

## SPS FIBER OPTIC LINK ASSESSMENT

T. O. Lindsay, E. J. Nalos  
Boeing Aerospace Company

### 1. INTRODUCTION

Fiber optic technology has been tentatively selected in the SPS baseline design to transmit a stable phase reference throughout the microwave array. Over a hundred thousand microwave modules will be electronically steered by the phase reference signal to form the power beam at the ground receiving station. The initially selected IF distribution frequency of the phase reference signal has been set at 980 MHz or a submultiple of it.

Fiber optics offers some significant advantages in view of the SPS application. Optical transmission is highly immune to EMI/RFI, which is expected to be severe when considering the low distribution power (<1mW). In addition, there will be savings in both mass, physical size, and potentially in cost.

### 2. FIBER OPTIC LINK VERIFICATION PROGRAM

#### 2.1 TASK DESCRIPTION

The purpose of the present program is to demonstrate feasibility of a fiber optic link at 980 MHz for SPS application. The specific tasks are: 1) Analyze existing optical fibers for use in the phase distribution fiber/optic link with emphasis on phase change effects and ability to transmit high frequency IF signals; i.e., low attenuation and adequate bandwidth; 2) Analyze suitable optical emitters and detectors to determine feasibility of operation and usage at 980 MHz; 3) Select and purchase optical emitters, detectors, and fibers for link development; 4) Design and construct impedance matching systems for matching the optical emitter and detector to laboratory equipment; and 5) Assemble and test a two-way link at 980 MHz consisting of matched detectors, emitters, and a two-fiber cable of minimum length of 200 meters.

In the present phase control system for SPS, a two-way link is required in the phase distribution system at each level to achieve phase compensation for phase changes induced by temperature changes and other property changes in the electronic circuit.

#### 2.2 FIBER OPTIC LINK DESIGN

The results of the component selection for the fiber optic link are summarized in Table 1 below.

TABLE 1: COMPONENT SELECTION FOR FIBER OPTIC TEST LINK

Component	Type	Features
Emitter	GaAlAs Multi-Mode Injection Laser Diode	1. Moderate cost 2. High power 3. High modulation bandwidth
	GaAlAs Single-Mode Injection Laser Diode*	1. High power 2. High coupling eff. 3. High bandwidth 4. Low distortion 5. Low threshold 6. High reliability 7. Narrow spectral width
	Light Emitting Diode (LED)	1. No threshold current 2. Low distortion 3. Low cost 4. Stable operating point

TABLE 1: COMPONENT SELECTION FOR FIBER OPTIC TEST LINK (Continued)

Component	Type	Features
Detector	Silicon Avalanche Photodiode*	<ol style="list-style-type: none"> <li>1. Gain - BW product = 80 GHz</li> <li>2. High RCVR S/N</li> <li>3. Moderate cost</li> </ol>
	Silicon PIN Photodiode	<ol style="list-style-type: none"> <li>1. Low bias voltage</li> <li>2. Stable operating point</li> <li>3. Low cost</li> </ol>
Fiber	Step-index glass Multi-mode	<ol style="list-style-type: none"> <li>1. Low cost</li> <li>2. Low attenuation</li> </ol>
	Graded-index glass Multi-mode*	<ol style="list-style-type: none"> <li>1. Moderate cost</li> <li>2. High bandwidth</li> <li>3. Low attenuation</li> </ol>
	Step-index glass Single-mode	<ol style="list-style-type: none"> <li>1. Extremely high bandwidth</li> <li>2. Low attenuation</li> <li>3. Poor coupling efficiency</li> </ol>

\*Selected for link development

As a result of the investigations, multi-mode graded index fiber was chosen due to its high bandwidth, low attenuation, availability, and high coupling efficiency with injection laser diodes; single-mode injection laser diode was selected for its high bandwidth, high output, and excellent linearity; and an avalanche photodiode was selected because of its high bandwidth and superior sensitivity.

The link will operate at a wavelength of 820 nm where present laser diodes and avalanche photodiodes are readily available and offer good reliability. Fiber attenuation, although not minimum, reaches an acceptable value at 820 nm also.

The injection laser diodes were purchased from Nippon-Electric in Japan; the two-fiber cable was obtained from Siecor (fibers manufactured by Corning Glass Works); and the avalanche photodiodes from RCA.

One of the problems to be solved for the 980 MHz feasibility link was to develop simple, but effective, signal coupling techniques for the emitter and detector. The approach chosen is illustrated schematically in Figure 2. The use of the  $47\Omega$  resistor in series with the injection laser diode causes approximately  $50\Omega$  to be seen by the driver amplifier and it also aids in converting the driver output to a current source which is needed by the diode for linearity. The output signal current from the avalanche photodiode flows directly into the  $50\Omega$  input impedance of the laboratory amplifier. In both cases, the dc biasing networks are isolated from the signal paths by shorted quarter-wave microstrip techniques.

### 2.3 EXPERIMENTAL RESULTS

The results of an initial test to couple 980 MHz through a sample link are shown by Figure 2. The fiber length was 300 meters and the type is similar to that to be used in the two-way link development. Results are listed for two values of detector biasing. The output voltage waveforms were monitored using a sampling oscilloscope and, in both cases, the trace was stable and noise-free.

The test setup was similar to that shown in Figure 3. The emitter and detector modules are towards the right foreground shown with a length of coiled fiber optic cable. Laboratory equipment includes a 980 MHz frequency synthesizer, a vector voltmeter, oscilloscope, preamplifier, and biasing and monitoring equipment.

The emitter and detector modules used in the initial test are shown in Figure 4a and 4b. The thermal environment aboard the SPS is expected to be widely variable with values anticipated between  $-50^{\circ}\text{C}$  and  $+150^{\circ}\text{C}$ . Therefore, a major subject of interest involves the variation in propagation time through a fiber as temperature is changed. Propagation time is directly related to the transmitted phase and is known to be affected by thermal expansion and refractive index variation. Data was also taken to determine the magnitude of the phase variation versus temperature as illustrated in Figure 6. The phase sensitivity is not low enough to obviate the need for phase compensation except possibly for the shortest (last) level of phase distribution.

For a one-way link length of 200 meters, the transmitted phase would vary approximately 2.5 degrees for every  $^{\circ}\text{C}$  of temperature change at 980 MHz. This rate is acceptable with the present phase control system because of the two-way link length compensation. The two lengths of fiber will be adjacent for the total link, providing accurate tracking and matching.

At the outer levels of the phase reference distribution network, the link lengths average  $<10$  meters and comprise over 90% of all of the elements. It may be possible to eliminate the return link in such cases as the phase shift will be greatly reduced for the short runs, averaging 0.125 degrees of shift per  $^{\circ}\text{C}$ .

As fiber optic technology progresses, longer wavelengths should be investigated where bandwidth and attenuation characteristics are superior for fused silica fibers. It is anticipated that phase shift sensitivity may be reduced at longer wavelengths because of dispersive changes in the refractive index. Fiber optics represent a promising approach for the phase distribution system for the SPS and merit further development to realize their full potential.

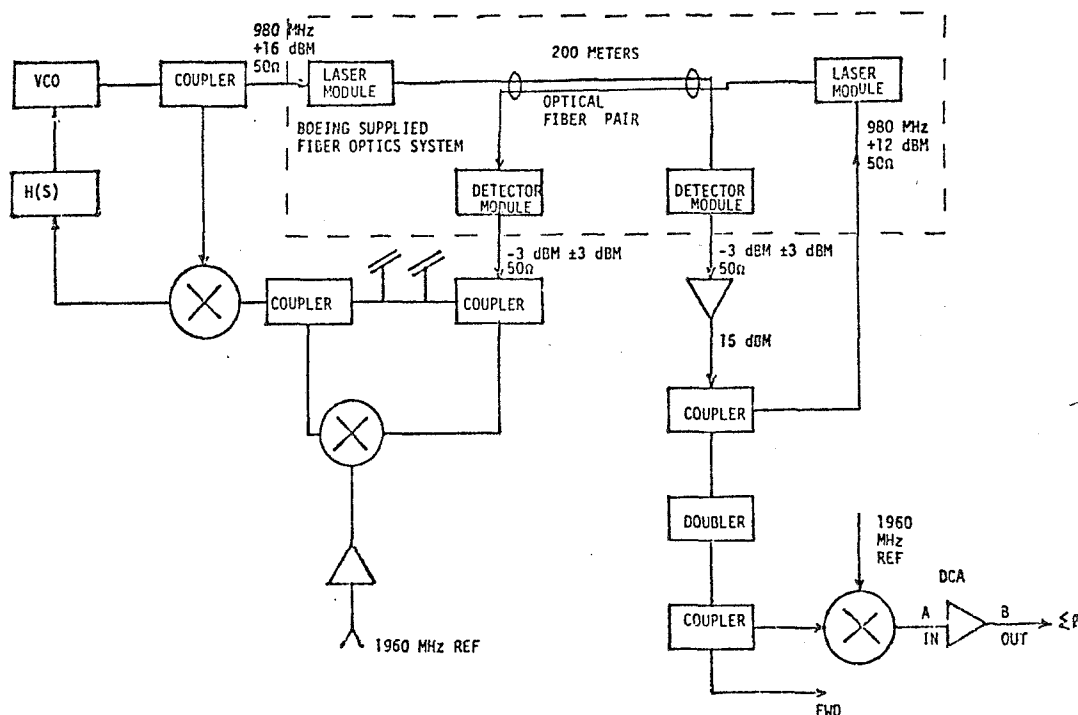
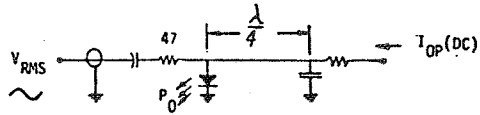


FIGURE 1 TEST CONFIGURATION FOR 2 WAY FIBER OPTIC LINK.

**EMITTER MODULE:**

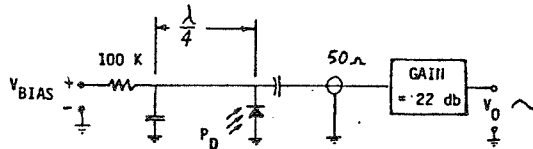
$I_{THRESH} = 60 \text{ ma}$   
 $I_{OP} = 67 \text{ ma DC}$   
 $V_{MOD} = 0.7 \text{ V RMS}$   
 $P_0 = 262 \mu\text{Watts}$



**DETECTOR MODULE:**

$V_{BIAS}$	185 Volts	315 Volts
$V_0$	71 MV RMS	283 MV RMS
$P_D$	19.1 $\mu$ Watt	19.1 $\mu$ Watt

Out



**FIBER: CORNING JVP0**

Length = 303 Meters  
 Atten = 3.9 db/km @ 900 nm  
 BW = 870 MHz-km  
 N.A = 0.218

FIGURE 2 FIBER OPTIC LINK DESIGN SPECIFICATIONS

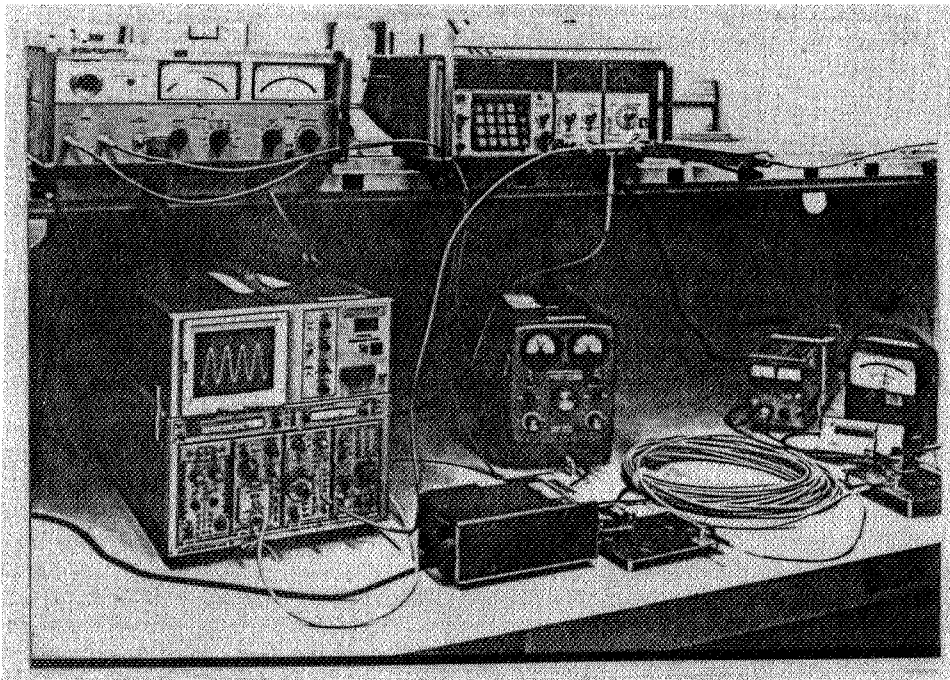


FIGURE 3 INITIAL 980 MHz LINK TEST SETUP

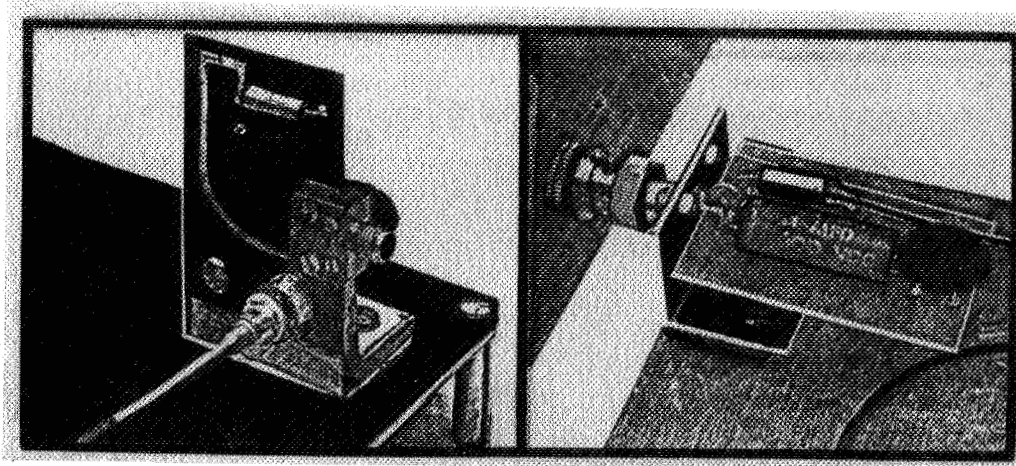


FIGURE 4A EMITTER MODULE BOARD. FIGURE 4B DETECTOR MODULE BOARD

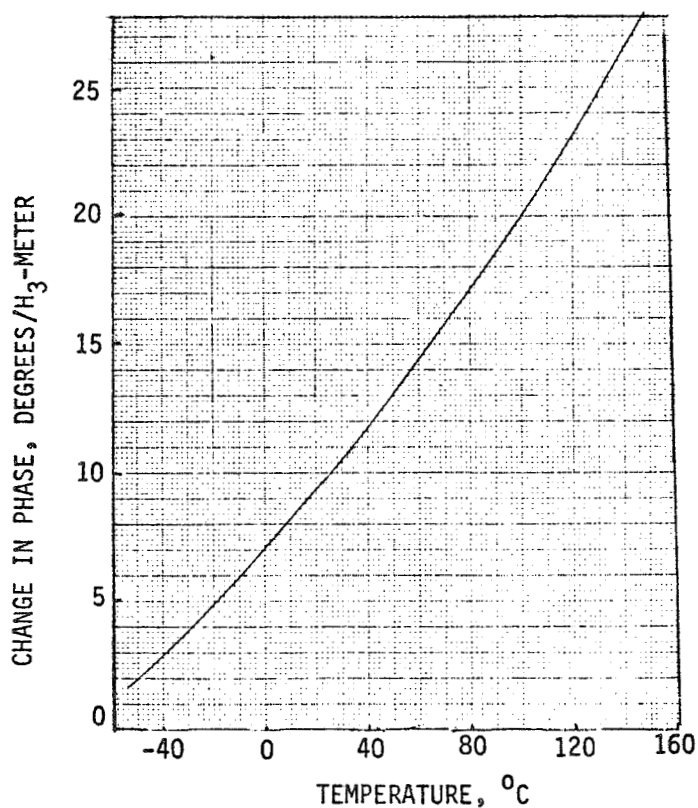


FIGURE 5 PHASE CHANGE OF GRADED INDEX FIBER vs. TEMPERATURE

- CORNING FIBER 303 METERS LONG
- FREQUENCY 980 MHZ