(54) **OPTICAL FIBER TERMINATION USING A REFERENCE SOURCE**

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(57) **ABSTRACT**

Examples disclosed herein illustrate systems and methods to determine and evaluate the quality of mechanical splices of optical fibers using insertion loss estimation. In at least some of the disclosed systems and methods, an optical fiber termination system may include a reference fiber coupling a light source and a stub fiber of a fiber optic connector, a digital camera sensor and lens to capture images of scattered light emanating from a portion of the fiber optic connector and a portion of the reference fiber both in a field of view (FOV) of the digital camera sensor, and a processor. The processor may analyze digital images of scatter light emitted from at least a portion of the fiber optic connector and the reference fiber to estimate insertion loss at the fiber optic connector.
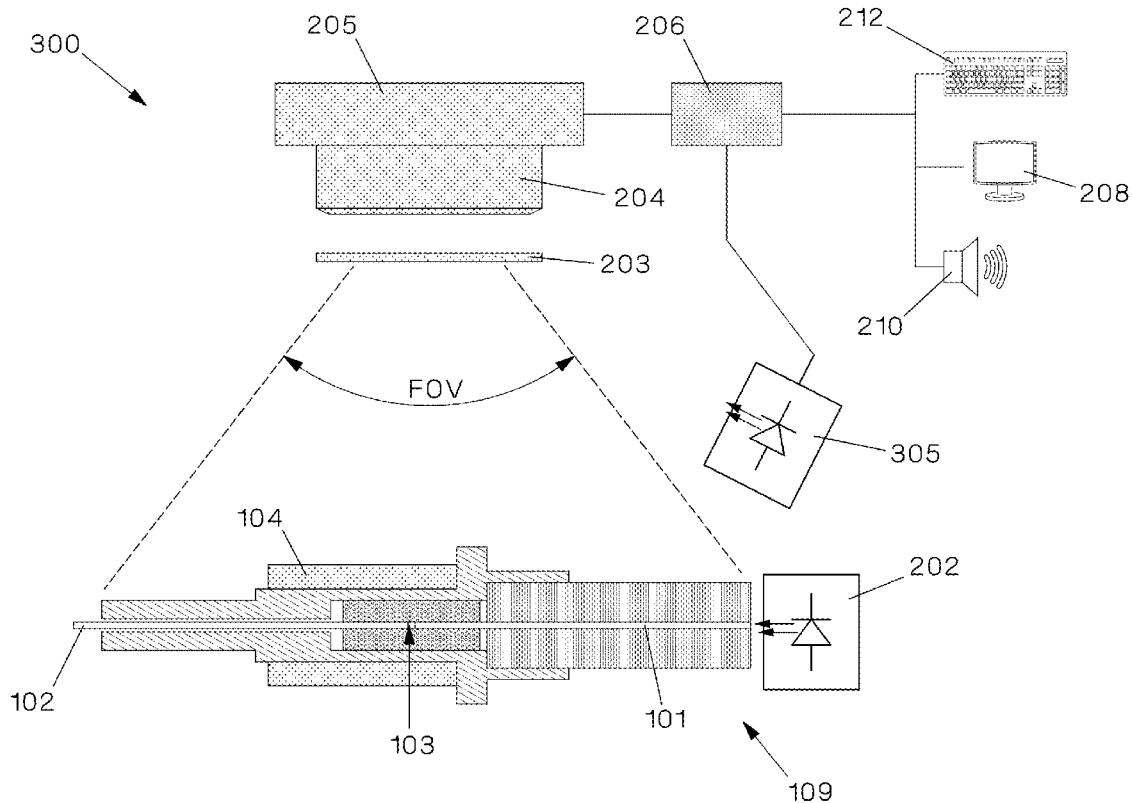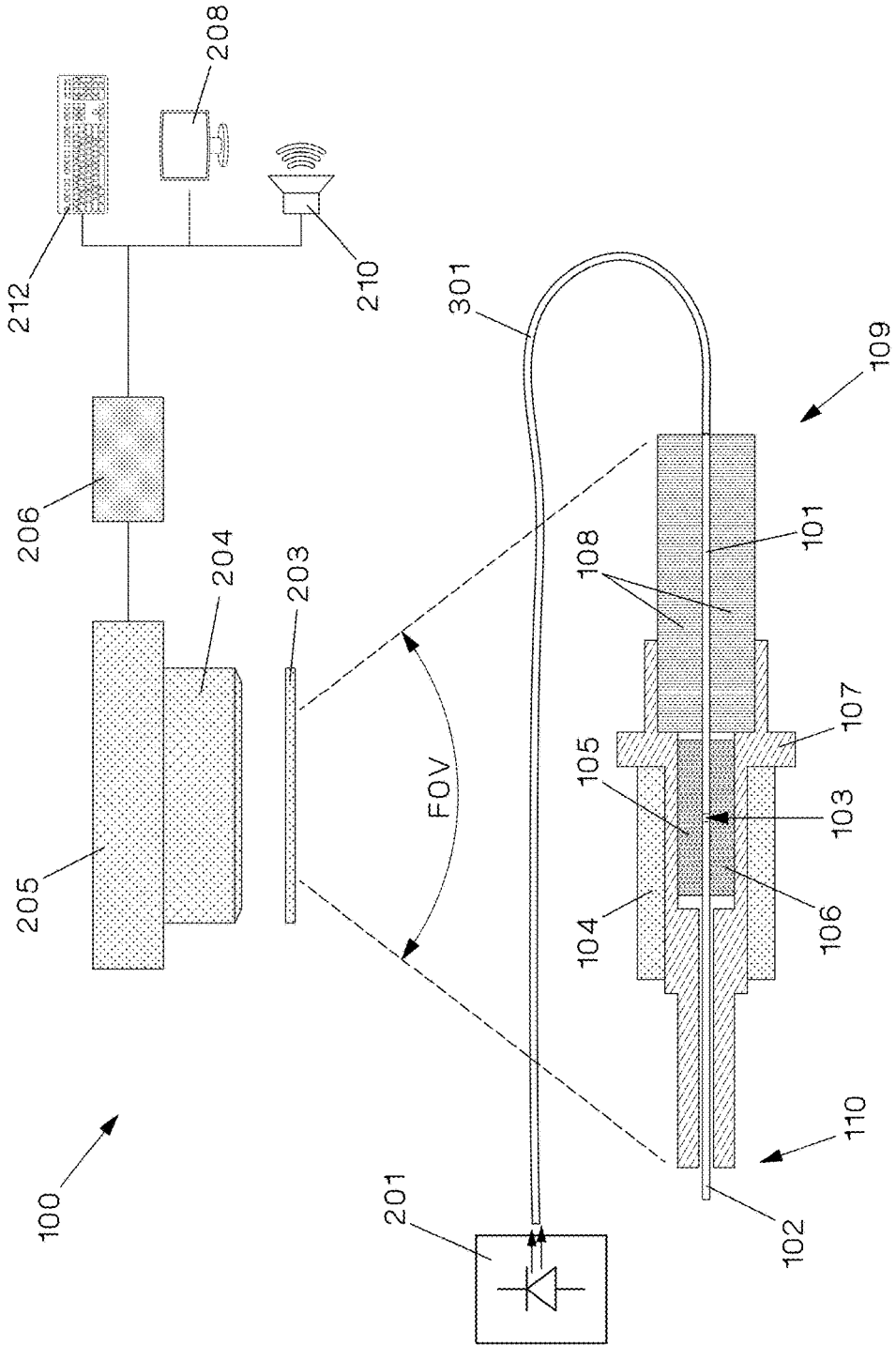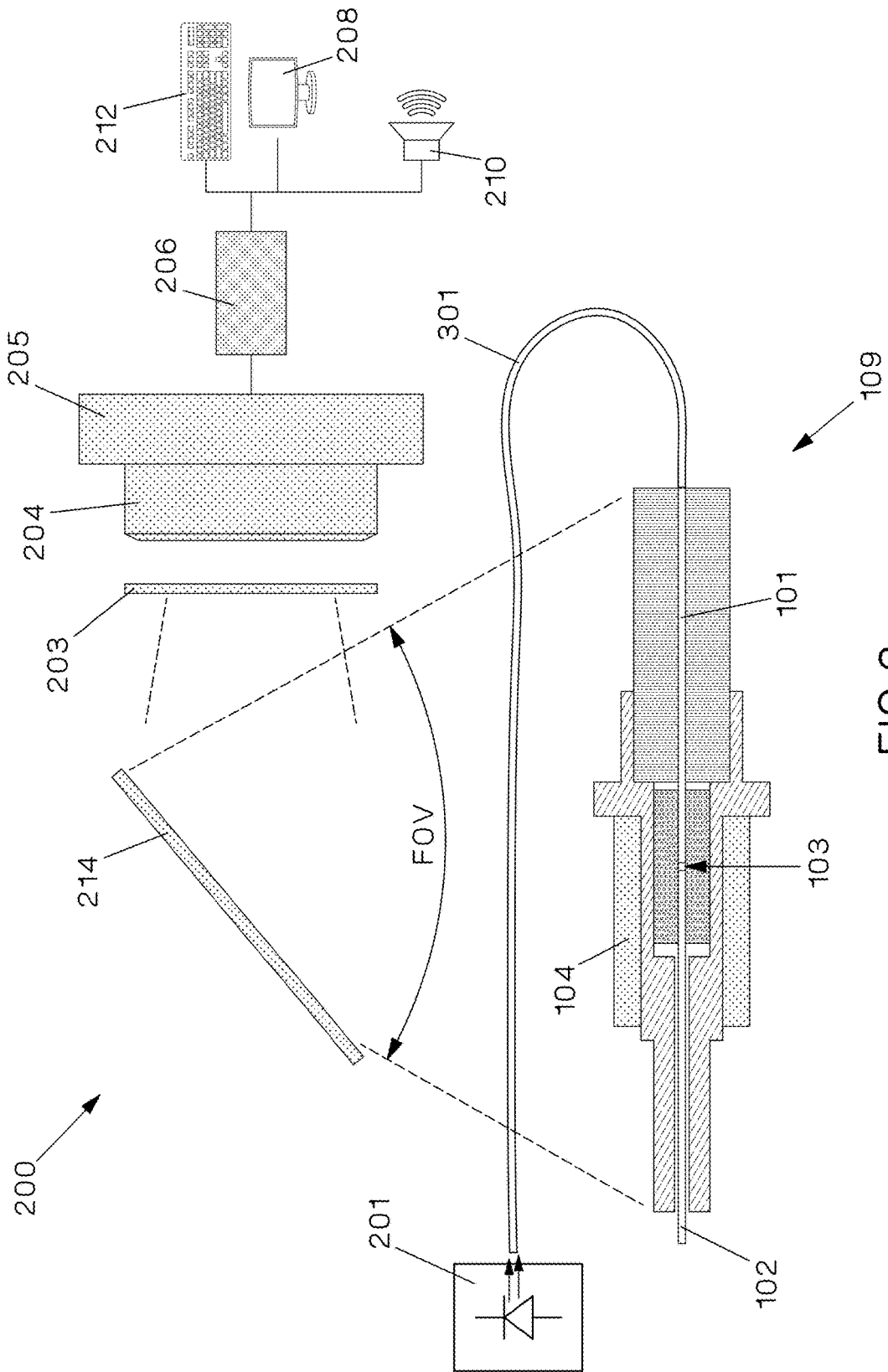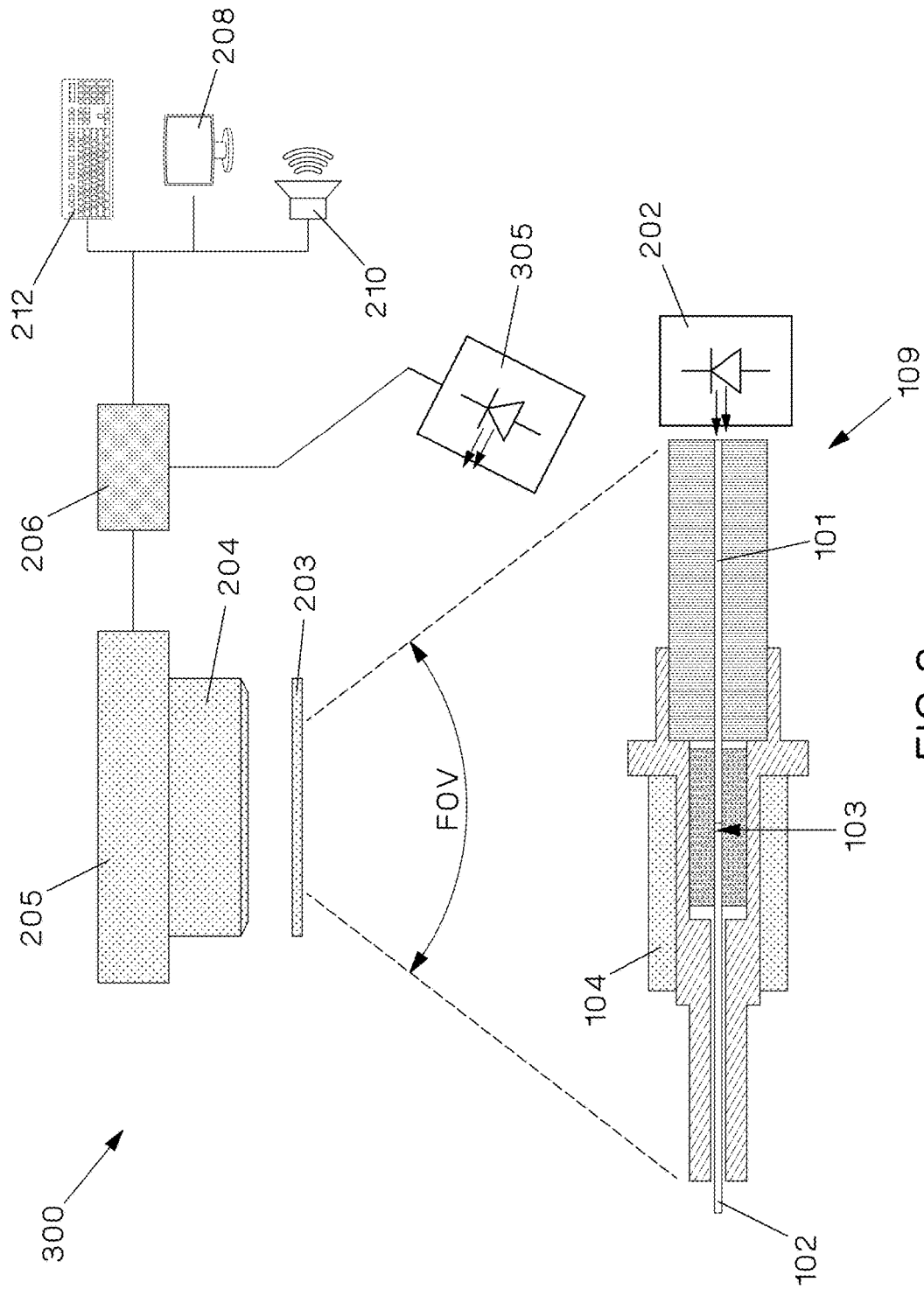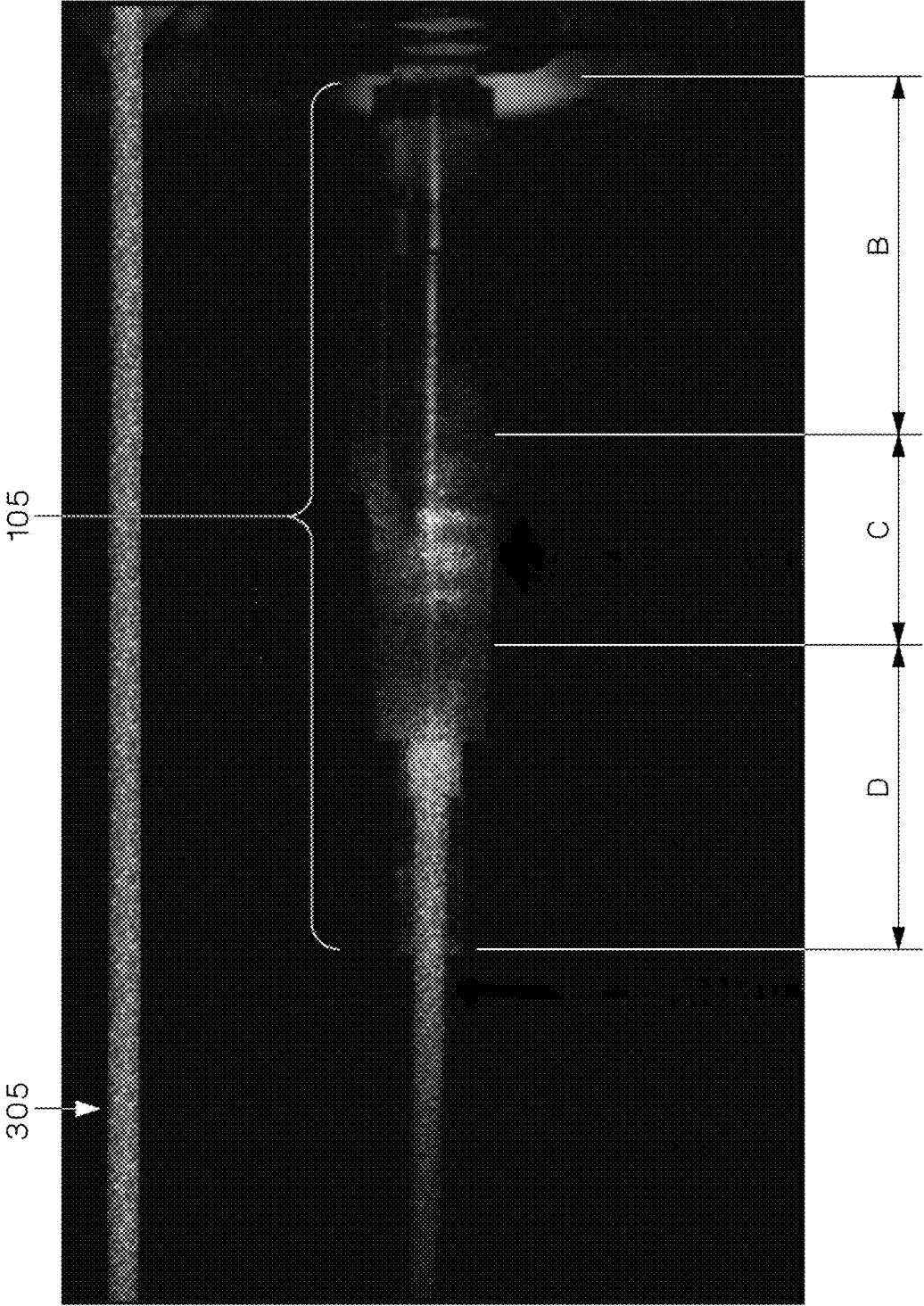
FIG.1

FIG.2

FIG.3

FIG.4

FIG.5

FIG.6

700

702

Prior to inserting the optical field fiber
into the fiber optic connector, capturing,
by a digital camera sensor, a first image
of scattered light emanating from a portion
of the fiber optic connector and a portion of
a reference fiber both in a field of view (FOV)
of the digital camera sensor

704

After fully inserting the optical field fiber into
The fiber optic connector but prior to
mechanically splicing the optical field fiber
to the stub fiber, capturing, by the digital
camera sensor, a second image of scattered light
emanating from the portion of the fiber optic
connector and the portion of a reference fiber
both in the FOV of the digital camera sensor

706

Estimating, by a processor, an insertion
loss value at the fiber optic connector based
on a spatial pattern of the scattered light in
the first image and a spatial pattern of the
scattered light in the second image; and

708

Presenting, by the processor on an electronic display,
the estimated insertion loss value and a pass indicator
in response to determining that the estimated insertion
loss value is less than a threshold insertion loss value.

FIG.7

800

802 — Capture image of
scattered light
prior to optical
field fiber insertion

804 — Insert optical field fiber
into fiber optic connector

806 — Capture second mage of
scattered light

808 — Estimate insertion loss

810 — Insertion loss
less thean
threshhold

Yes

No

816 — Display insertion
loss value and
pass indicator

818 — Complete
mechanical splice

808 — Remove optical
field fiber
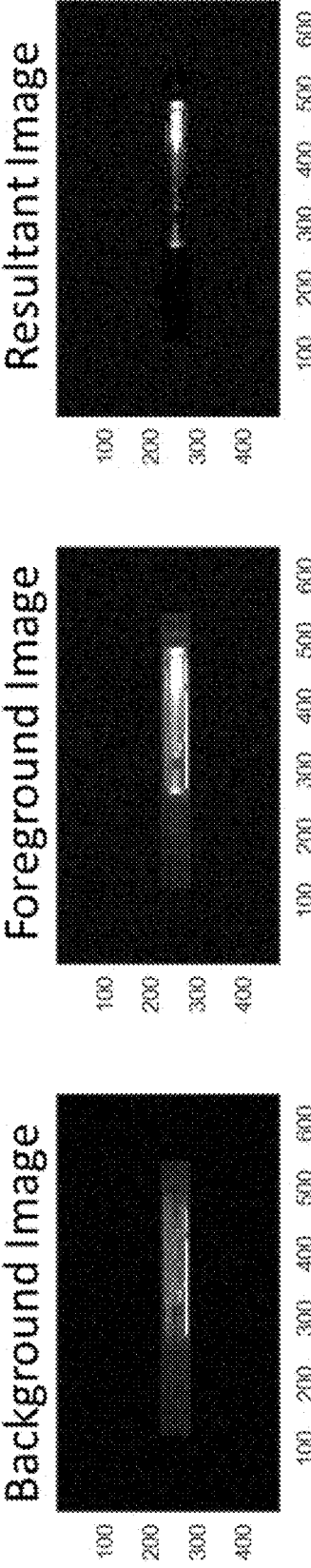
812 — Display insertion
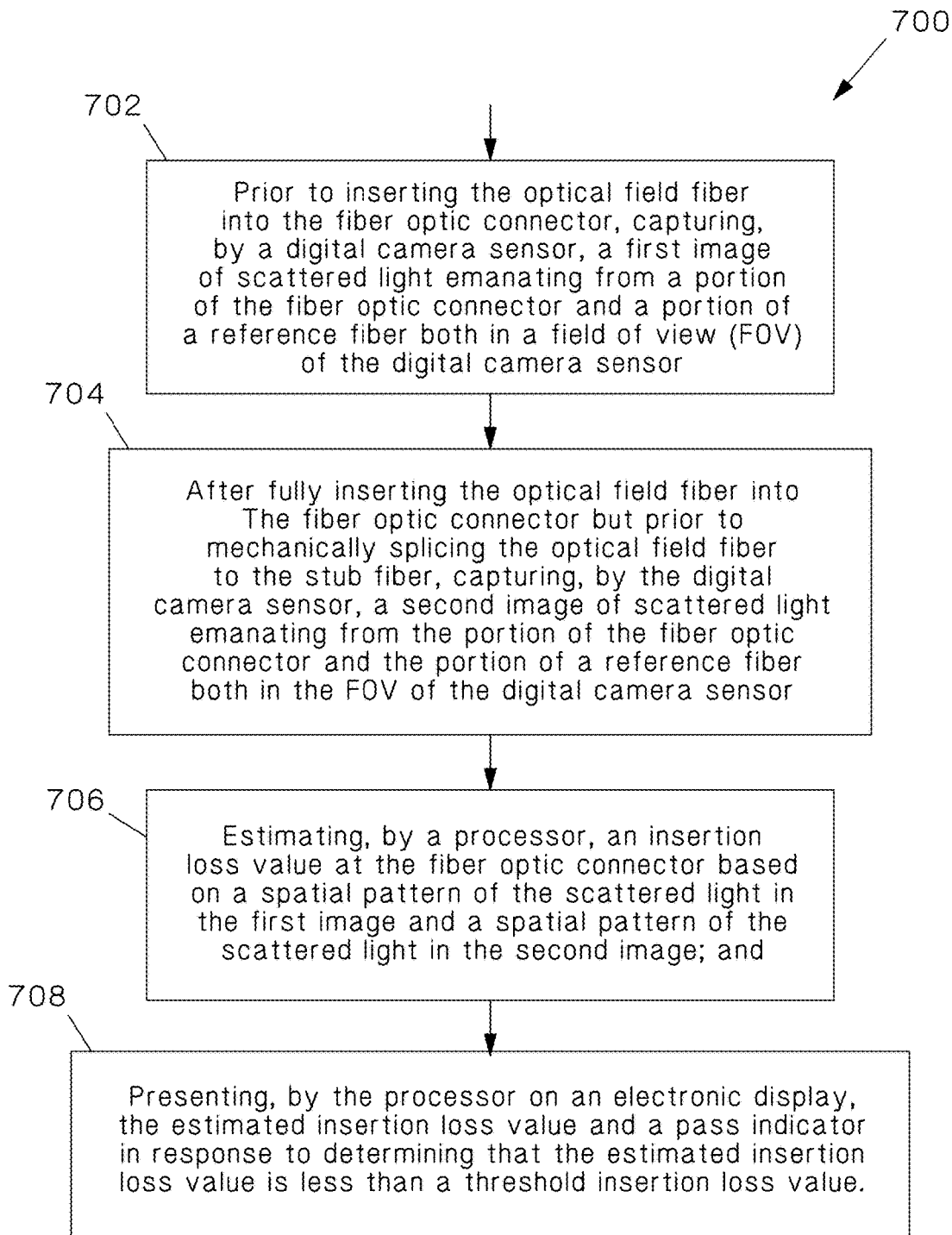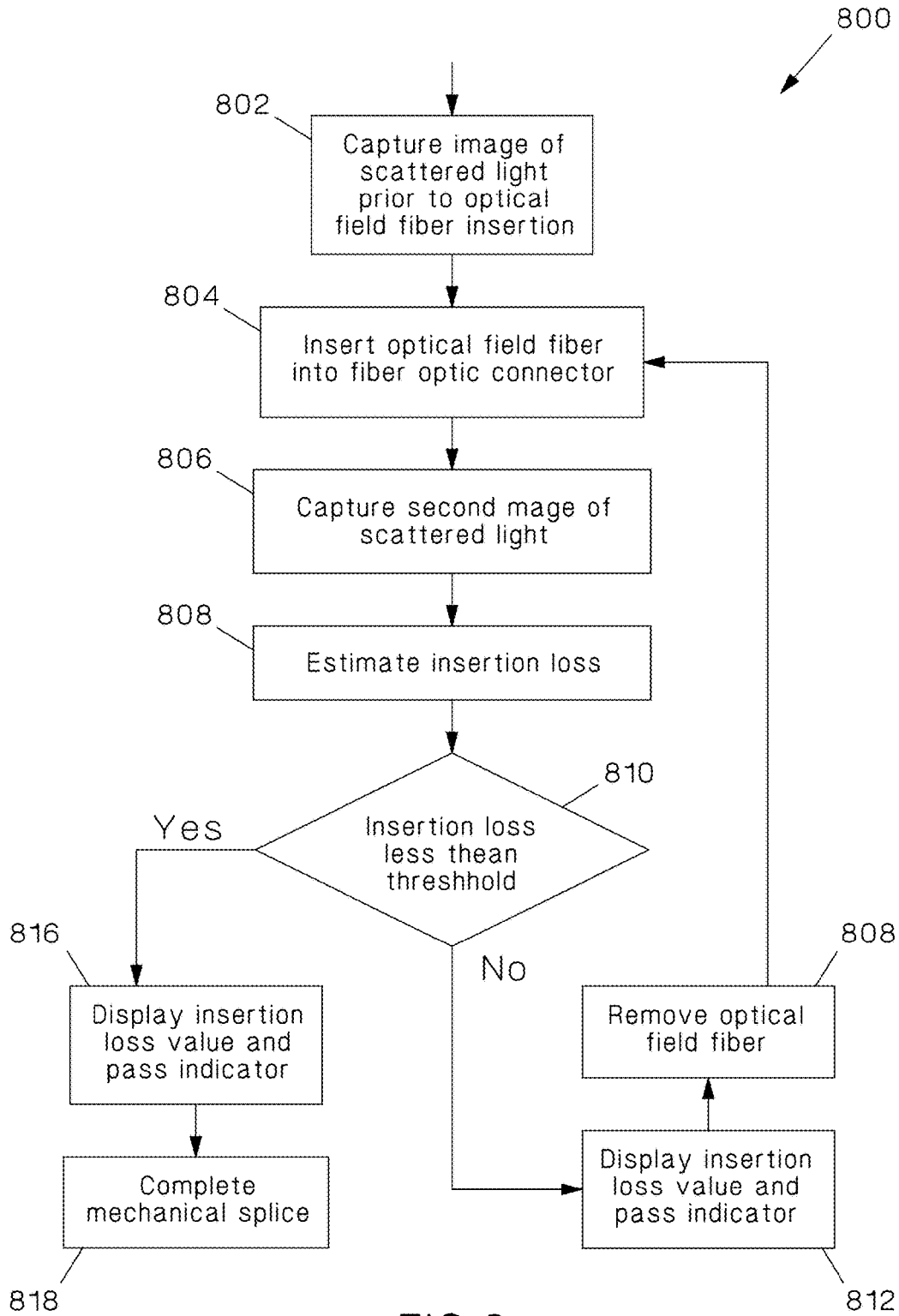loss value and
pass indicator

FIG.8

OPTICAL FIBER TERMINATION USING A REFERENCE SOURCE

BACKGROUND

[0001] When working in the field of fiber optics, operators often establish connections between non-connectorized ends of optical fibers or fiber ribbons. This is generally referred to as splicing, and it may involve creating temporary or permanent joints between two fibers.

[0002] In certain instances, the two fibers are precisely aligned and then fused together using localized intense heat often times created with an electric arc. This is referred to as fusion splicing and is widely employed to create high performance permanent joints between two optical fibers. However, fusion splicer apparatuses are somewhat bulky, expensive and relatively fragile.

[0003] Alternatively, the two fibers may simply abut one another in an alignment fixture often referred to as a mechanical splice. The alignment fixture may be an alignment tube or V-groove which receives two ends of separate fibers on either side and has the means of physically securing the fibers. In other instances, the alignment device may be a fiber optic connector with a stub fiber embedded therein made to be connectorized to a field fiber. In this case the field fiber can be terminated utilizing a mechanical splice to the stub fiber inside the connector.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The following detailed description references the drawings, wherein:

[0005] FIG. 1 is an illustration of an example implementation of an optical fiber termination system;

[0006] FIG. 2 is an illustration of an example implementation of an optical fiber termination system;

[0007] FIG. 3 is an illustration of an example implementation of an optical fiber termination system;

[0008] FIG. 4 is an example spatial pattern of scattered light emanating from a portion of a fiber optic connector and a portion of a reference fiber;

[0009] FIG. 5 is an example spatial pattern of scattered light emanating from a portion of a fiber optic connector and a portion of a reference light source;

[0010] FIG. 6 shows example image captures of scattered light illustrating background correction;

[0011] FIG. 7 is a flowchart of an example method for terminating an optical field fiber to a stub fiber in a fiber optic connector; and

[0012] FIG. 8 is a flowchart of an example method for terminating an optical field fiber to a stub fiber in a fiber optic connector.

DETAILED DESCRIPTION

[0013] Mechanical splicing often occurs when a field optical fiber is connectorized to a pre-manufactured fiber optic connector with a stub fiber embedded therein. In order to avoid significant loss of signal and minimize the potential reflectance or light leakage within these joints, the fiber(s) need to be properly cleaved, and the operator ensures that there is a precise alignment between the fibers and that transparent gel or optical adhesive applied between the fibers matches the optical properties of the glass. These details are not always easy to detect and/or ensure. There is an uncertainty that can result in insertion loss values that exceed specified limits of the channel, making them unsuitable for the required reaches, data rate, or bit error rate (BER) application. The poor-quality splice joints that result can drive up cost and reduce channel performance.

[0014] Examples disclosed herein illustrate systems and methods to determine and evaluate the quality of mechanical splices of optical fibers using insertion loss estimation. In at least some of the disclosed systems and methods, an optical fiber termination system may include a reference fiber coupling a light source and a stub fiber of a fiber optic connector, a digital camera sensor and lens to capture images of scattered light emanating from a portion of the fiber optic connector and a portion of the reference fiber both in a field of view (FOV) of the digital camera sensor, and a processor. The processor may analyze digital images of scatter light emitted from at least a portion of the fiber optic connector and the reference fiber to estimate insertion loss at the fiber optic connector.

[0015] Reference will now be made to the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the following description to refer to the same or similar parts. It is to be expressly understood, however, that the drawings are for illustration and description purposes only. While several examples are described in this document, modifications, adaptations, and other implementations are possible. Accordingly, the following detailed description does not limit the disclosed examples. Instead, the proper scope of the disclosed examples may be defined by the appended claims.

[0016] FIG. 1 is an illustration of an example implementation of an optical fiber termination system 100. As shown in FIG. 1, system 100 may include various components, such as a reference light source 201, optical filter 203, lens 204, digital camera sensor 205, processor 206, display 208, speaker 210, input interface 212, and an optical reference fiber 301. The number and arrangement of these components is an example only and provided for purposes of illustration. Other arrangements and numbers of components may be utilized without departing from the examples of the present disclosure.

[0017] Optical fiber termination system 100 may be used to terminate an optical field fiber 102 to a fiber optic connector 109. Various types of fiber optic connectors may be used in optical fiber termination system 100, including, for example, LC connectors, SC connectors, and ST connectors. Fiber optic connector 109 may generally include a ferrule holder 107 with a ferrule 108 positioned at the front end thereof, and a top plank 105 and a bottom plank 106 positioned between the ferrule 108 and a distal end 110 of fiber optic connector 109. Fiber optic connector 109 may also include a stub fiber 101, which may be embedded in fiber optic connector 109 at the time of manufacture. Stub fiber 101 may extend from the outer edge of the ferrule (which can later interface a corresponding adapter (not shown)) to the inner portion of fiber optic connector 109 in the general area of top and bottom planks 105, 106.

[0018] Optical fiber termination system 100 may terminate optical field fiber 102 to fiber optic connector 109 by mechanically splicing optical field fiber 102 with stub fiber 101. To mechanically splice stub fiber 101 with optical field fiber 102, optical field fiber 102 may be inserted into fiber optic connector 109 through its distal end 110 and aligned with stub fiber 101. A cam 104 may be activated to clamp

optical field fiber **102** and stub fiber **101** in place, forming a stub fiber/optical field fiber interface **103** (also referred to as a splice joint).

[0019] In order to ensure that light leakage and reflection are reduced or minimized at splice joint **103**, the insertion loss of the connection between optical field fiber **102** and stub fiber **101** at fiber optic connector **109** may be estimated using optical fiber termination system **100** prior to mechanically splicing the fibers together. To estimate the insertion loss, digital camera sensor **205** may capture images of scattered light patterns, and processor **206** may analyze the captured images by, for example, based on the spatial pattern of the scattered light emanating from fiber optic connector **109** relative to the spatial pattern of the scattered light emanating from reference fiber **301**. Digital camera sensor **205** may capture the images of scattered light at various stages of optical field fiber **102** insertion into fiber optic connector **109**. For example, digital camera sensor **205** may capture images prior to insertion, at various points during insertion, and when optical field fiber **102** is fully inserted into fiber optic connector **109**.

[0020] Reference light source **201** may be optically coupled to reference fiber **301**, which may be optically coupled to stub fiber **101** of fiber optic connector **109**. Reference light source **201** may emit light into reference fiber **301**. Reference light source **201** may be implemented by a semiconductor laser capable of emitting light having a spectral range within the optical sensitivity of the digital camera sensor **205**. For example, the spectral range of reference light source **201** may be between about 700 nm and about 1700 nm. The light may travel along reference fiber **301** and into stub fiber **101**. The emitted light may travel from stub fiber **101**, across splice joint **103**, and into optical field fiber **102**. As the emitted light travels along this path, light may be scattered at various points. For example, scattered light may be emitted from reference fiber **301**, stub fiber **101**, splice joint **103**, and field fiber **102**.

[0021] At least a portion of fiber optic connector **109** may be positioned within the field of view (FOV) of digital camera sensor **205** along with a portion of reference fiber **301**. The portion may include various regions of fiber optic connector **109**, such as the region including splice joint **103**. The scattered light emanating from all the regions of fiber optic connector **109** in the FOV of digital camera sensor **205** and the portion of reference fiber **301** may pass through optical filter **203**, focused by lens **204**, and captured by digital camera sensor **205**. Processor **206** may generate spatial patterns of the scattered light captured by digital camera sensor **205**.

[0022] FIG. **4** is an example of a spatial pattern of the scattered light from fiber optic connector **109** and reference fiber **301**. As shown in FIG. **4**, regions B, C, and D of fiber optic connector **109** were captured. Moreover, as shown in FIG. **4**, reference fiber **301** and fiber optic connector **109** are located in the FOV of digital camera sensor **205** in such a way that there is not interference or overlap with each other.

[0023] In some implementations, the images captured by digital camera sensor **205** may be background corrected so that optical fiber termination system **100** can be used without a cover or protection from environmental illumination. FIG. **6** illustrates example images captured during a background correction procedure. To background correct the captured images, processor **206** may turn off reference light source **201**, capture an image using digital camera sensor **205**

(referred as the background image), and store the background image in a memory (not shown). Processor **206** may then turn on reference light source **201** and capture another image using digital camera sensor **205** (referred to as the foreground image), and store the foreground image in the memory. Processor **206** may perform the background corrections by subtracting the capture background image from the capture foreground image. Processor **206** may be capable of performing the background correction in 10's of milliseconds, and therefore can be referred to as a real-time background correction (RTBC). The RTBC can be performed by processor **206** in all stages of the fiber termination process, such as prior to insertion of optical field fiber **102**, at various points where optical field fiber **102** is partially inserted into fiber optic connector **109**, and when optical field fiber **102** is fully inserted into fiber optic connector **109**.

[0024] Referring back to FIG. **1**, the scattered light from reference fiber **301** in the captured images may be used to baseline the optical intensity profile of the images. Processor **206** may analyze the scattered light images utilizing various digital signal processing algorithms to estimate insertion loss at fiber optic connector **109**. Processor **206** may be a single processor or a plurality of physical and/or logical processors or processing cores. Processor **206** may be implemented by various types of processors, such as a central processing unit (CPU), a dedicated integrated circuit such as an ASIC (application-specific integrated circuit), a dedicated FPGA (field-programmable gate array), or a digital signal processor (DSP). Processor **206** may be capable of executing instructions (e.g., stored on a machine-readable storage medium not shown) that, when executed (e.g., by processor **206**), implement the algorithms described herein.

[0025] In one implementation, the insertion loss algorithm may include estimating insertion loss based on the light leaked from selected regions of fiber optic connector **109**. The regions may be selected based on the connector type. In one example, and referring back to FIG. **4**, the regions may be region B, C, and D. Processor **206** may capture an image of fiber optic connector **109** and reference fiber **301** (via digital camera sensor **205**) prior to the insertion of optical field fiber **102** into fiber optic connector **109** (ima0(x,y)) and after optical field fiber **102** has been fully inserted into fiber optic connector **109** (ima1(x,y)), where x and y represent the horizontal and vertical coordinates of the pixels in the images. In addition, the position of the reference fiber **301** in digital camera sensor **205** may be stored in a memory (e.g., during factory calibration) and accessed by processor **206**. The average and maximum levels of the pixel coordinates corresponding to reference fiber **301** are stored in variables S0_ave, S0_max for ima0(x,y) and S1_ave, S1_max for ima1(x,y).

[0026] Processor **206** may estimate the accumulated light leakage in regions B, C, and D using:

$$SumB0 = \sum_{[x \varepsilon Region\_B]} \sum_{y} ima0(x, y) \qquad (1)$$

$$SumC0 = \sum_{[x \varepsilon Region\_C]} \sum_{y} ima0(x, y) \qquad (2)$$

$$SumD0 = \sum_{[x \varepsilon Region\_D]} \sum_{y} ima0(x, y) \qquad (3)$$

-continued

$$SumB1 = \sum_{[x\varepsilon Region\_B]} \sum_y ima1(x, y) \quad (4)$$

$$SumC1 = \sum_{[x\varepsilon Region\_C]} \sum_y ima1(x, y) \quad (5)$$

$$SumD1 = \sum_{[x\varepsilon Region\_D]} \sum_y ima1(x, y) \quad (6)$$

Where the y-regions are the vertical regions in digital camera sensor **205** that capture only fiber optic connector **109** and not reference fiber **301**. Processor **206** may estimate the relative light leakage of fiber optic connector **109** from the estimated accumulated light leakage in regions B, C, and D using:

$$R_1 = \frac{SumC1}{SumD1} \quad (7)$$

$$R_2 = \frac{SumC1}{SumB1} \quad (8)$$

$$R_3 = \left(\frac{SumC1 - K_0 SumB0}{SumC0 - K_0 SumB0}\right)\frac{S0}{S1} \quad (9)$$

Where S0 and S1 are either the average or peak levels of reference fiber **301**. The decision of using the average or peak levels for S0 and S1 depends on the linearity and noise of digital camera sensor **205**.

[0027] Processor **206** may calculate the estimated insertion loss value at fiber optic connector **109** in dB based on the relative light leakage of fiber optic connector **109** using:

$$IL_{est} = K_1 + K_2 R_1 + K_3 R_2 + K_4 \log_{10}(1 - K_5 R3) \quad (10)$$

[0028] Where K0, K1, K2, K3, K4, and K5 are calibration constants that depend on the type of fiber optic connector **109** and the optical properties of lens **204**, filter **203**, and other apparatuses in the optical path. In one example, using calibration constants of K0=0.05, K1=0.02, K2=0, K3=0.02, and K4=10 may yield an estimated insertion loss accuracy of about ±0.15 dB.

[0029] In some implementations, processor **206** may tune the intensity of scattered light emanating from reference fiber **301** by adjusting the duty cycle of reference light source **201** to modulate reference light source **201**. Therefore S0_max, S0_ave and S1_max, S1_ave can be modified to match the maximum or average levels of the pixels in the zone of interest. Since the power of reference light source **201** can be known for a set of duty cycles, DC, a table that relates the DC with the estimated insertion loss can be used.

[0030] In another implementation, the insertion loss algorithm may include estimating insertion loss using:

$$IL_{est} = K_1 + K_4 \frac{SumC1 - K_0 SumB1}{N \ S1_{ave}} \quad (11)$$

Where N is the total number of pixels in the sum area of digital camera sensor **205** and S1 the average level value of reference fiber **301**.

[0031] In another implementation, the insertion loss algorithm may include estimating insertion loss using power

tunable reference sources described above to produce a calibration table that maps exposure time to the power level of reference light source **201**. The table may be generated before insertion loss estimate. During the insertion loss estimate, processor **206** executes a sensor auto exposure algorithm that changes the exposure time until it detects that there is not saturation in the image. The table may be used to convert exposure time to a factor used to estimate the insertion loss as follows:

$$IL_{est} = K_1 + K_2 R_1 + K_3 R_2 + K_4 \log_{10}(1 - f(T_{exp})K_5 SumC1 - K_0 SumB0) \quad (12)$$

[0032] Where $f(0)$ is a function that represents the calibration table and T_{exp} represents the input to the table the exposure time of the system that avoids or minimizes saturation of the image.

[0033] Processor **206** may compare the estimated insertion loss value at fiber optic connector **109** to a threshold insertion loss value. An example threshold insertion loss value may be 0.75 dB. The threshold insertion loss value may be set and adjusted by a user via input interface **212**. Input interface **212** may be a keyboard, mouse, touchscreen, joystick, etc. If processor **206** determines that the estimated insertion loss value is less than the threshold insertion loss value, processor **206** may display the estimated insertion loss value along with a visual pass indicator on display **208** (and play an audio tone via speaker **210** in some implementations) indicating that optical field fiber **102** is in position and ready to be mechanically spliced with stub fiber **101**. Cam **104** may then be actuated to complete the mechanical splice, thereby terminating optical field fiber **102** to fiber optic connector **109**.

[0034] If processor **206** determines that the estimated insertion loss value is equal to or greater than the threshold insertion loss value, processor **206** may display the estimated insertion loss value along with a visual fail indicator on display **208** (and play an audio tone via speaker **210** in some implementations) indicating that optical field fiber **102** is not ready to be mechanically spliced with stub fiber **101**. Optical field fiber **102** may then be removed from fiber optic connector **109** and reinserted so that processor **206** can re-estimate the insertion loss value.

[0035] In some implementations, processor **206** may continuously capture images and estimate the insertion loss as optical field fiber **102** is being inserted into fiber optic connector **109** until optical field fiber **102** is positioned in a location where the estimated insertion loss value is less than the threshold insertion loss value. At that point, processor **206** may display the estimated insertion loss value along with a visual pass indicator on display **208** (and play an audio tone via speaker **210** in some implementations) indicating that optical field fiber **102** is in position and ready to be mechanically spliced with stub fiber **101**.

[0036] FIG. **2** is an illustration of an example implementation of an optical fiber termination system **200**. Optical fiber termination system **200** may be similar to, and operate using the same principles as, optical fiber termination system **200**. However, optical fiber termination system **200** may include an angled reflector **214** between filter **203** and fiber optic connector **109** to redirect the FOV of digital camera sensor **205** at an angle toward fiber optic connector **109** and reference fiber **301**. The number and arrangement of these components is an example only and provided for purposes of

illustration. Other arrangements and numbers of components may be utilized without departing from the examples of the present disclosure.

[0037] The angle may be a 90° angle as shown in FIG. **2** or any other angle. The purpose of adding angled reflector **214** is to make optical fiber termination system **200** and/or to increase the FOV of digital camera sensor **200**.

[0038] FIG. **3** is an illustration of an example implementation of an optical fiber termination system **300**. Optical fiber termination system **300** may operate similarly to optical fiber termination system **100**, except that light a reference light source **305** emits light directly into the FOV of digital camera sensor **205** instead of through a reference fiber. In addition, a connector light source **202** illuminates fiber optic connector **109**. The number and arrangement of these components is an example only and provided for purposes of illustration. Other arrangements and numbers of components may be utilized without departing from the examples of the present disclosure. For example, while reference light source **305** and connector light source **202** are shown to be separate light sources in FIG. **3**, these light sources may be implemented by one light source or additional light sources. As another example, connector light source **202** may be connected to a launch fiber (not shown), which may couple light from connector light source **202** to fiber optic connector **109**.

[0039] Digital camera sensor **205** may capture images of scattered light emanating from a portion of fiber optic connector **109** and reference light source **305** both in the FOV of digital camera sensor **205**. Processor **206** may adjust an optical intensity profile of the captured images based on an intensity of the scattered light emanating from reference light source **305**, and then generate a spatial pattern of the scattered light emanating from the portion of fiber optic connector **109** and reference light source **305** in the FOV of digital camera sensor **305**. Processor **206** may estimate an insertion loss value at fiber optic connector **109** based on the spatial pattern of the scattered light emanating from the portion of fiber optic connector **109** relative to the spatial pattern of the scattered light emanating from reference light source **305** using the algorithms described above.

[0040] FIG. **5** is an example of a spatial pattern of the scattered light from fiber optic connector **109** and reference light source **305**. As shown in FIG. **5**, regions B, C, and D of fiber optic connector **109** were captured. Moreover, as shown in FIG. **5**, reference light source **305** and fiber optic connector **109** are located in the FOV of digital camera sensor **205** in such a way that there is not interference or overlap with each other.

[0041] FIG. **7** is a flowchart depicting an example method **700** for method for terminating an optical field fiber to a stub fiber in a fiber optic connector. Method **700** may be executed or performed by some or all of the system components described above in optical fiber termination system **100** and **200** of FIGS. **1** and **2**, respectively. In some implementations, steps of method **700** may be executed substantially concurrently or in a different order than shown in FIG. **7**, and more or less steps may be performed than shown. In some implementations, some of the steps of method **700**, or method **700** in general, may, at certain times, be ongoing and/or may repeat.

[0042] At block **702**, prior to inserting an optical field fiber into a fiber optic connector, a first image of scattered light emanating from a portion of the fiber optic connector and a

portion of a reference fiber both in a FOV of a digital camera sensor may be captured by the digital camera sensor.

[0043] At block **704**, after fully inserting the optical field fiber into the fiber optic connector but prior to mechanically splicing the optical field fiber to the stub fiber, a second image of scattered light emanating from the portion of the fiber optic connector and the portion of a reference fiber both in the FOV of the digital camera sensor may be captured by the digital camera sensor.

[0044] At block **706**, a processor connected to the digital camera sensor may estimate an insertion loss value at the fiber optic connector based on a spatial pattern of the scattered light in the first image and a spatial pattern of the scattered light in the second image. In some implementations, the insertion loss estimation may include estimating an amount of accumulated light leakage from each of a plurality of sub regions of the fiber optic connector using the spatial pattern of the scattered light in the first image and the spatial pattern of the scattered light in the second image, calculating a relative amount of light leakage from each of the plurality of sub regions based on the amount of accumulated light leakage from each of a plurality of sub regions and average or peak levels of intensity for the scattered light emanating from the portion of a reference fiber both in the FOV of the digital camera sensor, and calculating the estimated insertion loss value based on the calculated relative amount of light leakage from each of the plurality of sub regions and a plurality of calibration constants.

[0045] At block **708**, the processor may present the estimated insertion loss value and a pass indicator in response to determining that the estimated insertion loss value is less than a threshold insertion loss value on an electronic display. In some implementations, method **700** may also include mechanically splicing the optical field fiber to the stub fiber using a cam in response to the processor determining that the estimated insertion loss value is less than a threshold insertion loss value.

[0046] In some implementations, method **700** may be modified to be performed by optical fiber termination system **300** of FIG. **3**. For example, instead of capturing scattered light emanating from a portion of a reference fiber, method **700** may include capturing scattered light emanating from a reference light source.

[0047] FIG. **8** is a flowchart depicting an example method **800** for method for terminating an optical field fiber to a stub fiber in a fiber optic connector. Method **800** may be executed or performed by some or all of the system components described above in optical fiber termination system **100** and **200** of FIGS. **1** and **2**, respectively. In some implementations, steps of method **800** may be executed substantially concurrently or in a different order than shown in FIG. **8**, and more or less steps may be performed than shown. In some implementations, some of the steps of method **800**, or method **800** in general, may, at certain times, be ongoing and/or may repeat.

[0048] At block **802**, prior to inserting an optical field fiber into a fiber optic connector, a first image of scattered light emanating from a portion of the fiber optic connector and a portion of a reference fiber both in a FOV of a digital camera sensor may be captured by the digital camera sensor.

[0049] At block **804**, the optical field fiber may be fully inserted into the fiber optic connector. At block **806**, after fully inserting the optical field fiber into the fiber optic connector but prior to mechanically splicing the optical field

fiber to the stub fiber, a second image of scattered light emanating from the portion of the fiber optic connector and the portion of a reference fiber both in the FOV of the digital camera sensor may be captured by the digital camera sensor.

[0050] At block **808**, a processor connected to the digital camera sensor may estimate an insertion loss value at the fiber optic connector based on a spatial pattern of the scattered light in the first image and a spatial pattern of the scattered light in the second image. In some implementations, the insertion loss estimation may include estimating an amount of accumulated light leakage from each of a plurality of sub regions of the fiber optic connector using the spatial pattern of the scattered light in the first image and the spatial pattern of the scattered light in the second image, calculating a relative amount of light leakage from each of the plurality of sub regions based on the amount of accumulated light leakage from each of a plurality of sub regions and average or peak levels of intensity for the scattered light emanating from the portion of a reference fiber both in the FOV of the digital camera sensor, and calculating the estimated insertion loss value based on the calculated relative amount of light leakage from each of the plurality of sub regions and a plurality of calibration constants.

[0051] At block **810**, the processor may determine whether the estimated insertion loss value calculated at block **808** is less than a threshold insertion loss value. If the processor determines that the estimated insertion loss value calculated is not less than the threshold insertion loss value (**810**—NO), the processor, at block **812** may present the estimated insertion loss value and a visual fail indicator on an electronic display. At block **814**, the optical field fiber may be removed from the fiber optic connector, and method **800** may return to block **804**, where the optical field fiber is reinserted into the fiber optic connector for another insertion loss estimation.

[0052] If the processor determines that the estimated insertion loss value calculated is less than the threshold insertion loss value (**810**—YES), the processor, at block **816** may present the estimated insertion loss value and a visual pass indicator on the electronic display. At block **818**, method **800** may include mechanically splicing the optical field fiber to the stub fiber using a cam to terminate the optical field fiber to the fiber optic connector.

[0053] In some implementations, method **800** may be modified to be performed by optical fiber termination system **300** of FIG. **3**. For example, instead of capturing scattered light emanating from a portion of a reference fiber, method **800** may include capturing scattered light emanating from a reference light source.

[0054] Note that while the present disclosure includes various embodiments, these embodiments are non-limiting (regardless of whether they have been labeled as exemplary or not), and there are alterations, permutations, and equivalents, which fall within the scope of this invention. Additionally, the described embodiments should not be interpreted as mutually exclusive, and should instead be understood as potentially combinable if such combinations are permissive. It should also be noted that there are many alternative ways of implementing the embodiments of the present disclosure. It is therefore intended that claims that may follow be interpreted as including all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present disclosure.

1: An optical fiber connector loss measurement system, comprising:
   a reference fiber connected to a fiber optic connector,
   a digital camera sensor and lens to capture images of scattered light emanating from a portion of the fiber optic connector and a portion of the reference fiber both in a field of view (FOV) of the digital camera sensor; and
   a processor to:
      generate, from the captured images, a spatial pattern of the scattered light emanating from the portion of the fiber optic connector and the portion of the reference fiber in the FOV of the digital camera sensor; and
      estimate an insertion loss value at the fiber optic connector based on the spatial pattern of the scattered light emanating from the portion of the fiber optic connector relative to the spatial pattern of the scattered light emanating from the portion of the reference fiber.

2: The optical fiber loss measurement system of claim **1**, wherein the processor is to:
   compare the estimated insertion loss value to a threshold insertion loss value.

3: The optical fiber loss measurement system of claim **2**, comprising:
   a display;
   wherein the processor is to display, on the display, the estimated insertion loss value along with a pass indicator or a fail indicator based on the comparison.

4: The optical fiber loss measurement system of claim **1**, comprising:
   an angled reflector to redirect the FOV of the digital camera sensor toward the fiber optic connector and the reference fiber.

5: The optical fiber loss measurement system of claim **1**, wherein the processor is to estimate the insertion loss value at the fiber optic connector by using the spatial pattern of the scattered light emanating from the portion of the reference fiber to baseline the spatial pattern of the scattered light emanating from the portion of the fiber optic connector.

6: The optical fiber loss measurement system of claim **1**, wherein the reference fiber is to couple a light source to the fiber optic connector.

7: The optical fiber loss measurement system of claim **6**, wherein the reference fiber is to couple the light source to a stub fiber of the fiber optic connector.

8: The optical fiber loss measurement system of claim **6**, wherein the processor is to modulate a duty cycle of the light source to tune an average and maximum power level of pixel coordinates corresponding to the portion of the reference fiber in the FOV of the digital camera sensor.

9: The optical fiber loss measurement system of claim **1**, wherein the digital camera sensor is to capture the images of scattered light emanating from the portion of the fiber optic connector and the portion of the reference fiber prior to the optical fiber being mechanically terminated to the fiber optic connector.

10: An optical fiber loss measurement system, comprising:
   a reference light source;
   a digital camera sensor and lens to capture images of scattered light emanating from a portion of a fiber optic connector and the reference light source both in a field of view (FOV) of the digital camera sensor; and

a processor to:

adjust an optical intensity profile of the captured images based on an intensity of the scattered light emanating from the reference light source;

generate, from the adjusted captured images, a spatial pattern of the scattered light emanating from the portion of the fiber optic connector and the reference light source in the FOV of the digital camera sensor; and

estimate an insertion loss value at the fiber optic connector based on the spatial pattern of the scattered light emanating from the portion of the fiber optic connector relative to the spatial pattern of the scattered light emanating from the reference light source.

11: The optical fiber loss measurement system of claim 10, comprising: a display, wherein the processor is to:

compare the estimated insertion loss value to a threshold insertion loss value; and

display, on the display, the estimated insertion loss value and a pass indicator in response to determining that the estimated insertion loss value is less than the threshold insertion loss value.

12: The optical fiber loss measurement system of claim 10, comprising:

a launch fiber to couple light from a light source to the fiber optic connector.

13: A method for terminating an optical field fiber to a stub fiber in a fiber optic connector, the method comprising:

prior to inserting the optical field fiber into the fiber optic connector, capturing, by a digital camera sensor, a first image of scattered light emanating from a portion of the fiber optic connector and a portion of a reference fiber both in a field of view (FOV) of the digital camera sensor;

after fully inserting the optical field fiber into the fiber optic connector but prior to mechanically splicing the optical field fiber to the stub fiber, capturing, by the digital camera sensor, a second image of scattered light emanating from the portion of the fiber optic connector and the portion of a reference fiber both in the FOV of the digital camera sensor;

estimating, by a processor, an insertion loss value at the fiber optic connector based on a spatial pattern of the scattered light in the first image and a spatial pattern of the scattered light in the second image; and

presenting, by the processor on an electronic display, the estimated insertion loss value and a pass indicator in response to determining that the estimated insertion loss value is less than a threshold insertion loss value.

14: The method of claim 13, wherein estimating the insertion loss value at the fiber optic connector comprises:

estimating an amount of accumulated light leakage from each of a plurality of sub regions of the fiber optic connector using the spatial pattern of the scattered light in the first image and the spatial pattern of the scattered light in the second image;

calculating a relative amount of light leakage from each of the plurality of sub regions based on the amount of accumulated light leakage from each of a plurality of sub regions and average or peak levels of intensity for the scattered light emanating from the portion of a reference fiber both in the FOV of the digital camera sensor; and

calculating the estimated insertion loss value based on the calculated relative amount of light leakage from each of the plurality of sub regions and a plurality of calibration constants.

15: The method of claim 14, wherein the plurality of calibration constants is selected based on a connector type of the fiber optic connector.

16: The method of claim 15, wherein the connector type of the fiber optic connector is one of an LC, SC, and ST connector.

17: The method of claim 13, comprising:

mechanically splicing the optical field fiber to the stub fiber in response to determining that the estimated insertion loss value is less than a threshold insertion loss value.

18: The method of claim 17, comprising:

mechanically splicing the optical field fiber to the stub fiber using a cam.

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