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Noise figure and conversion loss measurements
of a set of L.O. tripler-mixer assemblies
for Q-band receivers

Arturo Velazquez*

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***On sabbatical leave from Centro de Investigacion Cientifica y Educacion Superior de Ensenada CICESE, and Instituto de Astronomia UNAM**

NOISE FIGURE AND CONVERSION LOSS MEASUREMENTS OF A SET OF L.O. TRIPLER-MIXER ASSEMBLIES FOR Q-BAND RECEIVERS

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Introduction

This document describes measurement procedures to adequately characterize both the noise figure and conversion loss of a set of L.O. tripler-mixer assemblies intended to be used as the frequency conversion element in the new 40 to 50 GHz cryogenically-cooled low-noise receivers for the VLA. Typical results are shown to give an idea of the performance of these devices.

Receiver configuration

Each receiver consists of a dual-channel low-noise amplifier system, that allow both left and right circularly polarized signals (LCP and RCP) to be received. The complete receiver is very similar to the 43 GHz cryogenics front end as described by R. Norrod and M. Masterman [1].

The L.O. tripler-mixer assembly is located outside the dewar and receives at its RF input a signal in the 40-50 GHz range coming from the five stage cryogenically-cooled low-noise HFET amplifier which provides approximately 30 dB gain with a noise figure of approximately 0.52 dB (37 oK), while at its L.O. input receives a frequency signal in the 16-21 GHz range with +18 dBm power level, which is then tripled in frequency and injected to the mixer. The output signal from this conversion stage is an I.F. signal at a frequency of 8.4 GHz. The signal is sent through an isolator, a 8.4 GHz bandpass filter and then amplified by the second stage comercial amplifiers.

Description of the measurements

The L.O. tripler-mixer assemblies are supplied by a commercial vendor, Spacek Labs., model 3XM45-8.4-01, with serial numbers from 3F01 to 3F18 and 4B15-4B17. The mixer assembly consists of a tripler, bandpass filter, mixer and isolators. A single channel for the mixer is shown in figure 1.

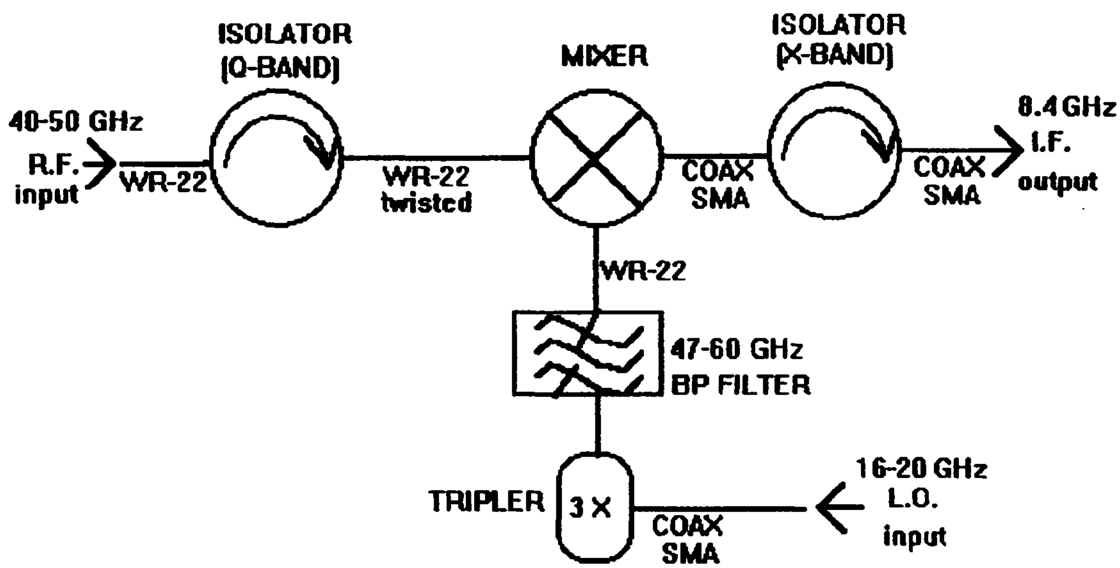

FIGURE 1. LO TRIPLER-MIXER ASSEMBLY

According to preliminary tests made on the receiver prototype, it is believed that the noise contribution from this L.O. tripler-mixer assembly is higher than expected based on theoretical noise figure calculations made using the manufacturer data sheet corresponding to each of the mixers. It was decided that some measurements were performed to the mixer assemblies to get experimental verification of their noise figure and conversion loss performance.

The method used to measure the mixers noise figure, was the Twice-Power Method of manual noise figure measurement. The basic equation for noise figure measurements is described as [2]:

$$F_{dB} = 10\log\frac{(T_2 - T_0)}{T_0} - 10\log\left[\frac{N_2}{N_1} - 1\right]$$

In this equation, the ratio $(T_2 - T_0)/T_0$ is a measure of the relative excess-noise power available from a noise source and is specified by the manufacturer. N_1 represents the noise power at the receiver output (and an input termination) with the excess-noise source "cold" and N_2 consists of N_1 plus the amplified excess-noise power (excess-noise source "fired") viewed at the receiver output. In actually measuring the N_1 and N_2 of the previous equation, if N_2 was set to be 2 N_1, then the equation reduces to:

$$F_{dB} = 10\log\frac{(T_2 - T_0)}{T_0}$$

With the proper equipment, the condition $N_2 = 2\ N_1$ can be established by varying the relative excess-noise power of the noise source. Using the equipment shown in figure 2, the procedure was as follows:

1.- Set a convenient reference on the power detector with the excess-noise source "cold" and the 3-dB pad out. This is N_1.

2.- Insert the 3-dB pad and fire the excess-noise source.

3.- Vary the rotary vane attenuator until the original power detector reference point is reached. This creates a condition of $N_2 = 2\ N_1$. Since this excess-noise ratio was adjusted with the attenuator equal to input termination noise plus receiver noise, it can be seen that the attenuated excess-noise ratio is equal to the noise figure of the receiver.

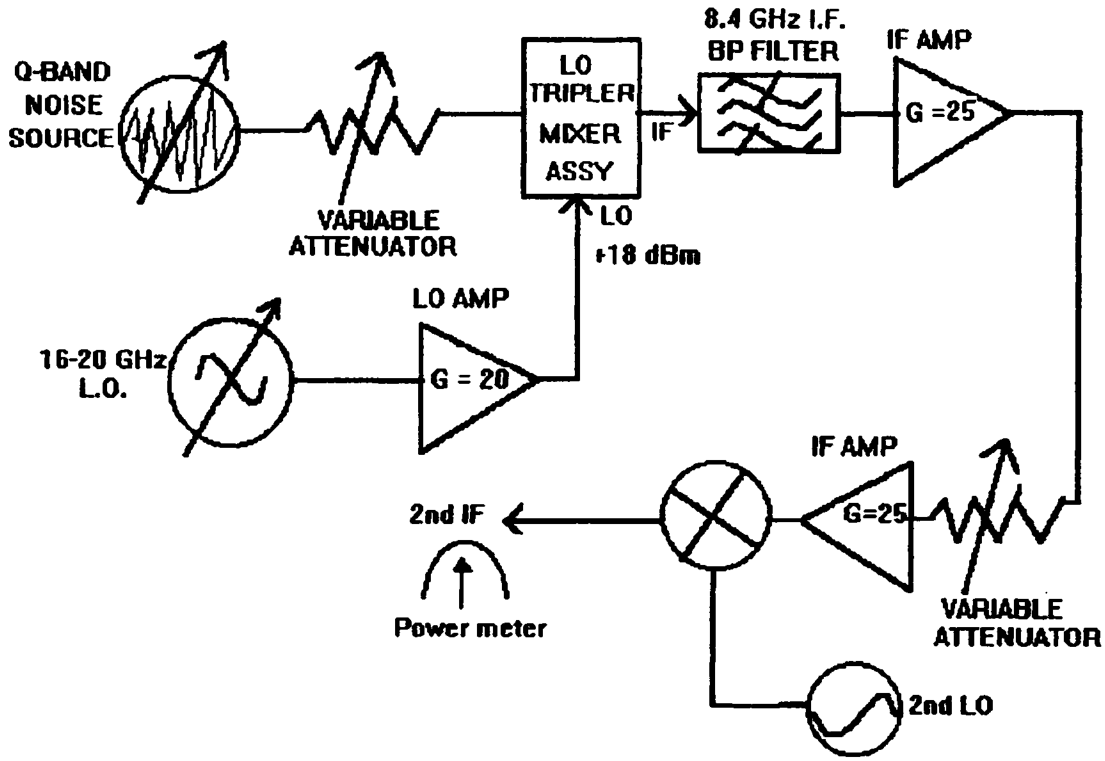

FIGURE 2. TEST SET-UP FOR NOISE FIGURE MEASUREMENTS

For example, in the case of a noise diode used as a source the noise figure is obtained by substracting the attenuator setting (in dB) from the excess-noise ratio or ENR of the diode at the frequency of interest. For the noise diode used in the measurements the ENR ranges from 19 dB to 23 dB.

Another set of measurements were performed to evaluate the conversion loss characteristics of the mixers. The conversion loss of the mixers was taken as the ratio of the IF single sideband output to the RF input level, and all measurements were based on a 50 system. The test set-up used in this measurements is shown in figure 3. In this case, attenuator pads are connected to all three ports so the mixers see 50 at the frequency of interest and all harmonics. This is further improved by connecting isolators at the RF and IF ports. The RF input level is selected so that it is high enough to operate the mixer in its "linear" region and not so low to allow LO leakage to degrade the integrity of the measurements [3]. For the local oscillator, the manufacturer recommended power level was selected and controlled by means of a variable attenuator in conjunction with an amplifier to maintain the same level across the L.O. band (+18 dBm from 15 to 20 GHz).

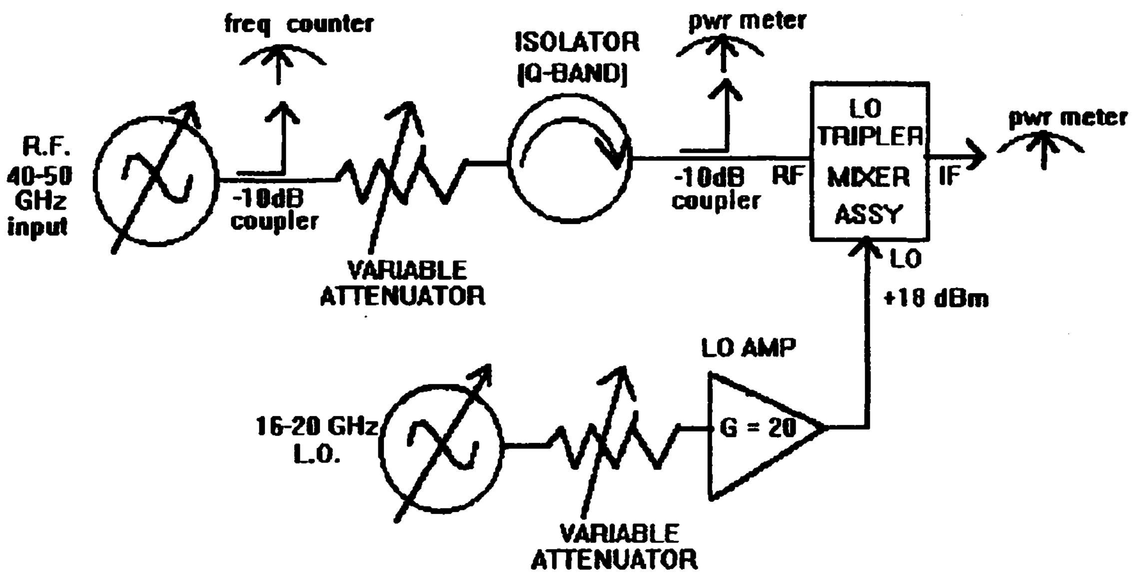

FIGURE 3. TEST SET-UP FOR CONVERSION LOSS MEASUREMENTS

Results

Various results taken from different units are shown on figures 4 through 19. For the unit S/N 3F04, figure 4 shows how the noise figure and the conversion loss values are very close to each other and how they have a tremendous degradation above 46 GHz. A very similar situation arises for unit S/N 3F07 in which the noise figure and conversion loss increase above 45 GHz, as can be seen in figure 5. In the case of unit S/N 3F13, figure 6 shows that the conversion loss is increasing slowly above 45 GHz while the noise figure has a sudden increase at 47 GHz and above. Figure 7 shows the best noise and conversion loss performance measured and figure 8 illustrates the typical performance of some mixers assemblies. In figure 9 appears the worst noise performance corresponding to unit 3F13 starting to degrade at 45.6 GHz and maintaining that tendency throughout the upper sideband.

Figure 10 illustrates the noise figure performance at three different values of intermediate frequencies. As expected, the response is optimal at the center of the band and degrades at the upper sideband. For the unit shown (S/N 3F01) a very high noise figure value appears at 50 GHz for an IF of 9 GHz, following the same tendency of performance degradation at the upper sideband. In figure 11 the variations in noise figure values are shown against LO power level. As it is known, the conversion loss will change slightly when the local oscillator power level deviates from the recommended level.

Just to give a general idea about the performance of the complete set of mixer assemblies, in figure 12 is shown the noise figure response for several units, while in figure 13 the conversion loss for the same units is illustrated. The same tendency to degrade at the upper sideband (especially for noise figure and above 46 GHz) is noticed in a great percentage of the complete set of units.

It was believed that this degradation in performance was due to some mismatches between components of the mixer assembly, possibly caused for variations in waveguide sizes, variations in cavities dimensions or variations in the filters and circulators. These units were sent to the manufacturer for evaluation of those aspects and when the units were sent back the measurements were repeated.

Figures 14 and 15 present the results obtained with units S/N 3F06 and 3F13. As can be seen the noise figure performance has been improved giving a flatter response across the band. To check for possible discontinuities in the performance at intermediate frequency points, conversion loss measurements were made at smaller intervals with the results shown in figures 16 and 17. As is shown, unit S/N 3f17 has a very nice response with C.L. below 7 dB up to 48 GHz, but has a big jump at 49 and 50 GHz.

Finally, figures 18 and 19 show the conversion loss performance with changes in R.F. signal level and L.O. power level respectively, both responses showing an adequate dynamic range in the two power levels.

Conclusions

Based on the above results it is concluded that the reworked and new units have better and more reliable performance than the first set of units. A complete characterization of these devices is required in order to have a good lot of mixer assemblies with very similar responses because for the present application they are used in pairs and their characteristics must be very close to each other, so they can be used properly as the conversion elements in wide-band, low-noise receivers for 6 mm radioastronomy.

REFERENCES

[1] Norrod, R. and Masterman, M., "Model F110, 43 GHz cryogenic front-end", VLBA Tech. Rep. No. 11, NRAO, June 11, 1991.
[2] Adam, S.F., Microwave Theory and Applications, Prentice Hall, 1969.
[3] Maas, S.A ., Microwave Mixers, 2nd Ed., Artech House, 1993.

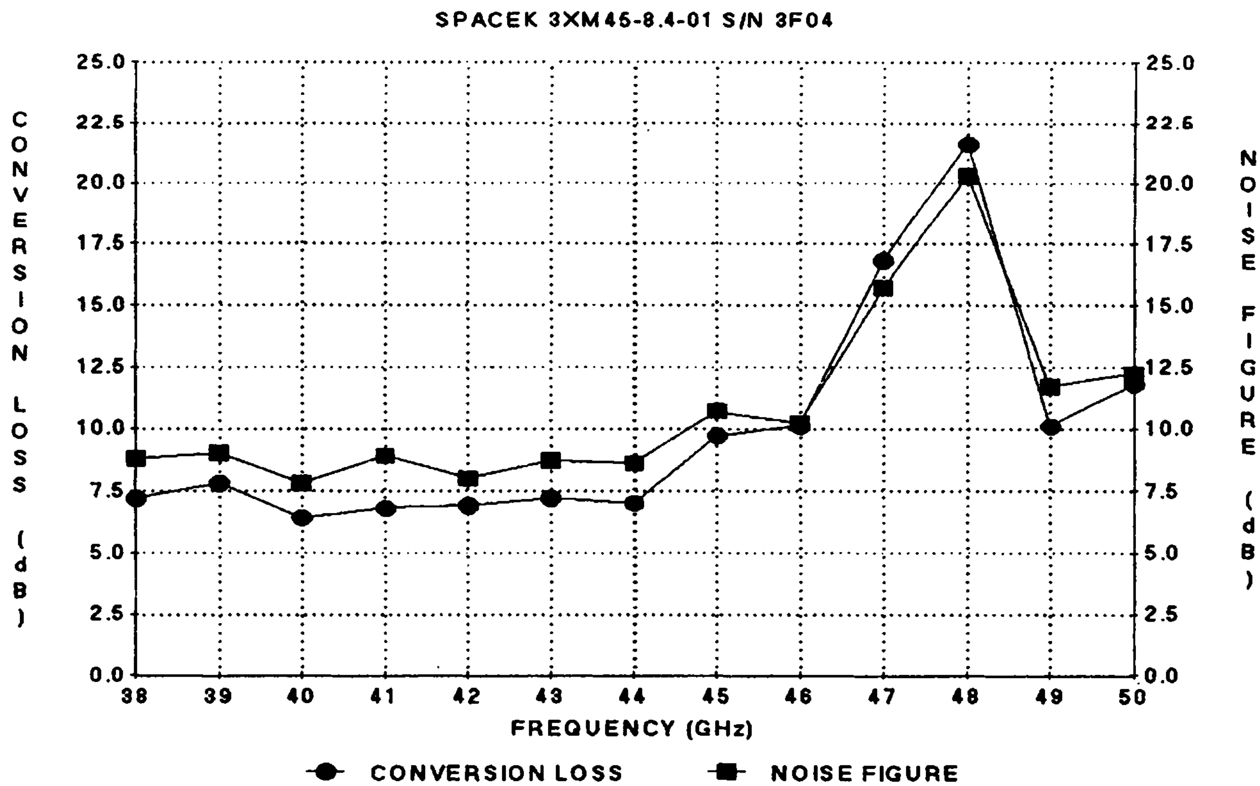

FIGURE 4. NOISE FIGURE-CONVERSION LOSS DEGRADATION AT UPPER SIDEBAND

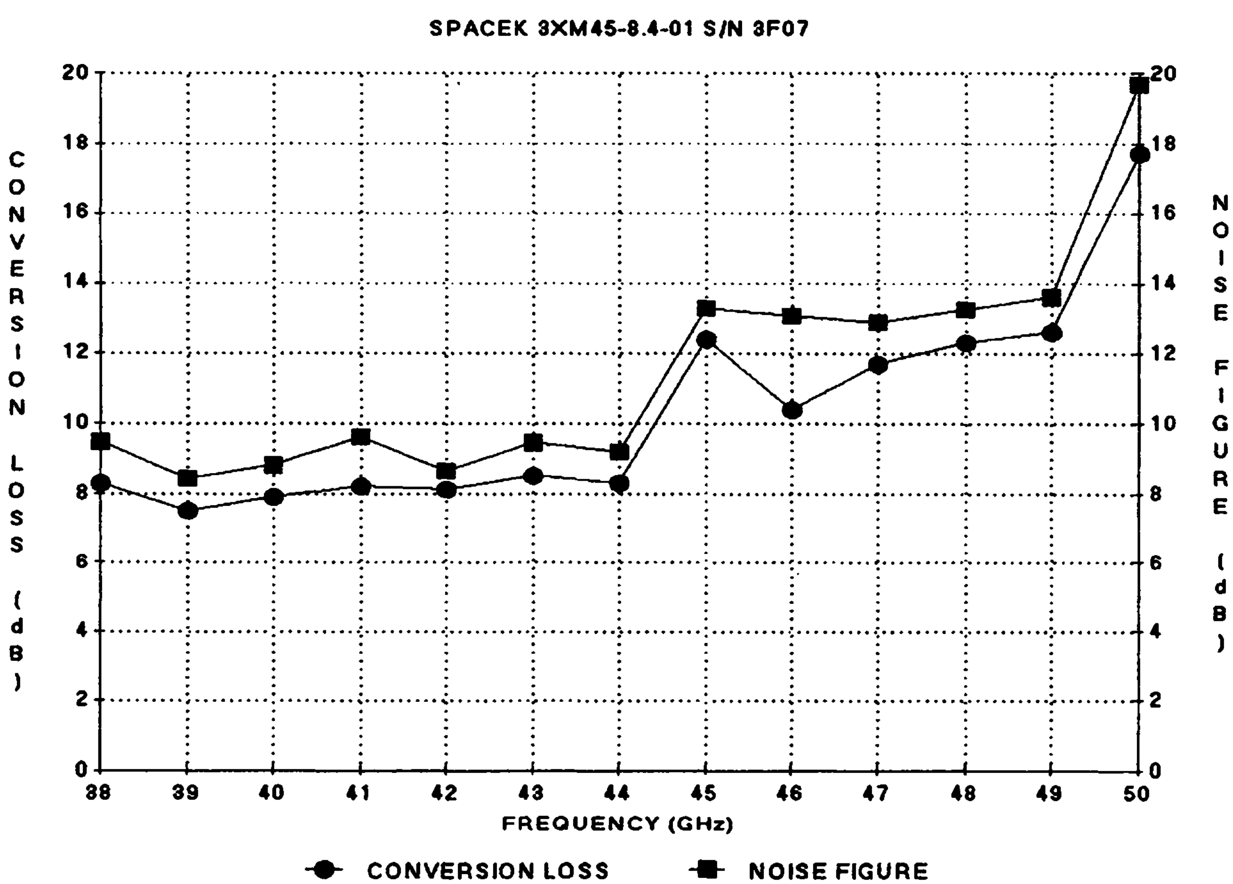

FIGURE 5. DEGRADED PERFORMANCE AT UPPER SIDEBAND

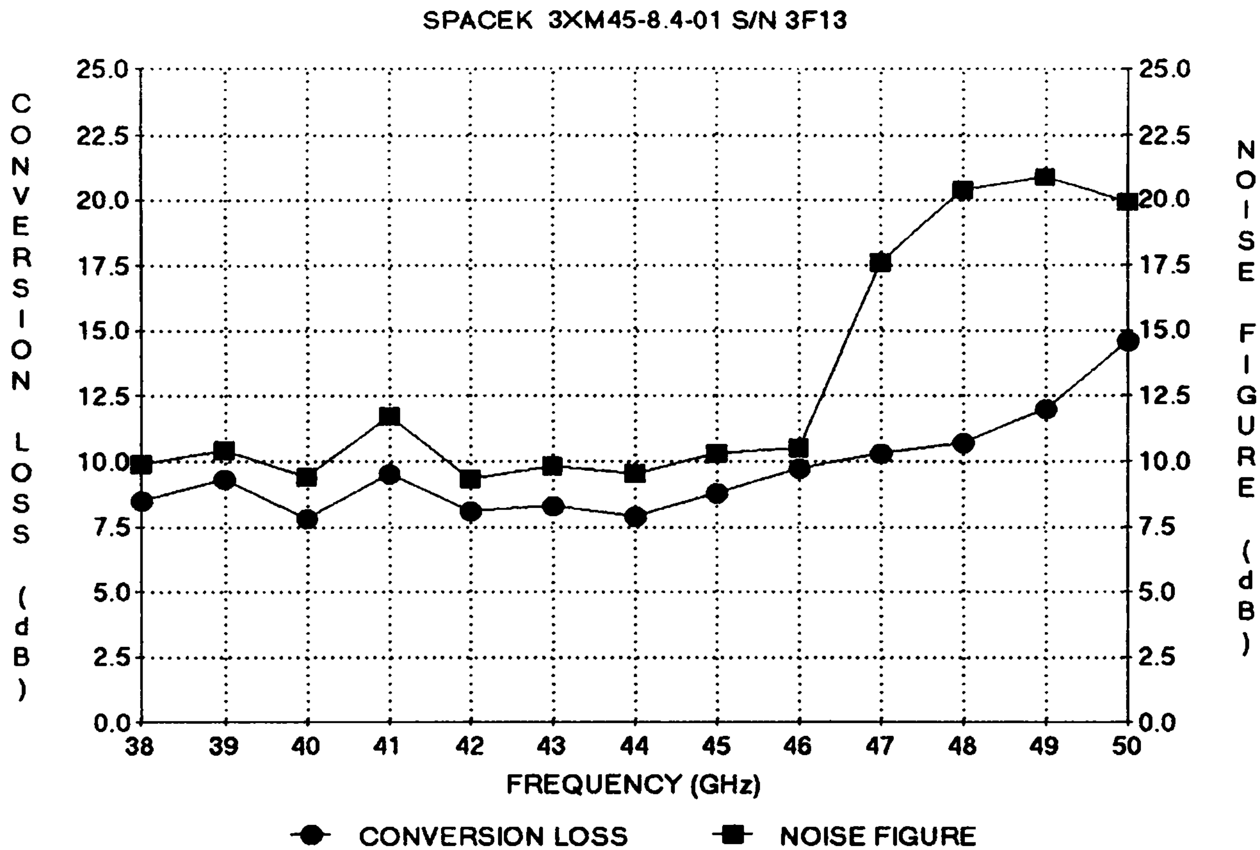

FIGURE 6. NOISE FIGURE PERFORMANCE DEGRADED AT UPPER SIDEBAND

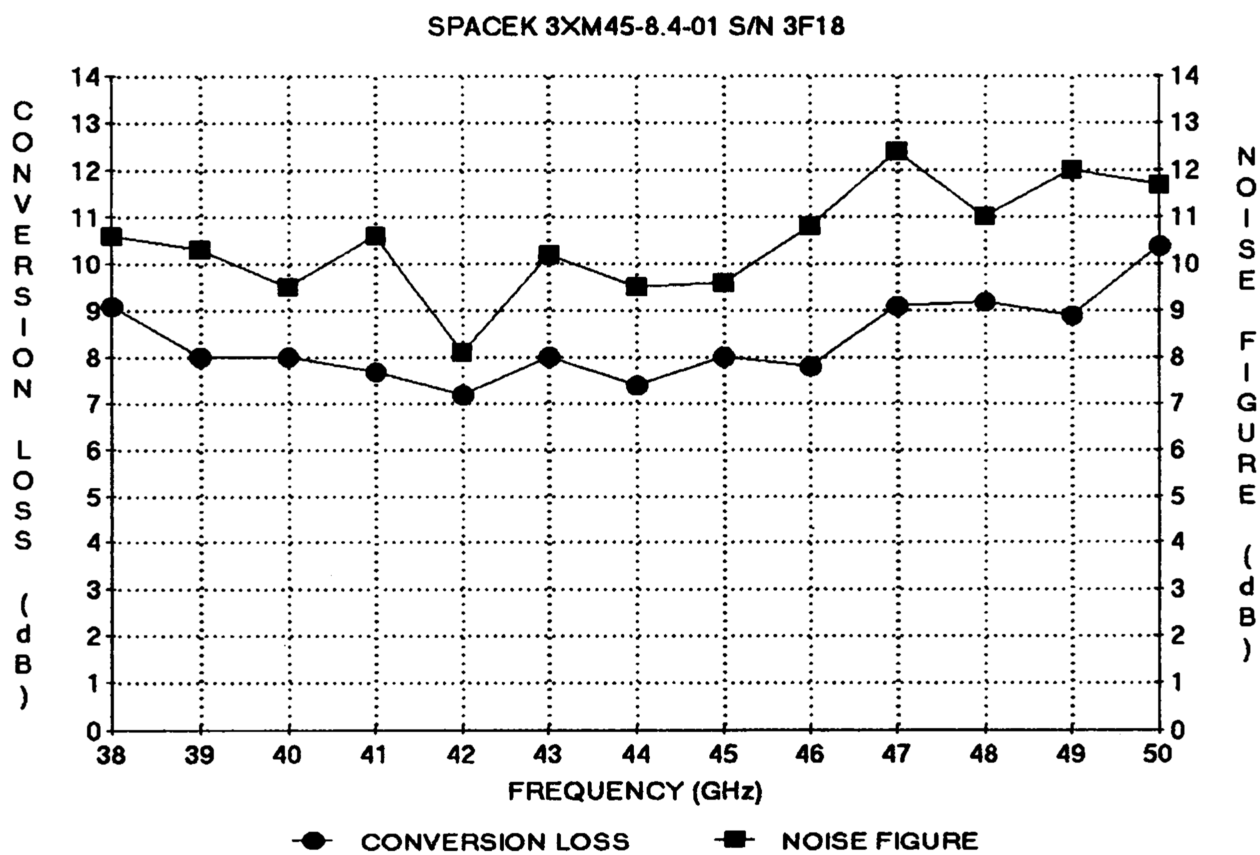

FIGURE 7. BEST NOISE FIGURE AND CONVERSION LOSS PERFORMANCE

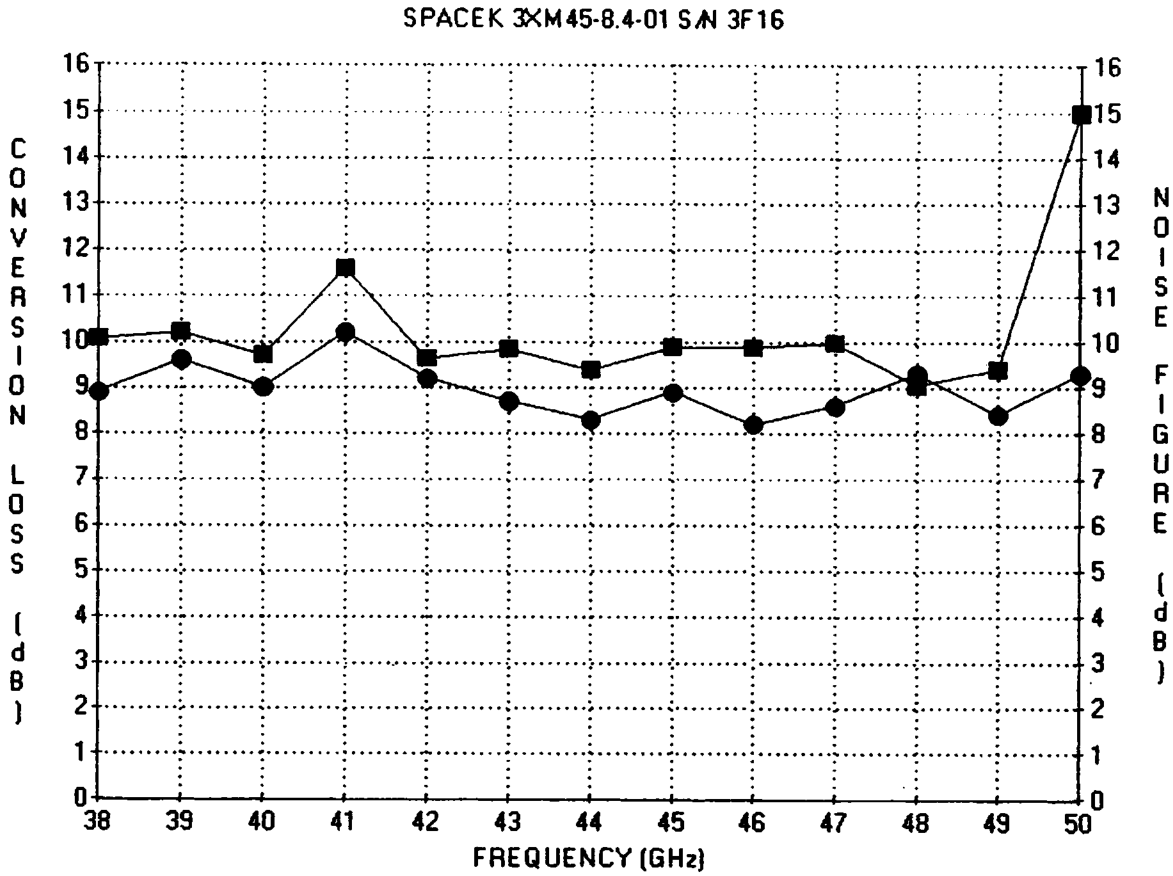

FIGURE 8. TYPICAL NOISE FIGURE AND CONVERSION LOSS

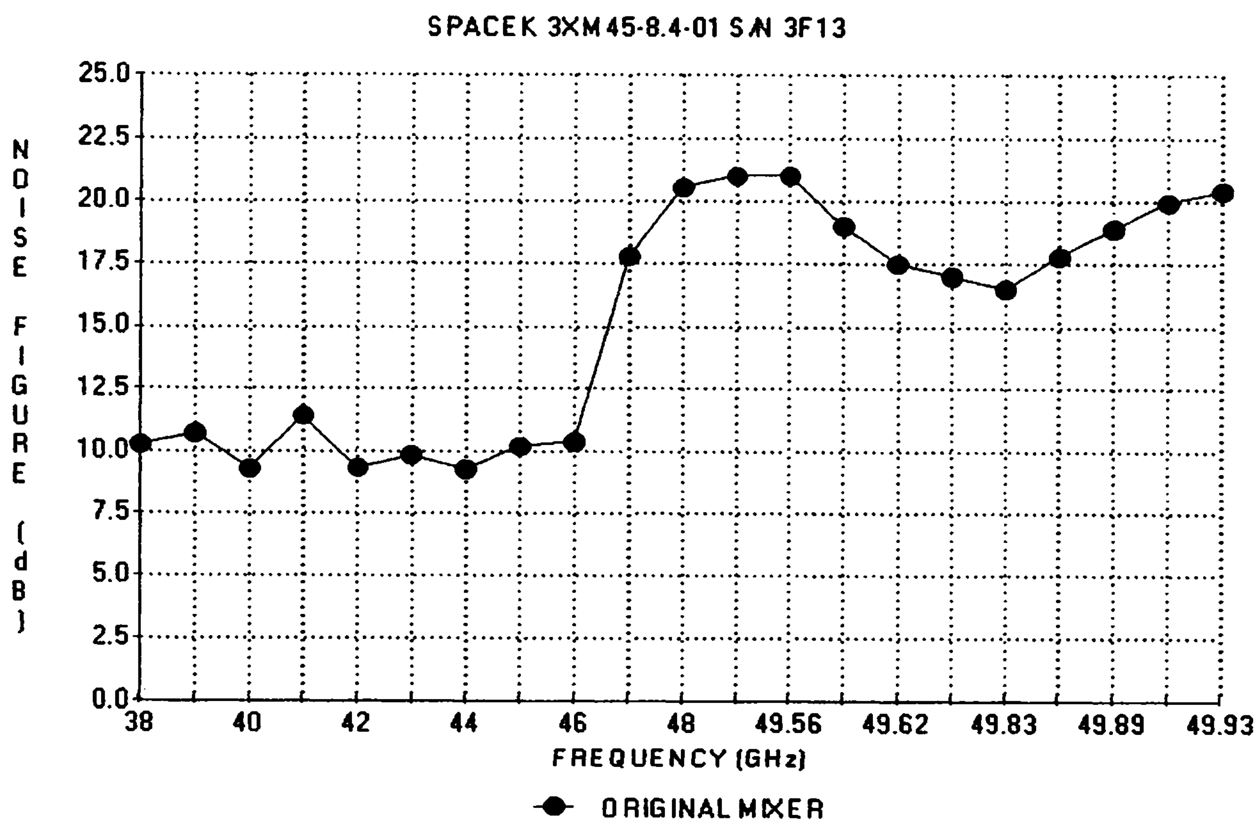

FIGURE 9. WORST NOISE PERFORMANCE AT UPPER EDGE OF THE BAND

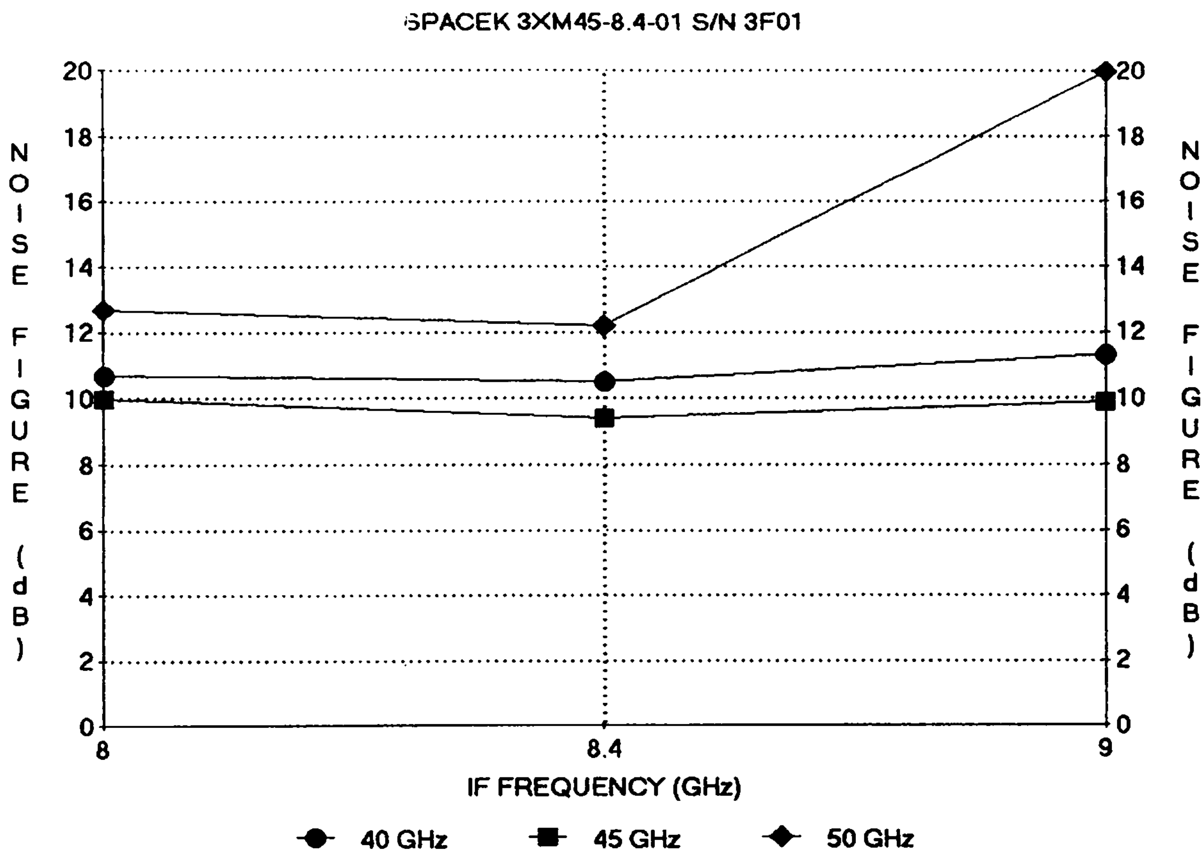

FIGURE 10. NOISE FIGURE AT THREE I.F.s

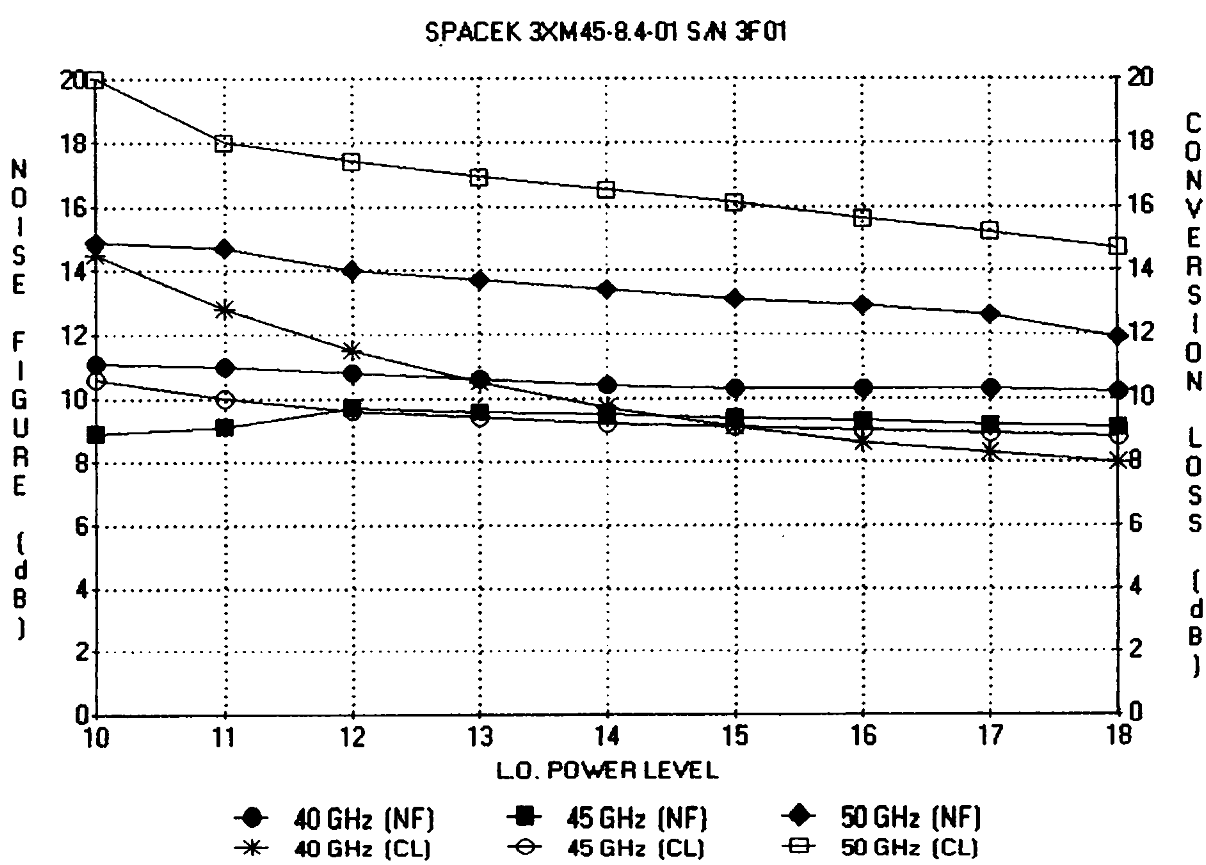

FIGURE 11. NOISE FIGURE AND CONVERSION LOSS VS LO POWER LEVEL

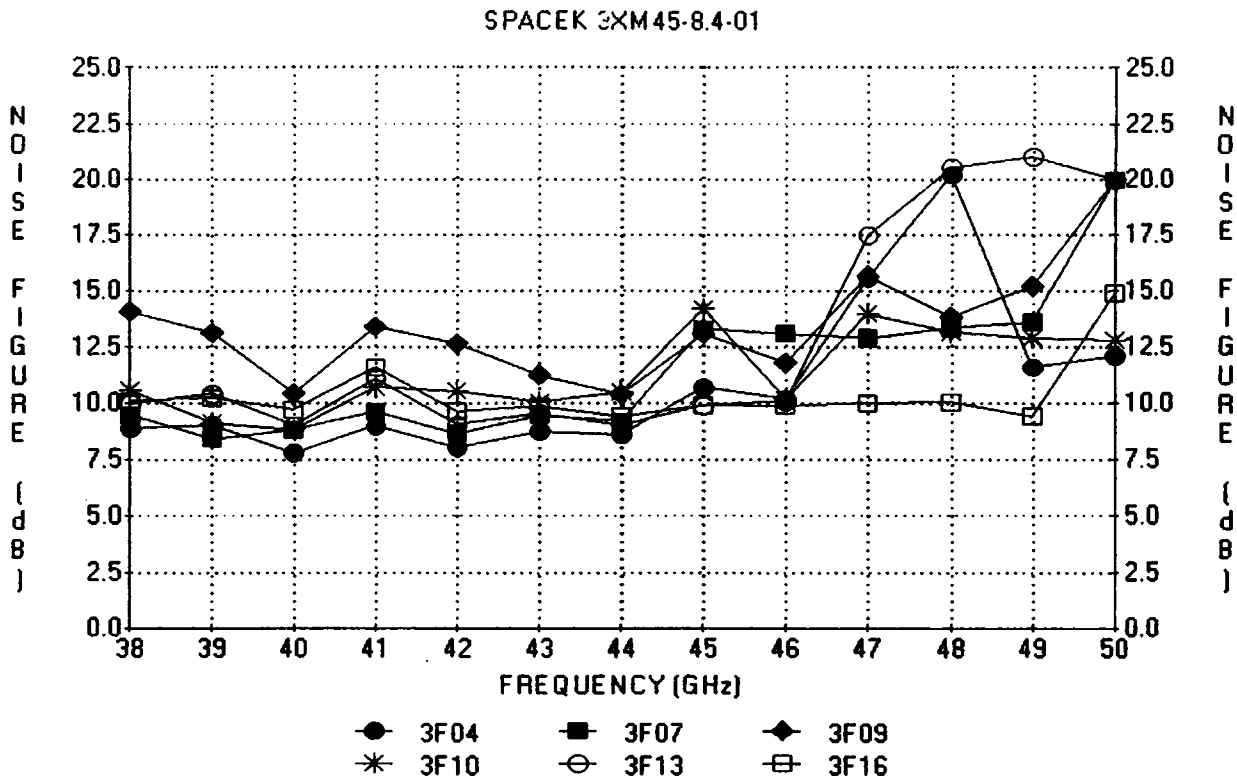

FIGURE 12. NOISE FIGURE OF SEVERAL UNITS

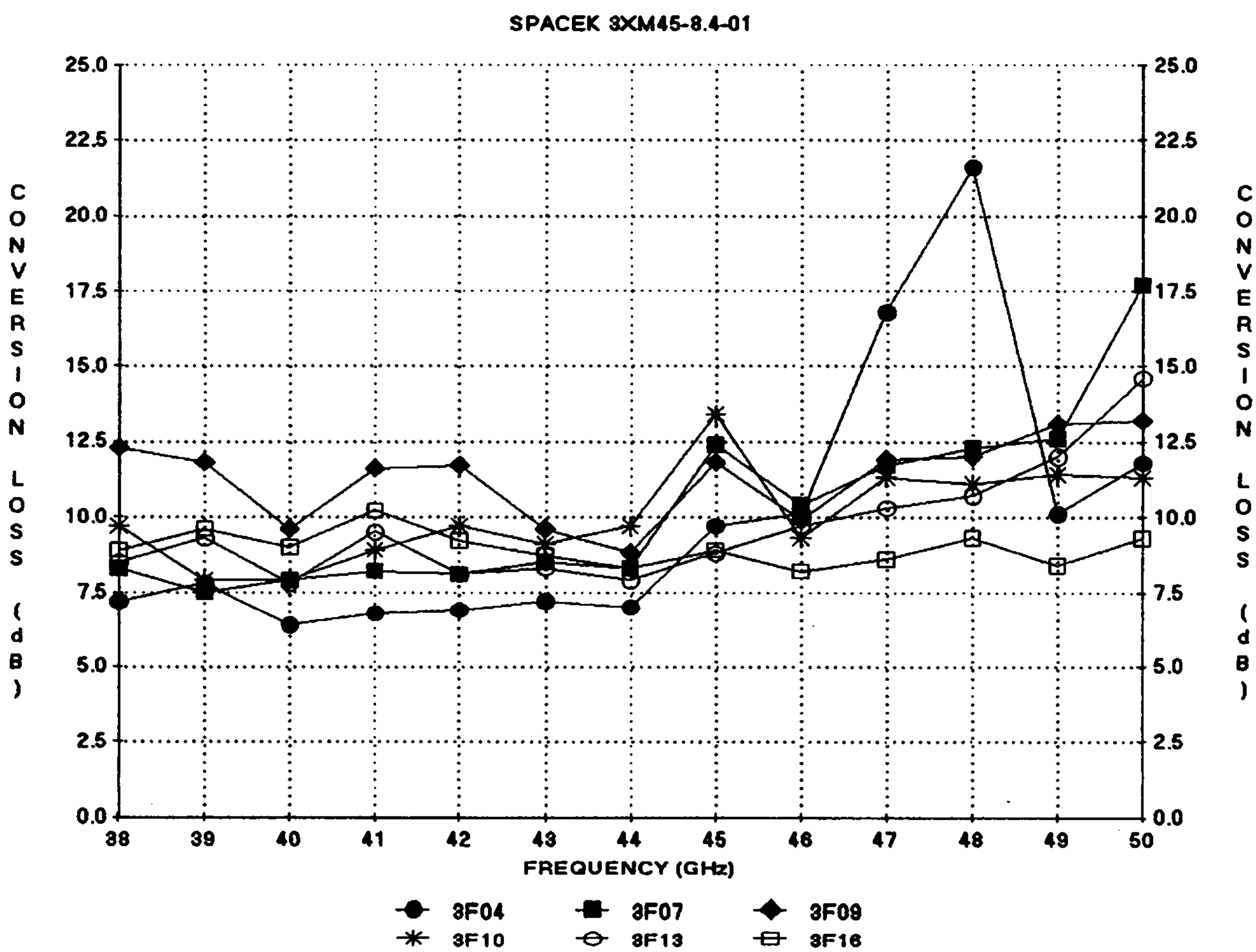

FIGURE 13. CONVERSION LOSS OF SEVERAL UNITS

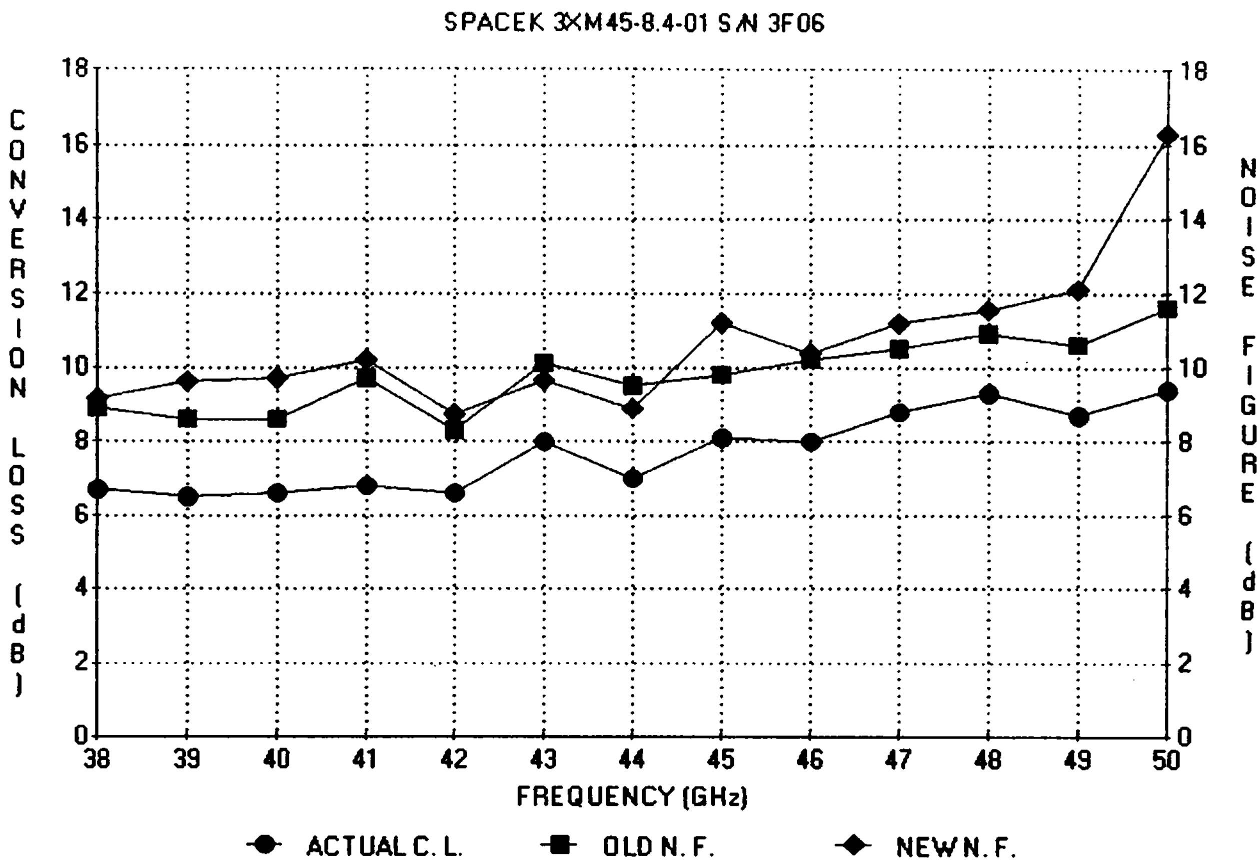

FIGURE 14. REWORKED UNIT PERFORMANCE

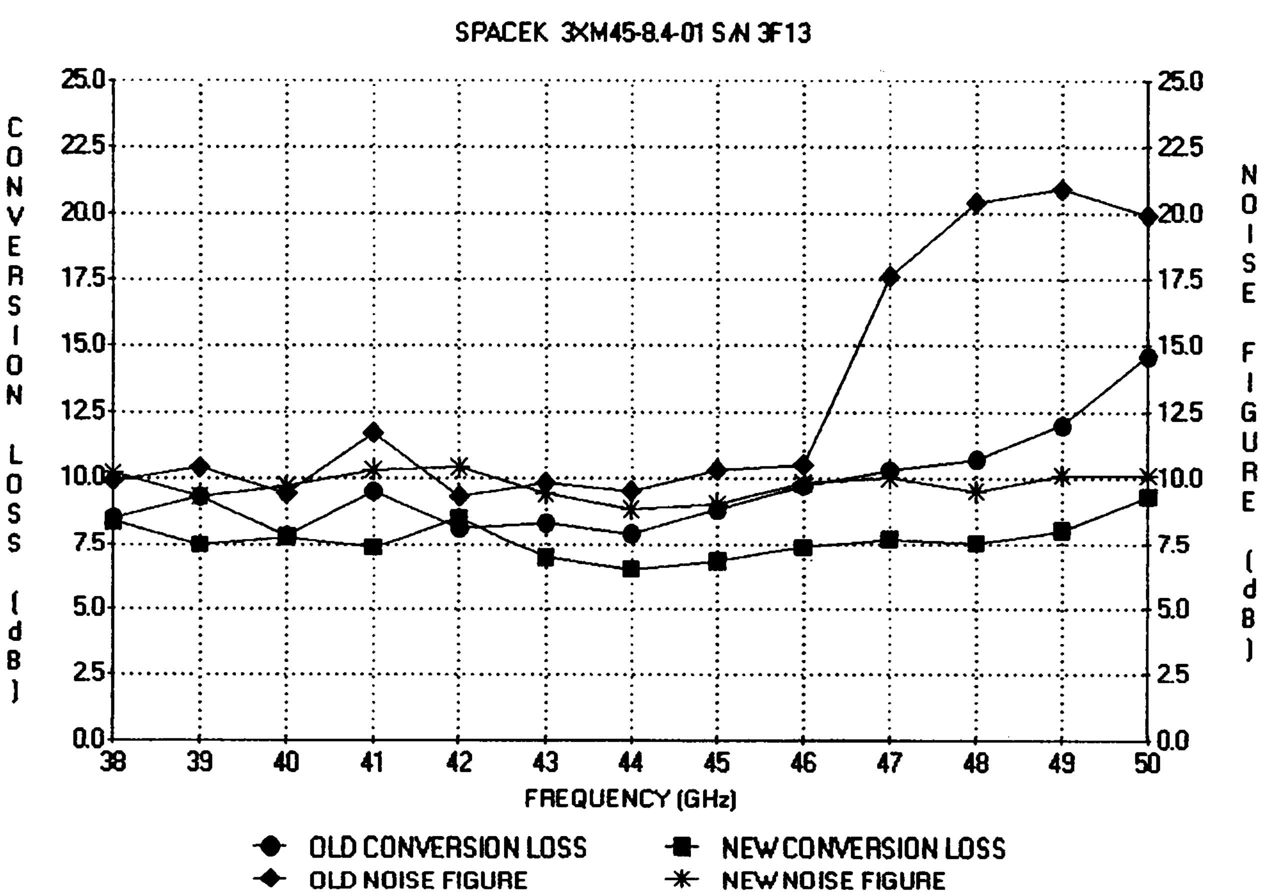

FIGURE 15. PERFORMANCE BEFORE AND AFTER REWORK THIS UNIT

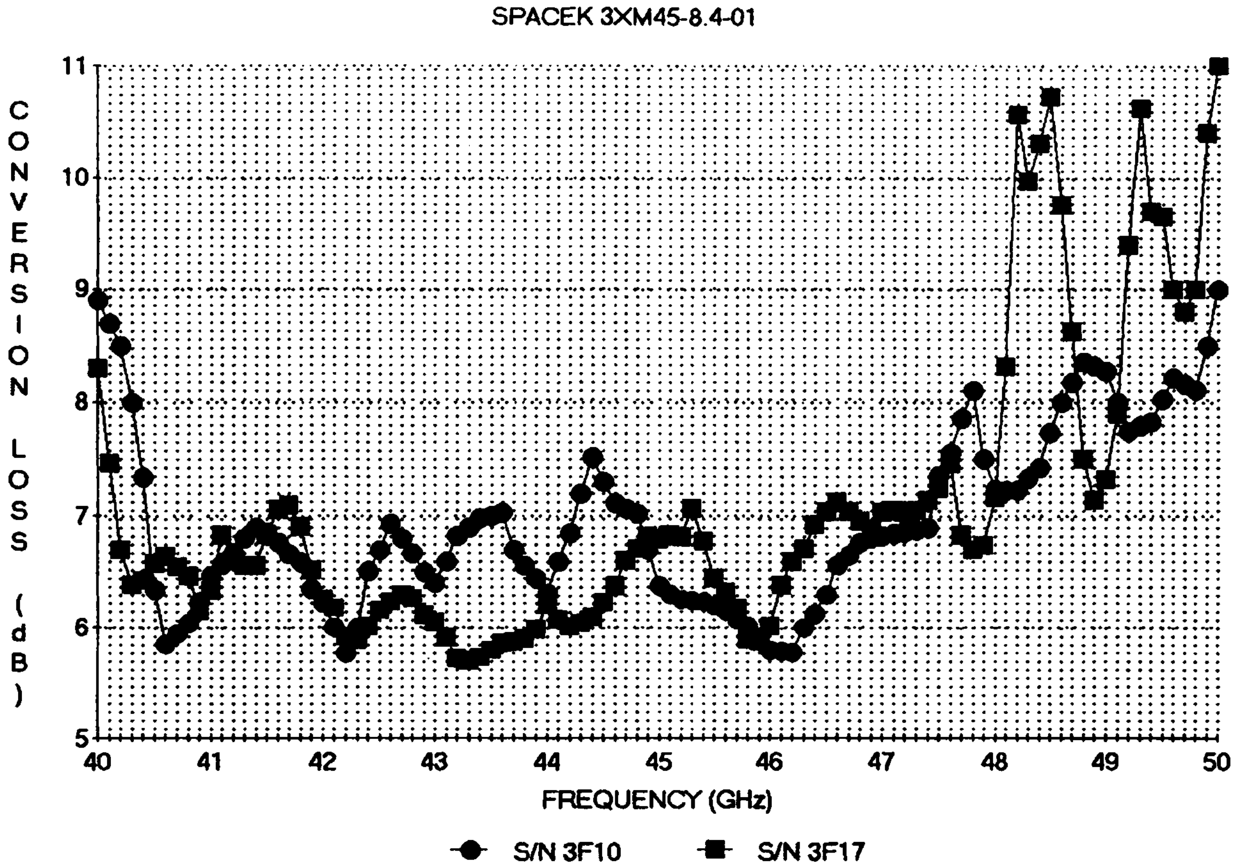

FIGURE 16. CONVERSION LOSS MEASUREMENTS AT SMALLER INTERVALS

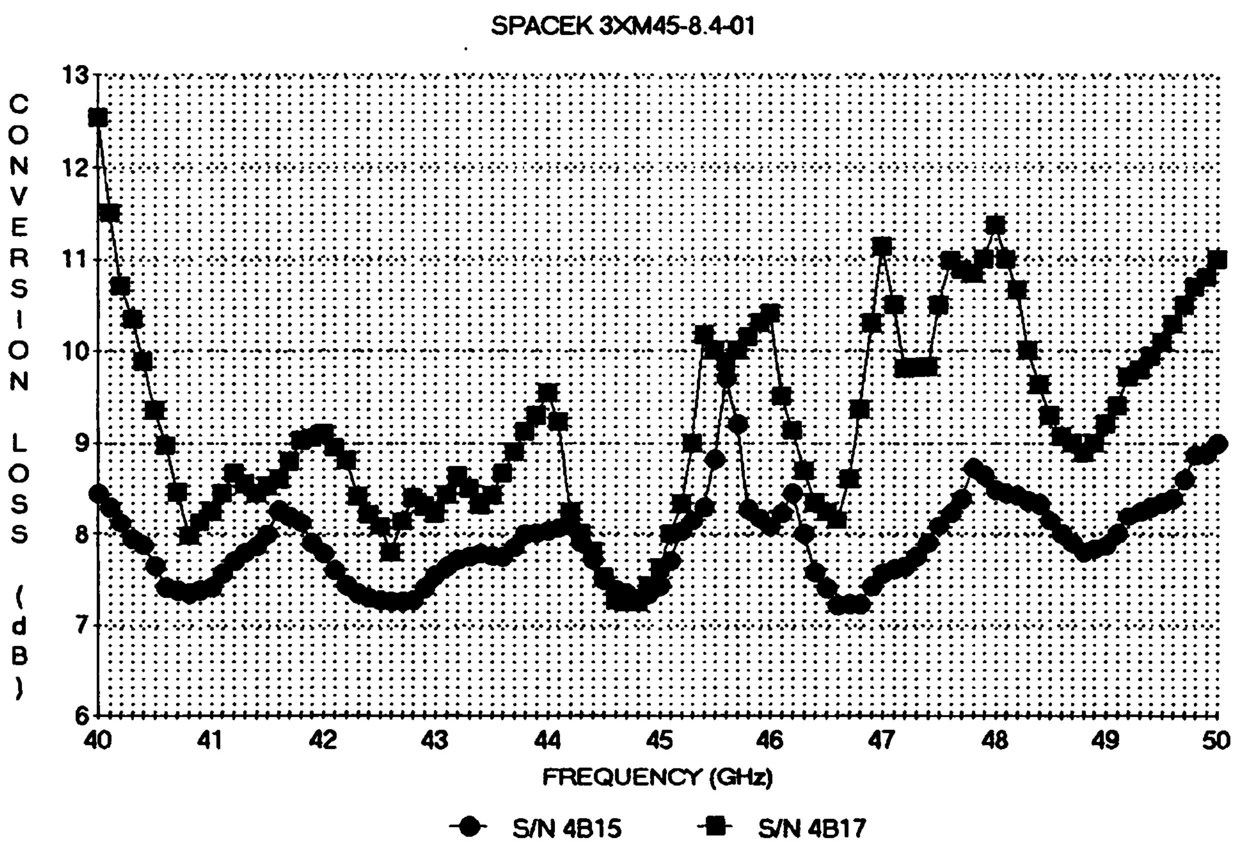

FIGURE 17. CONVERSION LOSS MEASUREMENTS AT SMALLER INTERVALS

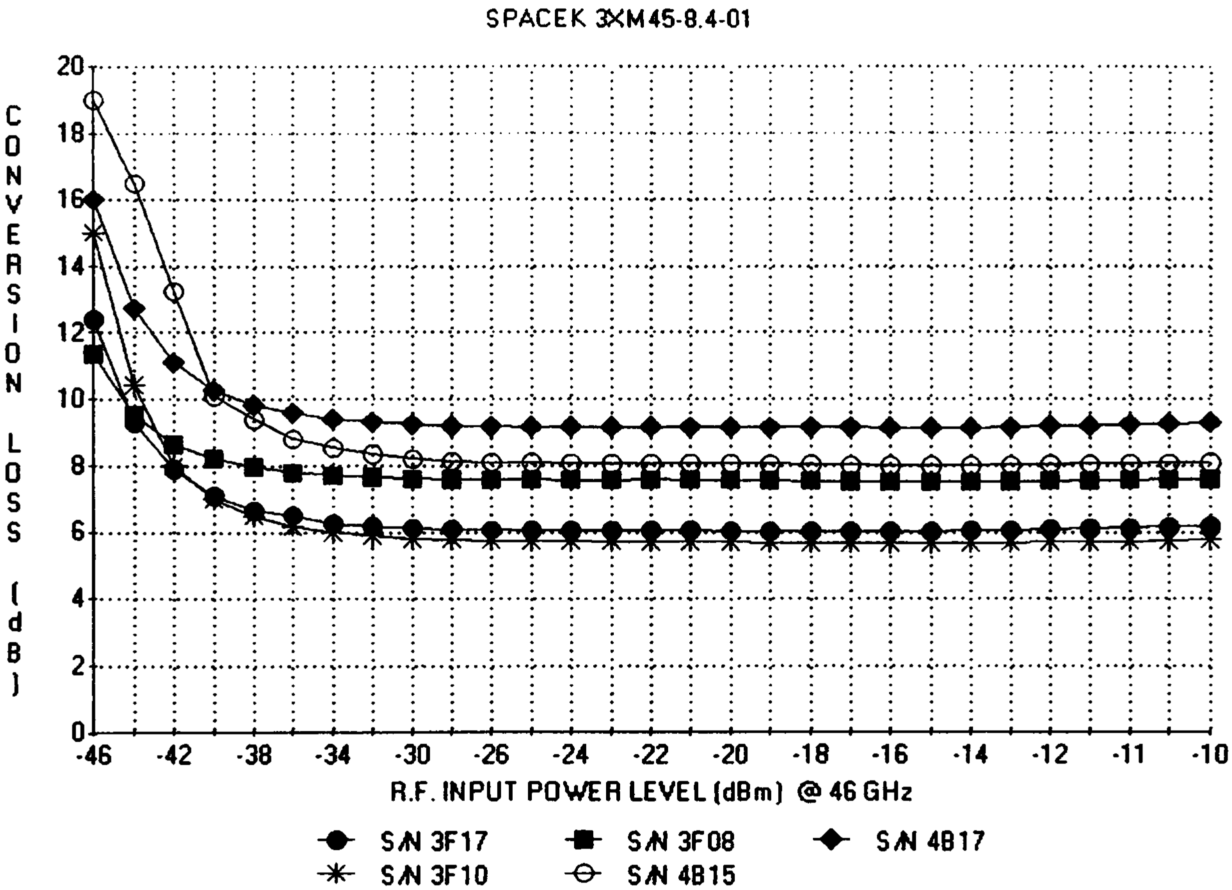

FIGURE 18. CONVERSION LOSS VS RF INPUT LEVEL

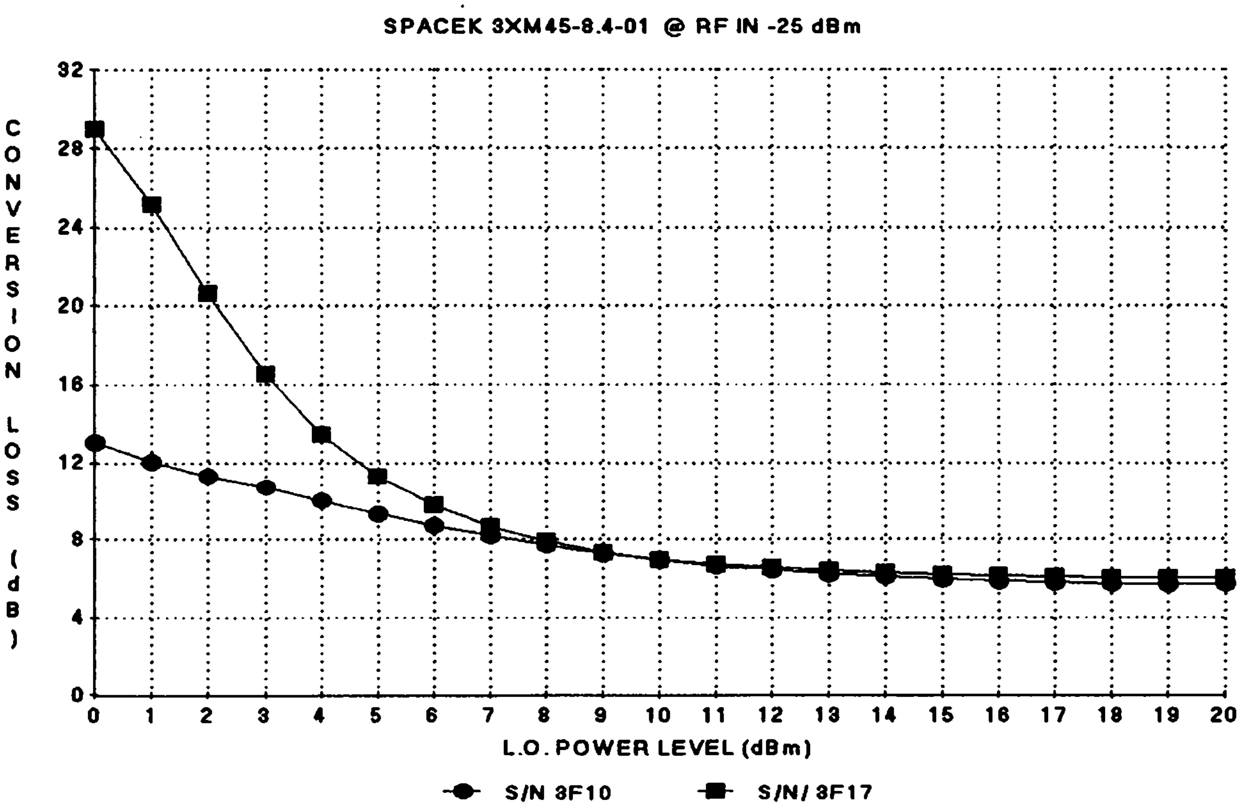

FIGURE 19. CONVERSION LOSS VS L.O. POWER LEVEL