# WIDE-BANDWIDTH SPECTROMETER MEASUREMENTS AT X-BAND

**Brian Dennison**
**dennison@astro.phys.vt.edu**

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## Abstract

Observations of W3 with 800 MHz bandwidth at X-band reveal a complex bandpass after correcting for system gain. The spectral modulations are highly correlated in both polarizations and are traced to the feed and/or antenna. In addition, a time-variable component exhibits $\approx$ 1% spectral modulations on minute time scales over $\approx$ 100 MHz frequency scales. Temporal averaging appears to reduce this component. The time variable component also appears to be produced in the feed and/or antenna. Interference might contribute to the temporal modulations, although it does not seem likely to account for virtually perfect correlation between orthogonal polarizations, and the lower modulation observed when the telescope is off source. Further tests are needed to discern the cause(s) of these modulations and perhaps suggest a remedy.

## 1. Introduction

During the a.m. hours of August 20, 2001 the spectrometer was used at X-band to study spectral baseline properties over a very wide bandwidth. The total bandwidth was 800 MHz centered on 9800 MHz, with 2048 frequency channels. The high speed samplers were used in 3-level mode. The dual IF channels (orthogonal circular polarizations) were analyzed redundantly in each of four quadrants of the spectrometer; only the first quadrant produced useable results, however. This memo will focus on the results from three ON-OFF sequences on the source W3 in an attempt to discern the sources and stabilty of spectral baseline structure.

## 2. Standard Reduction

Figures 1 and 2 show the on-source and off-source spectra for the second and third W3 pairs, respectively. These were reduced in the standard manner incorporating the noise cal which was fired for 2 seconds of a 4-second cycle. The high cal was employed because the low cal was evidently not working. A cal value of 18 K was used. Both graphs are for IF channel 1 only.

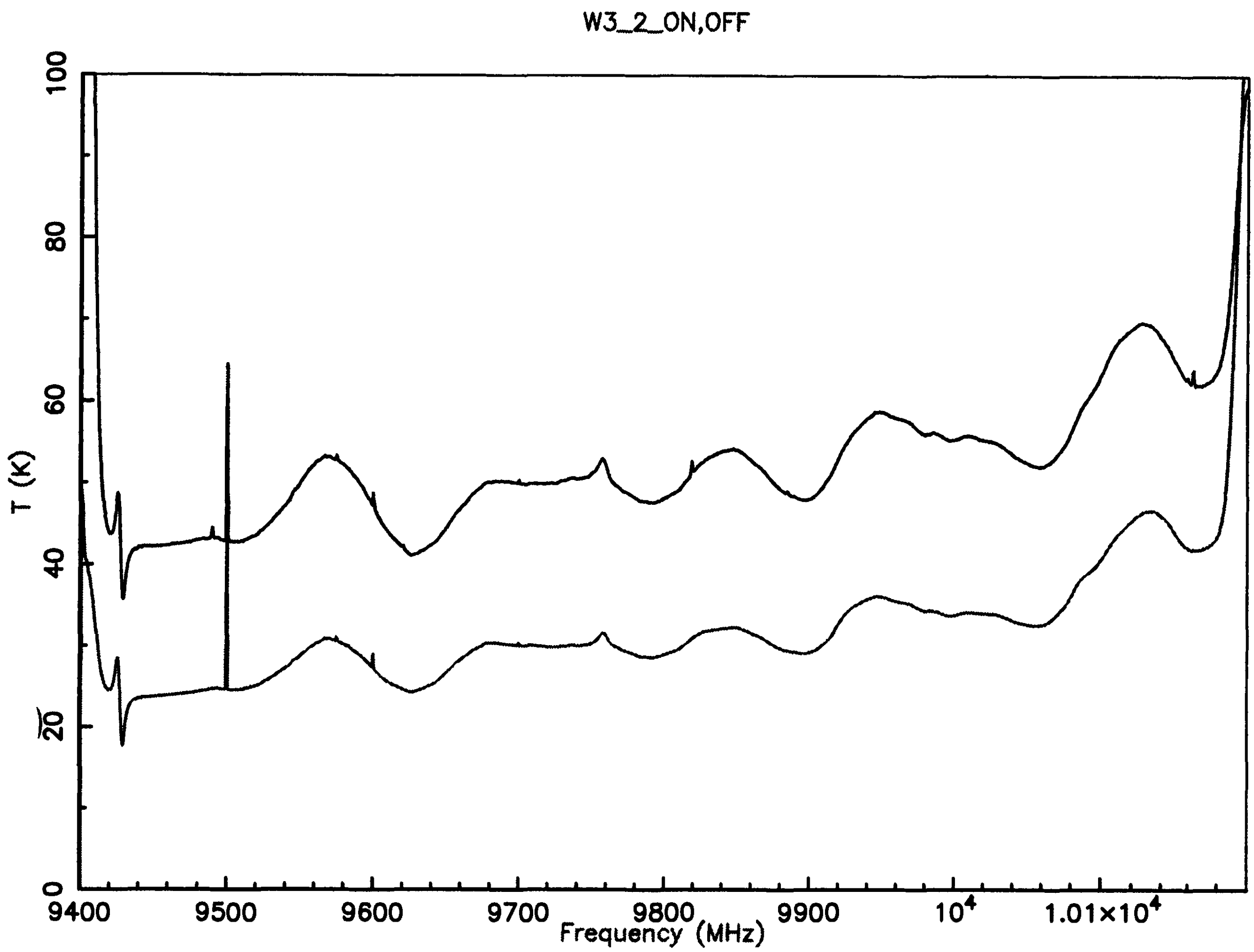


Fig. 1— Wideband spectra taken ON and OFF the source W3 for scan pair 2.

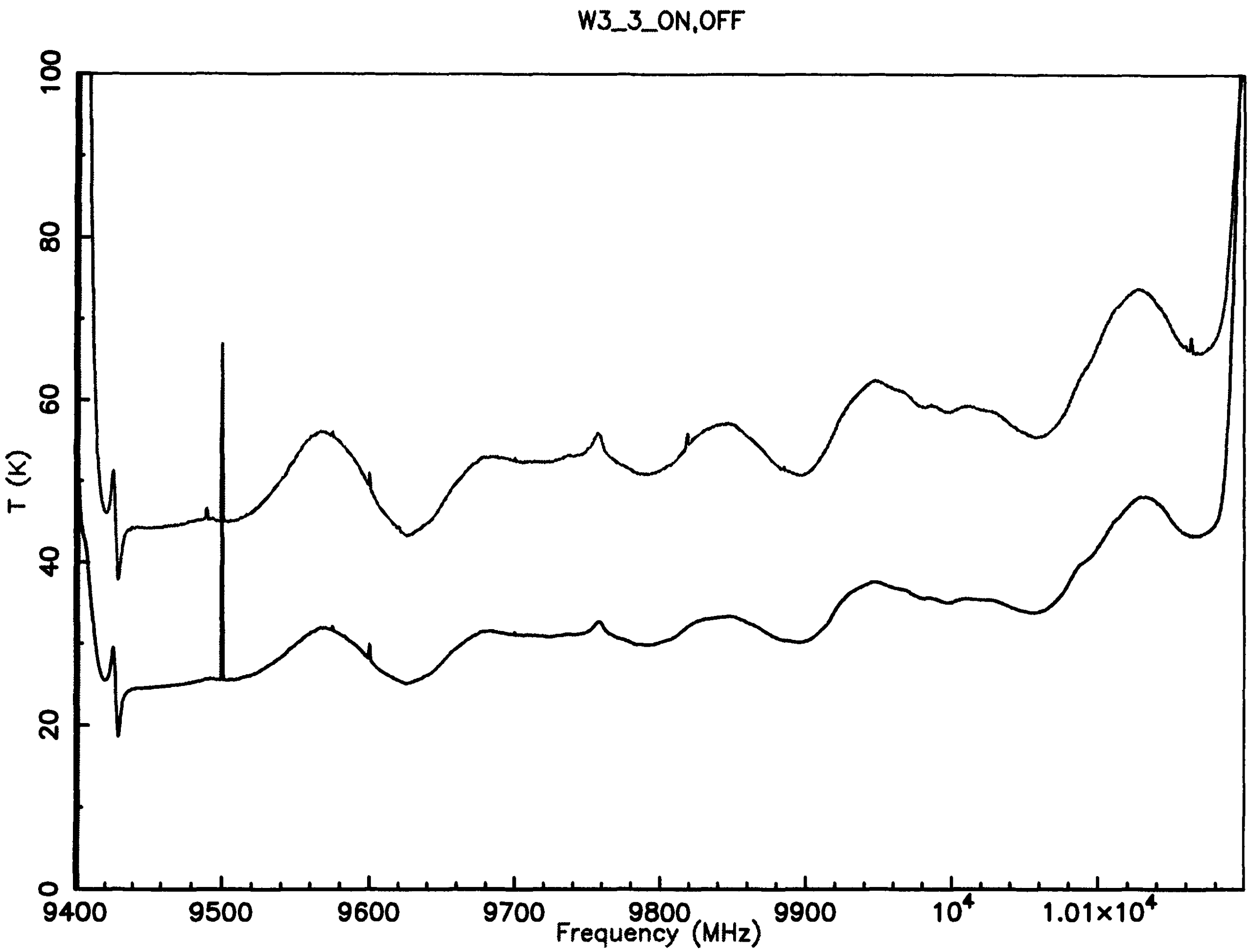


Fig. 2.— Wideband spectra taken ON and OFF the source W3 for scan pair 3.

Figures 3 and 4 show the spectra obtained by calculating 30K(ON – OFF)/OFF for each scan pair. The following recombination lines are apparent: H88$\alpha$(9488), H110$\beta$(9618), H87$\alpha$(9817), H109$\beta$(9883), H108$\beta$(10157), H86$\alpha$(10161).

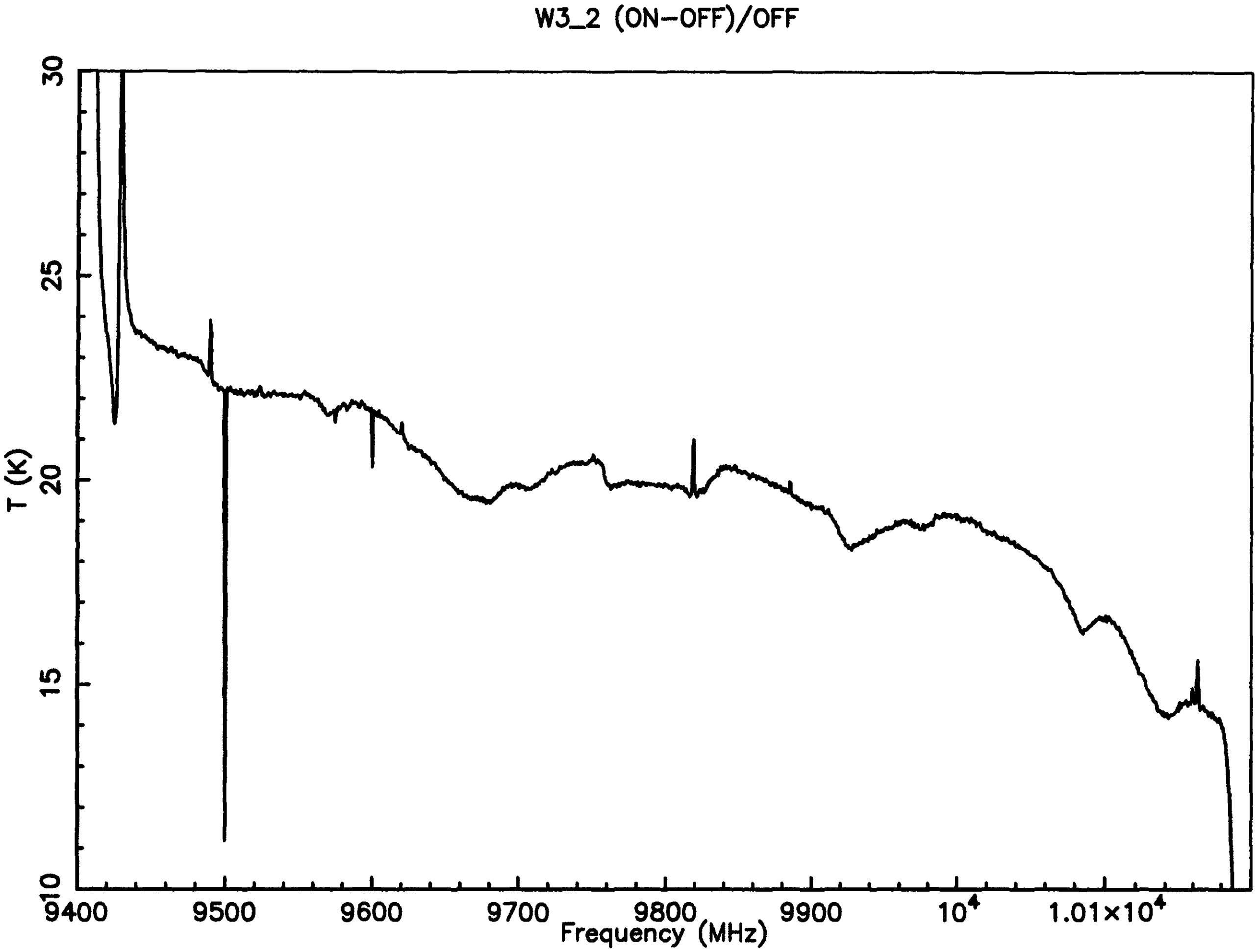


Fig. 3— Spectrum of W3 calculated from scan pair 2. A mean OFF system temperature of 30K was used. Recombination lines appear at 9488 (H88$\alpha$), 9618 (H110$\beta$), 9817 (H87$\alpha$), 9883 (H109$\beta$), 10157 (H108$\beta$), and 10161 MHZ (H86$\alpha$). Negative "lines" are not astronomical. (See OFF spectra in Figs 1 and 2.)

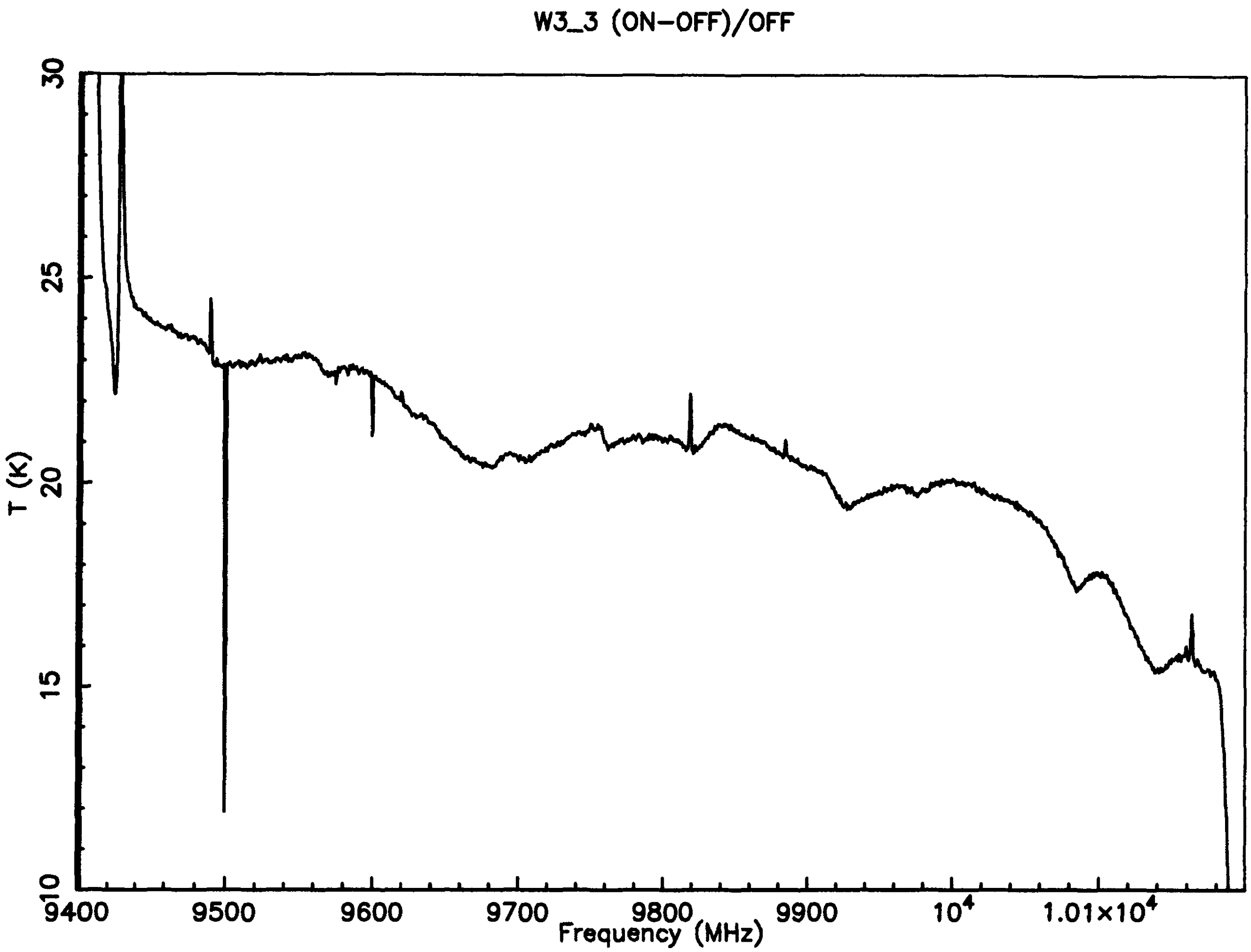


Fig. 4.— Spectrum of W3 calculated from scan pair 3. A mean OFF system temperature of 30K was used.

Clearly, the spectra of W3 are quite lumpy across the 800 MHz bandpass. To gauge the feasibilty of using spectrally smooth sources to calibrate the bandpass, I calculated the ratio of the two W3 spectra. Unfortunately, this shows $\approx 1\%$ fluctuations on frequency scales of $\approx 100$ MHz (Figure 5). These fluctuations are not obviously correlated with the structure in Figures 3 and 4.

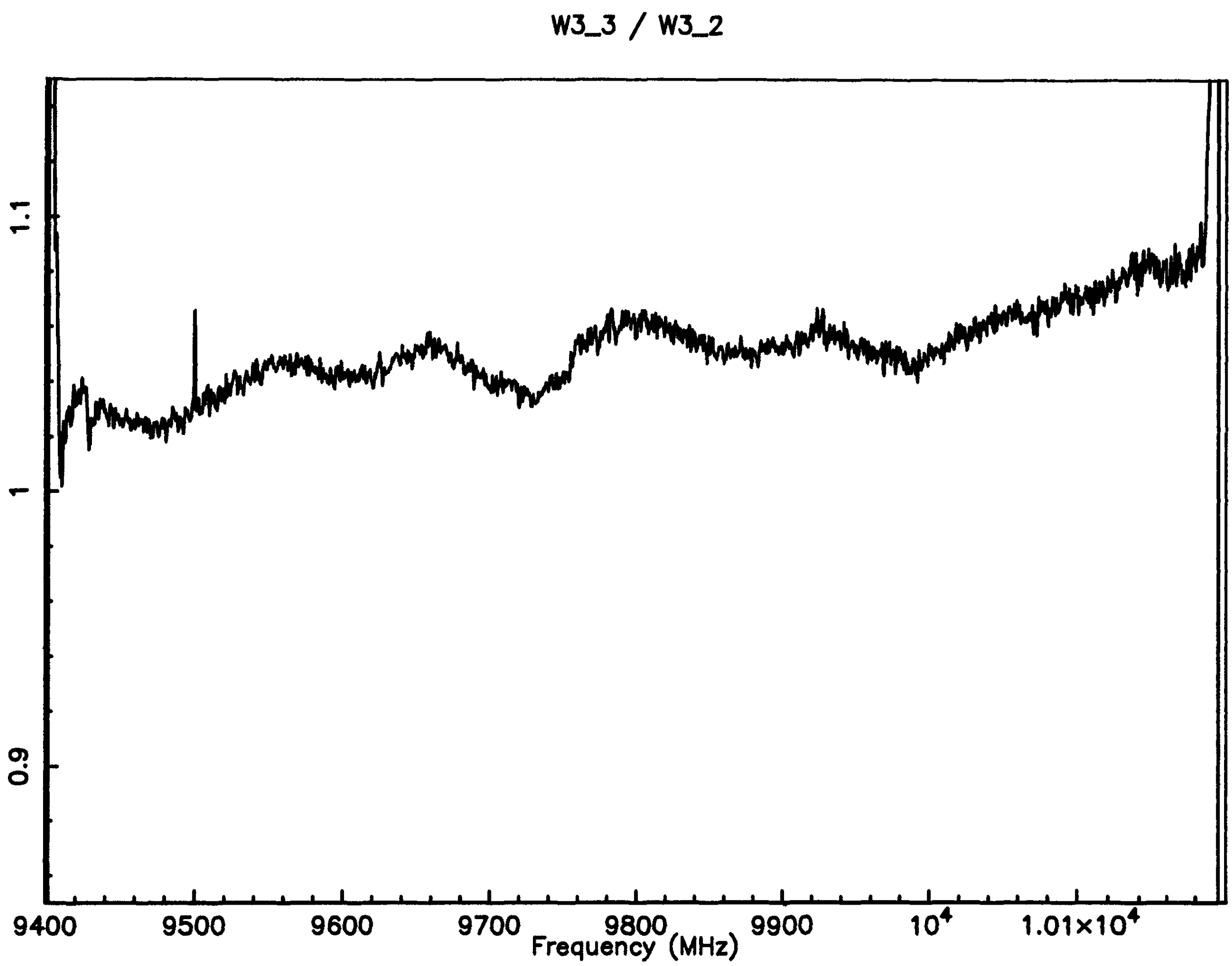


Fig. 5.— Ratio of W3 spectra.

## 3. Sources of Bandpass Structure

The response $R$ of the antenna is influenced by the noise temperature $T_n$, the cal temperature $T_c$, and the antenna temperature $T_a$, through the gain $G$. If the system is linear, then

$$R = G(T_n + T_c + T_a) \ .$$

*All* of the quantities in the above equation should be regarded as frequency dependent in the most general case. Because $T_n$, $T_c$, and $T_a$ all couple to the system differently each may acquire a unique frequency dependence as a result. (In the case of $T_a$ the coupling to the system may impress a frequency dependence in addition to that which is astronomical in origin - the ultimate object of the observations.)

The available measurements include spectra taken on-source (ON) and off-source (OFF), with the cal on (calon) and the cal off (caloff). Of course, the noise temperature is always present. Thus the three terms contributing to the antenna response can be isolated through the following combinations:

$$GT_n = \text{OFFcaloff} \ ,$$

$$GT_c = \text{OFFcalon} - \text{OFFcaloff} \ ,$$

$$GT_a = \text{ONcaloff} - \text{OFFcaloff} \ .$$

Figure 6 shows these three terms using data from the second W3 scan pair. As they are all highly correlated, these curves predominantly show the effects of the gain $G$.

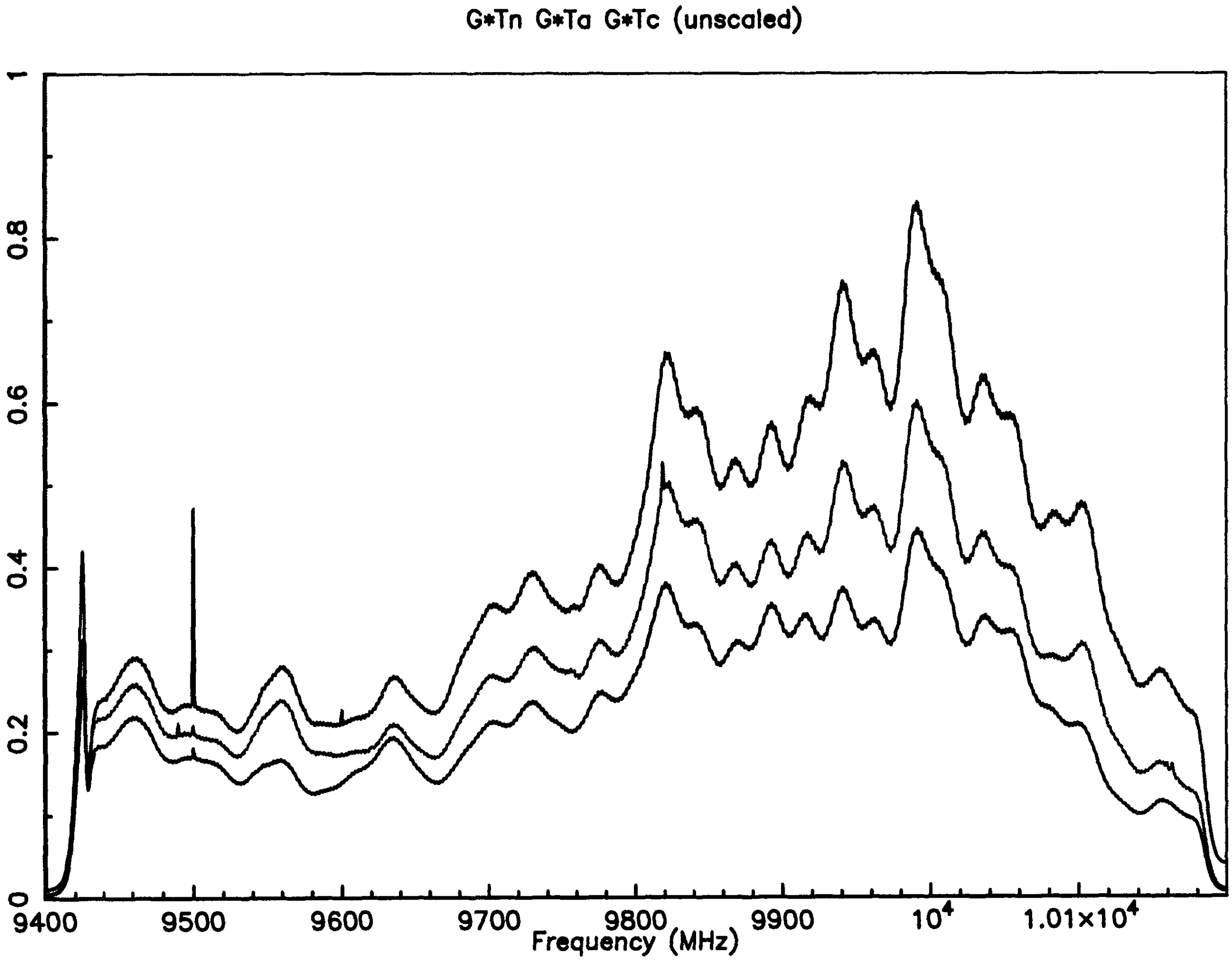


Fig. 6.— Measured spectra of $GT_n$ (top curve), $GT_c$, and $GT_a$ (bottom curve) for scan pair 2.

Unfortunately, $T_n$, $T_c$ and $T_a$ cannot be separately measured. We can, however, calculate their ratios which are shown in Figures 7 and 8. Of course, the effects of $G$ disappear completely and new frequency behavior becomes apparent.

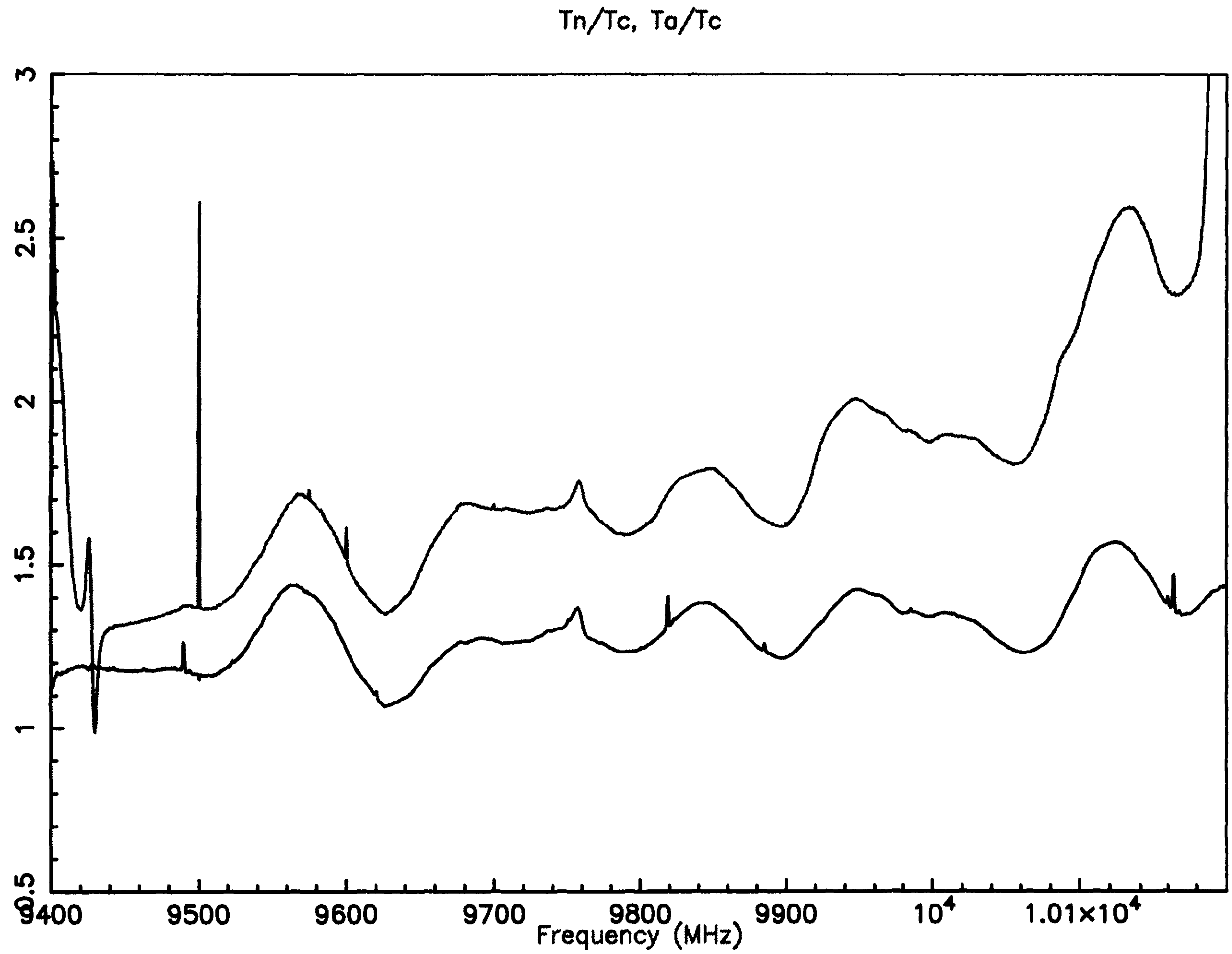


Fig. 7.— $T_n/T_c$ (top curve) and $T_a/T_c$ (bottom curve).

The strong correlation of $T_n/T_c$ with $T_a/T_c$ suggests that these curves are dominated by spectral structure in the cal ($T_c$). This is confirmed by the $T_a/T_n$ curve (Figure 8) which apparently has no correlation with the $T_n/T_c$ and $T_a/T_c$ curves. Not surprisingly, the $T_a/T_n$ curve is remarkably similar to the reduced W3 spectra (Figues 3 and 4). Clearly, frequency structure in $T_a$ may be a key contributor to the passband irregularities observed in the W3 spectra.

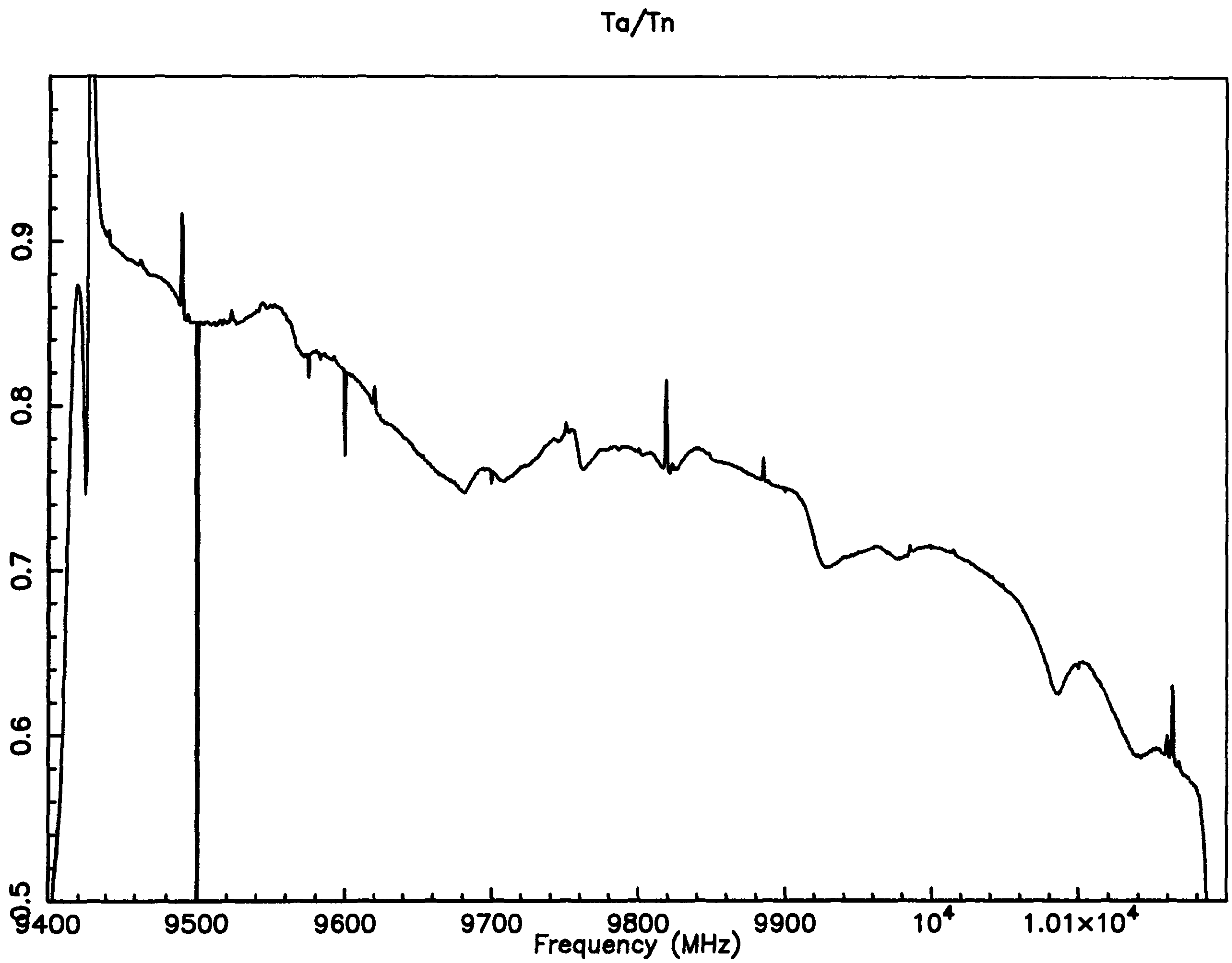


Fig. 8.— $T_a/T_n$.

To examine this further, I reduced selected 30-sec integrations in the orthogonal polarization (channel 2). (Combining the integrations in a scan is somewhat tedious at this stage of software development.) The channel 2 ON and OFF-source spectra are very similar in appearance to those in channel 1 (Figs 1 and 2). Reduced spectra [30K(ON − OFF)/OFF] from 30-sec ON-source and OFF-source integrations during the second and third W3 scan pairs are shown in Figure 9. These spectra are obviously very highly correlated with the same spectra seen in the orthogonal polarization (Figures 3 and 4). Therefore, the source of the fluctuations in the W3 passband originate in the feed and/or antenna, the only components common to both polarizations. This is of course consistent with the evidence discussed above that this frequency structure originates in the $T_a$ term.

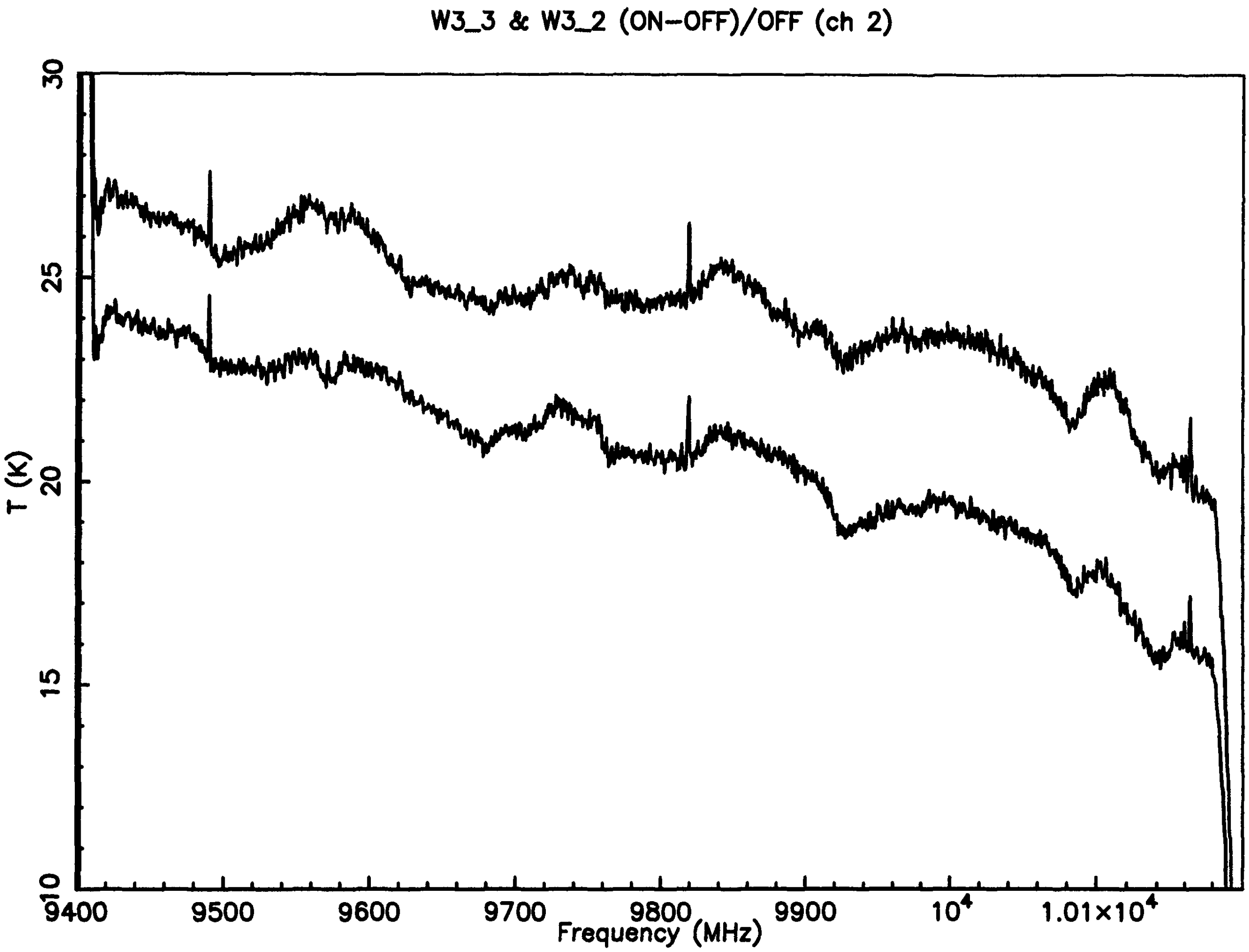


Fig. 9.— Wideband spectra of W3 in IF channel 2, calculated from a 30-second ON-source integration and a 30-second OFF-source integration in the second scan pair (lower curve) and the third scan pair (upper curve).

## 4. Time-Variable Bandpass Structure

Were the passband shown in Figs 3, 4, and 9 stable it could in principle be calibrated using sources having known spectra. However, there are percent changes in the passband between the second and third scan pairs on W3 (Fig 5). What is the origin of these temporal changes? To investigate this, I calculated the ratio of the channel 2 spectra shown in Fig 9 and the corresponding ratio of spectra produced from the same 30-second integration periods in channel 1. The ratios for channel 1 and channel 2 are shown in Fig 10. The temporal spectral changes are almost perfectly correlated in the two polarizations. (The channel 2 ratio was displaced downward by 0.1 in the graph to facilitate comparison.) Since

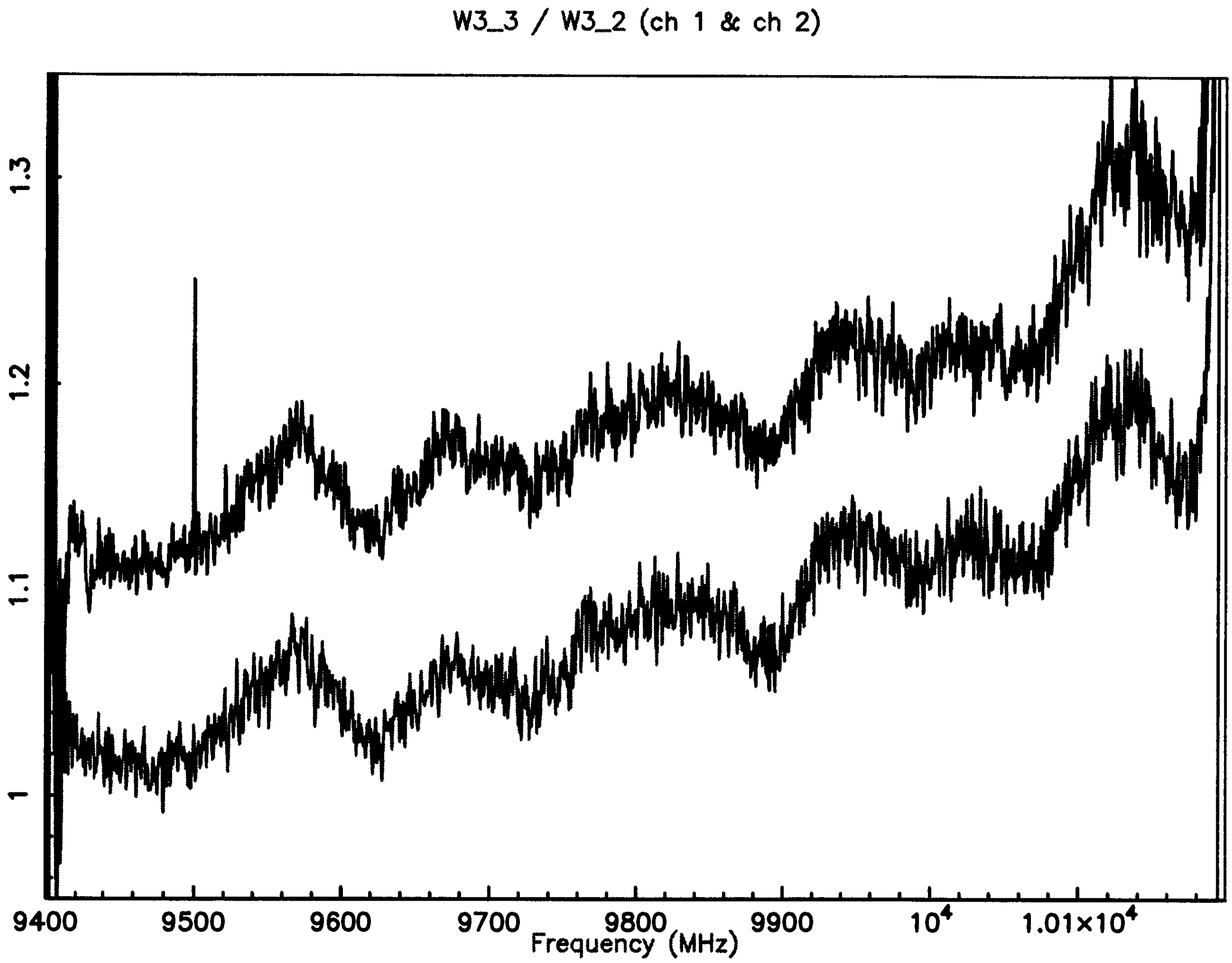


Fig. 10.— Ratio of the channel-2 spectra in Fig 9 (lower curve), and the ratio of the corresponding channel-1 spectra. The temporal flucautions are so similar that the channel-2 ratio has been displaced downward by 0.1 to facilitate comparison.

virtually *all* of the temporal fluctuations appear highly correlated across polarizations, they must originate in the feed or antenna.

Comparison of Fig 10 (which used just 30-second integrations) with Fig 5 (which used full 6-minute ON and OFF scans) suggests that the temporal fluctuations are reduced by longer integrations.

As a final test, the ratio of two 30-second OFF integrations was calculated (Fig 11). Interestingly, temporal fluctuations are apparent, but rather smaller in magnitude than those found by examining ratios of W3 integration pairs (Fig 10). This may be consistent with the conjecture that the temporal fluctuations are modulations of the antenna temperature (presumably in the feed and/or antenna) since in an OFF scan $T_a \approx 15$K compared with $T_a \approx 45$K in an ON scan. Thus, the smaller ripples in the OFF ratio may be just a reflection of the smaller (but nonzero) antenna temperature in this state. To check this, the ratio of two ON spectra were calculated, showing somewhat independent fluctuations about three times bigger than those seen in Figure 11.

## 5. Conclusions & Acknowledgments

Complex spectral structure is seen in the 800 MHz bandpass at X-band. In addition to constant spectral modulation, a time-variable component with amplitude $\approx 1\%$ and frequency scale $\approx 100$ MHz occurs on timescales of minutes. Temporal averaging appears to reduce the amplitude of the time-variable component. Both the constant and time-variable spectral modulations appear to be produced in the feed or antenna. Further tests may reveal the source(s) of these modulations and perhaps suggest a remedy. Until then, wide bandwidth observations may require long integrations to reduce the time-variable component and facilitate calibration of the constant bandpass using sources with smooth spectra.

The time dependent fluctuations, exhibiting a frequency scale of $\approx 100$ MHz, would correspond to a delay path of 3 meters, not an obvious scale in the antenna structure!

An alternative explanation for the time variable component might involve interference. This seems somewhat less likely, however, because of (i) the virtually perfect correlation between receiver channels (Fig 10), and (ii) the apparently reduced level of time-dependent modulation when OFF-source integrations are used (Fig 11).

Thanks to Dana Balser, Tom Bania, Bob Brown, Richard Fisher, Glen Langston, Ron Maddalena, Toney Minter, and Barry Turner for helpful discussion.

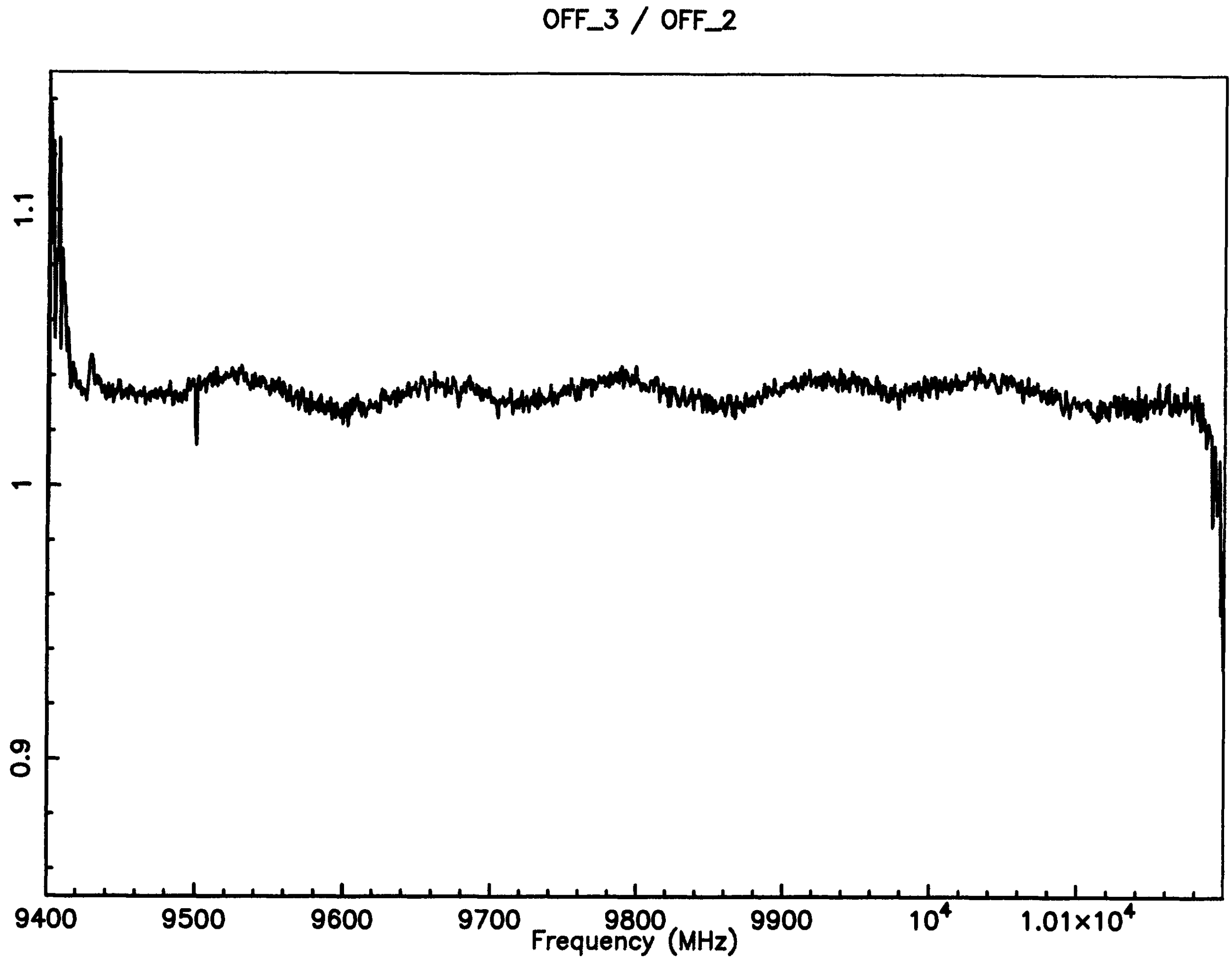


Fig. 11.— Ratio of 30-second OFF integrations from scan 3 and scan 2.