Enhancing Microwave Spectroscopy in Astrophysics Applications

Application Note

Overview

In popular perception, the vastness of space is an empty vacuum dotted with stars, planets, black holes and other celestial formations. In reality, astrophysicists have shown that space contains low-density matter - gas clouds, dust grains, and more - existing in ionic, atomic or molecular phases.

Here on Earth, astrophysicists use techniques such as microwave spectroscopy to investigate the chemical composition of the matter that exists within this so called interstellar medium (ISM). Similar to the spectrum analyzers used to characterize the content of wireless communication signals, a spectrometer connected to a radio telescope displays the unique spectra emitted by the atoms and molecules present in the ISM. In this case, the goal is to precisely determine the structure of gas-phase molecules.

The basic approach is to use spectroscopy to create a database of “fingerprints” from known gases and then compare the stored readings to those captured with a spectrometer. In most cases, the process of creating the database can be quite time-consuming. This application brief describes an approach that is faster and more accurate than typical methods. The key element of the solution is an arbitrary waveform generator (AWG) that can provide a fast broadband signal such as a linear frequency sweep or “chirp.”

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81180B and M8190A Wideband Arbitrary Waveform Generator

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Problem

Our application engineering organization worked with a customer to enhance a system that includes absorption cells. The medium in the cells absorbs those parts of the frequency spectrum that resonate with the molecules in the sample material; a detector behind the cell makes the actual measurement.

In the original system, supersonic jets of gas were being stimulated with a continuous-wave (CW) source. It would typically take about 30 minutes to step the CW source - one frequency at a time - across the required range of frequencies.

Because the source was running for the duration of the measurement process, the detector would be exposed to both the "relaxation spectrum" from the absorption cell and the emanations from the "hot" source and its imperfections such as fluctuations in frequency and amplitude. These issues were limiting the dynamic range and sensitivity of the measurement apparatus.

Solution

The revised system addresses the root problem in the original system by eliminating the long, slow sweep of a CW signal at a series of discrete frequencies. Instead, the system now uses a high-performance AWG to provide a fast broadband signal that stimulates the full range of frequencies in a matter of microsecond or milliseconds - and then the source is switched off. Because the detector sees only the relaxation spectrum emitted by the absorption cell, measurements have greater sensitivity and dynamic range. This configuration also makes it easy to quickly calibrate the system before or between measurements.

Figure 1 shows a block diagram of the system, which handles experiment control, data acquisition and data analysis. Starting with the AWG at the left, system operation proceeds as follows under the control of a PC:

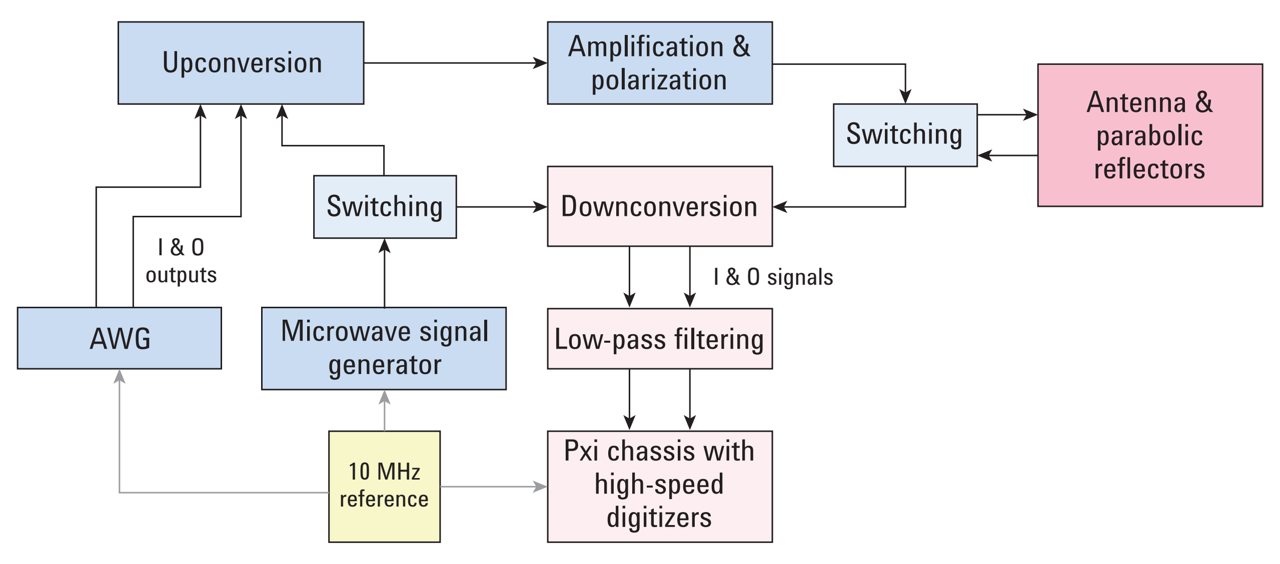


Figure 1. This simplified system block diagram shows the major signal flows to and from the sample chamber, which contains the antenna and parabolic reflectors.

- An AWG such as the Agilent M8190A creates a pair of linear frequency chirps, each having a bandwidth of 500 MHz to 1 GHz. These chirps provide the same high resolution of the CW approach but in much less time (Figure 2).

- A microwave signal generator such as the Agilent E8257D PSG is used to provide a precise carrier signal for the upconversion. The target frequency range covers 2 GHz to 26 GHz.

- A switch directs the signal generator output to the upconverter during the stimulus phase and to the downconverter during the measurement phase.

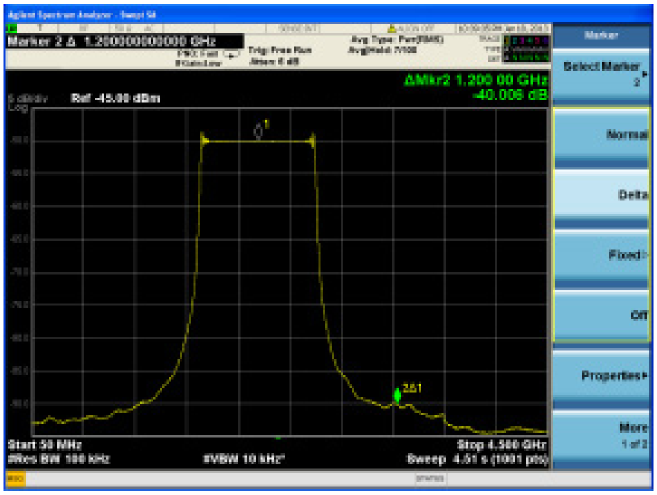
- After amplification and polarization, the upconverted broadband stimulus is directed to the antenna and the signal is beamed at the sample gas using a parabolic reflector. When exposed to a microwave field, the sample experiences molecular polarization.

- The return signal is reflected back to the antenna, which detects the relaxation spectrum.

- Within the switching system, the return signal is directed to the downconverter for translation into the frequency range of the digitizers. The downconverter outputs are low-pass filtered to attenuate out-of-band signals and minimize the likelihood of signal fold-back or "aliasing" into the frequency range of interest.

- High-speed PXI digitizers such as the Agilent U1061A-002 sample the incoming signals. These are converted into the frequency domain via fast Fourier transform (FFT) and the spectral composition of the transient emission is obtained.

Using a frequency chirp as the stimulus has another important benefit: it has inherently phase-invariant repeatability. Because the molecular signal is extremely weak, it is usually far below the level of thermal noise in the system. Phase-synchronized repetitions of the stimulus are essential to improving the signal-to-noise ratio through the phase-correct addition of individual measurements (Figure 3).



Marker 2 Δ 1.200000000000 GHz

ΔMkr2 1.200 00 GHz
-40.006 dB

Ref -45.00 dBm

Start 50 MHz
#Res BW 100 kHz
#VBW 10 kHz
Stop 4.500 GHz
Sweep 4.51 s (1001 pts)

Figure 2. As shown in this spectrum measurement, a 1-GHz chirp sweeps from 700 MHz to 1.7 GHz in 2 µs and has a dynamic range of 40 dB.

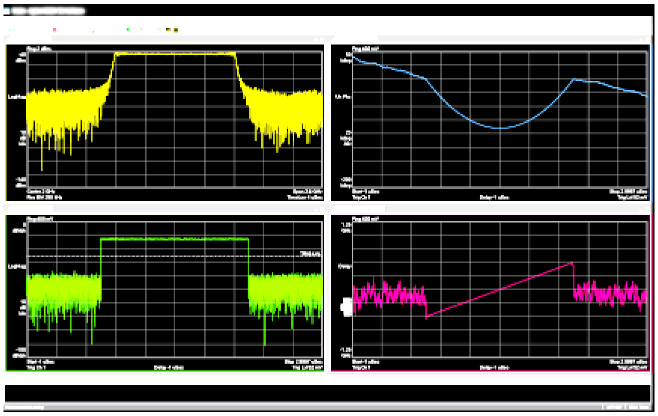


Figure 3. This quad display shows the spectrum of the frequency chirp (upper left), time envelope of the chirp (lower left), frequency ramp of the demodulated chirp (lower right), and continuous phase of the demodulated chirp (upper right).

Conclusion

In astrophysics applications, the net result of the AWG-based measurement solution is a deeper understanding of the chemical composition of the ISM. This technique is equally applicable, and similarly beneficial, to measurements in other fields:

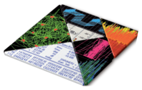
- Molecular physics: Perform basic research such as the fundamentals of molecular physics and the analysis of molecular structures.
- Bio-molecular spectroscopy: Investigate and understand the behavior and structure of biological molecules.
- Environmental research: Compare measurements to results from satellite-based measurements of chemical activity in Earth's atmosphere and oceans.

Related information

- Data sheet: *Agilent M8190A 12 GSa/s arbitrary waveform generator,* publication 5990-7516EN
- Data sheet: *Agilent E8257D PSG microwave analog signal generator,* publication 5989-0698EN
- Data sheet: *Agilent N5183A MXG microwave analog signal generator,* publication 5989-7572EN
- Technical overview: *Agilent U1061A Acqiris eight-bit, two-channel high-speed PXI digitizers,* publication 5989-7361EN

The Modular Tangram

The four-sided geometric symbol that appears in this document is called a tangram. The goal of this seven-piece puzzle is to create identifiable shapes—from simple to complex. As with a tangram, the possibilities may seem infinite as you begin to create a new test system. With a set of clearly defined elements—hardware, software—Agilent can help you create the system you need, from simple to complex.



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