NUMERICAL MODELING OF FIBER OPTIC BUNDLES FOR IN SITU REFLECTANCE SPECTROSCOPY

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Introduction: Solar system exploration has entered a phase in which subsurface analysis has assumed an increasingly important role. Orbital observations have enabled specific global compositional trends to be identified while rovers and landers have allowed glimpses of what lies beneath the surface. If we hope to analyze deep into the subsurface we have two options, 1) to bring the material to the surface such as with the scoop on the Phoenix mission, or 2) utilize instruments that can penetrate into the subsurface. Here we will show the feasibility of utilizing optical fiber bundle configurations similar to those which have already been space qualified, to allow subsurface reflectance spectroscopy. They will be experimentally investigated and numerically modeled.

Description: Optical fibers and bundles have been used for decades in terrestrial applications ranging from communication conduits to biomedical and geological probes. With advances in the manufacturing process optic fibers have made their way into an array of satellites and spacecrafts (1). The most recent is the Mars Science Lab (MSL) which uses optic fibers in its ChemCam instrument to transmit the signal from the mast unit into the spectrometer that is housed in the rover body (2). The Lunar Reconnaissance Orbiter (LRO) also utilizes optical fibers arranged in a bundle, and in this satellite the fiber bundle is used to transport a laser signal used for ranging to an onboard detector (3). By using the same type of fiber array configuration as used in the LRO (six equally sized fibers around a central fiber) we have demonstrated the feasibility of applying the same type of space qualified bundles to the field of subsurface reflectance spectroscopy in spacecraft landers and rovers. One such application would be to integrate these fiber optic bundles into a spike-like instrument that would then be pushed into a planetary subsurface such as that proposed by the OPRA instrument (4) (5). This would allow subsurface spectroscopy with minimal disturbance to the layering structure. Here we will experimentally investigated and numerically model several fiber optic bundle

Experimental Setup: The experimental setup illustrated in Figure2, consisted of a fiber optic probe with one leg coupled to a light source and with the common end held at a known, adjustable, perpendicular distance above a sample of optical grade Spectralon (a white standard). The second leg of the probe was coupled to the detector which was a Newport 1916-C power meter. The reflected light was modeled and measured as a function of the probe distance from the sample.

Numerical Modeling: Output from a fiber optic probe can influenced by the following probe characteristics: fiber array configuration (*Figure 1*(A) shows a standard six around one configuration), designation of input/output fibers, the Numerical Aperture (NA), (*Figure 1* (B)) where $NA = sin^{-1}(\emptyset)$ and the fiber core diameters. The numerical model is constructed as follows: 1)Photons leave the transmitting fiber in a Gaussian distribution profile, 2) The illuminated sample area is broken down into a high density grid 3) each grid point is considered separately and the reflected light from that grid is reflected in a spherical wave 4) the receiving fiber is also broken down into a high density grid with each of its grids summing up the total flux received from the illuminated sample that falls within the overlapping zone of the illumination and receiving fiber as shown in *Figure 1*. Each probe

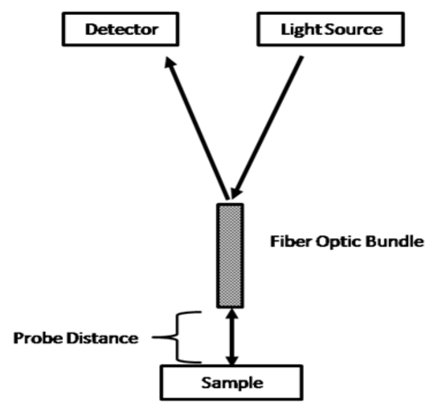

Figure2. Experimental illustration. The first leg of a fiber optic probe is coupled to a light source with the second leg coupled to a light power meter. The common end is held at varying distances above a white standard and the reflected light power readings are recorded as a function of probe distance

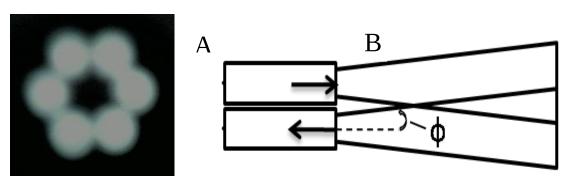

Figure 1 (A) Contact image of a fiber optic bundle with 6 transmitting fibers (illuminated) around a single, central receiving fiber (not illuminated). **(B)** A simplified 2 fiber illustration of a single transmit fiber with an axially aligned receiving fiber next to it. Here we have three zones 1) the illumination zone 2) the receiving zone and 3) the overlap zone. The overlap zones represents the regions of the illumination zone that can actually be "seen" by the receiving zone

model was run twice, first with the central fiber as the transmitting fiber and the surrounding six as the receiving fibers and, second, having the central fiber as the receiving and the surrounding six as the transmitting. Both models were run over a range of sample distances and the corresponding total light collected was recorded. The arrays investigated had numerical apertures of the transmit fiber(s) between 0.5-0.2.

Results and Discussion: Model validation was performed by comparing numerical models to experimental results on purchased off the shelf probes. *Figure 3* shows the good agreement between model and experiment. Figure 4A are the results with the central fiber as the transmit and Figure 4B shows the results with the central fiber as the receiving. Results indicate that it is always more efficient to have the central fiber as the transmit fiber, in these cases an increase of around 8% was observed. Decreasing the NA of the transmitting fiber will decrease the collection efficiency whilst increasing the distance from the sample to reach a the peak percentage.

It has been shown that is possible to increase the collection efficiency of a fiber optic probe by careful selection of the NA of the fibers. There has been no increase in mass or size as the result of the this increase in performance which is particularly attractive in terms of space craft instrumentation design when both mass and weight need to be minimized. This work has focused on flat faced fiber bundles and will be expanded to angled edge fibers which offer even greater collection efficiency at little to no mass/size cost

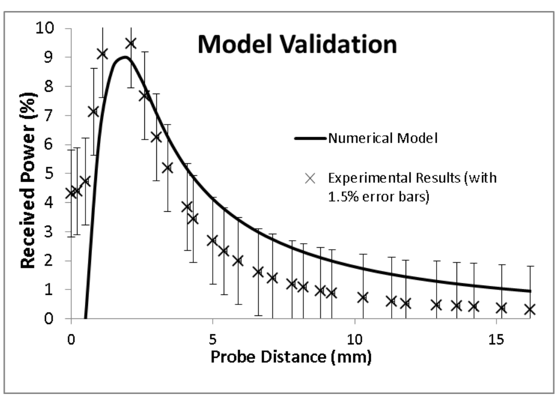

Figure 3 Comparison of numerical model and experimental results. This particular plot is of transmitting fiber surrounded by six receiving fibers all with numerical apertures of 0.53. and fiber core diameters of 600μm The error bars shown are 1.5%. For clarity I have only shown a single model probe comparison, but all experiments agreed with the numerical models to around 2% absolute.

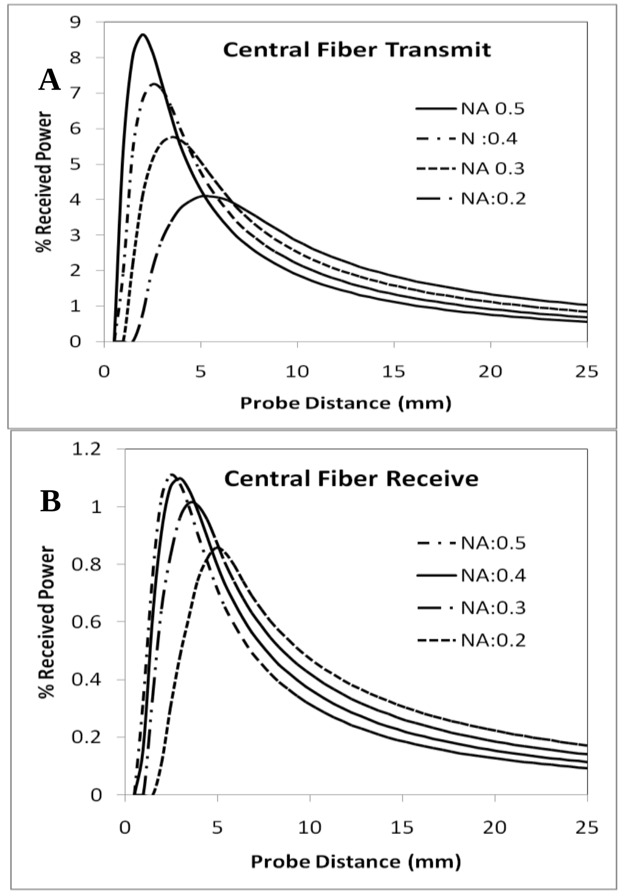

Figure 4 Simulation results of transmitting fibers numerical apertures of 0.5, 0.4, 0.3 and 0.2 for a probe with the 6 around 1 configuration. In all models the receiving fiber(s) numerical aperture is held constant and it is the transmitting fiber(s) NA that is changing. **(A)** Shows the models with the central fiber as the transmit, **(B)** are models with the central fiber is the receiving fiber.

References:

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