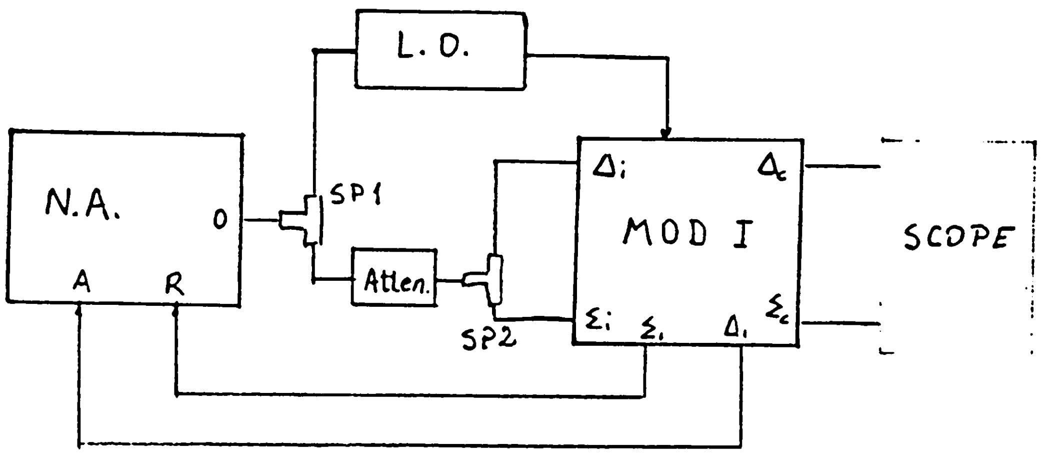
<u>Other variables</u> :

When AMPLI. : 360 mVrms, then : VAGC (IC2) ≃ VAGC (IC 18) ≃ 77 mVdc and dc output from sync. det. SBL 1-1 is approx. 160 mVdc.

- OUTPUT LEVEL
- COMPRESSION RANGE
- COMPRESSION RATIO

MODULE I

Arrange the set-up shown in the figure



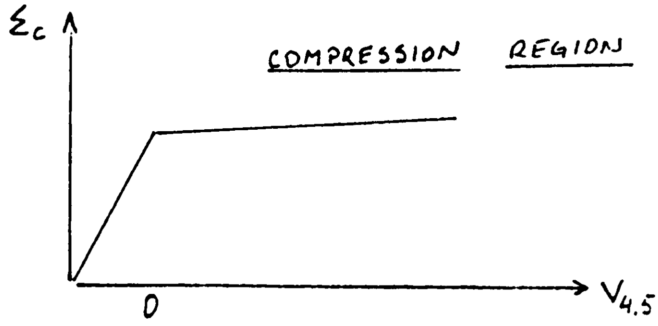
N.A. Operating conditions :

SWEEP TYPE	:	CW
FREQ.	:	2 MHz
AMPL	:	500 mVrms
ATTEN	:	Zin R : 1 MΩ Zin A : 1 MΩ !!

Attenuator : Reduce the level at Σ and Δ inputs below the compression level. This condition is fulfilled when a 10 dB input variation produces approx. 10 dB output variation.
Use the scope for this observation.
Another way of determining the compression level is by observing the voltage at pins 4 and 5 of IC 2 : when

$U_{4,5} \geq 0$ volts → compression

$_{4}U_{5,4,5} < 0$ Volts → no compression



1. Tune the Σ side IF filter at the converter stage (IC30) to maximum Σc level. (Use the scope). Check that you still are in the compression region. Otherwise reduce input level.

2. Repeat 1)

3. Set the attenuator to OdB and tune the Δ side IF filter (IC4) to maximum Δc output and check that the Δc signal is in phase with the Σc signal (Use the scope).

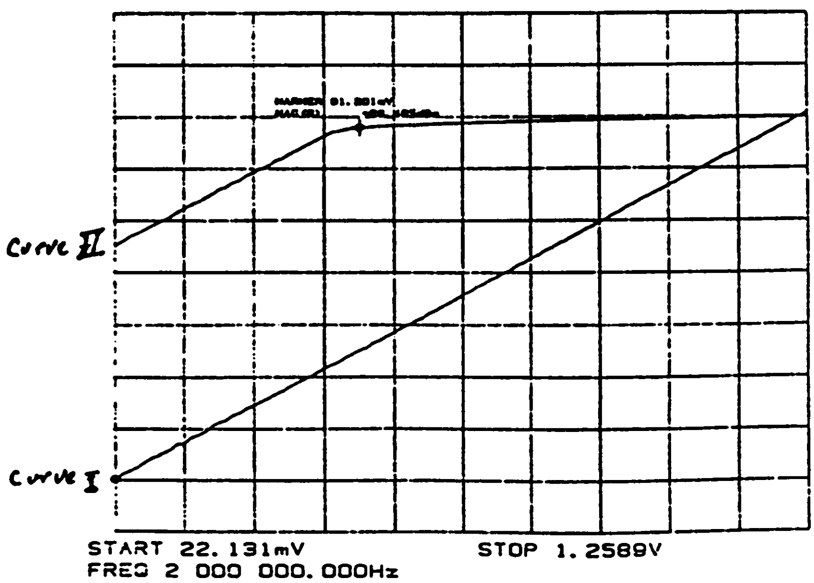
4. Adjust output level pot (P/5) on Mod. I to an output level of 260 mV peak. Check that the synchronous detectors reference signal is + 7 dBm. Otherwise adjust (P/8) and repeat 4).

Change the N.A. operating conditions to :

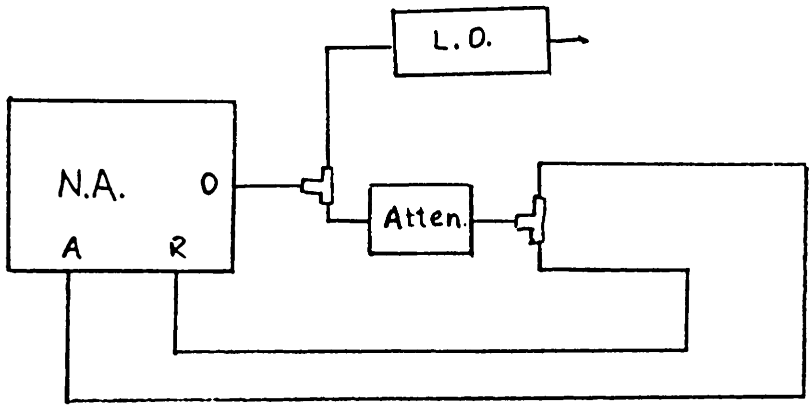
SWEEP TYPE	:	AMPL. SW.
FREQ.	:	2 MHZ
AMPL.	:	START 22 mVrms STOP 1200 mVrms
SWEEP MODE	:	SINGLE

CURVE I (ATTEN : ZiR = 50Ω
(MENU : ZiA = 50Ω

CURVE II (ATTEN : Zin R = 1 MΩ !
(MENU Zin A 1 MΩ !



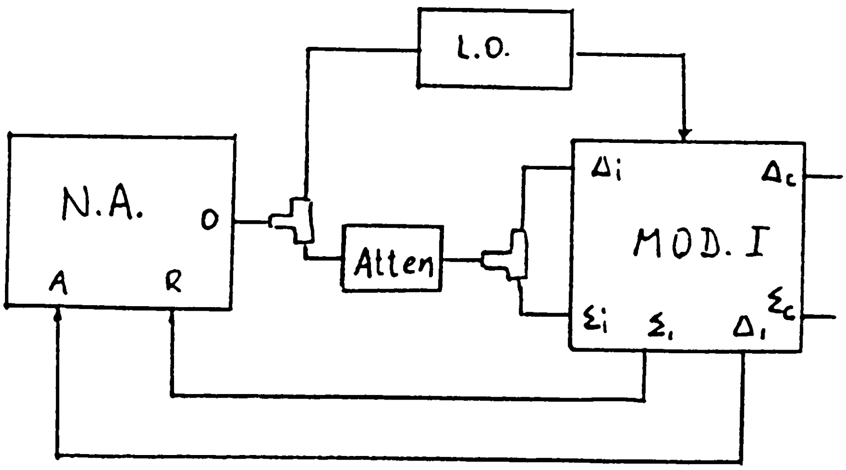
CURVE I   Input test signal



- Set attenuator to 30 dB
- Connect splitter # 2 to N.A. as indicated
- Select ATTEN. menu and set ZA and Zr to 50 Ω

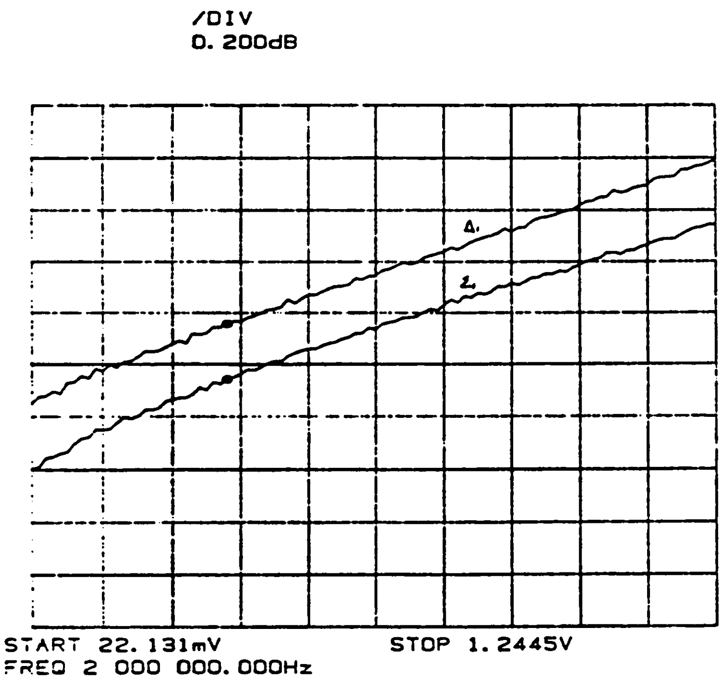
CURVE II

- Compression characteristics with ATTEN = 30 dB



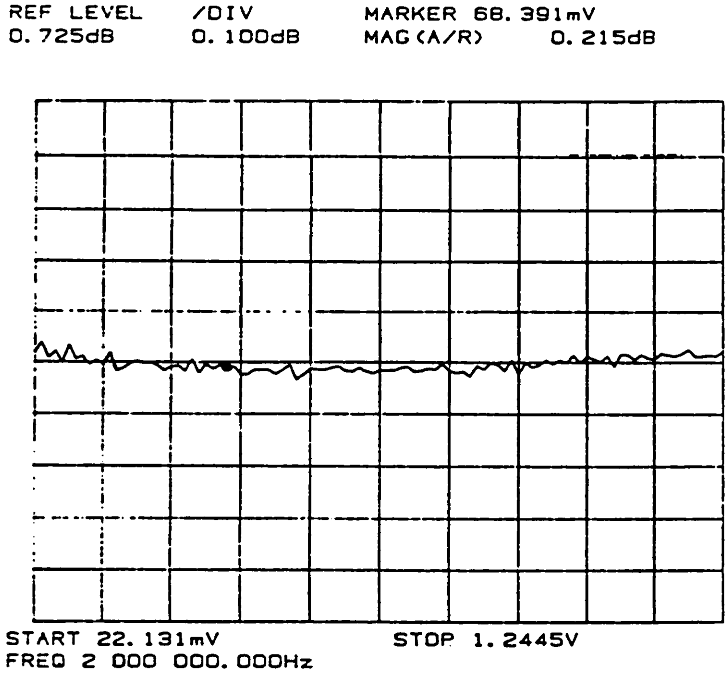
- Connect splitter # 2 as indicated in the preceeding figure
- Select ATTEN menu and set ZA and Zr to 1 MΩ

5) Set ATTEN.to 10 dB and adjust loop gain (P16) and output level (P15) on MOD. I until the following condition is attained.



Δ_1 and Σ_1 after compression in MOD. I. Start amplitude within the compression region.

6) Set Input to A/R and adjust the tracking pot (P/4) till the least variation is attained over the full amplitude range of the compressor (.1 dB/div scale)



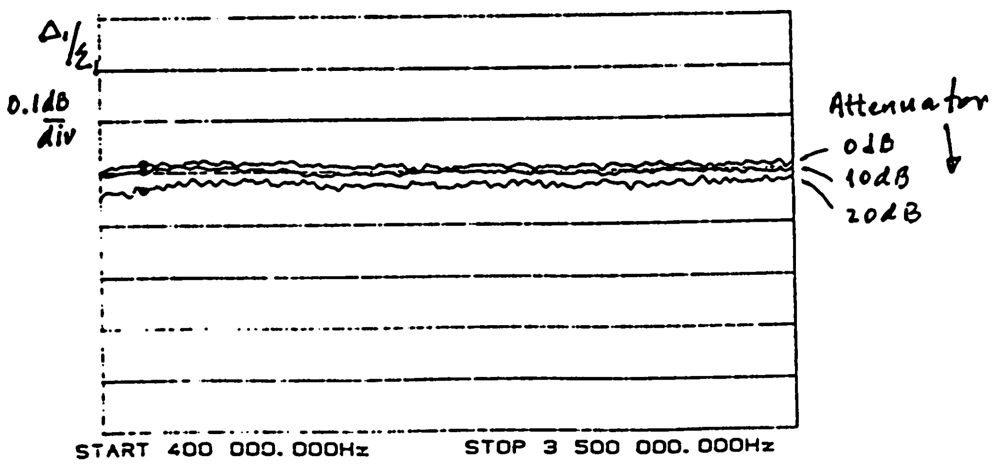
7. After several hours warm-up, readjust the tracking pot (P/4) as before.

<u>SET N.A.</u> to the following conditions :

SWEEP TYPE :	LIN FREQ. SW.		
FREQ. :	START :	0.4 MHz	
	STOP :	3.5 MHz	
	AMPL :	.4 Vrms	

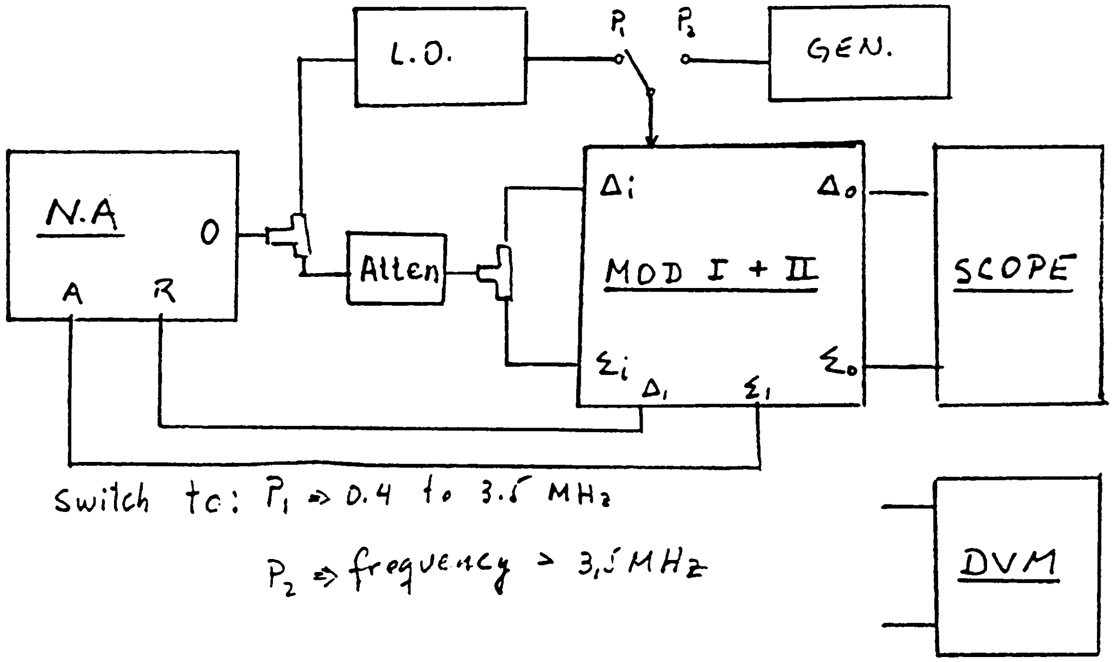
8. Set N.A. Input to R, then to A and then to A/R and observe :

A/R should remain within ± 0.1 dB over the entire amplitude and frequency range of the compressor.



MODULE I and MODULE II
Overall amplitude and frequency response

(Σ - Σ connection)

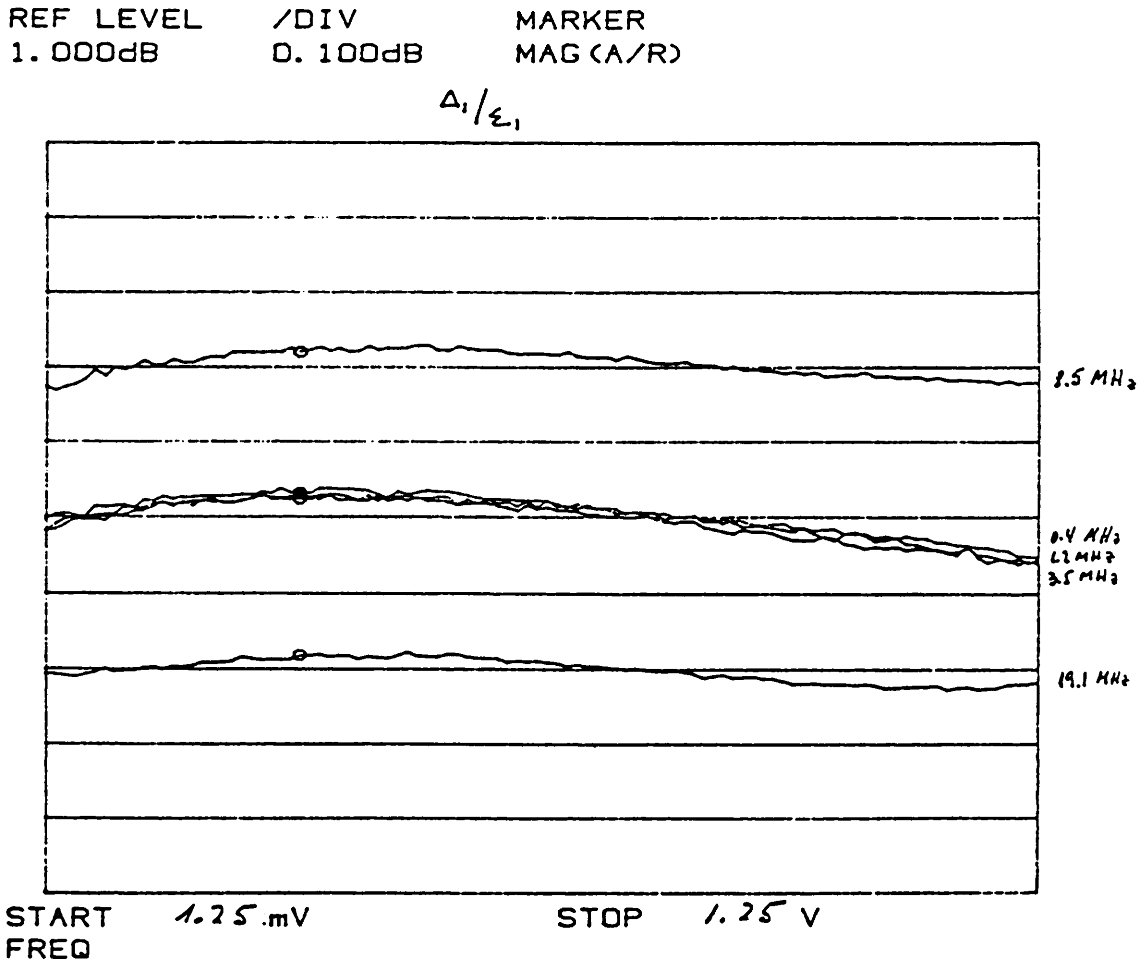


Set the N.A. to the following conditions :

SWEEP TYPE	:	LIN FREQ. SW
FREQ.	:	START 0.4 MHz STOP 3.5 MHz
AMPL.	:	1.2 V_{RMS}
SWEEP TIME	:	20 sec

1. Observe the Σo dc output with the scope (or the DVM) and change input level by 10 dB steps by means of the Attenuation (Σo should remain constant within ± 2% full scale, over the full ampl. range).

2. Observe the Δo dc output as indicated in 1).
Δo should remain constant within e ± 1% of full scale over the full amplitude range.



Note: a) use external generator as L.O.
for this measurement. (switch to P_2)

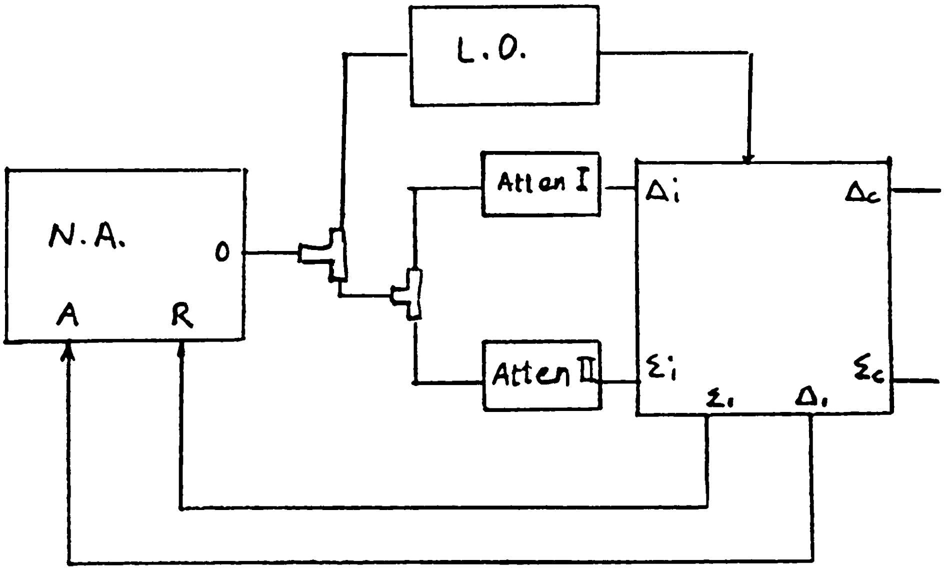
v_{P2} = 200 mVpeak

$f = f_i + 4.8$ MHz

b) the reference level has been changed
for f = 8.5 MHz and 19.1 MHz

MODULE I

Δ channel linearity



ATT MENU: $Z_A = 1 M\Omega$ $Z_R = 1 M\Omega$

A linearity check can be made at different Σ levels changing the attenuation of the two attenuators. The lowest Δ attenuation has to be equal to the Σ attenuation in order that Δimax = Σi.

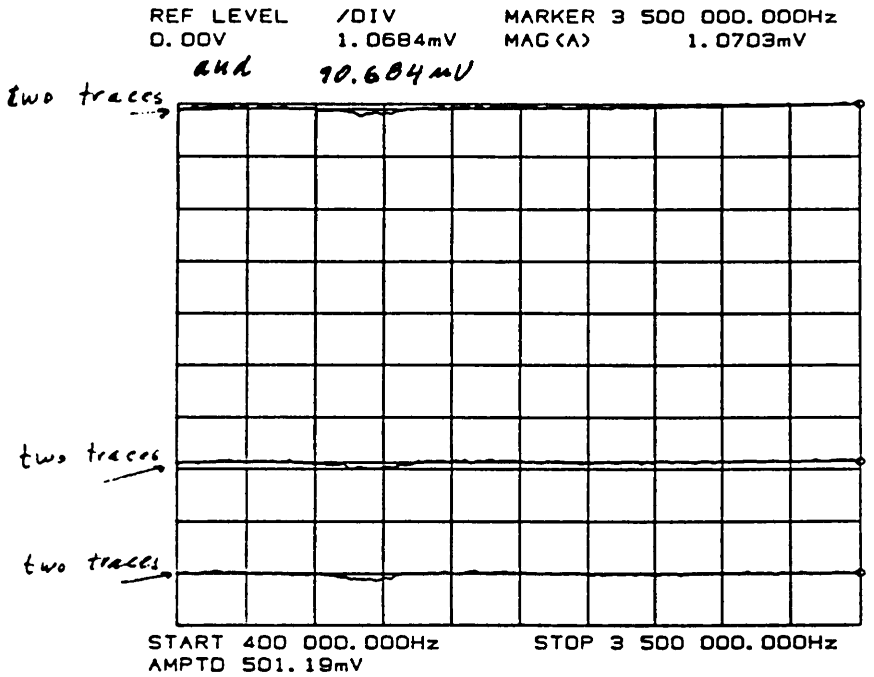
Set the N.A. to the following conditions :

SWEEP TYPE	:	LIN FREQ. SW
FREQ.	:	START 0.4 MHz STOP 3.5 MHz
AMPL.	:	$0.5\ V_{RMS}$
SWEEP TIME	:	20 sec

Attenuator I : 0dB

Scale 10mV/div — Scale 1mV/div

Atten II 0 dB — Atten II 20 dB

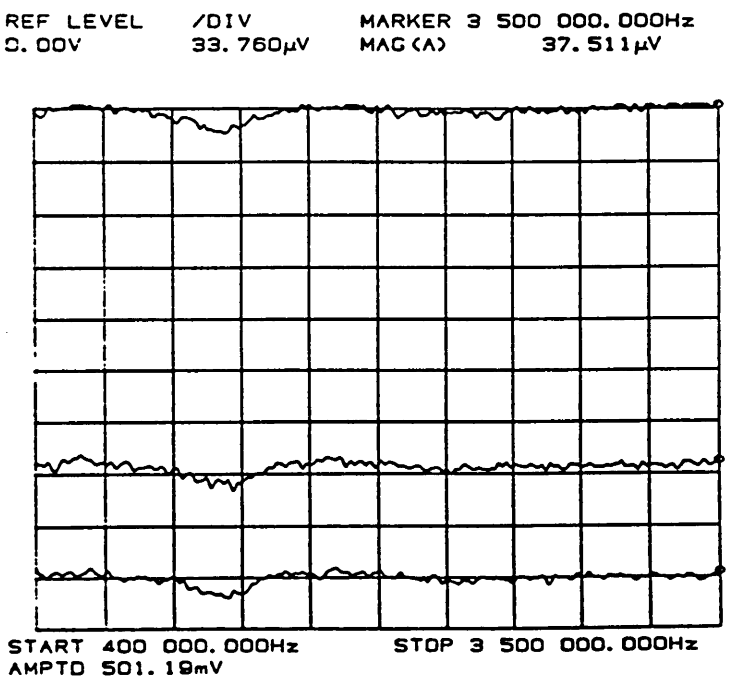


10 dB — 30 dB

20 dB — 40 dB

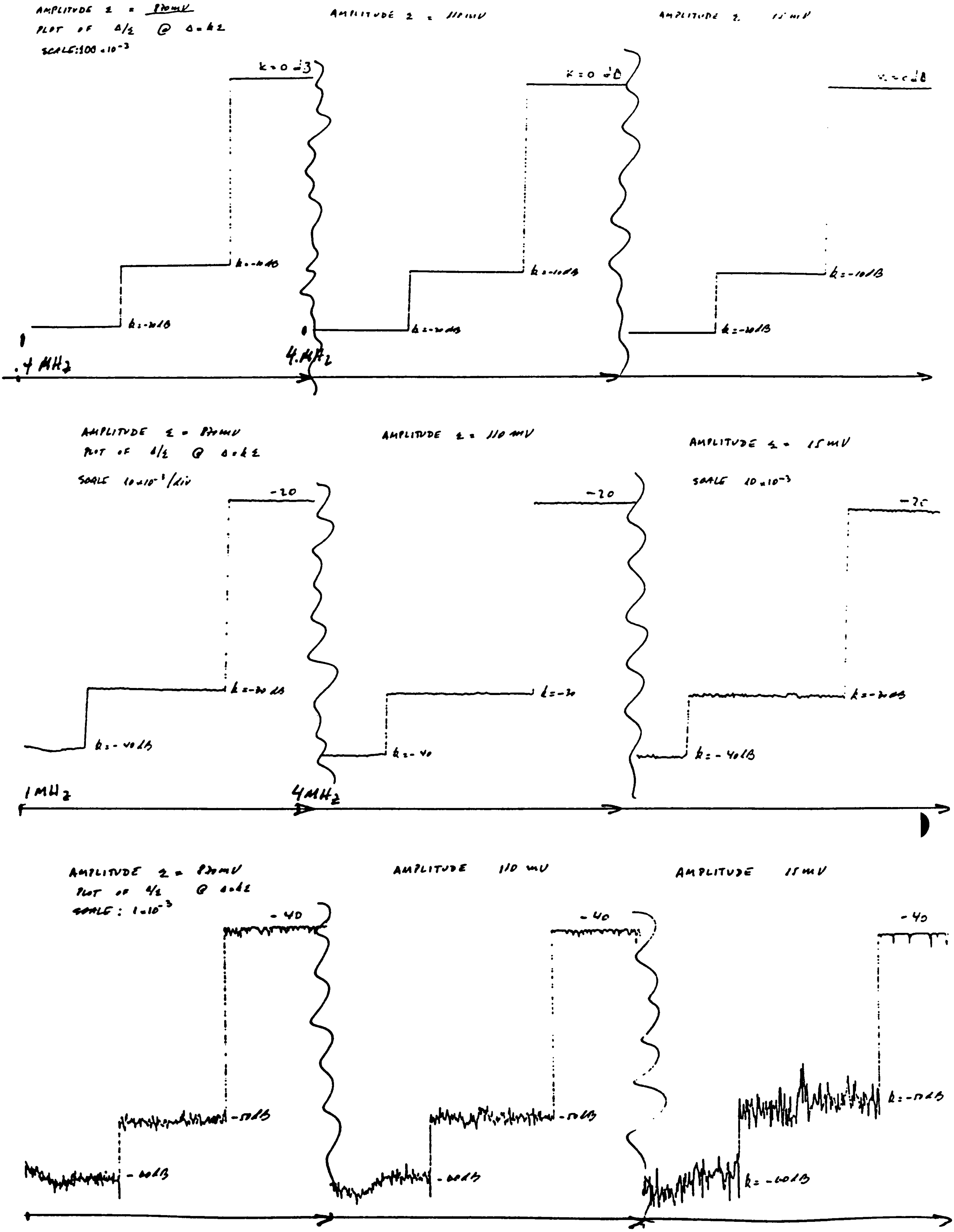
0.33mV/div

30 dB

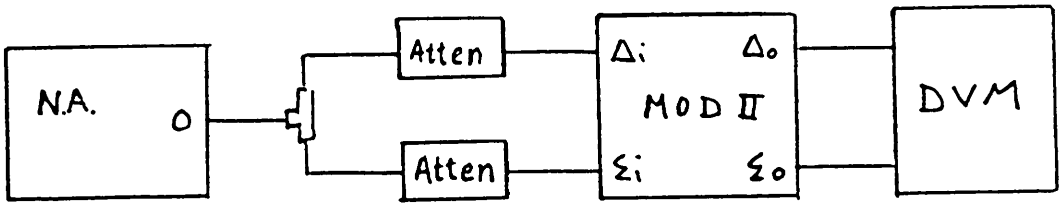


40 dB

50 dB


AMPLITUDE Σ = 110 mV
AMPLITUDE Σ = 15 mV
k = 0 dB
k = -10 dB
k = -20 dB
.4 MHz
4 MHz
SCALE 10×10⁻³/div
SCALE 10×10⁻³
-20
k = -20 dB
k = -40 dB
1 MHz
4 MHz
AMPLITUDE 110 mV
AMPLITUDE 15 mV
SCALE : 1×10⁻³
-40
-50 dB
-60 dB
k = -60 dB

MODULE II
Linearity (Δ channel)



N.A. operating conditions

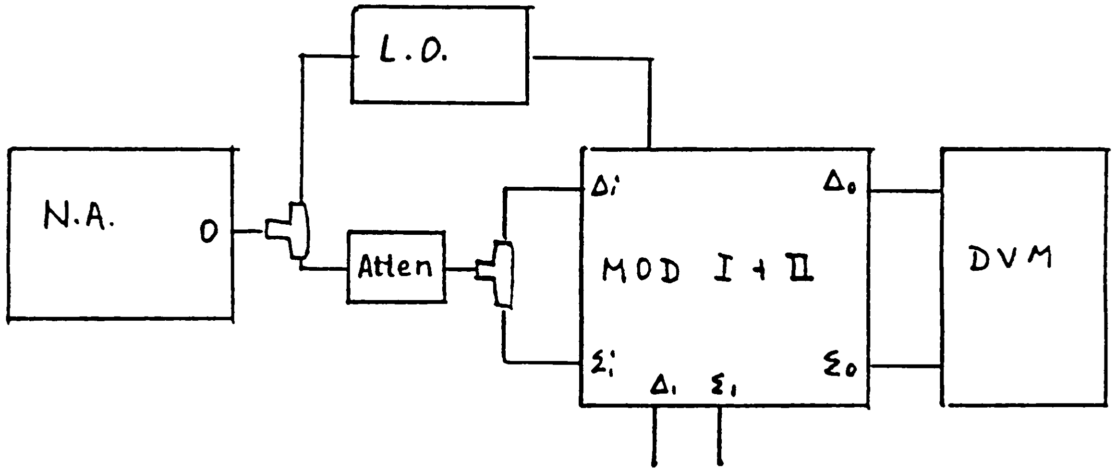
SWEEP TYPE : CW

AMPL : 500 mVrms

FREQ. : I.F. → 4.8 MHz

Set At (Σ side) to 0 dB and read Δo and Σo when the Δ side. Atten. is set to 0 ; 10 ; 20 ; 30 ;..., 60 dB.

MODULE I + II   Linearity (Δ channel)



N.A. operating conditions

Δo[mV]	Δo/1.0275
1.027.5	100.0
326.0	31.7
103.1	10.0
32.6	3.1
10.3	1.0
3.2	0.3
1.0	0.1

SWEEP TYPE : CW

AMPL. : 1 Vrms

FREQ. : 2 MHz

1. Set the Σ side at the 10 dB and read Δo on the DVM when the Δ side Attenuator is set to 10, 20 ..., 60 and 70 dB.

2. Set Δ side Attenuator to 100 dB and adjust offset pot on MOD II P2) to 0 mV.

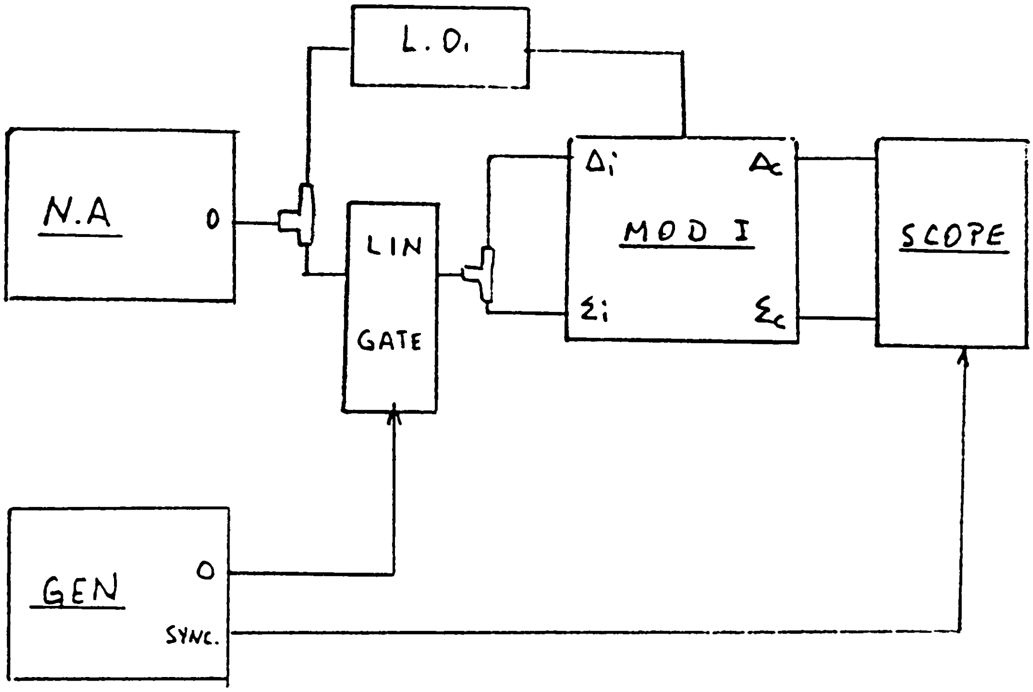
3. Set Δ side Attenuator to 10 dB and adjust the output level pot (P3) on MOD II to desired dc output.

4. Repeat 1).

5. Adjust Σ side output to desired level with P9

TRANSIENT RESPONSE

MODULE I



Set GEN to :	Set N.A. to :
- Adequate amplitude to trigger the linear gate	SWEEP TYPE : CW
	AMPL. : 100 mVrms
- FREQ : 100 Hz	FREQ : 2 MHz

1. Observe Δ_c and Σ_c with the scope.

TRANSIENT RESPONSE

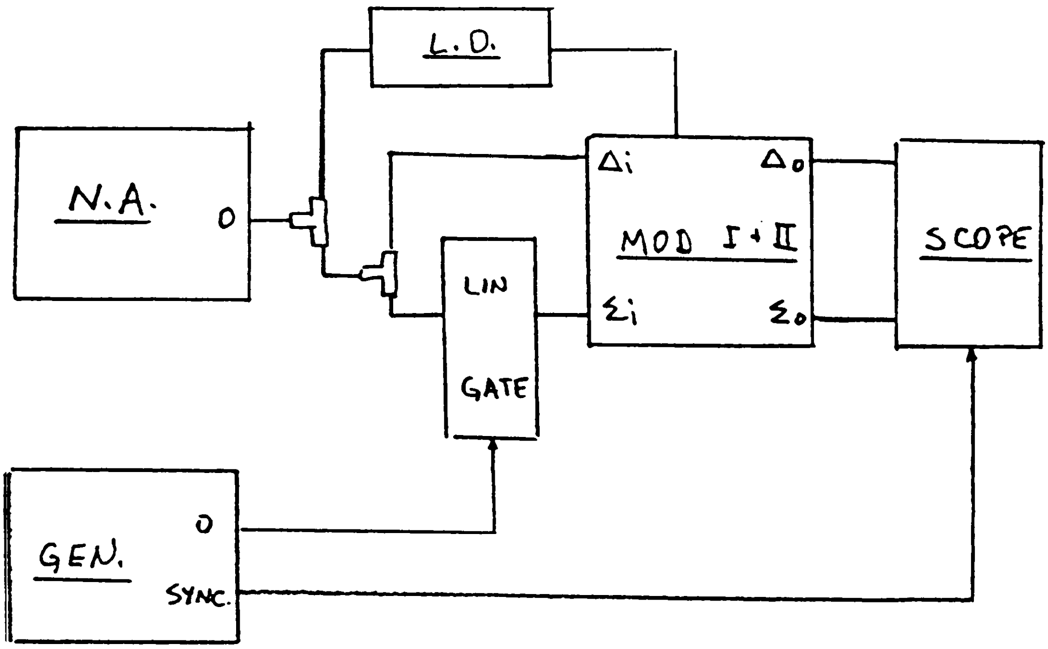
MODULE I + MODULE II

a) Arrange the same set-up as for MOD. I transient response measurement.

b) Connect MOD. II to MOD. I and observe ΔO and Σo with the scope.

TRANSIENT RESPONSE

MOD. I + II
Δ Channel



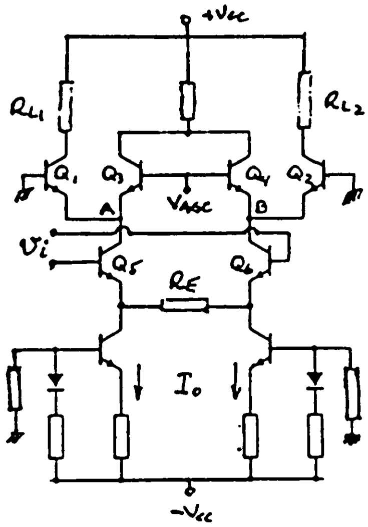
Set GEN to :	Set N.A. to :
a) AMPL. : adequate value	SWEEP TYPE : CW
	AMPL. : 200 mVrms
b) FREQ : 100 Hz	FREQ : 2 MHz

For a given intensity, Σi will remain approximately constant except for slight changes in the pick-ups and associated circuity. Nevertheless, Δi can be expected to show big changes since the beam could be centered at one of the pick-ups and far away from centre at another one.
The proposed test set-up serves the purpose of showing the transient response of the Δ channel at a fixed compression level.

Appendix A

The compressor

The TCA 240 is a transistor array which can be used as a Gilbert cell, having a wide dynamic range and about 90 dB of gain control.



When V_{AGC} is sufficiently negative, approximately 300 mV, Q_3 and Q_4 are cutoff, and Q_1, Q_5, Q_2, Q_6 becomes a broadband cascade differential amplifier with a lineal range controlled by RE and Io.

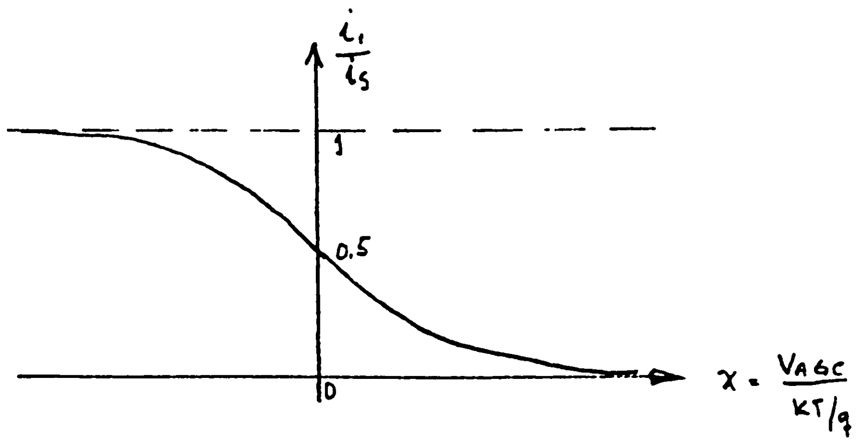
Q_5 and Q_6 act as signal current sources controlled by Vi ; if V_{AGC} is now varied between ± 300 mV d.c., then the current arriving at nodes A or B is shared by transistors $Q_1$and Q_3 at node A and by transistors Q_2 and Q_4 at node B. The amount of signal current flowing through the load resistors R_{L_1} and R_{L_2} becomes an exponential function of V_{AGC}

$$i_1 = \frac{is}{1 + e^x}$$

where $$x = \frac{V_{AGC}}{kt/q}$$

$$is = Vi \frac{gmo}{1+gmoRE}$$

and $$gmo = \frac{Io}{kt/q}$$



The gain of the stage can be expressed as :

$$G = \frac{\Delta V1}{\Delta Vi} = \frac{gm\ RL}{1+e^{x}}$$

where $gm = \frac{gmo}{1 + gmo\ RE}$

If $gmo\ RE >> 1$ then

$$G = \frac{RL}{RE} \frac{1}{1+e^{x}}$$

The input signal Vi will be amplified linearly if

$$Vipeak < Io\ RE$$

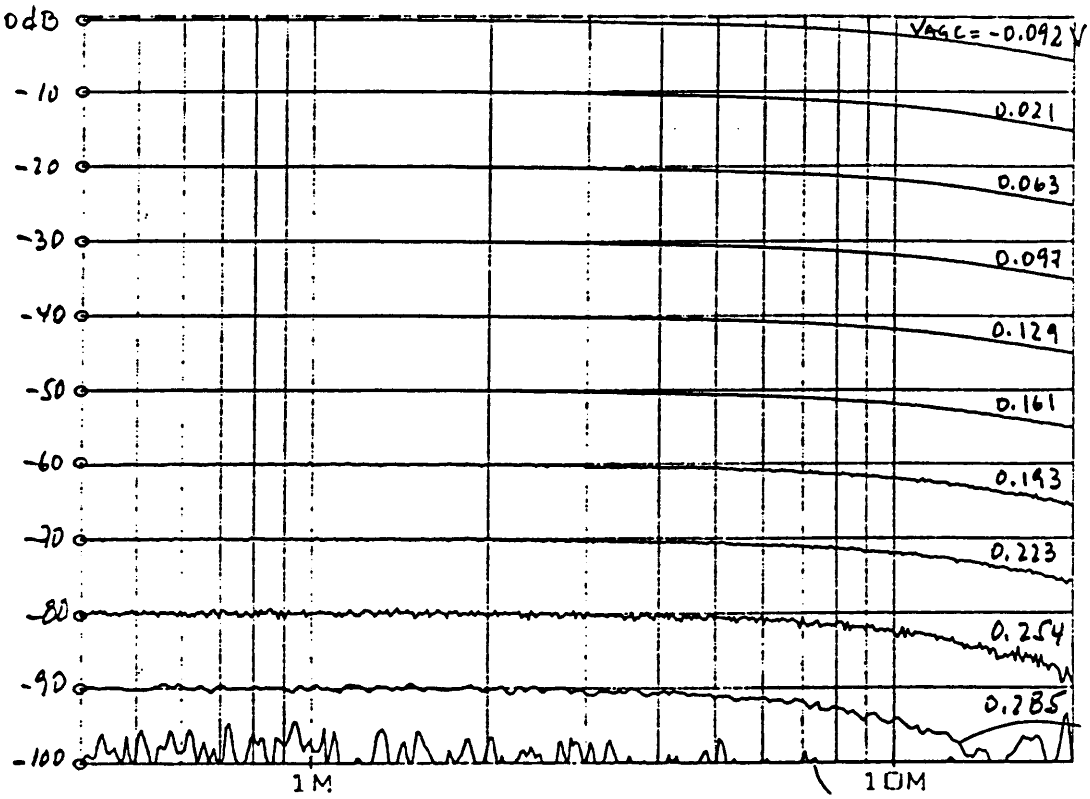
Taking Vipeak = 1/3 Io RE, a good linearity is assured.

It should be pointed out that as linearity increases increasing RE, gain decreases and a compromise must be adopted.

In the figure is shown the gain as a function of frequency for a stage with Io = 8 mA

RL = 511 Ω and

$- 0.092\ V \leq V_{AGC} \leq + 0.285\ V$



Compressor open loop performance

Distribution

Battisti S.	)	
Damiani M.	)	
Durand J.	)	
Gelato G.	)	PS
Gonzalez J.	)	
Le Gras M. (3)	)	
Schulte E.	)	
Williams D.J.	)	