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OLYMPUS RECEIVER EVALUATION AND PHASE NOISE MEASUREMENTS

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This paper describes a set of measurements performed by the Michigan Tech Sensing and Signal Processing Group on the analog receiver built by VPI and JPL for propagation measurements using the Olympus Satellite. Measurements of local oscillator (LO) phase noise were performed for all of the LOs supplied by JPL. In order to obtain the most useful set of measurements, LO phase noise measurements were made using the complete VPI receiver front end. This set of measurements demonstrates the performance of the receiver from the RF input through the high IF output. Three different measurements were made: LO phase noise with DC on the VCXO port; LO phase noise with the 11.381 GHz LO locked to the Reference signal generator; and a reference measurement with the JPL LOs out of the system.

INTRODUCTION

The Olympus satellite has three beacon frequencies, all derived from a common high stability oscillator. If an earth station receiver is phase or frequency locked to any one of the beacons, the local oscillator frequencies for the other two beacons may be obtained. In the Virginia Tech Olympus receiver, the 12.5 GHz receiver frequency locks to the Olympus 12.5 GHz beacon. The local oscillator signals for the 20 and 30 GHz beacon receivers are then derived from the locked 12.5 GHz receiver. In this way, the 20 and 30 GHz receivers can remain locked even during deep fades of the 20 and 30 GHz signals. Phase noise on the earth station local oscillators is important for three reasons: the frequency locked loop (FLL) will be unstable if the phase noise is poor; received signals are modulated by the local oscillator phase noise; and the minimum receiver predetection bandwidth and hence sensitivity is limited by the short term fluctuations of the receiver local oscillator.

PREPARATION

The measurements were made at Virginia Tech the week of January 22 to 27, 1990. During the week before the trip, the 1296 IF system, Reference and PCM audio recorder were set up and calibrated at Michigan Tech. The system was then broken down and packed for shipping, along with a set of adapters and cables to connect the Michigan Tech and Virginia Tech systems.

TRAVEL TO VPI

The 1296 IF system, Reference oscillator and other critical components were taken as carry on baggage. The PCM recorder (Toshiba DX 900) was too large to be carried on, so it was packed in its shipping box and checked.

SET UP AT VPI

Tuesday, January 23, the 1296 IF system was connected to the VPI receiver with the assistance of Dennis Sweeney, as shown in Figure 1. The system was allowed to stabilize overnight while Dennis reviewed the current status of the receiver system.

JANUARY 1990 STATUS OF OLYMPUS RECEIVER

As of the end of January 1990, the analog receiver was working in breadboard form. Dennis was still working on minor modifications to the frequency locked loop dynamics before committing the design to a PC board layout. The system was capable of receiving the 12 GHz Olympus beacon signal, but an on-the-air test was not practical due to the high feedline loss between the outdoor antenna and the bench where the breadboard receiver was located. In final form, the receiver front end will be located in an outdoor cabinet near the dish feed.

Dennis demonstrated capture, lock and tracking of a weak CW signal from the HP 8673 signal generator. The system is capable of tracking any changes in beacon frequency over the life of the satellite. Since day to day variations will be much smaller, it is possible to improve loop stability by reducing the range of the tracking loop and providing a front panel manual adjustment with a zero center meter to compensate for long term variations.

PHASE NOISE MEASUREMENTS

Three different types of measurements were made:

1. Measurements of downconverted LO phase noise, using the apparatus shown in Figure 1. These measurements were made on all three analog receiver front ends, using both the primary and spare LOs. The VCXO frequency change terminal was grounded for these measurements. In order to insure that the dynamic range of the measurement system was not exceeded, two measurements were made on each LO: the first measurement was made with the signal level adjusted 10 dB lower than the maximum input to the digital audio recorder; and the second measurement was made with the signal level 20 dB lower than the maximum to the digital audio recorder. Since the dynamic range of the digital record is 86 dB, this provides two records, one with the signal 76 dB above the digital tape recorder noise floor and one with the signal 66 dB above the noise floor. The no signal receiver output was adjusted so that it just indicated on the recorder output. Either of these measurements has sufficient dynamic range to see the close-in phase noise on the LO and verify that it is within specifications at 100 Hz separation.

2. A measurement of the phase noise of the 11.381 GHz LO was made with the LO locked to the HP 8673 signal. This measurement was made with the signal downconverted to 10 kHz using the breadboard VPI receiver system. The downconverted signal was recorded on the right channel of the digital audio recorder, and the 10 kHz reference was recorded on the left channel. This permits not only a phase noise analysis of the locked LO, but a measurement of loop behavior by doing a cross-spectrum between the locked LO and the reference. This measurement also demonstrates direct digital audio recording of the 10 kHz IF signal which can be used to obtain data during propagation events with rapid fluctuations, as in thunderstorms.

3. The third measurement was made to determine the phase noise of the measurement system itself. As shown in Figure 2, the 576 MHz reference from the 1296 MHz IF receiver (derived from a 5 MHz Vectron CO-203 oscillator) is multiplied by 4 in a Campbell multiplier board. The 2304 MHz signal is then multiplied by 5 in a harmonic mixer (Mini-Circuits ZFM-4212) to 11.520 GHz. The HP 8673 is adjusted to 11.6641 GHz. The output of the harmonic mixer is then 144.1 MHz, which is downconverted to 1024 Hz using the low IF receiver as in the first set of measurements.

Table 1 shows the time, frequencies, levels and tape counter indications for all the measurements.

PROCESSING OF PHASE NOISE DATA AT MICHIGAN TECH

The lab was set up to process the recorded IF signal as shown in Figure 3. All of the data at 1024 Hz IF was processed, but the 10 kHz data (measurement "a" in Table 1) has not been processed.

The power spectra for the JPL LOs were obtained by playing the 1024 Hz recorded IF signals as analog audio into the HP 5451C Fourier analyzer. For each spectrum plot, 100 sequential 1024 sample time records were Hanning windowed, Fourier transformed, converted to a power spectrum and averaged to obtain a 500 Hz wide spectrum with 1.5 Hz noise bandwidth and 1 Hz spacing between frequency domain points.

The JPL LO phase noise plots are shown as Figures 5-14. All of these plots have phase noise at the 100 Hz points that are very close to the Olympus LO specification shown schematically in Figure 4. These LOs meet the specifications set at the beginning of the receiver development program. The ± N x 60 Hz noise sidebands are discussed in the next section.

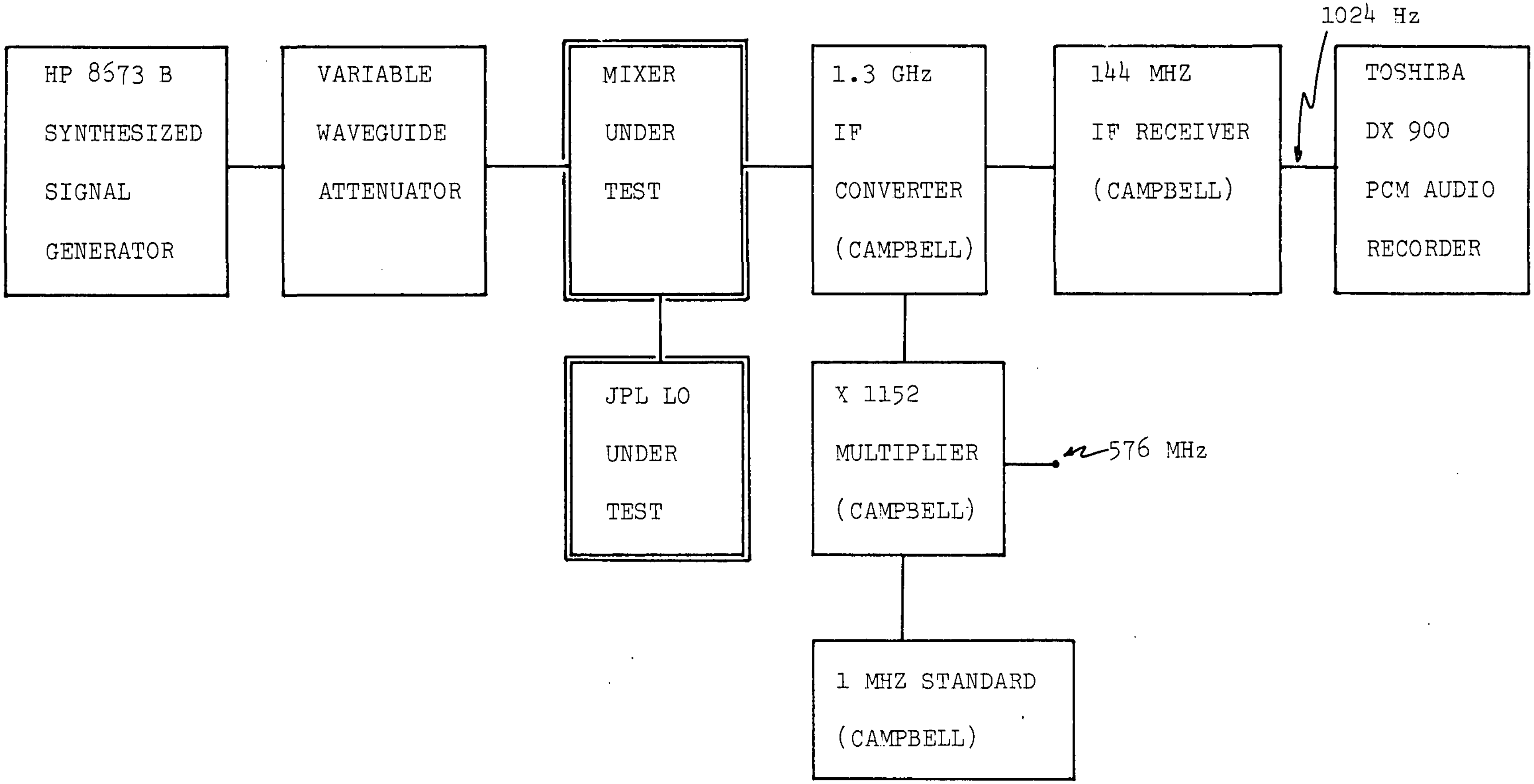
PHASE NOISE MEASUREMENT SYSTEM CALIBRATION

In order to prove that the phase noise being measured was actually that of the JPL LOs rather than the measurement system, a measurement was made of a very low phase noise microwave LO built by R. Campbell. Unfortunately, the output of the Campbell LO was contaminated by 60 Hz noise on the bench at Virginia Tech. This may have been 60 Hz noise transmitted over the power supply lines or it may have been magnetically coupled from a nearby power transformer into the ovenized crystal oscillator in the Campbell LO. It would have been easy to remove the 60 Hz noise from the reference LO by running it on a different power supply and moving it away from any nearby magnetic AC devices, but the 60 Hz contamination was not suspected at the time of the measurements.

In any case, Figure 15 demonstrates that the phase noise measurement system used to measure the JPL LOs has a phase noise floor at least 10 dB below the best JPL LO within 50 Hz of the carrier and at least 5 dB better at + 100 Hz from the carrier.

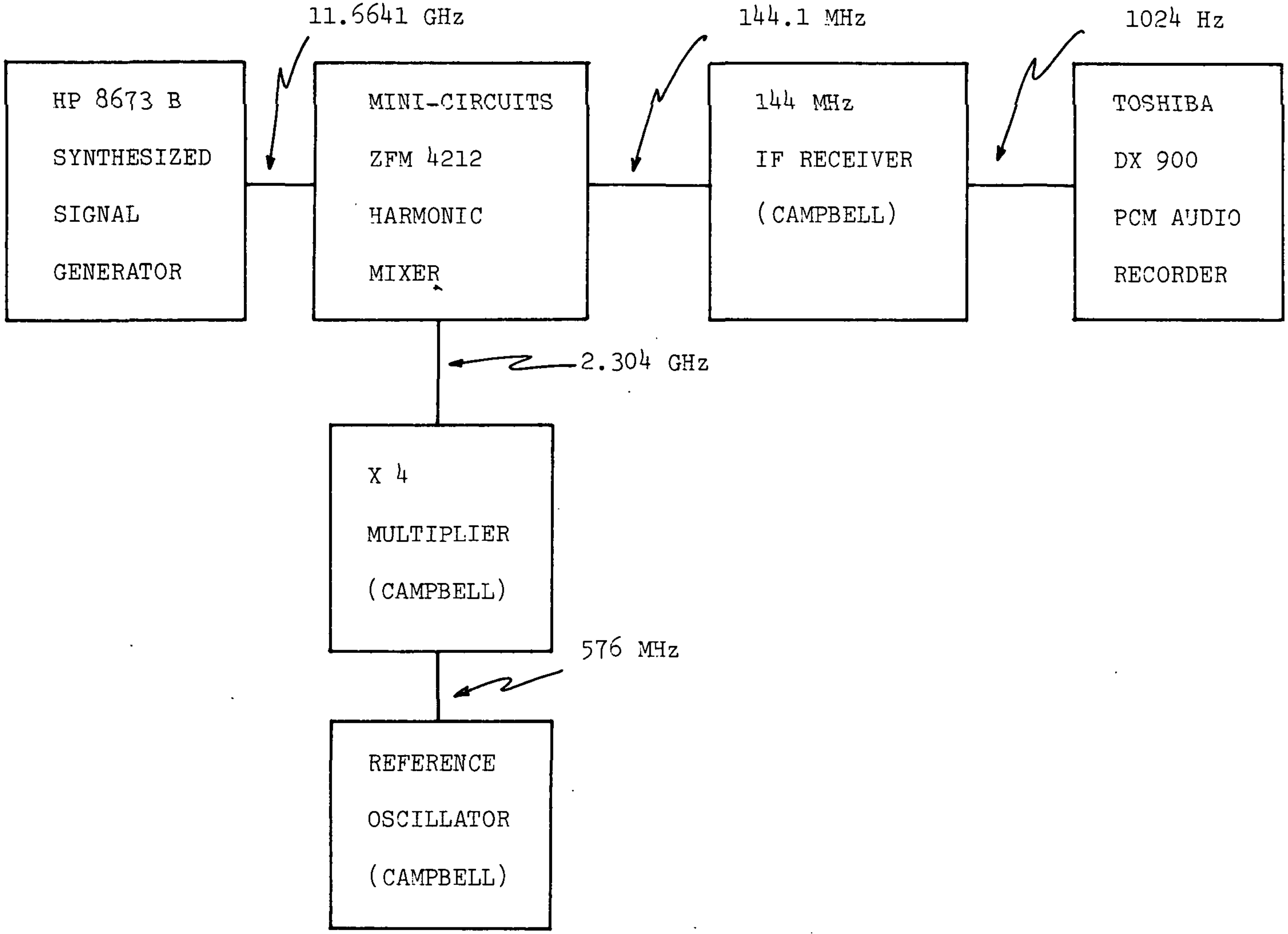
APRIL 1990 STATUS OF THE OLYMPUS RECEIVER AT VIRGINIA TECH

As of April, 1990, the 12.5 GHz beacon receiver and radiometer are on the air at Virginia Tech, as discussed in the companion paper by Warren Stutzman. The signal was first received with a carrier to noise ratio of 30 dB in March 1990. The FLL locks from -115 to -150 dBm. Three additional IF systems are now under construction for the 20 and 30 GHz receivers.



PHASE NOISE TEST

FIGURE 1



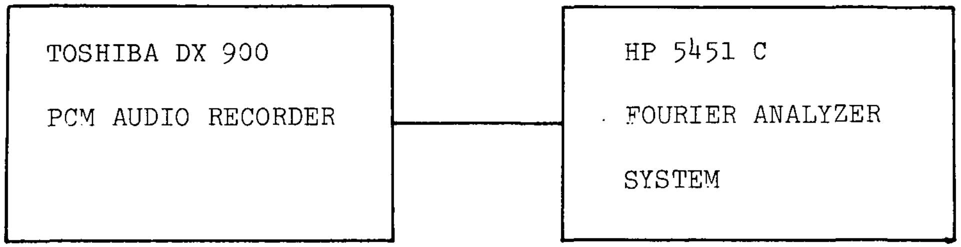
REFERENCE TEST

FIGURE 2

TABLE 1

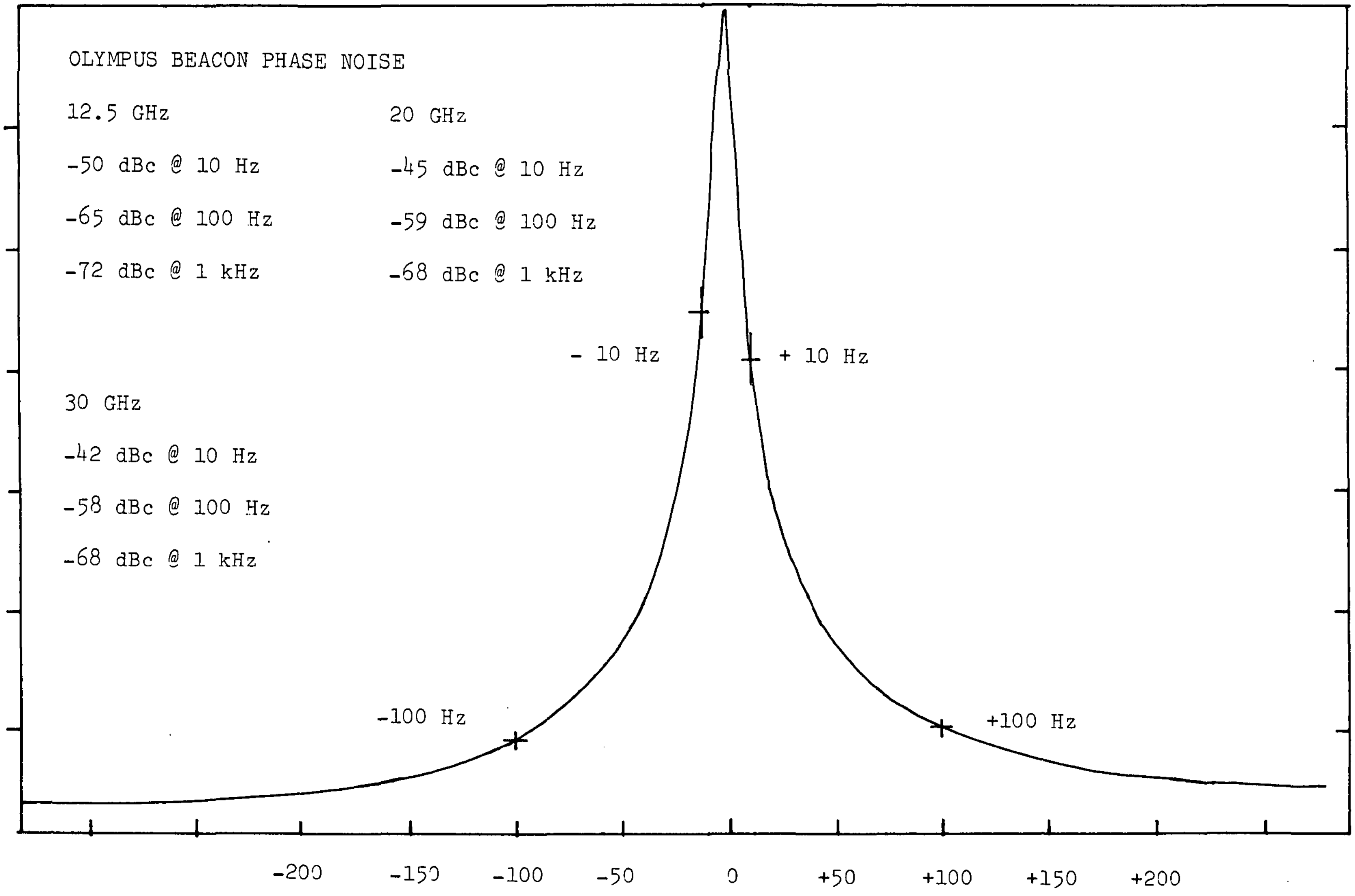
Run #	LO Freq. and SN	HP 8673 freq. GHz	HP 8673 level dBm	Record level dB	Start time EST	Start count	Stop time EST	Stop Count	Notes
1	--	--	--	--	--	--	--	--	
2	10.3819 SN 35267	12.678006							1
3	same	same	-40	-15	11:21	0615	11:36	1665	2
4	same	same	-30	0	2:51	1670		1713	3
5	same	same	-30	0	2:54	1713	3:04	2290	
6	same	same	-40	-15	3:08	2290	3:16	2714	4
7	10.3819 SN 35268	same	-40	-15	3:20	2716	3:25	2926	
8	same	same	-30	0	3:26	2926		3219	
9	4.4640 RLC LO	5.7601	-80	0	3:42	3219	3:45	3367	5
a	10.3819 SN 35268	12.5019		0	4:03	3365	4:09	3629	6
b	28.535684 SN 35270	29.831784		-10	4:45	3633	5:00	4237	
c	same	same		0	5:02	4240	5:12	4620	
d	18.650456 SN 35273	19.946492	-64	0	9:57	4619	10:07	4945	
e	same	same	-74	-10	10:09	4945	10:14	5121	
f	18.650456 SN 35272	same	-64	0	10:30	5121	10:30	5464	
g	same	same	-74	-10	10:41	5464	10:46	5632	
h	11.520 reference	11.66410		0	11:11	5640			7
Tape # 2	same	same		0	11:37	0020	1:00		8

Notes:
1. Data is at 1024 Hz unless otherwise noted.
2. Runs 1, 2 and 3 were setup runs. Don't use.
3. Aborted run 4 to ground VCXO terminal.
4. "0" and "-15" on recorder are approximate from LED bar graph
5. Diagnostic measurement of free running 5th OT Butler oscillator
6. Measurement of locked 11.381 GHz LO. Data is at 10 kHz
7. Run h aborted -- end of VHS tape.
8. Tape #2 is 1.5 hours of 1024 Hz reference sine wave downconverted from 11.6641 GHz



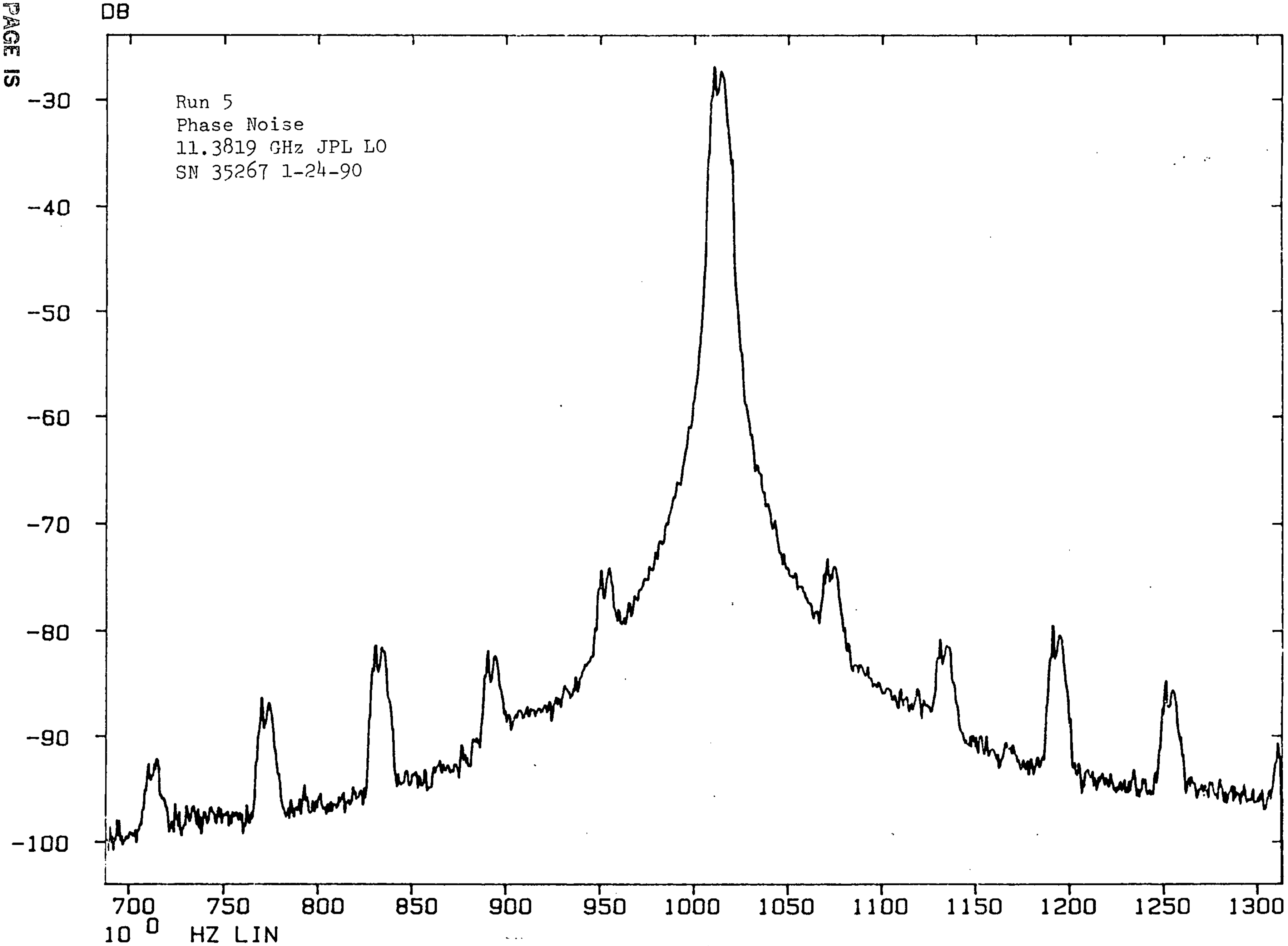
1024 HZ IF SIGNAL PROCESSING

FIGURE 3



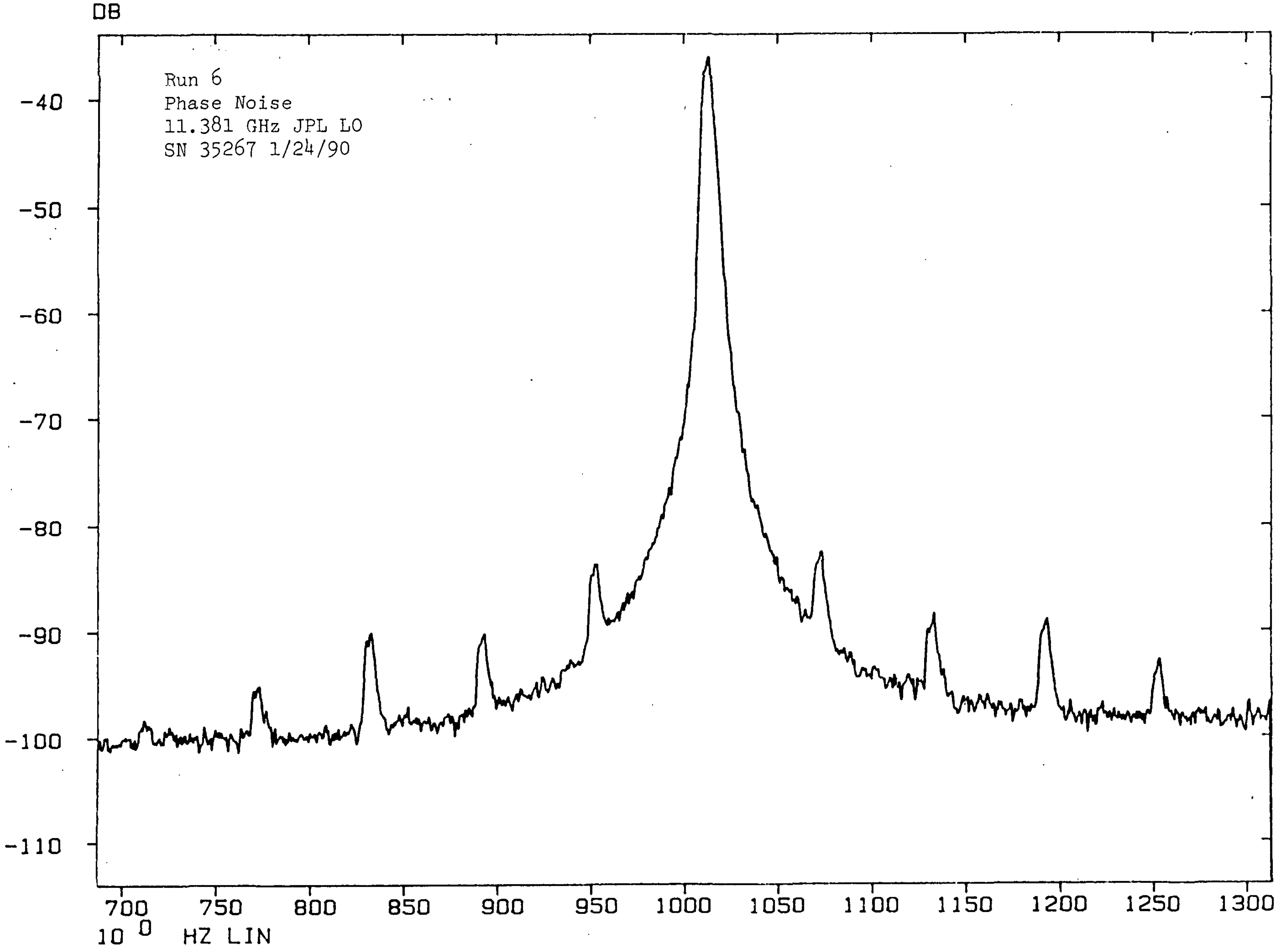
OLYMPUS BEACON PHASE NOISE

FIGURE 4



Run 5
Phase Noise
11.3819 GHz JPL LO
SN 35267 1-24-90

FIGURE 5



Run 6
Phase Noise
11.381 GHz JPL LO
SN 35267 1/24/90

Figure 6

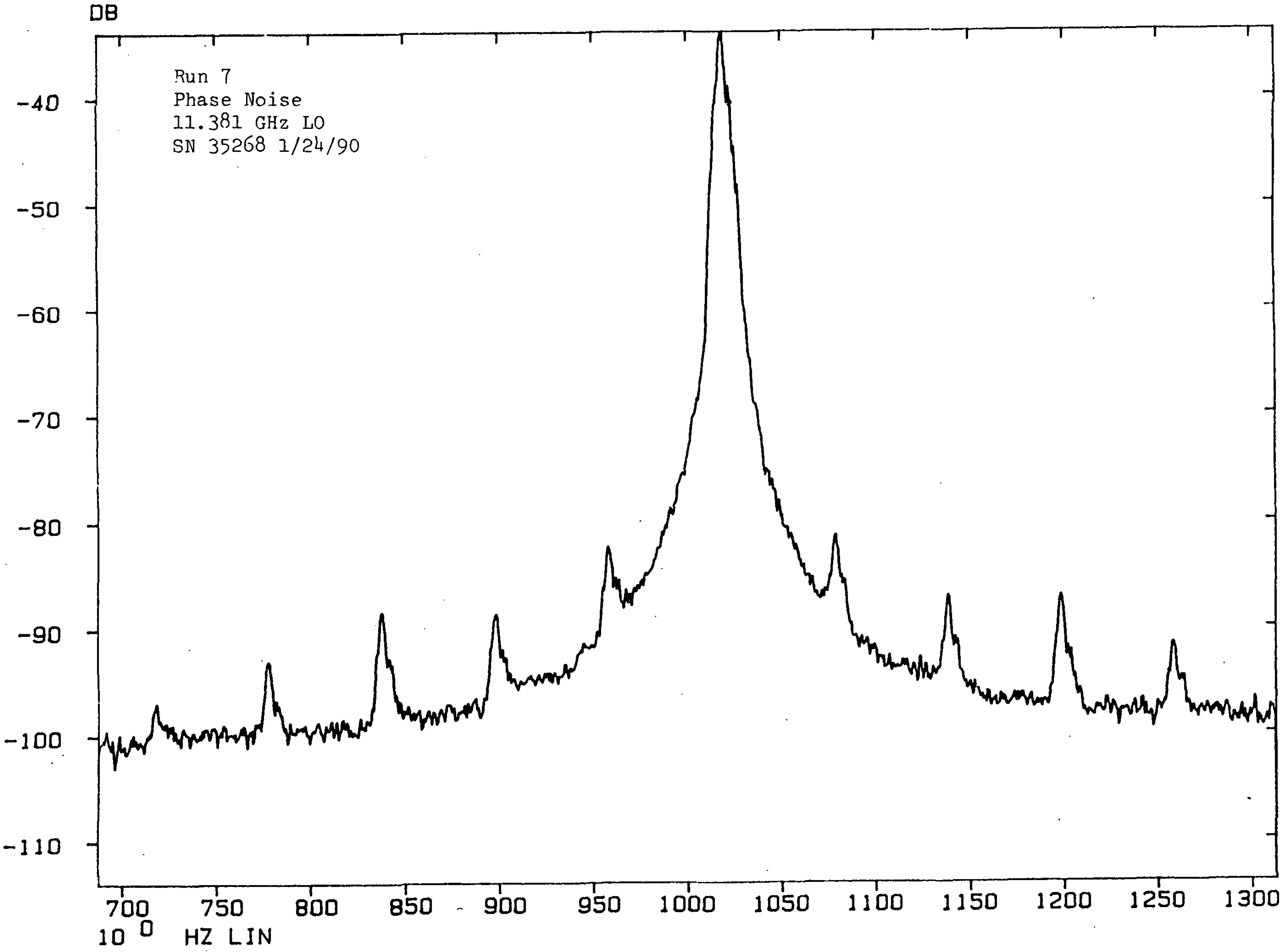

DB
Run 7
Phase Noise
11.381 GHz LO
SN 35268 1/24/90
-40
-50
-60
-70
-80
-90
-100
-110
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
10 ^{0} HZ LIN

Figure 7

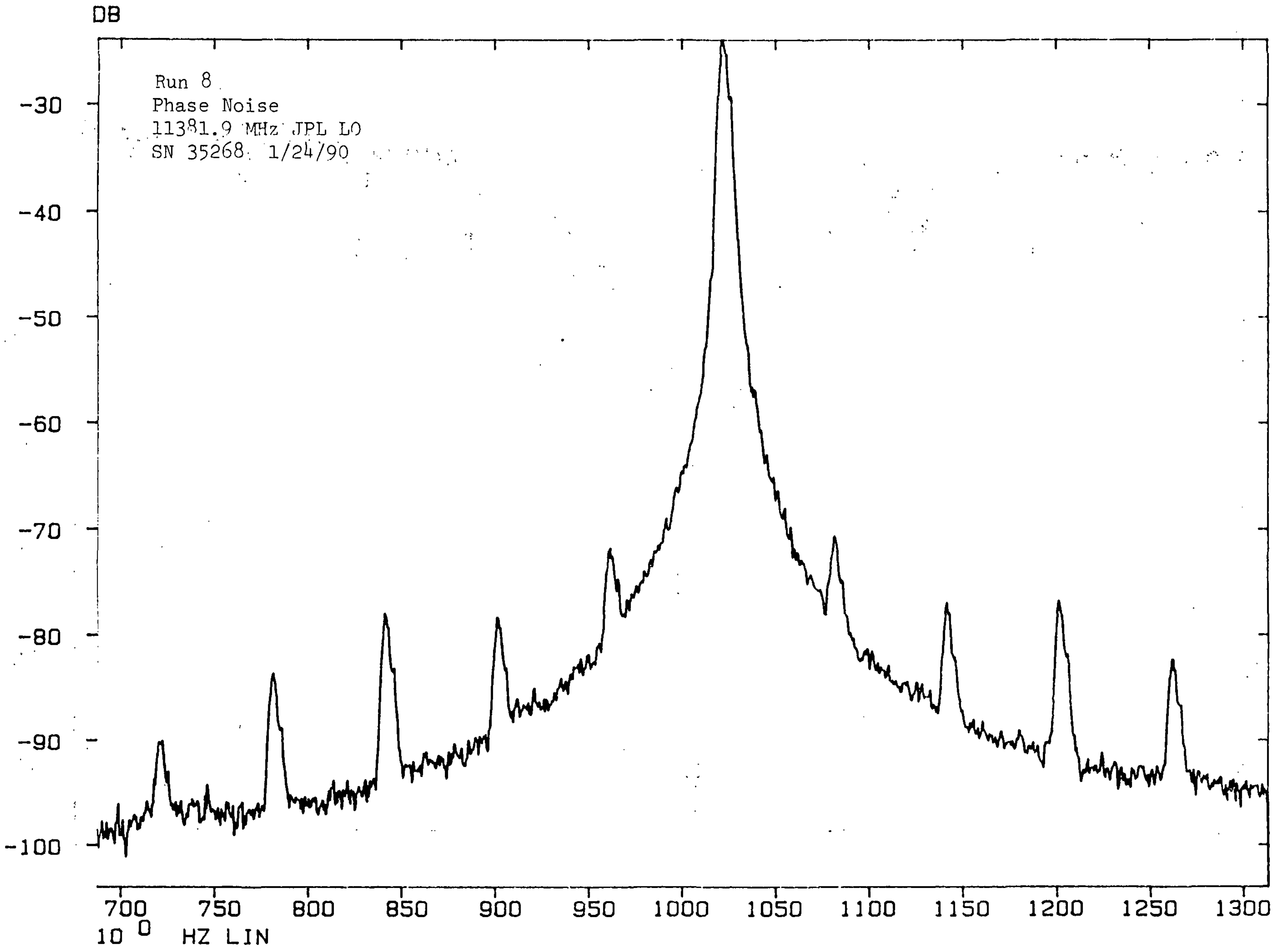

DB
Run 8
Phase Noise
11381.9 MHz JPL LO
SN 35268 1/24/90
-30
-40
-50
-60
-70
-80
-90
-100
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
10 0 HZ LIN

Figure 8

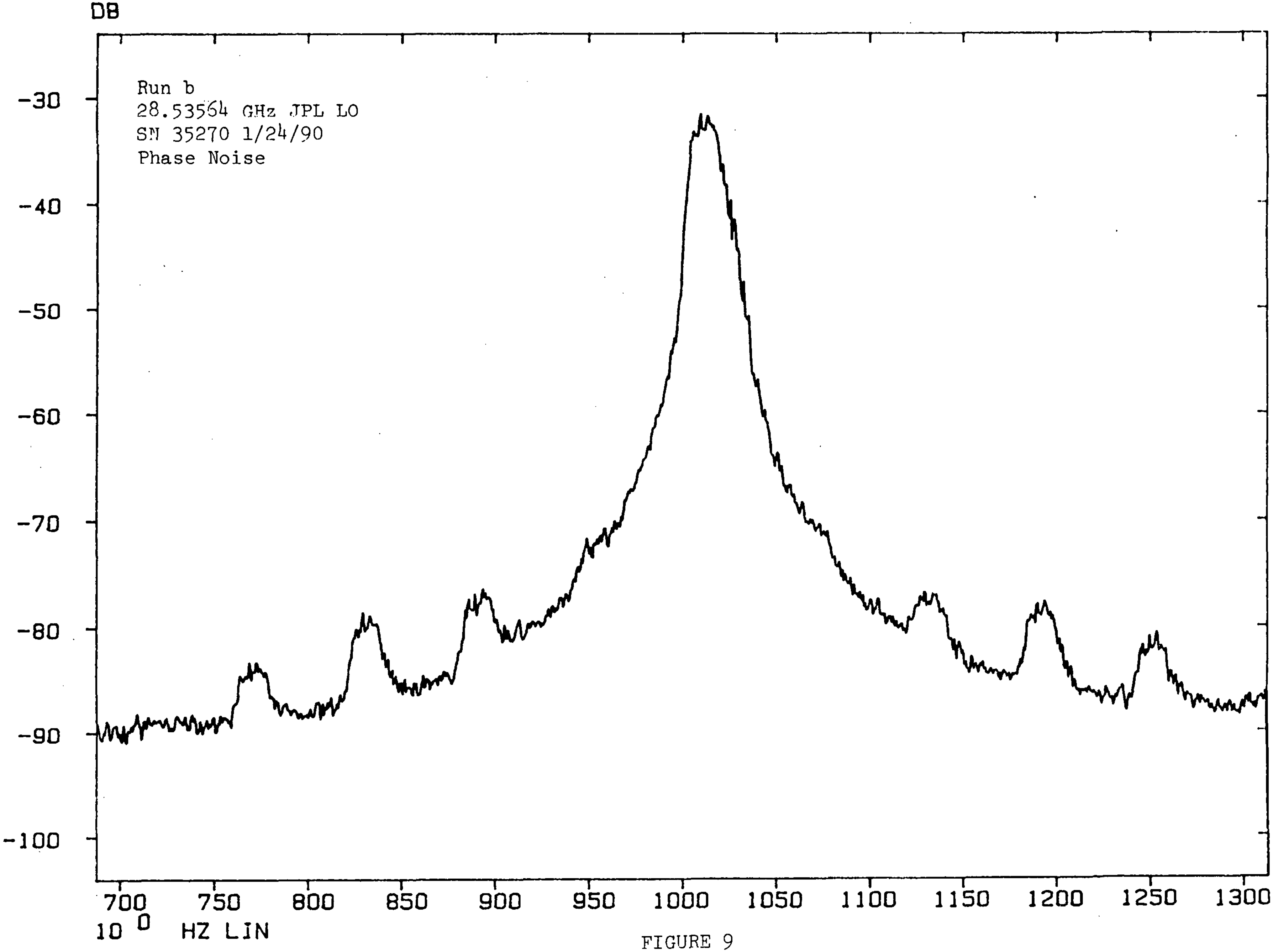
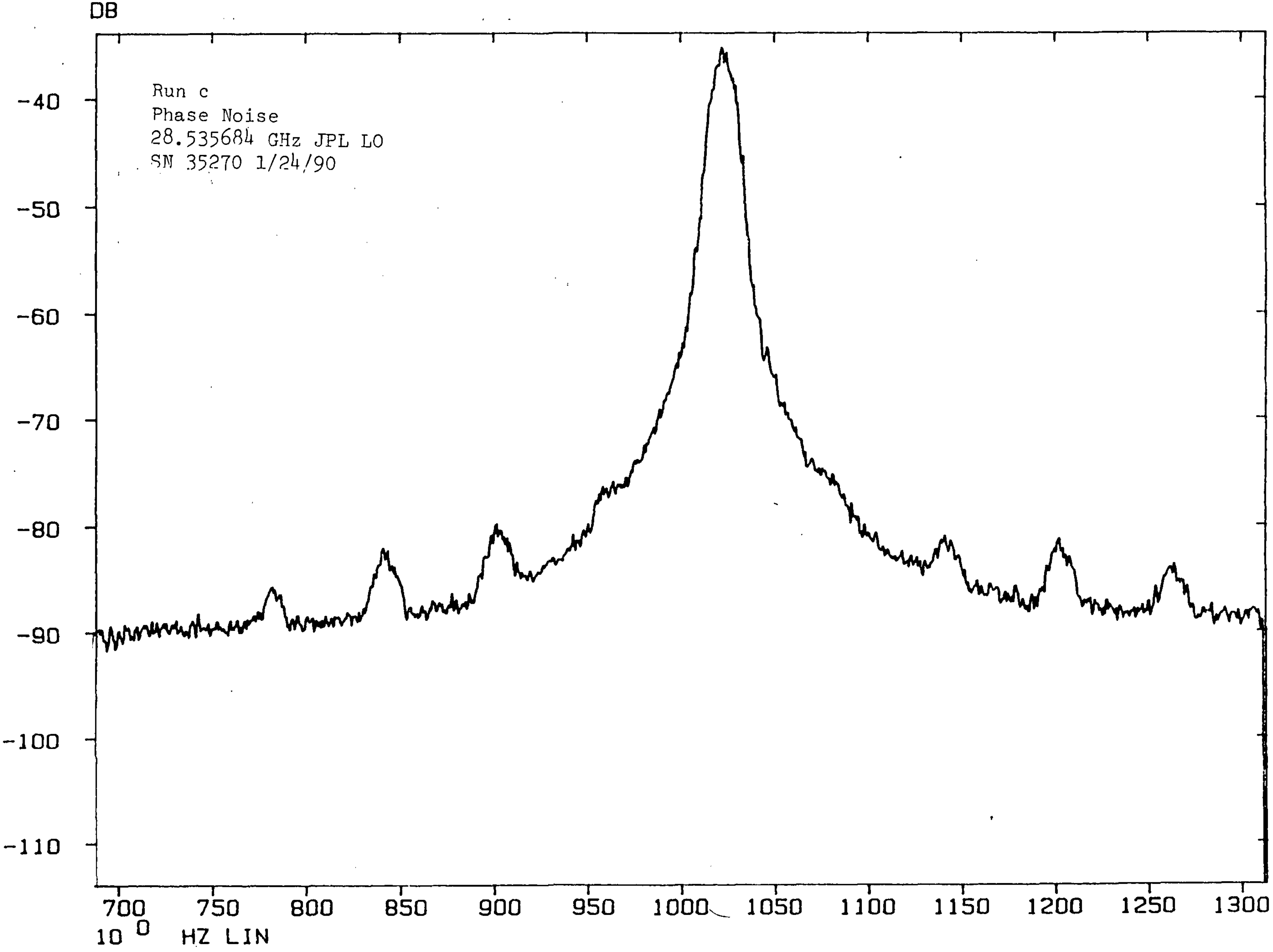

DB
Run b
28.53564 GHz JPL LO
SN 35270 1/24/90
Phase Noise
-30
-40
-50
-60
-70
-80
-90
-100
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
10 0 HZ LIN

FIGURE 9



Run c
Phase Noise
28.535684 GHz JPL LO
SN 35270 1/24/90

Figure 10

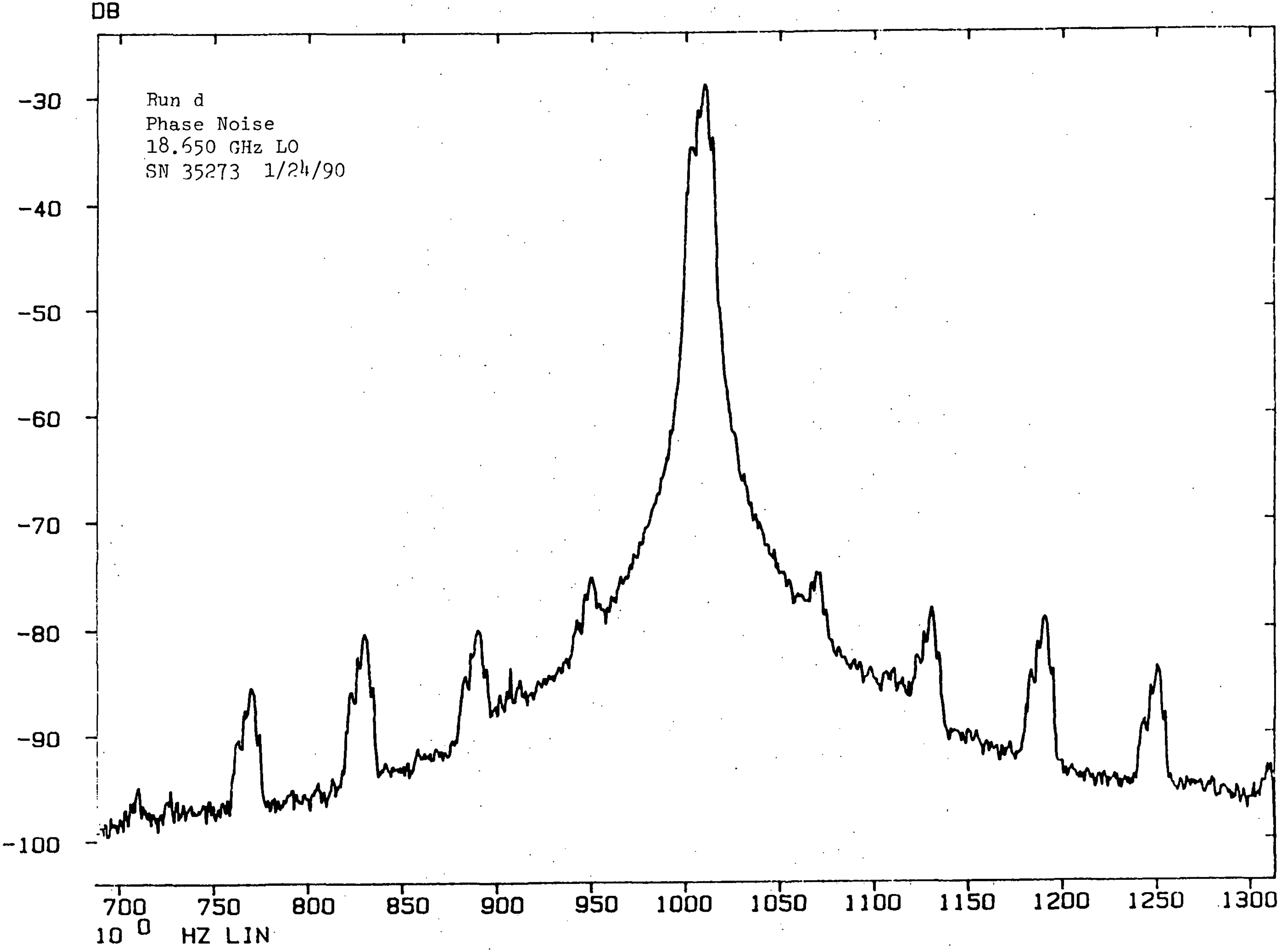

DB
Run d
Phase Noise
18.650 GHz LO
SN 35273 1/24/90
-30
-40
-50
-60
-70
-80
-90
-100
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
10 0 HZ LIN

FIGURE 11

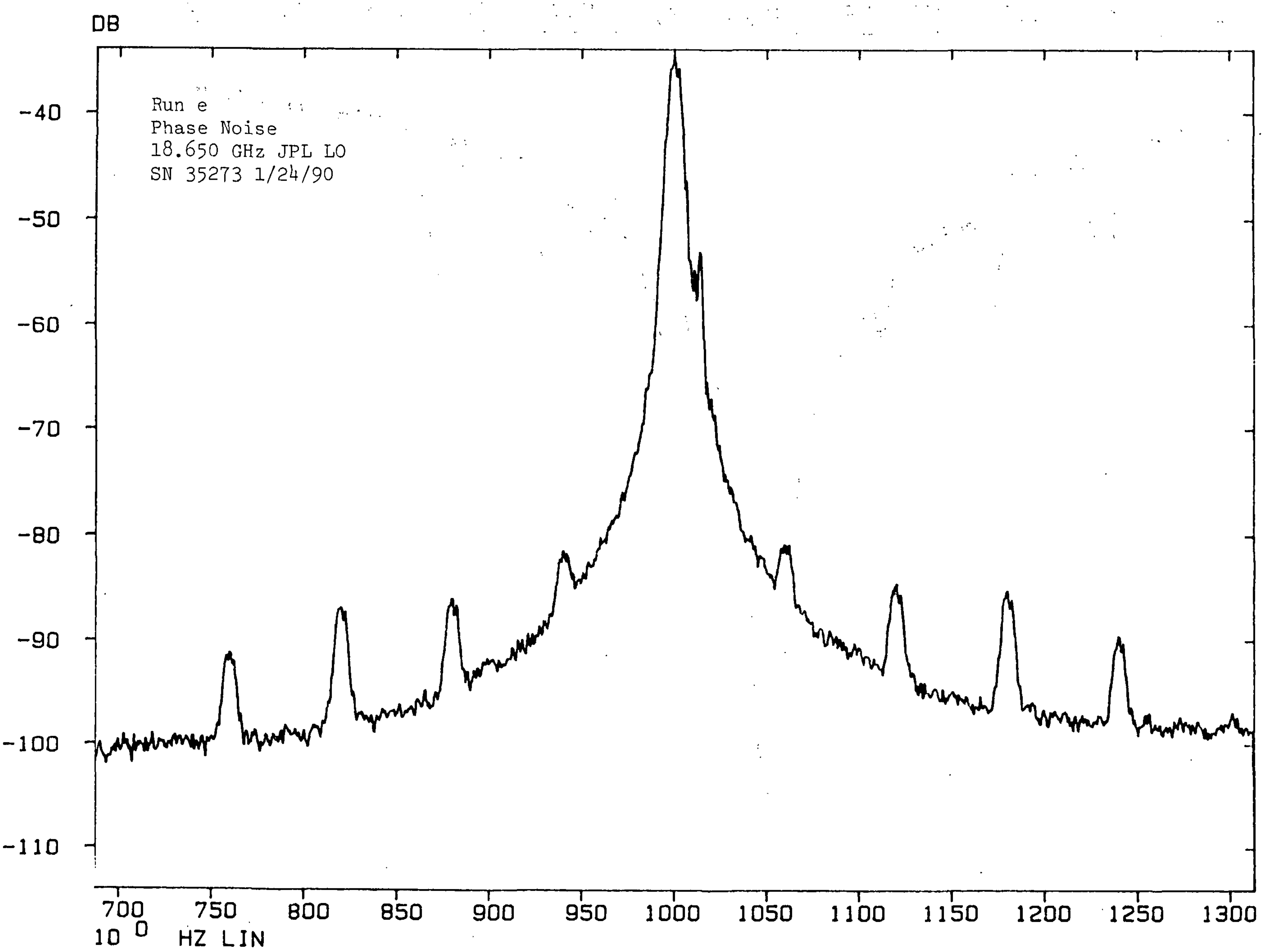

DB
Run e
Phase Noise
18.650 GHz JPL LO
SN 35273 1/24/90
-40
-50
-60
-70
-80
-90
-100
-110
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
10 0 HZ LIN

FIGURE 12

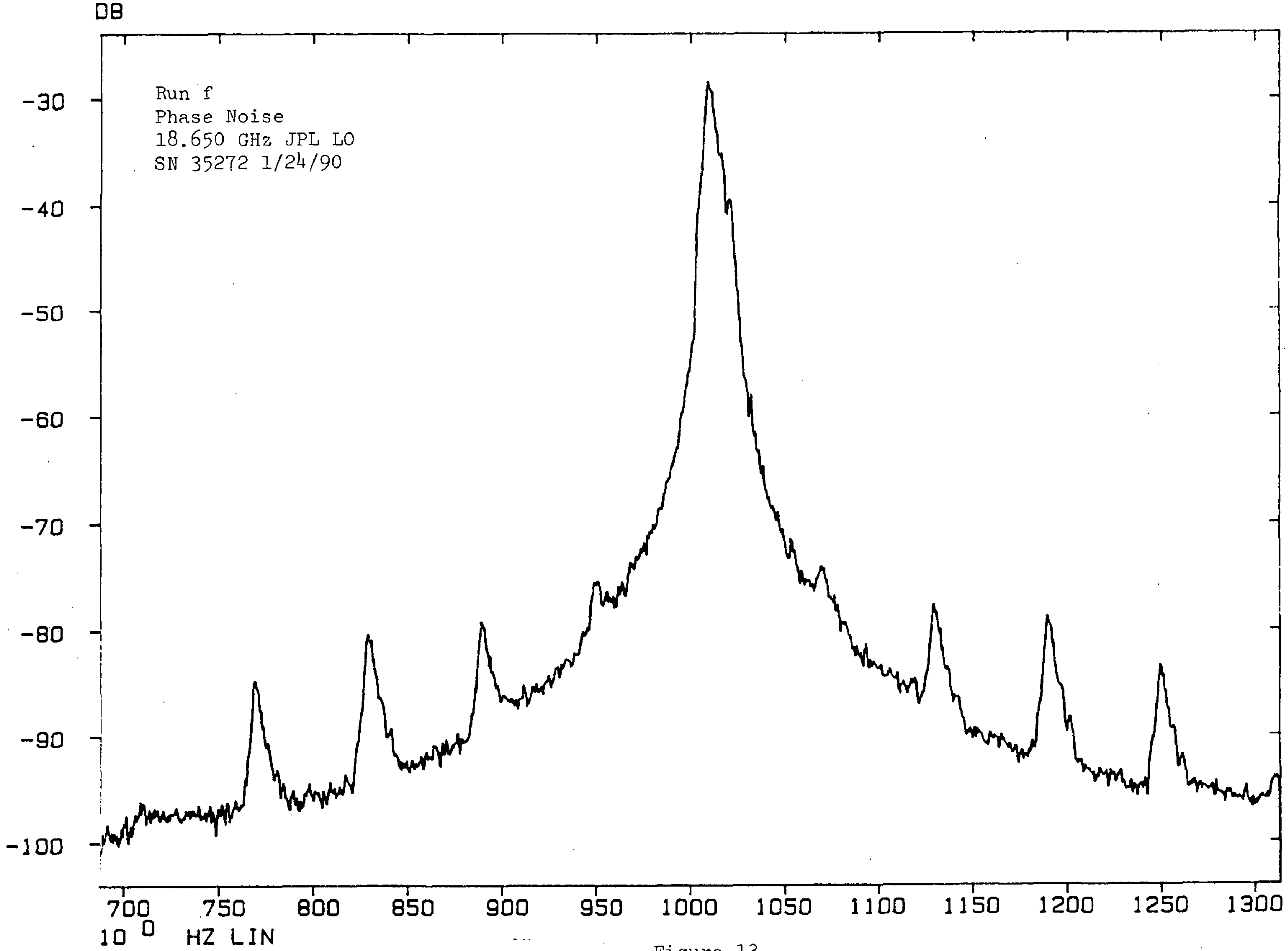

DB
Run f
Phase Noise
18.650 GHz JPL LO
SN 35272 1/24/90
-30
-40
-50
-60
-70
-80
-90
-100
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
10 0 HZ LIN

Figure 13

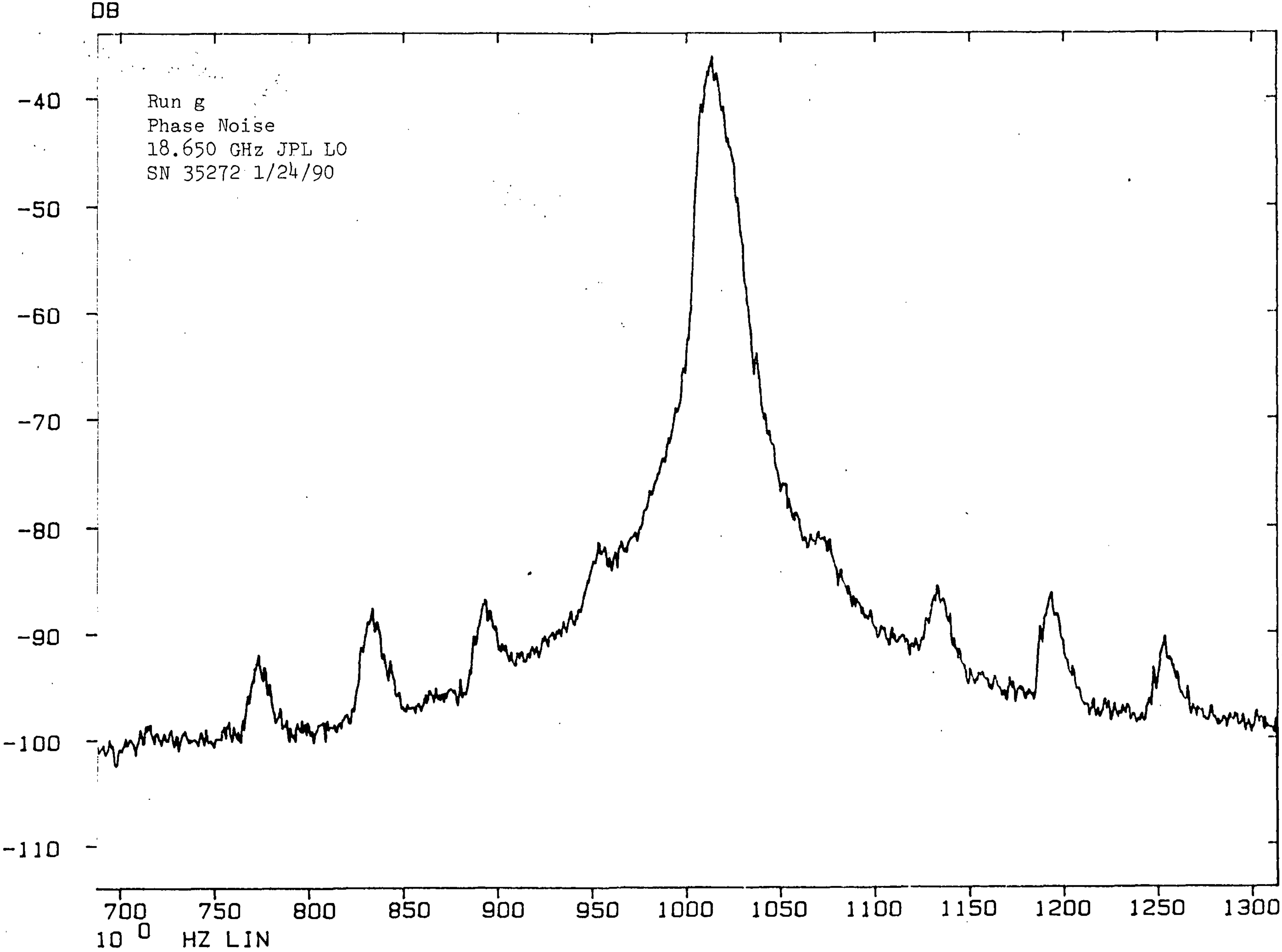
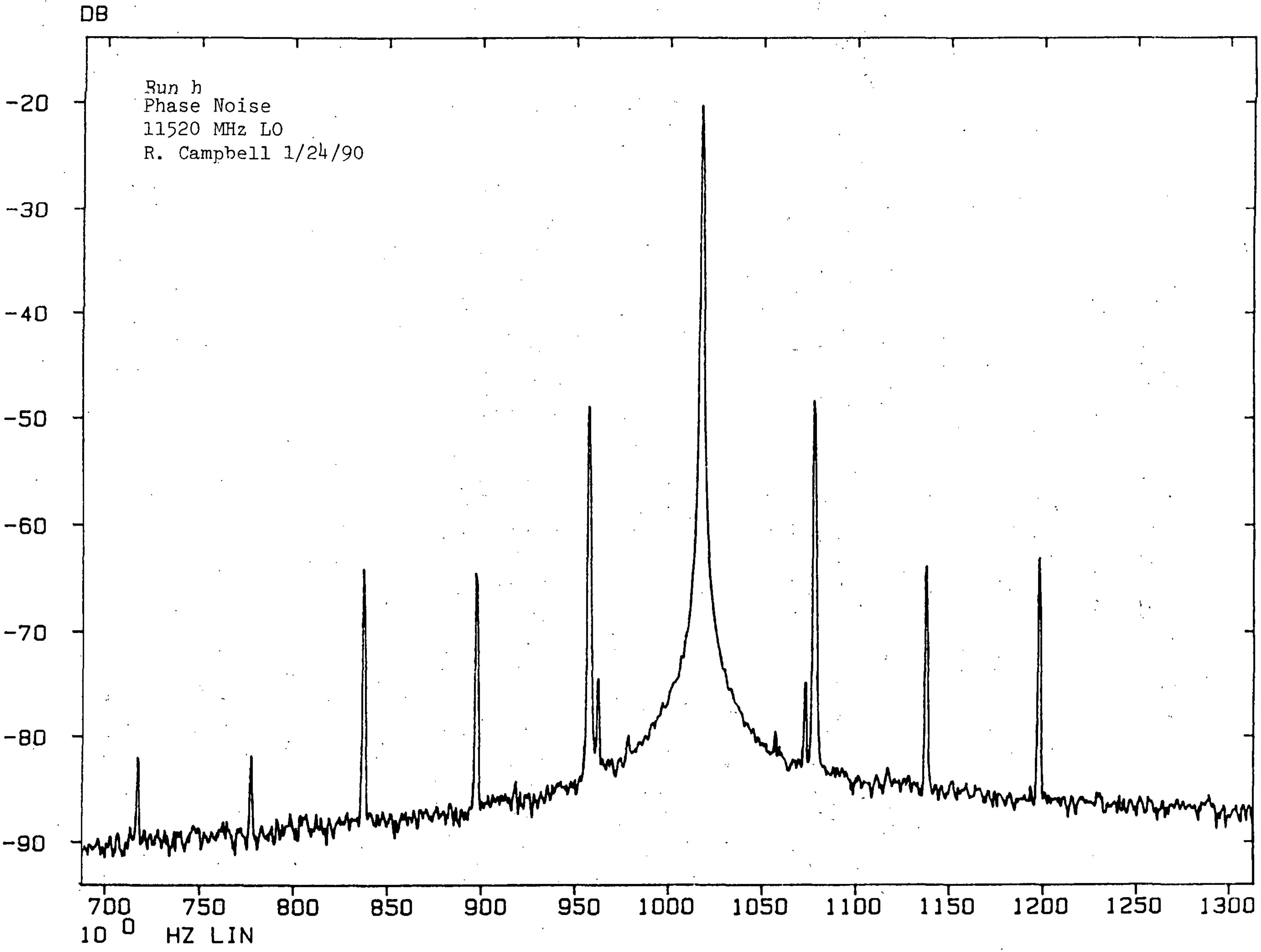

DB
Run g
Phase Noise
18.650 GHz JPL LO
SN 35272 1/24/90
-40
-50
-60
-70
-80
-90
-100
-110
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1300
10 0 HZ LIN

FIGURE 14



Run h
Phase Noise
11520 MHz LO
R. Campbell 1/24/90

FIGURE 15