National Radio Astronomy Observatory
Socorro, NM

VLA TEST MEMO 201

IMPROVEMENT IN L-BAND IMAGE REJECTION FROM $\lambda/2$ PHASE SWITCHING AT 200 MHz

D.S.Bagri
1996 NOV 09

ABSTRACT
A simple scheme of phase switching the first LO to improve L-band image rejection was proposed last year (Bagri, 1995, VLA Electronics Memo No. 224). It employs $\lambda/2$ phase switching of the 200 MHz reference used to generate the first LO, instead of phase switching the second LO. The Walsh Function signal, normally used to phase switch the 10.1 MHz from the Fringe Generator (L7) which is used to generate the second LO, is instead used to phase switch the 200 MHz reference in each antenna for the L-band observations. This improves the L-band image rejection by more than 25 dB. It is an economical solution to ameliorate the image problem instead of using alternate frequency conversion scheme of F15 (Bagri, 1994, VLA Electronics Memo No. 223).

INTRODUCTION
We have known about the L-band image problem and its cause for some time. The problem can be explained using the simplified block diagram in Fig. 1. The L-band RF signals are first mixed with the LO at 3200 MHz from the F2 Module to upconvert to first IF in 4.5-5 GHz frequency range using a double balanced mixer. Then the 4.5-5 GHz IF is mixed with the second LO from 2-4 GHz Synthesizer (L6 Module) to generate 1000-1050 MHz second IF. The image problem arises because alongwith the desired signals of $(3200 + f_{RF})$ MHz in the frequency range of 4500-5000 MHz we also get undesired $(2 * 3200 - f_{RF})$ MHz signals. Here f_{RF} is frequency of the RF signal in MHz. These undesired signals are called image signals and have about 20 dB lower response than the desired signals.

ALTERNATE FREQUENCY CONVERSION SCHEME OF F15
To solve the image problem it was natural to consider changing the frequency conversion scheme. This was suggested in the VLA Electronics Memo 223. The scheme directly converts the L-band RF signals to 1000-1050 MHz IF by mixing it with the LO signal from the 2-4 GHz Synthesizer (L6). This eliminats the image problem but inverts the signal spectrum in 1000-1050 MHz IF with respect to the spectrum of the signal in the original frequency conversion scheme. However, inspite of this drawback, it was decided in 1994 to go ahead with the new frequency conversion scheme. To evaluate it three antennas were outfitted in early 1995 with the new frequency conversion hardware (F15 Modules) which costed more than $5k per antenna for materials only.

PHASE SWITCHING FIRST LO

While we were testing the performance of the F15 Modules, it occured to me that we can improve the image rejection easily by more than 20 dB by introducing 180° phase switching in the first LO and controlling the phase switches for different antennas using different Walsh Functions. This way the desired signals in the first IF will have 180° phase switching but the undesired image signals will not have any phase switching. This is because twice the 180° phase shift is same as no phase shift and therefore the image signals produced by mixing with the second harmonic of the LO signal will not have any phase switching. When the phase switching is removed at the backend the desired signals will be coherent from different antennas but the undesired image signals will have 180° Walsh Function phase switching introduced. Therefore the image signals will become incoherent from one antenna to another, and their product between any two antennas will be zero when integrated over a complete period of the Walsh Function sequency.

To see how to achieve 180° phase switching of the first LO with minimum hardware changes we have to understand how the 3200 MHz first LO and the 2-4 GHz synthesizer second LO signals are generated in an antenna. This is also shown in Fig. 1. The first LO at 3200 MHz is generated in the F2 Module by mixing a 3200 MHz voltage controlled oscillator (VCO) output with the 3000 MHz reference. The difference signal is phase detected with the 200 MHz reference and the output is used to phase lock the VCO. The second LO in the 2-4 GHz range is generated by combining 2400 or 3000 MHz reference with the comb of 50 MHz, and the 10.1 MHz from the Fringe Generator (L7 Module). The 10.1 MHz signal from L7 has both fringe rotation and 180° phase switching. Now, if we move the phase switching from L7 to 200 MHz without affecting the LO performance (like phase locking etc.), then we will have phase switching of the first LO instead of the second LO and that should improve the image rejection.

Further more the F15 frequency conversion scheme has another disadvantage: spurious signals generated due to undesired mixing products between RF signals at frequency f_{RF} and LO signal at frequency f_{LO} appear in the IF passband of 1000-1050 MHz. The potential spurious products are $(2*f_{RF}-f_{LO})$ and $(3*f_{RF}-f_{LO})$, though these spurious signals should be much weaker than the undesirable image responses. This is because the mixing products due to harmonics of the RF are generally much weaker than those due to the harmonics of the LO as the RF power is generally much smaller than the LO power in a mixer.

Also the F15 scheme is a new approach and we may not have visualized all the problems. On the other hand we are already familiar with all the problems of the existing conversion scheme. Therefore if we continue with the present frequency conversion scheme then we do not have to worry about any unpleasant surperise.

$\lambda/2$ PHASE SWITCHING OF THE 200 MHz REFERENCE

The 180° phase switching of the 10.1 MHz signal from L7 is described in detail by Thompson (1975, VLA Technical Report No. 6). Basically phase of a 100 kHz digital signal is controlled using a Walsh Function control signal. This 100 kHz is then combined with the 10 MHz reference to generate the 10.1 MHz phase switched signal. In principle it should be possible to generate 200 MHz with exact 180° Walsh Function phase switching, but that would have required some development work. Instead from practical considerations it was decided to use a switchable

$\lambda/2$ cable in the path of the 200 MHz reference using semi-conductor switches and control the switches using the Walsh Function signal.

EFFECT OF $\lambda/2$ CABLE NOT EXACTLY 180°

In practice a $\lambda/2$ switching cable at 200 MHz may not provide exact 180° phase switching because of a number of reasons like: (1) incorrect length of the cable, (2) VSWR of the switches used for switching in/out the cable, and (3) their variations with time due to changes in operating conditions. It means the phase switching may not be exact 180° as desired. This has following affects on the performance:

Loss of coherence of the signal – If the $\lambda/2$ phase switching in the first LO is not exact 180° but at the backend the phase removed is exactly 180° (because it is done digitally), then there will be a residual phase error between signals from various antennas, and this will result in loss of coherence. For a small phase error of θ the actual coherence will be $cos(\theta/2)$. This is negligible loss for θ less than a few degrees.

Image response – The phase error in 180° phase switching will also cause the image rejection to be finite. For a phase deviation of θ from exact 180° phase switching the image response will be $sin^2\theta$ instead of being zero. For a phase error of 3° it will still provide an image reduction of more than 25 dB.

This phase error should not affect the performance due to sampler DC offset or due to positive and negative thresholds being different. This is because the phase switching introduced at the backend is achieved by inverting the digitized sampler data bits. Also the phase error is antenna dependent and therefore it should not cause any closure errors.

One may think that the varying noise power due to the switching noise calibration signal and inadequate Van Vleck correction for the sampler thresholds variations may cause some problem of inaccurate cancellation during the two states of the phase switch. But, the injected noise calibration signal is modulated using a square wave of same period, which is also one of the Walsh Functions. Therefore it is orthogonal with respect to other phase switching Walsh Functions. Thus any contribution due to this should average out to zero over a complete period of the Walsh Function sequency.

The variations of the input and output VSWR may affect the switch phase in its two states so that the phase change between its two states is different from 180°, and it may vary with operating conditions. This should be minimized. This is being achieved by providing isolation at both the input and the output of the switch. We are putting an attenuator at the input and an amplifier at the output of the $\lambda/2$ phase switching network to maintain the power level and provide isolation.

INDEPENDENT PHASE SWITCHING FOR SIMULTANEOUS LP BAND OBSERVATIONS

For the L-band image problem it is desirable to phase switch the first LO at 3200 MHz (F2) instead of the second LO from the 2-4 GHz Synthesizer (L6). This is true for both AC and BD IFs while observing at L-band. But if we were to make simultaneous observations at L and

P bands, then need to phase switch the 200 MHz reference instead of the L6 signal used for frequency conversion of the L-band RF, and allow phase switching of the other L6 signal used for frequency conversion of the P-band RF. Therefore the $\lambda/2$ phase switch in the 200 MHz path can be controlled by Walsh Function control signal from either AC or BD side. This allows, under the online software control, choosing 200 MHz phase switching as well as choosing either one of the AC or BD L6 to have phase switching but not both. Also both the L6s can be phase switched but in that case the 200 MHz will not be phase switched.

TEST RESULTS

The VLA L-band RFI is periodically monitored using SYSLQUIK observe file. In this test we observe with the array at L-band using backend bandwidth of 12.5 MHz with 32 channels (observing mode=2AB) for each of the two IFs A and B. We observe looking at the North Celestial Pole (NPOLE) for about one minute at each frequency setting, and scan the observing frequency from 1220 to 1750 MHz, in steps of 10 MHz. The output spectra are scalar averaged over the baselines of interest. This provides amplitude of scalar averaged RFI with 390 kHz/channel resolution for about one minute integration looking towards the NPOLE.

Fig. 2 gives SYSLQUIK type RFI plot for 95AUG02 with antennas in A-array. A few strong RFI signals and their image (IM) responses are indicated in the plot. The image responses are about 20 dB below the RFI signals. Also notice the level of the 1400 MHz system generated RFI.

Fig. 3 shows a SYSLQUIK plot observed in D-array on 1996SEP20 for baselines between all available antennas not having 200 MHz phase switching (antennas other than 4,5,8,12 and 24). I have identified four RFI signals and their image (IM) responses on the plot. From a comparision of the plots in Figs. 2 and 3 we notice the following: (1) Most serious RFI on 96SEP20 seems to be in the frequency range of about 1530 to 1630 MHz, rather than at frequencies above 1675 MHz on 95AUG02. This has caused severe image response problems for OH observations in 1660-1670 MHz radio astronomy band. (2) Also notice that the 1400 MHz RFI is weaker than what it was in 1995. This is due to the X-band LO phase detector cleanup in about half of the antennas at the time of this testing (see VLA Test Memo No. 200 for the 1400 MHz RFI improvements).

Fig. 4 shows SYSLQUIK plot on 20SEP96 for baselines between all antennas multiplying with the five antennas having phase switching at 200 MHz. The spectrum in the frequency range of 1620-1675 MHz appears clean except some RFI at 1650 MHz, which is perhaps caused by the system (see VLA Test Memo N0. 194 for a probable cause of the 1650 MHz RFI).

A more sensitive measurement of the image rejection is shown in Fig. 5. The figure shows two spectra measured on 96SEP20 over 1654 to 1674 MHz with a resolution of 25 kHz/channel looking towards NPOLE. Top trace is for L7s phase switching in all antennas and the bottom trace is for the five modified antennas (antennas 4,5,8,12 and 24) with 200 MHz phase switching and the rest having L7 phase switching. In both cases baselines between all except antennas 4,5,8,12 and 24 multiplied with antennas 4,5,8,12 and 24 are averaged with amplitude scalar averaging. A comparision of the two traces shows that the image resposes are reduced by at least 25 dB for the five antennas with the 200 MHz phase switching.

We repeated the measurements in Fig. 5 on 96SEP24 with only three of the five modified antennas available (antennas 3,5 and 12) for the tests. The results show similar image rejection improvement (Fig. 6) and provide confidence in the measurements.

CONCLUSION

The measurements with the five modified antennas indicate that at least 25 dB image rejection improvement is achieved by phase switching the first LO using $\lambda/2$ phase swithing at 200 MHz. It also reduces the coherent internal 1400 MHz RFI.

ACKNOWLEDGEMENTS

I thank Ken Sowinski and Paul Lilie for helpful discussions and the FE and LO-IF groups for the modifications and for help in conducting various tests. I also thank Bill Brundage for his helpful comments on the draft of this report.

FIGURE CAPTIONS

Fig. 1: A simplified block diagram showing the frequency conversion of the L-band RF signals to first IF in 4.5-5 GHz using the first LO at 3200 MHz, and then to second IF in frequency range of 1000-1050 MHz using second LO from a 2-4 GHz Synthesizer. It also shows how the two LO signals are generated and how phase switching of these signals is done.

Fig. 2: L-band RFI plot for all antennas in A-array on 95AUG02 measured using SYSLQUIK observe file . A few RFI signals and thier image responses are marked on the plot. Also the 1400 MHz RFI is indicated. Note that the strongest RFI signals are around 1.7 GHz and the image responses are about 20 dB lower than the RFI signals.

Fig. 3: L-band RFI plot for baselines formed between all unmodified antennas on 96SEP20 in D-array. Note RFI is stronger in frequency range of 1530-1630 MHz than the forest service band RFI around 1.7 GHz. Again we have identified a few strong RFI signals and corresponding image signals on the plot. Strong RFI around 1.53 GHz has made it very difficult to make 1667 MHz OH line observations in the 1660-1670 MHz band protected for the radio astronomy. Also notice that the 1400 MHz internal RFI is reduced in this plot than it was in the 1995 plot. This is because of the F12 modifications (see VLA Test Memo No. 200).

Fig. 4: L-band RFI plot for baselines formed between all antennas multiplying with the modified antennas 4,5,8,12 and 24 which have 200 MHz phase switching instead of L7 phase switching. Note the image signals shown in Fig. 3 are reduced below noise in this plot.

Fig. 5: RFI plots measured on 96SEP20 over 1654-1674 MHz frequency range for baselines formed by all unmodified antennas multiplying with the antennas 4,5,8,12 and 24. The top trace is for all antennas with L7 phase switching. The bottom trace is for antennas 4,5,8,12 and 24 having 200 MHz phase switching.

Fig. 6: RFI plots measured on 96SEP24 over 1654-1674 MHz frequency range for baselines formed by all unmodified antennas multiplying with the antennas 5,8 and 12. The top trace is for all antennas with L7 phase switching. The bottom trace is for antennas 5,8 and 12 having 200 MHz phase switching.

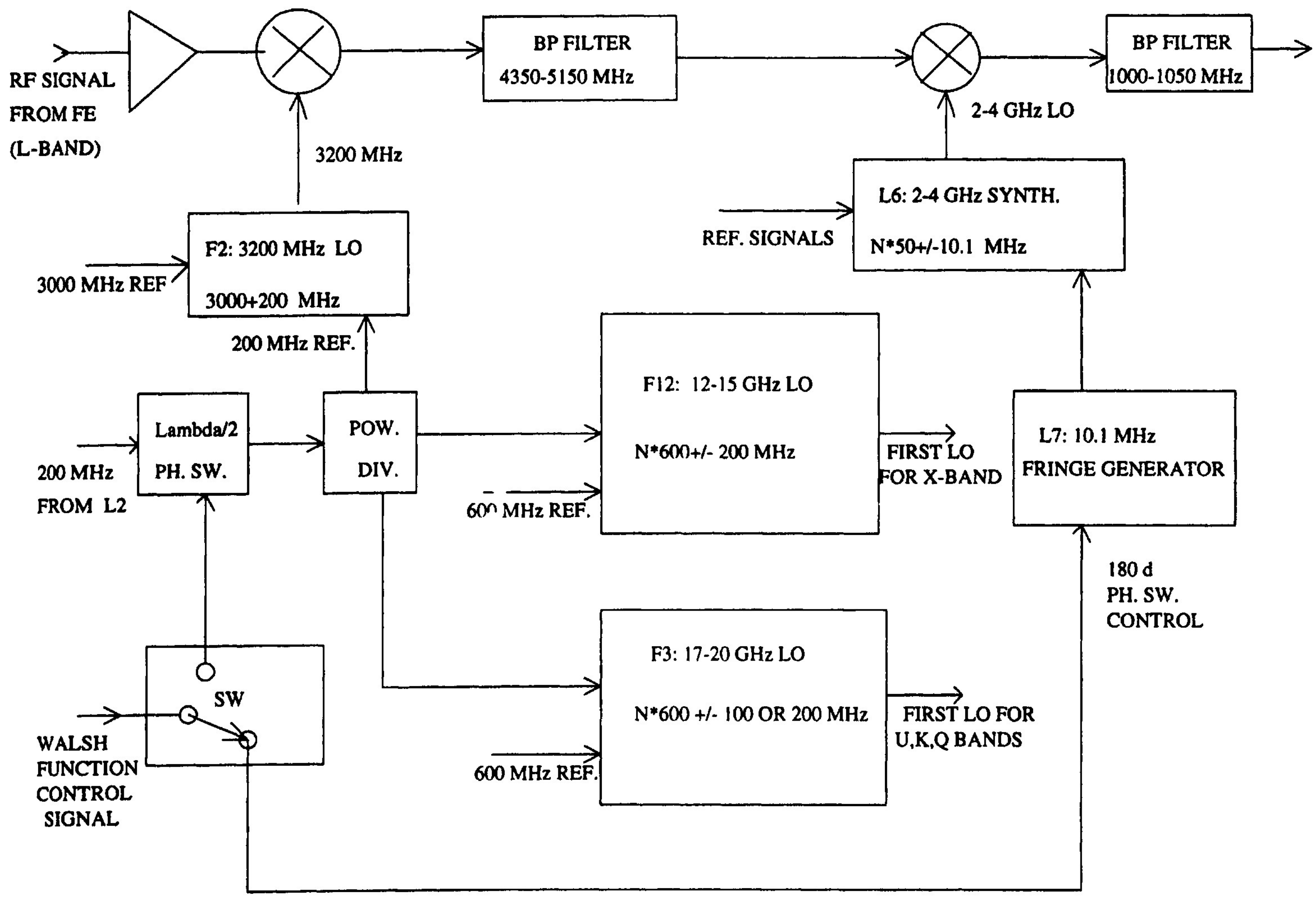
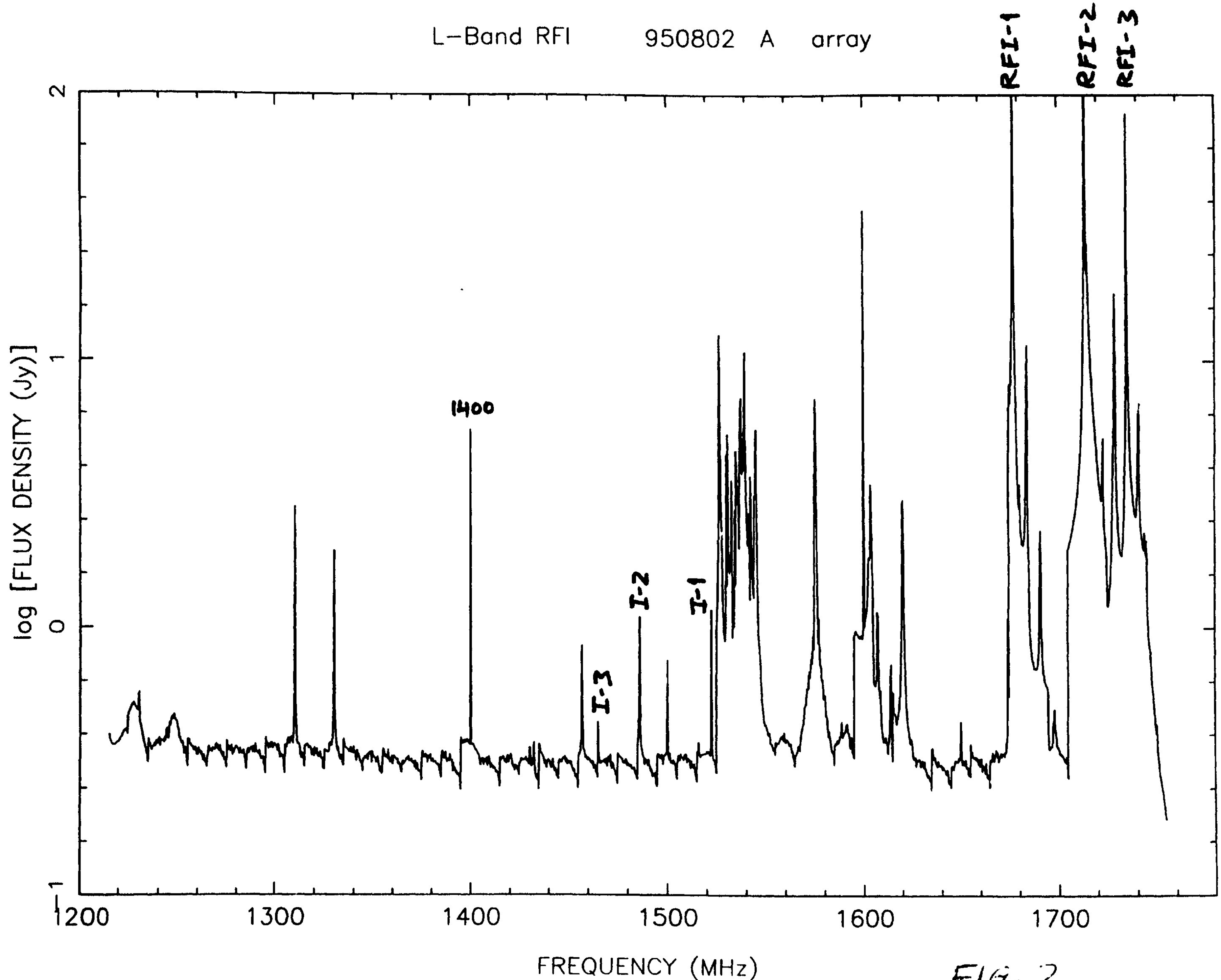

RF SIGNAL
FROM FE
(L-BAND)
BP FILTER
4350-5150 MHz
BP FILTER
1000-1050 MHz
2-4 GHz LO
3200 MHz
L6: 2-4 GHz SYNTH.
N*50+/-10.1 MHz
REF. SIGNALS
F2: 3200 MHz LO
3000+200 MHz
3000 MHz REF
200 MHz REF.
F12: 12-15 GHz LO
N*600+/- 200 MHz
FIRST LO
FOR X-BAND
L7: 10.1 MHz
FRINGE GENERATOR
Lambda/2
PH. SW.
POW.
DIV.
200 MHz
FROM L2
600 MHz REF.
180 d
PH. SW.
CONTROL
F3: 17-20 GHz LO
N*600 +/- 100 OR 200 MHz
FIRST LO FOR
U,K,Q BANDS
SW
WALSH
FUNCTION
CONTROL
SIGNAL
600 MHz REF.

FIGURE 1



L-Band RFI 950802 A array
RFI-1
RFI-2
RFI-3
1400
I-3
I-2
I-1
log [FLUX DENSITY (Jy)]
2
1
0
-1
1200
1300
1400
1500
1600
1700
FREQUENCY (MHz)

FIG. 2

960920-(D-ARRAY)

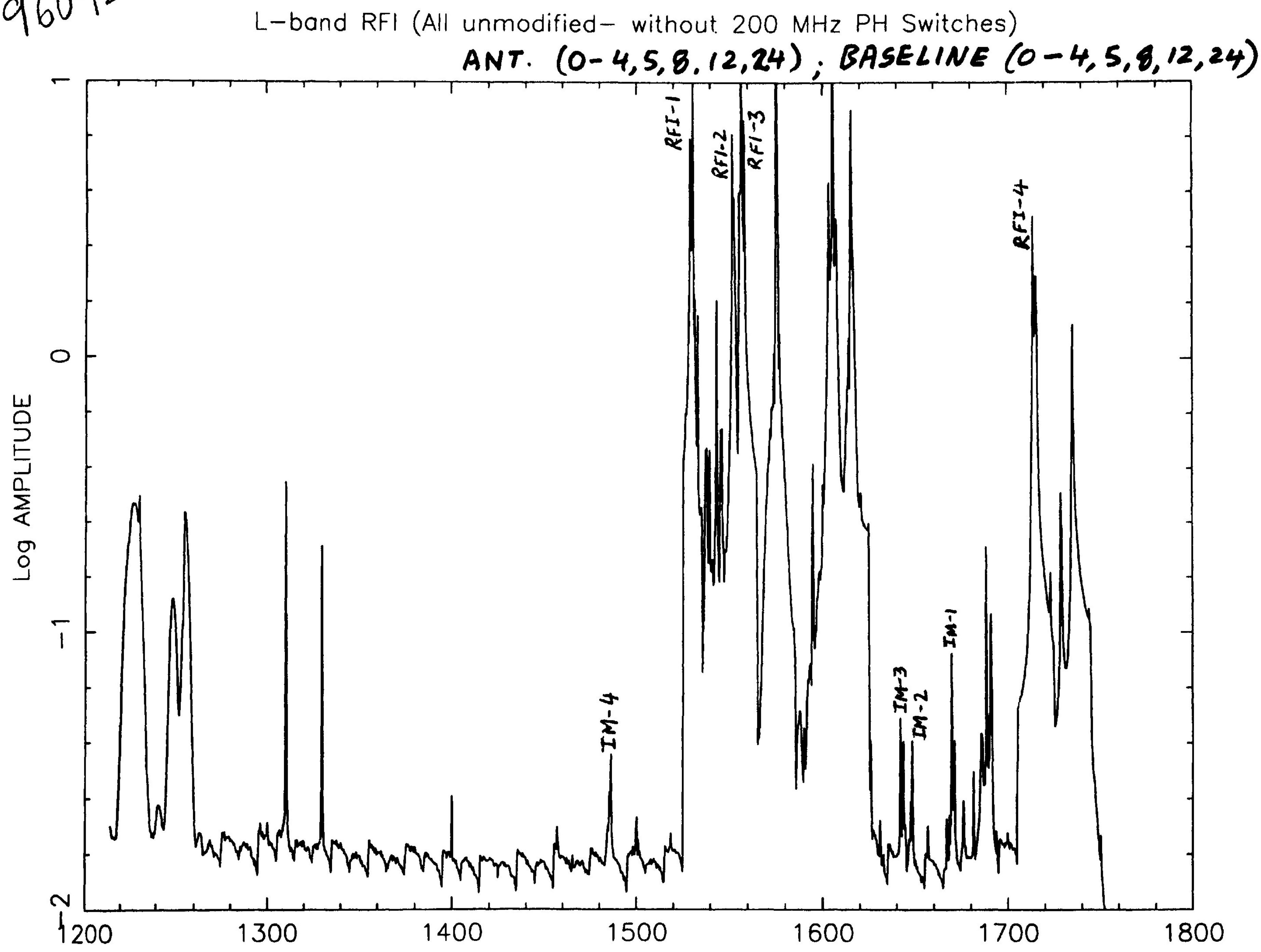


FIG. 3

960920

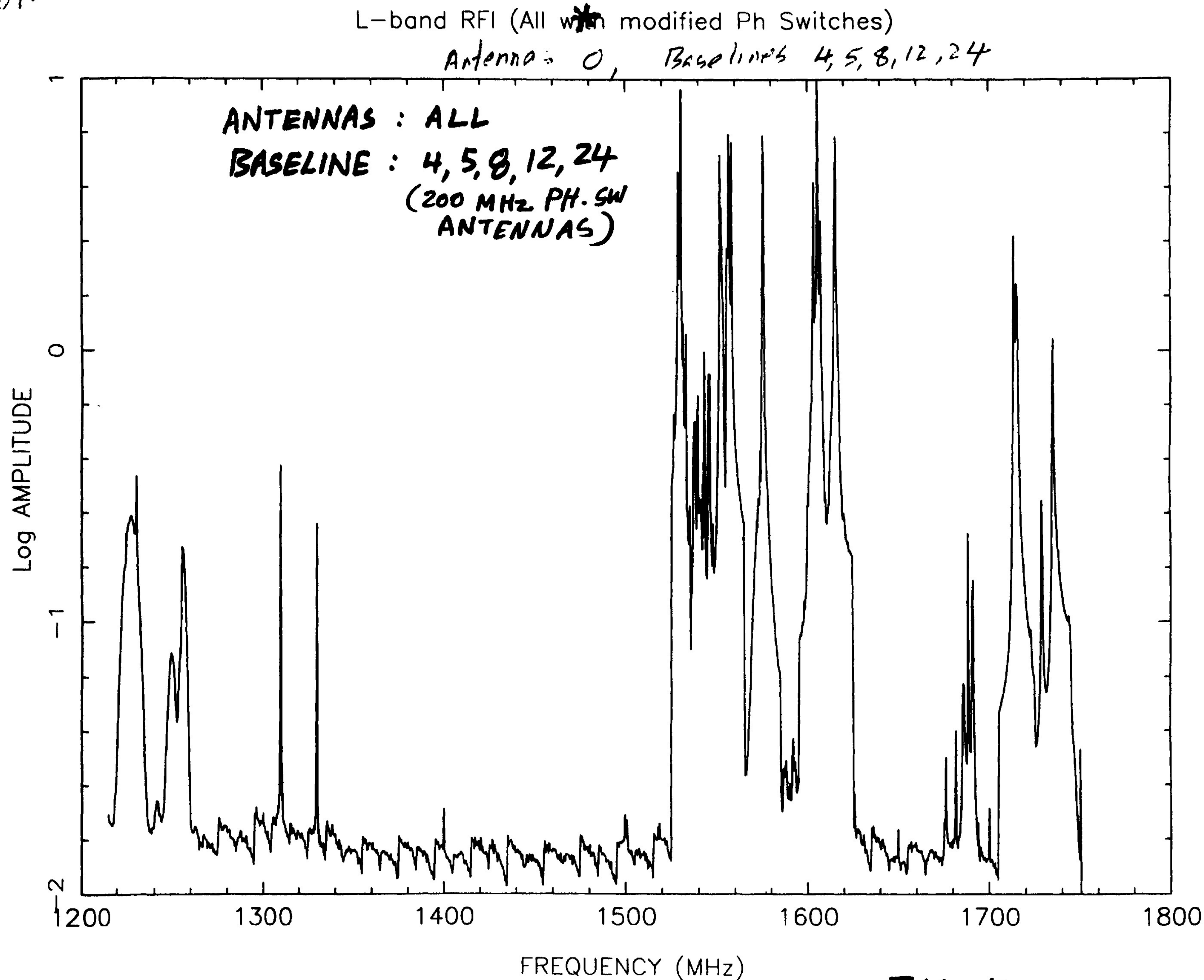

L-band RFI (All with modified Ph Switches)
Antenna: 0, Baselines 4,5,8,12,24
ANTENNAS : ALL
BASELINE : 4,5,8,12,24
(200 MHz PH. SW ANTENNAS)
Log AMPLITUDE
1
0
−1
−2
1200
1300
1400
1500
1600
1700
1800
FREQUENCY (MHz)

FIG. 4

96NOV20 DATA

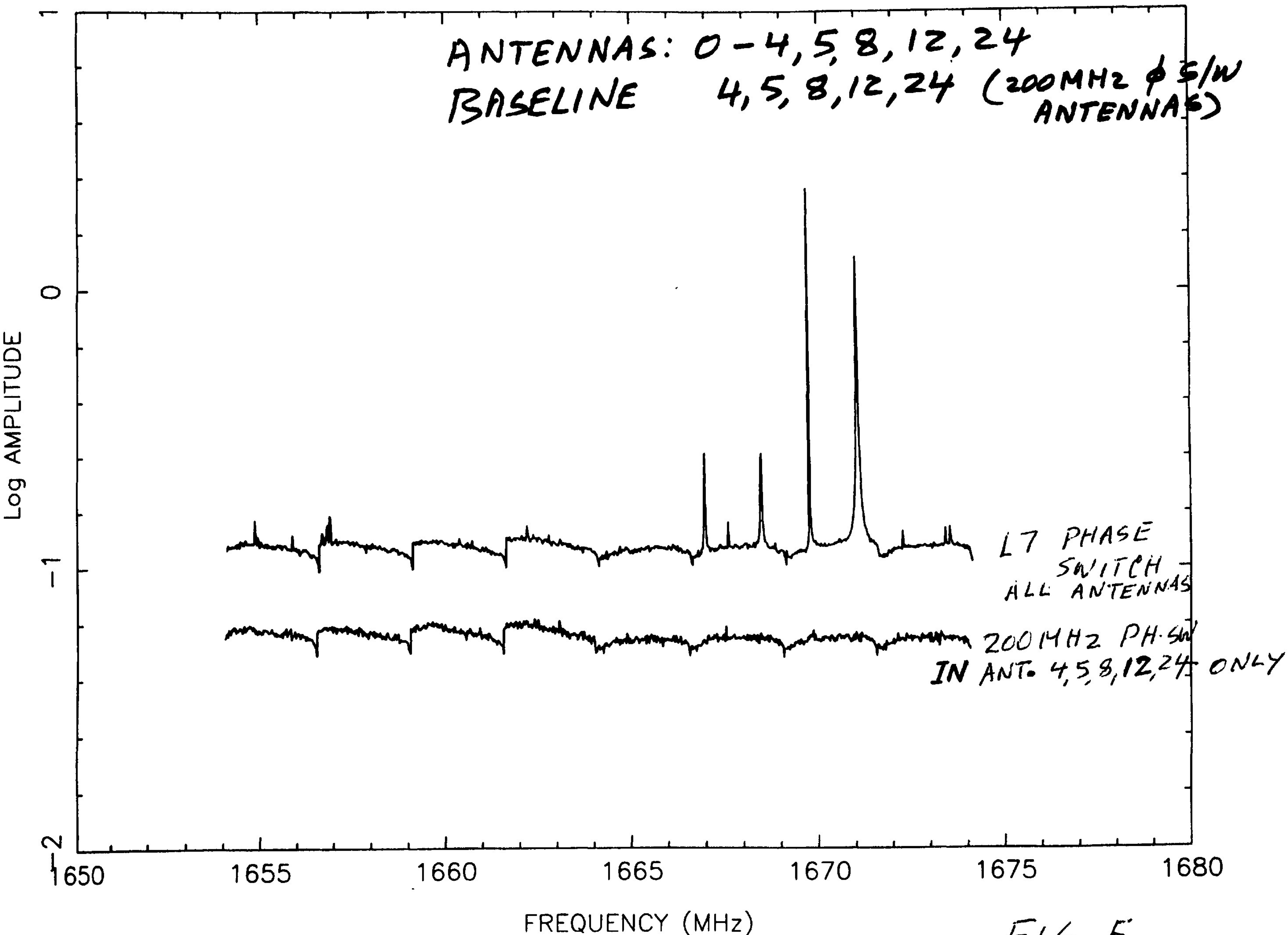
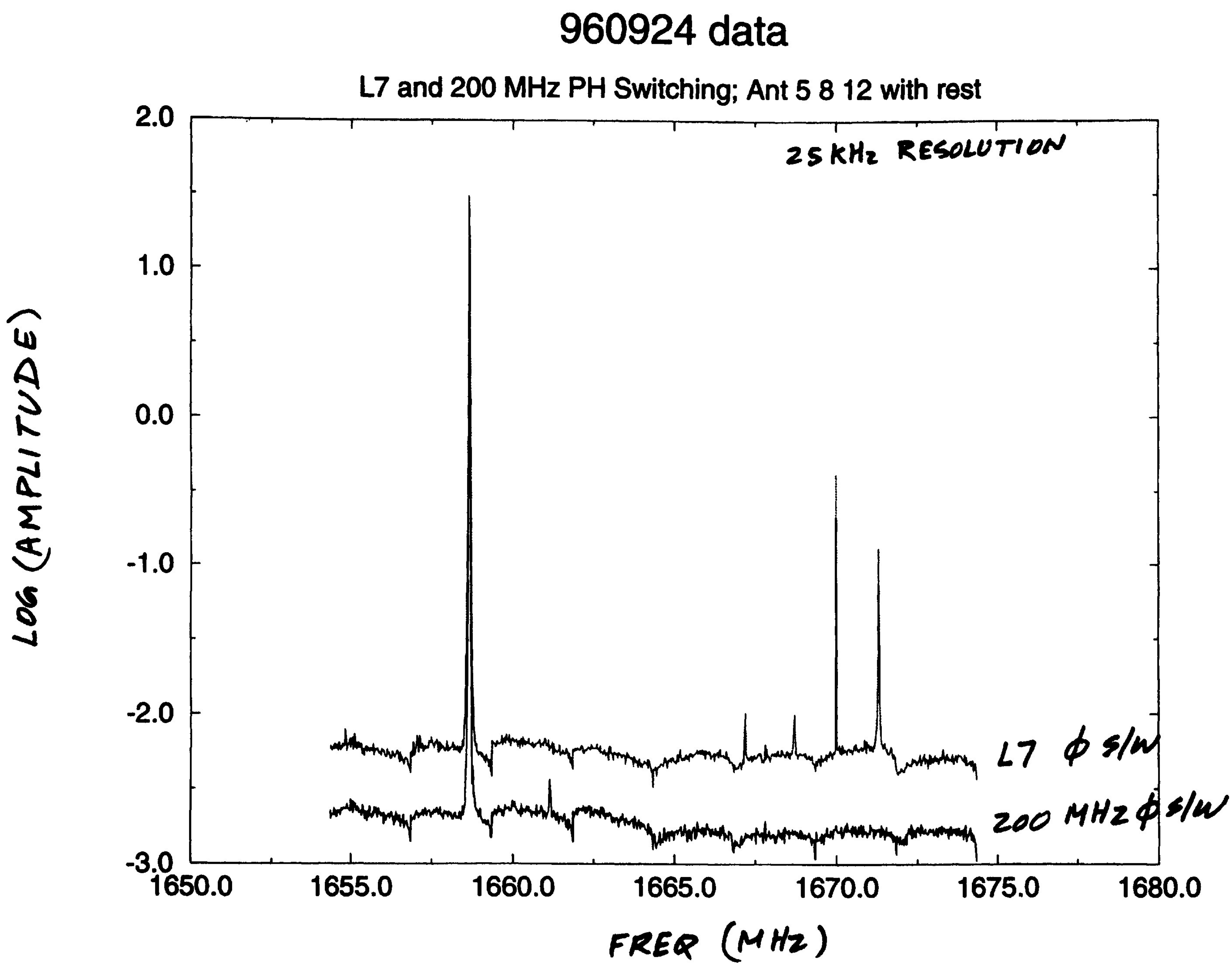


FIG. 5



960924 data
L7 and 200 MHz PH Switching; Ant 5 8 12 with rest
25 kHz RESOLUTION
LOG (AMPLITUDE)
2.0
1.0
0.0
-1.0
-2.0
-3.0
1650.0
1655.0
1660.0
1665.0
1670.0
1675.0
1680.0
L7 φ s/w
200 MHz φ s/w
FREQ (MHz)

FIG. 6