Critical signal strength for effective decoding in diode laser chaotic optical communications

S. Sivaprakasam and K. A. Shore*
School of Electronic Engineering and Computer Systems, University of Wales, Bangor, Dean Street, Bangor, LL57 1UT Wales, United Kingdom

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Synchronized external-cavity diode lasers are used for chaotic optical encryption and decryption. It is shown that effective decoding requires the signal strength to exceed a certain value determined by the precise operating conditions.

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I. INTRODUCTION

The use of chaos in nonlinear systems has attracted much attention, motivated by the possibilities for achieving secure communications. The possibilities were explored initially in electronic circuits [1–3]. The underlying concept for such work is that the transmitted message should be encoded within the noiselike output of a chaotic transmitter. Extraction of the message requires a receiver in which the same chaos is generated as in the transmitter; this requires synchronization of the chaos of the transmitter and the receiver. Chaotic synchronization was examined theoretically [4–7] and recently demonstrated experimentally [8–10]. Secure communication systems based on chaos in erbium-doped fiber lasers were proposed and studied with message masking and chaos shift keying [11]. Work was done on digital communication with synchronized chaotic single-model Nd:YAG (yttrium aluminum garnet) lasers [12]. Useful progress was made toward the experimental encryption and decryption by use of a form of wavelength chaos [13]. A successful demonstration of chaotic transmission of a message was reported recently using fiber laser [14] and external-cavity diode lasers [15,16]. With such a demonstration, attention turned to the issue of security of data transmission within chaotic encryption. It is apparent that signal masking within the chaotic carrier can be made more effective by the use of relatively weak message signals. In this Brief Report we show, however, that signal recovery requires that the signal strength is, above a certain value, determined by precise operating conditions.

II. EXPERIMENT

The experimental arrangement is shown schematically in Fig. 1. We have used two single mode FP lasers emitting at 850 nm, with a linewidth of 200 MHz (Access Pacific, Model No. APL 830-40.) for our experiments. The side mode suppression ratio is −20 dB. These lasers are driven by ultralow noise current sources (ILX-Lightwave, LDX-3620), and are temperature controlled by thermoelectric controllers to a precision of 0.01 K (ILX-Lightwave-LDT-5412). The laser output is collimated using AR coated laser diode objective (Newport-FLA11). Both the lasers are subjected to an optical feedback from external mirrors ($M1$ and $M2$), and the feedback strength is controlled using continuously variable neutral density filter (NDF1 and NDF2). The cavity length is 25 cm in both cases. The optical isolators (OFR-IO-5-NIR-HP) ensures the lasers are free from back reflection, and the typical isolation is −41 dB. Isolator (OI1) ensures that the transmitter is isolated from the receiver. The coupling attenuator enables the percentage of transmitter power fed into the receiver to be controlled. PD1 and PD2

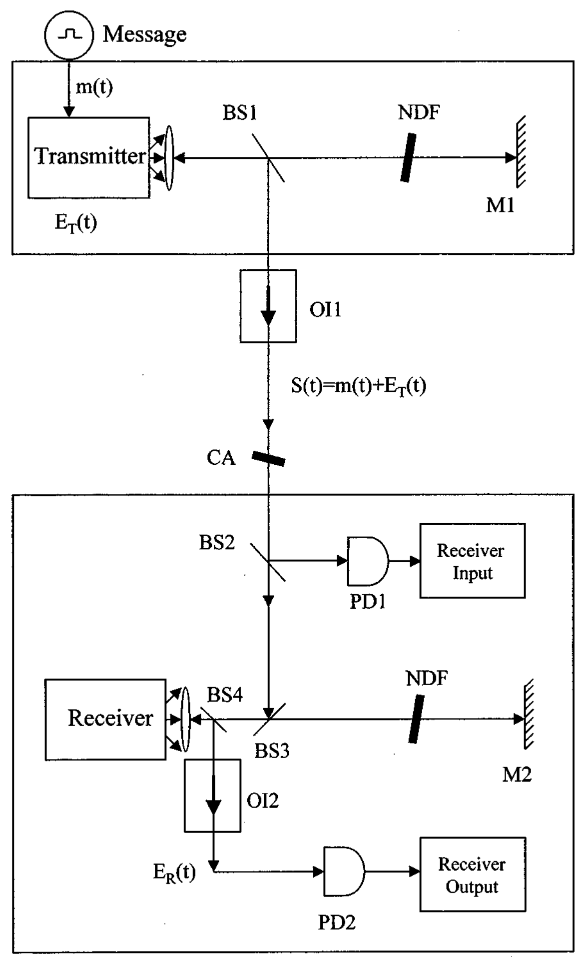

FIG. 1. Schematic diagram of the experimental arrangement: BS1–BS4, beam splitters; PD1 and PD2, photodetectors; OI1 and OI2, optical isolators; $M1$ and $M2$, mirrors; NDF's neutral density filters; CA, coupling attenuator; CRO, digital oscilloscope.

*Electronic address: alan@sees.bangor.ac.uk

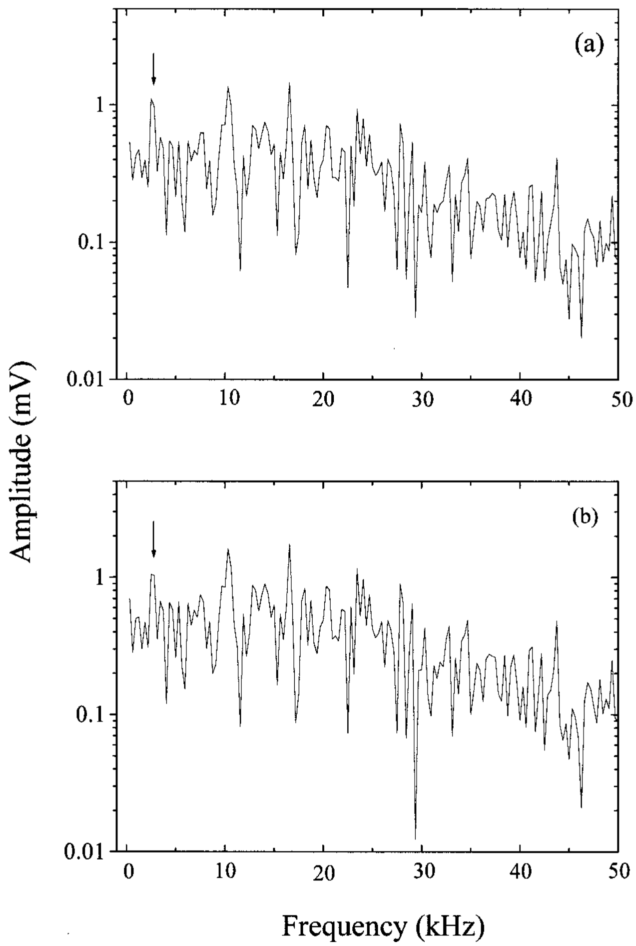

FIG. 2. Power spectra of (a) the transmitter output and (b) the receiver output. (An arrow shows the message component.)

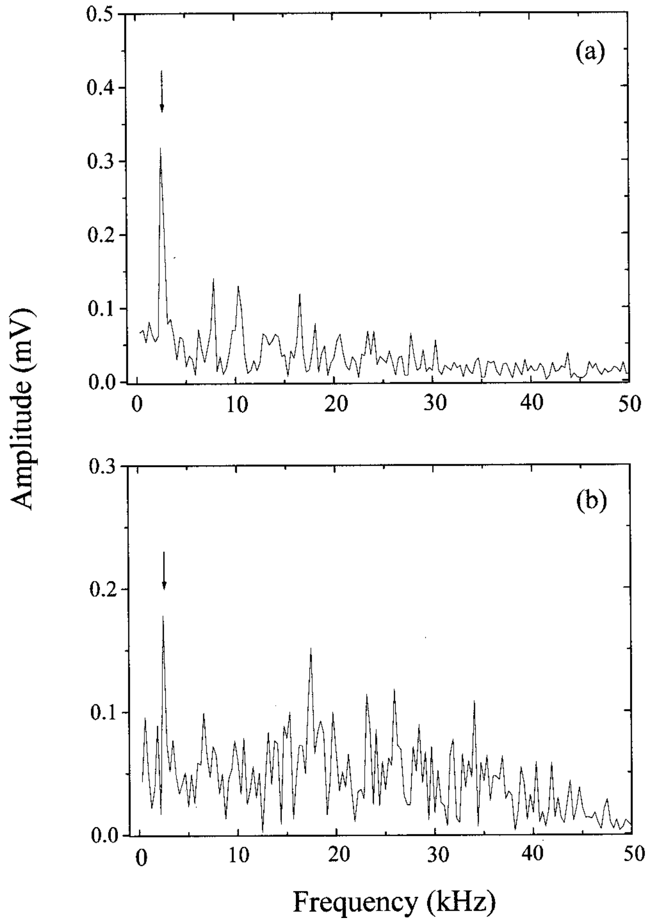

FIG. 3. Power spectra of decoded message for signal strength (a) 1.0 mV and (b) 0.6 mV. (An arrow shows the message component.)

are two identical fast photodetectors (EG&G-FFD040B) with a response time of 2.5 nS. The output of the transmitter is coupled to photodetector PD1 by beam splitters BS1 and BS2. Beam splitter BS3 acts as a coupling element between the transmitter and receiver. Beam splitter BS4 couples the receiver output to photodetector PD2. Photodetector outputs are stored in a digital storage oscilloscope (Fluke Combiscope PM3394B, 200 MHz) and then acquired by a personal computer. The output of a frequency generator is used as a message to be encoded.

Due to the limitation imposed by the available oscilloscope, the research reported here considers a part of that chaotic dynamics within a 200-MHz bandwidth of the central frequency. It is noted that the chaotic spectrum is relatively flat around the central frequency, and thus the present measurements are expected to give a good representation of the dynamical behavior. It would, of course, be of interest to extend the frequency range which is sampled.

III. RESULTS

In recent work it was demonstrated that synchronization is robust over large time scales (or order several hours) and with large coupling coefficient windows [16], and thus encoding a message into the chaotic laser for transmission and decoding is relatively easy. A 1-mV, 2.5-KHz square wave from the signal generator is used as the message, $m(t)$, and is added to the chaotic transmitter laser output $E_T(t)$, by direct amplitude modulation. The encoded transmitter output is therefore, $S(t)=m(t)+E_T(t)$. A part of the transmitter output is taken by BS2 and is coupled to the photodetector PD1. The transmitter output is coupled to the receiver by beam splitter BS3. The receiver laser setup is as identical to the transmitter laser setup as possible, especially in terms of cavity length, feedback strength, and operating current (1.2 times the threshold). The receiver output is taken by beam splitter BS4, and is coupled to photodetector PD2. Output of both PD1 and PD2 are monitored on an oscilloscope.

The transmitter output $S(t)=m(t)+E_T(t)$ is recorded from the output of photodetector PD1, and its power spectrum is shown in Fig. 2(a). The receiver output $E_R(t)$ is recorded from the output of photodetector PD2, and its power spectrum is shown in Fig. 2(b). The intensities at photodetectors PD1 and PD2 are thus $|m(t)+E_T(t)|^2$ and $|E_R(t)|^2$, respectively. The message is seen to be effectively encoded, so that it is necessary to use an arrow to indicate its location within the chaotic carrier. The message is decoded using the similar technique of that of Van Wiggeren and Roy [14] by taking the difference between the output of photodetectors PD1 and PD2. The power spectrum of the decoded message, as shown in Fig. 3(a), establishes the signal recovery. The presence of the message is clearly revealed.

The process of encoding and decoding is repeated for a signal with a smaller peak-peak voltage (0.6 mV) square wave with the same frequency. The power spectrum of the decoded message is shown in Fig. 3(b). Comparison between Figs. 3(a) and 3(b) shows that in the latter case the recovered signal strength is comparable to the unfiltered chaotic components. This means that the decoding process is less effective. These observations are of considerable importance in relation to practical applications, where accurate signal extraction must be obtained while ensuring the security of the data transmission. Further work is being undertaken to establish the optimum conditions for secure optical chaotic communications with the present configuration.

IV. CONCLUSIONS

In conclusion, a simple message is encoded to the chaotic transmitter laser, and transmitted to the chaotic receiver laser. The message is decoded by taking the difference between the photodiode intensities. It has been shown that for effective decoding the signal strength must exceed a certain value determined by the precise operating conditions the configuration.

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