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Optical Fiber Amplifiers: Optimization and Performance Evaluation

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Abstract

This work demonstrates the simulation of two different types of optical fiber amplifiers (OFA) utilizing OptiSystem–10, namely, 3 m length of erbium doped fiber amplifier (EDFA) and 7 km length of Raman fiber amplifier (RFA). The counter-pumped architecture is adopted for both proposed optical amplifiers. The optimum pump power (OPP) for each amplifier determines in which the longest 3–dB flat gain bandwidth (3–dB BW), reasonable average gain level (G_{av}), proper average noise figure (NF_{av}) and lower gain variation (G_{var}) were achieved. The EDFA shows best performance at conventional band (C–band) within the pump power of 30 mW.While the better performance is observed at long band (L–band) within the pump power of 600 mW for the RFA.

Keywords: optical fiber amplifier; EDFA counter pumped; Raman fiber amplifier.

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1.Introduction

The OFA is simply a fiber laser with the absence of the positive feedback, and can be classified into two categories, namely, linear OFA (rare earth doped fiber amplifier) and nonlinear OFA (Raman and Brillouin fiber amplifier). The most popular linear OFA is the EDFA because it covered the low loss conventional communication band [1]. While the RFA is the common nonlinear FA due to the following points: (i) the gain can be achieved at any communication band within the proper pumPing wavelength choice; (ii) very fast amplification processes; (iii) wide amplification bandwidth [2].

The main difference between these two amplifiers is the amplification mechanism. The amplified input signal in EDFA depends on the population inversion between the energy levels of the erbium ions which called a linear amplification mechanism [3]. While, the nonlinear stimulated Raman scattering phenomenon is the core mechanism of the RFA [4].

In addition, all performance parameters of these two amplifiers depend on the amplification mechanism, such as the gain bandwidth, gain saturation and the noise figure, as well as the required pumPing power. For the EDFA a few tens of milliwatts are sufficient to reach the required pumPing power [5], while the RFA need a hundreds of milliwatts to exceed the stimulated Raman scattering threshold power and reach the required pumping power [6].

In this paper, the erbium pump power (EPP) for 3 m of the EDFA and Raman pump power (RPP) for 7 km of the RFA was optimized utilizing OptiSystem–10. At OPP of 30 mW the EDFA produced G_{av} of 20.17 dB, G_{var} of 2.928 dB, NF_{av} of 4.448 dB and 3–dB BW of 25 nm. While, G_{av} of 11.946 dB, G_{var} of 1.703 dB, NF_{av} of 4.646 dB and 3–dB BW of 27 nm is obtained from the RFA at OPP of 600 mW.

This paper is organized as follows. Section 2 describes the simulation design for both of the EDFA and RFA, Section 3 is devoted to the results and discussion, finally, Section 4 ends with conclusions based on the simulation results and present the contribution of the work.

2.Simulation Design

In this section the proposed designs for both EDFA and RFA are simulated via OptiSystem-10 utilizing counter-pumped configuration within a single pump wavelength of 1480 nm.

A.EDFA Model

The EDFA simulation model utilizing counter-pumped configuration is illustrated in Figure 1. The input signal power (P_{in}) is obtained from a tunable laser source (TLS) with a line width of 10 MHz (λ=30 nm), wavelength ranging from 1535 nm –to– 1565 nm and maximum output power of 5dBm. The erbium amplification is achieved from 3 m of erbium doped fiber pumped by laser diode with maximum power of 60 mW at 1480 nm. The

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Er^{+3} ions concentration is 440 ppm, core radius is 1.9 µm, and cutoff wavelength is 1300 nm. In this work, the input signal and the pump power are injected to the EDFA via wavelength devision multiplexer (WDM). Both of the gain level and the Noise Figure for the proposed EDFA are calculated utilizing a dual port WDM analyzer. Three optical isolators were used to prevent any reflected light from damaging the TLS or the EPP source.

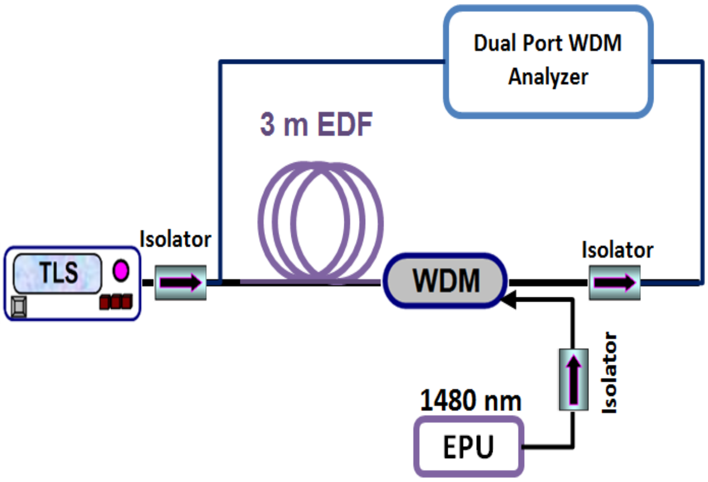

Figure 1: Simulation setup of EDFA utilizing counter–pumped configuration

B.RFA Model

In the simulation design of the RFA a 7 km of dispersion compensating fiber (DCF) is adopted as a Raman gain medium, which counter pumped by a Raman pump unit (RPU) with center wavelength at 1480 nm as illustrated in Figure 2. The input signal is provided from same TLS that used in EDFA. An optical spectrum analyzers (OSA) are used to record the Brillouin Stokes power via port 3 of the optical circulator.The DCF based RFA can provide several advantages in comparison with the single mode fiber due to its small effective core area and high germanium concentration.

This result in a high Raman gain of 10–20 dB, a high Rayleigh scattering coefficient, and usually, nonlinearity 7–8 times higher than the SMF [7, 8]. The gain level and the NF are calculated utilizing a dual port WDM analyzer.

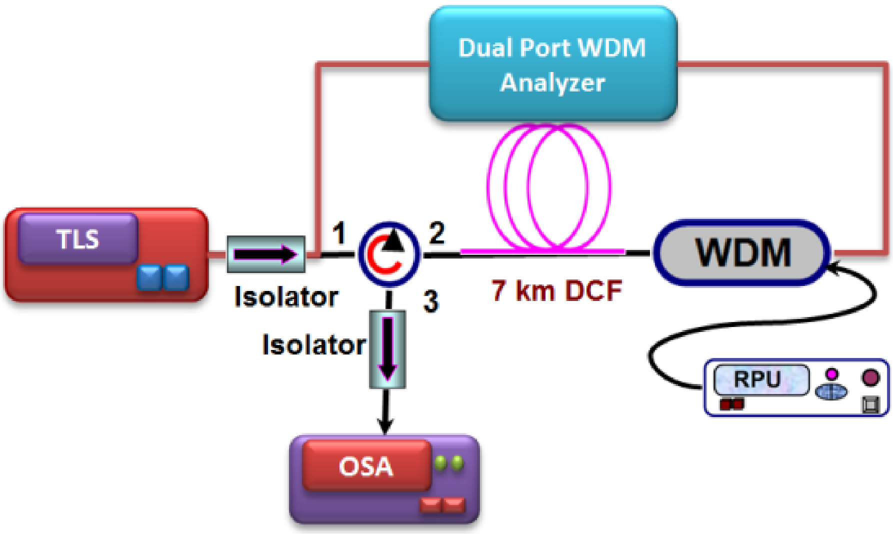

Figure 2: Simulation setup of RFA utilizing counter–pumped configuration

3.Results and Discussion:

A.Pump Power Optimization

In this work the Pin is set at –30 dBm, the wavelength is tuned from 1535nm to 1565 nm with a step of 1 nm for the EDFA as depicted in Figure 3**Error! Reference source not found.**, while, is tuned from 1550nm to 1600 nm with a step of 5 nm for the RFA as depicted in Figure 4. The EPP is increased from 20 mW to 60 mW with a step of 10 mW and the RPP is increased

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from 400 mW to 800 mW with a step of 100 mW. According to the results, for both amplifiers the average gain increases quickly as the pump power is increased, and starts to saturate at a certain pumPing level. This can be attributed as following; in EDFA the EPP is fully inverted the population in the erbium ions, while in RFA the pump depletion and the red shift effect caused the gain saturation and deviated the amplification factor.

The analyzed data from Figures 3 and 4 show three main parameters are taken into account through this pump optimization within 3–dB gain variation, namely, the G_{av}, G_{var}, and 3–dB BW as depicted in Table-1 and Table-2 for both EDFA and RFA, respectively. While the fourth parameter (NF_{av}) is collected directly from the dual port WDM analyzer and analyzed within the 3–dB BW for each amplifier. For the EDFA, the OPP is about 30 mW at which the EDFA shows 3–dB flat gain bandwidth of about 25 nm from 1537 nm –to– 1562 nm within G_{av} of 20.17 dB, G_{var} of 2.928 dB and NF_{av} of 4.448 dB. While the OPP for RFA is about 600 mW at which the RFA produces a 3–dB flat gain bandwidth of about 27 nm from 1567 nm –to– 1594 within G_{av} of 11.94 dB, G_{var} of 1.703 dB and NF_{av} of 4.646 dB.

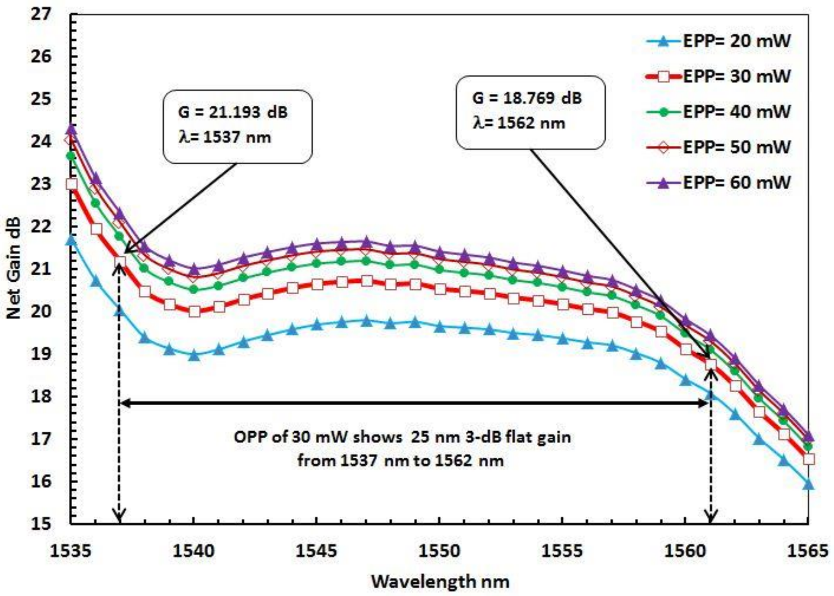

Figure 3: Gain profile of 3m EDFA, at Pin of –30 dBm, for the different EPP of 20 MW, 30 mW, 40 mW, 50 mW and 60 mW, at OPP = 30 Mw

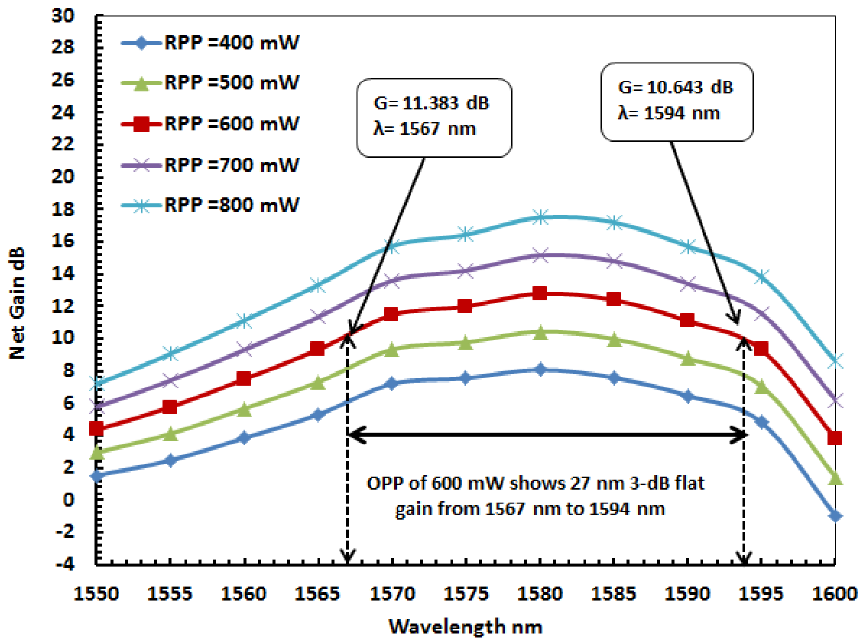

Figure 4: Gain profile of 7 km RFA, at Pin of –30 dBm, for different RPP of 400 mW, 500 mW, 600 mW, 700 mW and 800 mW, at OPP = 600 mW

Table 1 The analyzed data from Figure 3.

EPP mW	G_{av} dB	G_{var} dB	NF_{av} dB	3-dB BW nm
20	19.457	2.323	4.606	24
30	20.17	2.928	4.448	25
40	20.463	3.23	4.373	25
50	20.695	3.23	4.325	24
60	20.864	3.381	4.309	24

Table 2 The analyzed data from Figure 4.

RPP mW	Gav dB	Gvar dB	NFav dB	3-dB BW nm
400	7.025	2.774	4.635	25
500	9.267	3.124	4.684	26
600	**11.946**	**1.703**	**4.646**	**27**
700	14.234	1.748	4.636	23
800	16.521	1.794	4.615	24

B.Performance Evaluation

The performance of both amplifiers in terms of; saturation power, gain profile and NF is evaluated under OPP conditions and at different Pin levels.

(i) Saturation Power

In optical amplifier, the gain level is constant at small signal power values, and start to degrade when the P_{in} exceeds a certain value. This power level is called a saturation power (Psat) and this phenomenon is known as the “gain saturation”. Figure 5 shows the Pin versus the gain level for both amplifiers at OPP. In this work the input signal wavelength is tuned at the peak location of 1530 nm and 1580 nm for EDFA and RFA, respectively. The P_{in} is varied from –30 dBm –to– 5 dBm with a steps of 1 dBm. The gain saturation is determined when the gain factor is dropped to half its constant value, this corresponds to the 3–dB gain level and the Pin at this level is known as P_{sat}. In EDFA the gain saturation occurs due to large signal when it’s dropped all the excitation erbiumions [3], while in RFA the gain saturation ocuurs due to stimulated Brillouin scattering [9][10]. The Psat is about –15 dBm and 2 dBm for EDFA and RFA, respectively.In order to validate, the proposed RFA model the gain level and the Stokes power as a function of the Pin within a certain wavelength of 1580 nm are illustrated in

Figure 6. The results clarify the increase in Brillouin Stokes power when the RFA gains decreased, (i.e., the degradation in the gain starts exactly when the Brillouin Stokes appears due to stimulated Brillouin scattering effect.

(ii) Gain Profile and Noise Figure

In order to investigate the performance of the proposed amplifiers under two different input signal regions, namely, small and large regions,the gain profile and NF for both EDFA and RFA at OPP within different P_{in} are depicted in Figure 7 and Figure 8, respectively. The input signal wavelength is tuned from 1540 nm –to– 1580 nm with a step of 5 nm to obtain the gain spectra at the Pin of –30 dBm and –15 dBm for EDFA.While the wavelength is tuned from 1550 nm –to– 1600 nm with a steps of 5 nm to obtain the gain spectra at the Pin of –30 dBm and 2dBm for the RFA. Both EDFA and RFA were working within a small input signal region when the Pin is set at –30 dBm, and worked within a large input signal region at –15 dBm and 2 dBm for the EDFA and RFA, respectively.

When the P_{in} is increased from -30 dBm to -15 dBm, the G_{av} of the EFDA is reduced of about 1 dB from 20.17 dB to 19.31 dB, while both of

NFav and BW were constant at 4.45 dB and 25 nm, respectively. In RFA, the increased signal power from -30 dBm to 2 dBm caused a decreased in the G_{av} of about 4 dB from 11.94 dB to 7.97 dB, and the NF_{av} is slightly increased from 4.64 dB to 4.85 dB, while the BW is increased from 27 nm to 40 nm, respectively.

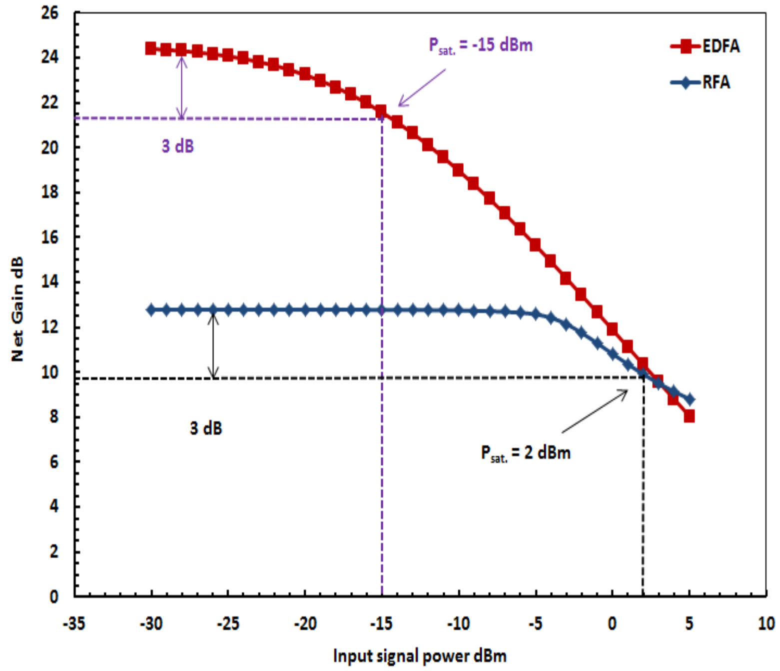

Figure 5: Gain level versus the P_{in} at 1530 nm within OPP of 30 mW, P_{sat} = -15 dBm , and at 1580 nm within OPP of 600 mW, P_{sat} = 2 dBm for EDFA and RFA, respectively

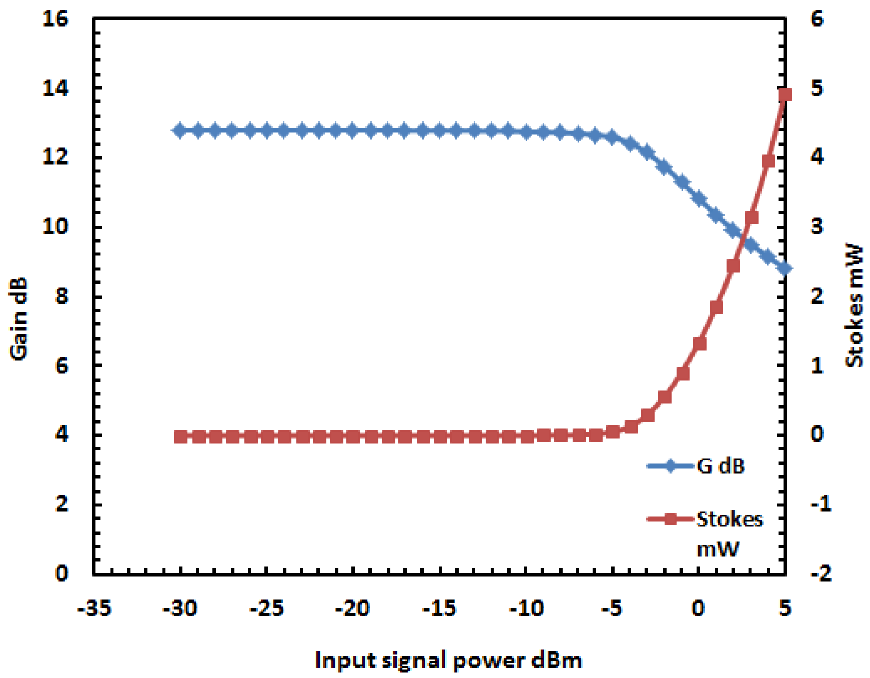

Figure 6: Raman gain and Stokes power versus Pin at OPP and input signal wavelength of 1580 nm

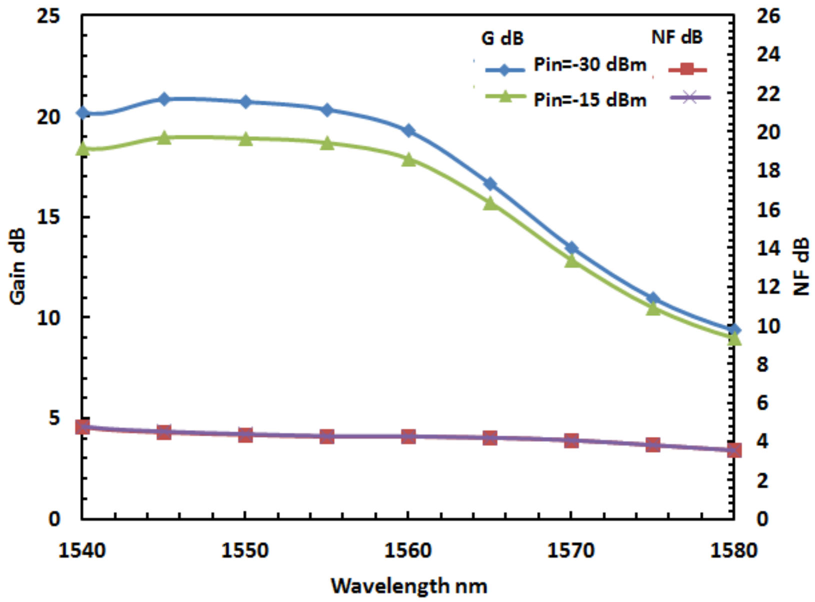

Figure 7: The gain profile and noise figure of EDFA, at different Pin of –30 dBm and–15 dBm, at the OPP of 30 mW

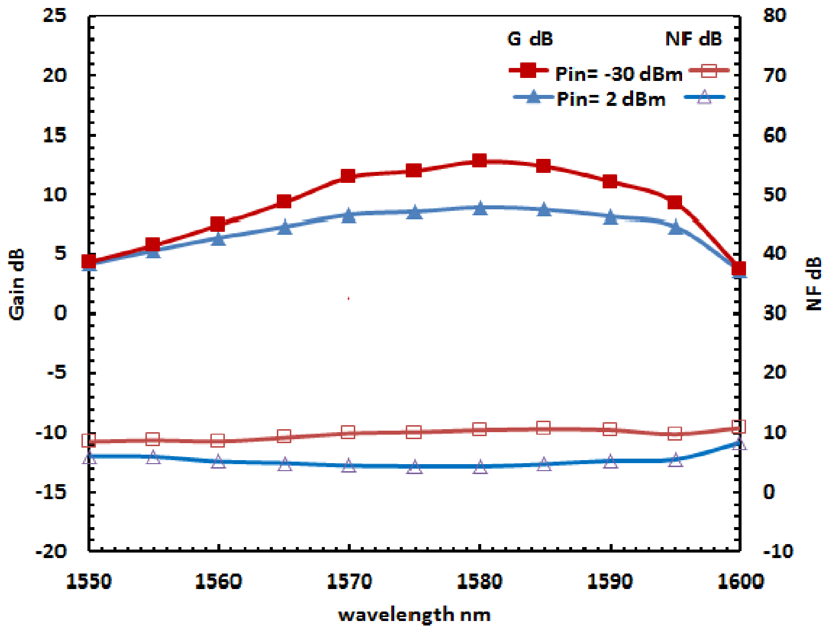

Figure 8: The gain profile and noise figure of RFA, at different Pin of –30 dBm and 2 dBm, at the OPP of600 Mw

4.Conclusions

In this work, the OPP for the fiber amplifier is defined as the pump power in which the longest 3–dB flat gain bandwidth, reasonable G_{av}, proper NF_{av} and lower G_{var} were achieved. The performance of both proposed amplifiers is evaluated at OPP, which is determined at EPP of 30 mW and RPP of 600 mW for the EDFA and RFA, respectively. RFA requires a longer gain medium length as well as a higher pump power than the EDFA due to the differences in the amplification mechanism.

Research Contributions

The contribution of this work is the deep investigation both of the EDFA and RFA within a wide amplification bandwidth by utilizing OptiSystem-10. The bidirectional fiber model is adopted as a gain medium for the proposed RFA. The SBS effect is covered in this model, as a result, the gain saturation due to the large input signal can be investigated. In addition, determining the OPP at which the OFA provides higher G_{av} as well as accepting NF_{av} and wide flat gain bandwidth is the other contribution of this research paper.

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