Noise Bursts and Intermodulation Products Caused by Multiple Carriers at X-Band

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Projections for space exploration in the next few years call for several vehicles at Mars at the same time. Since all these vehicles will be in the field of view of a single DSN antenna, it would be advantageous if more than one carrier could be transmitted at the same time. Previous experience at S-band (2110 to 2120 MHz) indicated that multiple-uplink carriers would generate noise bursts and intermodulation products (IMP) under certain conditions. This article describes some experiments done on the beam waveguide (BWG) at DSS 13 looking for these effects at X-band (7145 to 7190 MHz).

Two carriers produced both noise bursts and IMP at 10 kW/carrier, IMP without noise bursts at 7 kW/carrier, and neither noise bursts nor IMP at 5 kW/carrier. Three carriers produced small amounts of IMP without noise bursts at 6 kW/carrier (the upper limit of our ability to test). The preliminary conclusion is that a system using two or three carriers at 5 kW/carrier would probably work satisfactorily, but additional testing is required before committing to such a system.

I. Introduction

The idea of communicating with multiple spacecraft at Mars with a single antenna was thoroughly explored in the 1970s [1]. At that time, the uplink frequency was S-band (2110 to 2120 MHz), and the conclusion was that it could be done but that it involved very close attention to the preparation and maintenance of all the areas of the antennas exposed to high radio frequency (RF) power to avoid the creation of noise bursts and intermodulation products (IMP). Later work using one carrier at S-band and one at X-band (7145 to 7190 MHz) did not find any IMP problem [2], but so far no one had investigated the effect of using two or more X-band carriers.

II. Test Configuration

Figure 1 is a block diagram of the test configuration. Three synthesizers connected to the input of the 20-kW X-band transmitter are set at $F_1 = 7151.910$ MHz, $F_2 = 7161.157$ MHz, and $F_3 = 7176.184$ MHz. For the single-carrier test, the frequency F_3 is used. The two-carrier test uses frequencies F_1 and F_3, and the three-carrier test uses all three frequencies. In all cases, the levels are adjusted so that total

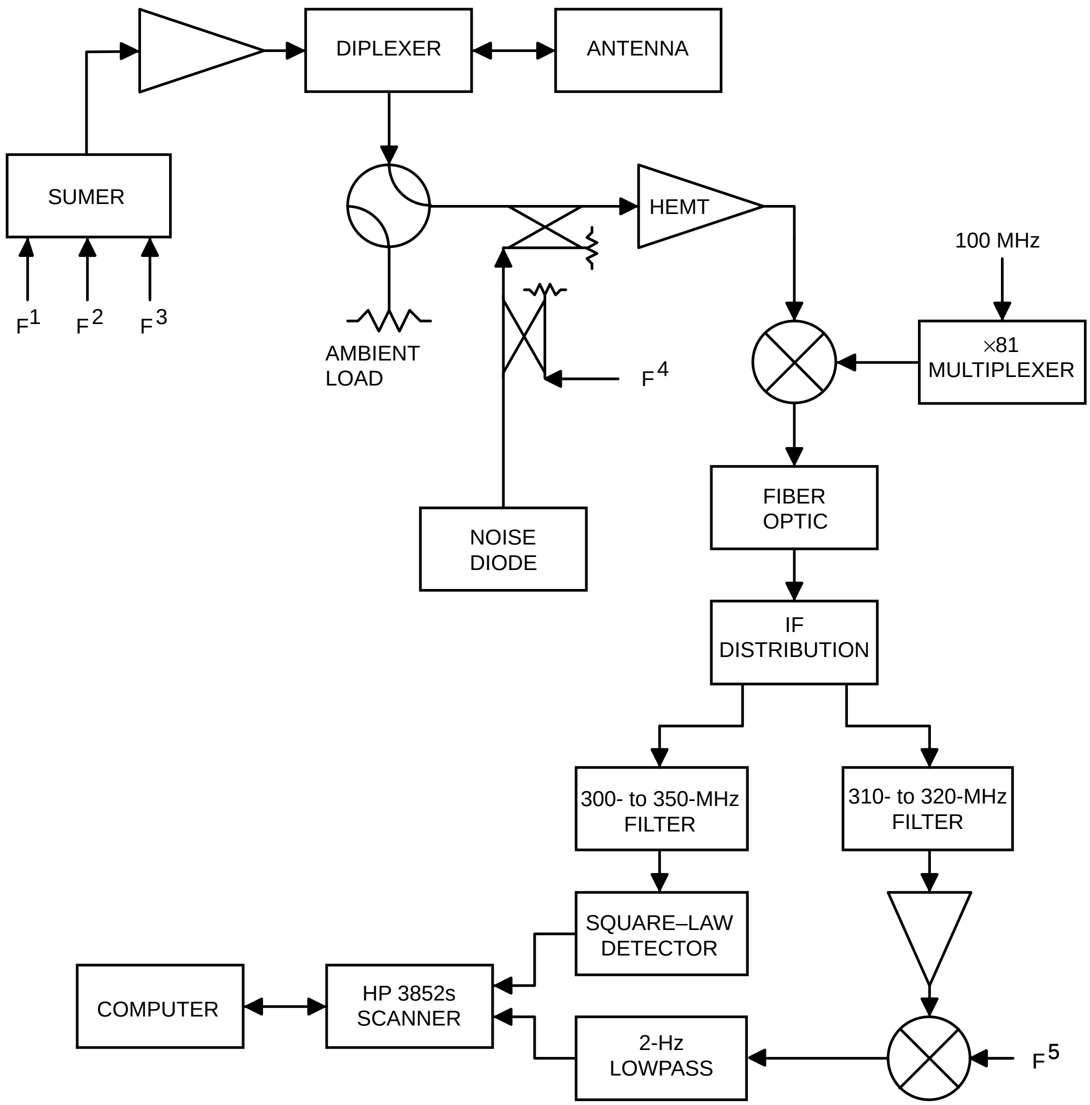

Fig. 1. Diagram of the multicarrier test configuration.

transmitter power is more or less evenly divided among the number of carriers being used. There is some nonlinearity in the transmitter, which limits the total power available in the presence of multiple carriers. The maximum power is 22 kW for a single carrier, 20 kW for two carriers (or 10 kW/carrier), and 18 kW for three carriers (6 kW/carrier.)

The IMP at $F_4 = 8414.158$ MHz $= 52 \times F_3 - 51 \times F_1$ is the lowest-order product falling in the receive band for both the two-carrier and three-carrier tests. The order of an IMP is the sum of the multiples of the frequency components required to produce it, so this one has the order of $52 + 51 = 103$. We chose the spacing between F_1 and F_3 to be fairly large to reduce the order of the first IMP falling in the receive band. Frequency F_4 is both the frequency of the expected IMP and the frequency of the calibration signal injected into the high electron mobility transistor (HEMT), a type of low-noise amplifier.

Two outputs of the station intermediate frequency (IF) distribution system were used. One was filtered with a 300- to 350-MHz bandpass (which corresponds to the receive band at 8400 to 8450 MHz) and then detected with a broadband square-law detector. This is our “wideband channel.” The other IF was downconverted with a synthesizer set at the frequency $F_5 = 314.158001$ MHz so that the IMP at F_4 will be converted to 1 Hz at baseband and filtered with a 2-Hz lowpass filter. This is our "narrowband channel." The outputs of both narrowband channels were sampled and recorded at about 5 Hz. The wideband channel was calibrated in terms of system noise temperature by comparison of its output with the system radiometer under the following conditions:

(1) Out of the horn, with a system noise temperature of about 38 K.

(2) Out of the horn, with the noise diode on for a system noise temperature of about 58 K.

(3) With the ambient load connected to the HEMT for a system noise temperature of about 300 K.

The narrowband channel was calibrated by injecting a signal at two different known levels, injected at F_4. It was also correlated to the system noise temperature. Comparison of these methods gave an equivalent noise power at the input of -172 dBm and a noise bandwidth of 10 Hz.

Our authorization to radiate was only for operation at zenith, so all tests were conducted that way. The antenna was moved in azimuth during two tests, but no changes were observed due to the motion.

III. Single-Carrier Results

Several tests were made with a total RF power of 22 kW in a single carrier at F_3. No IMP generation is possible with a single carrier, and no noise bursts were detected. This result is consistent with previous tests. The system noise temperature was 38 K, and the equivalent noise power in the narrowband channel was -172 dBm.

IV. Two-Carrier Results

Two-carrier tests were done at a total RF power of 20, 14 and 10 kW. In each case, the total power was equally divided between F_1 and F_3, so that the individual carrier powers were 10, 7 and 5 kW. Substantial amounts of noise and IMP were detected. Figure 2 is a plot of the wideband detector output converted to system temperature during one such test. The transmitter is off at the start of the data record and is turned on at the 20-kW level 30 s into the run. This results in an immediate jump of almost 5 K. The transmitter was also turned off from 360 s to 420 s to verify that the effect was real. Figure 3 shows the power in the narrowband channel for the same run. This shows the power in the one particular IMP being measured briefly reaching a level of -136 dBm and a level of -145 dBm for almost a minute. The power returns to the normal background level of -172 dBm when the transmitter is off.

Figure 4 is the system noise temperature as measured by the wideband channel at three different transmitter power levels. The power was 20 kW at the start of the test and was reduced to 10 kW at 180 s, showing an immediate reduction in the temperature. At 600 s, the power was increased to 14 kW. Figure 5 shows the corresponding IMP power. This figure shows that even though the system noise does not change when the level is increased to 14 kW, the IMP is created at that level. A spectrum of the narrowband channel can be obtained by treating the sampled data as a sequence of fixed-length records, and then taking the fast Fourier transform (FFT) of each of these records to generate a two-dimensional plot showing spectral distribution as a function of time. Figure 6 presents this type of plot for the first 200 s of the test. Although there is some spectral distribution, there is a clear concentration of power along the 1-Hz line, which proves that it is from an IMP and that all of the synthesizers used in the system are properly set. The 1-Hz IMP disappears immediately at 180 s, when the power per carrier was reduced from 10 kW to 5 kW.

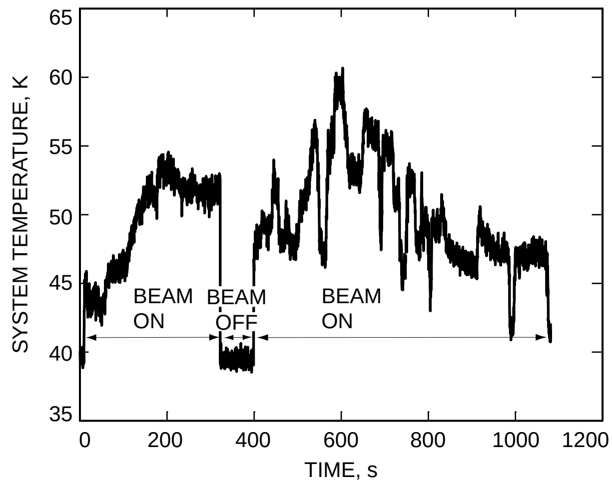

Fig. 2. System noise temperature as a function of time with two carriers at 10 kW each.

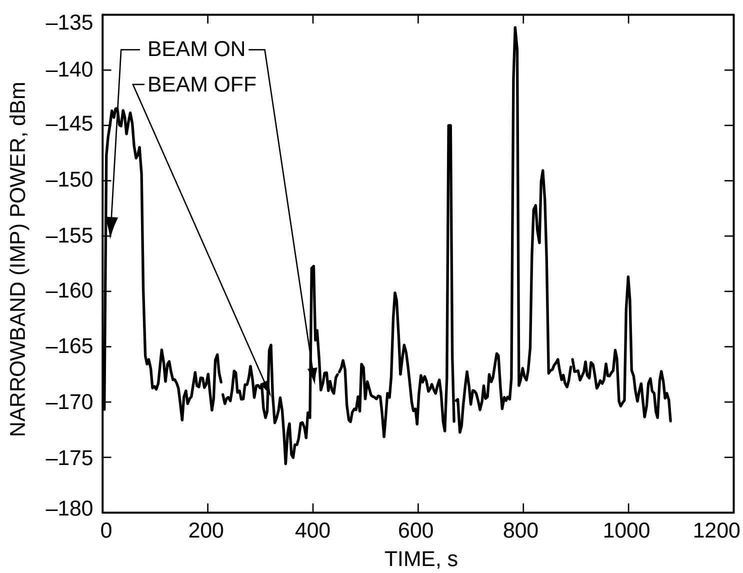

Fig. 3. Narrowband power measured at the predicted IMP frequency with two carriers at 10 kW each.

V. Three-Carrier Tests

The three-carrier tests are less dramatic. The maximum power available from the transmitter was only 17.8 kW when three carriers were present, resulting in a power per carrier of less than 6 kW. There were four runs at this power, each about 22 min in length, for a total test time of 88 min. During this time, there was a total of two IMP events, each at a level of about −165 dBm and lasting about 20 s. Figure 7 shows the narrowband power trace of one of the events, and Figure 8 is a close-up of its spectral distribution, which shows some clustering of power around 1 Hz.

No significant response was observed in the wideband channel during any of the three-carrier tests. The fact that so few episodes of IMP creation were observed indicates that the maximum available power of 5.93 kW per carrier is at or below the level where the effect begins. This is consistent with the two-carrier tests that showed a dramatic increase in IMP between 5 kW per carrier and 7 kW per carrier.

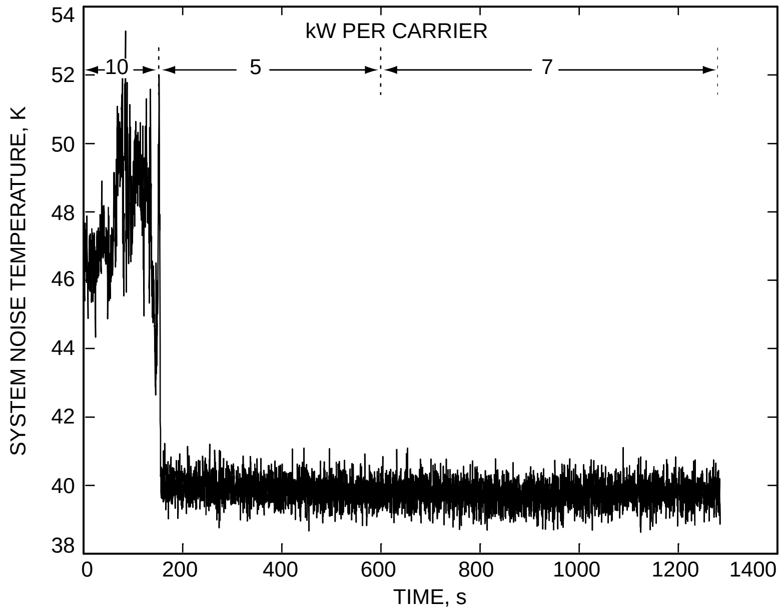

Fig. 4. System noise temperature during the two-carrier test at zenith. The power per carrier at the start of the test was 10 kW. At 180 s, it was reduced to 5 kW, and at 600 s it was increased to 7 kW.

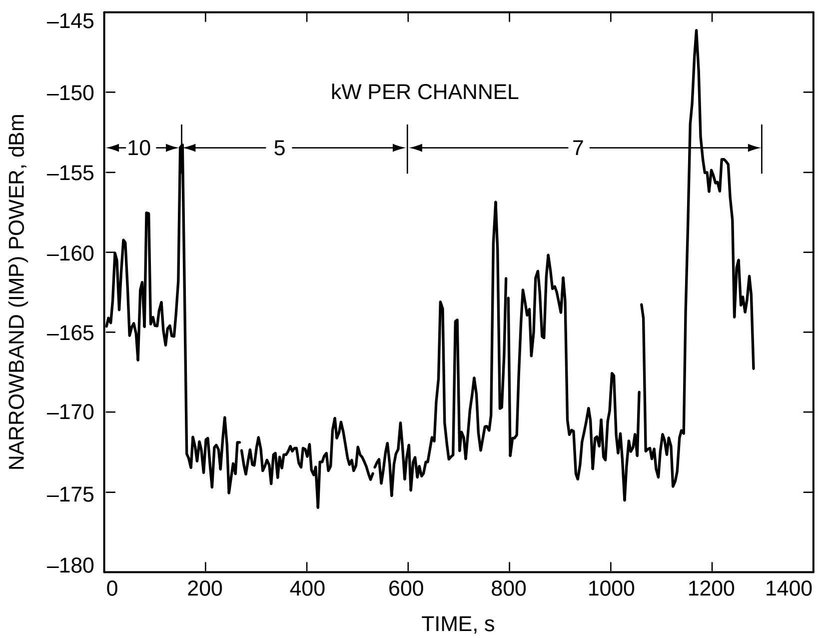

Fig. 5. Measured IMP power during the same test as in Fig. 4.

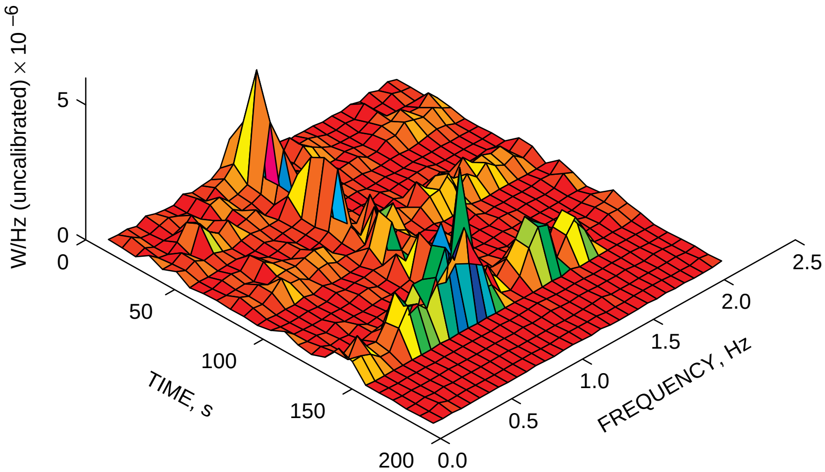

Fig. 6. Spectral distibution of power in the narrowband channel for the first 200 s of the test shown in Fig. 4, showing the concentration of IMP power at 1 Hz and the cessation of IMP when power per carrier was reduced from 10 kW to 5 kW.

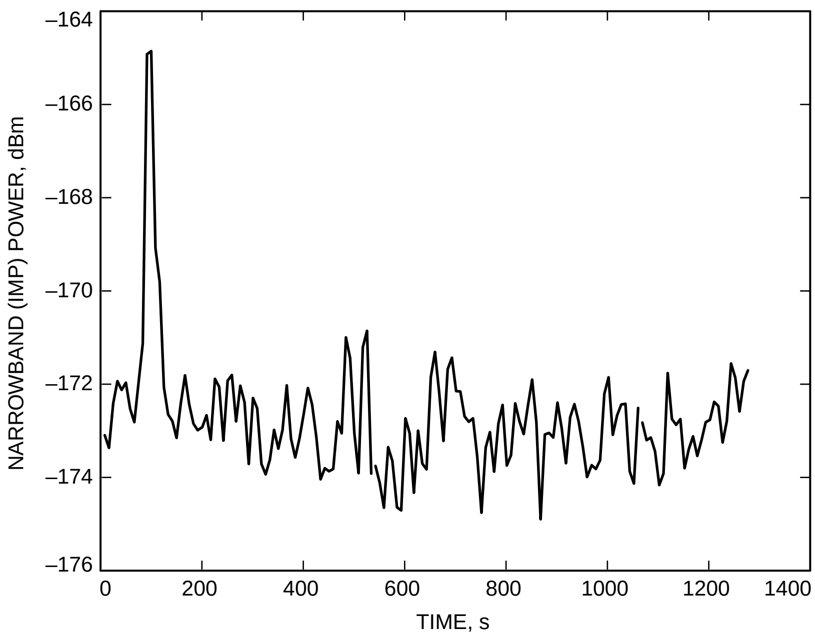

Fig. 7. Narrowband (IMP) channel power during one of the three-carrier tests, showing a single 20-s event.

VI. Conclusion

Table 1 is a summary of the results as a function of the number of carriers and the power per carrier. From these data, we can conclude that, in the specific configuration and under the conditions tested, the DSS-13 BWG antenna is free of noise bursts with a single continuous-wave (CW) carrier up to 22 kW. In the presence of either two or three carriers, IMP creation begins at about 6 kW per carrier.

The fact that substantial IMPs were observed at 7 kW per carrier shows that IMPs can be created on a relatively clean BWG antenna, and that the problem occurs at lower levels than were found in previous

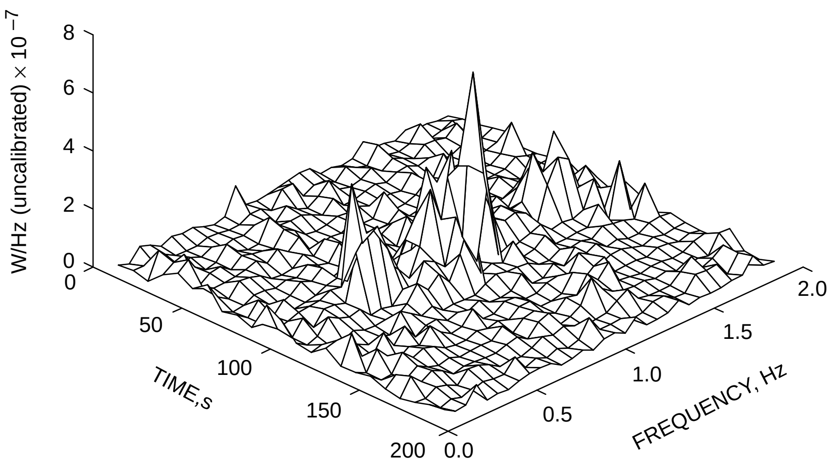

Fig. 8. Spectral distribution of power for the event shown in Fig. 7.

Table 1. Summary of X-band noise-burst and IMP tests at DSS 13, February 5 and 6, 1996.

Carriers	Power per carrier, kW	Noise bursts	IMP at F_4	Peak IMP level, dBm
1	22	No	N/A	None
2	10	Yes	Constant	−137
2	7	No	Constant	−147
3	6	No	Some	−165
2	5	No	None	None

S-band measurements. The lower levels should not be too surprising, however, since this antenna is smaller than the one used for the S-band tests. In fact, the power-per-antenna area for IMP creation is very close to the previous results.

Unfortunately, the effects causing noise bursts and IMP creation are highly dependent on configuration and conditions, so it is impossible to conclude from the measured data that multiple carriers at 5 kW each would be safe under different conditions or on different antennas. Although it is possible that it would be satisfactory, additional testing should be done before this is committed to operational missions.

VII. Recommendations for Further Tests

The charter of the current project was simply to determine if IMP generation on a BWG antenna at X-band was likely to be a problem for transmitting separate carriers to several spacecraft. It did not include identifying the specific part of the antenna causing the IMP or taking any corrective action. In particular, we did not do a thorough visual inspection of the antenna to see if the alignment plugs were taped over.

Future tests could isolate the offending region on the DSS-13 antenna by replacing the horn with a water load. If IMPs occur, they are in the metallic waveguide run. Also, an angled reflector could be placed at the vertex focus F_1 to direct the RF power away from the subreflector. If IMPs occur here, they are from the BWG portion of the antenna.

Since the effect being measured is dependent on so many factors, it would be worthwhile to come up with expected scenarios for the future missions so that any further testing could be limited to a configuration as close as possible to one that would actually be used for communicating with multiple spacecraft. In addition, the tests described here were all done with totally unmodulated carriers, and there is a possibility that some combination of modulation schemes would further stress the system. Future tests should concentrate on simulating realistic modulation.

Acknowledgments

These tests were done in a short time under adverse conditions on a highly committed antenna, and could not have been done without enthusiastic cooperation by the station personnel. In particular, we had George Farner climbing around the antenna with a rusty chain to simulate a noisy antenna, Juan Garnica and Gary Bury checking and rechecking the frequency distribution to find and correct frequency offset between the pedestal and control room, and Chuck Goodson rescheduling the station personnel so we could make the best use of our limited time. Thanks to all.

References

[1] D. A. Bathker, D. W. Brown, and S. M. Petty, *Single- and Dual-Carrier Microwave Noise Abatement in the Deep Space Network*, Technical Memorandum 33-733, Jet Propulsion Laboratory, Pasadena, California, August 1, 1975.

[2] A. J. Freiley, "Simultaneous S- and X-Band Uplink–Downlink Performance at DSS-13," *The Telecommunications and Data Acquisition Progress Report 42–94, April–June 1988*, Jet Propulsion Laboratory, Pasadena, California, pp. 93–101, August 15, 1988.