# RF SPECTROMETERS FOR HETERODYNE RECEIVERS

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Spectral line receivers require a spectrometer to divide the detected signal into a number of high resolution channels for display and analysis of a molecular line profile. Several types of spectrometers have been developed for radio astronomy receivers which utilize RF filters, multiple oscillators and mixers, digital auto-correlators and acousto/optic devices. In the infrared the heterodyne receiver places severe requirements on the spectrometer, particularly if it is to be used with a balloon or space flight receiver.

Heterodyne spectroscopy began 30 years ago with the discovery of lines due to hydrogen (HI) and then hydroxyl (OH) in various galactic gas clouds. These early receivers operated at L-band (1-2 GHz) and used maser and parametric amplifiers to achieve high sensitivity. Subsequent higher frequency receivers revealed a number of galactic molecular species (figure 1). Activity was particularly intense in the mm spectrum, leading to the discovery of over 50 interstellar molecules. The spectral lines of these molecules continue into the far infrared (FIR) where line intensities should increase. In addition to the rotational lines shown in figure 1 there are vibrational lines of molecules in the infrared. This is illustrated in the energy level diagram in figure 2. Rotational lines of SiO are shown as bars while vibrational lines are shown as arrows marked 8 and 4 $\mu$. The rotational level separations are exaggerated, being approximately 1000 times weaker than the vibrational levels. The molecular spectrum for Orion (Figure 2) shows a width of 50 km/s with a spectral detail requiring a resolution of < 1 km/s. Hence the spectrometer must be capable of providing several hundred channels with a total bandwidth approaching 100 km/s.

A block diagram of a typical heterodyne receiver is shown in figure 3. For most receivers in the infrared the phaselock system is generally a frequency stabilizer. IF amplifiers vary from bandwidths of 100 MHz to several GHz depending on the line widths expected. Generally there is a trade off between low noise and wide bandwidth. The GaAs FET amplifier is now widely used because of its low noise, power and weight.

The RF spectrometer has been developed at GSFC to provide wide bandwidths (> 1 GHz) as well as high resolution (5 MHz). This is accomplished by dividing the 128 channel filter bank into high and low resolution sections. The high resolution section is tuneable by providing a second mixer ahead of the filter bank. This is necessary because infrared receivers which use gas lasers as local oscillators are only tuneable to specific laser frequencies. To compensate for astronomical doppler shifts and molecule frequency differences a second local oscillator and mixer is needed. A diagram of the RF section of the filter bank is shown in figure 4.

This RF spectrometer was designed for a 10$\mu$ $CO_2$ laser receiver. The mixer is a HgCdTe diode made by D. Spears (Lincoln Lab). Output of the mixer is useable to 1.5 GHz and so the low resolution section of the filter bank has a bandwidth of 1.6 GHz and a resolution of 25 MHz. The high resolution section has a bandwidth of 320 MHz and a resolution of 5 MHz. Tuneability is provided by a balanced mixer and oscillators which tune from 1.6 to 3.2 GHz. This allows the high resolution section to be set at any point within the low resolution section where the spectral feature is located. This is illustrated in figure 5 which shows an atmospheric absorption line of Ozone as seen against the solar continuum. The left hand spectrum is the low resolution section running from 0 to 1.6 GHz with respect to the $CO_2$ laser frequency. The high resolution section on the right is set on the wings of the line profile and shows a 320 MHz detail of the wing shape. In terms of velocity for an astronomical source, 1 km/s is equal to 100 MHz at a wavelength of 10$\mu$. Hence the filter bank bandwidth corresponds to $\pm$16 km/s and $\pm$3.2 km/s and the resolution to 0.25 km/s and 0.05 km/s for the two sections.

The RF diagram in figure 4 starts at the output of the HgCdTe mixer where the RF signal goes thru a bias T and a low noise preamp located close to the mixer dewar. A variable attenuator is at the input to the filter bank rack and provides a level set as well as a remotely control zero function for recording the DC channel offsets. The signal is then split in half for the 0-1 and 1-2 GHz amplifier chains. After boosting the signal level to 100 mw it is split by power dividers and fed to the individual filter trays which contain 8 filters each. In addition the 0.1-2 GHz signal is split to drive the balanced mixer and the high resolution amplifier chains. Various bandpass filters are present in the high resolution section to prevent amplifier saturation. The RF signal from each filter is passed through a square law detector so that the voltage output is proportional to the power input. A variable gain op amp boosts the signal level and then the individual channel outputs are sent to an integrator/multiplexer which integrates and converts the signals to 12 bit numbers which are accumulated separately as signal and reference in a 32 bit memory. Further synchronous detection and spectral processing are done by an LSI-11 computer or HP 9830 calculator connected to a Tektronix terminal. This provides on line spectral analysis capability for immediate retrieval of molecular line profiles.

A 64 channel filterbank was developed for use with 10$\mu$ and 500$\mu$ receivers. The 10$\mu$ configuration is similar to the filterbank described previously. The 500$\mu$ system requires narrower bandwidths since the doppler shift is 2 MHz for 1 km/s. The bank contains a 5 MHz low resolution section and a 1 MHz high resolution section which are both tuneable. The RF section of the spectrometer is shown in figure 6. At the input to the filter bank is a mixer driven by two transistor oscillators which can be selected to acquire any RF frequency up to 5 GHz. Following this there is an optional amplifier and a variable attenuator to provide the correct gain or attenuation to set the level in the filter channels. Two amplifiers and a filter boost and bandlimit the signal before it is split into the high and low resolution paths. At this point the high resolution signal is sent thru another mixer to down convert it to 165 MHz. Final power amplifiers then drive the individual filter trays through a power splitter. The rest of the system is similar to the 128 channel filter bank. The 64 channel spectrometer has been used with a 10$\mu$ diode laser receiver (ref. 1). Figure 7 shows some 32 channel spectra of excess noise in the mixer caused by noise sidebands and multiple modes in the diode laser local oscillator. The first three (a,b and c) show broadband noise with different spectral shapes. The next two (d and e) show beats between different modes of the laser. The numbers inside the figures indicate the reduction factors which were used on the spectra (a,d and e). The last spectra shows the noise of the preamp which has been subtracted from the other spectra. These figures illustrate the problem of designing a spectrometer which is able to cope with the large dynamic range in the noise and its change in spectral shape, which is determined by the mixer RF response and the noise profile of the local oscillator.

The 5/1 MHz configuration of the filterbank is scheduled to be used with a 500$\mu$ receiver (ref. 2, 3 and 4). For an astronomical spectroscopy experiment at the NASA 3m telescope on Mauna Kea in May, 1980. Despite the large atmospheric absorption (> 10 db) several interstellar or planetary molecules should be detected. This is the first major astronomical spectroscopy experiment in the 500 micron region an should give an indication of the intensity, width and complexity of far infrared molecular profiles on which to base future spectrometer designs.

The RF spectrometer will continue to provide the best means of achieving ultra-wide bandwidths for infrared heterodyne receivers. For high resolution with a large number of channels, the acousto/optical spectrometer will be the principle instrument, particularly for balloon or space flight applications (ref. 5).

## REFERENCES


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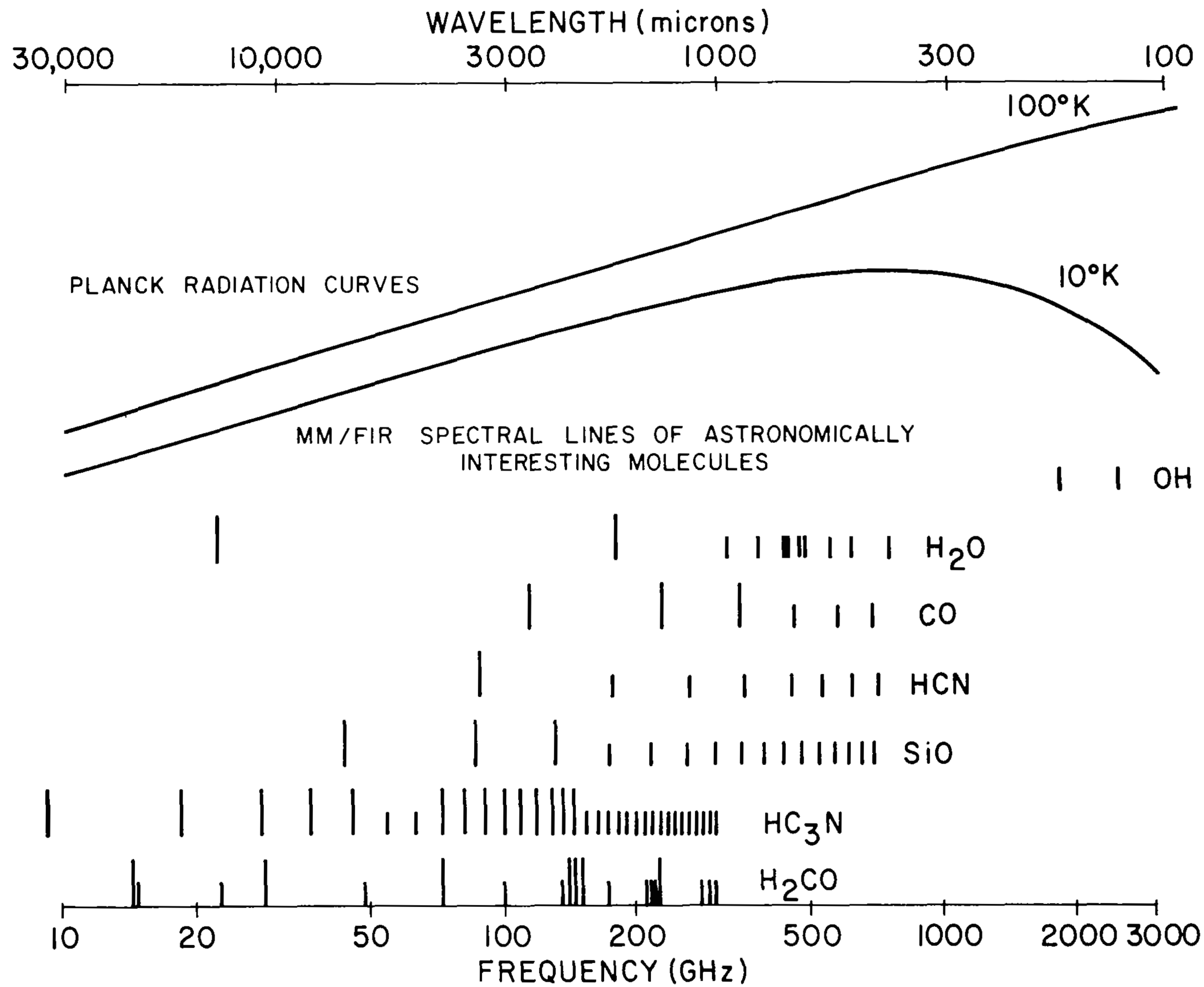


Figure 1.- Molecular lines in the radio and far infrared spectrum. The taller bars represent presently detected interstellar lines.

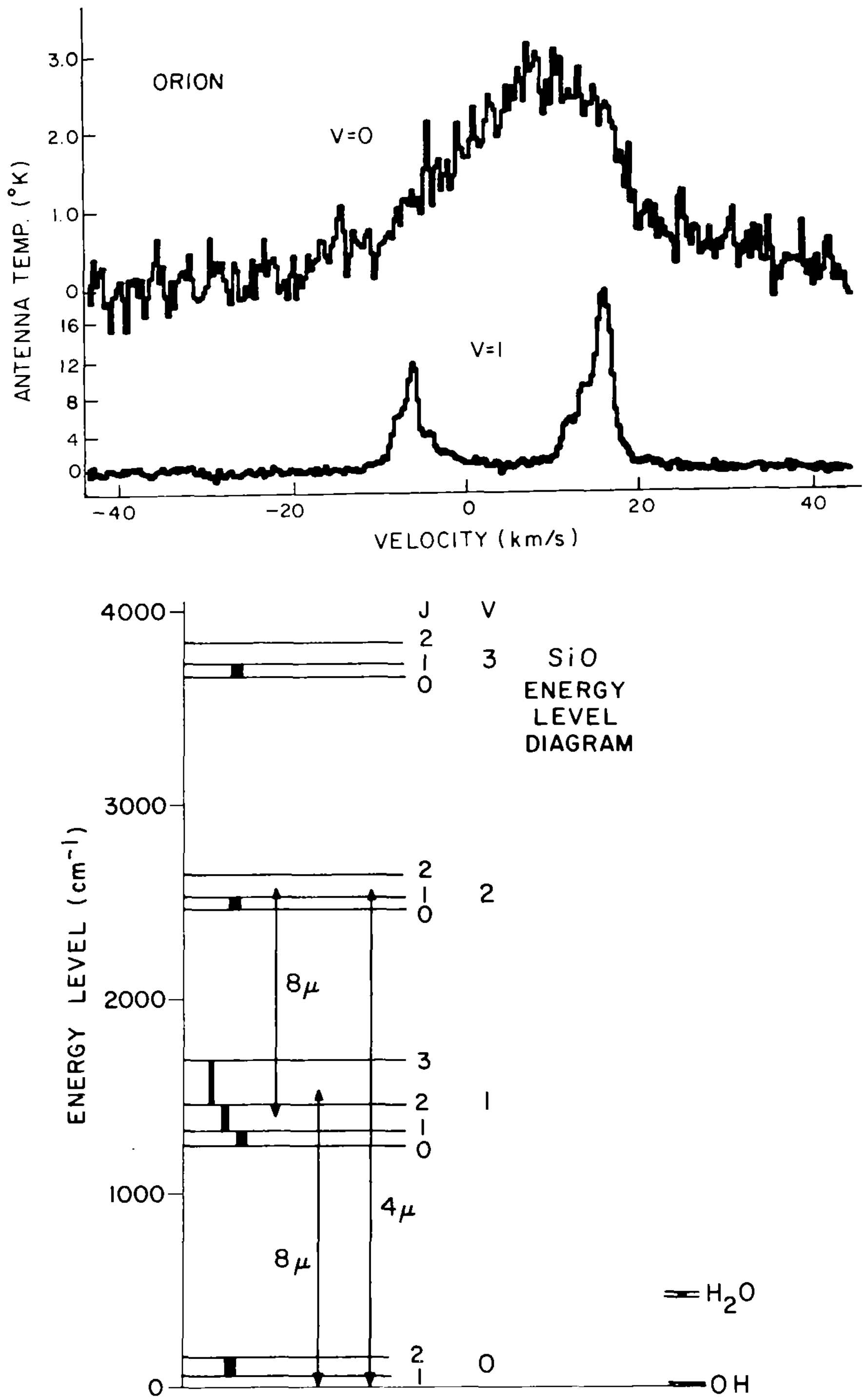


Figure 2.- The spectrum and energy level diagram for the SiO molecule illustrating the dramatic difference between the ground state (v=o) and first vibrational state (v=1) of the molecule.

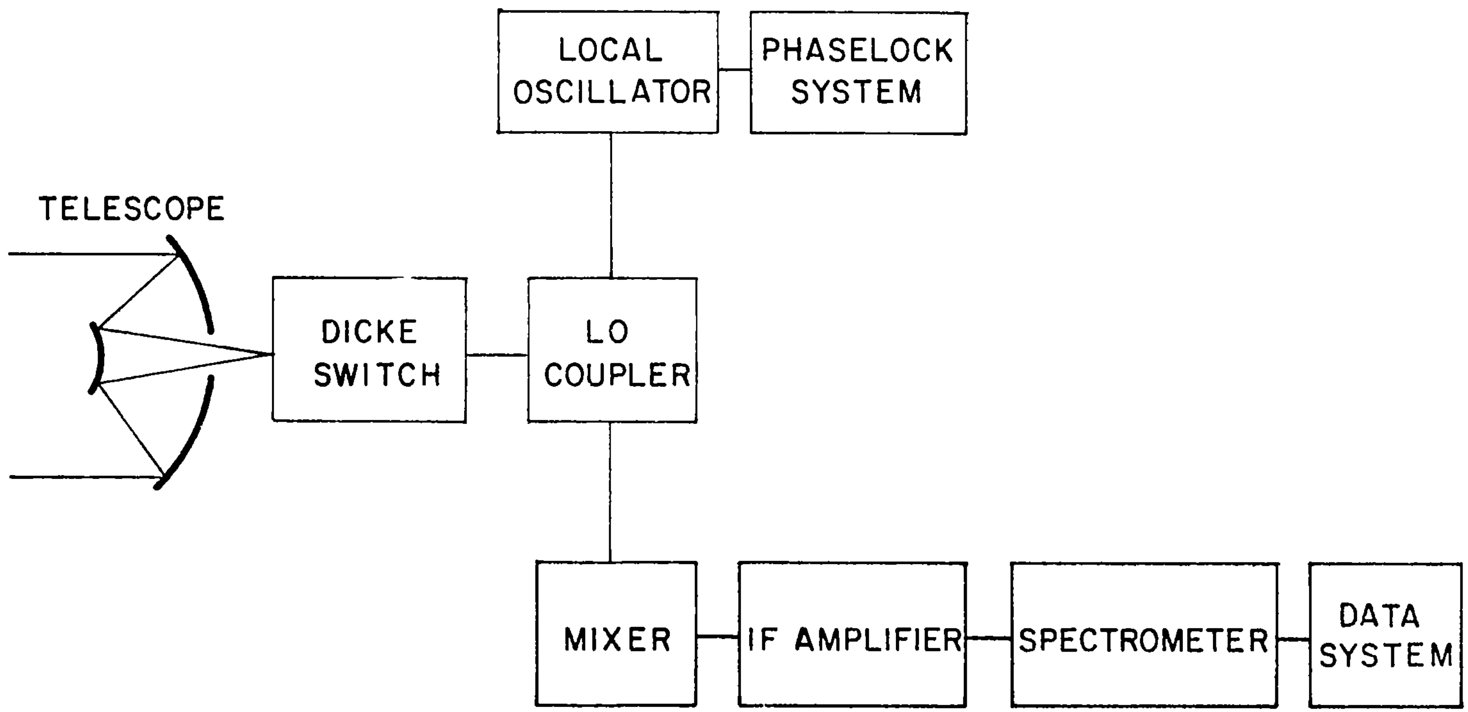


Figure 3.- Block diagram of a heterodyne receiver.

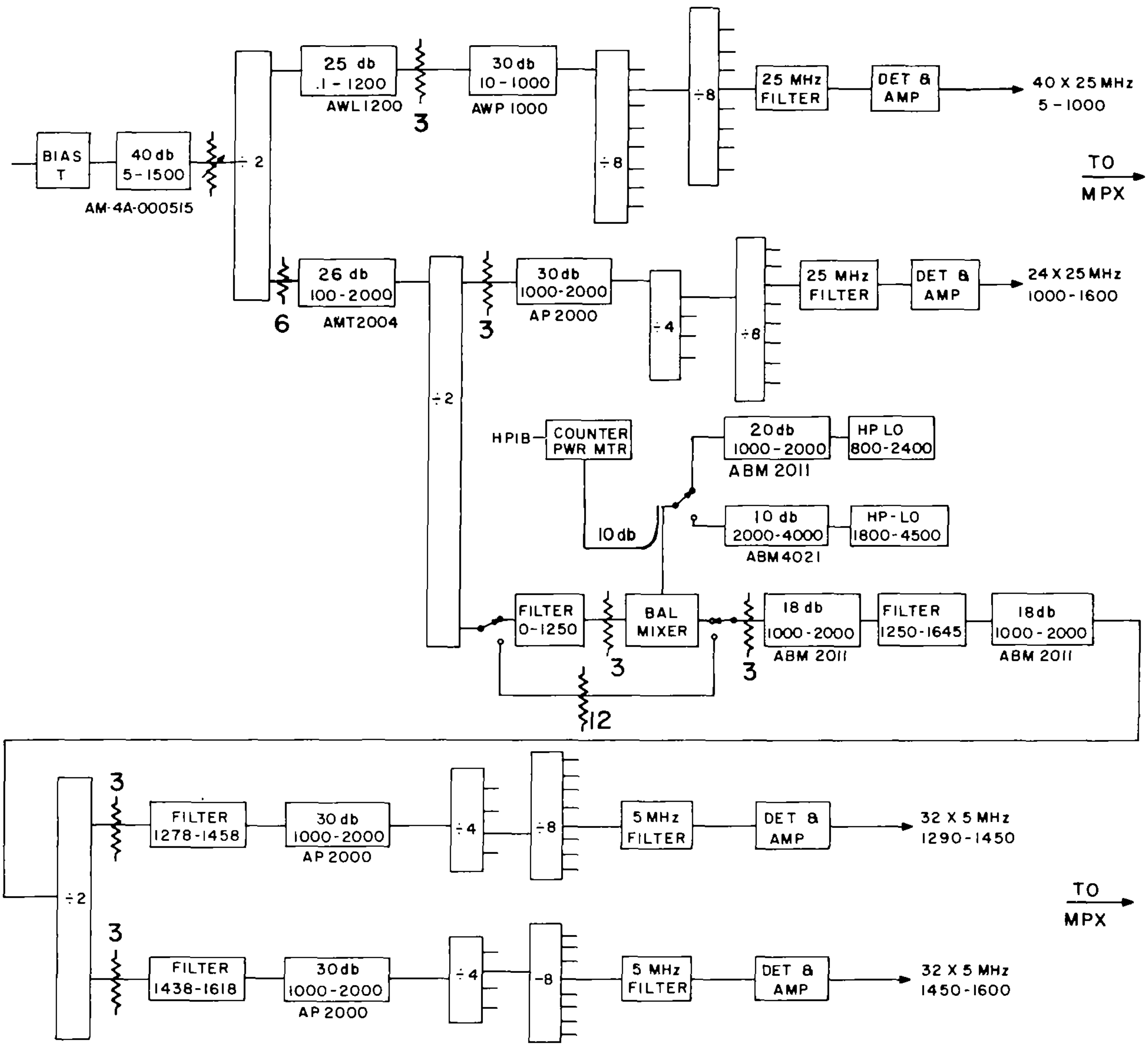


Figure 4.- 128 channel filter bank RF section: attenuation of pads between amplifiers is indicated in db, gain and bandwidth of amplifiers is shown inside boxes, filter bandwidths are also shown and power dividers are indicated as ÷2, ÷4 and ÷8. Numbers underneath amplifier boxes are Avantek model nos.

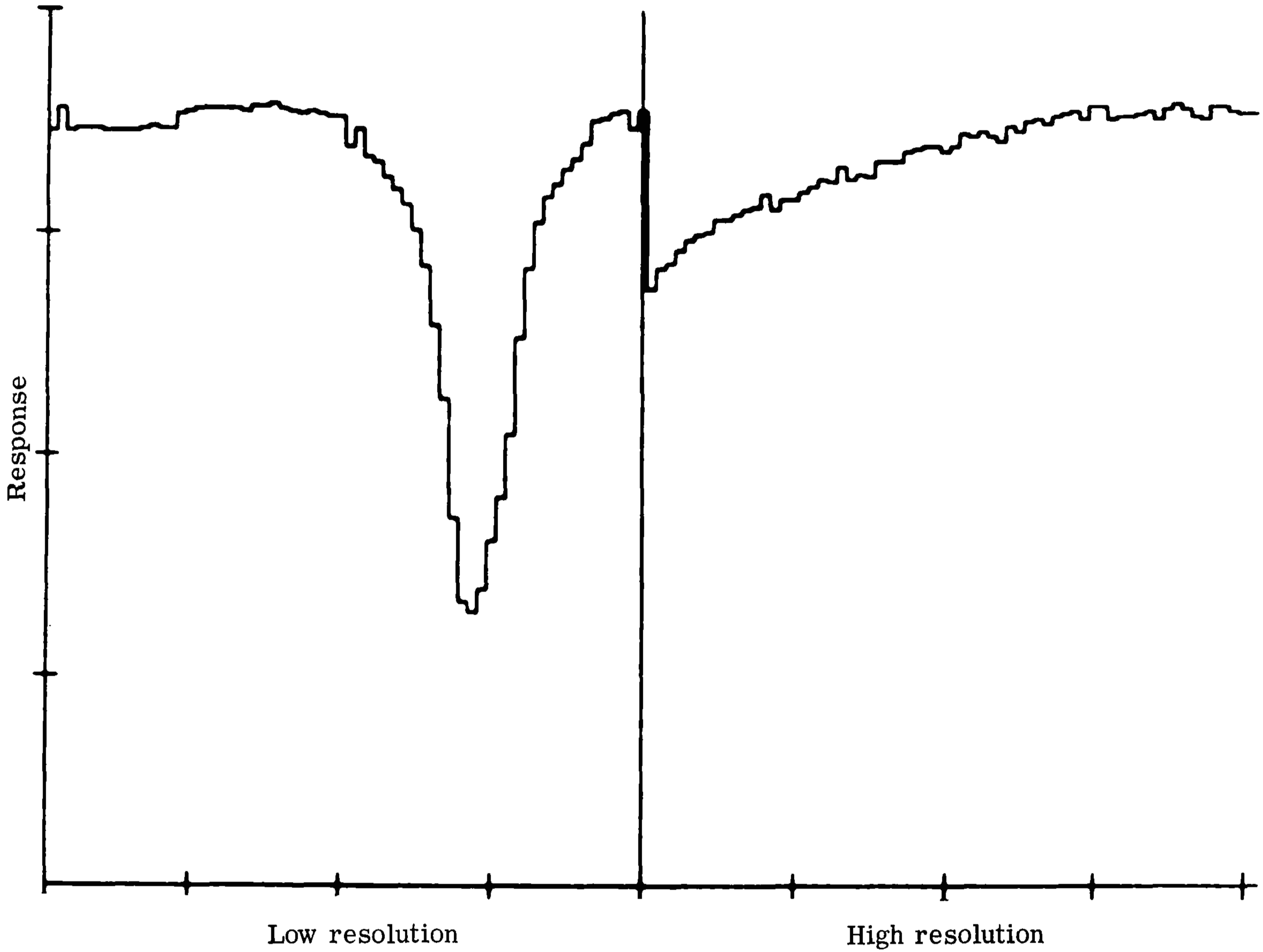


Figure 5.- Solar absorption spectrum of ozone. Low resolution section is 1.6 GHz wide and high resolution section is 320 MHz wide.

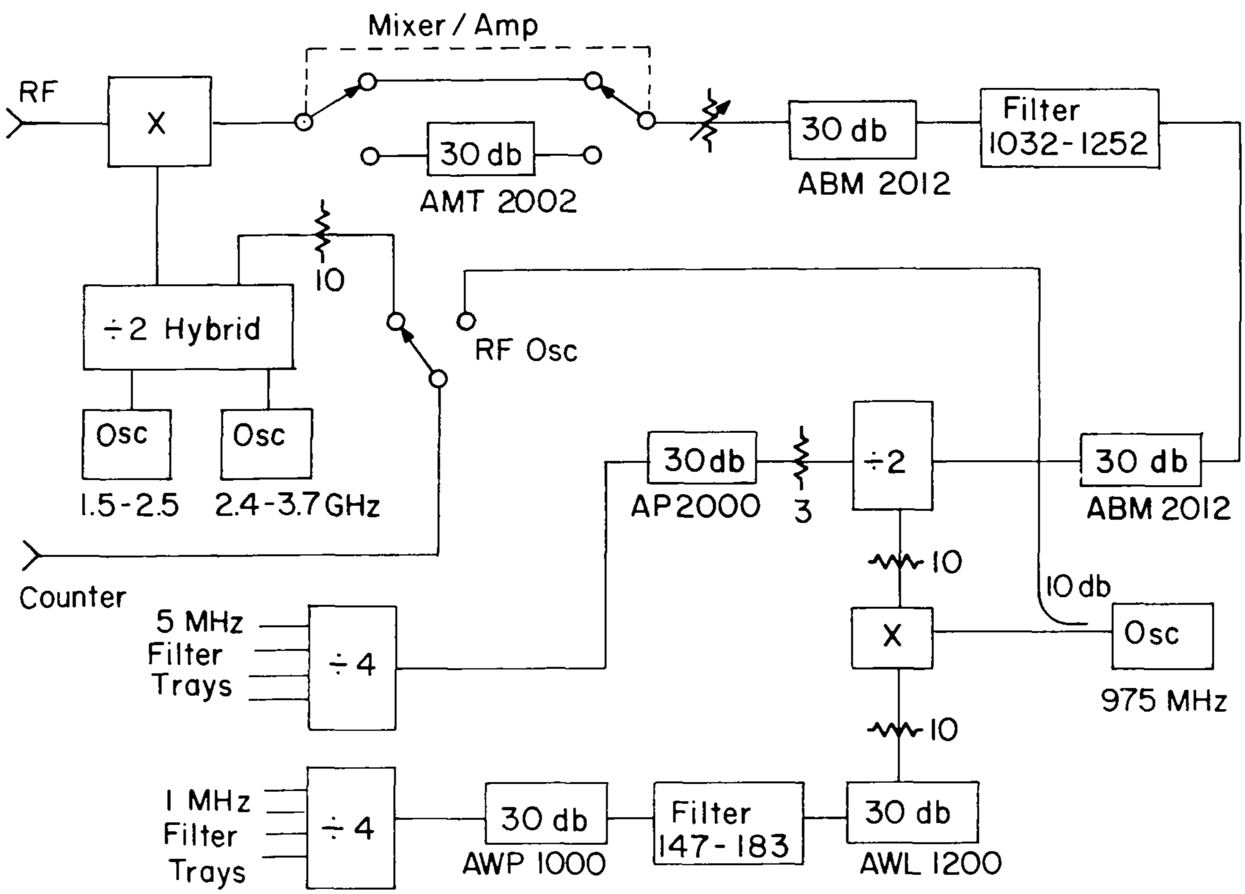


Figure 6.- 64 channel filter bank RF section showing wideband tunability of the spectrometer using a mixer and transitor oscillator.

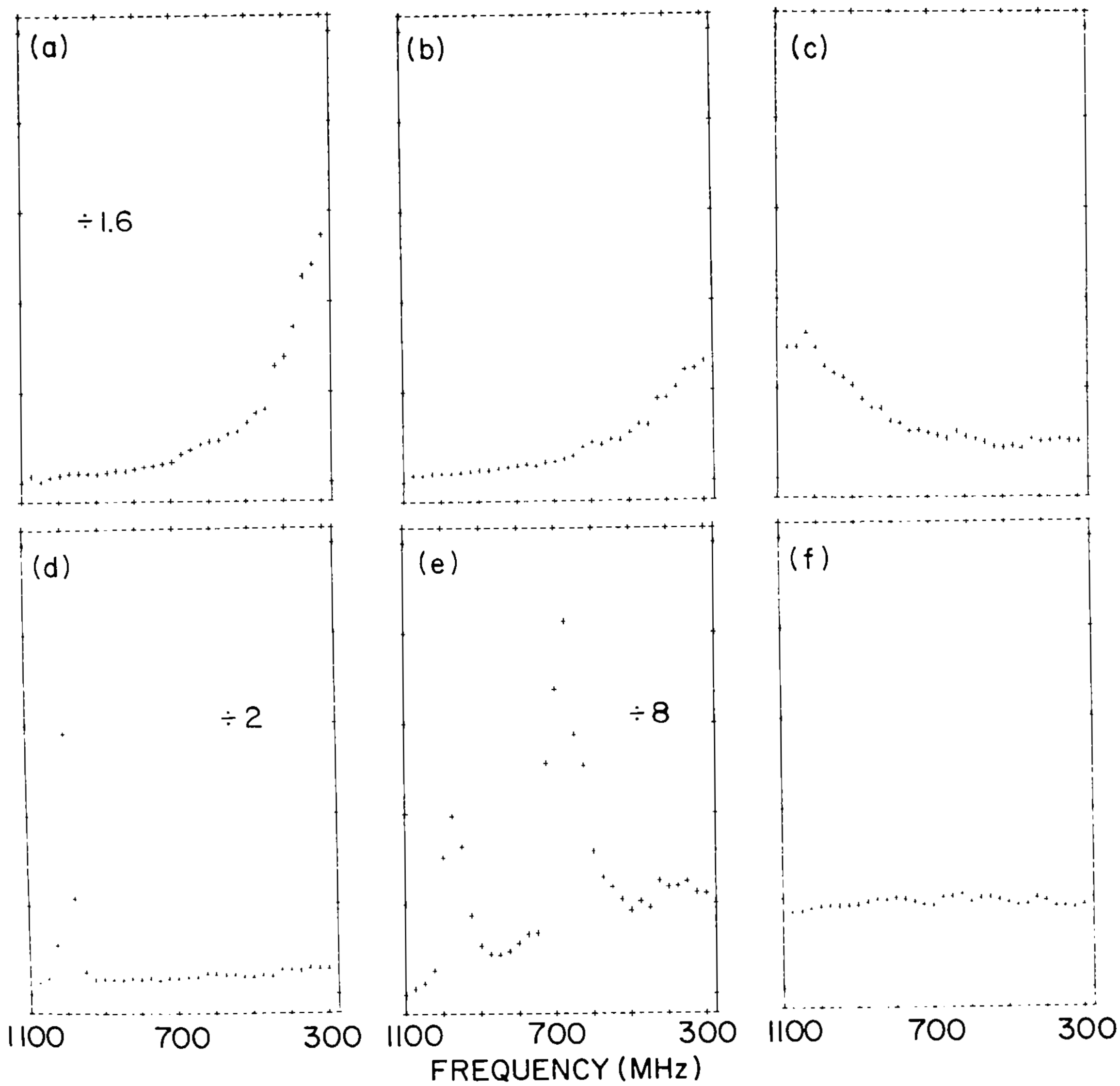


Figure 7.- 32 channel spectra of a 10μ laser diode receiver. The preamp spectrum (f) has been subtracted from the other spectra so that they show only the excess noise due to the laser. (d) and (e) illustrate multiple mode beats from the laser. Numbers inside boxes indicated reduction factors for that spectrum.