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# TESTS ON INDEPENDENTLY-PUMPED AIL PARAMPS AND ASSOCIATED EMI PROBLEMS

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## I. INTRODUCTION

The main aim of these measurements was to determine to what extent the front end system performance would be affected by independently pumping the two 4·7 GHz AIL parametric amplifiers in each receiving channel, at pump frequency differences of up to 200 MHz.

There were two main areas of concern:

1) Generation of spurious sidebands with $\Delta f_{pump}$ separation, in the presence of strong interfering signals, particularly at L-Band.

2) Generation of multiple harmonics of the pump difference frequency ($\Delta f_p$), which could lead to possible interference, particularly at L-Band.

The following results are from tests carried out on the AB and CD channels of Front End No. 10. This system is equipped with a pair of AIL paramps in each channel which were fitted with individual pump sources in order that the pump frequency of one paramp could be varied with respect to the other.

## II. EXPERIMENTAL PROCEDURE

A block diagram of the test setup is shown in Figure 1.

The tests were carried out in two stages:

1) C-BAND MEASUREMENTS

The paramps were pumped with their independent Gunn oscillators at approximately the same frequency of 26·27 GHz. This was the nominal pump frequency for this current batch of AIL paramps. The pump drive level and varactor bias of each stage was then adjusted to give an overall gain of ∿ 25 dB centered on 4·65 GHz. The output was then passed via a C-Band GAsFET amplifier to a spectrum analyzer.

A c.w. signal at 4·65 GHz (∿ - 60 dBm level) was then fed to the paramp input and the resulting output spectrum examined.

The pump frequency of one paramp was then varied at least ± 100 MHz with respect to the other and the resulting output spectra monitored. Care was taken to maintain the overall paramp gain and bandpass by appropriate bias and pump drive adjustments after each pump frequency change.

2) L-BAND MEASUREMENTS

In these tests the upconverter was tuned to an appropriate L-Band frequency. (In this case 1420 MHz.) The C-Band output was then taken via the GaSFet amplifier to the spectrum analyzer as before.

A c.w. signal at 1420 MHz was then fed to the L-Band input (∿ - 60 dBm level) and the C-Band output spectrum examined as before. Particular attention was paid for evidence of spurious sidebands which may have been related to harmonics of the pump difference frequency $\Delta f_p$.

## III. RESULTS

1. SIDEBAND LEVELS

These results are shown as sideband levels relative to the main amplified input signal plotted as a function of pump frequency separation $\Delta f_p$. (See Figures 2-5.)

They can be summarized as follows:

A. C-Band

1) Sidebands with separation $\pm \Delta f_p$ and $\pm 2\Delta f_p$ are seen at levels of approximately - 40 dB and below, over a pump separation range of ± 100 MHz in the AB pair of paramps. These levels increase to a maximum of - 33 dB with wider pump separations.

2) Sidebands with separation $\pm \Delta f_p$ only are seen at levels of approximately - 40 dB and below over a pump separation range of ± 100 MHz in the CD pair of paramps.

3) In general the sideband levels tend to increase as the pump frequency sepration is increased. This applies to both sets of paramps.

4) A search for direct mixing products of the two pump frequencies in the paramp output showed that with a $\Delta f_p$ = 100 MHz, there was no signal above - 85 dBm at this frequency or its harmonics over the range 100 MHz to 2 GHz.

5) It should be noted that the sideband levels appeared to be quite sensitive to changes in varactor bias. In some cases the levels could change by up to 5 dB with a few tens of millivolts change in varactor bias. Consequently, to obtain reasonably consistent results, the paramp gains and passbands were kept as identical as possible with each pump frequency change.

B. <u>L-Band</u>

With the upconverter input frequency set to 1420 MHz the C-Band output spectrum gave relative sideband levels to the 4·62 GHz output signal essentially the same as those found in the C-Band tests.

With a pump separation of 155 MHz, no C-Band frequency corresponding to a harmonic of 155 MHz was seen above an absolute power level of - 80 dBm.

There was, however, a signal corresponding to the second harmonic of the upconverter pump beating with the input signal at 1420 MHz to produce an output of 4·98 GHz. This signal was roughly - 50 dB down on the main output signal and easily identifiable.

2. ORIGIN OF SIDEBANDS

The generation of the observed sidebands appears to be quite a complex process involving fairly high levels of pump leakage from one paramp stage to another.

Suffice it to say at this stage that, interaction of the incoming signal, the first stage pump and pump leakage from the second stage generate the two sidebands with a separation of $\pm \Delta f_p$. These then pass via the circulator along with the main signal where they interact with the second stage pump and pump leakage from the first stage to generate the third sideband with a separation of $\pm 2\Delta f_p$.

Two simple tests to verify this were performed thus:

1) Consider the situation with both paramps operating with pump frequencies separated by a convenient frequency $\Delta f_p$.

   Paramp No. 2 is now biased into the off condition but its pump oscillator left running. The resulting output spectrum indicated that the $\pm \Delta f_p$ sidebands were still present but with a reduced amplitude ($\sim$ - 10 dB less).

   If the pump oscillator for Paramp No. 2 is now turned off, the $\pm \Delta f_p$ sidebands disappear down to below the detection limit of the spectrum analyzer.

   If, however, we bias off Paramp No. 1 and leave its pump running, with Paramp No. 2 operating, we find that the $\pm \Delta f_p$ sidebands are below the detection limit of the spectrum analyzer.

   This would tend to suggest that:

   A. There is much more pump leakage from No. 2 paramp than there is from the first stage.

   B. The generation of the $\pm \Delta f_p$ sidebands is much stronger in the first stage (by virtue of the greater pump leakage from No. 2 paramp), and that these sidebands are enhanced by the gain of No. 2 paramp which makes them much more easily recognizable.

2) To verify if the second set of sidebands with $\pm 2\Delta f_p$ is generated in the No. 2 paramp, the paramps were operated with a pump frequency difference which gave a strong sideband with a $2\Delta f_p$ separation as well as the two sidebands with $\pm \Delta f_p$ separation.

   On biasing off the No. 2 paramp but leaving its pump oscillator running, the two sidebands with $\pm \Delta f_p$ separation were still visible but the $2\Delta f_p$ sideband was below the detection limit of the spectrum analyzer (in this case - 75 dB down on the main signal). This would tend to suggest that generation of an idler current by interaction of a $\Delta f_p$ sideband with the No. 2 pump in the second stage paramp is essential to generating the $\pm 2\Delta f_p$ sidebands.

## IV. DISCUSSION OF RESULTS

On examining Figures 2-5 it would seem that for both sets of paramps the $\pm \Delta f_p$ sideband rejection is in general greater than - 40 dB with respect to the main signal, over a pump frequency separation range of ± 100 MHz.

There does appear to be a general tendency for the sideband levels to increase near the limits of the pump tuning range, and in fact on channel AB one sideband gets up to - 33 dB at a pump separation of 150 MHz.

At a pump frequency separation of about 50 MHz (No. 2 pump frequency less than No. 1) there appears to be a tendency for the $\pm \Delta f_p$ sideband levels to drop significantly in both paramp pairs. This may, of course, just reflect the fact that the pump reject filter is more effective at this frequency in Paramp No. 2, and that the pump leakage is consequently minimized. This is also supported somewhat by Figure 5 where the pump frequency of the No. 2 paramp was set 50 MHz lower than the nominal 26·27 GHz and the No. 1 paramp pump frequency varied.

In this case the $\pm \Delta f_p$ sideband levels were in general lower over the full ± 100 MHz pump separation range.

However, reference to Figure 3 indicates that in the AB pair of paramps at least, the sharp drop in $\pm \Delta f_p$ sideband levels coincides with an increase in the $2\Delta f_p$ sideband level. As has been pointed out earlier, the generation of the $2\Delta f_p$ sideband requires the presence of the $\pm \Delta f_p$ sidebands in the second paramp. If this is the case then it is puzzling as to why the $2\Delta f_p$ sideband is so strong if the pump reject filters are working effectively.

It seems significant that the CD paramp pair did not exhibit the $2\Delta f_p$ sideband to anywhere near the same extent as the AB pair. In fact in practically all cases the $2\Delta f_p$ sideband was not measurable. This more than likely reflects the fact that the pump drive levels were lower for the CD pair of paramps than for the AB pair. This would mean lower pump leakage levels and generally lower sideband level generation.

## V. EFFECTS OF SPURIOUS RESPONSES ON SYSTEM PERFORMANCE

This section considers what effects the spurious responses due to independent paramp pumps will have on VLA observations.

The most likely problem will be out of band RFI being brought in band via the spurious responses. This situation will be worse at L Band (see Reference 1). Figure 6 which is taken from Reference 1 shows that there are strong RFI signals at 1315/1335 MHz and at 1667/1672 MHz. The signal at 1315/1335 MHz is an Albuquerque Airport radar and for 10% of the time it is stronger than $10^{-10}$ watts/m$^2$ and for 20% of the time it is stronger than $10^{-11}$ watts/m$^2$. If a front end system using independently pumped paramps suffers from the problem of sideband generation as we have seen, then it is possible to get interference sidebands generated at H and OH observing frequencies using pump frequency separations within the range that has been proposed (i.e., $\sim$ 200 MHz).

e.g.

$$\text{H-LINE BAND} \quad \begin{cases} (1420-1315)\ \text{MHz} = \sim 105\ \text{MHz} \\ (1420-1335)\ \text{MHz} = 85\ \text{MHz} \end{cases}$$

$$\text{OH SATELLITE LINES} \quad \begin{cases} (1672-1612)\ \text{MHz} = 60\ \text{MHz} \\ (1667-1612)\ \text{MHz} = 55\ \text{MHz} \\ (1720-1672)\ \text{MHz} = 48\ \text{MHz} \\ (1720-1667)\ \text{MHz} = 53\ \text{MHz} \end{cases}$$

The first important point to make about these spurious signals is that, since all paramp pumps are free running, they will not be coherent between antennas. The expected frequency variation of the temperature controlled paramp pumps is approximately 100 KHz RMS on a time scale of about an hour. Thus, the spurious signals will not appear as "lines" in the spectral line system.

Although they will not get through the correlator, the spurious signals will change the effective system temperature.

In order to get some idea of what effect these interference levels would have, the following simple analysis will be made.

We first make two assumptions:

1) The interference emissions are received through the far sidelobes of the antenna.
2) The energy is contained within the bandwidth used for the VLA observation.

Taking assumption 1) first, the effective area of the antenna system would be that of an isotropic radiator. Thus:

Effective area $A_e = \frac{\lambda^2}{\Omega_A}$ and if $\Omega_A = 4\pi$ steradian

then $A_e = \frac{441}{4\pi}$ $\left\{ \begin{array}{l} \lambda = 21 \text{ cm} \\ \quad = 441 \text{ cm}^2 \end{array} \right.$

$$A_e = \underline{35 \times 10^{-4} \text{ M}^2}$$

If the interference flux is $10^{-10}$ Watts/$M^2$ then power in the interference band $\underline{W_{int.}} = \underline{3 \cdot 5 \times 10^{-13}}$ $\underline{\text{Watts}}$

Now the L-Band System Temperature is

$T_{sys} = 60K$

$\left\{ \begin{array}{l} k = 1 \cdot 38 \times 10^{-23} \\ \text{Boltzmans constant.} \end{array} \right\}$

and the system total power:

$$W_{sys} = kTsys \text{ Watts/Hz}$$

$$= 8 \cdot 4 \times 10^{-22} \text{ Watts/Hz}$$

and for a 100 KHz bandwidth $\left\{ \text{minimum operating bandwidth} \right\}$

then $\underline{W_{sys}} = \underline{8 \cdot 4 \times 10^{-17}}$ $\underline{\text{Watts}}$.

Thus the increase in total power due to one of the sidebands falling in the observing band is simply:

For - 40 dB down, and $B = 10^5$ Hz

$$\frac{W_{int}}{W_{sys}} = \frac{3 \cdot 5 \times 10^{-17}}{8 \cdot 4 \times 10^{-17}} = \underline{0 \cdot 416}$$

Thus the system total power would be increased by $\sim$ $\underline{42\%}$.

Similarly, for -50 dB level sidebands the system total power would be increased by $\sim$ $\underline{4 \cdot 2\%}$.

Whilst a 42% increase in system temperature appears significant, several factors decrease the importance of this result. This increase in system temperature occurs only for the 100 KHz bandwidth; for wider bandwidths the effect will be reduced in proportion to the bandwidth. The RFI signals are present at this high level for only 10% of the time and are seen only in those front ends which have exactly the correct difference in pump frequency. The paramps would be operated at their optimum pump frequencies so that the pump power, and hence the spurious sideband level, would be minimized. A sideband level of -50 dB would be more likely than -40 dB. And finally, in the unlikely event that the spurious sidebands do cause a problem, there exists the straightforward solution of placing a filter between the two paramps to prevent crosscoupling of the pumps and idlers.

In view of the above considerations it appears safe to allow individual pumps for the VLA paramps.

## VI. CONCLUSIONS

It has been demonstrated how spurious sidebands with a frequency separation equal to the difference and twice the difference of the pump oscillator frequencies could be generated in pairs of cascaded paramps with a strong interfering input signal. It is also possible that these sidebands could fall into observing bands providing the difference between the pump oscillators is just right.

A simple analysis of the interference flux levels found at the VLA site (particularly at L Band) suggests that sideband levels of -50 dB relative to the main signal produce no significant effect on VLA observations. Sideband levels of -40 dB can cause a significant increase in the system temperature at the narrowest observing bandwidths, but the probability of this occurring is very low. Since the sidelobe levels found in the two sets of paramps examined varied from around -40 dB down to levels around -60 dB down, it is concluded that it is safe to allow individual pumps for the VLA paramps.

Reference:

G. Bonebrake, "Results of EMI Surveillance," *VLA Electronics Memorandum No. 139*, May 26, 1976.

TEST SET UP BLOCK DIAGRAM.

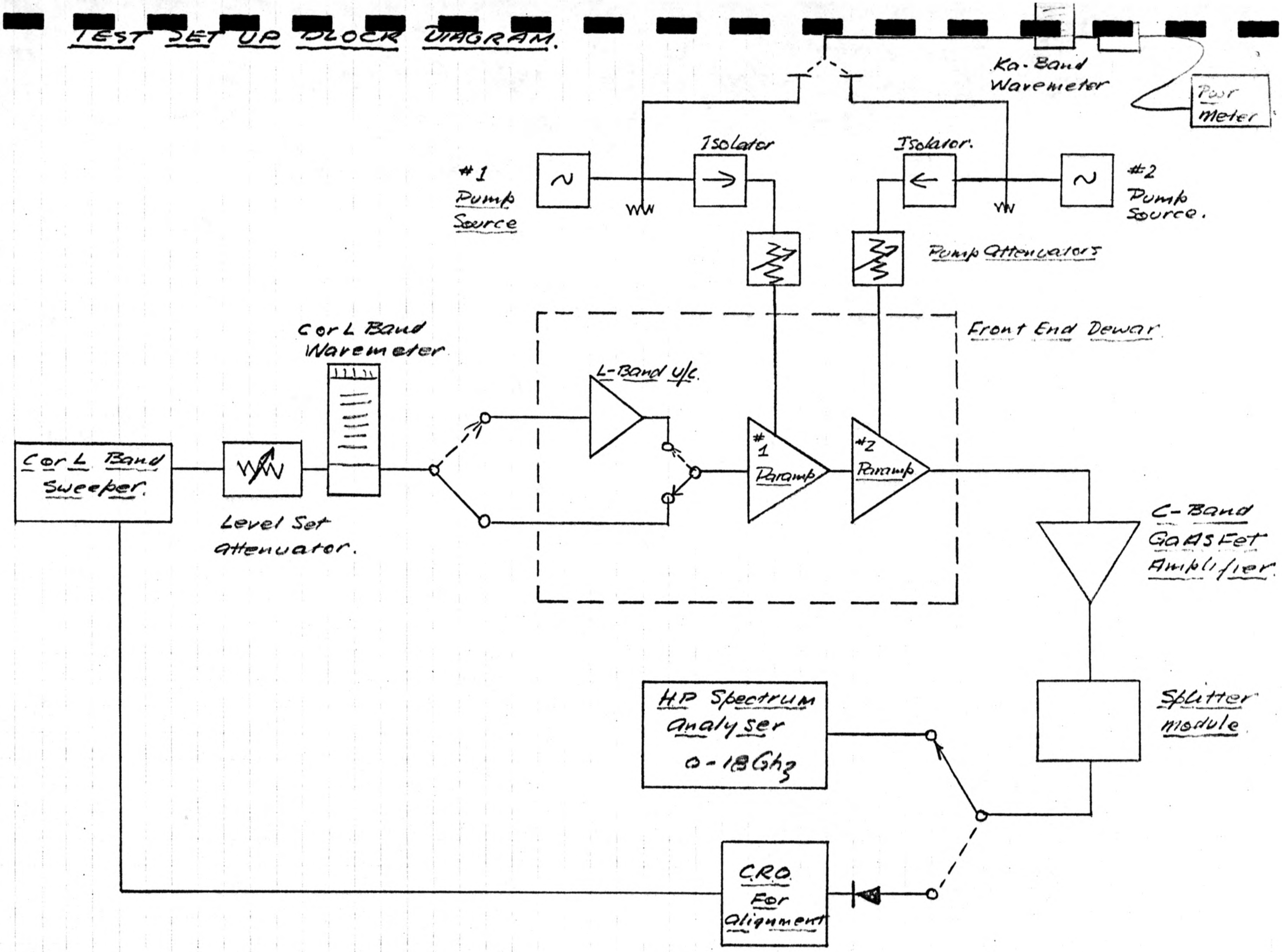


FIG 1.

FRONT END #10.

AB Channel Paramps.

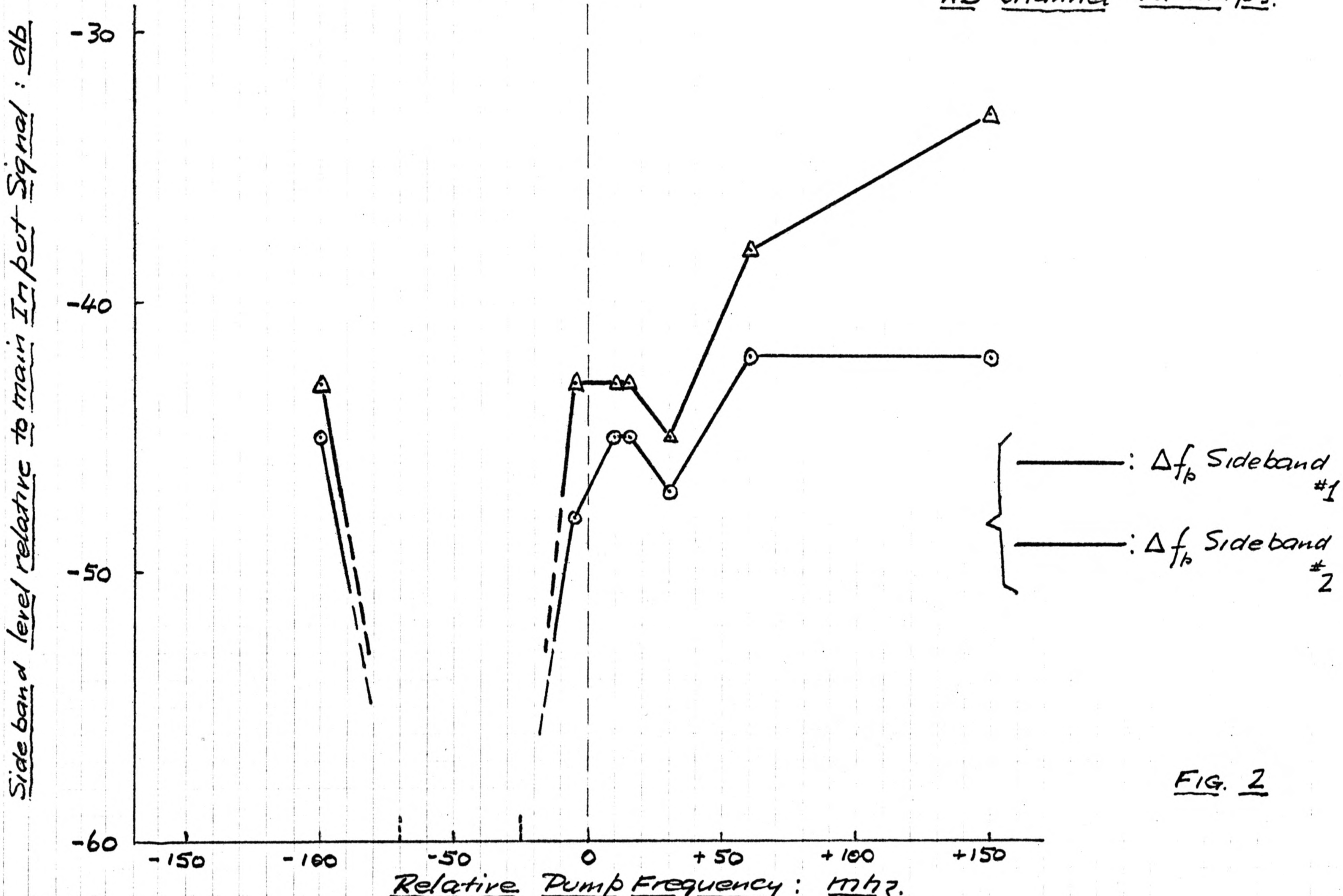


FIG. 2

Pump Frequency #1 Paramp = 26.27 Ghz.
" " #2 " = 26.27 ± 0.15 Ghz

FRONT END #10

AB Channel Paramps.

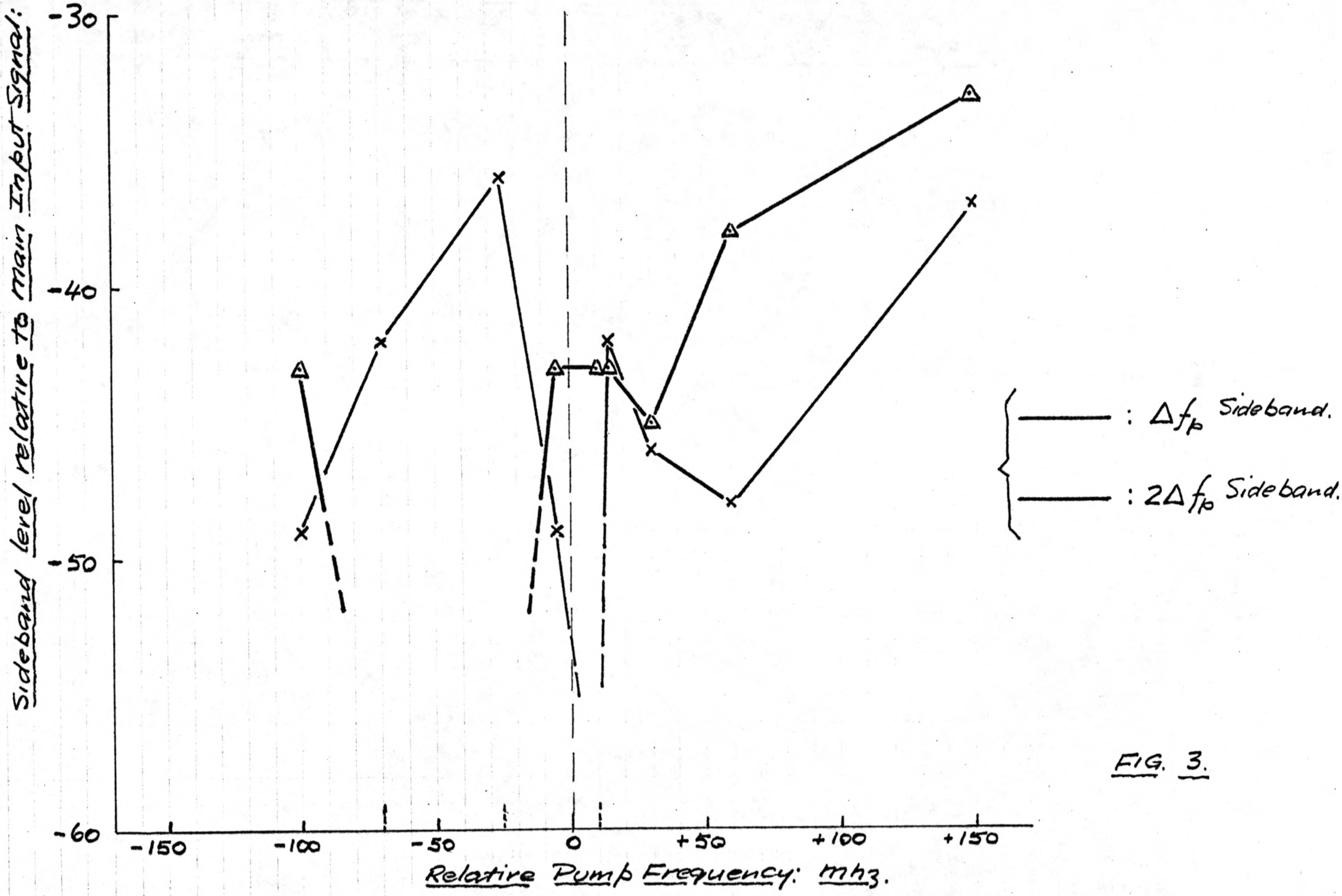


FIG. 3.

{ Pump Frequency #1 Paramp = 26·27 Ghz.
" " #2 " = 26·27 ± 0·15 Ghz }

FRONT END #10

CD Channel Paramps.

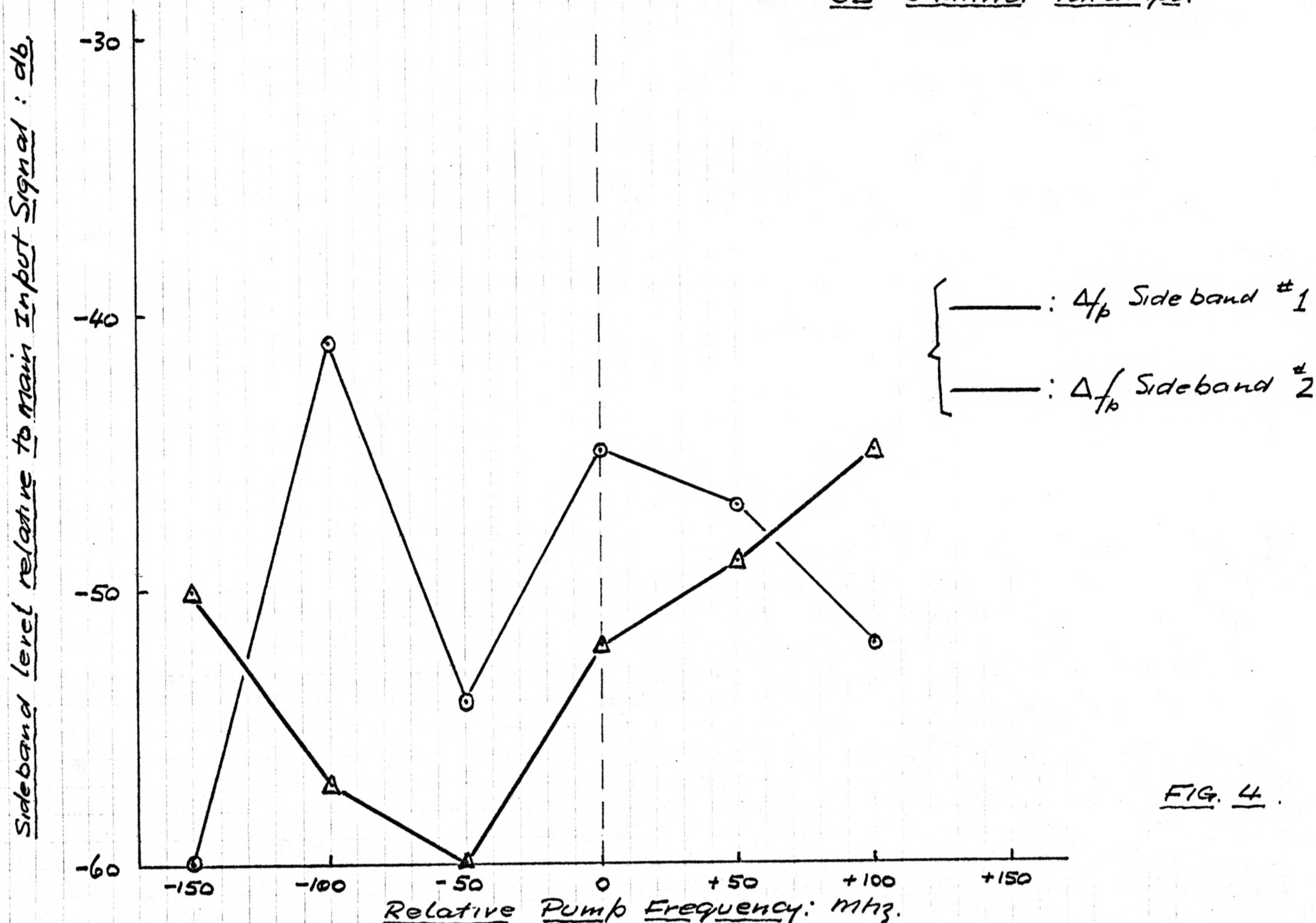


FIG. 4.

Pump Frequency #1 Paramp = 26.27 Ghz.
" " #2 " = 26.27 $^{+0.1}_{-0.15}$ Ghz.

FRONT END #10.

CD Channel Paramps.

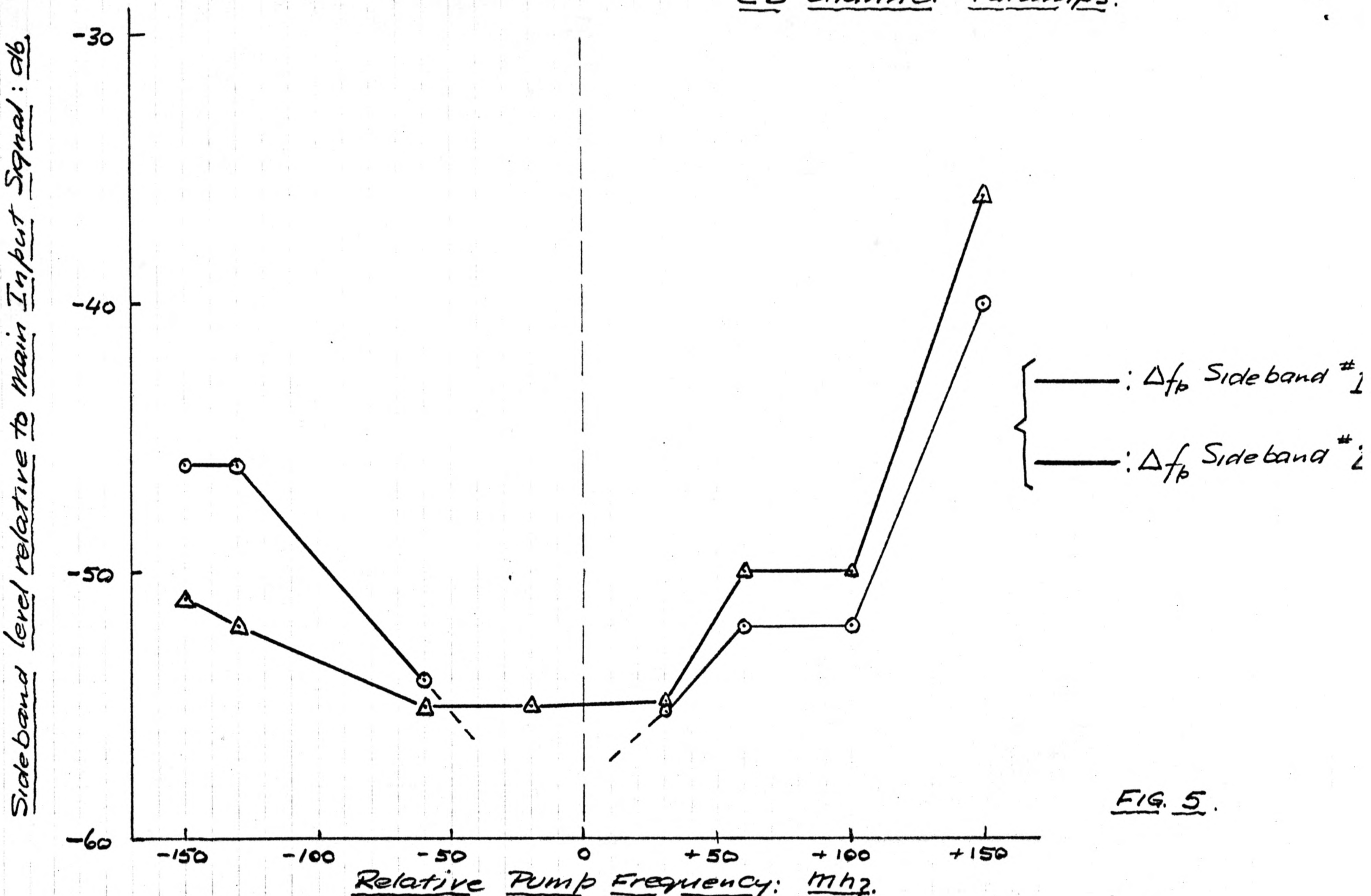


FIG. 5.

{Pump Frequency #2 Paramp = 26.225 Ghz.
" " #1 " = 26.225 ± 0.15 Ghz}

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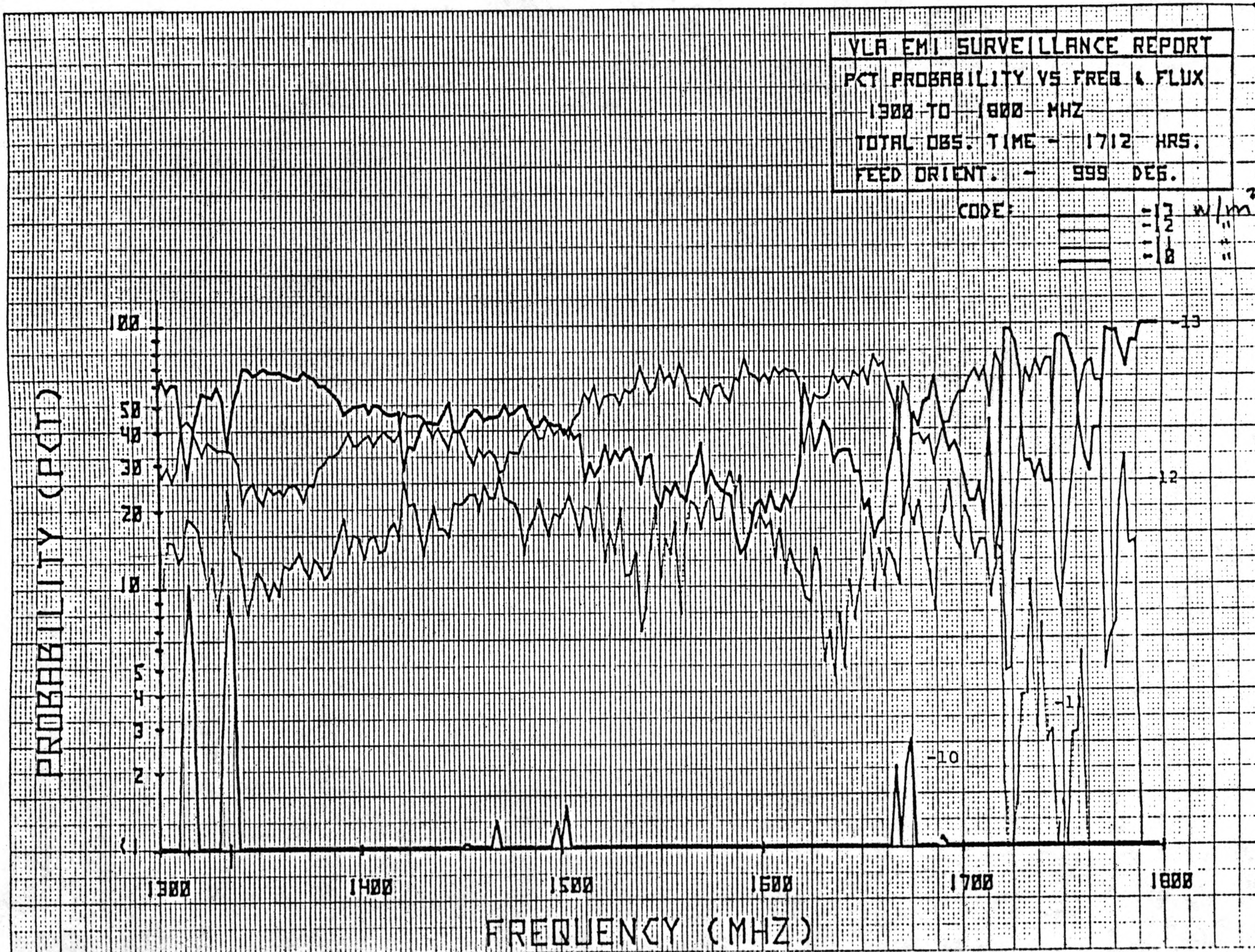


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