Broadband high-resolution programmable radio frequency signal analysis

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The optical serial coherent analyzer of radio frequency combines aspects of electronic and photonics-assisted devices.

Broadband instantaneous radio frequency (RF) analysis has always been a popular research topic because of its critical applications to radar and electronic warfare. As the frequency of the broadband signal increases, however, traditional electrical implementations of this frequency become more limited and the so-called electronics bottleneck is created. Photonics-assisted RF analysis methods are now being studied as a promising alternative technique. Photonics-assisted RF analysis methods have inherently large bandwidths and low loss levels. However, an important problem with these methods is the coarse frequency resolution compared with traditional electrical methods. The typical frequency resolution of photonics devices is greater than 0.1nm (about 12.5GHz), whereas the requirement for RF analysis is usually about three to four orders of magnitude lower. This greatly limits the applications of photonics-assisted methods.

We have developed a new approach, in which we take advantage of the wide bandwidth associated with photonics-assisted devices, as well as the high resolution of electronic methods. With our proposed optical serial coherent analyzer of radio frequency (OSCAR), we apply an optical frequency shifting technique to serially channelize the RF signals in a wide spectrum. We also use mature digital signal processing methods to realize signal analysis with high resolution. We are able to conveniently adjust the bandwidth of each channel so that the requirements of different applications are satisfied. Furthermore, we equip the recirculating frequency shifting (RFS) loop on either the signal link or the local oscillator (LO) link. We are thus able to achieve RF analysis in a continuous or a burst mode, using the same OSCAR system architecture.

Our OSCAR system configuration for burst mode is shown in Figure 1. The key component in this system is the RFS loop, in which the complex modulator is used to realize a single sideband frequency shift. In addition, the polarization controller is used to adjust the polarization of the signal so that the maximum modulation efficiency can be achieved. The loop also contains an erbium-doped fiber amplifier that compensates for transmission loss. Lastly, the bandpass filter is used to constrain the signal power within the proper frequency range and to suppress out-of-band noise. In our system, we can shift the central frequency of the input signal according to the frequency of the channel control signal \( f_c \) without producing any residual or mirror components. At the receiving end of OSCAR, we include a coherent receiver to minimize the bandwidth requirement and to acquire more signal information (amplitude and phase). Time-frequency diagrams of OSCAR operating in both

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Figure 2. Measured spectra when OSCAR is operated in burst mode. Spectra from each part of the radio frequency (RF) signal are shown in (a) to (d). (e) The original measured RF signal. (f) The recovered OSCAR RF signal.

Figure 3. Signal measured with OSCAR in continuous mode. (a) Time-frequency diagram of the RFS loop output. L: Low. H: High. (b) Linear frequency modulation spectra measured in the third channel (3–5GHz). A.U.: Arbitrary units.

continuous and burst mode are also shown in Figure 1. When OSCAR is configured to burst mode, the up-converted RF signal is fed into the RFS loop. The central frequency of the signal is then shifted by $f_c$ every time it passes the modulator. In this way, different parts of the spectrum are serially captured and the signal can finally be analyzed in the digital domain.

The measured spectra from the four parts of the RF signal analyzed by OSCAR in burst mode are shown in Figure 2(a) to (d), and the constructed spectrum of the RF signal from each of these fragments is shown in Figure 2(f). The constructed spectrum is the same as the original RF signal—shown in Figure 2(e)—except that it does not contain the accumulated noise floor. The under-measured RF signal we obtained was a 50ns ultra-short pulse with nine tones, as shown in Figure 2(e). The frequency of the channel control signal is 12GHz and the bandwidth of the balanced photodetector is 8GHz, which could be the 6GHz minimum. In this case, the receiving bandwidth (12GHz) is equal to the channel bandwidth.

When we configure OSCAR in continuous mode, the continuous wave is led into the RFS loop. The output of the RFS loop is a laser scanner, whose time-frequency diagram is shown in Figure 3(a). The length of the loop is about 80nm and $f_c$ is

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2GHz. The frequency spacing in Figure 3(a) is therefore 2GHz, and the duration of each frequency is about 400ns. We combined the scanning LO with the under-test linear frequency modulation (LFM) signal (with width of 22.5μs, and frequency range of 3.700–3.802GHz) and measured the spectra that are depicted in Figure 3(b). We obtained these spectra via eight measurements in the third channel. The measured starting and ending frequencies, and the slope of the LFM signal are 3.710GHz, 3.790GHz, and 4.53MHz/μs, respectively. These results are in good agreement with the original LFM signal.5,6 When OSCAR works in burst mode it can acquire all details of the signal, but the signal that is subsequently obtained during the analyzing process is ignored. On the other hand, continuous mode OSCAR operations allow uninterrupted signal measurement for a ‘sampling’ method. The two modes are therefore complementary to one another.

We have designed a new approach to broadband instantaneous RF analysis. With our OSCAR method we combine positive aspects of traditional electronic and more-recent photonics-assisted devices to achieve high-resolution signal analyses. In our future work we will focus on improving the measuring range and flexibility (i.e., for coverage at 0–100GHz and beyond), programmable speed, and resolution of OSCAR. We also aim to minimize the system size and to develop our methodology for real electronic warfare applications and other related areas.

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