# Time-Domain Fabry–Perot Resonators Formed Inside a Dispersive Medium

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In this summary, we show that the temporal analog of a Fabry–Perot resonator (FPR) can be realized by using two moving temporal boundaries inside a dispersive medium, such as an optical fiber.[1–3] In practice, such boundaries are created by using a pump–probe configuration in which one or more short pump pulses are launched together with a probe pulse. Each pump pulse increases the refractive index of the single mode of the fiber through the nonlinear Kerr effect, but this increase occurs only over the duration of the pump pulse. The temporal FPR can be probed by an optical pulse that is injected into the fiber after the pump pulse is injected. The frequency of the probe pulse must be such that it propagates faster than the pump pulse. Physically, when the probe pulse crosses the pump pulse (the temporal slab), a part of the probe pulse changes its frequency such that it speeds up and travels ahead of the pump pulse, while part of the probe changes frequency so that it appears to move more slowly than the pump pulse. Inside this slab, the index change is small, $3 \times 10^{-7}$, and can be realized in practice using a short, intense 1-ps pump pulse. To calculate the transmissive properties of time-domain FPR's, we develop a transfer-matrix method similar to that used for analyzing the reflectivity of a spatial structure containing multiple thin films. We show that this method can be used for calculating the transfer matrix of pump pulses of any shape. As a simple example, we first consider a temporal slab formed by using a single pump pulse with sharp leading and trailing edges (rectangular shape pulse) and acting as a simple FPR. We found that such an FPR has several transmission peaks corresponding to resonances similar to spatial FPR's. If the frequency of the probe pulse is at the peak of the first resonance, more than 90% of the pulse energy is transmitted through the slab. Reflective losses (about 7%) occur due to the finite distance it takes for the probe pulse to cross the slab. Indeed, we see two reflected pulses that correspond to reflections at the two interfaces of the slab. If the probe pulse is centered on the first minimum of the temporal FPR, the reflected pulse contains most of the input energy. The bandwidth (or $Q$ factor) and contrast of these peaks, however, decrease rapidly with increasing frequency. In contrast with spatial FPR's, for which mirror reflectivity remains constant over a wide bandwidth, temporal reflection is very sensitive to the frequency of incident light.

We propose an improved design for time-domain FPR's by using two temporally separated pump pulses such that each pump pulse acts as a reflective element of the FPR. We apply our transfer-matrix method to this design for pulses of arbitrary shapes and obtain an expression for the transmissivity of such FPR's that appears identical to the corresponding result for space-domain FPR's. To illustrate the performance of the proposed FPR, we consider a practical configuration: The pump pulses' wavelength is in the anomalous dispersion region of the optical fiber while the probe pulse is in the normal dispersion region. Two pump pulses propagate as two optical solitons and their center is delayed by $T_c$ (Ref. 4). A high-index region forms over the width of each pulse because of a Kerr-induced increase in the refractive index of the fiber's mode. Choosing the pump pulses to have a secant-squared temporal shape with a width of 90 fs (FWHM) and a separation of 1.4 ps with an intensity such that $\Delta n = 3 \times 10^{-7}$, we calculated the transmission characteristics for the two cases of the input spectrum center at the first maximum of the zeroth-order peak, and input spectrum at the first minimum below the zeroth order peak. These results are shown in Fig. 1.

We also show that temporal FPR's formed in the anomalous group-velocity dispersion region of optical fibers by using two short solitons to form multiple sharp transmission peaks with relatively high $Q$ factors. We verified the results of the transfer-matrix method by directly solving the pulse-2 propagation equation with the split-step Fourier method. We showed that a probe pulse can

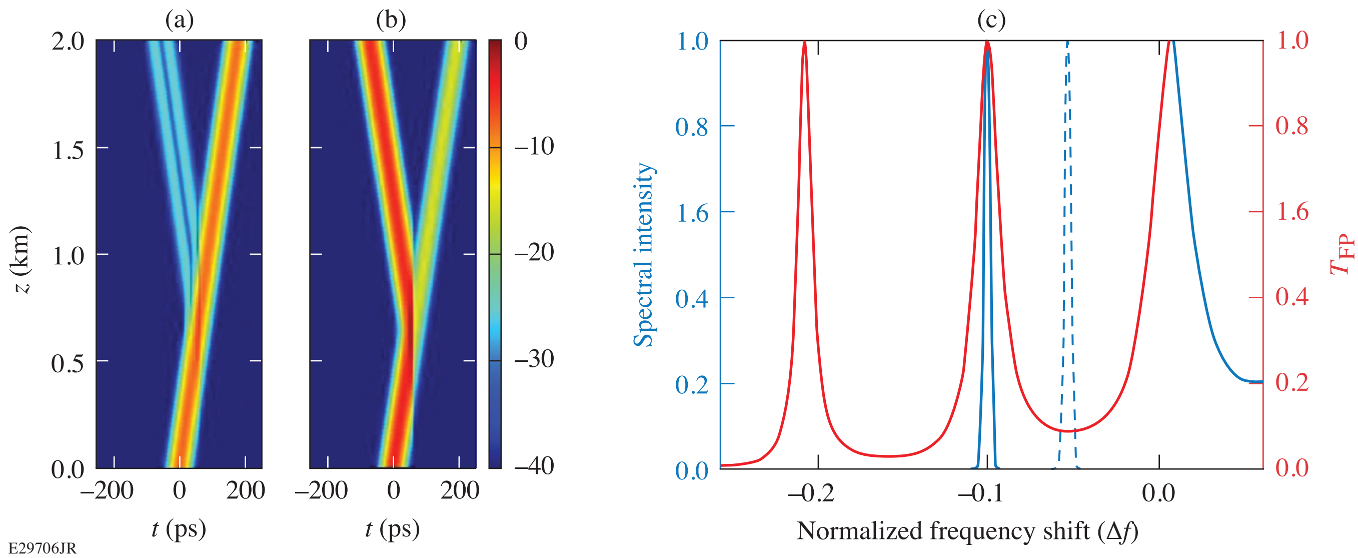


Figure 1
Temporal evolution of a 20-ps Gaussian pulse when its spectrum is centered at (a) a transmission peak and (b) a transmission valley. (c) Location of pulse spectra within the transmission curve (red) of the FPR. The solid blue curve is the incident spectrum in (a) and the dashed line is the incident spectrum in (b); spectral intensity is plotted. Both blue curves plot the spectral intensity.

be fully transmitted through such an FPR when its spectrum overlaps with that of a transmission peak of the FPR. If the spectral bandwidth is larger than the transmission peak width, the temporal FPR acts as an optical filter, analogous to spatial FPR's.

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