Giant Pulse Phenomena in a High Gain Erbium Doped Fiber Amplifier

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ABSTRACT

High gain Erbium Doped Fiber Amplifiers (EDFAs), while revolutionizing optical communications, remain vulnerable to optical damage when unseeded, e.g. due to nonlinear effects that produce random pulses with high peak power, i.e. giant pulses. Giant pulses can damage the components in a high gain EDFA or external components and systems coupled to the EDFA. We explore the conditions under which a reflective, polarization-maintaining (PM), core-pumped high gain EDFA generates giant pulses, provide details on conditions under which normal pulses evolve into giant pulses, and provide results on the transient effects of giant pulses on an amplifier's fused-fiber couplers, an effect which we call Fiber Overload Induced Leakage (FOIL). While FOIL's effect on fused-fiber couplers is temporary, its damage to forward pump lasers in a high gain EDFA can be permanent.

Keywords: Erbium Doped Fiber Amplifier, giant pulse, Stimulated Brillouin Scattering (SBS), Self-Q Switching (SQS)

1. INTRODUCTION

Figure 1 shows an implementation of a high gain PM reflective amplifier that generates giant pulses both when unseeded and when seeded by priming pulses as described in section 2. The amplifier comprises an isolator (IS), PM tap couplers, a polarization beam splitter (PBS), singlemode pump-signal combining wavelength division multiplexers (WDMs), erbium doped fiber (EDF), 978 nm pump lasers, and a band-pass Faraday mirror (FM) hybrid. In normal operation, input signals at 1550 nm, e.g. CW, periodically pulsed, or randomly modulated seed laser signals, polarized on the slow axis of PM fiber, are presented to port 1 and extracted from port 8. While fiber-optic elements at the input and output of this reflective amplifier are PM, the elements between the PBS and FM need not be, i.e. these can be single-mode (non-PM) components.

A rightward-traveling or forward signal from the PBS is combined with the forward pump light from diode #1 in WDM1, amplified in EDF#13-17, coupled through WDM2 along with power from forward pump diode #2, and amplified by a EDF#20-24 in the EDFA's second stage. The forward signal from the second stage EDF couples through WDM3 to the FM, which reflects the orthogonal polarization state of the forward signal thereby forming a leftward-traveling or reverse signal. The reverse signal then traverses both EDF#20-24 and EDF#13-17, completing a round trip through four stages of gain, then exits this PM, reflective, high-gain amplifier through port 8. We note that while pump diodes #1 and #2 provide forward pumping and pump diodes #3 and #4 can provide reverse pumping, only forward or reverse pumping are used at any given time, i.e. this amplifier does not use bidirectional pumping. Instead pump diodes #3 and #4 are reserved or redundant; these reverse pumps are only used if pump diodes #1 and/or #2 fail.

Unlike the reverse pumps, both forward pumps are coupled to the EDF not only by pump-signal combining WDMs (WDM1 and WDM2) but also by WDM4 and WDM5, respectively. These interposed WDMs serve to both protect their pumps from reverse-coupled giant pulses and monitor such pulses, i.e. at ports 16 and 23. We tested both the protective isolation provided to the pumps by WDM4 and WDM5 and the overload characteristics of fused fiber couplers [1], [2], i.e. Kerr-switching based Fiber Overload Induced Leakage (FOIL), using the setup of Figure 2. Our discussion and results on tests of giant pulse generation in the reflective amplifier of Figure 1 necessarily begins with sizing the protective WDMs for pump diodes #1 and #2, i.e. determining both the isolation of and number of WDMs needed to protect these forward pumps. While we do not exclude the possibility that the reverse pumps of Figure 1 might also need such protective elements, we have not examined the susceptibility of these pumps to damage through FOIL-conducted giant pulses.
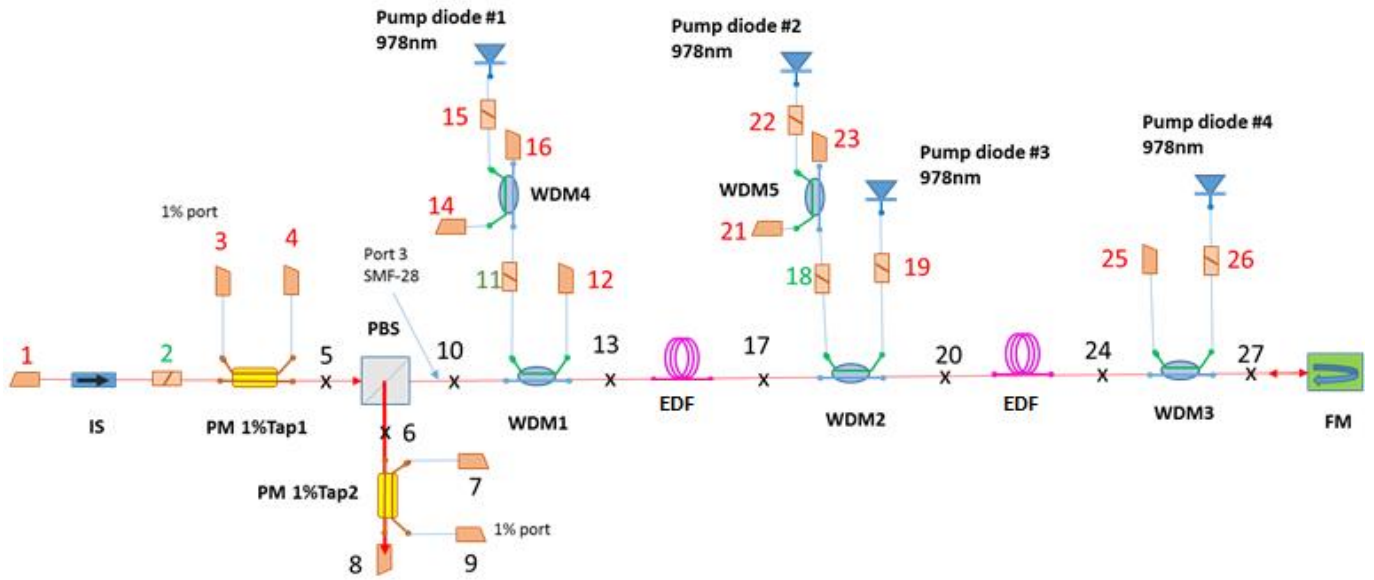
Figure 1. Polarization maintaining (PM) high gain reflective amplifier
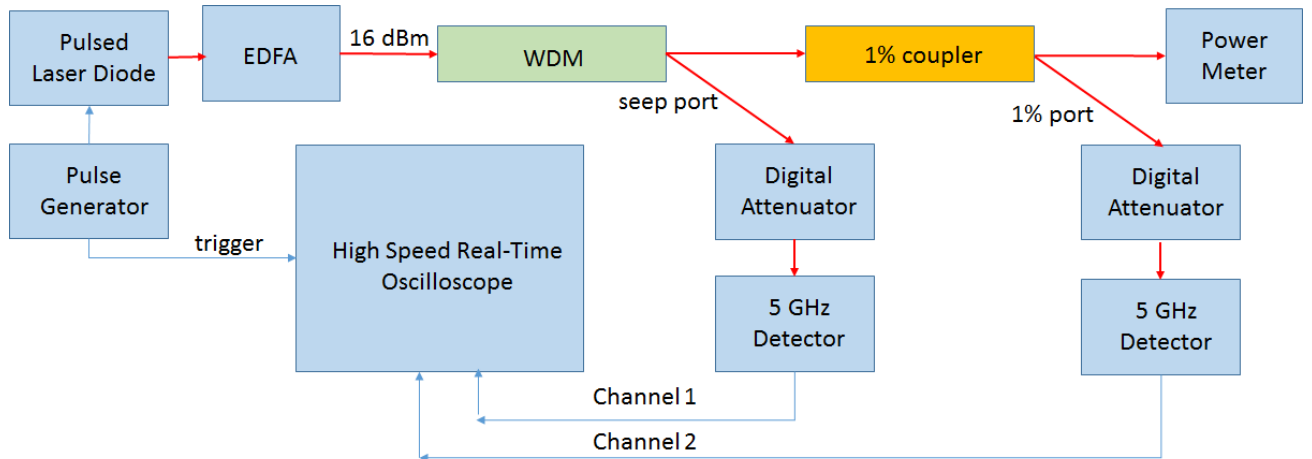

Figure 2. Setup for testing the main (normally signal + pump) and seep output ports of a WDM and the main and tap port of a broadband fused-fiber couplers; the input signal to the WDM is a high peak power or giant pulse from the high gain PM reflective amplifier EDFA per Figure 1.

2. FIBER OVERLOAD INDUCED LEAKAGE (FOIL) TESTS

Using the setup of Figure 2, we tested the isolation of 1550 nm signal pulses at the WDM's seep port as a function of the peak power of the 1550 nm signal. The seep port primarily dumps uncoupled 978 nm pump light but can also include significant amounts of 1550 nm light during a FOIL event. In other words, the signal isolation of the seep port can degrade significantly during a FOIL event. Conversely and vitally, the reverse-direction isolation of the WDM can collapse during a giant-pulse induced FOIL event, coupling a damaging 1550 nm pulse to the WDM's pump port. In other words, the setup of Figure 2 is a hardware emulation of the reverse-traveling pulses into WDM2 and especially WDM1 of the PM EDFA of Figure 1, e.g. the seep port of Figure 2 corresponds to forward pumping port 11 of Figure 1.

Figure 3 shows the results of isolation tests on WDMs of the same type as those used in the PM reflective EDFA. The WDM's seep-port isolation decreases by approximately 13 dB as the peak power of test pulses increases, i.e. from 33 dB to approximately 20 dB at 1 kW. Figure 3 also shows relative narrowing of the FOIL-conducted pulse at the seep port. In other words, pulse from the seep port pulse narrow relative to pulses at the WDM's main (combined) output. The existence of relative pulse narrowing emphasizes the nonlinear behavior of fused-fiber coupler overload, i.e. FOIL. We note that we also observe FOIL in tap couplers and find that the FOIL occurs more readily for 10% tap couplers versus lower values, e.g. 1% tap couplers, as shown in Figure 2. In other words, the tap coupling fraction is a factor in FOIL susceptibility as described in [2].
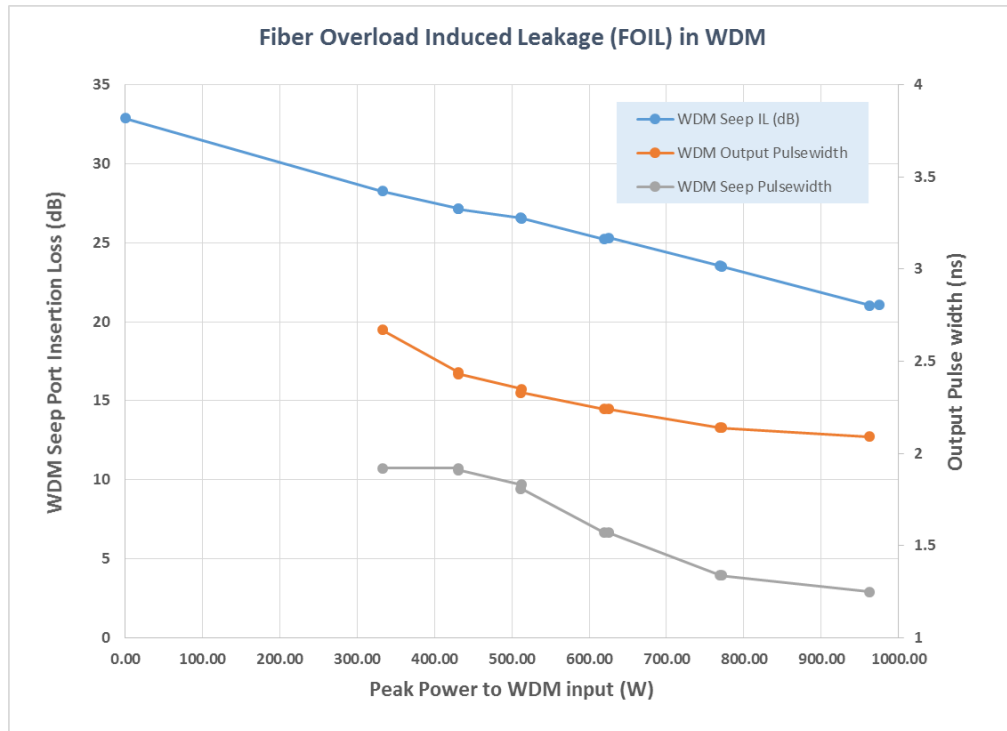

Figure 3. Reduction of Isolation and narrowing of pulses from the WDM seep port relative to the WDM main (combined) output port.

Based on the measurements of Figure 3, we determined that a single additional WDM in series with each of the forward pumps would provide adequate protection for the amplifier of Figure 1.

3. DYNAMICS OF GIANT PULSES IN A REFLECTIVE EDFA

Self-Q switched fiber lasers can generate giant pulses when co-operative Rayleigh-backscattering (RS) and stimulated Brillouin scattering (SBS) processes plus amplifier gain exceed the SBS threshold [3]. The dynamics of self-Q switching in fiber lasers in lasers that couple RS and SBS are well described by the theory presented in [4]. In the case of the reflective EDFA of Figure 1, the FM filter hybrid supplants the ring resonator used in both [4] and [5]. The four (effective) stages of the reflective EDFA, i.e. two-pass amplification with two stages per pass, store enough energy to convert the seed pulse into a pedestal pulse and giant pulse of approximately 1 KW peak (Figure 4) at the output (port 8). As Figure 4 shows, the leading portion of the amplified seed pulse is retained, i.e. appears as a "precursor pulse" to the giant pulse, as the pumping interval increases, i.e. as the pulse repetition frequency (PRF) decreases from 60 to 10 kHz. A trailing edge forms as a portion of the amplified seed pulse is Brillouin-scattered, effectively raising the cavity Q, causing formation of a giant pulse that "exhausts the population inversion" [4].

a) 500ns, 60kHz   b) 500ns, 50kHz   c) 500ns, 40kHz

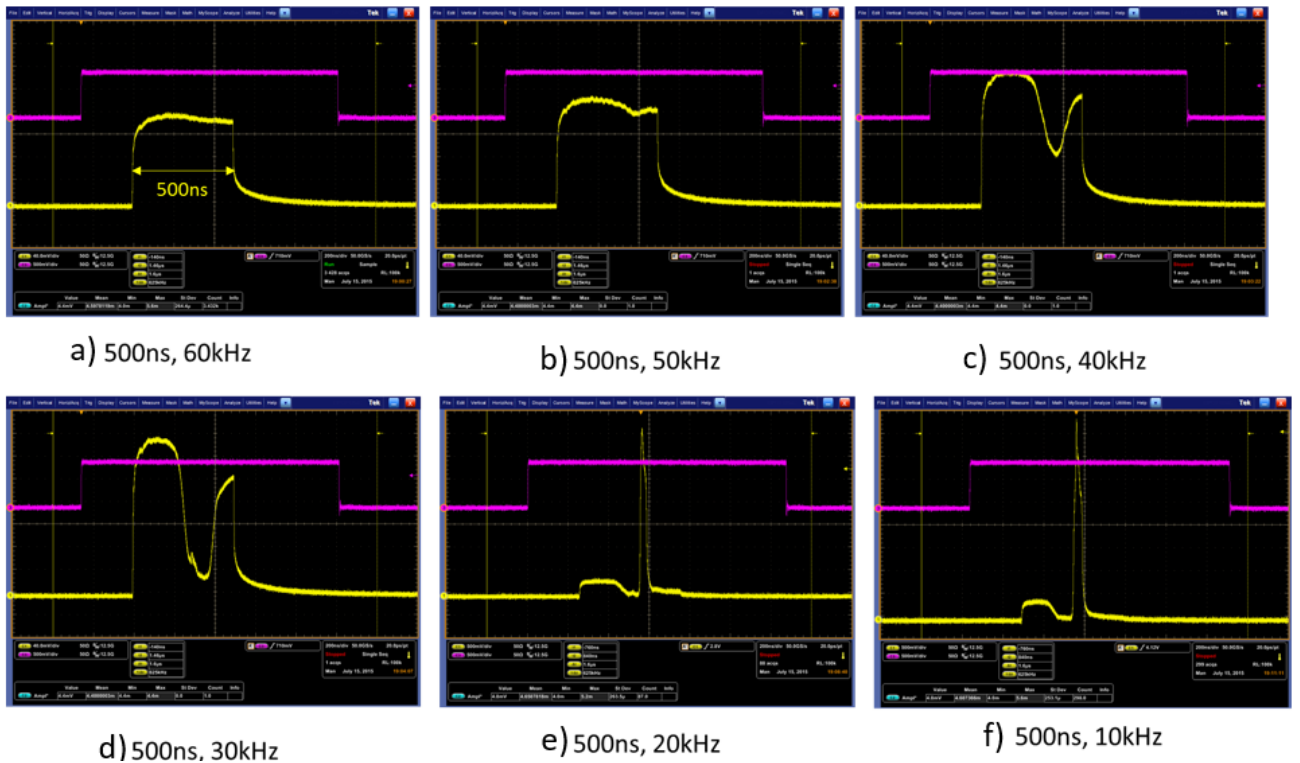d) 500ns, 30kHz   e) 500ns, 20kHz   f) 500ns, 10kHz

Figure 4. Dependence of output pulse shape (lower trace) on the repetition rate of the seed pulse. The scale of the lower trace is 40 mV/div for traces a), b), c) and d) and 500 mV/div for traces e) and f).

4. CONCLUSIONS

We tested the susceptibility of a reflective PM fiber amplifier to generate giant, self-Q-switched pulses by injecting seed pulses over a range of inter-pulse intervals that spanned the amplifier's SBS threshold. We find that the onset of pulse break-up (using a fixed seed pulse width and decreasing PRF) as shown in Figures 4c) and 4d) provides a leading indicator of the reflective amplifier's likelihood of generating SBS-induced giant pulses in unseeded operation. We used these results to produce "designed" giant pulses to test amplifier components, including pump-protective WDMs, for fiber overload induced leakage (FOIL) phenomena.

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