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REDUCTION OF COHERENT NOISE IN THE LANDAU PLACZEK RATIO METHOD FOR DISTRIBUTED FIBRE OPTIC TEMPERATURE SENSING

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Abstract

The Landau Placzek ratio method for distributed fibre optic temperature sensing is based on the ratio of the Rayleigh and Brillouin backscattered light. However, because of the coherent nature of Rayleigh scattering, use of the same narrow bandwidth source as required for the Brillouin signal, results in significant coherent noise in the Rayleigh signal. A novel technique is demonstrated whereby the amplified spontaneous emission noise and amplifying properties of an erbium doped fibre amplifier may be exploited to reduce the coherent noise on the Rayleigh backscatter signal. This results in a significant improvement in both temperature and spatial resolution over previously reported results.

1. Introduction

Amongst the vast range of technologies used for sensor systems, the distributed fibre optic sensor is unique in being able to provide a practical means by which a measurand may be determined at any point along a sensing fibre, extending to several tens of kilometres. Distributed fibre optic sensors based on Brillouin optical time domain reflectometry (BOTDR) offer the following important advantages: the ability to measure strain as well as temperature, the use of standard telecommunications type fibre and single ended operation.

The principle of operation of existing backscatter distributed fibre sensing (DFS) systems is similar to that of the optical time domain reflectometer (OTDR) [1]. In the OTDR, a short pulse of light is transmitted along the fibre and the backscattered energy due to Rayleigh scattering is measured at the sending end of the fibre. The time interval between sending the pulse and detection of the backscattered energy provides the spatial information, whilst the intensity of the backscattered energy provides a measure of the fibre attenuation. In

Brillouin OTDR (BOTDR) [2] DFS systems, the Rayleigh backscatter mechanism is replaced by Brillouin backscattering. Brillouin scattering [3] occurs in optical fibres [4] and results from the interaction between the incident light beam and thermally generated acoustic waves in the fibre. The frequency of the captured backscattered light is effectively Doppler shifted due to the velocity of the acoustic wave. The frequency shift is a function of both temperature [5] and strain [6] in the fibre. Hence, the measurement of the frequency of the backscattered light provides a measure of the combined effects of strain and temperature along the fibre.

Recent experimental work [7] has demonstrated how the intensity of the Brillouin backscatter signal may be used in the Landau Placzek Ratio (LPR) [8] method to uniquely measure the temperature along the fibre sensor. Once the temperature of the fibre is spatially resolved, measurement of the Brillouin shifted frequency allows the distributed strain to be computed. Hence the strain may then be determined.

The main problem with this method as previously reported, was the poor signal to noise ratio arising from the coherent (fading) noise on the Rayleigh backscatter signal due to the narrow linewidth source used. This paper describes how the noise and amplifying properties of an erbium doped fibre amplifier (EDFA) may be exploited to produce a dual source, one wideband, the other narrowband, suited to the requirements of an intensity based BOTDR system. This results in a significant improvement in the signal noise ratio and spatial resolution of the temperature profile.

2. Reduction of coherent noise.

In the previously reported work [7], the (LPR) was measured using a narrow linewidth laser source (500MHz) gated with an acousto optic modulator and amplified with an EDFA. The frequency of the source was swept over approximately 2GHz to increase the threshold of stimulated Brillouin scattering, thereby enhancing the magnitude of the backscattered anti-Stokes signal used for the determination of the LPR. Both the Rayleigh backscattered signal and the spontaneous Brillouin signal were measured with this pulsed source and identical measurement conditions were maintained for these two measurements, apart from retuning the Fabry Perot interferometer to each signal.

The Brillouin shift is only about 10GHz at 1550nm, and the source linewidth must be less than this in order for the backscattered Rayleigh not to over lap with the backscattered Brillouin signal whilst making the anti-Stokes measurement. However, a narrow source linewidth generates coherent noise on the Rayleigh backscatter signal. This is a well known problem with coherent OTDR (COTDR) systems [9] but will also cause noise with direct detection systems.

In practice, the fibre is subjected to minute mechanical and thermal changes which result in a changing phase of the backscattered waves at the detector. Hence the characteristic fading of the backscatter signal known as fading noise. Unfortunately, as the mechanical and thermal changes may vary only slowly with time, conventional signal averaging techniques cannot be used effectively to reduce fading noise. One technique which has been used to reduce fading noise is frequency shift averaging (FSAV) [10] whereby the average is determined from a large number of samples each measured at a different source frequency. It has been shown that the amplitude fluctuations on the backscatter trace decreases in proportion to the square root of the number of independent backscatter signals [11].

The same effect is obtained by using a broad band noise source. In this experiment, a convenient source of broad band noise is available in the form of the amplified spontaneous emission (ASE) from the EDFA. Since the Rayleigh backscatter signal is used only as a reference, it is not essential to know the absolute LPR to determine the temperature along the fibre. Hence it is not necessary for the Rayleigh source to be the same as the Brillouin source. It is however important that the fibre losses measured with the broadband source are representative of the losses at the Brillouin shifted wavelengths.

In this experiment, whilst the EDFA has been used as an amplifier to generate the pump source for the Brillouin backscatter signal, the EDFA ASE has been used as a second source to obtain the Rayleigh backscattered signal. As it is difficult to ensure that stimulated scattering of the Stokes signal is completely suppressed, the Rayleigh Anti-Stokes ratio (RASR) was used as a measure of the sensing fibre temperature instead of the true LPR (Rayleigh/(Stokes+anti-Stokes)). Furthermore, it is also experimentally more convenient to take a single measurement of the anti-Stokes than a measurement of both Stokes and anti-Stokes. In order to obtain an indication of the improvement in signal to noise of this method over that used previously, the standard deviations of the RASRs for each method are compared.

Since the noise is not present on the Brillouin signal to the same degree as on the Rayleigh signal, due to the non-coherent nature of the Brillouin backscatter process, eliminating the coherent noise from the Rayleigh backscatter signal provides a significant improvement in the measurement of fibre temperature.

3. Experimental

The experimental set up is shown in figure 1. The source used to generate the narrow band pulse was a distributed feedback laser (DFB) providing approximately 0.9mW at 1537nm. In order to suppress the generation of stimulated Brillouin scattering along the DFS, the injection current of the DFB was modulated to broaden its effective linewidth. A triangular wave of 3mA pk-pk at a frequency of 0.6MHz was used. This produced a source 'linewidth' of approximately 2GHz. The acousto optic modulator (AOM) was a fibre pigtailed device with an insertion loss of 4.5dB and a rise time of 44ns. The AOM was gated to produce pulses of 1.3μs with a period of 160μs. The output from the AOM was amplified by the erbium doped fibre amplifier (EDFA) which produced a pulse power of 18dBm. This was coupled to the sensing fibre by a 50% coupler C2, to maximise the backscattered signal.

The ASE from the EDFA was used as a source to generate the wideband pulse. This has a 3dB bandwidth of approximately 5nm. The output was gated using the AOM.

The sensing fibre consisted of three lengths each of 4.3km, 125μm telecommunications grade fibre with a specified cutoff of 1180-1280nm and attenuation of <0.22dB/km. The centre section was placed in an oven and maintained at a temperature of 55°C.

The backscattered signal was extracted from the sensing fibre via C2 and the fibre output was collimated and directed through the scanning Fabry Perot (FP) that was used to separate the Rayleigh and Brillouin components.

The FP was set to a free spectral range of 50GHz with a finesse of 100 and a transmission loss of approximately 10dB. The output from the FP was focused onto a 300μm InGaAs detector connected to a 100MΩ transimpedance amplifier with a bandwidth of 175kHz. A 3nm band pass filter was used in front of the detector to attenuate the Rayleigh backscatter from the interpulse EDFA amplified spontaneous emission for the anti-Stokes measurement. The FP was removed in order to measure the wideband Rayleigh backscatter signal. The Rayleigh and Brillouin traces were stored separately on a digital storage oscilloscope using 2048 averages and the temperature profile determined from P_R/P_{AS}, where P_R and P_{AS} are the measured backscatter Rayleigh and anti-Stokes powers respectively.

4. Results

The narrow band Rayleigh backscatter trace is shown in figure 2(a). The fluctuations due to polarization and fading noise are clearly seen. The anti-Stokes trace is shown in figure 2(b) and the resultant RASR representing the reciprocal of the temperature profile in figure 2(c). The mean values of RASR for the three sections are also shown. The average value of those of sections 1 and 3 is used as a reference value corresponding to the ambient temperature of 294K.

The wideband Rayleigh backscatter signal is shown in figure 2(d). The only visual disturbance to the Rayleigh backscatter trace is that due to the splice between sections 2 and 3 corresponding to 0.2dB one way loss. The resultant RASR is shown in figure 2(e) together with the mean values. Again, the average value of those of sections 1 and 3 is used as the reference value corresponding to the ambient temperature. The results are summarised in table 1.

Source	Average of sections 1 & 3 (Reference)		Section 2	
	RASR	Temp (K)±1SD	RASR	Temp (K)±1SD
Narrowband	75.19	294.0±8.2	67.03	327.8±8.6
Wideband	19.23	294.0±1.5	17.28	328.3±1.3

Table 1 Summary of results

5. Discussion

The improved accuracy of the RASR obtained using the wideband source is demonstrated by comparing the standard deviation of the RASR obtained using a narrowband source with that obtained using the wideband source.

In order to determine the actual temperature profile along the fibre, a calibration value is required to provide a known RASR at a known temperature. In this experiment this is provided by the first and third section of fibre at an ambient temperature of 294K. Using the narrowband Rayleigh signal, the first and third sections of fibre provide an average RASR of 75.19. The second section of fibre has a RASR of 67.03 therefore corresponding to a temperature of 327.8K which is in close agreement with the temperature measured in the oven (328±1) using a thermocouple in close proximity to the fibre.

For the wideband Rayleigh signal the average RASR for the first and third sections is 19.23. The second section has an RASR of 17.28 corresponding to a temperature of 328.3. This is also in agreement with the measured fibre temperature.

The foregoing results show that both methods result in a similar estimate of the average temperature along the sensing fibre. However, there is a 5-6 fold reduction of the standard deviation of the temperatures measured and hence a corresponding improvement in the temperature resolution measurement. Furthermore, the reduced fading and polarization noise on the Rayleigh signal has resulted in less ambiguity of the spatial features of the backscatter trace enabling a shorter pulse (1.3us) to be used and therefore greater spatial resolution (130m) to be obtained than with earlier results (600m) [7].

6. Conclusion

A novel technique has been reported whereby a single EDFA may be used as part of a dual source to generate both a wide band and narrow band signal for use in the Landau Placzek ratio method BOTDR DTS system. Using a wideband source to generate the Rayleigh backscatter signal has resulted in a considerable reduction in the coherent noise of this scattering. This has resulted in a significant improvement in the temperature and spatial resolution of previously reported results.

References

[1] M. K. Barnoski and S. M. Jensen, Appl Opt, 15, (1976), 2112.

[2] T. Kurashima, T Horiguchi, H. Izumita, S. Furukawa and y. Koyamada, IEEE Trans Commun, E76-B, (1993), 382.

[3] R. W. Boyd, Non Linear Optics, Academic Press, (1992), Chapter 8.

[4] G. P. Agrawal, Non Linear Fiber Optics, Academic Press, (1989), Chapter 9.

[5] T. Kurishima, T. Horiguchi and M. Tateda, Appl Opt, 29, (1990), 2219.

[6] T. Horiguchi, T. Kurashima, and M. Tateda, IEEE Phot Tech Lett, 1, (1989), 107.

[7] P. C. Wait and T. P. Newson, Optics Comms, to be published.

[8] J. Schroeder, R. Mohr, P. B. Macedo and C. J. Montrose, J Am Cer Soc, 56, (1973), 131.

[9] P. Healy, Electron Lett, 20, (1984), 30.

[10] H. Izumita, S. Furukawa, Y. Koyamada and I. Sankawa, IEEE Phot Tech Lett, 4, (1992), 201.

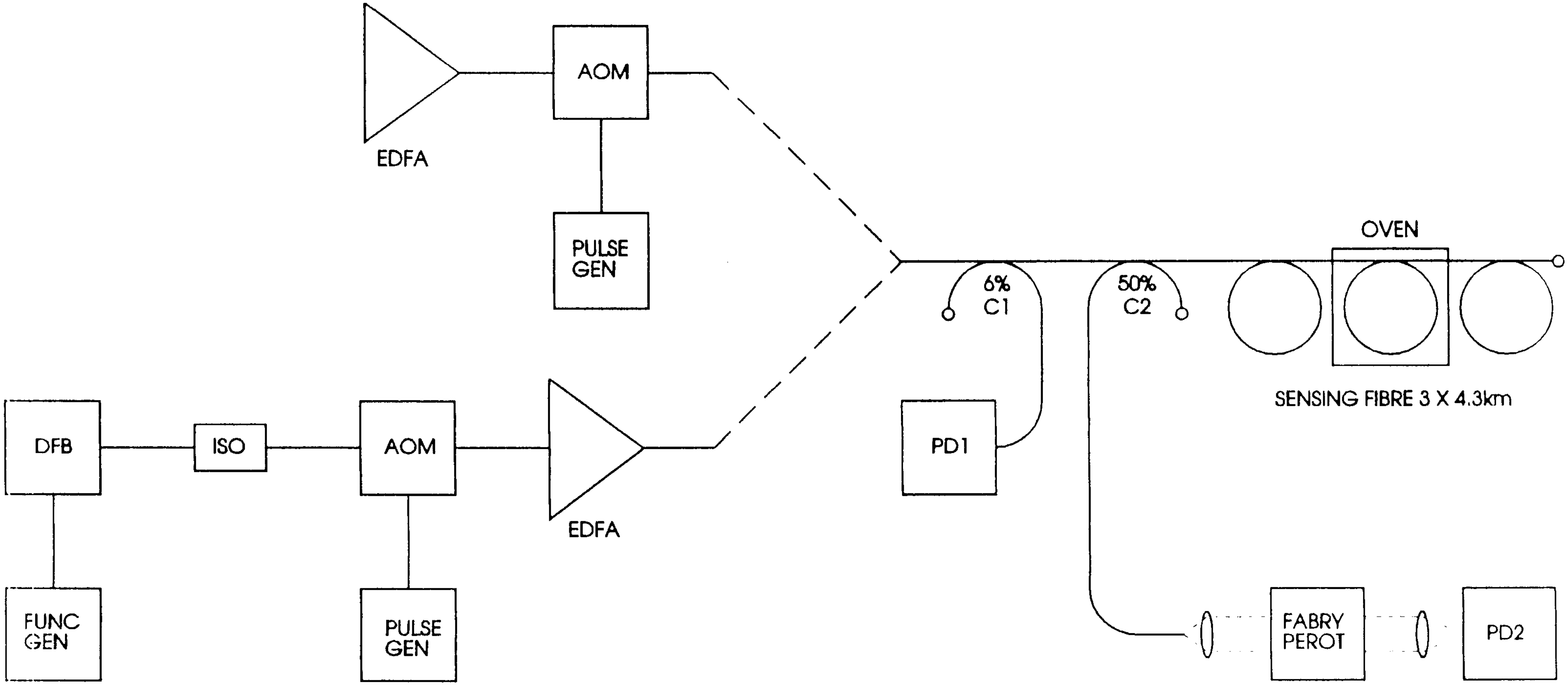
[11] J. P. King, D. F. Smith, K. Richards, P. Timson, R. E. Epworth and S Wright, J Light Wave Tech, LT-5, (1987), 616.

Figure captions

Figure 1 Experimental schematic

Figure 2 Sensing fibre backscatter traces.

(a), (b) and (c) Rayleigh, anti-Stokes and Rayleigh/anti-Stokes ratio respectively for the narrowband Rayleigh source. (d) and (e), Rayleigh and Rayleigh/anti-Stokes ratio for the wideband Rayleigh source.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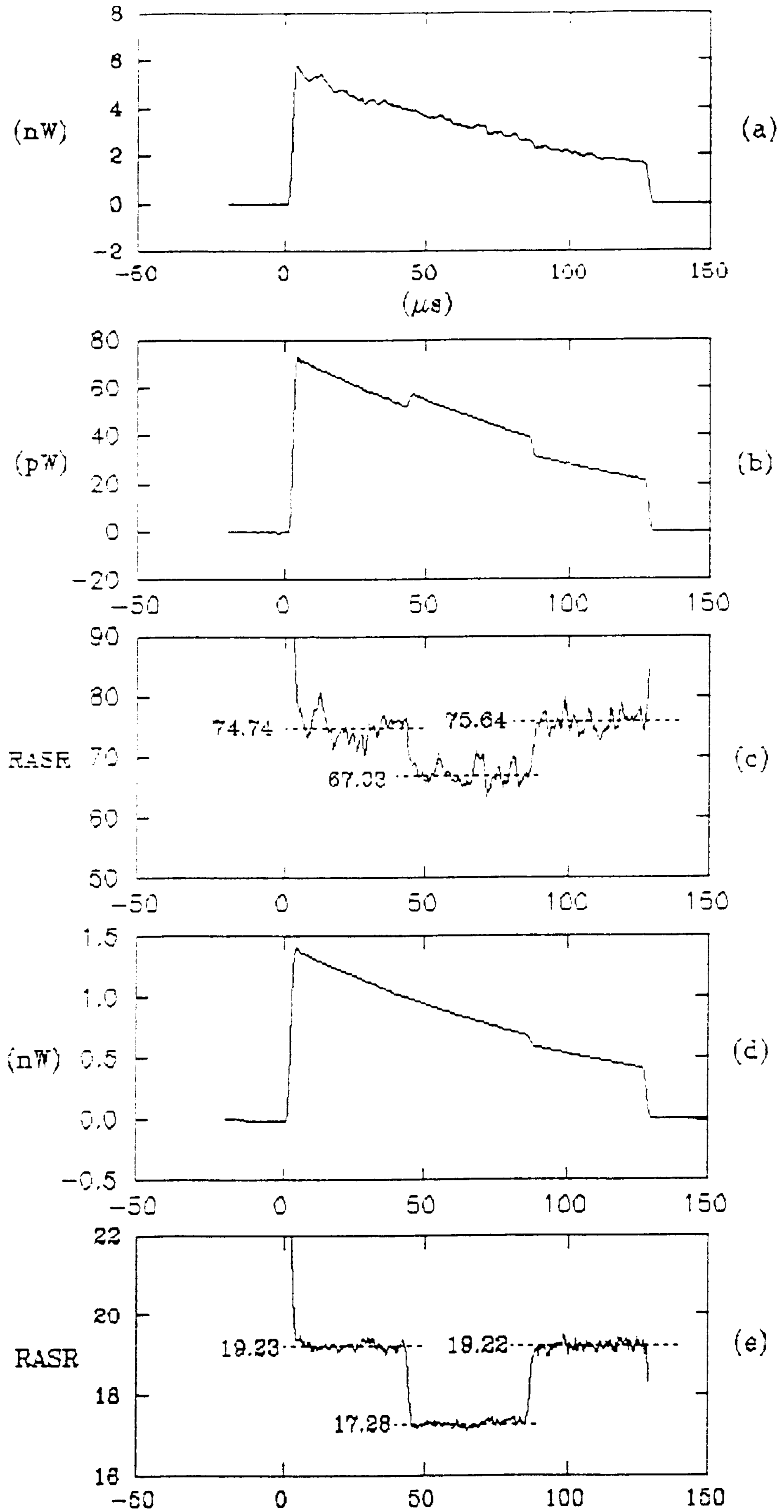

(nW)
(a)
(μs)
(pW)
(b)
74.74
75.64
67.03
RASR
(c)
(nW)
(d)
19.23
19.22
17.28
RASR
(e)