The development of a cost effective Fibre Optic Delay Line

G.Papastergiou (MSc)*, S.Matakias (MSc)*, I.Koukouvinos (MSc)*
G.Stratakos (PhD)**, Prof. N.Uzunoglou (PhD)**

* OPTRONICS EYT,
El. Venizelou 222, 175 63 Palaio Faliro,
Athens Greece

** National Technical University of Athens,
Department of of Electrical Engineering & Computing,
Electroscience Division,
Iroon Polytechniou 9., 157 80 Zografou Campus,
Athens , Greece

ABSTRACT

A Fibre Optic Delay Line was designed and developed to be used in a microwave signal processing system.
The device was based on a 10km 9/125microns single mode fiber delay line (50μsec). A single mode 1550nm / 1mW laser diode was used as a transmitter modulated up to 500MHz. A PIN photodiode with incorporated Transimpedance Amplifier (TIA) was used to convert the optical signal back to the electrical.
The paper presents full technical details and optical performance characteristics of a low cost easy to use fibre optic delay line.

KEYWORDS

Fibre optics, delay line, communications systems, signal processing, microwave antennas.

1. INTRODUCTION

Delay lines are used in a very wide area of applications in processing of microwave and RF signals.
Such applications include, Radar systems, Timing control for multiple antennas, Communication systems, Moving objects indication, etc.
The unique properties of optical fibres such as low loss, wide bandwidth, Electro-Magnetic (EM) immunity, light weight and small size provide the best technological infrastructure available to design a fibre optic delay line.
The phase velocity ($Vp = c / n1$) of a given optical signal in the fibre is approximately 2e8 m/sec . Where c is the speed of light in free space and n1 is the refractive index of the fibre optic medium.
Therefore the delay of the light propagated in an optical waveguide (fibre) should be approximately 5μsec/km.

2. SYSTEM DESCRIPTION

The delay line system is based on the simple principle of modulated light transmission through a given optical fibre length. The light is launched by a monochromatic light source and recovered by a suitable photodetector. Proper selection of the component parameters offer the required dynamic range and noise figure.
The system comprises the following subsystems and modules (see Figure 1):
a. The Laser Subsystem includes the *Laser Module* with the *Laser Diode Current Source* , the *Temperature Controller* and the *Bias Tee.*
b. The Receiver Subsystem includes the *Optical Receiver Module* .
c. The Optical Fibre Subsystem.

2.1.Subsystems description

2.1.1 *Laser Module*

The laser module selected was a GaInAsP Multi Quantum Well Distributed FeedBack (MQW DFB) laser made by Nortel (LC111*E-18 @1550nm) with maximum output of 2mW. The particular module was designed for use in ultra long distance optical fibre trunk systems with very narrow spectral line-width (typ. 0.4nm). High spectral stability is controlled through the incorporated thermo-electric heat pump and precision thermistor. The bandwidth of the laser source selected is 1.2Gbit/s (ie. ~ 600MHz).

Laser Diode Current Source and the *Temperature controller*

Two very advanced modules used to control the laser module. The Temperature controller (LDT-5100) and the Laser Diode current Source (LDX-3100)made by ILX Lightwave. Both were selected to offer extremely stable and high precision control to the laser source.

The Bias Tee

The signal was introduced to the laser module through a special Bias Tee (ZFBT-FT) with BW from 0.1-6000MHz made by Mini Circuits.

2.1.2 *Optical ReceiveQ Module*

The photodetector used as receiver incorporated a PIN with a Transimpedance Amplifier (TIA) and Automatic Gain Control. The receiver module was made by EPITAXX Opteoelectronic Devices. The fiber optic receiver was suitable to be used from 10Mbps (~5MHz) to 1.5Gbps (ie ~750MHz).

2.1.3 *The Optical Subsystem*

The optical fibre used was single mode fibre by Plasma Optical Fibres with attenuation of 0.18dB/km (ie. ~1.8dB/10km).

A critical parameter here is the use of special angled connectors suitable to eliminate backreflections that cause instability of the laser source. Angle polished connectors (APC) were spliced in every fibre input an output. The connector and adaptor types used in all cases was FC-APC. Splicing was performed with fusion splicers and in all cases special splice protectors with metallic element was also fitted. All external connections used special patchcords terminated with APC connectors.

3. SYSTEM DESIGN CONSIDERATIONS AND PERFORMANCE

The Fibre Optic Delay Line design is governed by three major factors:
The time delay required, the system bandwidth and the system dynamic range.
The system requirements were the following :

Delay time:	50μsec (ie optical fibre of 10km length)
Bandwidth (BW):	5-500MHz
Dynamic range:	30dB (RF IN from -30dBm to 0dBm, RF OUT from -50dBm to -20dBm)
System Impedance (Zo):	50 Ohms

3.1 System losses

The losses in the fibre optic system are shown in figure 2 and they sum up to 2.7dB only. The main sources of losses in the fibre optic link are due to splicings, insertions losses on the various connectors used and losses in the actual optical fibre length.
Quantitatively they arose from :

a. Patchcords (0.25dB x 2)	= 0.5dB
b. Fibre optic length with 2 splices	= 2.2dB
Total losses	= 2.7dB

Losses in the electrical part of the system predominantly arose from the resistive mismatch effects. Usual impedance matching procedures were used to transform the low impedance of the laser and the high impedance of the photodiode to meet the 50Ω.
The losses of the electrical signal without the optical delay was 8dB from the "RF IN" to "RF OUT". By including the required attenuators at the Input and Output (4dB + 4dB) as well as the fibre optic delay line we have a Total loss of 21.4dB.

3.2 System packaging

The fibre optic delay line system was developed in two separate packages. One of them included all the electronic and optoelectronic devices. The other one included the fibre optic spool with length of 10km with the appropriate optical terminations and protection.
The two separate boxes approach, was selected to allow the usage of alternative lengths in experimental work since immediate connectivity was allowed by available fibre optic adaptors at the front panel of each package.
The optoelectronic parts were placed inside the first package in especially designed metallic (aluminum) enclosures for use in microwave environment. The aluminum enclosures were also carefully designed and manufactured to serve as heat sink of the devices and particularly for the laser diode.
The electronic parts including all control units and drivers were also placed inside the same package as well as the rest of copper wire connections.
The whole packaging and layout of the system was such as to allow immediate experimental modifications in the field and laboratory.

3.3 Environmental considerations

The system was designed to be used in friendly environments with enough robustness suitable for experimental field use.
The operating temperature is from 0 to +50 degrees Celsius.
Mean Time Between Failures (MTBF) for the system is estimated to be more than 75.000 hours under normal conditions. Todays techniques for pigtailed lasers yield a lifetime of more than 1 million hours at room temperatures. For the case of photodiodes lifetime is even longer. The electronics and fibre optic parts in this case meet the highest standards. So in this case we are limited by the lifetime and the MTBF of the power supply units which were not assembled in this system.
Significant increase by at least of 2 times in the MTBF for the system is expected with the incorporation of a power supply in the package of such system.

3.4 System performance

Figure 3 shows the Transmission Losses or Amplitude Response of the fibre optic delay line. The HP-8510C Vector Network Analyser was used and it comes out to that the ripple was 3dB from peak to peak. The bandwidth (BW) was approximately 600MHz surpassing the requirements. The amplitude response depends on the response of the optoelectronic parts used (ie laser diode and photodiode) in the system. The laser selected was a DFB laser (narrow spectral line width) so that possible dispersive effects for longer delay lines can be avoided. Additionally the photodiode used was fast enough to cover the required BW.
Return Losses are shown on figure 4. The Return Loss is better (less) than 14dB across the whole BW. A typical rule of thumb is that Return Loss should be better than 10 dB.
Phase is maintained linear throughout the BW.
The Dynamic Range of the system was fairly constant 40-50dB for the entire 600MHZ fiber optic delay line BW. The RF Input was from 0dBm to -40dBm and produced RF Output from -20dBm to -60dBm.
Typical Time Delay measurements were performed on a 40MHz storage oscilloscope with a signal of pulse width 50 microseconds and duty cycle of 50 per cent. The time difference between output and input pulse edges in the time domain was then measured to be approximately 50 as expected for the 10km delay line.
No measurable dispersion effect was detected. The only apparent change was the 21.4 dB decrease in pulse amplitude due to transmission losses.

4. COMMENTS

Losses can be reduced significantly by optimising the splicing procedure.This reduction in fibre optic losses would result into an increase in the Dynamic Range of the system. This occurs since the photodetector performs as square law device and so every 1dB of decrease in optical losses results to 2dB decrease in the total link losses (ie increase of the dynamic range).

The Input compression point at 1dB was found to be +1dBm to +2dBm.
The overall system performance in repeated field tests was shown to be of excellent stability.

5. REFERENCES

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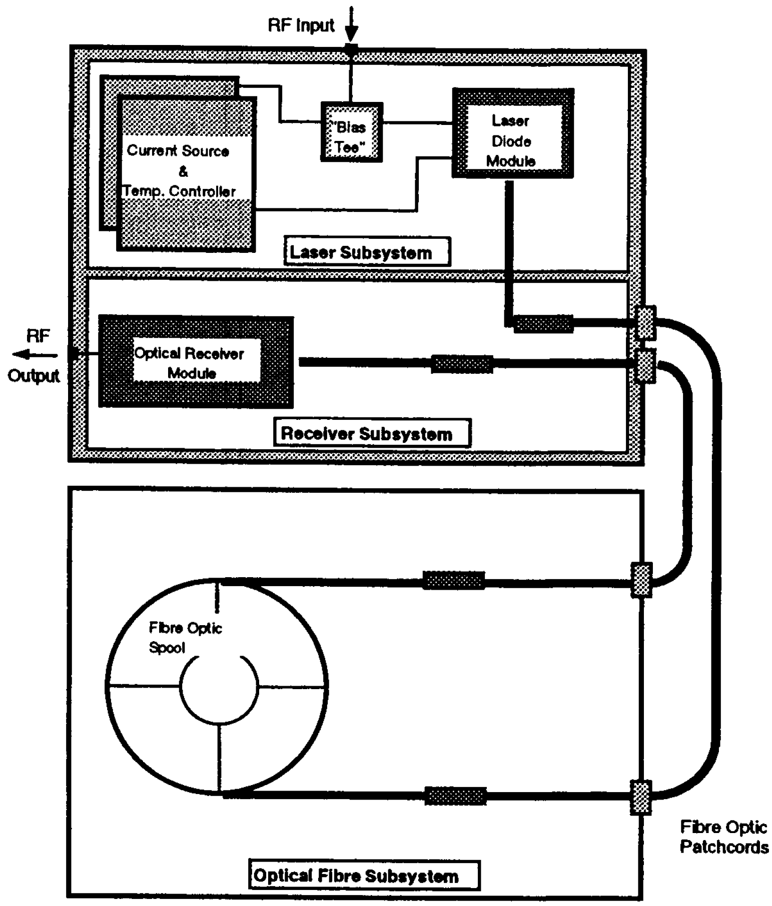

Figure 1. "Fibre Optic Delay Line system"

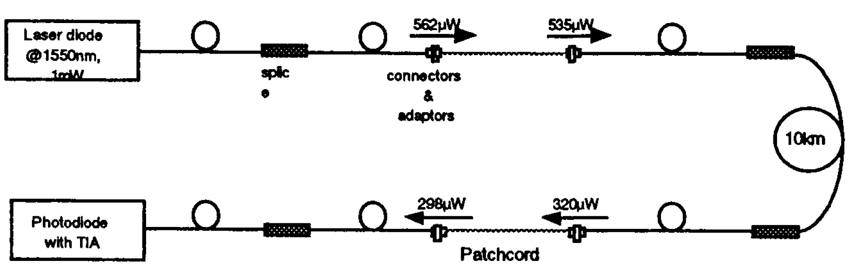

Figure 2. "Fibre Optic Link Losses"

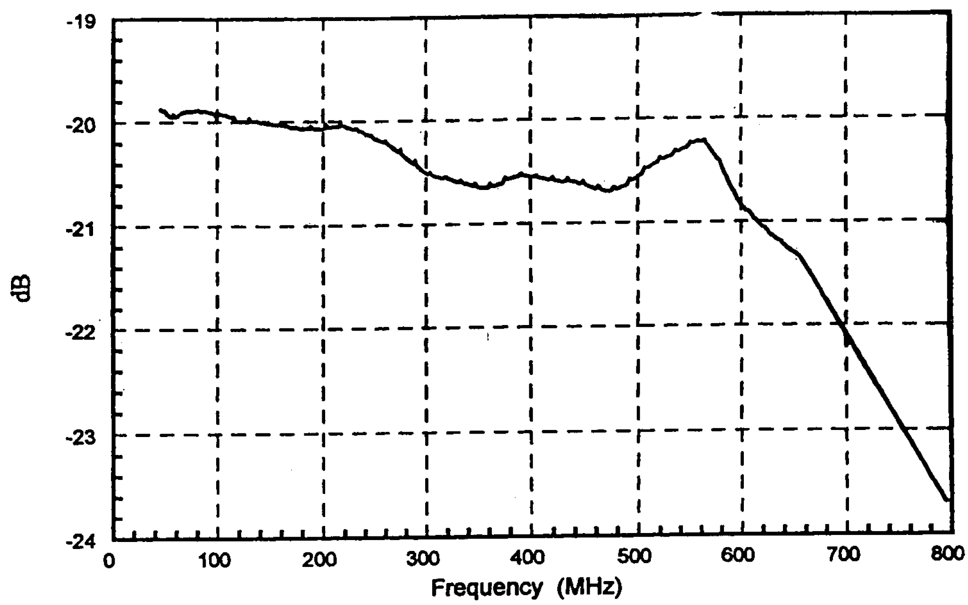

Figure 3. "Transmission losses"

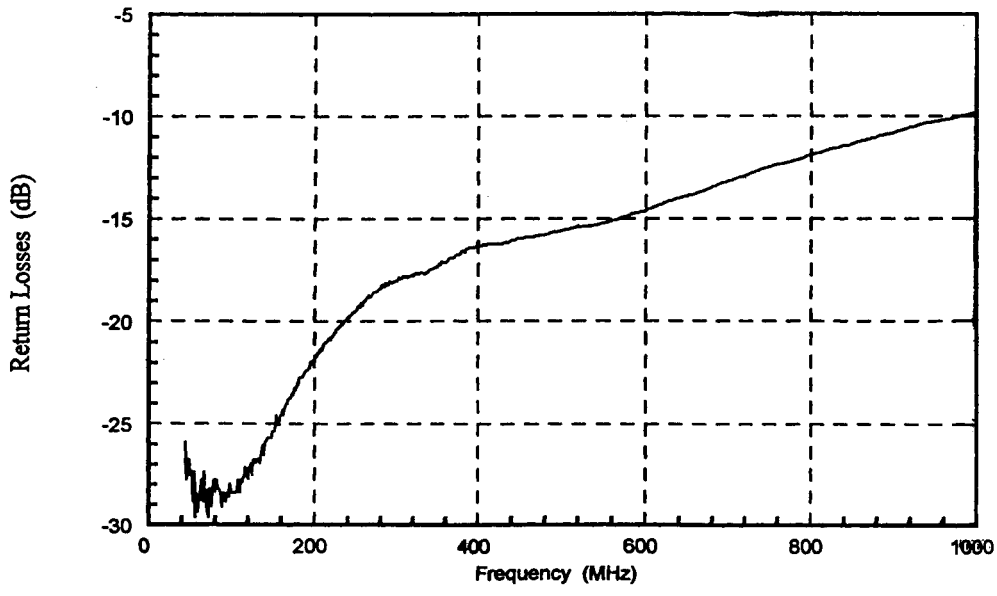

Figure 4. "Return losses"