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An interferometric spectrum analyzer with high dynamic range

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The dynamic range improvement and realization of the acousto-optic spectrum analyzer are reported. When two RF signals of equal strengths and frequencies f_1 and f_2 are applied simultaneously to the signal Bragg cell, the analyzer demonstrates a dynamic range of 50 dB and frequency resolution 10 kHz. © 1998 Elsevier Science Limited. All rights reserved.

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INTRODUCTION

In the power spectrum analyzer PSA which uses direct detection, the photodetector current is proportional to the power of the RF signal. A significant improvement of the dynamic range of the analyzer can be obtained only by increasing the laser power or the sensitivity of the photodetector and associated video amplifiers. Since the PSA based on rf analyzer detects only the intensity and the frequency of the diffracted light, not only is the phase information of the rf signals lost, but also the dynamic range of detection is severely limited. In this paper, the dynamic range improvement and realization of AO interferometric spectrum analyzer ISA are reported.

THE PRINCIPLE OF HETERODYNE

In the ISA scheme, the photodetector current of heterodyne detection is proportional to the square root of the product of the signal and reference[1–3]. The acoustic-optic ISA continuously forms the spectrum of a broadband electrical signal in the meantime reconstructs from that spectrum an exact replica of the input signal. The important feature of this process is that the spectrum is spatially distributed. Therefore it is available for editing or removing undesired portions of the spectrum. A typical example is to excite narrowband interference from broadband signals.

A general description of an acoustic-optic ISA is shown in *Figure 1.*

The electrical input signal $s(t)$ can be nearly an octave in bandwidth and is typically derived from a system consisting of a broadband antenna, downconverter, and amplifiers. This signal excites an electrical-to-acoustical transducer in the acousto-optic modulator. The acoustical signal travels in the modulator and is absorbed at the end of the modulator.

When the analyzer is illuminated with spatially coherent light, the acoustical signal $s(t, z)$ modulates the phase of the light passing through the acousto-optic modulator. The resulting spatial distribution can be considered to be equivalent to a superposition of plane waves of various phases and amplitudes. By using a lens to focus the various diffracted plane waves, each wave can be separated, and the amplitude and phase of each spectral component of the original input signal can be measured. As described so far, the acousto-optic ISA seems to be a power spectrum analyzer.

In addition to diffracting the plane waves in accordance to the spectrum of the input signal, the acousto-optic modulator also Doppler-shifts the diffracted plane waves. The amount of Doppler shift is exactly equal to the frequency of the input signal. Therefore, if the amount for Doppler shift can be measured, the frequency of the input signal can be measured. A straightforward technique for measuring an optical shift is to add some unshifted light from the optical source to shifted light and then to get by means of a square-law-detector. The resulting frequency of the beat signal is equal to the frequency difference between the optical signals and hence to the amount of Doppler shift. The changed optical amplitude will result in a proportionate change in the heterodyne component of the output signal $i(t)$. In general there is a linear relationship between the input signal $s(t)$ and the heterodyne component of the output signal $i(t)$ for weak acousto-optic diffraction.

However, each input frequency will be in a different location on the front of the photodetector. The ability to resolve two closely spaced signals is limited by the optical quality, apertures of the optics and the acousto-optic modulator. The total number of resolvable frequency cells depends on the time–bandwidth product and optical apodization of the acousto-optic modulator.

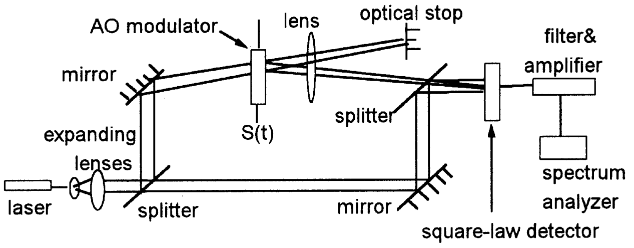

Figure 1 ISA system

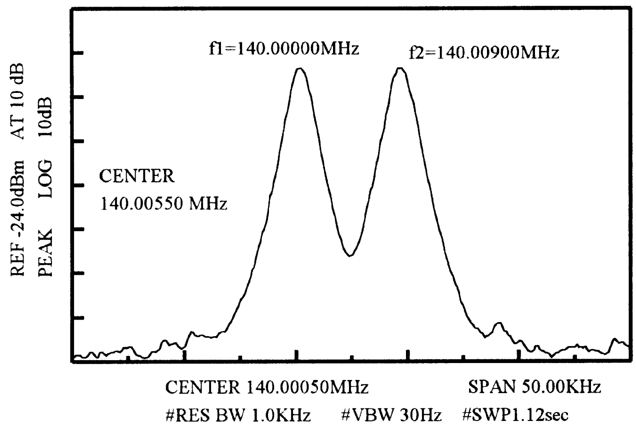

Figure 2 Measured dynamic range of rf signals and frrequency resolution

DYNAMIC RANGE

The dynamic range of an acousto-optic spectrum analyzer is limited by the available laser power, the optical loss in the system, the noise equivalent power of the photodetector and associated amplifier and the acceptable spurious level generated in the Bragg cell when multiple signals are simultaneously present. Since the diffraction efficiency of the Bragg cell is linearly proportional to the input RF power, the dynamic range of AO analyzer can be defined as

$$R = n_{\max} / n_{\min}, \qquad (1)$$

where $n_{\max}$ and $n_{\min}$ are the Bragg cell efficiencies at the maximum input power and at the threshold, respectively.

The maximum Bragg cell efficiency $n_{\max}$ is limited by the acceptable level of spurious signals. In AO Bragg cells, the dominant spurious signal is the third order intermodulation products (IMP) generated by the nonlinear response of the cells. When two signals of equal strength are simultaneously present in the Bragg cell, the third order IMP is given by

$$n_3 = n_{\max}^3/36. \qquad (2)$$

The above relation is valid only when the dominant nonlinear response is the multiple AO diffraction rather than nonlinear acoustics.

Supposing that the level of the third order IMP, n_3 is chosen to be equal to $n_{\min}$ when the strength of the two equal signals is equal to $n_{\max}$, from equations (1) and (2), we have

$$R = (6/n_{\min})^{2/3}. \qquad (3)$$

In this paper the dynamic range is defined with the threshold set at the level of tangential sensitivity.

In terms of dB, the dynamic range of the PSA and the ISA are given by[4]

$$R = \frac{2}{3}(I_o + T_o - I_{\min}) + 5.2\,(\text{dB}) \qquad (\text{PSA})$$

$$R = \frac{4}{3}(I_o + T_o - I_{\min}) + 5.2\,(\text{dB}) \qquad (\text{ISA})$$

where I_o is the laser power and T_o is the overall optical loss, $I_{\min} = I_o T_o n_{\min}$.

EXPERIMENTAL RESULT

Increased dynamic range of ISA is demonstrated by using the cascaded Bragg cell configuration shown in *Figure 1.* Two RF signals of equal strengths with frequencies f_1 and f_2 are applied simultaneously to the signal Bragg cell. The two-tone intermodulation free dynamic range of the ISA (defined by the above experimental procedure) is therefore 50 dB. *Figure 2* shows the measurement results of the two-tone intermodulation products of the ISA.

Considering that the dynamic range of the third order still surpasses 50 dB, it shows that when a RF signal input power is 14 dBm, the dynamic range of analyzere has much to be improved.

The analyzer has provided a dynamic range of 55 dB above tangential sensitivity for an RF signal, at the bandwidth of 20 MHz centered at 140 MHz at the optical wavelength of 0.6328 μm and an optical power of (3–5 mW).

In the range of the frequency channel, the difference 10 KHz of the two output signals did not produce the so-called 'obscure' phonomenon, and they can be clearly separated. This is the resolution limit of HP, not that of the analyzer.

Using semi-conductor laser ($\lambda = 0.63$ µm, output power 5 mW), though it is not one-direction polarization, yet it remains steady. The measured dynamic range is about 50 dB. So if one-direction polarization laser with large power can be used, the dynamic range will be improved.

There are other factors such as the abnormal Bragg diffraction (changing the polarization direction of the optical beams), laser mould, the splitter (having different reflection rates to the different polarization direction optical beams)which will influence mixed frequncy efficiencies.

Therefore, in theory the dynamic range of an ISA is expected to be double that of a PSA. But, in practice due to the division of laser power in the signal channel and multiple reference channels, etc. the overall dynamic range improvement is about 15 dB.

CONCLUSION

The analyzer demonstrated the capabilities for channelized detection of the amplitude, frequency, and phase of wideband rf signals and thus the capability to perform interferometric rf spectral analysis with significantly improved performances which are superior to the conventional AO Bragg cells.

Compared to the conventional spectrum analyzer, the present one shows an improvement of the dynamic range by atleast 15 dB. More improvement can be obtained with further research.

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