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STUDY OF SELF-GENERATED INTERFERENCE IN THE VLA AT L-BAND

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Broadband interfering signals of terrestrial origin have little effect on the sensitivity of the VLA unless they are strong enough to increase the system noise temperature, because they are diminished by delay resolution and are not likely to be coherent at different antennas. Narrow-band interfering signals are much more troublesome because they can maintain coherence in all the antennas and because the system requires synchronized local oscillators to be located near each antenna and front end. The presence of such narrow-band signals radiated from the local oscillator components in B-Rack has been described in VLA Electronics Memorandum No. 130. I describe here a series of experiments intended to diagnose the sources and paths for coupling narrow-band self-generated signals into the VLA in the frequency range 1350 to 1720 MHz. In particular the study is concentrated on the fairly strong signal at 1400 MHz. Such signals are referred to herein as birdies. They have observed bandwidths much less than 1 kHz and appear to be very stable in frequency.

EXPERIMENT I SPECTRUM OF RADIATION IN VERTEX ROOM

In the vertex room at antenna 5 the L-band waveguide to the A receiver was broken at the flexible section. A waveguide to coax adapter was installed on the receiver side and a second adapter connected by a short length of flexible coax to the first. The second adapter serves as an antenna which points at B-Rack, supplying its output to the A receiver. (Since the vertex room can be regarded as a closed cavity the receiver also detects any other radiation present in the room of sufficient strength.)

A Hewlett-Packard 8555 spectrum analyzer obtained the output signal at the last 4.5 to 5.0 GHz amplifier.

All the harmonics of 100 MHz in the L-band frequency range of the receiver were observable with this system. Those at 1400 and 1600 MHz were stronger than the others. Harmonics of 50 MHz were observable only at the lower end of the frequency range.

One concludes that there is potential interference from the local oscillator system at all the harmonics of 50 MHz and that these frequencies should be avoided in choosing the frequency for continuum observations.

EXPERIMENT II ORIGINS OF THE 1400 MHz BIRDY

The upconverter pump is a 3.2 GHz locked oscillator which derives its frequency and phase from 3 GHz and 200 MHz reference signals from B-Rack. In antenna 11 the 200 MHz reference signal to A-Rack is replaced by an HP8640B signal generator. Thus the amplitude and frequency of the signal are adjustable; and the signal generator is set about 5 kHz above the normal value. The noise calibration input to the input directional coupler of receiver A is replaced by a coaxial line to the comb generator output of B-Rack. The HP8555 spectrum analyzer is tuned to 4600 MHz (the corresponding L-band frequency is 1400) and connected to the output of the 4.5 to 5.0 GHz transistor amplifier of receiver A. Figure 1 gives a diagramatic spectrum as observed with 1 kHz resolution, where the 5 kHz displacement of the reference is labeled X.

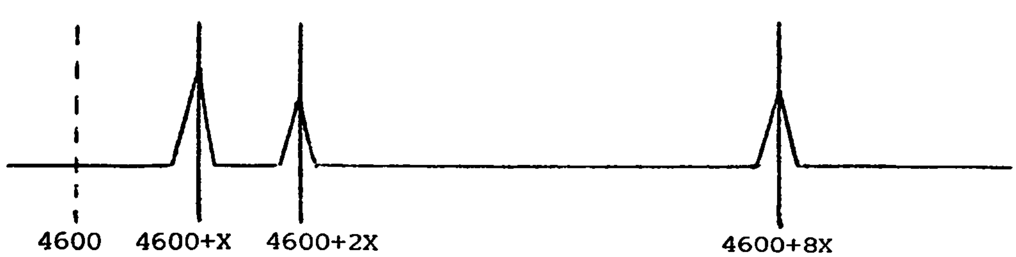

FIGURE 1

When X is decreased to zero all three features coalesce at 4600 MHz, keeping the same relative spacing.

The left-hand feature in Figure 1 is the L2 harmonic generator's 1400 MHz output displaced by X because the pump frequency has been displaced by this amount. The right-hand feature is the 7th harmonic of the 200 MHz reference, generated in one of the phase detectors which are operated by this reference signal. The amplitude of the right-hand feature is critically dependent on the amplitude of the 200 MHz reference as is to be expected in such a harmonic generator. A further test was made in which B-Rack was turned off and the upconverter pump was locked to the 6th harmonic of a signal generator at 510.5 MHz (in place of the 3 GHz reference) and a 137 MHz reference signal from a synthesizer (in place of the 200 MHz reference). The amplitude sensitive feature in this case was observed at the 11th harmonic of the 137 MHz reference plus the 3200 MHz pump frequency or 4707 MHz.

The amplitude of the feature is weakened by closing the door of the vertex room and it can be strengthened by adding a one inch extension of the center conductor of the BNC receptacle on F2 labeled "IF Monitor". The latter change couples the harmonics of the reference 200 MHz more effectively into the radiation field and thence to the feed horn.

The center feature in Figure 1, involving twice the pump frequency, is the interaction between the second harmonic of the pump signal and 1800 MHz from B-Rack. The amplitude of this feature can be increased by increasing the pump amplitude to the upconverter, and the amplitude can be decreased by tuning a band-pass filter inserted in the antenna line away from 1800 MHz. Proper tuning* of the upconverter for the two units in antenna 11 has been able to reduce the birdy below detectability and has not increased the noise temperature.

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*i.e., minimum pump amplitude to give required noise temperature.

EXPERIMENT III SIGNAL GENERATOR MEASUREMENTS

A signal generator covering the L-band frequency range of the receiver was installed in the vertex room. This instrument (HP8614A), connected to a vertical 1" probe mounted at the bottom front of B-Rack, could produce easily detectable responses in the receiver throughout the range. Detailed measurements were made near 1400 and 1600 MHz. The responses were measured with the HP8555 spectrum analyzer at the usual output port, and the same sensitivity was observed at both frequencies. A signal generator output of +20 dBm gave a typical receiver output of -30 dBm with the vertex room door open and this value dropped 5 to 10 dB with the door closed. When the receiver input was terminated with a shielded coaxial load, a typical receiver output was -50 dBm. All these measurements have ±5 dB uncertainty because of the variation with position of the observer.

Thus by about 20 dB the easiest path for radiated energy in the vertex room to the receiver is through the walls, ceiling or floor into the feed horn. The insertion loss between the probe on B-Rack and a waveguide to coax adapter connected to the feed is 90 dB with the door closed.

Moving the probe to other locations and other orientations in the vertex room generally changes the power measured from the feed by less than ±10 dB. Let us assume that this variation is unimportant and consider how to examine all birdies that arise from radiation in the vertex room that couples to the feed horn.

If birdy power contributes less than the power fluctuations of the interferometer we can tolerate it. This power expressed as a temperature for a bandwidth of 1.5 MHz, system noise temperature of 50 K and observing time of 12^h is 2×10^{-4} K. (A radiometer constant of unity was used.) Birdy power that is injected in phase at two identical antennas at a level of 8×10^{-21} watts would give an equal response. Let us allow a factor of 10 for fringe frequency attenuation of the birdy. Then 8×10^{-20} watts of birdy power is marginally tolerable. The corresponding power level in a 1" probe in the vertex room is 8×10^{-11} watts (-71 dBm) a value easily measured by the existing spectrum analyzers. Thus, to the 10 dB accuracy due to the variation with position of the probe, we can determine the frequencies of all birdies that radiate to the feed horn and their amplitudes subject to the assumption that there is little frequency variation in the coupling constant found above. The fact that the measurements at 1400 and 1600 MHz agree suggest that this assumption is correct.

CONCLUSIONS

Only strong birdies are observable with the methods used above, and only those injected prior to the local oscillator.

Phase detectors with 200 MHz reference signals are sources of strong birdies in F2 and F3. These propagate by radiation to the feed. These units should be redesigned in small well-shielded and filtered boxes. It is desirable to include the loop IF amplifier in the shielded box since it is capable of generating harmonics too.

The birdy that is an interaction between the second harmonic of the upconverter pump and stray 1800 MHz seems to be curable by proper adjustment of pump amplitude, but a more comprehensive set of measurements on other units is desirable, for the VCOS, current controlled attenuators and upconverters all play a role in generating the second harmonic.

A comprehensive search of the spectrum of radiated power in the vertex room could yield a good estimate of the strengths of birdies too weak to be measured directly with the present equipment.

The VLA ought to own an L-band signal generator and an impedance bridge capable of measurements in the 100 MHz region of .05 μHy inductors and 10 pf capacitors, so that filtering components can be evaluated.

ACKNOWLEDGEMENTS

I am indebted to many members of the VLA staff for assistance and advice that was both quick and able. I apologize for omitting some factors of $\sqrt{2}$ or 2 from the analysis.

APPENDIX I THE APPARENT FLUX OF AN OBSERVABLE BIRDY

Let $\Delta\nu_a$ be the bandwidth of a spectrum analyzer connected to one receiver of an identical pair of interferometer receivers having system noise temperatures T_e. Let G be the receiver gain ahead of the analyzer and suppose that the noise generated in the analyzer can be neglected.

The receiver noise power that reaches the spectrum analyzer is

$$P_r = k\ T_s\ \Delta\nu_a\ G. \tag{1}$$

where k is the Boltzmann constant. Assume that 4 P_r is the power of a readily measurable body. The constant 4 is arbitrary and the reader may prefer a different value. The effective temperature that such a birdy contributes to the receiver output is obtained from the equation

$$4\ P_r = k\ T_e\ \Delta\nu_r\ G, \tag{2}$$

where $\Delta\nu_r$ is the receiver bandwidth.

It follows that

$$T_e = 4\ T_s\ \Delta\nu_a/\Delta\nu_r \tag{3}$$

If an identical birdy is present and in phase at the second receiver the value of flux that corresponds to T_e is

$$S_e = 2\ k\ T_e/A \tag{4}$$

where A is the effective area of each antenna. A commercial spectrum analyzer allows a minimum $\Delta\nu_a$ of 100 Hz. Take the system temperature to be 50 K; the effective area of the antenna, 280 m^2. The minimum value for the receiver bandwidth for continuum observations is 1.5 MHz, a value that gives the worst effect. With the above constants, equation (4) gives 130 mJy for the least observable birdy power. Changing the receiver bandwidth to 50 MHz reduces the least observable birdy power to 3.9 mJy, however in practice the chance of encountering more than one birdy increases with bandwidth. Another practical consideration is that fringe frequency resolution will reduce the effect of birdy power on synthesis maps, especially for long baselines, but not when the fringe frequency vanishes as it does twice each day for any region in the sky.

APPENDIX II RECOMMENDED ADDITIONAL TESTS

1. The radiated power in the vertex room should be surveyed with 1 kHz resolution from 1200 to 1800 MHz with an HP8555 spectrum analyzer connected to a 1 inch monopole antenna. The instrument should have a long time to warm up and its calibration should be tested with a signal generator. Although this is a laborious task it will give an invaluable starting point for birdy removal.

2. Since paths into the receiver outside of the antenna are only 20 dB weaker than those through the antenna, these should be investigated. (A) A signal generator in the vertex room should radiate power toward the L-band waveguide operated with a termination at the antenna end and a spectrum analyzer at the receiver end. (B) Signal generator tests on two receivers (on different antennas) should be made where power is radiated from the generator and measured with the receiver and spectrum analyzer. Both receivers should have both input leads terminated in shielded resistors at room temperature, and one of the receivers should have all bias leads rearranged in shielded and filtered conduits.

3. Paths into A-Rack through cables can also be investigated, individually with the signal generator and a directional coupler. The general method is the same as that used above. Find a frequency and amplitude that will create an observable birdy when the generator is connected to the coupler. Then measure what is actually present on the given input cable.

4. Tests of the DCS leads in A-Rack can be made similarly to 2(B).