Broad-Pulse Fibre Laser for Incoherent Distance Measurement

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Abstract—We describe a 'Figure-of-Eight' fibre laser in the NALM (Nonlinear Amplifying Loop Mirror) configuration for use in a laser distance measurement device. By varying the length of the NALM loop we produce a variety of long pulses in the nanosecond range. The length of the pulses depend on the length of the NALM loop and the pump power. A low autocorrelated binary sequence is modulated onto one of these long pulses and sent to a target. After reflection, the signal is detected and cross-correlated to obtain the time of flight for the pulse.

Index Terms—figure-eight fibre laser, laser distance measurement, least autocorrelated binary sequence

I. INTRODUCTION

RARE-EARTH doped optical fibres offer wide gain bandwidths and provide an ideal medium for the generation of ultra-short optical pulses. For example the Er^{3+} doped optical fibre laser has a bandwidth of approximately 30 nm. Q-switching and passive mode-locking have been demonstrated in figure-eight lasers in both the NOLM (nonlinear optical loop mirror) and NALM (nonlinear amplifying loop mirror) configurations [1].

The figure-eight laser has been intensively investigated in the short pulse region down to femtoseconds. At higher powers these systems developed randomly spaced multiple pulses in the cavity. We investigated the generation of long pulses with a mode-locked figure-eight fibre laser because it has the advantage of low peak power, yet with compression we may obtain a short pulse for improved resolution and improved signal-to-noise ratio. In the long pulse region, where the pulses are stable and of low power, we propose a figure-eight fibre laser as radiation source in a laser distance measurement system.

II. BACKGROUND

The proposed system functions much like an electromagnetic radar system and thus many of the radar equations and principles also apply for this system. Consider the following pulse:

$$s(t) = \begin{cases} Ae^{i2\pi ft} & \text{for } 0 \le t < \tau \\ 0 & \text{elsewhere} \end{cases} \tag{1}$$

where A is the amplitude of the pulse and τ the pulse width. The instantaneous power of the transmitted pulse is given by $\mathrm{P}=|\mathrm{s(t)}|^2$ and the energy in the signal can be obtained by

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$$\mathrm{E_t} = \int_0^{\tau} \mathrm{P(t)dt} = \mathrm{A}^2\tau \tag{2}$$

Similarly the energy in the received signal can be shown to be $\mathrm{E_r}=\mathrm{K}^2\mathrm{A}^2\tau$, where K is a constant. Suppose σ is the standard deviation of the noise, then the signal-to-noise ratio (SNR) is given by

$$\mathrm{SNR}=\frac{\mathrm{E_r}}{\sigma}=\frac{\mathrm{K}^2A^2\tau}{\sigma} \tag{3}$$

As can be seen, the SNR is directly proportional to the pulse duration, thus the longer the pulse the better the SNR. The spatial resolution or distance resolution of the system can be determined by [2]

$$\rho=\frac{\mathrm{c}\tau}{2}=\frac{\mathrm{c}}{2\mathrm{B}} \tag{4}$$

where ρ is the spatial resolution, c is the speed of light, τ is the pulse duration and B is the signal bandwidth. The spatial resolution of the system is thus directly proportional to the pulse duration. The shorter the pulse, the better the spatial resolution.

These two requirements are in contradiction, because we require a high SNR (long pulse) as well as a small spatial resolution (short pulse). We must transmit a long pulse that has the bandwidth corresponding to a short pulse. It is for this reason that pulse compression is used to achieve the required spatial resolution. This is done by modulating a code onto the transmitted pulse. The pulse received back from the target must now be processed to achieve the desired spatial resolution (ρ), this is usually done by cross-correlation.

An appropriate binary modulating code with low autocorrelation is needed to improve the spatial resolution of the system.

A. Least Autocorrelated Binary Sequences

Two classes of binary sequences are frequently used for synchronization or pulse compression [3]. The first class is named pseudo-noise (PN) and can be generated by a shift register in which the modulo 2 sum of some bits are fed back as the newest bit in the shift register. PN sequences have an optimal periodic autocorrelation property and are mostly used when the sequence can be sent several times in succession. Periodic autocorrelation treats the sequence as though it were circular, in other words the end wraps around to the beginning. The second class is binary sequences with an optimal aperiodic autocorrelation property. These sequences are used when the sequence can only be sent once. With aperiodic autocorrelation, the sequence is not treated as circular and the correlation is calculated as shown in [4]. The best known sequences of this class are the Barker codes. A list of all known Barker codes is given in Table I.

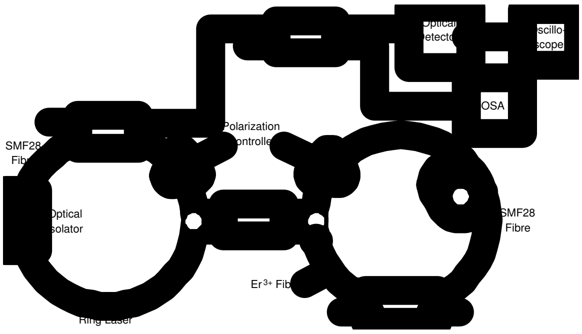
Since the sequence will only be sent once in our distance measurement system, sequences with good aperiodic autocorrelation will be used. The next step is to decide what length of sequence must be used and the autocorrelation properties of that sequence. An indication of the appropriateness of a sequence in terms of autocorrelation is the merit factor. The merit factor (F_N) of a binary sequence is the relationship of the energy in the mainlobe, to the energy in all of the sidelobes of the autocorrelation function and can be determined by [5]

$$F_N = \frac{N^2}{2E} \tag{5}$$

where N is the length of the sequence and E is the energy in the sidelobes. The least autocorrelated binary sequence (LABS) for $N \leq 60$ has been found using a sequential search [6, 7, 8]. A lower bound on the merit factor has been found for $61 \leq N \leq 271$ by using stochastic search methods [9, 10, 11]. The best known merit factors of sequences up to length 304 are shown in Fig. 1 [12].

The largest known merit factors are $F_{13}=14.083$ and $F_{11}=12.1$, no other sequences are known with $F_N \geq 10$. A Barker code of length 13 seems to be the optimal code for our distance measurement system.

III. EXPERIMENTAL LAYOUT OF THE FIGURE –EIGHT FIBRE LASER



In Fig. 2 a figure-eight fibre laser is displayed in the NALM configuration. The fibre laser is a ring laser and consists of a NALM loop with its output connected to its input. The NALM loop is connected to the feedback loop with a 50/50 coupler. In the NALM loop close to the coupler one finds a 3.2 m Er^{3+}-doped fibre containing 3100 ppm/wt Er^{3+}. The core diameter is 3.5 μm and the confinement factor is 0.5. The absorption peak of this fibre is 11.8 dB/m at 980.2 nm and 17.0 dB/m at 1533.4 nm. This fibre is pumped by a laser diode with an emission peak at 975.9 nm. We operate this diode up to a current of 550 mA which corresponds to 320 mW output. The pump power is introduced into the Er^{3+}-fibre via a 980/1550 nm WDM coupler. The rest of the NALM loop consists of normal single-mode telecommunication fibre (SMF28). The length of this fibre varies from 500 to 3500 m in our experimental investigation. Both the NALM loop and the return loop contain polarization controllers.

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ERROR: invalidrestore
OFFENDING COMMAND: restore

STACK:

-savelevel-
-savelevel-
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