DESIGN AND PERFORMANCE OF A 6 GHZ ANALOG OPTICAL LINK

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Abstract

Applied Physical Electronics, L.C. (APELC) has designed and constructed an analog optical link with a bandwidth of 250 kHz to 6 GHz. The system is controlled from a LabVIEW-based remote platform that provides the user with control and monitoring of the system standby function, battery charge, temperature, and attenuation. The internal step attenuator provides 60 dB of dynamic range in 1 dB increments. Internal temperature compensation allows the system to operate without recalibrations in environments where the temperature fluctuates over a wide range in one day. The link is housed in a rugged and shielded enclosure for use in external environments with extremely high field strengths. This paper describes design considerations and performance of the system.

I. INTRODUCTION

While other optical link technologies include the ability to remotely control attenuation, gain, integration, probe verification, and termination; bandwidth limitations, temperature instability, and EMI susceptibility remain limiting factors in the usage of these optical links by those in the Electromagnetics and Environmental Effects (E^3) community. Moreover, no analog link system yet existed in the market place that provided those features along with a bandwidth extending from <1 MHz to 6 GHz.

Utilizing the Microwave Photonics MP-5000TX [1] as a basis component, APELC integrated the transmitter and RF electronics into a housing designed to provide immunity for >100 kV/m electric fields. A computer interface was also implemented to provide monitoring and control for the optical link.

II. 6 GHZ LINK DESIGN CRITERIA

While the primary objectives for this effort were the 6 GHz bandwidth, temperature stability, and EMI immunity, other target specifications were requested by the customer. All of these target design specifications are listed in Table 1. A block diagram detailing the signal flow of this architecture is shown in Figure 1. Detailed descriptions for each criteria are also outlined in the following subsections. These items were used as target design criteria, however, the final system did not include the PVS, integrator, gain, and switchable termination.

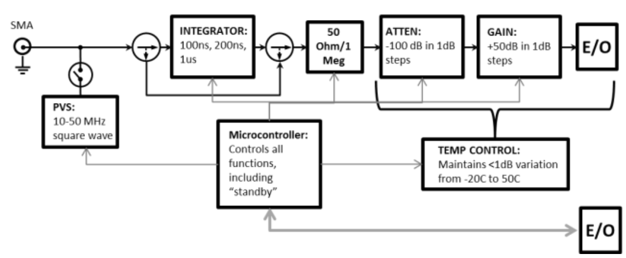

Figure 1 Desired components for the initial 6 GHz link design

Figure 2. The APELC 6 GHz Analog Fiber Optic link

Table 1 Desired specifications for the 6 GHz optical link

Specification	**Threshold**
RF 3 dB Bandwidth	1 MHz – 6 GHz
RF Flatness across Band	3 dB
RF Input Impedance	50 Ohm
Built-in RF input attenuation	-63 dB
RF attenuation step size	1 dB
Built-in RF Gain	0
Built-in Selectable RF Integration	None, 100ns, 200ns, 1us
Transmitter Continuous runtime	6 hrs
Transmitter Auto standby	After 3 min
System operating temperature	-20°C - 50 °C
System gain variation over temperature	<1 dB
Overall system gain variation	< 3 dB
EMI operational compatibility	100 kV/m
Remote operational software	Matlab or LabView
Additional software features	Battery voltage feedback to Matlab or LabView

A. Integrator

Electromagnetic Pulse (EMP) simulators deliver a fast-rising (~2ns), double-exponential pulse to a Device Under Test (DUT). The electric field in the simulator is typically measured with a capacitive probe which differentiates the signal. As a result, an integrator is required to resolve the original pulse at the oscilloscope. Since EMP waveforms can vary in their pulse width, the ability to select the time-constant of the integrator is desired.

B. Switchable 50 Ohm/1 MegaOhm Termination

Passive integrators develop their time constant by a combination of discrete capacitance and a 1 Megaohm termination resistance. This makes a 1 MegaOhm termination a requirement when using a passive integrator. When integration is not being used, the termination would be switched to 50 Ohms.

C. Attenuation

Because a laser diode circuit has a finite dynamic range, attenuation is required at the front end to reduce the amplitude of the measured signal to a level that will not saturate the input to the laser diode's trans-impedance amplifier. Moreover, since the optical link will be placed in a remote location from the operator, remote control of the attenuation in 1 dB steps is required.

D. Gain

Similar to the attenuation, the gain stage would be a remotely controllable stage that amplifies a small signal to one that would be well above the noise floor of the optical link.

E. Temperature Control

Because these optical links are to be used outdoors in temperatures ranging from -20C to 50C, and because system operators do not want to recalibrate the link as the temperature changes throughout the day, temperature stability is critical.

F. Microcontroller

The function of the microcontroller is to convert incoming serial data from the optical link (USB, RS-232, or Ethernet over fiber) to control signaling for the individual components mentioned above. Also the microcontroller would automatically place the system into a low-power standby state after a pre-determined amount of time. The system would be taken out of the stand-by state by activity at the operator end of the link (host/control computer).

III. SHIELDING DESIGN

One of the more critical aspects of the 6 GHz transmitter design was the external shielding. Field strengths as high as 100 kV/m are common in large Electromagnetic Pulse (EMP) simulators. Because the double exponential pulse created by these simulators has an extremely wide bandwidth, shielding for these devices considered not only small aperture points of entry for high frequencies, but also the metallic shielding skin-depth for low frequencies.

High Frequency Shielding:

High-frequency shielding was ensured by creating a seamless metal enclosure through the use of a custom-manufactured aluminum housing, metallized gasket material, and conductive o-rings as EMI shaft-seals on switches and connectors. A detail of these components is shown in Figure 3.

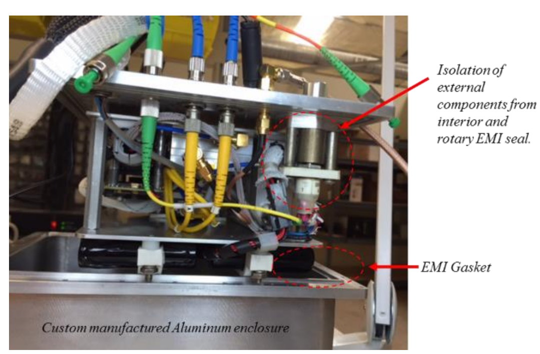

Figure 3 Shielding components for the 6 GHz link

Low-frequency shielding:

To ensure the total shielding effectiveness of the system accounted for the low-frequency components of an HEMP pulse, a low-frequency was determined for the unclassified EMP environment [2] shown in Figure 4.

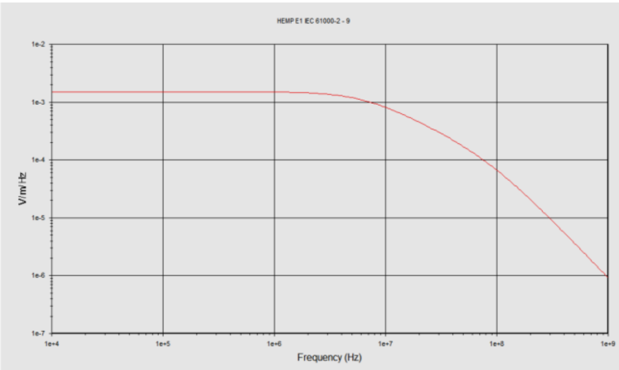

Figure 4 Unclassified HEMP E1 spectrum from IEC 61000-2-9 [2]

From this, a low-frequency target of 250 kHz was chosen and the following calculations [3] were made based upon a total shielding effectiveness of 100 dB.

$$\frac{E_o}{E} = 100dB \text{ (desired SE)}$$

$$10^{(\frac{100dB}{20})} = 1E^5$$

$$E = E_o \times e^{-\frac{x}{\delta}} \text{ (absorption loss)}$$

$$\frac{x}{\delta} = \ln(\frac{E_o}{E})$$

$$x = \delta \times \ln\left(\frac{E_o}{E}\right) = \delta \times \ln(1E^5) = \delta \times 11.5$$

$$\delta = \left(\frac{1}{f \cdot \pi \cdot \mu \cdot \sigma}\right) = \ .000184\ m \text{ (skin depth)}$$

where,

$$\mu = 1.257E^8\ \frac{H}{m}, \sigma = 3.00E^7\ \frac{S}{m}, f = 250\ E^3\ Hz$$

Because x is the distance the wave is attenuated to 1/e or 37%, we multiply by 3 to ensure complete attenuation of the wave.

$$x = .002117\ m\ \cdot 3 = \ .006351\ m\ \equiv\ .25004\ in$$

Therefore, an aluminum shield thickness of .250 inches was sufficient for this design.

IV. COMPLETED PROTOTYPE

The completed prototype based upon the target specifications included the MP-5000TX integrated along with a step attenuator, microcontroller, media converter (to allow communication and control via fiber-optic) and Li-Ion battery pack. The unit was housed in the custom aluminum enclosure described in the previous section and testing was performed to characterize the RF performance of the system from 250 kHz to 6 GHz.

While the MP-5000TX was capable of performance down to 9 kHz, the low-end response was limited by the amplifiers and attenuators required to achieve a link gain of 0.0 dB. A Vector Network Analyzer (VNA) measurement was made of the completed link and demonstrated a 3 dB roll-off point of approximately 200 kHz as shown in Figure 5.

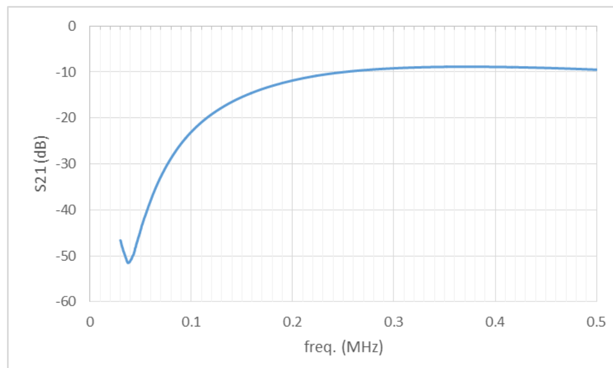

Figure 5 low-end frequency performance of the 6 GHz optical link

S21 VNA measurements were made for discrete steps of 0, 6, 10, 20, 30, 40, 50 and 60 dB as shown in Figure 6. Again, performance of the optical link was limited by the amplifier and attenuation stages, which did demonstrate considerable drift across the spectrum.

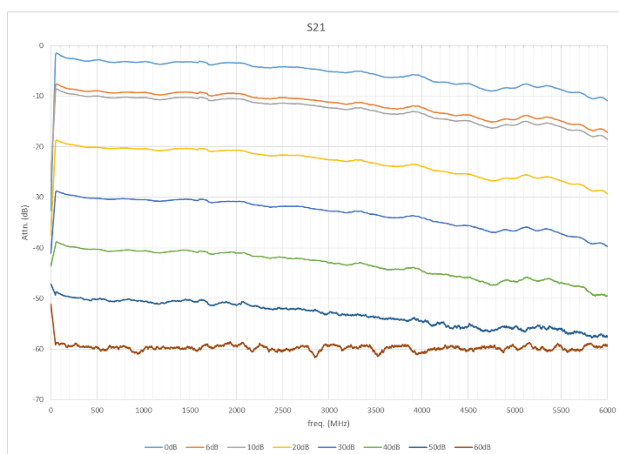

Figure 6 S21 measurement at 0, 6, 10, 20, 30, 40, 50, and 60 dB

A LabView™ control platform was also developed for the link that provided for adjustment of the attenuation, battery standby control, remote battery monitor, and remote temperature monitor. The LabView™ front panel for this system is shown in Figure 7.

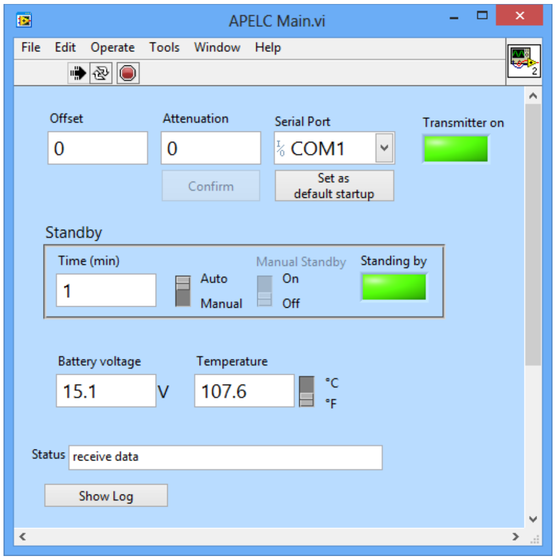

Figure 7 LabView™ Control software for the 6 GHz optical link

V. CONCLUSION

A 6 GHz optical link was constructed based upon customer-specifications using APELC-designed EMI-hardened packaging and layout with internal RF components from Microwave Photonics Inc. This initial prototype system did not fully integrate all of the desired functions (integration, PVS, adjustable gain), but did demonstrate the fundamental ability to accurately transmit RF signals over analog fiber from 250 kHz to 6 GHz with a relatively flat response across the frequency band, and with a temperature compensated transmitter assembly. Shielding of the system was designed to provide up to 100 dB of shielding effectiveness from 250 kHz to 6 GHz, and ruggedized fiber-optics were implemented to provide resistance against dust and moisture.

VI. REFERENCES

[1] https://www.b2bphotonics.com/

[2] Compatibility, Electromagnetic. Part 2: Environment—Section 9: Description of HEMP Environment—Radiated Disturbance. IEC 61000-2-9, 1996

[3] Henry W. Ott, Electromagnetic compatibility engineering. John Wiley & Sons, 2011