Alternative Fiber Optic Conductor For Laboratory Practices.

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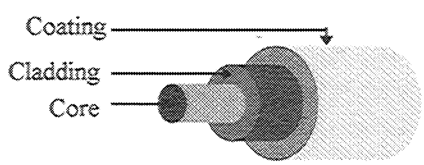
Abstract

Due to the high cost and difficulty in obtaining a optical fiber sample to be used in laboratory tests, we have given ourselves the task of looking for an adequate optical-fiber alternative for laboratory practices. We have as a result, found an object that can be used as an alternate optical conductor. This object called *"Venoclisis Hose"*, is a cylindrical plastic tube, hollow inside, whose main use has been in medical applications as a conveyor of liquids going in or coming out of the human body. In this document, the tests carried out and the results obtained to characterize the venoclisis as an optical fiber are described. This project was undertaken in order to propose the use of Venoclisis as an alternate optical fiber for laboratory work, due primarily to its low costs, as well as how easy it to acquire and measure its parameters as an optical fiber.

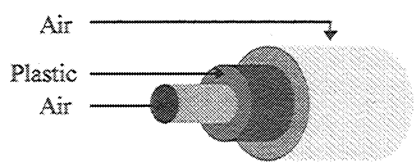
Keywords: Venoclisis Hose, Optical Fiber, Alternative Optical Fiber.

2. The Venoclisis Hose as an Optical Fiber.

The Venoclisis hose is a small plastic tube utilized in medicine as a means to transport liquids, such as intravenous solutions, blood serum, antibiotics, etc. To compare Venoclisis as an optical fiber we must take a commercial optical fiber which consists of a core, cladding and coating. The Venoclisis hose is an equivalent optical fiber with the same characteristics distributed as follows:



Commercial Fiber Optics



Venoclisis Hose

This fiber's optical characteristics are found with an air core. This core will be later filled with other substances different from air (water and liquid silicone), to also find its optical characteristics.

3. Air-Core Venoclisis Hose characterization

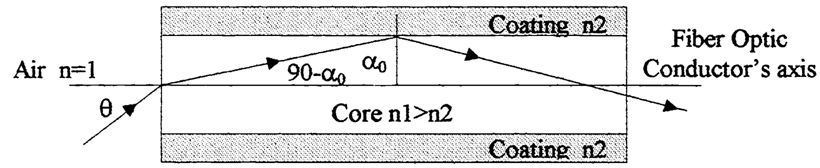
Transmission parameters of a fiber optics cable not only depend on the fibers themselves, but on the cable's laying, the cable's stranding, weather conditions cable coupling, etc. To characterize the Venoclisis we begin with an uncoiled cable, the working temperature is room temperature (25° C) and there are no couplings on the cable.

Though to determine the fiber's transmission parameters we must keep in mind not only the intrinsic natural mechanisms but also those that depend on the manufacturing processes as well, we, however only have at hand those analysis and tests that are done to the fiber in its physical mechanisms (of intrinsic nature). Those kinds of tests are the ones we shall describe next to characterize it.

The following are a Fiber Optics Conductor general characteristics.

3.1 Numeric aperture measurement.

Total-internal-reflection effect in fiber-optic conductors is utilized to transmit the luminous light in virtue of the fact that these conductors have at their center a core with an n_1 refractive index and, being coated in a layer with an n_2 refractive index.



Total-Internal-Reflection

Figure 1

All luminous light with an incidence angle less than (90° -αo) with respect to the optical fiber axis is conducted through the core.

For an external light to travel through the core the angle must meet Snell's refraction law, and taking into account the condition of the limit angle $\alpha o = n_2 n_1$ the following equation is obtained:

$$\mathrm{sen}(\theta) = \sqrt{n1^2 - n2^2} \qquad (3.1)$$

The acceptance angle sine (θmax) is called numeric aperture (NA). NA = Sin (θmax) and the following approximation was carried out to find it:

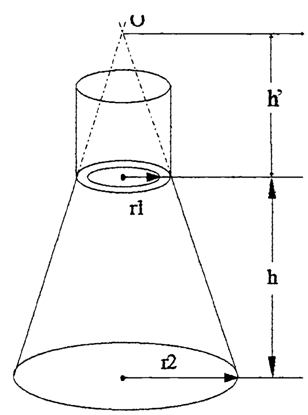


Figure 2

To calculate the numeric aperture the cone with vertex in h' is found above the Venoclisis edge, thus total height will be h_{total} = h + h'. If we calculate h_{total} (as will be seen later on, it depends on the incidence-light wave length) and the slope generated by this cone, we obtain the numeric aperture in function of these physical characteristics:

$$h_{Total} = \frac{-h}{r2 - r1} * r2 \qquad (3.2)$$

And this height is used to calculate the numeric aperture NA (depending on the wave length):

$$AN = \frac{r2}{\sqrt{r2^2 + h_{Total}^{\ 2}}} \qquad (3.3)$$

3.2 Fiber refraction index measurement (n_1).

The fiber (plastic) refraction index is found taking as parting point the refraction index of air and the fiber's numeric aperture, as follows:

$$n2(\lambda) = \sqrt{AN(\lambda)^2 + 1.0029^2} \qquad (3.4)$$

3.3 Attenuation measurement (α_{total})

The light that propagates through an optical fiber conductor experiments an attenuation, which produces a loss of energy. This loss of energy depends on the light wave length. That is why to determine the adequate different wave-length scales for optical transmission with low attenuation, it is better, as a general rule to measure an optical fiber conductor in function of the wave length. To find the attenuation the cut-back method was used, where the optical power is determined at two points L_1 and L_2 on the fiber. The attenuation coefficient α (in dB/cm.) for the optical fiber conductor is calculated with the expression:

$$\alpha = \frac{10}{L2 - L1} * Log(\frac{P(L1)}{P(L2)}) \qquad (3.5)$$

For venoclisis lengths of L_1=4.16 cm. and L_2=9.8 cm., the attenuation was measured at L_1 and L_2 using the following circuit.

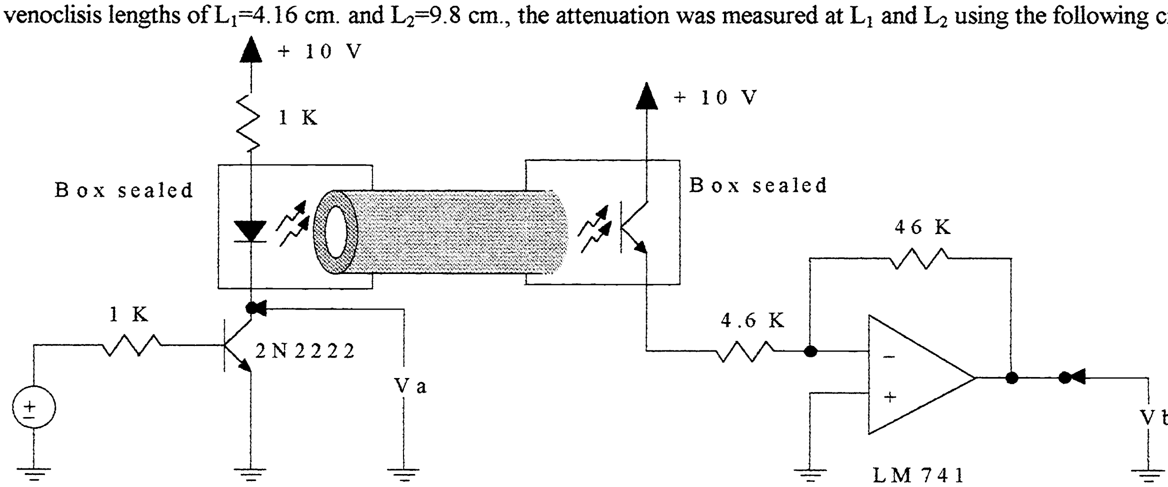


Figure 3

The attenuation was measured for different frequencies, this way the characteristic attenuation curve in function of the frequency is achieved.

3.4 Parameter calculation of the hose as optical fiber.

An optical fiber scattering variables such as scattering in the wave guide (σwave), the modal dispersion (σmod), the Material's dispersion (Mo(λ)), the Chromatic Dispersion (σc) and Total Dispersion (σtotal), parameter V, number of N modes, group velocity (Cg), group time (tg), group refraction index (ng) and Band width (BW) were calculated with conventional multi-mode commercial-optical-fiber equations. The results were in function of the optical transmitter frequency.

4. Tests done on a venoclisis hose.

Work was undertaken on a venoclisis fiber using the measurement procedures described above, converting the solid part of the fiber into a cylinder with a radius equivalent to the average of the venoclisis' two radii (external and internal). The spectral width values, air refraction index, etc. were obtained from the data sheets of the items utilized. To calculate the numeric aperture, three different radius were obtained measuring the height or distance from which the circle's fiber's end is located, the above in order to average the final numeric aperture and thus obtain a more precise NA. To characterize the frequency numeric aperture three LEDs Green, Yellow and Red were used. A special measurement was taken for the Infrared LED using the trial and error method to look for a predetermined height in which the phototransistor still receives a signal.

5. Analysis of the results obtained from the Venoclisis Hose characteristics.

It was established that the Numeric Aperture increases as wave length increases, with an infrared maximum (900 nm) and a minimum for the green LED (548), see figure 4.

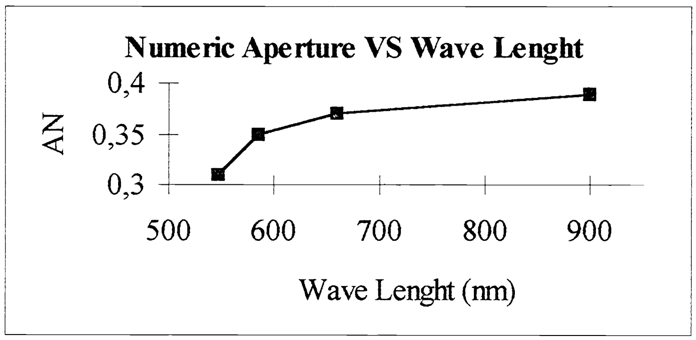


Figure 4

As can be seen the acceptance angle varies approximately 5 degrees for the used frequency range. This difference seems small, but it was practically established that these 5 degrees were indeed important at the moment of coupling the LED to the venoclisis, keeping in mind that the color LEDs had to be very well coupled so the light could be transmitted adequately. For the infrared LED, however, this coupling did no have to be as perfect, which permitted a small LED deviation range with respect to the venoclisis. This is an indication that the fiber will conduct more efficiently as wave length increases.

The characteristic obtained from attenuation in function of the frequency (figure 5) shows how good a light conductor the venoclisis is, letting us know the attenuation the signal will obtain. Attenuation decreases as wave length increases. The results obtained show that the least attenuation happens when the infrared LED is used; for the other LEDs, the attenuation is too great, making it impossible for these to be used for signal transmissions in lengths greater than 10 cm.

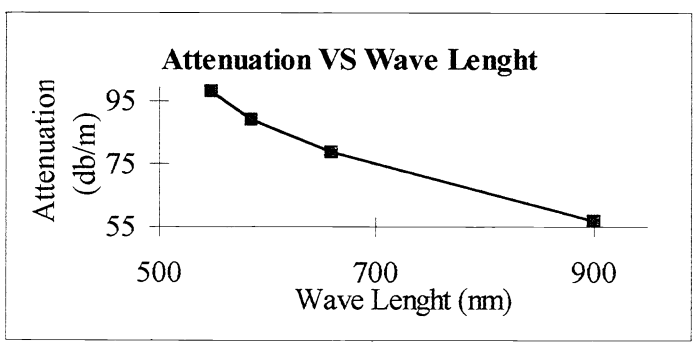


Figure 5

A 0.58 dB/cm. attenuation was obtained for the infrared LED. Though it is the lowest attenuation in the curve, it is nevertheless a high value for it to be used in long distance transmissions. Good reception levels were obtained for a 30-cm-long venoclisis. This value, however is too low if the idea is to use the venoclisis as an efficient transmission line. There is the possibility to improve reception levels using better incoming-signal amplifiers, to attempt increasing this length to at least one meter and in any case, with small, low cost, intermediate repeating systems a data transmission system for short distances could be developed (For example a computer room internal network) which would permit good communications between terminals. It was established that when working with shorter wave-length LEDs, the venoclisis increased its sensibility to curves and deflections produced when pressure was applied to its surface.

It was observed that the quantity of modes that propagate through the venoclisis is very great. This helps explain the reason why the great attenuation values; the greater the number of modes the more energy necessary to transmit all these modes, since each mode consumes energy to be transmitted.

The results obtained in the band width (figure 6) shows the amount of information that can be sent through a venoclisis conductor. Studying the figure, it can be seen that the band width of a venoclisis used as an optical fiber is great. It presents a maximum in 6.5 GHz for the wave length corresponding to the green, and a minimum of 4.1 GHz for the infrared. This figure is the reverse of the total attenuation, which had shown a minimum attenuation for infrared and a maximum attenuation for green. Nevertheless the venoclisis band width is good to establish a communication line with it, since it would permit voice and video signals, as well as digital computer signals using standard serial communication speeds, etc. As established, for wave lengths lower than infrared's, the venoclisis attenuation level does not permit efficient data transmittal, it is preferable then to sacrifice those 2.5 GHz difference between green and infrared and transmit using an infrared LED.

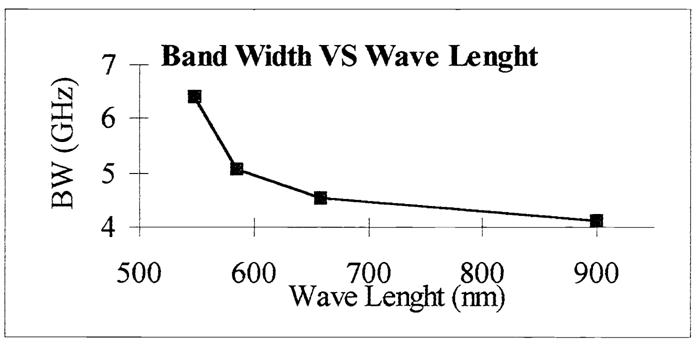


Figure 6

6. Analysis with other cores (Water and Liquid Silicone).

Once the air-core venoclisis-hose parameters were obtained, ways to optimize its characteristics as optical conductor were investigated. To this end water and liquid silicone were poured in its interior to see if this would improve its characteristics as optical conductor. The venoclisis hose was subjected to the same tests it had been subjected to when its interior was only filled with air. The following was obtained:

Encouraging results were obtained observing the refraction index. The core's refraction indexes in function of the wave length, agree with water's theoretical refraction index (1.33 at room temperature). This shows that procedures followed up to now to parametrize the venoclisis have been correct, and that the method used to measure any core's refraction index in a venoclisis, can be used to determine the refraction index of any element with very valid results.

But the other results obtained, demonstrated that instead of improving, characteristics as an optical conductor worsened, not only when water was used but also when liquid silicone was used. Attenuation increased considerably, as well as the number of modes, parameter V and band width decreased.

Using water as core is significant, since as can be seen, in nature water is the compound which has a refraction index greater than air at room temperature (around 1.33). This assures us that a representative sample was taken for the tests. Analyzing the results obtained, it can be said that the core that makes the venoclisis hose behave more efficiently as an optical conductor is air, and there is no other element that could help improve its characteristics as optical conductor.

7. Characterization of a Plastic Multi-Mode Optical Fiber and comparison with an Air-Core Venoclisis Hose.

In item 2 we described and talked about the parts and functions of a venoclisis hose fiber and how it could be used as an optical fiber. As mentioned before, the venoclisis fiber has a plastic cladding which in some tests was used as cladding and in others as core.

The question is: If the venoclisis fiber were to be a solid cylinder with the same volume and length of plastic, as it has being a hollow cylindrical tube, would it behave as a conventional graded index multimode optical fiber? Are the results obtained with this fiber the same as those obtained with an air-core venoclisis? And lastly, can an air-core venoclisis hose be considered an optical fiber?

The intention in this item is to answer these questions characterizing the plastic multi-mode fiber and comparing it to an air-core venoclislis hose.

To characterize the plastic fiber the following parameters are held: L_1 = 9.8 cm, n_2=1.0029, λ = 659nm, r1=0.165mm , r2=0.195mm. To find the radius equivalent to the volume occupied by the air-core venoclisis fiber, we begin with the following:

The cross section occupied by the air-core venoclisis fiber will be the same area as that occupied by the plastic fiber, this can be seen better in the following figure:

The results obtained lead us to conclude that the supposed solid plastic fiber has an expected behavior as an optical fiber with respect to its physical parameters.

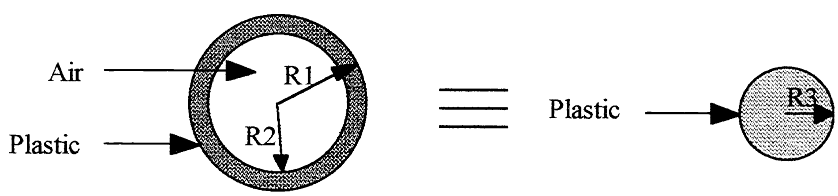


Figure 7

The results obtained, which directly depend on the fiber's radius (a) are well outside a multimode commercial fiber work range. However other factors such as band width, group parameters, etc., lead us to think that this fiber is acceptable for short distances and short work periods (with a very wide band width). The results obtained with respect to means of propagation indicate that this fiber "is very multi-mode".

It can clearly be seen that an optical fiber's parameters do not directly depend on the cross section's area or its form but on the radius associated to said surface. It can be concluded then, that the two fibers referred to in this item (air-core venoclisis hose and solid-plastic fiber) differ in their behavior as fibers even though they have similar physical characteristics (the same).

Depending on the application, the fibers behave differently, one may be very efficient for one application, while the other is not. This is the case when one fiber is used as an angular-position measuring parameter. In this instance the venoclisis hose is very well adapted due to its great bending sensibility.

If an air-core venoclisis hose is compared not only in its frequency (wave length) behavior but in all its parameters with a typical multi-mode optical fiber, it can be seen that the curves correspond in their form, the only difference being that said parameters are useful in the applications the fiber is to be used in.

8. Conclusions and Observations of the Investigation.

In this item we will work with all practical observations done during the test design process, during data gathering or during the mathematical modeling, which have not been included in previous items. Very important aspects are studied here, such as: Losses due to curves, safety measures that must be taken with the fiber, other loss factors, couplings, etc.

As this paper is being written, tests to prove practical applications that can be done using a venoclisis hose as an optical conductor, are being carried out. We will lightly touch here, on the description of these applications, since we still do not have sufficient laboratory data which would permit us to ensure that the applications described here work well. But we are sure, and our efforts are focused in this direction, that at the end of our investigation we will obtain results which will permit us manufacture with great precision, laboratory equipment such as curve and weight sensors inexpensively and easily.

8.1 Losses due to curvature and venoclisis deformation.

When the venoclisis-produced total attenuation was analyzed, neither losses due to curvature and deformation nor due to couplings, were taken into account. Even though we did not delve on attenuation-producing factors, some observations were made which will be of great importance in practice when some application using this type of fiber is to be undertaken.
Theoretically it is known that every optical fiber has a minimum-curvature radius which allows light to go through depending on the way light is transmitted inside the fiber (total internal refection). This curvature radius is very important, since in a data-transmission system in which an optical fiber is used as transmission line, it is always difficult to encounter long stretches without bending or detouring the transmission line. That is why it is important to know the losses that happen when there is a curve in the fiber.

In our case we could observe that this curve had great influence in total fiber attenuation. The data which would permit us establish a statistical figure or mathematical formula binding attenuation with fiber curvature are still under study and are therefore not included in this writing.

It was further discovered that when the fiber was bent, the pressure applied made the light beam on its walls deflect, which in turn produced attenuation. This is of great importance since we realized that attenuation also depends on the venoclisis never losing its cylindrical form, and that small pressure on its surface caused it to bend, immediately attenuating the signal arriving at the receptor.

8.2 Technical precaution measures to be had when using a Venoclisis Hose.

These safety measures are taken so there is a better data transmission through the venoclisis, and to somewhat protect its physical structure.

As said before, curves and pressures on the venoclisis produce attenuation of the signal being transmitted through it. Thus if it is to be used as a transmission line it should have no curves nor suffer any pressures anywhere along its length. If none of these characteristics can be avoided, the transmitter must have enough power so the signal after attenuation reaches the receiver with sufficient power.

Theoretically it is accepted that an optical fiber is not affected by electromagnetic noise present in the environment, it was shown that outside light radiation, affects data being transmitted through the fiber. The following test was done: *As a 1 KHz square signal was transmitted through a length of venoclisis a neon lamp was slowly brought closer to it. It was observed that as the lamp came closer to the venoclisis, the data in the receptor suffered deformations. This showed that the venoclisis is not immune to outside radiations.*

Furthermore another test was carried out to find out if the venoclisis itself emits radiations. The test was as follows: The same transmission conditions from the previous experiment were used. A phototransistor was put on and around the venoclisis and it could be seen that the phototransistor did indeed receive a signal. This test was carried out in a darkroom using the red LED as transmitter, in order to make sure the phototransistor would not receive light from a source other than the venoclisis.
The solution suggested to these two problems is to cover the venoclisis with a dark coating, to block light from going in or out. This coating could be of a solid hard substance to prevent radiations from going through and at the same time protect the venoclisis from external phenomena which may damage it physically.

To test the previous hypothesis we covered the venoclisis with black electrical tape. This tape provided the necessary insulation against radiations as was observed when the above mentioned tests were conducted again. The data were not affected by the neon lamp, nor was any radiation received by the external phototransistor. Likewise, the tests used in the venoclisis parameterizing were repeated and the same results were obtained as when no covering had been used.

Another aspect to be kept in mind is that the venoclisis is made of plastic material which is not a very resistant to adverse environmental factors. Care should be taken with the temperature in the room where the venoclisis is used. At normal room temperatures there is no danger, but if installed in industrial areas, care must be taken if it goes near ovens or boilers, since plastic melts at high temperatures (near 90° C). Furthermore plastic can break easily, thus neither heavy nor sharp objects should be permitted to fall or come in contact with it to avoid damaging it.

8.3 Couplings and other losses.

The connector joint between the LED transmitter and the venoclisis and between the venoclisis and the receptor was done in a closed and dark wooden box, built by ourselves. The LED and phototransistor axis were aligned with the venoclisis axis, permitting maximum transference of the luminous intensity between one and the other. In the analysis, coupling losses were not considered due to the way in which we carried out the attenuation measurement, which was already described in a previous item. This is valid since we are taking measurements with which we can interact; but in the case of setting up a transmission line, improvements on this coupling would have to be made, making sure the sealed box where the coupling is being done, meets minimum technical specifications for coupling losses.

Furthermore, the sealing method to keep the liquid core inside the venoclisis (water and silicone), produced losses, since the stopper made light passage difficult. Besides due to the flexibility of the venoclisis, this stopper did not adhere entirely to the plastic walls, and if any pressure was applied at the ends, it could come off. A glass stopper could be used which would allow the passage of light but care would have to be exercised on how to adhere it to the plastic, and in its fragility since it would have to be a very small and thin glass disk (.39 mm. in diameter).

8.4 Applications

This is perhaps the most important item in our investigation; in it the main applications deduced in the entire project are highlighted. The following are the applications we have been able to find:

8.4.1 Data Transmission Line.

As can be seen, the venoclisis acts as a transmission line which works at wave lengths near and within visible light. It can be considered as a multi-mode optical fiber with graded index, with solid plastic core, with air cladding and as suggestion with solid coating which avoids light passage and protects it from adverse environmental conditions. If used as line transmission, wave lengths near infrared must be used, since it is here where less attenuation occurs. Distances between transmitter and receptor must be small, somewhere around 30cm. We assume that improving the transmission system, its power and sensibility, sections of at least one meter may be achieved.

Perhaps this is not the best way to use the venoclisis, but in any case it constitutes an alternate transmission line with a good band width, low distortion and good immunity to electromagnetic noise. Its main application as transmission line lies in its use in very noisy environments (electrically speaking), where purity of data is necessary, with no interference. For example, communication can be achieved between electronic equipment found in industrial environments with large noisy machinery, in environments saturated by radio-frequency waves which can affect any two-phase or coaxial equipment which use it as antenna. Furthermore it permits analog and digital data transmission, in both cases very efficiently.

8.4.2 Measuring instrument to determine refraction indexes.

Venoclisis can be used as a good, quick, simple and economic means to determine refraction indexes of chemical compounds. The method to be followed to achieve this, is identical to the method used when water and silicone core indexes were found. Comparing the water-core refraction index obtained, with water's theoretical index, we can see that the practical results are very near the theoretical ones. This assures us the venoclisis' efficiency if used to measure refraction indexes. A small station could be installed in chemical laboratories to carry out these measurements. The cost would be very low, especially when compared to commercially available instruments that carry out these tests.

8.4.3 Deflection-angle sensor.

Contrary to the transmission line where an infrared LED must be used, here a visible-light-working LED must be used, preferably a red LED, which is the one that less attenuation presents and which has very good sensibility. In a previous item, we explained that the signal traveling through the venoclisis suffered great attenuations for very small curves over its axis.
Contrary to what can be thought, this could be greatly beneficial if it were to be used as a sensor to measure angles or curve radii. An example of this type of application could be in medicine and inclusively in industry, where a moving object (such as a human or robot hand) could be covered with venoclisis, adapting it to the form of the object being covered. If the object were to move, for example a bending finger, the venoclisis would also curve, producing an attenuation which would be proportional to the bending angle. This method is currently used in virtual reality, where an optical fiber is used to measure the curvature of each finger.

8.4.4 Weight sensor

We also saw in curvature loss analysis, it was uncovered that the signal attenuated when the venoclisis was deformed. This can be used as a small-objects weight sensor. With this sensor a digital scale for light weights could be built, since a proportion could be established between the force exerted on the venoclisis walls and the signal attenuation traveling through it.

8.4.3 Optocouplers.

It is well known by all that the need to electrically isolate certain circuits, in case a short occurs on one side of the circuit it won't be transmitted to the other where there could possibly be delicate and costly elements. Such is the case with the PLC and computers with which a controlling action is carried out with a peripheral circuit. This isolation can be achieved by means of an optical coupler between the peripheral and the PLC or the computer. If there is a short circuit or an overvoltage in any of the circuit ends and since they are optically coupled with no common connecting line for either of them, the other end of the circuit is protected. This coupling could be easily done between an infrared LED and a phototransistor putting one in front of the other without the need for special light transmission means. Using a venoclisis this connection can be done even if there is physical space separiting transmitter and receptor, besides it can be insured that the phototransistor is not activated by any other external luminous signal, improving coupling conditions.

8.4.6 Light guide

It has been seen that when a visible light LED is coupled to one of the venoclisis extremes, light is reflected on its walls, and the venoclisis form, with the LED color can be observed as a florescent tube. This means the venoclisis could be used as small light guides in areas where darkness is necessary, to point out objects and inclusively the way from one place to another.

Though this might seem to be a simple application, it may be the one with the most commercial applications, since it could be used as training systems in darkrooms, in advertising or as visible information systems, since a laser light could be simulated by this method (the venoclisis looks like a very defined laser-produced beam).

9. Conclusions

9.1 A venoclisis hose behaves as a multi-mode optical fiber with a graded index, conformed as follows: A plastic core, with air cladding for which a solid black material is suggested as coating to isolate and protect it from external light radiations.

9.2 Since the venoclisis is a hollow tube, it can be filled with some element to improve its optical fiber properties. Tests were carried out with air, water and liquid silicone cores and it was found it worked better with an air core.

9.3 The venoclisis hose is an alternate optical fiber to set up an optronics laboratory. Given its low cost and similar characteristics with a multi-mode commercial fiber, the latter's behavior can be simulated by the former, cheaply and creatively.

9.4 Thanks to its optical conductor characteristics, the venoclisis hose can be used in many and different applications, such as weight and curvature sensor, etc.

10. Acknowledgments.

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