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Fiber-Optic Radar Calibration

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ABSTRACT

A simple fiber-optic radar calibration target is described. Its operation is based on a wideband fiber, a laser transmitter that is directly modulated by the down-converted radar signal and an optical diode receiver recovering said signal. Further up-conversion having a common local oscillator with the first mixer ensures fidelity of the calibration return. Measured useful bandwidth exceeds 200 MHz and practically any radar RF frequency can be handled when suitable mixers are employed. Amplifiers can be added to the down-converted path as desired to compensate for the fiber loss. Modulation and LO sweep provide easy ways of introducing artificial fluctuations and Doppler frequencies. Particularly pulsed radars are readily tested with the proposed scheme as no restrictions are posed by the radar's TR-switch delays.

INTRODUCTION

During the past sixty years, engineers and scientists have been using more and less ingenious hardware and even some tricks in order to be able to test and evaluate pulsed radars in their laboratories [1]. Commercial dedicated devices have been available in the open market since the late 1950s or so [2] and normal measuring instruments such as signal generators, spectrum analyzers, and amplifiers have been arranged to perform the required task. One of the very fundamental issues in radar calibration and testing has been – and still is – the need for a precisely delayed but otherwise very high-fidelity copy of the transmitted pulse [3]. Of course, a delay is mandatory if we want to simulate the physical distance between the radar and its target in our laboratory environment. However, even if we did not want that feature, the radar's TR (Transmit/Receive) switch and its dead-time, unavoidably, call for some postponement of the reply. This basic part of radar construction is highlighted in Figure 1 [4]. Besides this, many radar designs employ some form of sensitivity control as a function of distance (or time) [3] and thus a reply coming at zero delay would be processed in a way not representing the radar's true characteristics.

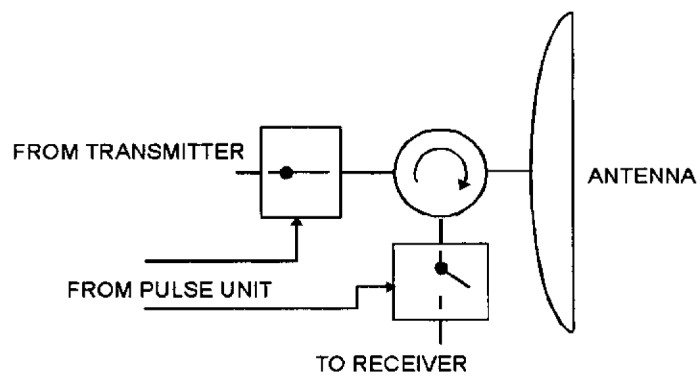

Fig. 1. Pulsed radar TR switch arrangement prevents zero delay calibration

One elementary solution is to use a microwave signal generator with its built-in pulse modulator and take from the radar under test a sample of its PRF logic pattern, put some delay to it, and feed this to the generator's modulation input. Also the carrier frequency is rather easily phase locked to the radar's master oscillator, because in the lab we can utilize short cables [5]. Unfortunately, this scheme illustrated in Figure 2 will become more tedious when our radar gets additional advanced features into its RF signature. If the real processing performance must be evaluated, we have to find other means of creating the desired replies. Optical fiber provides a promising possibility to overcome some of the limitations of previously used delay chains [6]. They are stable, have very wide bandwidths and, after the introduction of modern communication applications, the cost of hardware has substantially dropped [7].

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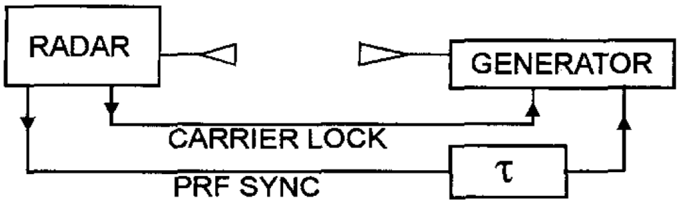

Fig. 2. Using a pulse modulated microwave generator as a target simulator

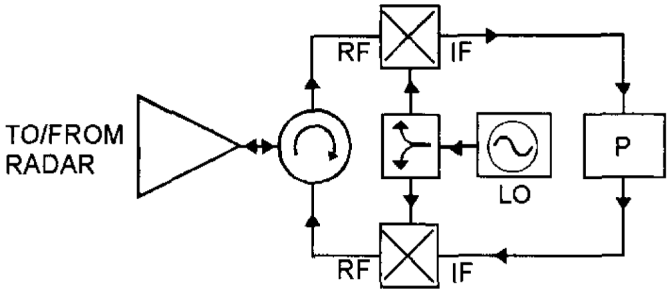

Fig. 3. A real delayed-echo radar calibration target with down and up conversion. "P" indicates the delay-processing unit

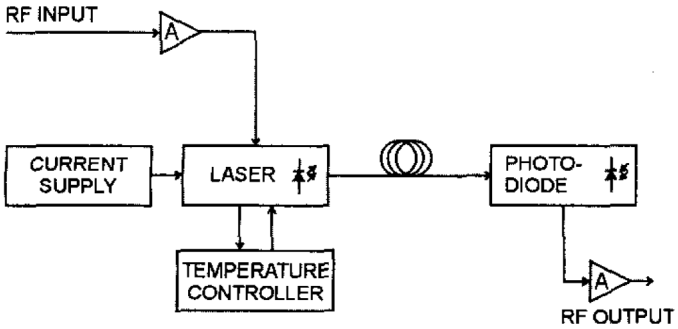

Fig. 4. Detailed view of the fiber optic delay module of the calibrator

CONSTRUCTION OF THE TEST SET-UP

Our experimental design is illustrated in Figure 3. Two RF mixers are connected to a ferrite circulator that provides the common port to be connected to the radar under test. An adjustable or controllable attenuator can be used between the two units as required or, as shown in the picture, we can have a short free space path and two horn antennas. This works well if we can satisfy the far field requirement in our lab at the radar's carrier frequency. One mixer works as a down-converter and the other as an up-converter. The mixers have a common local oscillator; for example, a DRO or a VCO, which is needed to perform a frequency translation to the operating band of the processing part marked as P and connected between the IF ports of the mixers. The difference in signal levels between the two mixer RF ports is so large that there is no practical risk of unwanted rat race coupling.

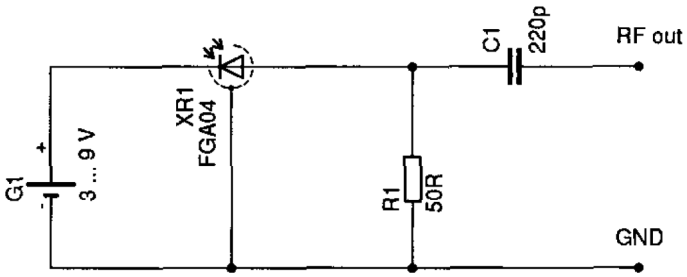

Fig. 5. Fiber optic receiver schematic showing diode grounding and 50 ohm matching resistor

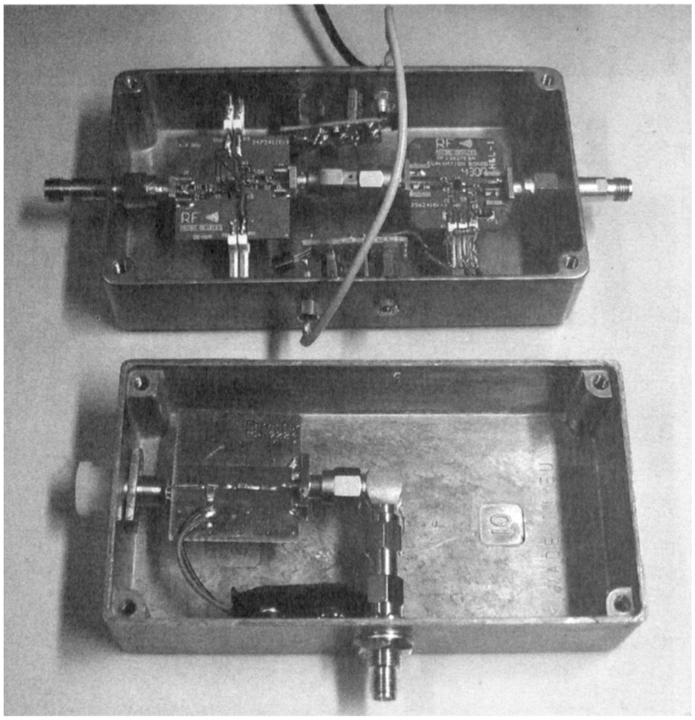

Fig. 6. Completed transmitter pre-amplifier and diode receiver (bottom) in die-cast aluminum enclosures

The processing part is further illustrated in Figure 4 in more detail. An optical fiber of predefined length produces the desired delay in time and has a very wide bandwidth, in practice several gigahertz [8]. Two amplifiers are used, one at the input and another at the output. They provide a flexible way of amplitude adjustment and have response times short enough for echo shaping, too. A diode laser transmitter and a suitable detector form the converter pair between the IF and optical signals. Figure 5 is a simplified diagram of the optical receiver that operates on 9 V battery power for months, because its bias current is just some micro amps. Dedicated electronics is needed to maintain optimum operation of the laser, most notably for constant bias current, and operating temperature [9]. The lease unit has a built-in thermistor as a sensor and the heating/cooling function is provided by a peltier element.

The prototype versions of the fiber-optic interfaces are shown in Figure 6. Commercially available RF/IF building

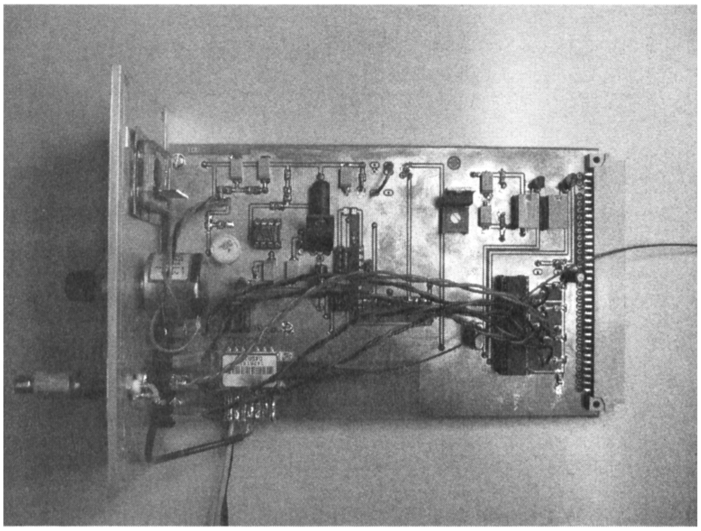

Fig. 7. Laser constant current and laser module (bottom left). A DC block is visible in the input

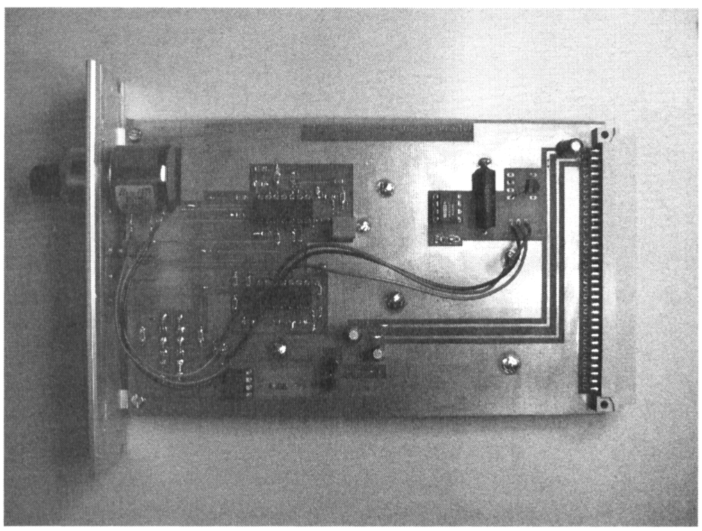

Fig. 8. Temperature controller for the laser. This unit is connected to a thermistor sensor and to a peltier element that performs the heating or cooling

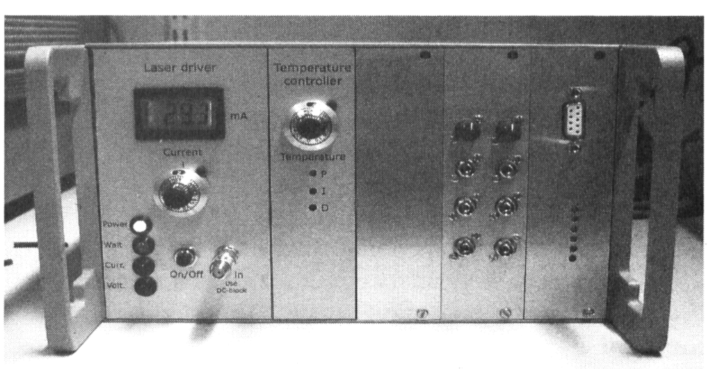

Fig. 9. Assembled 19-inch laser unit with its current monitoring display

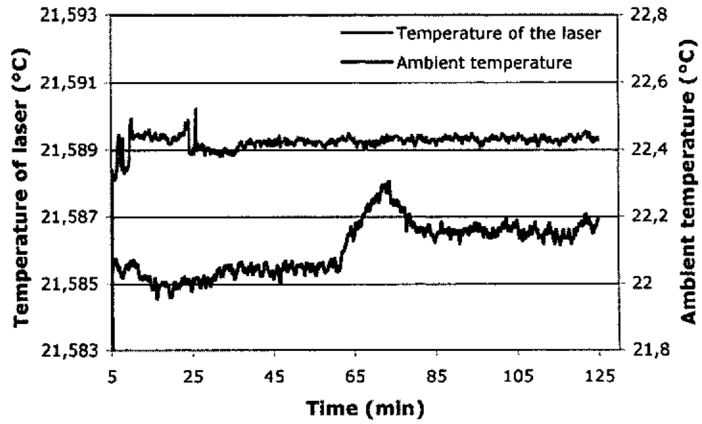

Fig. 10. Measured temperature controller performance as a function of time indicates 0.1 mK settability

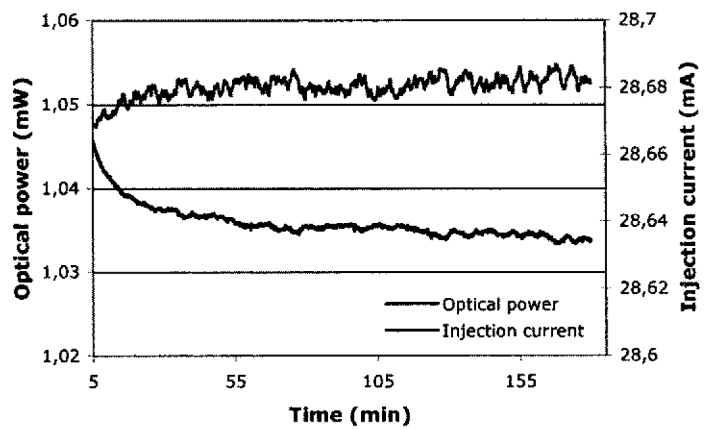

Fig. 11. Measured optical power stability target echo level uncertainty far below 1 dB

blocks were used as amplifiers. The low signal levels call for good shielding, which is here taken care of by the die-cast aluminum housings, and supply line feed throughs. The two control electronics boards were assembled in normal 19-inch rack style. Figure 7 illustrates the constant current supply [10] for the laser diode and the laser transmitter itself, mounted on the same circuit board. Some adjustment is provided for the laser temperature with the multiturn potentiometer that is visible in Figure 8, which depicts the PID controller [11]. The entire assembled processing unit is shown in Figure 9. It has a monitoring display for the diode current and some LEDs to aid in a smooth start-up procedure.

MEASUREMENT RESULTS

Some preliminary tests have been carried out with the set-up but by using ordinary laboratory instruments instead of a real radar. Two parameters have been found to be vital for successful implementation as a low-cost alternative to ready-made calibrators. First, the laser power must be stable enough to allow a precise control of the echo characteristics. Our results are quite promising in this respect. Figure 10 shows the behavior of the temperature controller over an arbitrary

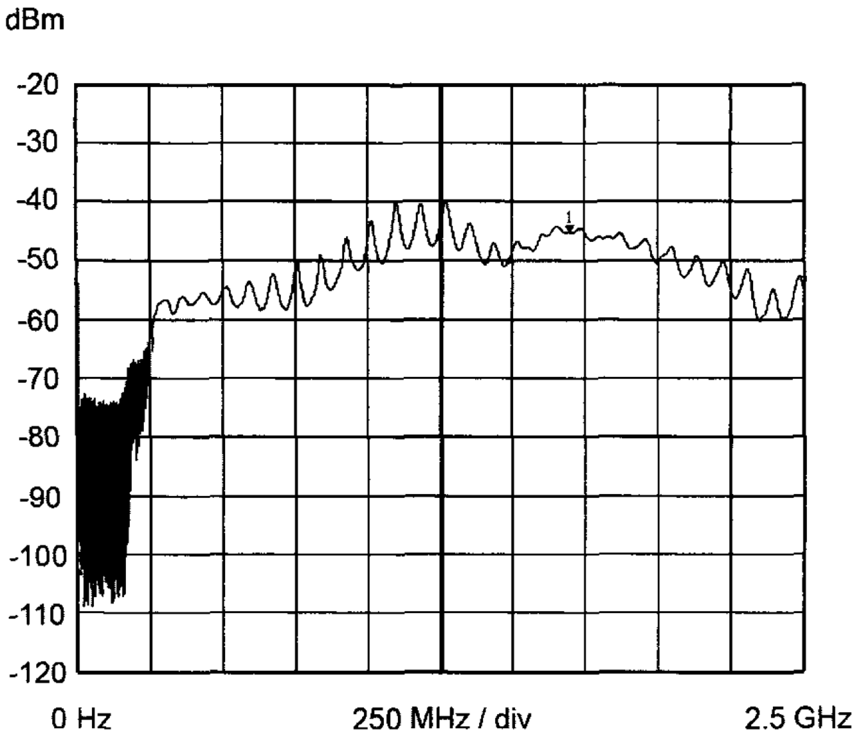

Fig. 12. Measured optical power stability allows target echo level uncertainty far below 1 dB

observation time. We have been able to maintain 0.1 mK settability. Then, in Figure 11 we see that the optical output power is stable within some tenths of a dB thus allowing echo amplitude setting well better than 1 dB.

IF amplifier matching and gain performance remain challenges. We notice in the plot of Figure 12 that both multiple reflections caused by impedance mismatch (rapid fluctuations at 1-1.5 GHz) and the reduced net gain at lower frequencies (below 1 GHz) limit the available bandwidth. A target distance of 1 km has been selected for this measurement. However, for many real applications the region around 2 GHz (marked with the cursor) is very adequate. If more bandwidth is needed, some design effort must be devoted to the two RF/IF amplifiers.

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