circuits on RT Duroid 5880, with $\varepsilon_r = 2.2$, and dielectric thickness of 1.57 mm.

The measured responses of S_{11} and S_{21} of the 1:2:4 filter are shown in Figure 9. Also shown are the simulated responses as well as the calculated performance. Similar responses are given for the 1:2:3 filter in Figure 10.

7. CONCLUSION

For both the simulated and measured responses, the performance deteriorates at the high frequency end of the filter; as this is to be applied as a pseudo-lowpass filter, it is not of any concern. It is caused by the increased loss in the substrate material, as well as incresed dispersion from the microsrtip lines, especially in view of the extremities of impedance in the structure.

Tradeoffs exist between lower passband return loss, lower passband bandwidth, stopband attenuation level, and rate of cutoff. Of the multitude of possible solutions, two have been presented that could be considered to be typical.

A comparison with the Cauer filter prototypes shows responses that perform extremely well at bandwidths of the order of 150%, where very few alternative planar designs with similar performance are available.

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WIRELESS INTERROGATION OF AN OPTICALLY MODULATED RESONANT TUNNELLING DIODE OSCILLATOR

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ABSTRACT: *In this work, a resonant tunnelling diode-photo-detector based microwave oscillator is amplitude modulated using an optical signal. The modulated free running oscillator is coupled to an antenna and phase locked by a wireless carrier that allows remote extraction of the information contained in the modulation. An off-the-shelf demodulator has been used to recover the envelope of the baseband data originally contained in the optical signal. Data were successfully transmitted at a rate of 1 MSym/s with a bit error rate below 10^{-6}.* © 2013 Wiley Periodicals, Inc. Microwave Opt Technol Lett 55:1728–1730, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27734

Key words: *microwave oscillator; optical modulation; resonant tunneling diode*

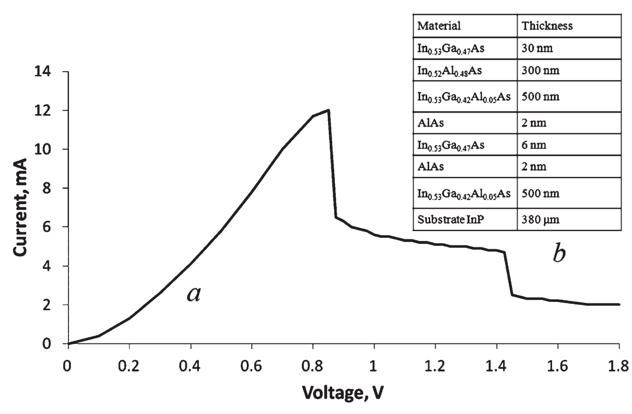
1. INTRODUCTION

Amplitude shift-keying (ASK) is a modulation technique popular in fiber optic communication systems due to its ease of implementation [1]. In this article, a two-level ASK (2-ASK) scheme is reported to optically modulate a resonant tunnelling diode (RTD)-based microwave oscillator which can be interrogated wirelessly for remote data extraction. RTDs are the fastest electronic devices known to date [2] and can be exploited also as photo-detectors [3] with potential applications in optical communication systems. In this study, a single RTD-based oscillator device is used to photo-detect a 2-ASK optical signal, phase-lock to a wireless interrogator, and finally to transmit the binary data contained in the modulation. The principle of operation investigated here should be fully scalable to millimetre wave-photonics applications where data rates would be primarily limited by the bandwidth capacity of the RTD photo-detector.

2. SYSTEM DESCRIPTION

The RTD device used in this study has been previously described in [3]. Its current–voltage characteristic and epitaxial structure are shown in Figure 1. It consists of an AlAs/InGaAs/AlAs double-barrier quantum-well (DBQW) structure grown on a semiconducting InP substrate. The device is mounted on a hybrid circuit and biased into the negative differential resistance region to produce a fundamental microwave oscillation. As described in [3], the RTD DBQW region embedded in a 1 μm thick InGaAlAs photoconductive layer can be illuminated with light, which has the effect of altering the impedance across its electrodes. Thus, the oscillator can be directly modulated in order to produce amplitude shift-keyed wireless data.

A schematic diagram of the wireless system is shown in Figure 2. An optical fiber containing the modulated data illuminates the RTD oscillator in Figure 2(a), which has its RF output coupled to an antenna. An auxiliary antenna in Figure 2(b) is used to monitor the modulation of the free space propagated signal. The interrogator in Figure 2(c) has two functions: it sends a



Material	Thickness
$In_{0.53}Ga_{0.47}As$	30 nm
$In_{0.52}Al_{0.48}As$	300 nm
$In_{0.53}Ga_{0.42}Al_{0.05}As$	500 nm
AlAs	2 nm
$In_{0.53}Ga_{0.47}As$	6 nm
AlAs	2 nm
$In_{0.53}Ga_{0.42}Al_{0.05}As$	500 nm
Substrate InP	380 µm

Figure 1 RTD physical characteristics. (a) Current-voltage characteristic (b) Epitaxial layer structure

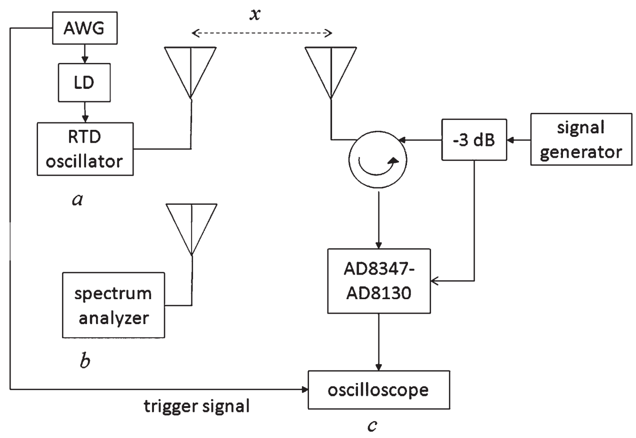


Figure 2 Diagram of wireless interrogation system elements ($x \sim 30$ cm). (a) Optically modulated RTD-based oscillator attached to antenna. (b) Auxiliary antenna used for wireless monitoring of signal locking. (c) Locking signal transmitter and wireless received signal demodulator

master locking carrier within the locking range of the RTD oscillator and also extracts the baseband information from the received wireless signal, once the RTD is phase locked.

3. EXPERIMENTAL SETUP

The RTD is illuminated with an optical lensed fiber from the top and at an angle as illustrated in Figure 3. The wavelength of the light used is 1550 nm and the average fiber optical power is 0.2 mW. The 2-ASK signal is obtained from the optical output of a communications laser diode (LD) identical to the one previously described in [3]. The LD is switched on and off by means of an arbitrary waveform generator (AWG Agilent 33250a) programmed to produce a nonreturn to zero (NRZ) pseudo-random bit sequence (PRBS). The pattern used in the experiments was 100 bits long with a clock frequency of 1 MHz.

The connectorized RTD oscillator RF output/input is directly attached to an omnidirectional 0 dB gain antenna used to propagate the signal in free space. The power of the fundamental oscillation from the RTD circuit is −10 dBm at a frequency of 892 MHz. The signal generator in Figure 2(c) is tuned to that frequency and produces a power of −8 dBm that serves to injection lock the free running RTD oscillator shown in Figure 2(a). The path loss (including the effect of free space loss and antenna gain) from the output of the signal generator to the RTD device has been estimated to be 25 dB ($x = 30$ cm). The signal frequency locking range was monitored with the auxiliary monopole antenna in Figure 2(b). A frequency

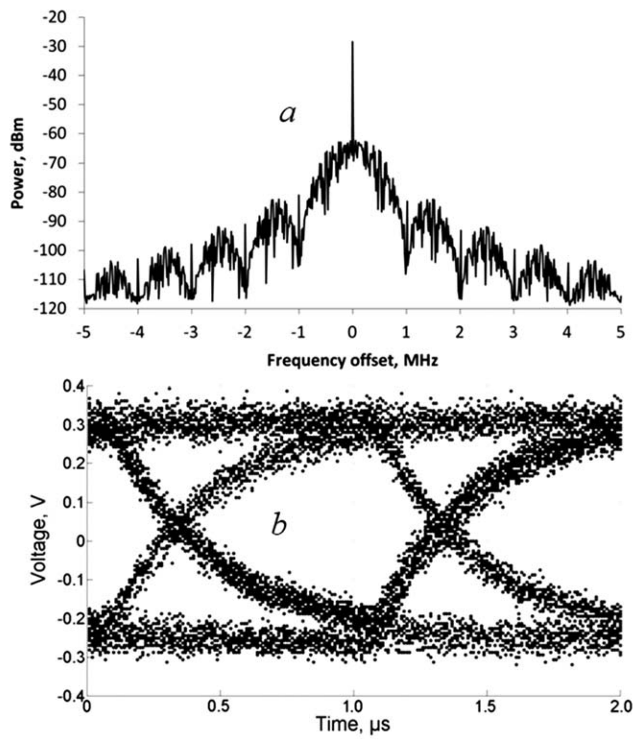


Figure 4 Measurements of optically modulated transmitted signal. (a) Spectrum of phase locked RTD oscillator wireless signal (892 MHz). (b) Eye diagram of the retrieved PRBS data

locking range of 1 MHz was observed between the RTD oscillator and the signal generator. The locking gain of the propagated signal was 10 dB measured from the monitoring antenna.

The received locked signal is coupled to a demodulator board using a microwave circulator as shown in Figure 2(c). The demodulator is a connectorized printed circuit board assembly based on the off-the-shelf chip AD8347. The output from the signal generator in Figure 2(c) is split between the antenna and the local oscillator (LO) port of the AD8347 demodulator. The power reaching the LO port is −11 dBm.

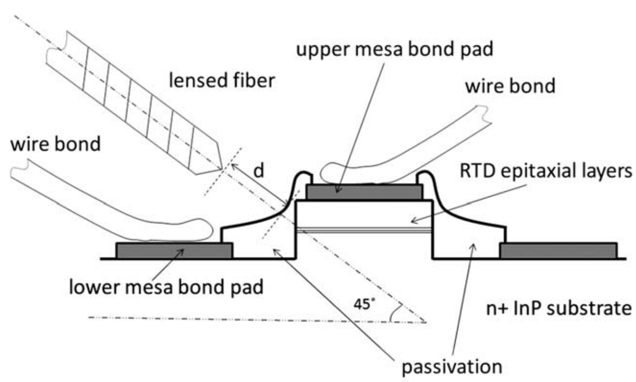


Figure 3 Schematic illustration of RTD optical modulation technique using lensed fiber ($d \sim 300$ μm)

4. MEASUREMENTS AND RESULTS

The spectrum of the phase locked signal as seen from the auxiliary antenna in Figure 2(b) is shown in Figure 4(a). The effect of the PRBS pattern contained in the optical modulation is seen to produce spectral components 35 dB below the peak power of the propagated locked RTD oscillator signal. The frequency span of the measurement was 10 MHz.

The propagated locked signal reaches the demodulator in Figure 2(c), which recovers the baseband information through the in-phase output port connected to an oscilloscope (MSO6104A). The instrument is synchronized with the PRBS pattern using the trigger reference (1 MHz) of the AWG. A number of waveforms (10^4) of the 100 bit long PRBS were stored for latter comparison with the original NRZ data stream.

A computer software routine was used to compare the measured waveform from the demodulator in-phase output port to the waveform used at the input of the switched LD shown in Figure 2(a). The calculated bit error rate (BER) showed that there were no errors transmitted in a sample of 10^6 bits. This result was obtained after discrete integration of each symbol at the sampling rate of the oscilloscope and after normalizing each received symbol power to the reference signal power.

Figure 4(b) shows the measured eye diagram of the transmitted bits through the system in Figure 2. The diagram was obtained after superposition of the time period of 100 bits in a single waveform.

The signal-to-noise ratio (SNR) of 40 dB observed in Figure 4(a) can be used to estimate the system maximum achievable BER after considerations of the required baseband filter bandwidth or Nyquist limit (2 MHz), the noise figure of the demodulator circuit (11 dB), and after the assumption is made that the system noise follows a Gaussian distribution. Under these conditions, a propagated SNR of 40 dB for 2-ASK modulation should theoretically be able to achieve BER values below 10^{-9}. These considerations, however, do not take into account the negative impact on BER of undesired effects such as multipath propagation and interchannel interference, which are more difficult to estimate without specific practical considerations.

5. CONCLUSION

Wireless interrogation of an optically modulated RTD-based oscillator has been reported in this article. No errors were found after transmission of 10^6 bits at a data rate of 1 Msym/s. The measurement took place after phase locking of the modulated RTD oscillator and demodulation of the received wireless signal using a commercial circuit. The system RTD technology should be fully scalable to millimetre wave frequency operation where multigigabit data rates can be achieved.

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DESIGN AND OPTIMIZATION OF A BROADBAND X-BAND BIDIRECTIONAL AMPLIFIER

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ABSTRACT: *This article presents the design of a simple and inexpensive X-band bidirectional amplifier based on two microstrip quadrature hybrid rings and two low cost microwave monolithic integrated circuit monolithic amplifiers. Each subsystem of the amplifier was designed and optimized, by means of an optimization methodology to obtain the best performances. In particular, the design problem was recast as an optimization one by defining suitable cost functions that are then minimized with an evolutionary optimization technique, namely the particle swarm optimizer. An experimental prototype has been designed, developed, and measured. The obtained results demonstrate the capabilities of the proposed broadband bidirectional amplifier and envisage future and possible advances in the application of such devices for the development of advanced telecommunications systems.* © 2013 Wiley Periodicals, Inc.
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Key words: *bidirectional amplifier; optimization techniques; evolutionary algorithms*

1. INTRODUCTION

The design of new microwave circuits and systems is needed in several important areas for civil and military telecommunication systems, industrial and medical equipments. Standard microwave synthesis techniques are quite effective for the design of basic microwave filters [1,2], combiners [3], and broadband couplers [4,5]. Miniaturization, cost reduction, and quick time to market are the challenging issues of nowadays and future research trends in a variety of practical applications ranging from UWB systems [6] to large arrays working at medium and high frequencies, both in civil and military applications. In particular, the design of complex microwave devices such as bidirectional amplifiers [7] is a key issue. Usually, these devices require complex design techniques, high level of expertise and a final tuning phase that dramatically increase the costs and the time to market of the device. In this situation, microwave computer-aided design (CAD) tools [8–10] offer a possible solution to reduce the time to market. In fact, these tools can analyze, design, and modify microwave devices in an unsupervised manner and they necessarily do not request an experienced microwave engineer to operate. In this work, we propose the design of a new inexpensive broadband bidirectional amplifier based on standard microstrip components. In particular, two quadrature hybrid rings, filters, and matching transformers were considered and optimized with an unsupervised methodology based on a powerful evolutionary technique, namely the particle swarm optimizer (PSO) [11–14]. This optimizer has the advantage of escaping local minima, and it is jointly used with a circuital and electromagnetic simulator to maximize the performances of the amplifier.

2. SCHEMATIC OF THE BIDIRECTIONAL AMPLIFIER

The proposed bidirectional amplifier is shown in Figure 1. It includes two microstrip hybrid rings, two amplifiers, a couple of filters, and matching transformers. As it can be noticed from the schematic of Figure 1, in the forward direction the incident signal at port 1 is splitted by the first hybrid ring. Half of the signal power travels on the upper side of the circuit and it is amplified by the forward amplifier. Then the signal reaches the second hybrid ring and half of power reaches port 2, the other half is dissolved by the matching load R_2. While the other half power splitted by the first hybrid is reflected down by the output of the second amplifier and further splitted by the first hybrid, only a quarter of the incident power is reflected down at port 1. The behavior in the reverse direction with the signal that impinges on port 2 is similar. The two passband filters are mandatory to avoid instability when the signal is present in both directions at the same time. As far as the general structure of the considered system is concerned, eight different subsystems have been used. However, considering the symmetry of the structure, the simplicity of the matching transformer and the fact that the off-the-shelf commercial