

a result, the bandwidth was reduced to ~ 40 GHz. This reduction is caused by the larger microwave and optical velocity mismatch. This result reveals that the electrode works, at least in major aspects, in a travelling-wave manner.

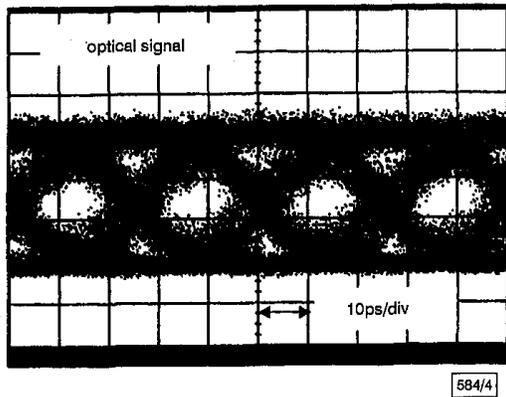


Fig. 4 40 Gbit/s eye-diagram

Fig. 4 shows the eye-diagram of the 40 Gbit/s modulated light from the TW-EADFB. The injection current of the DFB laser was set to 110 mA, and the modulating-amplitude to the TW-EA modulator was 1.5 V. As shown in Fig. 4, the eye opening was successfully observed.

Conclusion: The first-ever EA-DFB with a travelling-wave electrode has been developed. It exhibits a very wide bandwidth of over 50 GHz. A 40 Gbit/s eye-diagram was successfully observed.

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Microphotonic modulator for microwave receiver

D.A. Cohen, M. Hossein-Zadeh and A.F.J. Levi

Experimental results from a new microphotonic modulator with direct electrical-to-optical conversion are presented. The modulator consists of high- Q RF and microphotonic electro-optic resonators that are operated in simultaneous resonance. RF, optical, and time-domain results approach 100% optical modulation at gigahertz frequencies.

Recently a new microphotonic radio frequency (RF) receiver architecture with direct electrical-to-optical conversion was pro-

posed [1] for use at microwave frequencies and with potential applications for indoor wireless and micro-cell wireless systems [2]. This receiver uses high quality factor (Q) RF and microphotonic electro-optic resonators that are operated in simultaneous resonance. Central to such an architecture is the microphotonic optical modulator. This component directly converts the received RF carrier frequency to an optical carrier frequency by interaction of optical and RF electric fields via the electro-optic effect.

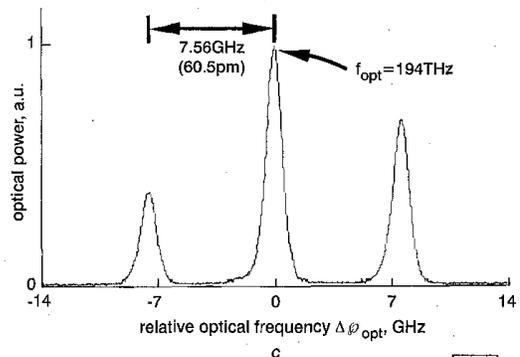
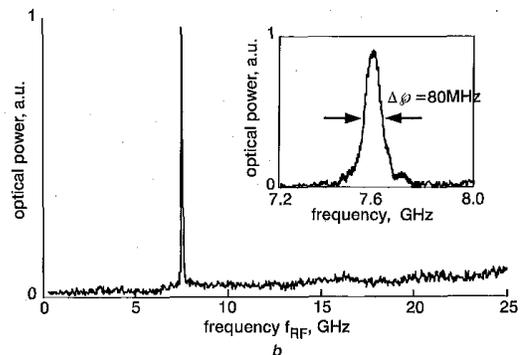
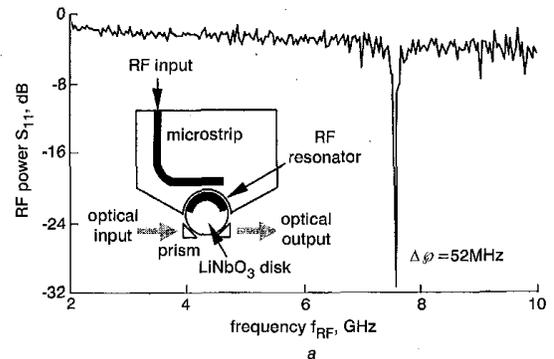


Fig. 1 Measured reflected RF power S_{11} , detected output optical power against input RF frequency and detected output optical power against optical frequency

a Measured reflected RF power. Absorption $Q = 144$

Inset: Geometry of side-coupled microstrip resonator

b Detected optical output against input frequency

c Detected optical output against optical frequency

An initial approach to develop a microphotonic optical modulator uses a z -cut LiNbO_3 disk-shaped resonator with optically-polished curved side-walls [3]. Standard evanescent prism-coupling [4] is used to couple laser light into and out of a resonant TE-polarised high- Q optical whispering-gallery mode (WGM) which exists at the periphery of the disk. A metal electrode structure fed by an RF signal is designed to overlap and be in simultaneous resonance with the optical field. The resonator's high optical Q is used to increase the effective interaction length of photons with an applied RF electric field. When combined with a simultaneously resonant RF structure designed to provide voltage gain between the electrodes, a highly sensitive receiver at microwave frequencies is achievable.

The free spectral range (FSR) of the optical resonator and the spatial pattern of the metal-electrode structure determine the centre modulation frequency of the optical carrier [2]. The frequency of the RF carrier f_{RF} should be an integral multiple m of the optical FSR such that $f_0 = 1/\tau_{disk} = n_{opt}2\pi R/c$ where τ_{disk} is the optical round-trip time of the disk and R is the disk radius. For a z-cut LiNbO₃ with $R = 2.92\text{mm}$, a value of $f_0 = 7.56\text{GHz}$ is measured.

The inset to Fig. 1a shows the RF and optical configuration. Prisms are used to couple laser light of approximate wavelength $\lambda = 1.55\mu\text{m}$ into and out of the WGM optical mode of the microphotonic resonator. The optical wavelength is tuned to a resonant wavelength of the optical resonator. An RF electric field propagating on a 50Ω metal microstrip line evanescently side-couples to a metal-electrode resonator on the LiNbO₃ disk. The fundamental resonant frequency of the electrode resonator is tuned to match the optical FSR of 7.56GHz , as indicated by the dip in the reflected RF excitation response shown in Fig. 1a. The measured voltage gain provided by this resonator is greater than 4. Improved resonator designs should be capable of achieving voltage gains in excess of 100. Fig. 1b shows the detected optical signal as a function of the applied RF frequency f_{RF} . The resulting optical modulation is centred at 7.56GHz with a -3dB bandwidth $\Delta f = 80\text{MHz}$.

RF modulation of the optical carrier is observed directly by passing light exiting the microphotonic resonator through a Fabry Perot interferometer with an optical resolution of $f_{-3\text{dB}} = 900\text{MHz}$. As indicated in Fig. 1c, the optical carrier at 194THz ($\lambda = 1.55\mu\text{m}$) is centred between two optical side-bands, each separated by 7.56GHz ($\Delta\lambda = 60.5\text{pm}$) from the optical carrier. The input light has an optical bandwidth of $< 0.5\text{MHz}$.

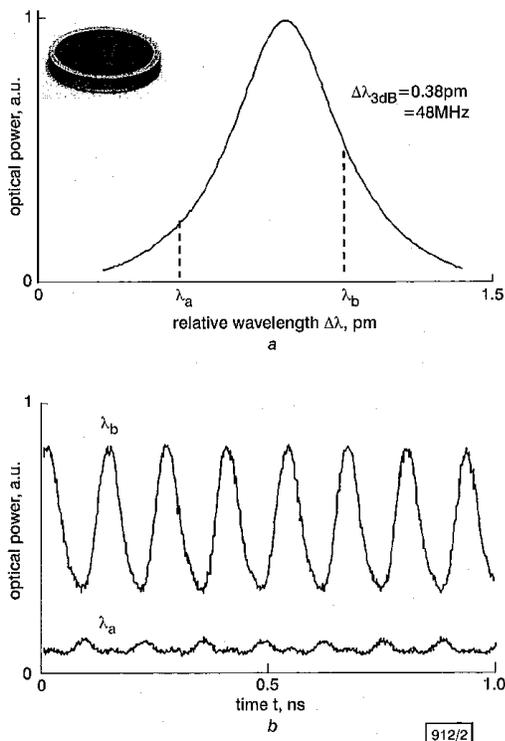


Fig. 2 Measured optical resonance and detected optical time-domain signal

a Measured optical resonance near $\lambda = 1.55\mu\text{m}$
 Inset: z-cut LiNbO₃ resonator with optically polished curved side-walls. Gold electrodes are placed in an annulus around disk to increase overlap of electrical bias and optical field. $R = 2.92\text{mm}$, $d = 0.74\text{mm}$
 b Detected optical time-domain signal

Fig. 2a shows the measured optical spectrum of the WGM resonance in the absence of RF modulation. Optical $Q = 4 \times 10^6$ results in an effective photon interaction length with an RF field of greater than 50cm . As shown in Fig. 2b, optical modulation is maximised for a fixed RF input power when the optical wavelength is located at the maximum slope of the WGM spectral shape.

Fig. 3 shows the modulated optical power at 7.6GHz for a fixed optical wavelength, where 1.0 equals 100% optical modulation. Small-signal modulation shows a linear increase with input RF voltage. At larger voltages, nearly 100% modulation is achieved. These voltages are found to be similar to values of V_π found in commercial LiNbO₃ Mach-Zehnder modulators. The minimum sensitivity in our initial experiments was found to be 90mV or $160\mu\text{W}$. A dramatic increase in RF sensitivity may be achieved by placing the metal electrodes closer to the optical WGM, improving the spatial overlap of the RF field with the optical mode, and increasing the Q of the RF resonator.

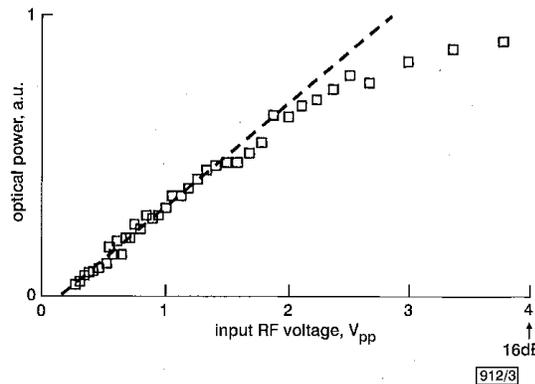


Fig. 3 Detected optical modulation against RF power launched onto RF microstrip resonator

Conclusion: A new type of electro-optic modulator using a z-cut LiNbO₃ disk-shaped resonator with optically-polished curved side-walls has been demonstrated. Initial experiments have achieved near 100% modulation at voltages comparable to Mach Zehnder modulators.

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Fuzzy hyperline segment clustering neural network

U.V. Kulkarni, T.R. Sontakke and A.B. Kulkarni

A fuzzy hyperline segment clustering neural network (FHLSCNN) and its learning algorithm is proposed. This algorithm can learn ill-defined nonlinear cluster boundaries in a few passes and is suitable for on-line adaptation. The FHLSCNN is superior compared to the fuzzy min-max clustering neural network (FMN) proposed by Simpson.