The High Resolution Spectrometer for SOFIA
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Abstract

The high sensitivity provided by SOFIA (Stratospheric Observatory For Infrared Astronomy) and the spectral resolution obtained with the CTS (Chirp Transform Spectrometer) combine in a unique tool in order to address a wide range of topics of modern astrophysics, from questions about comets, planetary atmospheres and the interstellar medium in the galaxy to investigations related to the early Universe. Thanks to high resolution spectroscopy we can obtain atmospheric information from the shape of a spectral line, and with this retrieve the altitude distribution of molecular species, for instance water vapor on Mars and HCl on Venus.

SOFIA Observatory

The strong IR absorption of our atmosphere encouraged the development of SOFIA, a flying observatory, mounted onboard a Boeing 747SP, that will open in 2004 a new era in the MIR (Medium InfraRed) and FIR (Far InfraRed) astronomy. The infrared radiation is strongly affected by absorption of molecules like water vapor and CO2, specially the range between 30µm and 1mm that is inaccessible from ground, even from observatories located at high altitudes as the Mauna Kea in Hawaii. SOFIA contains advantages of ground based observatories as high reusability, easy maintenance and the capability to avoid the first 12 Km of atmospheric absorption (85% of the earth atmosphere and 99% of the water vapor).

Chirp Transformation

The Chirp Transformation is a time-frequency domain transformation, the principle behind the CTS spectrometer. This can be derived from the Fourier Transform equation,

\[ F(w) = \int_{-\infty}^{\infty} f(t) e^{-j2\pi wt} dt \]

and substitute \( \omega = 2\mu t \) we have

\[ F(2\pi\mu t) = \int_{-\infty}^{\infty} f(t) e^{-j2\pi \mu t} dt \]

Using the identity \( 2t = t^2 + t^2 - (t - t)^2 \) this becomes the so called chirp transform. This can be interpreted as the input signal is mixed (i.e. multiplied) to a chirp waveform \( e^{-j\mu t^2} \) so that each Fourier component is converted into a chirp located in the frequency according to the component’s frequency and in the time domain according to the dispersion function of the acoustic filter. The mixed output is processed in the compressor chirp filter of matched slope which correlates, or pulse-compresses, the constituent chirps.

New developments

Several new developments have been done on different aspects of the spectrometer.
- As expander is used a digital chirp waveform generated by a quadrature phase digital synthesizer. The main advantages of using this modern digital technologies is the low-cost, optimum adaptation of the quadratic phase response of the compressor filter and high dynamic range.
- The realization of frequency filters at GHz frequencies was possible thanks to an intensive study of the electromagnetic field distribution over quasi-dielectric thin mediums (microstrip).
- Mathematical modeling and numerical simulations of the different RF components were important to estimate and optimize the performance of the complete spectrometer.

Preliminary results

The demanded high frequencies were achieved by digital generation, quadrature modulation and frequency multiplication. By the development of RF models and laboratory experiments, it is seen that the non-linear properties of an analog amplifier can be used as frequency multiplier. The simulation of matching features between the digital phase accumulator and the SAW filter (including spurious contribution) were confirmed by several measurements, leading us to estimate high dynamic range and high resolution.

Expected CTS specifications:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>204.8 [MHz]</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>50 [KHz]</td>
</tr>
<tr>
<td>Spectral density</td>
<td>-44 [dBm/MHz]</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>40 [dB]</td>
</tr>
</tbody>
</table>

Outlook

The joint between modeling, simulations and development of several technologies allow us to achieve the high scientific demands expected from the SOFIA observatory. This performance will let us address topics such as the distribution of atmospheric compounds on planets and comets. Based on a photochemical model of the Martian atmosphere (Nair et al. 1994), we can estimate how the spectra of the 1.893 THz (158.3 µm) rotational transition would be measured with the CTS.

References

