THE NATIONAL RADIO ASTRONOMY OBSERVATORY

SOCORRO, NEW MEXICO

VERY LARGE ARRAY PROGRAM

VLA ELECTRONICS MEMORANDUM NO. 194

THE LINEARITY OF THE DETECTOR IN MODULE F4

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I. Introduction

The detector in the F4 module is used to measure the ratio of the system noise temperature to the temperature of the switched noise source which is injected at the front end inputs for calibration purposes. In normal operation, a gated alc loop in the F4 holds the level of the system noise to a constant value, and the periodic increases when the calibration noise source is on are measured by means of a synchronous detector. The output of the synchronous detector should be proportional to the system gain, and it is used to correct the visibility data for gain changes that result from changes in antenna temperature and the action of the alc loop. It is particularly important to correct for any change of gain between observation of a source that is being mapped and observation of a calibration source. This calibration system is described in more detail in VLA Technical Report No. 40 by L. R. D'Addario.

A design modification introduced in July, 1980 (change order no. 166) has resulted in a decrease of 3.5 dB in insertion loss of the mixer in F8 that converts the frequency from 1025 MHz to 1325, 1425, 1575 or 1675 MHz. The signal from F8 goes to the detector in F4, and the alc attenuator acts on the 1025 MHz signal before it reaches F8 (see Fig 1.1 in VLA Technical Report No. 40). It is desirable to keep the operating point of the alc attenuator unchanged since this has been chosen to minimize phase changes. An increase of 3.5 dB in the signal from F8 to T2 is acceptable, and the simplest solution is to decrease the gain of the amplifier following the detector in F4 so that, with the alc loop operating, the power level to the detector is -19 dBm rather than -22.5 dBm as originally designed. This is option (c) in a memorandum by L. R. D'Addario dated June 19, 1980 which is appended to this memorandum. The measurements described here were undertaken to check that the detector is sufficiently linear in its power-law response with the 3.5 dB increase in its input level.

II. The Detector Linearity Requirement

With the switched noise source off the alc holds the detector output voltage at a value v_o for which the detector input power is p_o. When the noise source is on the alc gating circuit holds the gain constant and the corresponding values of detector power and voltage are $p_o + \Delta p_1$ and $v_o + \Delta v_1$. The synchronous detector measures Δv_1, and we assume that Δv_1 is proportional to Δp_1 which is a measure of the system gain. Now suppose that Δp_2 and Δv_2 are the corresponding quantities measured at some different time. The change in gain is $\Delta p_1/\Delta p_2$, and we want to know how much this differs from $\Delta v_1/\Delta v_2$.

Let the detector characteristic be given by $p = f(v)$. Then

$$\frac{\Delta p_1}{\Delta v_1} = \frac{f(v_o + \Delta v_1) - f(v_o)}{\Delta v_1} \tag{1}$$

When the antenna is looking at cold sky near the zenith, the system temperature is at its minimum and the magnitude of the calibration signal is such that $\Delta p_1/p_o \cong 0.1$. Suppose that in the next situation a large increase in antenna temperature has occurred so that there has been a large decrease in gain and Δp_2 is small

$$\frac{\Delta p_2}{\Delta v_2} = \left(\frac{dp}{dv}\right)_{v_o} \tag{2}$$

$$\frac{\Delta p_1}{\Delta p_2} = \frac{\Delta v_1}{\Delta v_2} \quad \frac{f(v_o + \Delta v_1) - f(v_o)}{\Delta v_1 \left(\frac{dp}{dv}\right)_{v_o}} \tag{3}$$

This situation represents the largest error in gain change that is likely to occur as a result of the detector linearity assumption.

Figure 1 shows the expected form of f(v), from which it can be seen that for a small departure from linearity f(v) can be approximated by a linear term plus a quadratic term. Measured values of p and v were therefore analyzed by a polynomial fitting routine rather than attempting to read a graph of the points to the required accuracy. In fitting the polynomial it is convenient to center the measured region on the origin, which in this case tends to minimize the higher order coefficients. For a second order polynomial,

$$(p-p_o) = a + b\ (v-v_o) + c\ (v-v_o)^2 \qquad (4)$$

and from (3) and (4)

$$\frac{\Delta p_1}{\Delta p_2} = \frac{\Delta v_1}{\Delta v_2}\ (1 + \frac{c\Delta v_1}{b})$$

The overall goal for accuracy of measurement of visibility data is usually quoted as 1%. The contribution resulting from the detector characteristic should not be more than half of this, i.e. we require $|c\Delta v_1/b|<0.005$.

III. The Detector Measurements

Measurements were made using the F4 test setup in the Front End Lab, which is essentially the system shown in Figure 4.2 of VLA Technical Report No. 40, except that the CW signal source can be replaced by a broadband noise source, which was the case in these measurements. Also the 10 dB pad between J1 of F4 and the isolated power divider was replaced by 7 dB to simulate the lower loss in the modified F8, The detector output voltage was measured at the Total Power BNC output on the front panel of the F4 using a Data Precision 245 digital voltmeter. The detector output has been amplified by one stage of dc gain at this point. The power level into the detector was measured at one port of the 1-2 GHz isolated power divider using a General Microwave 460B Power Meter with 1 mW head (N422C, Ser. 212715). The power meter output was read using a second Data Precision 245. Integrated circuit A10, a solid state switch (AD7512), was removed from the F4 printed circuit board, to deactivate the alc loop and put the alc attenuator into the minimum attenuation condition.

The gain of the stage following the detector was adjusted by means of a trimpot on the circuit board for an output voltage close to 3.00v for an input power of -19.5 dBm. These are the nominal values of v_o and p_o. Measurements of v and p were taken at ½ volt intervals in v from 1.5v to 6v. It is clearly important to measure over a wide enough range to detect any non-linearity, but not so wide a range that departures from linearity that are outside the normal operating range affect the results. The range of the power meter was not changed during the measurements. Measurements were repeated two or more times with decreasing and then increasing power, and averaged to reduce drifts when the results did not repeat accurately. The voltage readings were stable to about 0.2%. A different power meter, HP 435A with 8482A head, was tried but the General Microwave appeared to give better accuracy.

Measurements were made on three F4 modules, serial numbers C72, C46 and C77. The values of p and v with v nearest to 3 volts were subtracted from the other values in each case, and analyzed using the polynomial regression routine on an H.P. 9830 calculator. The results for the three modules are given in the three following pages. In normal operation Δv is 10% of v_o, i.e. 0.3 volts, so the 0.5% gain accuracy requirement was met by all three modules.

The results do not show any consistant values for the second order coefficient. Furthermore, if one substitutes into equation (4) values of $(v-v_o) = 1$ volt, $b = .035$, $c = .0001$, the contribution of the second order term is roughly similar to that of an uncertainty of 0.2% in v. This suggests that the second and higher order coefficients in the polynomial solutions largely represent the measurement errors rather than the detector characteristics.

ART/ap

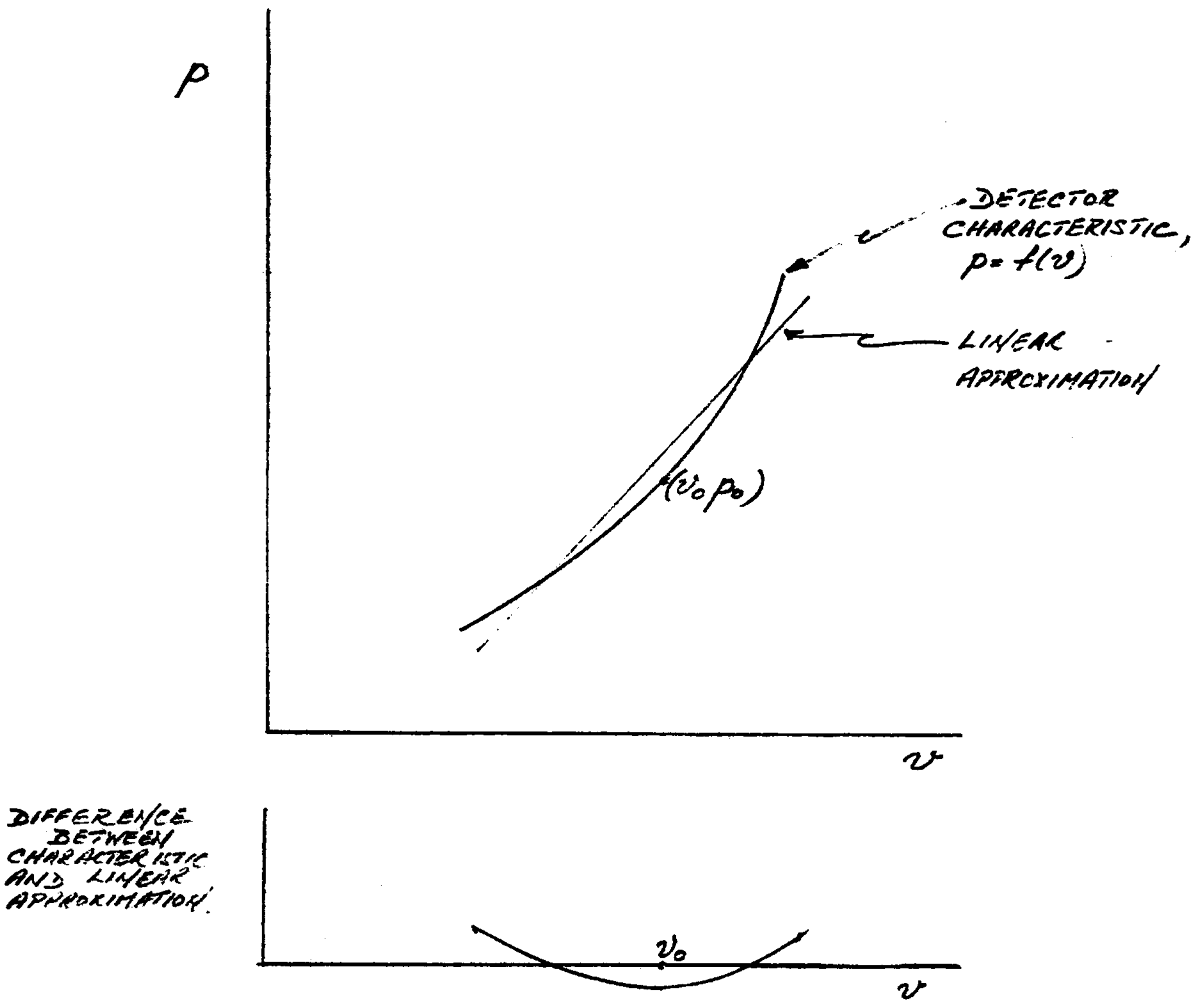

Figure 1 Detector characteristic represented by a linear term plus a second order term in $(v - v_0)$

F4 C46

MEASURED 8/07/80

$v_0 = 3.002$
$p_0 = 0.1106$

NO.	X $(v-v_0)$	Y $(p-p_0)$
1	1.9900	0.0690
2	1.4880	0.0514
3	1.0100	0.0349
4	0.4490	0.0174
5	0.0000	0.0000
6	-0.4490	-0.0173
7	-1.0010	-0.0350
8	-1.4980	-0.0529

NO. POINTS = 8

X: MEAN= 0.248625 ST.DEV.= 1.215908589
Y: MEAN= 8.43750E-03 ST.DEV.= 0.042555676

CORR.COEFF.= 0.999759340

COEFFICIENTS

6th degree solution

B(0)= 0.0003
B(1)= 0.0399
B(2)= -0.0030
B(3)= -0.0074
B(4)= 0.0037
B(5)= 0.0023
B(6)= -0.0011

R SQUARE = 0.999984024

X= 1.99 YHAT= 0.069006893

X= 1.01 YHAT= 0.035035472

X= 0 YHAT= 2.92662E-04

X=-1.001 YHAT=-0.034955615

X=-1.498 YHAT=-0.052906662

COEFFICIENTS

2nd degree solution

B(0)= 0.0000
B(1)= 0.0351
B(2)= -0.0003

$c/b = -1/117$ $c\Delta v_1/b = -2.6\times10^{-3}$

R SQUARE = 0.999570485

X= 1.99 YHAT= 0.068934503

X= 1.01 YHAT= 0.035257019

X= 0 YHAT= 4.59883E-05

X= 1.001 YHAT= 0.034945511

X=-1.498 YHAT=-0.053117385

NO.	X $(v-v_0)$	Y $(p-p_0)$
1	3.0030	0.1038
2	2.5080	0.0865
3	2.0250	0.0698
4	1.4950	0.0516
5	0.9990	0.0344
6	0.4960	0.0170
7	0.0000	0.0000
8	-0.5000	-0.0172
9	-1.0010	-0.0353
10	-1.4990	-0.0525

F4 C72

$p_0 = 0{\cdot}1103$
$v_0 = 3{\cdot}005$

MEASURED 8/11/80

NO. POINTS = 10

X: MEAN= 0.7526 ST.DEV.= 1.517405476
Y: MEAN= 0.02581 ST.DEV.= 0.052599397

CORR.COEFF.= 0.999990567

COEFFICIENTS *6th degree solution*

B(0)= 0.0001
B(1)= 0.0344
B(2)= -0.0006
B(3)= 0.0006
B(4)= 0.0001
B(5)= -0.0002
B(6)= 0.0000

R SQUARE = 0.999997821

X= 3.003 YHAT= 0.103812239

X= 2.025 YHAT= 0.069908679

X= 0.999 YHAT= 0.034333266

X= 0 YHAT= 8.07716E-05

X= 1.001 YHAT= 0.034402388

X=-1.001 YHAT=-0.035231532

X=-1.499 YHAT=-0.052512957

COEFFICIENTS *2nd degree solution*

B(0)= -0.0002 a
B(1)= 0.0348 b
B(2)= -0.0001 c

$c/b = -1/348$ $\frac{c\Delta v_1}{b} = -8.6\times10^{-4}$

R SQUARE = 0.999987250

X= 3.003 YHAT= 0.103614729

X= 2.025 YHAT= 0.069947167

X= 0.999 YHAT= 0.034487692

X= 0 YHAT=-1.75909E-04

X=-0.5 YHAT=-0.017575916

X=-1.001 YHAT=-0.035044752

X=-1.499 YHAT=-0.052442743

X DEGREE = 6

NO.	X (v-v₀)	Y (p-p₀)
1	1.9970	0.0725
2	1.4960	0.0542
3	1.0020	0.0366
4	0.4980	0.0182
5	0.0000	0.0000
6	-0.4980	-0.0183
7	-0.9960	-0.0361
8	-1.5070	-0.0544

$v_0 = 3.006$
$p_0 = 0.1108$

F4 C77

MEASURED 8/07/80

NO. POINTS = 8

X: MEAN= 0.249 ST.DEV.= 1.224342039
Y: MEAN= 9.08750E-03 ST.DEV.= 0.044403167

CORR.COEFF.= 0.999993039

COEFFICIENTS

first degree solution

B(0)= 0.0001
B(1)= 0.0363

R SQUARE = 0.999986077

X= 1.997 YHAT= 0.072481710

X= 1.002 YHAT= 0.036396333

X= 0 YHAT= 5.70891E-05

X=-0.996 YHAT=-0.036064554

X=-1.507 YHAT=-0.054596843

COEFFICIENTS

second degree solution

B(0)= 0.0000
B(1)= 0.0362
B(2)= 0.0000

$c/b < 1/362$ $\frac{c\,\Delta v_1}{b} < 8.3\times10^{-4}$

R SQUARE = 0.999987098

X= 1.997 YHAT= 0.072545781

X= 1.002 YHAT= 0.036369258

X= 0 YHAT= 1.13657E-05

X=-0.996 YHAT=-0.036056076

X=-1.507 YHAT=-0.054532409

Interoffice

National Radio Astronomy Observatory

Charlottesville, Virginia

To: P. Napier, P. Lilie, H. Richards, J. Campbell, G. Barrell — June 19, 1980

From: Larry R. D'Addario

Subject: F8 Modifications

New F8 modules will incorporate several modifications which should give much more repeatable performance from unit to unit and provide better input match. The modified design will be designated series B; the first unit of the series, F8-B23, was shipped to you yesterday.

Details of the internal changes will be sent to you shortly in a set of Change Orders, but you should immediately be aware of resulting changes in the external specifications and their consequences for the system. These specification changes are (cf. VLA Tech. Report No. 40, p. 10):

1. 50 MHz comb line levels needed to ensure that specs will be met are:

Line	New Spec	Previously
300 MHz	-7 ± 1.5 dBm	-6 ± 2 dBm
400 MHz	-8.5 ± 1.5	-9 ± 2
550 MHz	-9.0 ± 1.5	-9 ± 2
650 MHz	-12.0 ± 1.5	-12 ± 2
Total power in comb	≤ +4	Not specified

These correspond to levels actually measured in system tests on antennas 14 through 23, so no system changes should be needed provided that all other antennas conform.

2. The conversion loss has been reduced from 13.5 ± 1.5 dB to 10 ± 1 dB. Note that the F8 output level is determined by the set point of the ALC loop in F4. Thus, if the latter set point is unchanged and if the F4 input level from the front end is unchanged, the ALC attenuator will operate with 3.5 dB more loss than before, on the average. This is highly undesirable. We have several options:

a) Change the F4 module open loop gain from 66 ± 1.5 dB to 62.5 ± 1.5 dB by replacing the selected pad in the module. This would be expensive and time consuming (because a complicated test setup is needed), but would be straightforward.

b) Change the standard front end gain from 61 ± 1 dB to 57.5 ± 1 dB, thus reducing the F4 input level. This has the disadvantage that it cuts into F4's input noise figure margin, which is now about 10 dB.

Memo to: P. Napier, P. Lilie, H. Richards,
J. Campbell, G. Barrell
June 19, 1980
Page 2

c) Increase the F8 output level by 3 dB by changing the ALC loop set point in F4. This has the disadvantage that the detectors in F4 are less accurately square-law at the higher level, but it looks like the accuracy would still be acceptable. Note that this will affect T2/T1.

You should choose one of these options. I strongly advise against any "temporary" choice; make a definite decision and stick to it! If a) or c) is chosen, I will make appropriate changes in the F4/F8 documentation; please let me know as soon as possible.

3. The output power delivered to T2 cannot be held to as tight a tolerance as I had planned, due to component tolerances. I had expected ± 0.5 dB for each channel; it now looks like ± 1 dB can be held, but I would be prepared to guarantee only ± 1.3 dB. (The nominal level is -34.0 dBm/channel, but would become -31.0 if option c) above is adopted.) This must be taken into account in the modem gain budget.