Title
Remote Synchrotron Light Instrumentation Using Optical Fibers

Author
De Santis, S.

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REMOTE SYNCHROTRON LIGHT INSTRUMENTATION USING OPTICAL FIBERS*

S. De Santis# LBNL, Berkeley, CA 94720, U.S.A.
Y. Yin, YYLabs, Fremont, CA 94537, U.S.A.

Abstract

By coupling the emitted synchrotron light into an optical fiber, it is possible to transmit the signal at substantial distances from the light port, without the need to use expensive beamlines. This would be especially beneficial in all those cases when the synchrotron is situated in areas not easily access because of their location, or due to high radiation levels. Furthermore, the fiber output can be easily switched, or even shared, between different diagnostic instruments. We present the latest results on the coupling and dispersion measurements performed at the Advanced Light Source in Berkeley. In several cases, coupling synchrotron light into optical fibers can substantially facilitate the use of beam diagnostic instrumentation that measures longitudinal beam properties by detecting synchrotron radiation. It has been discussed in [1] with some detail, how fiberoptics can bring the light at relatively large distances from the accelerator, where a variety of devices can be used to measure beam properties and parameters. Light carried on a fiber can be easily switched between instruments so that each one of them has 100% of the photons available, rather than just a fraction, when simultaneous measurements are not indispensable. From a more general point of view, once synchrotron light is coupled into the fiber, the vast array of techniques and optoelectronic devices, developed by the telecommunication industry becomes available.

In this paper we present the results of our experiments at the Advanced Light Source, where we tried to assess the challenges and limitations of the coupling process and determine what level of efficiency one can typically expect to achieve.

INTRODUCTION

In several cases, coupling synchrotron light into optical fibers can substantially facilitate the use of beam diagnostic instrumentation that measures longitudinal beam properties by detecting synchrotron radiation. It has been discussed in [1] with some detail, how fiberoptics can bring the light at relatively large distances from the accelerator, where a variety of devices can be used to measure beam properties and parameters. Light carried on a fiber can be easily switched between instruments so that each one of them has 100% of the photons available, rather than just a fraction, when simultaneous measurements are not indispensable. From a more general point of view, once synchrotron light is coupled into the fiber, the vast array of techniques and optoelectronic devices, developed by the telecommunication industry becomes available.

The main challenges in realizing a beam diagnostic system that makes use of synchrotron light carried on optical fibers are to be found in the coupling efficiency and in the dispersion introduced by propagation along the fiber. These two aspects are indeed strictly correlated when one is trying to design such a system: since there are minimum requirements on the signal-to-noise ratio, if the coupling efficiency is too low, one is forced to couple light on a larger bandwidth, which in turn makes the dispersion worse, for example. Commercially available optical fiber can support transmission with low attenuation in a wide wavelength region from ~1600 nm to the visible spectrum. In practical applications one would have to transmit synchrotron light over distances of a few 100's of meters at most, so that fiber propagation attenuation is seldom an issue. In case of highly radioactive environments, radiation-hard fibers, usually Fluorine based, are available at the price of a slightly higher attenuation.

While for our applications optical fibers are inherently wide-band, as just said, other components one has to use (couplers, detectors, etc.) work instead on limited wavelength ranges. Commercially, three bands have seen the almost totality of technological developments and are readily available: 1550, 1310 and 850 nm.

A first choice the designer has to make is between single-mode and multimode fibers. This is another case where one has to find a compromise between coupling efficiency and dispersion:

- Multimode fibers allow for a substantially more efficient coupling into the fiber, up to a large fraction of the total available power. On the other end, they are dominated by intermodal dispersion. Fig.1a shows the classic bandwidth/distance curves for multimode fibers. Commercial graded-index fibers developed for LAN's can provide bandwidths around 30 GHz, for a 100 m long fiber, in the 850 nm range [2].
- Dispersion in single-mode fibers can in principle be cancelled out by using *dispersion compensated fibers*, even in the case of a wideband source. Fig. 1b shows the dispersion curves for several types of fibers. It can be seen that it is possible to obtain near-zero dispersion, if the bandwidth is kept small enough, once again underscoring the importance of obtaining the best possible coupling of synchrotron light into the fiber.

In general, best coupling is obtained through the use of telescopes, GRIN lenses, or collimators, depending on the specific characteristics of the light port and the source. It must be kept in mind that, in most cases, the source's modal spectrum cannot be transversally

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matched into a single-mode fiber propagating mode, so that the coupling efficiency is necessarily much lower than unity.

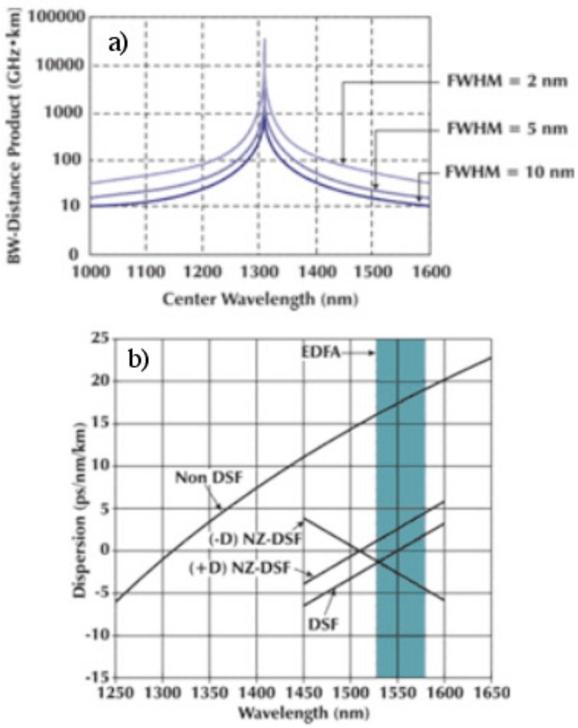

Figure 1. Bandwidth/distance curves for multimode fibers (a). Dispersion curves for single-mode fibers (b).

EXPERIMENTAL SETUP AT THE ALS

We performed experiment at the ALS, where a diagnostic beamline is available from time to time, using a variety of fibers, couplers and detectors.

Beamline 3.1 synchrotron radiation source is one of the ALS 1.3 T dipoles. The beamline, which is dedicated to an x-ray CCD camera during user operations, can be used for visible-IR wavelengths during dedicated shifts.

Figure 2 shows the photon flux out of an ALS dipole with 400 mA circulating in the machine.

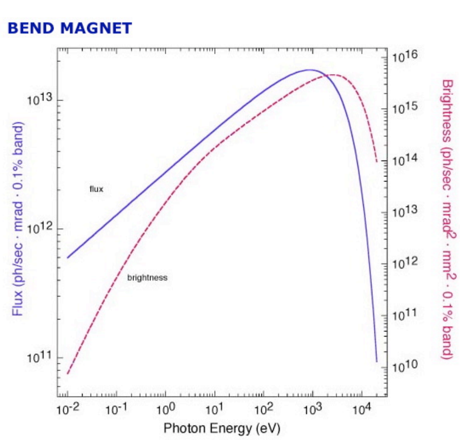

Figure 2. Photon flux for an ALS dipole.

The beamline optics have been described in [1].

We use the visible component for a first order alignment and then we optimize coupling by maximizing the readout on an optical powermeter at the desired wavelength. The average available power at maximum current can be calculated from Fig.2 and in the 1000-1600 nm band is found to be around 110 μW. One has to take into account losses on the mirrors: we measured the losses on the three external mirrors and found them to be around 3 dB. There is another in-vacuum mirror and the two K-B mirrors that focus the synchrotron radiation. At this point we don't have a definite value for the losses introduced by these mirrors, but we guess we could have only a quarter of the theoretical power available at the coupling element.

In our latest experiment we have used an OMS102-4-APC single mode collimator coupling into a GIF-625 graded-index 62.5 μm multimode fiber [2]. We can either use a short (~ 1 meter) fiber, or a 100 meter long one. For signal detection we used two InGaAs PIN photodiodes: the DSC50 with a 6 GHz bandwidth and the DSC30S with a 24 GHz bandwidth, manufactured by Discovery Semiconductors [4].

EXPERIMENTAL RESULTS

In our latest experiments reported in this paper our objective was to document the dispersion caused by propagation into the multimode fiber, since these fibers allow a better coupling as stated earlier. To this effect we compared the measurement of the bunch length of the ALS camshaft bunch obtained with the two photodiodes connected to the collimator by a short length of fiber and by a 100 m long spool. We did not apply any wavelength filtering, thus the photodiode entire span from 800 to 1650 nm was used. The attenuation characteristics of the fiber over that range go from -0.5 to -3.5 dB. The bandwidth distance product decreases to about 165 MHz-km at 800 nm. In this way we are putting ourselves in the worst possible situation from the dispersion point of view.

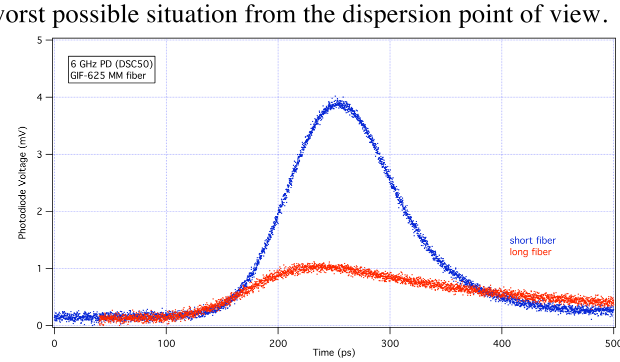

Fig.5 ALS camshaft measurement using the DSC50 photodiode. Short fiber (blue) and 100 m fiber (red).

Figure 5 shows the result using our 6 GHz photodiode. The FWHM after propagation in the short fiber is about 110 ps. After inserting the extra 100 meters of fiber the signal undergoes significant dispersion: the FWHM doubles and the maximum signal also decreases by a factor of 4, this also partly due to the increased attenuation at shorter wavelengths.

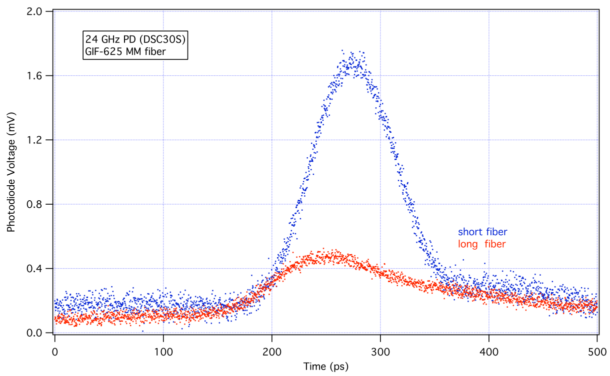

Figure 6. ALS camshaft measurement using the DSC30S photodiode. Short fiber (blue) and 100 m fiber (red).

Switching to the fast photodiode, there is an additional loss of -3 dB due to the presence of an internal matching resistor necessary to obtain the full bandwidth from the diode, which dissipates half of the signal. The FWHM measurement in this case yields about 90 ps, which is close to the value obtainable with other methods (streak camera), thus we assume this is the actual bunch length. Once again the long fiber insertion causes significant dispersion and a four-fold decrease in the peak signal.

CONCLUSIONS AND FUTURE PLANS

Our experiments have shown that propagation of short beam signals along long lengths of multimode fibers experiences substantial dispersive effects. Since we have managed to obtain coupling factors of the synchrotron light above 50% our signal level is large enough to allow try using wavelength filters in the next round of experiments in such a way to discard wavelengths far from the fiber zero-dispersion point therefore increasing the effective bandwidth-distance product.

Preliminary theoretical estimates show that this should greatly reduce dispersion, while maintaining a signal large enough to be detected by our photodiodes.

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