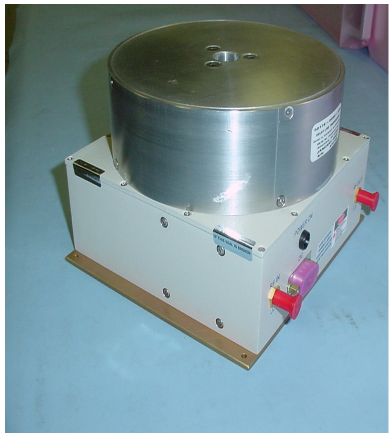
Fiber Optic Delay Line Systems

The 5017 delay lines system, incorporates a high-speed lasers and photodiodes to provide exceptionally high performance. The unit provides high bandwidth and sensitivity to operate with large delays, plus wide dynamic range for operation over a variety of loss budgets.



Applications

- Radar Systems
- MTI (moving target indications)
- Clutter Canceller
- BIT (built-in test
- Ground based System test
- Radar Warning Receiver
- EW Systems - Jammers
- Timing Control
- Path Delay Simulation
- Phase-shift Discriminator

Features

- High dynamic range lasers and photodiodes
- Delays to 110 microseconds
- Phase linearity better than 0.01%
- Bandwidths to 18 GHz

Performance Criteria

The source of this performance is Wideband lasers and photo-detectors designed for analog modulation. Such devices are being used for transmitting RF and microwave signal in a wide variety of applications, from CATV systems to satellite antenna links.

Contents

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Delay Line Applications

Some of the applications for delay lines include:

- Radar Systems
- MTI (moving targer indication)
- Clutter Canceller
- BIT (built-in test)
- Ground based System test
- Radar Warning Receiver
- EW Systems – Jammers
- Timing Control for multiple antennas
- Path Delay Similation
- Phase-shift Discriminator

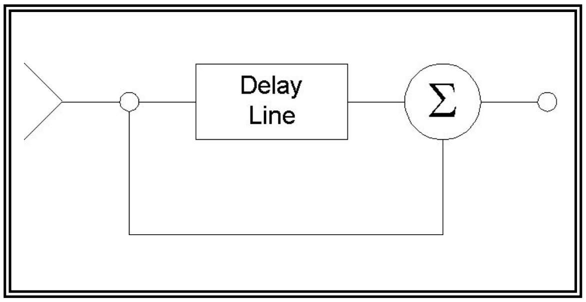

Figure 1. Delay Discriminator. Each pulse is sutracted from a delayed pulse. Unchanged signals (ground clutter or stationary targets) give zero output.

Moving Target Indication and the clutter canceller are basically the same system. The main component is indicated in Figure 1. Each received echo pulse is subtracted from the previous echo, which has been stored in the delay line. Any component of the signal that has not changed will thus be subtracted from itself to give a zero output. This could be ground clutter or a stationary target. A moving target will generally have an amplitude changes as well as a Doppler frequency shift. The difference between successive pulses in this case will result in a dc or low frequency output proportional to the frequency (phase) shift (speed information) and the change in amplitude.

Typical delay time in this application range from several hundred nanoseconds to several microseconds.

Another application uses the delay line as BIT (Built-in Test) equipment for radar systems Figure 2.

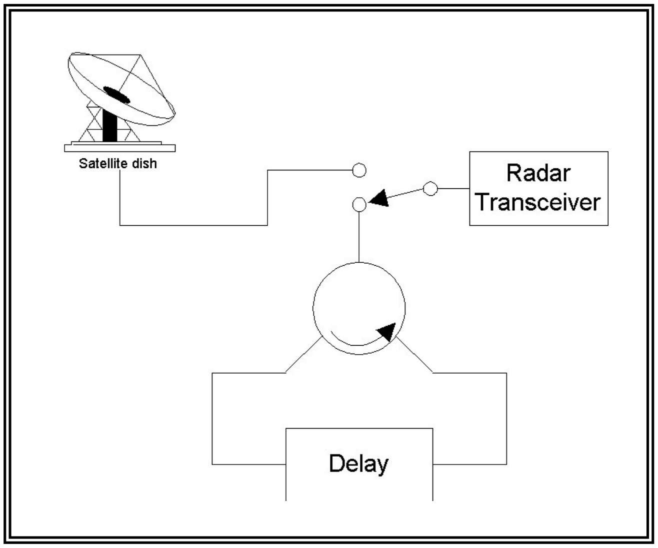

Figure 2. Radar Built In Test. During designated times, the radar switches to an external delay to simulatean echo for a self test.

Radar systems generally have some dead time between the last echo received and the next transmitted pulse. Some self testing is accomplished during this time (noise performance, dc tests, etc.) In addition, the system may periodically break it's operational cycle to perform self testing with a simulated echo.

The same kind of testing is also performed during regular manufacturing and also as part of regular testing on the ground. This kind of testing may involve a single fixed delay, a set of various delay which are interchanged manually.

Delays for this kind of testing can vary from a few nanoseconds to 110 microseconds.

In the radar warning receiver Figure 3 the echo is received at the IFM (Instantaneous

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Frequency Measurement) preprocessor which identifies the frequency and sets up the local oscillator so that the signal is downconverted to the IF of the signal post processor. The delay holds the signal long enough to allow the IFMto tune the L.O. (≈ 1 μsec).

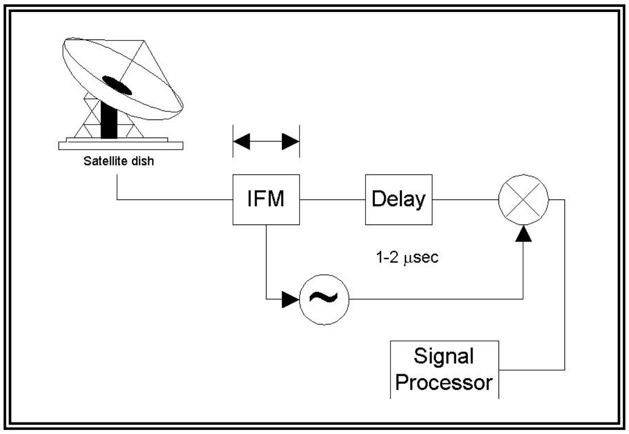

Figure 3. Radar Warning Receiver. The signal is held long enough for the IFM (Instantaneous Frequency Measurement) to tune to the signal processor IF.

For EW (Electronic Warefare) systems, there is a major interest in the fiberoptic delay line for jamming applications. Some of these applications involve receiving, processing, and retransmitting radar pulse as false echos with misleading information regarding the target size, speed and direction.

Another application is for multiple antennas at the input of one receiver. Here, progresively longer delays hold the signals (time limited) from a number of antennas. The signals are then time multiplexed and can be combined for processing at the same receiver as shown in Figure 4.

The delays used here can be from <100 nanoseconds to tens of microseconds.

In a similar set up, the delay lines could also be used to direct the beam pattern from a number of antennas. This system would then be a synthetic aperature or phased array antenna.

Delay lines could be used to simulate the natural time delays in communicating systems. This can range from the delays in cellular systems (tens of micoseconds) to the round trip delay for geo-synchronous satellites (250 microseconds).

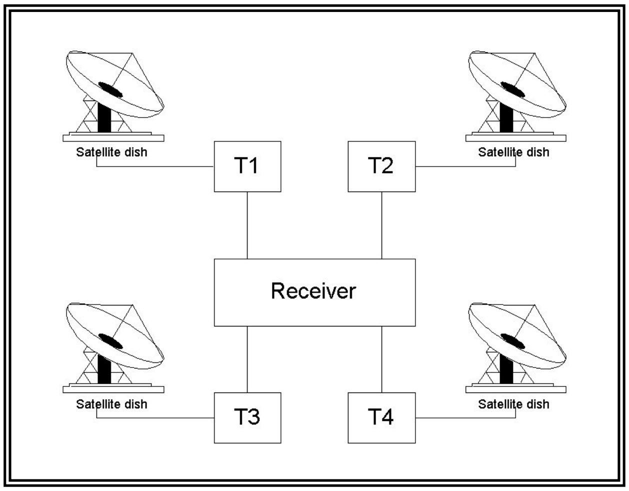

Figure 4. Delay lines for Multiple Antennas. Progressive delays TDM signals to a common processor. Or, delays used to steer antenna patterns as phased array.

These estremely long delays could be best realized using a a recirculating delay line Figure 5. The gain of the amplifier is chosen so that the link loss is zero dB and the length of the total delay. Of course, the signal must be limited in time in order to fit in the loop.

Finally, the phase shift discriminator shown in Figure 1 can be used as an FM demodulator and as an element in a phase noise measurement system. If the input signal is a CW signal then the ouput is proportional to the difference in the phase of the signal compared to the delay time, T. The longer delay, the slower the variations that are being detected. That is, long delays allow measurement of “close in” phase noise. Of course, this requires that the phase noise introduces by the delay is less than the noise to be measured.

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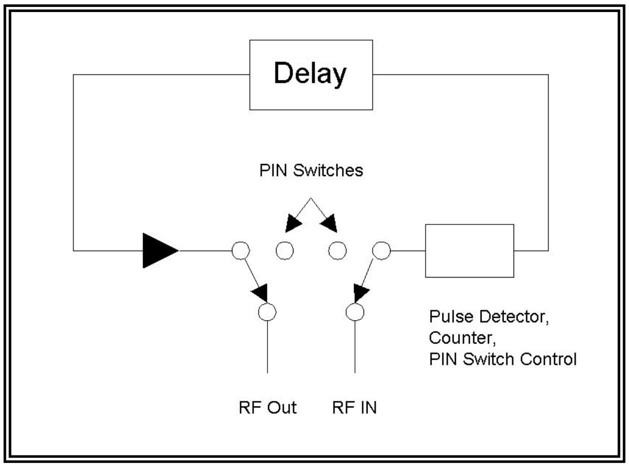

Figure 5. Recirculating Fiberoptic Delay. After the signal is input, the switches close and the passes are counted. During the last pass the switches open.

Delay Line Design

Fixed Delay:

The basic advantage of a fiberoptic delay line is that long lengths of optical fiber are extremely low loss, broadband, and can be coiled into small packages. Since the phase velocity of an optical signal in fiber is approximately the same as an RF signal in teflon filled coax, similar delays can be expected for a given length of cable, approxiametly 5 nanoseconds / meter or 5 microseconds / kilometer.

The loss of 1 kilometer of high quality optical fiber is less than 0.4 dB (optical), which means several kilometers of fiber constitutes an "electrically short" transmission line. In, fact the effect of cable loss due to distance does not generally become imprtant for distances less than 5 – 10 kilometers, which corresponds to delays of 25 – 50 microseconds.

The bandwidth of optical fiber is enormous compared to that of coaxial cable. The bandwidth of a length of fiber depends on the spectral width of the source and on the length. Expressed as a bandwidth-length product, singlemode fiber at 1300 nanometers easily exceeds 100 Gigahertz•kilometer and can approach 1000 Gigahertz•kilometer with singlemode distributed feedback (DFB) lasers. As a result, delays lines with bandwidth•time products exceeding 1000 Gigahert•microsceond are achievable without approaching the basic performance limits of the optical links.

The final advantage of fiber is its small cross section and flexabilty. Coils several kilometers long can be wound in spools which easily fit into the palm of one's hand. Fiber development of FOGM (Fiber Optic Guide Missile) applicatiions can be wound with dend radii less than 0.5 inch with neglible change in performance. An added advantage of fiber spools is the complete lack of cross-talk or electromagnetic radiation.

Variable Delay:

Variable delay lines are of considerable interest in a variety of applications including radar range simulation and signal processing. There are two basic techniques to consider; switched RF and switched fiber. Switched RF uses multiple (optical) delay lines and RF switches to select various delay values. This technique has good performance, but is relatively expensive because multiple delay lines are required.

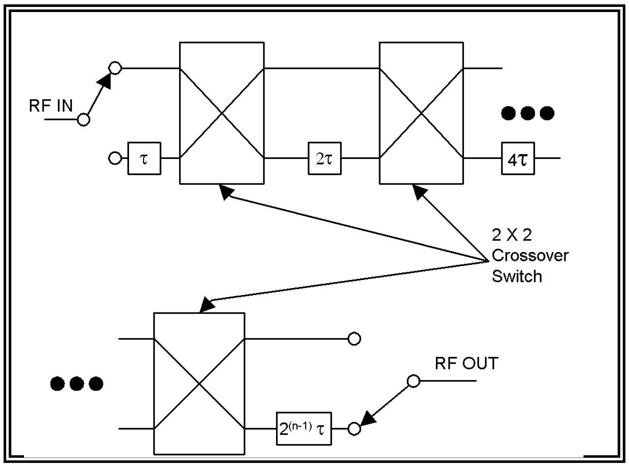

Figure 6. Step Variable Delay Line. "τ" is the smallest increment and "n" is the number of stages in the delay.

Switched fiber techniques vary the path length with optical switches. Figure 6 shows a schematic of a variable delay line that uses cascaded delay elements. The disadvantage of this approach is that the switches are relatively slow, switching in 5 –10 miliseconds. However,

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this is not a problem for most radar range simulation applications.

For the faster switching times needed for real time signal processing applications, Lithium Niobate (LiNbO3) integrated optic switches are available with submicrosecond switching times. However, their optical loss is too high to allow cascading multiple switches.

Insertion Loss:

The insertion loss of a basic analog fiberoptic link varies between 20 – 35 dB, depeding on the quantum effiecency of the laser and photodiode (see Section 2, Fiberoptic Link Design Guide). There are, however, techniques to reduce this value should the need arise. Reactive input and output matching has been used successfully to transform the low impedance laser and high impedance photodiode to 50 ohms. This reduces the insertion loss by illiminating the mismatch effect without losing power in resistive elements. Reactive matching is generally not practical for bandwidth exceeding one octave, and it works best for ralatively low bandwidths, say 10 – 20%.

The laser to fiber coupling efficiency is another source of loss. Common coupling efficiencies are 75 – 85%. By increasing this value, the link loss is also reduced. Since the photodetector acts as a square-law device, every 1 dB improvement in optical coupling efficiency reduces the link loss by 2 dB.

For broadband reduction in the loss of the delay line, microwave lasers with built-in optical isolators are used. Because the isolator blocks noise-producing optical reflections back into the laser, the laser to fiber coupling efficiency can be substantially increased. Standard devices now are available that provide a 10 –15 dB reduction in the loss of the delay line.

Packaging:

Figure 7 shows a typical package for a microwave laser or photodiode. Each delay line contains two such packages, supporting bias control circuits, and a spool of fiber. Internal fibers spools can be up to six microseconds. Without these basic elements, a fairly compact enclosure can be obtained.

Figure 8 shows an example of such an enclosure, suitable for design where space is limited, while Figure 9 shows a 19 inch rack mountable version for delays in excess of 280 microseconds. When using the rack mountable version the 5017 transciever is not needed. It is replaced with a Wideband MW DFB Laser and Wideband Photodiode

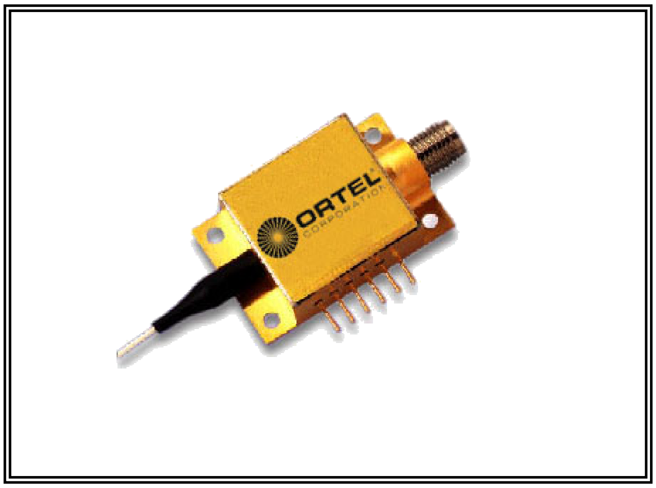

Figure 7. Microwave Laser Package. These modules are hemetically sealed and feature a SMA RF connector and a single mode fiber pigtail

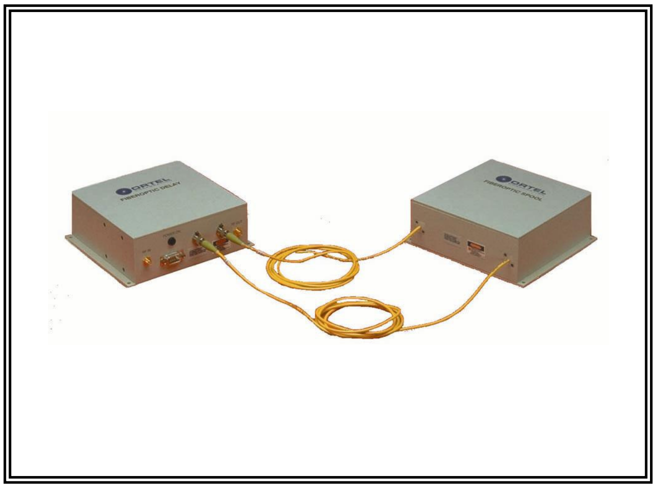

Figure 8. Fiberoptic Delay Line. The unit shown here is 10 GHz, 6 microsecond delay. The RF input and output connectors are standard SMA.

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Because of the unique properties of optical fiber, namely flexibility and immunity to RFI and EMI, systems could be built with the delay spool removed from the laser and photodiode, connected by a thin strand of fiber.

Figure 9. Rack Mountable Fiberoptic Delay Line. The unit shown here is 10 GHz, 280 microsecond delay. The RF input and output connectors are standard SMA.

Environmental and Reliability Considerations:

The basic laser and photodiode packages are quite rugged and capable of withstanding considerable shock and vibration without damage. For instance, Ortel a division of EMCORE, qualifies each module to MIL-STD-883, humidity qualifications to MIL-STD-810D and RF performance to -40°C to +70°C. The reliability of 1310 nm fiberoptic components has improved dramatically in recent years. Improvements in processing techniques and laser chip design have increasedboth yield and operating life. Extensive life testing has established the lifetime of laser chips at > 1 million hours when operated at room temperature. The photodiodes are longer lived, as the result is a highly reliable electronic system. Including all of the supporting electronic, fiber delay lines have an MTBF of around 200,000 hours. Fiber coupling techniques have improved tremendously so that laser fiberoptic links are available that can survive and operate in harsh conditions.

RF Performance

A typical amplitude time response of a 18 GHz delay line is shown in Figure 10. The response is purely a function of the combined laser and photodiode response for all but very long delays and very high frequencies (> 30 microseconds and > 10 Gigahertz) where effects of chromatic dispersion in the fiber start becoming noticeable.

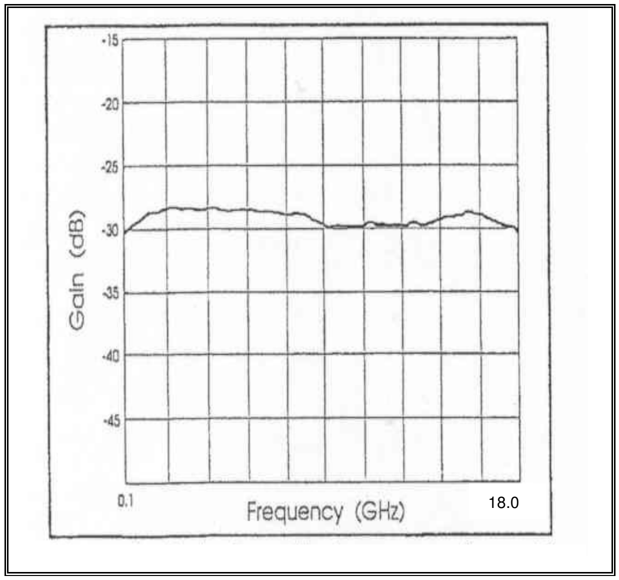

Figure 10. Typical amplitude response for a 18 Gigahertz fiberoptic delay. This response charcteristic is vitually independent of delay time.

By the use of distributed feedback (DFB) lasers long delay dispersive effects are minimized. These lasers have a single spectral line and thus virtually illiminate dispersion.

Unlike acoustic wave devices, the insertion loss is *not* a function of relative bandwidth or time spurious level. In fact the triple transit signal can be < -100 dBc. Figure 11 shows the time domain response of a 2.5 microsecond delay. The marker indicates where the triple transit signal. Clearly it is beyond the resolution of the

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analyzer, or < -70 dBc. The signal is very low because of the very low optical reflections from the photodiode as well as the optical fiber splices.

Figure 12 shows the phase response for a 10 Gigahertz fiberoptic delay line. The phase increases be low 1 Gigahertz because of the blocking capacitor at the input and ouitput. The phase response starts to roll off as it approaches the lasers relaxation oscillation frequency (around 8 GHz for the particular unit shown). However, the phase varies slowly with frequency as shown in Figure 13 (group delay is the slope of the pase response as a function of frequency). As the figures indicates, the delay remains very constant well beyond the rated bandwidth of the device. In fact, the delay time is determined solely by the length of the fiber. Therefore, even long delays can be produced with tolerances on the order of 5 nanoseconds (1 meter of fiber).

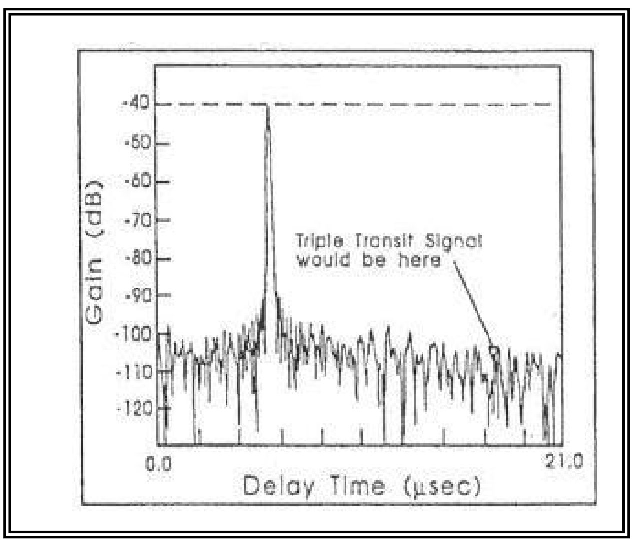

Figure 11. Time domain response for a 6 microsecond delay. The triple transit signal is practically un-measurable and remains so independent of bandwidth or delay time.

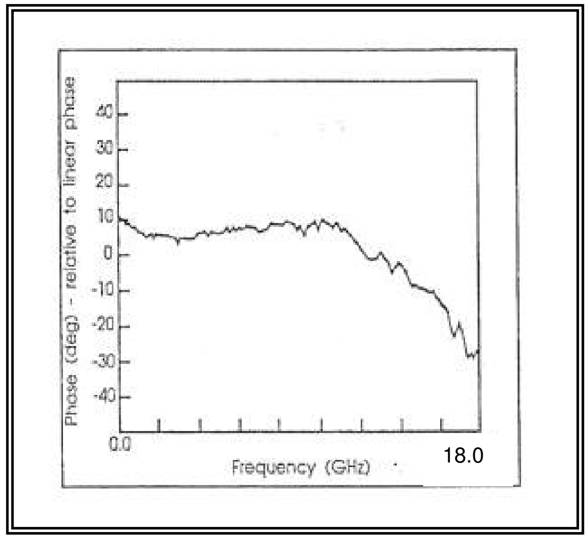

Figure 12. Phase response for a 18 Gigahertz fiberoptic delay. Multiple fiberoptic delays can be tuned to track each other in phase.

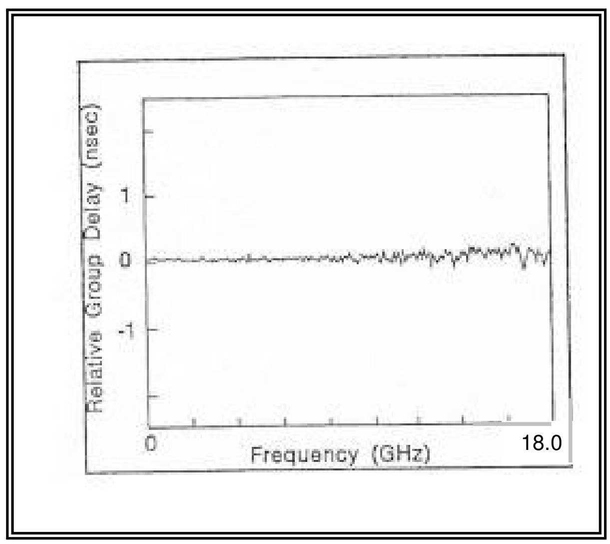

Figure 13. Group delay response for a 18 Gigahertz fiberoptic delay. The delay time is purely a function of the length of the fiber

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Another feature of fiberoptic delay lines is that tesing indicates that a simple tuning procedure during manufacturing will produce delays that closely track each other in amplitude and phase as a function of frequency – an important requirement for a number of EW applications.

The dynamic range of a device is limited by noise at low RF power and linearity at high power. The dynamic range for a 10 Gigahertz fiberoptic delay line is about 60–80 dB / Megahertz measured from the noise floor to the 1 dB compression point depending mostly on frequency. The dynamic range is fairly constant over range of delay. For short delays (< 20 microseconds) the laser noise is the limiting noise, whereas for longer delays optical backscattering noise, mode partion noise (a result of dispersion in the fiber), receiver thermal noise noise at the output limit the sensitivity. For long delays, lasers with built-in isolators can eliminate backscattering and reduce the receiver noise contribution. Photodiode reactive matching techniques at the photodiode output can further reduce the noise and loss of the delay line over less than single octave bandwidths. Distortion limits the maximum usable power input RF power. The input 1 db compression point is typically +13 dBm with input third order intercept point at +20 - +30 dBm.

Summary

Optical fiber is a compact, lightweight transmission medium with exceedingly low loss and high bandwidth. The limitations that do exict are due to the laser source and photodiode receiver. However, the reliability and microwave performance of the devices has improved tremendously over the past few years. Now, by packaging these devices with the fiber as a delay line, performance levels are achieved far beyond that of other technologies for the same size and weight. With fibers that can withstand very small bend radii and lasers with performance to 18 Gigahertz the fiber delay lines can be made smaller still. Even now, fiberoptic delay line are especially suited for applications requiring long delays, wide bandwidths, extremely low spurious, and small size and weight.

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