# Fiber Optic Engine for Full Color Micro Projection

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**Abstract** *In this paper we report a micro projector including of RGB sources, a 3×1 Fiber Optic Color Synthesizer (FOCS), and a two dimensional micro mechanical scanning mirror. We further report a modifier micro collimator which can enhance the resolution of the screened image.*

## Introduction

Along with fast growth of high definition displays and mobile telecommunication network devices, there exist rapidly growing and compelling needs to combine those two in to one; wearable displays, near eye displays (NED),or equivalently head worn display (HWD) are considered to be very close solutions to combine display technology with mobile communication technology[1]. In order to comply with demands for small size and light weight NEDs, optical waveguides are being investigated especially in projection displays. Fiber optic color synthesizer (FOCS)has been introduced to provide wide color gamut using fused taper fiber coupler technology[2]. Recently a compact scanning micro projection display system has been introduced, where a micro optical waveguide was adopted in color rendering along with grating light valves[3].

In this study a micro scanning display optical engine is introduced, which consists of a fiber optic color synthesizer (FOCS), fiberized collimating lens, and a micro mechanical scanning mirror, along with red, green, and blue LEDs. In the end of FOCS a special lens tip was integrated along with a separate fiberised ball lens to enhance the working distance of the beam, decrease the beam size, and enhance the beam resolution on the screen. The potential of the proposed optical engine for LED-based NED is discussed.

## Device fabrication

Fig. 1 shows the schematic diagram of the proposed device. The FOCS is made of three strands of hard polymer cladding fiber (HPCF). HPCF has a 200μm glass core ($SiO_2$), and 15 μm polymer cladding (PC-409). The core and clad refractive indices were 1.45 and 1.40, respectively.

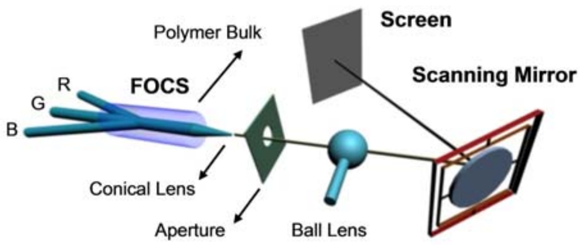


**Fig 1.** Schematic diagram of the scanning micro projector.

The FOCS is a 3×3 HPCF fused taper coupler fabricated by flame brushing technique[4]. The waist of the fused coupler was further tapered down by using an arc splicer (Ericson FSU 975) to form a conical-tipped output(Fig.2-a) whose diameter was 20 μm.

In order to further improve the focusing strength of the FOCS output, a fiberised ball lens was fabricated (Fig.2-b), in a similar manner by using a coreless silica fiber, whose final diameter was 500 μm. The conical output of the FOCS was positioned at the effective focal point of the ball lens (400 μm), and this arrangement yielded a fiberised micro collimator. Even though the taper was fabricated in an adiabatically reducing geometry[5], there were unavoidable light leakages from the the taper surface, which resulted in a significant noise. In order to eliminate this noise, a 30 μm aperture was placed in front of the taper. The assembly of FOCS was immersed in PC-409 polymer then cured, which served as a cladding.Three red, green, and blue chip LEDs with the wavelengths of 640 nm, 524 nm, and 463 nm were used as light sources. Since the diameter and numerical aperture (0.38) of HPCF are


**Fig. 2:** (a) A typical 3×3 coupler made and tip-shaped by the splicer. (b) The ball lens made of a coreless silica optical fiber.

 

large enough to receive light efficiently, butt-coupling method between LED and fiber was adopted.

The scanning micro mirror was a two dimensional scanning mirror (model: DM2Dk8, Hyperscan). The circular mirror was made of a thin high reflective aluminum with thickness of 30 μm and diameter of 1.2 mm. By using gimbals mounting technology, the suspended mirror can be manipulated independently in two directions to produce fast periodic deflection of light[6].Two function generators (HP 33120A) and a two-cannels fast high-voltage amplifier (Model F20AD, FLCE Electronics) were employed to render 1 $V_{PP}$ square waves with the resonance frequencies of 18.365 kHz and 2.615 kHz for vertical and horizontal directions, respectively. These driving signals were amplified to 50 $V_{PP}$ square waves.

## Experiments and Result:

Optical properties of the proposed device configuration were investigated in terms of the output power, power loss in the synthesizer, collimating strength of the micro collimator, and color gamut of the output. In order to estimate how equally the FOCS is transmitting the light through the three ports, a certain beam was launched to ports line by line. The result of their output power showed the power variation of 2.90%, 2.87%, and 2.67% among three ports for red, green, and blue input beams respectively.Another property which was taken in to account was the energy dissipation in the FOCS. The average insertion loss for each port was 1.8067 dB(Red), 2.3677 dB(Green), and 3.3637 dB (Blue). Thereby the overall loss of 7.5381 dB was measured.

To characterize the fabricated all-fiber micro collimator assembly "*collimating strength"* was defined, which is the ratio of the divergence angle of the beam spreading out of a HPCF to the divergence angle when comes out from the proposed all-fiber micro collimator at a certain wavelength..

By developing a program in MATLAB, and using second moment method[5], the spot size and the divergence angle of the beam were measured. The collimating strengths of the proposed device were 4.51, 4.28 for red 4.58, 4.53 for green and 4.62, 4.38 for blue in the vertical and horizontal direction, respectively. As an example, Fig. 3 illustrates the relative intensity distribution of the green beam for

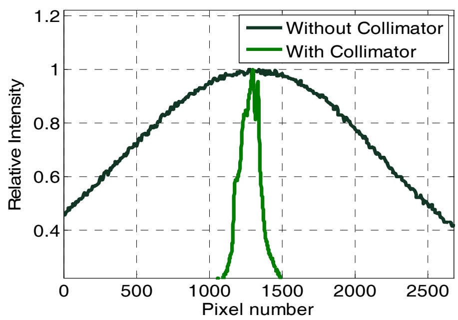


**Fig.3:** The effect of all-fiber collimating device for green color.

two cases through the proposed all-fiber collimator (light green line), and HPCF (dark green line). To estimate the color gamut of the display a colorimeter (CS-100A, Minolta) was applied. The CIE 1931 diagram of the proposed LED-based display was compared with those which belonged to NTSC, a typical CRT, and a TFT-LCD (Fig. 4).The widest gamut belonged to the LED-based display.

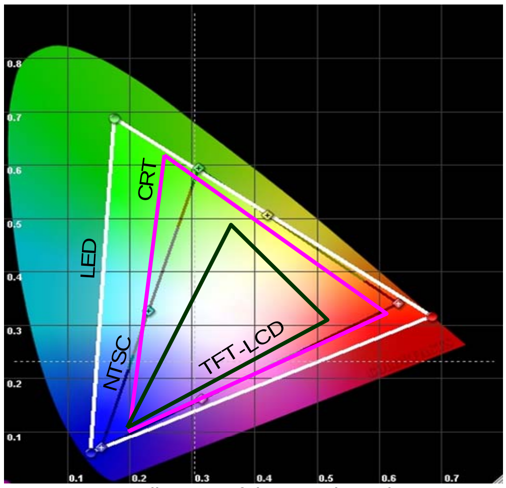


Fig. 4: CIE 1931 diagram of the LED-based, CRT, NTSC, and TFT-LCD display.

## Conclusion:

A color synthesizer for micro scanning displays with low insertion loss and low power consumption was introduced. The proposed micro collimator can improve the beam brightness and retain the beam size in the far distance. The color gamut of the micro scanning display ,shows that LED can be considered as a reliable source for near-eyes displays .

## Acknolegement :

This work was supported in part by the KOSEF (Program Nos. ROA-2008-000-20054-0 and R15-2004-024-00000-0), the KICOS (Program No. 2008-8-0506 and 2008-8-1893), the ITEP (Program Nos. 2007-8-2074 and 2008-8-1195), and the Brain Korea 21 Project of the KRF.

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