Office de la Propriété
Intellectuelle
du Canada

Un organisme
d'Industrie Canada

Canadian
Intellectual Property
Office

An agency of
Industry Canada

CA 2466970 A1 2005/11/12

(21) 2 466 970

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(22) **Date de dépôt/Filing Date:** 2004/05/12

(41) **Mise à la disp. pub./Open to Public Insp.:** 2005/11/12

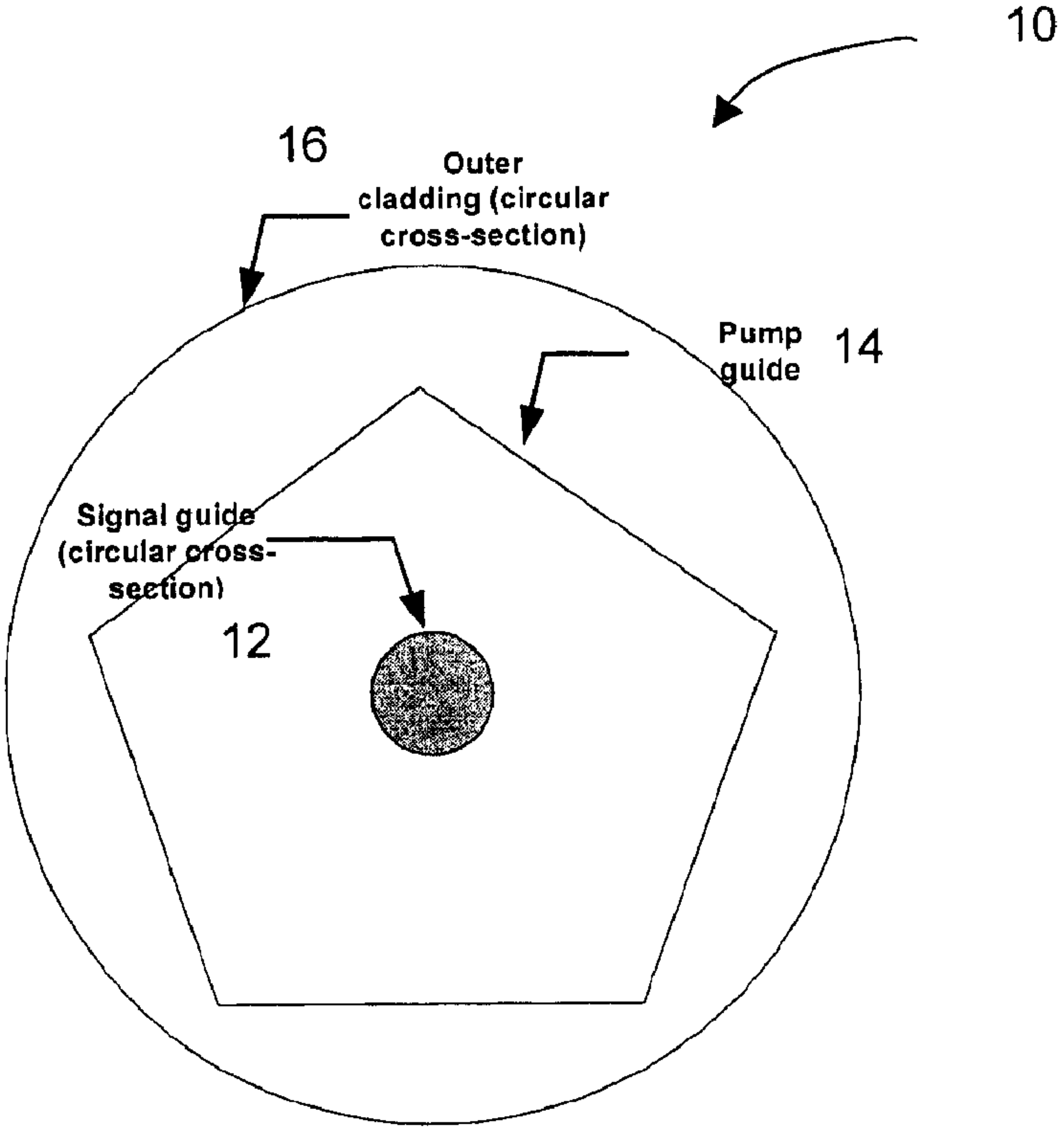
(51) **Cl.Int.^{7}/Int.Cl.^{7}** G02B 6/16, C03B 37/012, H01S 3/067

(71) **Demandeur/Applicant:**
CORACTIVE HIGH-TECH INC., CA

(72) **Inventeur/Inventor:**
CHATIGNY, STEPHANE, CA

(74) **Agent:** ROBIC

(54) **Titre :** FIBRES OPTIQUES A GAINE DOUBLE
(54) **Title:** DOUBLE-CLAD OPTICAL FIBERS



DOUBLE - CLAD OPTICAL FIBERS

FIELD OF THE INVENTION

The present invention generally relates to optical fiber devices and, more particularly to double-clad optical fibers particularly adapted for use as optical amplifiers, optical fiber lasers or spontaneous emission sources.

BACKGROUND OF THE INVENTION

Optical fiber lasers and amplifiers are today well known in the art. In such lasers and amplifiers, rare earth materials disposed in the core of the optical fiber laser or amplifier receive pump radiation and, responsive thereto, provide or amplify light for propagation in the core. For example, the well known erbium doped fiber amplifier (EDFA) receives pump radiation having a wavelength of 980 or 1480 nanometers (nm) and amplifies an optical signal propagating in the core at a wavelength in the 1550 nm region.

In such optical fiber lasers and amplifiers, the pump radiation can be introduced directly to the core, which can be difficult due to the small size of the core, or can be introduced to the cladding surrounding the core and absorbed by the core as the rays propagating in the cladding intersect the core. Lasers and amplifiers with the pump radiation introduced to the cladding are known as "cladding-pumped" optical devices, and facilitate the scale-up of lasers and amplifiers to higher power systems.

Absorption per unit length is a useful figure of merit for evaluating a cladding-pumped optical fiber laser or amplifier. It is typically desirable that the amplifier or laser have a high absorption per unit length, indicating that the pump radiation frequently intersects the core. Unfortunately, when the cladding has a circular outer circumference, a portion of the pump radiation can essentially propagate down the optical fiber while spiraling around the core without substantially intersecting the core. This leads to a low absorption per unit length of the optical fiber device, and hence detracts from the performance of the optical fiber laser or amplifier.

Various approaches are known in the art for enhancing the intersection of the pump radiation with the core and hence raising the absorption per unit length of the optical fiber amplifier or laser. For example, as disclosed in U.S. Pat. No. 4,815,079, issued Mar. 21, 1989 to Snitzer et al., the core can be offset from the center of the optical fiber so as to enhance the intersection of pump light with the core. In another approach, the inner cladding has a "D"-shaped outer circumference that includes a flat section, as disclosed in U.S. Pat. No. 5,864,645, issued Jan. 26, 1999 to Zellmer et al.. In another prior art optical fiber, the outer circumference of the cladding is shaped as a polygon, such as a diamond, as disclosed in U.S. Pat. No. 5,533,163, issued Jul. 2, 1996 to Muendel. Other approaches include providing a star-shaped outer circumference of the cladding, as disclosed in U.S. Pat. Nos. 5,949,941, issued Sep. 7, 1999, 5,873,923 issued Feb. 23, 1999, and 5,966,491 issued Oct. 12, 1999, all issued to DiGiovanni. Also of interest is U.S. Pat. No. 6,411,762 issued Jun. 25, 2002 to Anthon et al., disclosing an optical fiber having a core, inner and outer claddings, and a series of perturbations or irregularities formed in the otherwise circular outer boundary of the inner cladding. The optical fiber is drawn from a preform having rods inserted into holes drilled into the preform for producing the irregularities.

In the foregoing prior art fibers, the non-circular shape of the outer circumference is understood to cause ray distortion and mode mixing of light, thereby directing the light rays of the cladding radiation to the core, and avoiding trapping light in spiral paths that do not intersect the core.

Another approach disclosed in U.S. Pat. No. 6,157,763 issued Dec. 5, 2002 to Grubb et al. consists of providing a double-clad optical fiber having an inner cladding with a cross-sectional shape that is non-circular, but that maintains a good end-coupling profile. The cross-sectional shape of the inner cladding is such that two perpendicular distances across the shape, each of which passes through a geometric center of the core of the fiber, are equal for all angular positions. Thus, while mode mixing within the inner cladding is enhanced, the inner cladding does not suffer any oblong distortions of its shape, and is therefore more easily coupled to conventional fibers. The cross-sectional cladding shape may include various regions along its outer surface that do not conform to a circular geometry about a center of the core. These regions may include flat regions, or concave or convex regions.

Also known in the art is U.S. Pat. No. 6,477,307 issued Nov. 5, 2002 to Tankala et al.. In this patent, the outer circumference of the cladding includes a plurality of sections, where the plurality of sections includes at least one straight section and one inwardly curved section. An outer layer surrounds the cladding and has an index of refraction that is less than the second index of refraction. Tankala stated that the combination of the straight and inwardly curved sections in the outer circumference of the cladding enhances scattering of the pump radiation for more effective absorption of the pump radiation by the core. For example, the inwardly curved section can intercept the pump light reflected from the straight section in a substantially different direction, thus achieving a higher degree of randomization of the paths of the light rays of the pump light for increased interception of the light by the core of the optical fiber.

Also known in the art, there is U.S. Pat. No. 6,483,973 issued Nov. 19, 2002 to Mazzarese et al., disclosing an optical fiber wherein the cladding member has a circular exterior periphery and a predetermined refractive index n_C. The cladding member has an index modified region that directs light to the core member. The index modified region has a stress field portion with a predetermined refractive index n_S. The difference between the refractive index of the cladding member and that of the stress field portion ($n_C - n_S$) is within such a range that the stress field portion does not affect the polarization properties of the light traveling in the core member.

The designs discussed above have disadvantages. For example, a fiber having an offset core can be difficult to interconnect with other optical components.

Designs, such as the diamond and polygon designs discussed above, that require the circumference of the cladding to predominately consist of flat areas, can be difficult to fabricate. The flat areas, which are typically first machined into the preform from which the optical fiber is drawn, tend to deform and change shape when the fiber is drawn at the most desirable temperatures. Accordingly, often the draw temperature is reduced to preserve the desired shape of the outer circumference of the cladding. A reduced draw temperature typically produces optical fibers having higher attenuation and lower mechanical strength. In addition, the star shaped configuration disclosed in U.S. Pat. No. 5,949,941 can be difficult to manufacture.

Therefore, it would be desirable to provide an improved double-clad cladding-pumped optical fiber overcoming most of the above mentioned drawbacks. More particularly, it would be desirable to provide an improved double-clad cladding-pumped optical fiber which would be easily manufactured, easily interconnectable with other optical components, while providing a good efficiency.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a double-clad optical fiber that satisfies the above mentioned needs.

Accordingly, the present invention provides a double-clad optical fiber having a core member surrounded by an inner cladding member receiving pump energy and transferring the pump energy to the core member. The double-clad optical fiber is also provided with an outer cladding surrounding the inner cladding member. Advantageously, the outer cladding has a circularly shaped cross-section. The inner cladding member has a predetermined polygonal cross-section provided with an odd number of sides. This polygonal cross-section of the inner cladding provided with an odd number of sides perturbs the propagation of light beams therein for providing a chaotic propagation of the beams which increases interception of the beams by the core member of the optical fiber, thereby improving the absorption of the pump energy by the core. The cross-section of the inner cladding member is preferably pentagonally or heptagonally shaped.

Preferably, the double-clad optical fiber of the present invention can easily be fusioned with another optical component such as an optical fiber having a circular cross-section.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and advantages of the invention will become apparent upon reading the detailed description and upon referring to the drawings in which :

Figure 1 is a schematic representation illustrating a radial refractive-index profile of a double-clad optical fiber according to a preferred embodiment of the present invention.

Figure 2 is a cross-sectional view of a double-clad optical fiber having a pentagonal shaped pumped guide, according to a preferred embodiment of the present invention.

Figure 3 is a cross-sectional view of a double-clad optical fiber having a heptagonal shaped pumped guide, according to another preferred embodiment of the present invention.

Figure 4A is a cross-sectional view of a double-clad optical fiber wherein the core is off-centered, according to another preferred embodiment of the present invention.

Figure 4B is a cross-sectional view of a double-clad optical fiber wherein the core is off-centered, according to another preferred embodiment of the present invention.

Figure 5A is a cross-sectional view of a double-clad optical fiber provided with stress field portions, according to another preferred embodiment of the present invention.

Figure 5B is a cross-sectional view of a double-clad optical fiber provided with stress field portions, according to another preferred embodiment of the present invention.

Figure 5C is a cross-sectional view of a double-clad optical fiber provided with stress field portions, according to another preferred embodiment of the present invention.

Figure 5D is a cross-sectional view of a double-clad optical fiber provided with stress field portions, according to another preferred embodiment of the present invention.

Figure 6A is a cross-sectional view of a double-clad optical fiber provided with a ring core, according to another preferred embodiment of the present invention.

Figure 6B is a cross-sectional view of a double-clad optical fiber provided with a ring core, according to another preferred embodiment of the present invention.

Figure 7A is a cross-sectional view of a double-clad optical fiber provided with a ring core, according to another preferred embodiment of the present invention.

Figure 7B is a cross-sectional view of a double-clad optical fiber provided with a ring core, according to another preferred embodiment of the present invention.

Figure 8A is a cross-sectional view of a double-clad optical fiber provided with an elliptic core, according to another preferred embodiment of the present invention.

Figure 8B is a cross-sectional view of a double-clad optical fiber provided with an elliptic core, according to another preferred embodiment of the present invention.

While the invention will be described in conjunction with example embodiments, it will be understood that it is not intended to limit the scope of the invention to such embodiments. On the contrary, it is intended to cover all alternatives, modifications and equivalents as may be included as defined by the present description.

DESCRIPTION OF PREFERRED EMBODIMENTS

In the following description, similar features in the drawings have been given similar reference numerals and in order to weight down the figures, some elements are not referred to in some figures if they were already identified in a precedent figure.

The present invention provides double-clad optical structures having at least one rare earth doped core and a multimode waveguide for guiding a pump signal, as will be described in more details therein after. Optical structures of the present invention are particularly well-adapted for use in optical amplifiers and laser resonators fields. Such optical structures may also advantageously be used as a spontaneous emission source.

Referring to figures 1 and 2, there is shown a preferred embodiment of the double-clad optical fiber **10** of the present invention. The optical fiber **10** is provided with a core **12** which advantageously has a circular cross-section. The core **12** may also be provided with an elliptical cross section or any other convenient shaped cross section adapted for a particular application. In this preferred embodiment, the core **12** extends centrally in the optical fiber **10**. Preferably, the core is silica-based co-doped with elements increasing or decreasing the index of refraction of the core, and with rare earth elements providing an optical gain. However, it should be understood that other type of glass could also be used, according to a particular application. For example, fluoride or chalcogenide glasses that can be used to access transition forbidden in silica glasses due their lower phonon energy. The core **12** is surrounded by an inner cladding member **14** defining a pump guide for receiving pump energy and transferring the pump energy to the core **12**. The inner-cladding **14** is preferably a pure silica cladding having an index of refraction lower than the index of refraction of the core **12**. The inner-cladding **14** has a predetermined polygonal cross-section provided with an odd number of sides. This chaotically shaped cross-section perturbs the propagation of light beams in the inner cladding **14** for providing a chaotic propagation of the beams, which increases interception of the beams by the core **12**, thereby improving the absorption of pump energy by the core **12**. In this preferred embodiment, the inner cladding **14** has a pentagonal cross-section. The double-clad optical fiber **10** is also provided with an outer cladding **16** surrounding the inner cladding **14**. The outer cladding **16** is preferably made of polymer materials or a silicate glass with a refractive index lower than that of the inner cladding and advantageously has an index of refraction lower than the index of refraction of the inner cladding **14**. Preferably, the outer cladding **16** has a circular cross-section. The core **12** and the inner cladding **14** thus define a monomode or multimode waveguide in the rare earth materials amplification band while the inner cladding **14** and the outer cladding **16** define a multimode waveguide allowing to couple a pump longitudinally propagating therein.

Figure 3 shows another preferred embodiment of the double-clad optical fiber **10** of the present invention, wherein the cross-section of the inner cladding **14** is heptagonal. As explained above, the polygonal shape of the cross section of the inner cladding **14** comprises an odd number of sides for providing a chaotic propagation. In the present description, a pentagonal shape and a heptagonal shape have been described as preferred embodiments. However, it should be noted that other convenient shapes may also be considered, depending on a particular application. Thus, for example, the cross section of the inner cladding **14** may advantageously be nonagonally shaped, in other words, the cross section of the inner cladding may have 9 sides.

Figures 4A to 8B show other preferred embodiments of the double-clad optical fiber **10** of the present invention providing an optimization of the pump absorption by the core **12**, in combining different techniques. Figures 4A and 4B show double-clad optical fibers **10** wherein the core **12** is offset from the center of the inner cladding **14** of the optical fiber **10**. Figures 5A to 5D show double-clad optical fibers **10** provided with stress field portions **18** extending in the inner cladding **14** in order to perturb further the propagation of the pump signal in the pump guide. In figures 5A and 5B, the stress field portions **18** are stress rodes longitudinally extending in the inner cladding **14** while in figures 5C and 5D, the stress field portions **18** are bow tie type. These stress field portions in an appropriate geometry may advantageously provide a polarization maintaining fiber.

Referring now to figures 6A, 6B, 7A and 7B, there is shown four other preferred embodiments of the present invention wherein the core **12** is a ring core. In figures 6A and 6B, the core **12** comprises an outer portion **20** being rare earth doped and an inner portion **22** being rare earth undoped. In figures 7A and 7B, the core **12** comprises an outer portion **24** being rare earth undoped and an inner portion **26** being rare earth doped. In these two latter preferred embodiments, the outer portion **24** may advantageously have the same index of refraction than the doped inner portion **26**. Moreover, this outer portion **24** may be photosensitive for allowing a Bragg grating to be inscribed therein. Preferably, this photosensitive outer portion comprises a high content of GeO_2 or a B_2O_3-GeO_2 doping.

Figures 8A and 8B show two other preferred embodiments of the double-clad optical fiber **10** of the present invention wherein the core **12** is elliptically shaped. These embodiments may advantageously be used when a polarization maintaining fiber is required.

The optical structures described above provides an improved efficiency in comparison with optical structures proposed in the prior art while providing an easy manufacturing. Moreover, the optical structures of the present invention offer an interesting compromise regarding the ease of fusion with other optical components such as an optical fiber having a circular cross section.

Although preferred embodiments of the present invention have been described in detail herein and illustrated in the accompanying drawings, it is to be understood that the invention is not limited to these precise embodiments and that various changes and modifications may be effected therein without departing from the scope or spirit of the present invention.

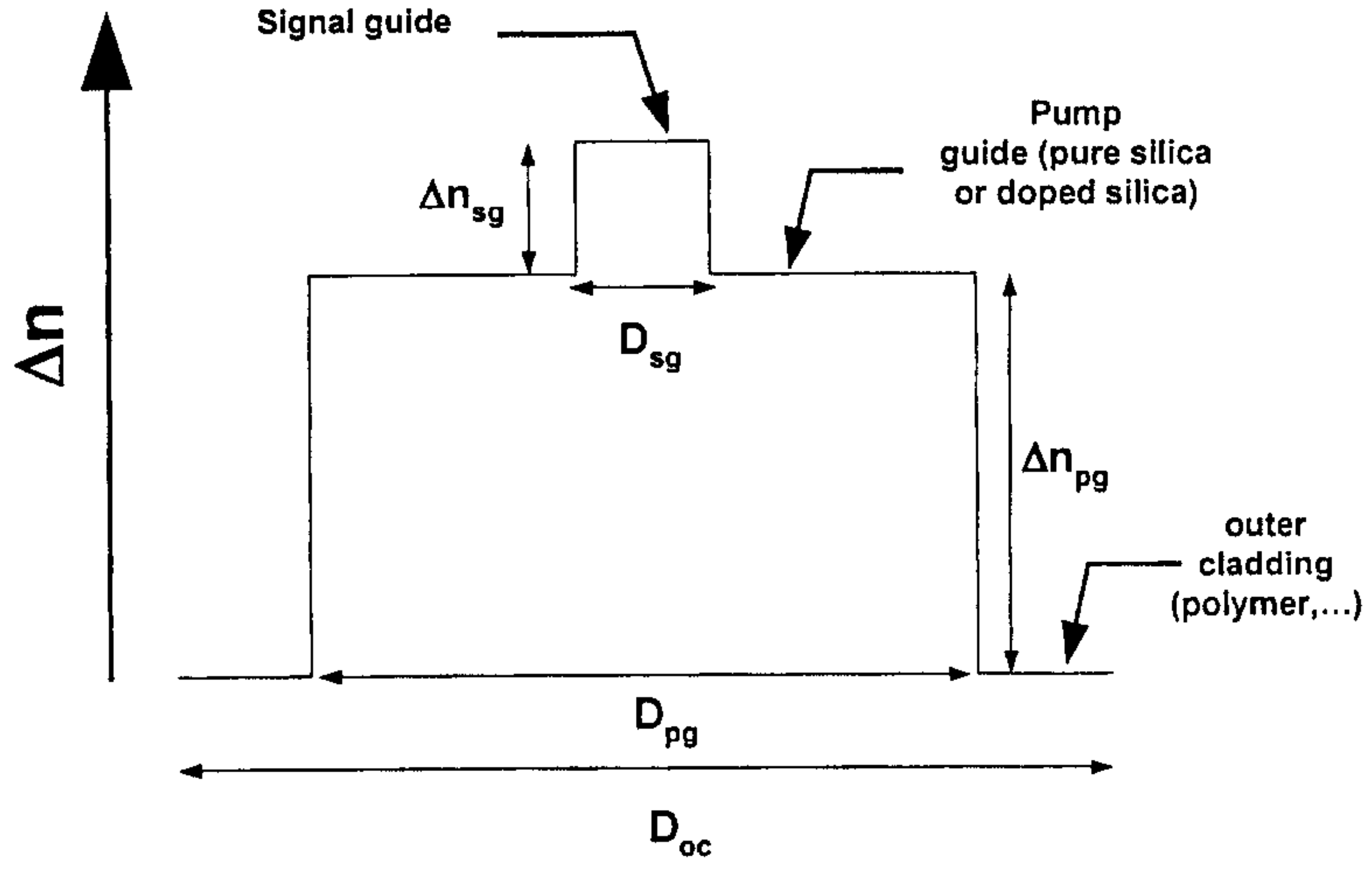


Figure 1

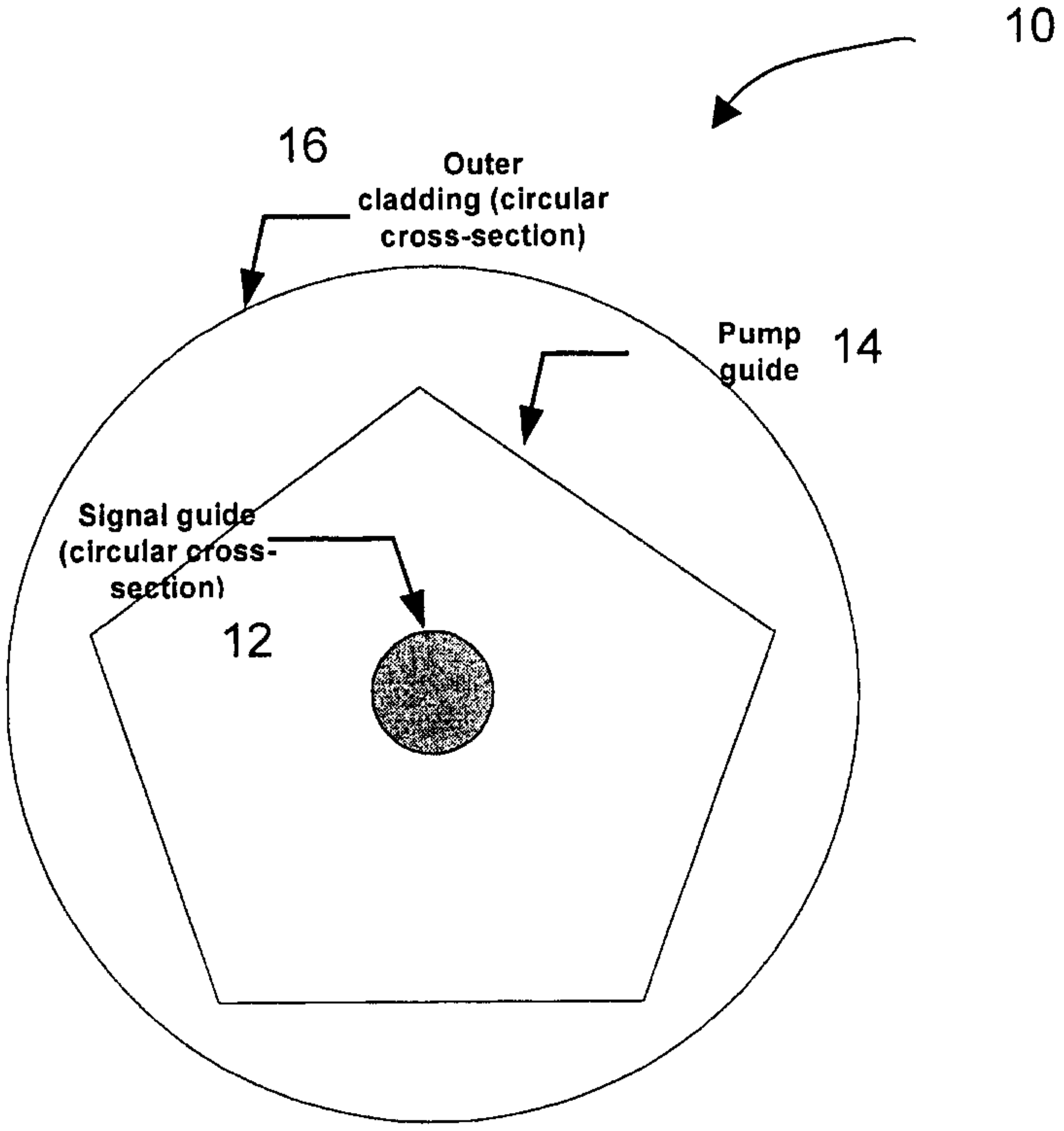


Figure 2

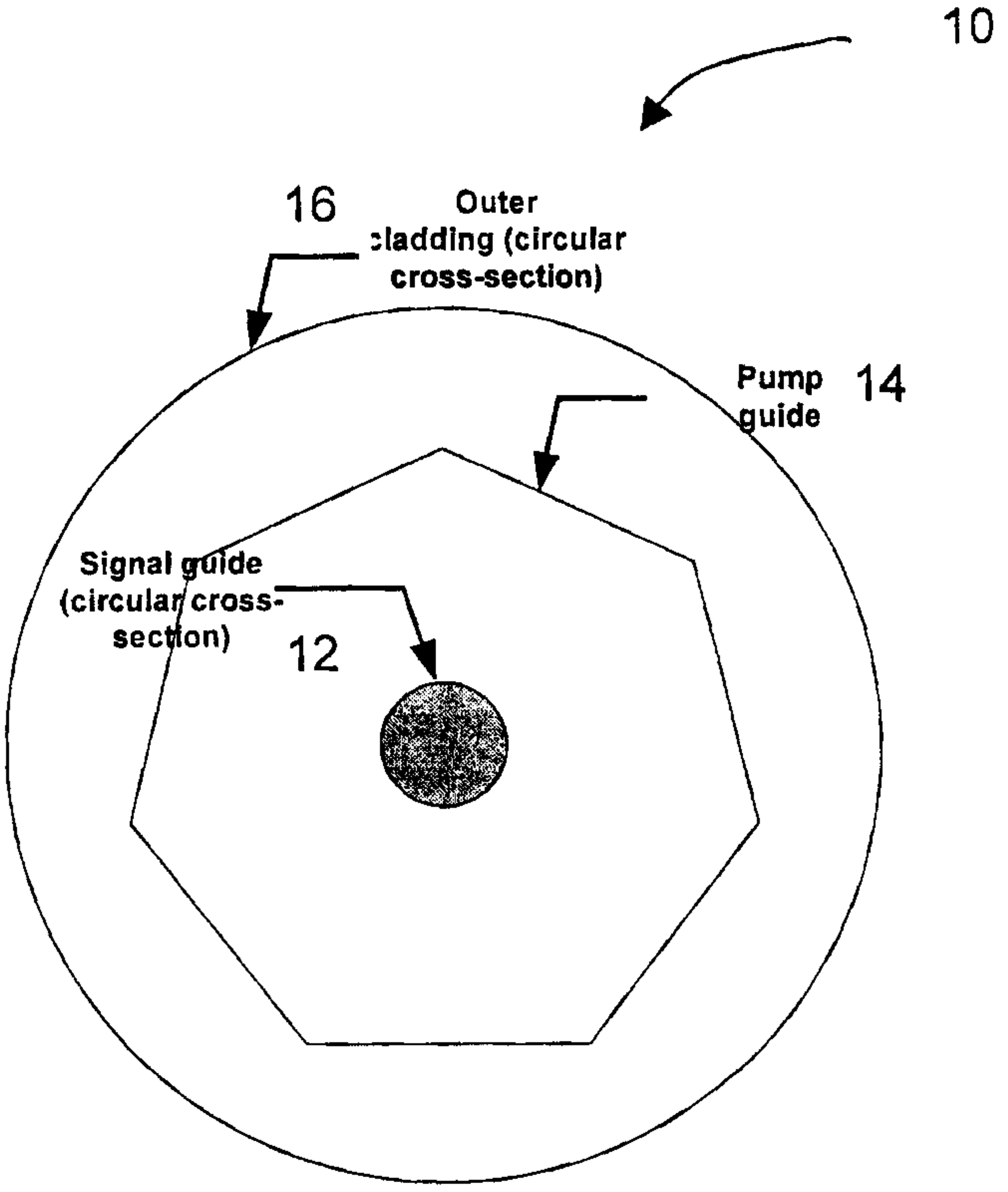


Figure 3

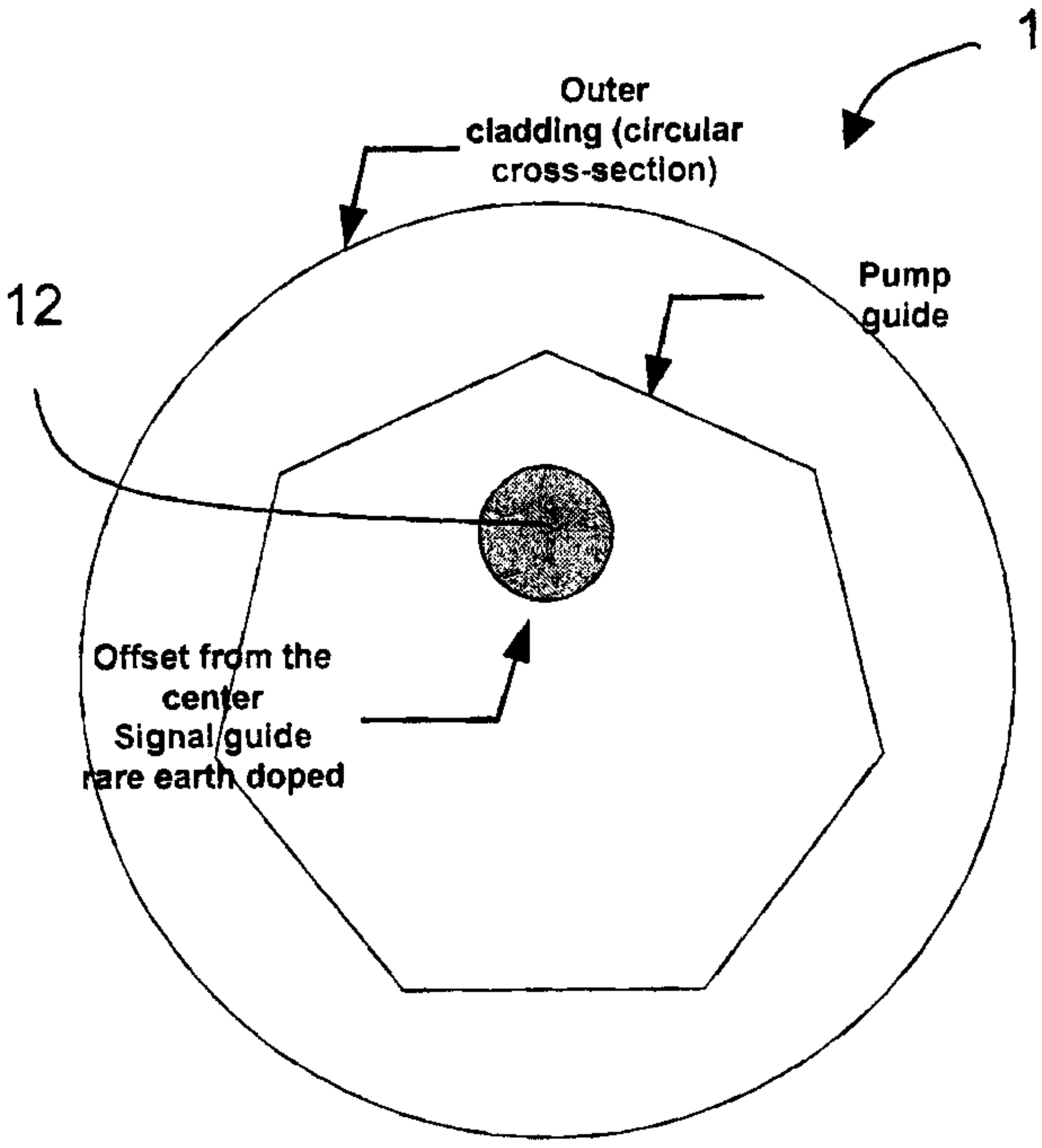


Figure 4A

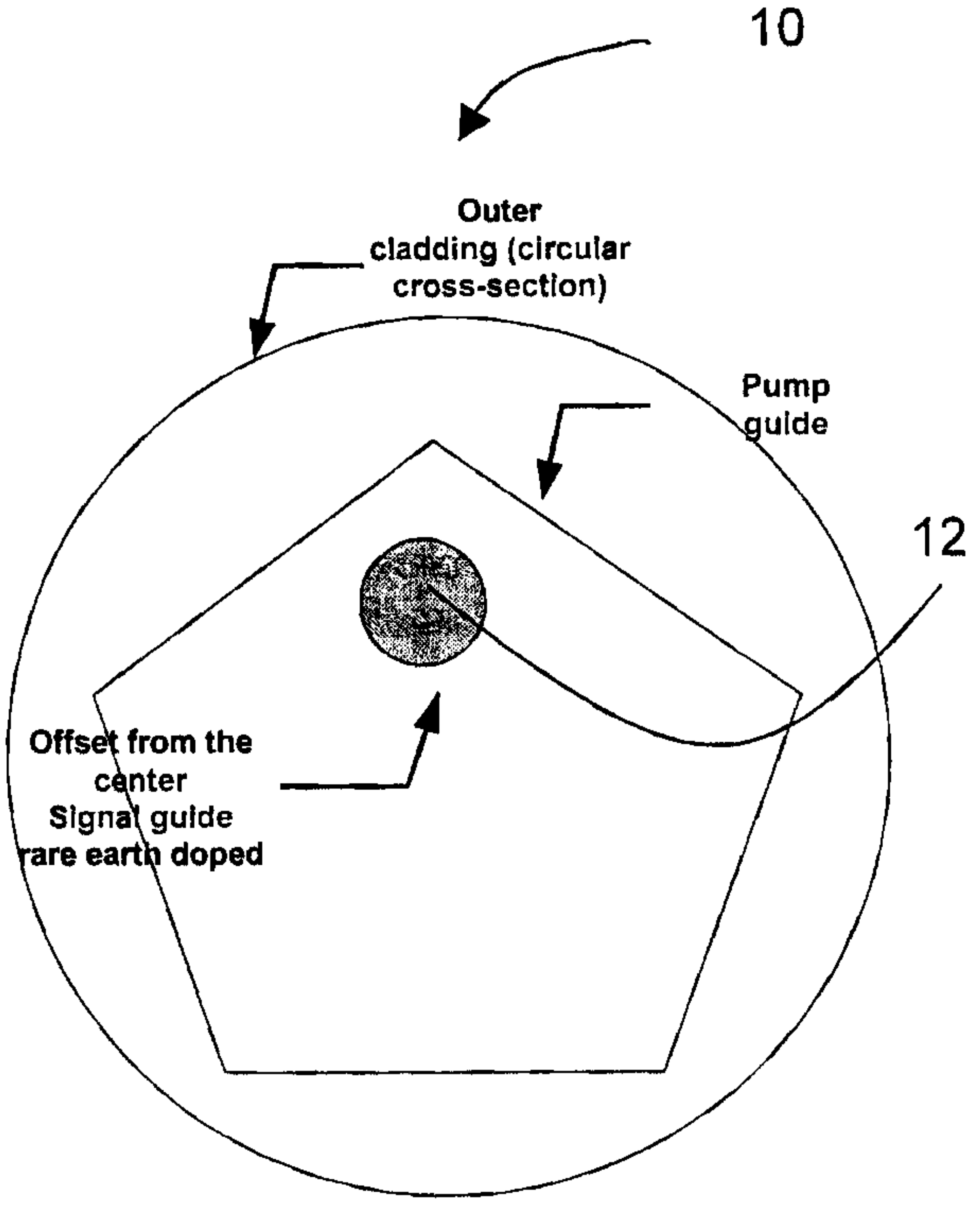


Figure 4B

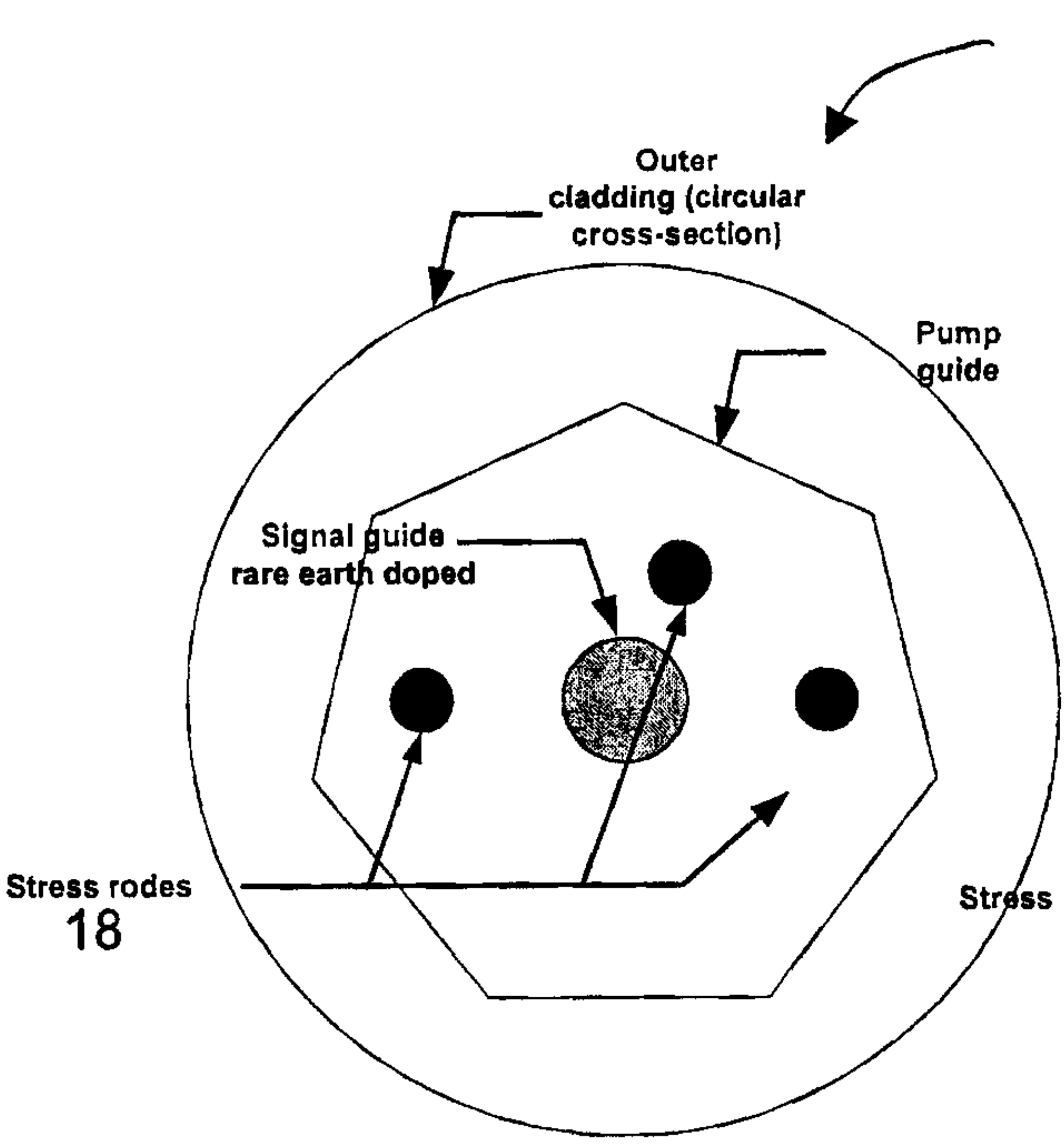


Figure 5A

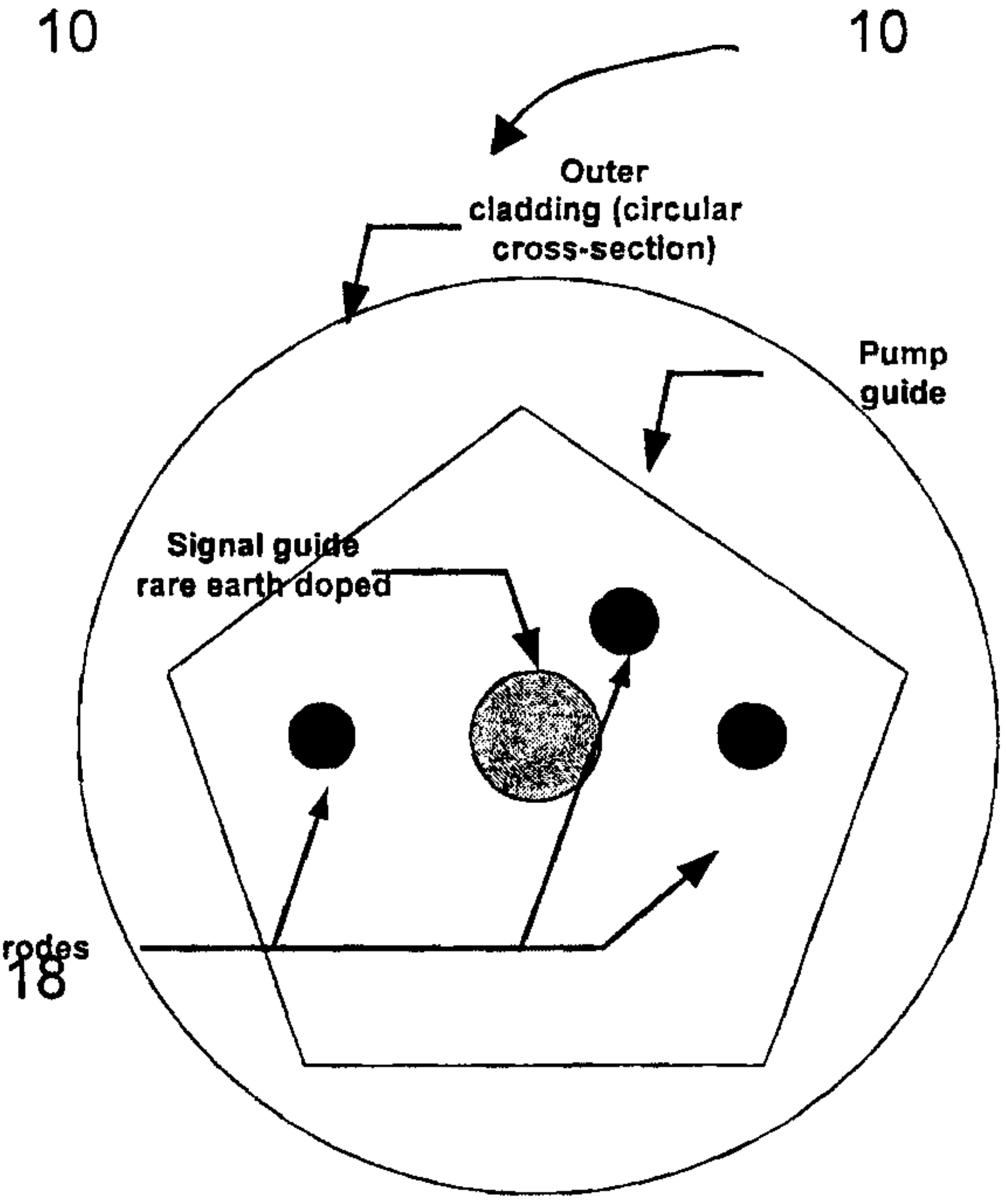


Figure 5B

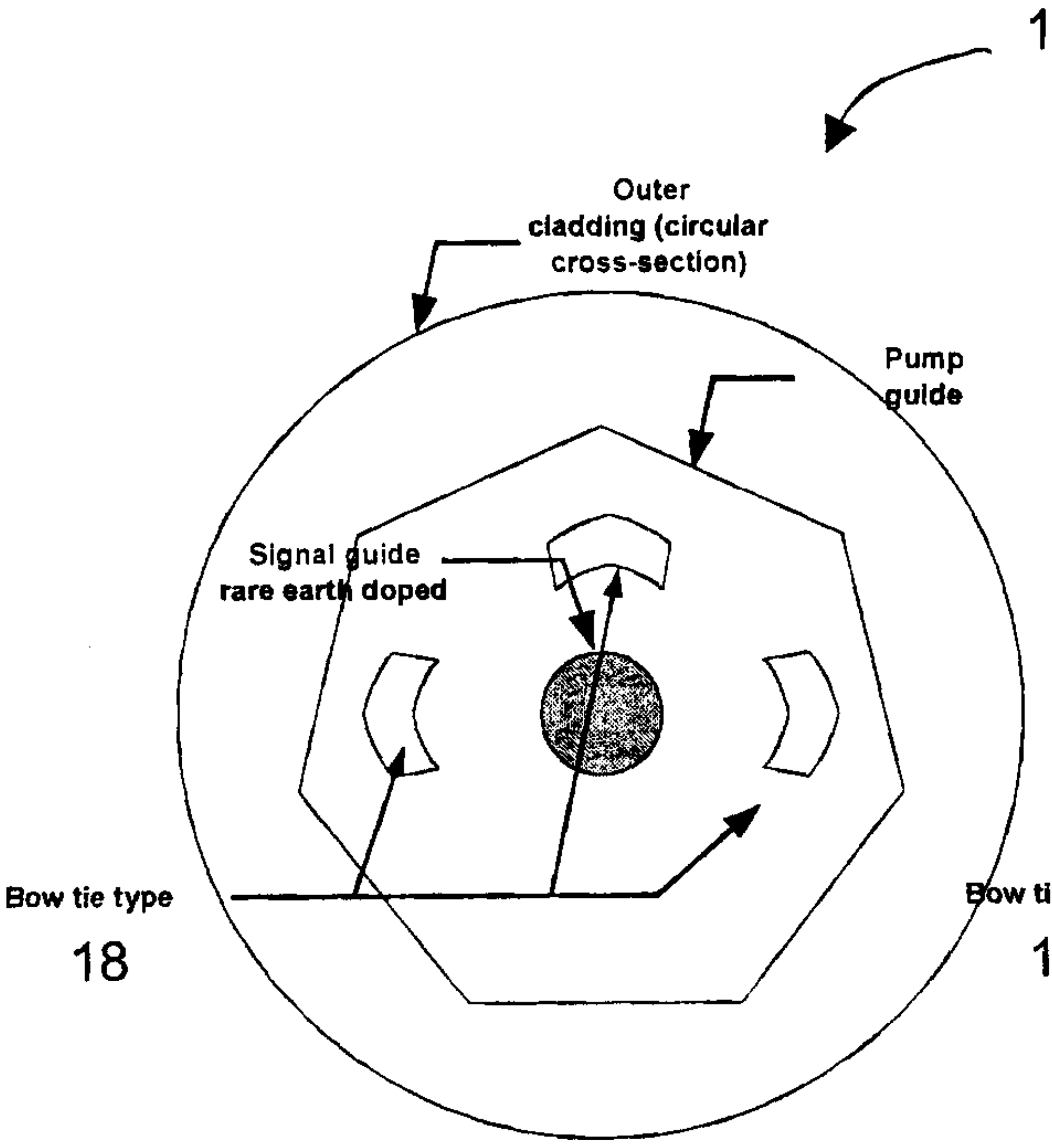


Figure 5C

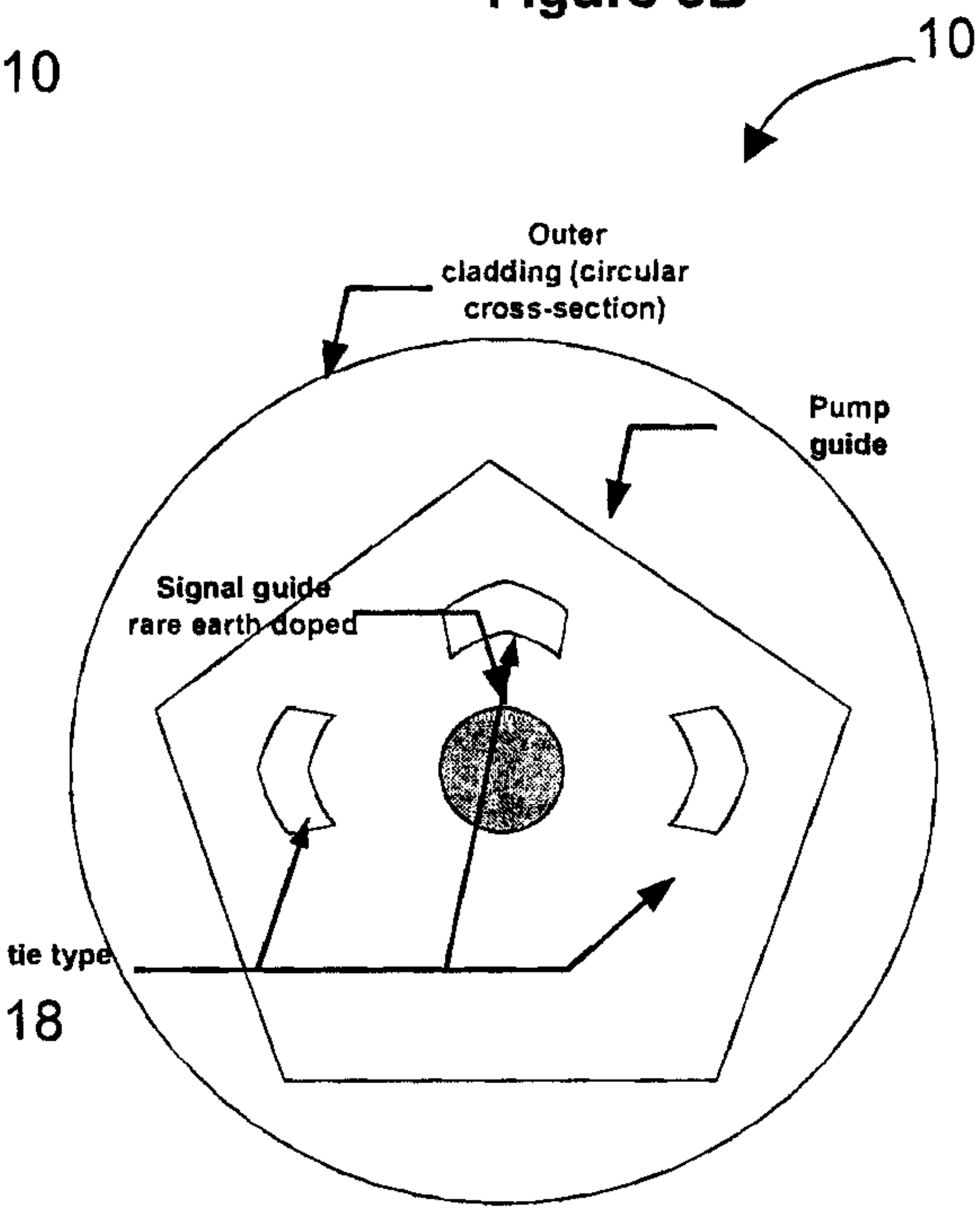


Figure 5D

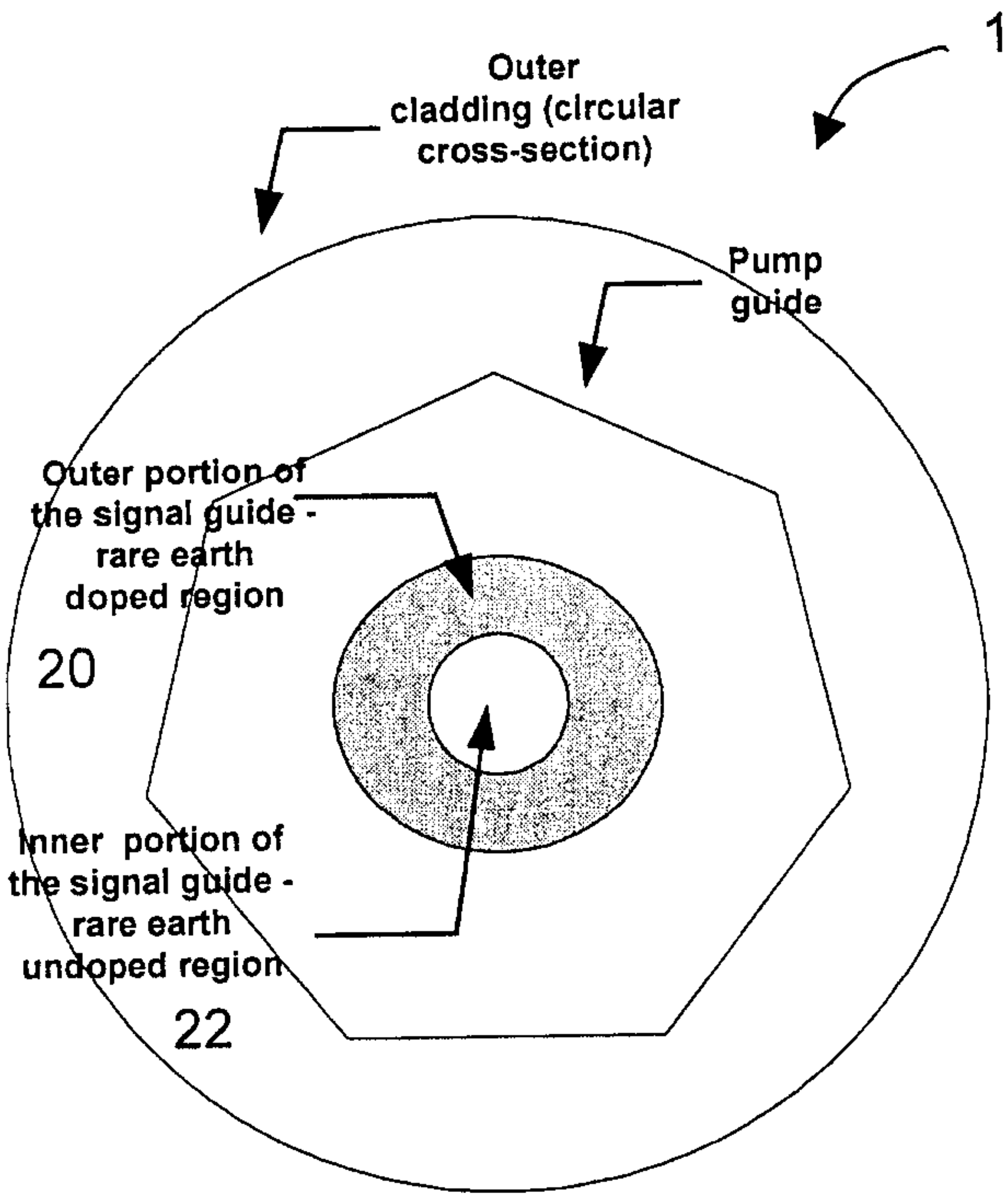


Figure 6A

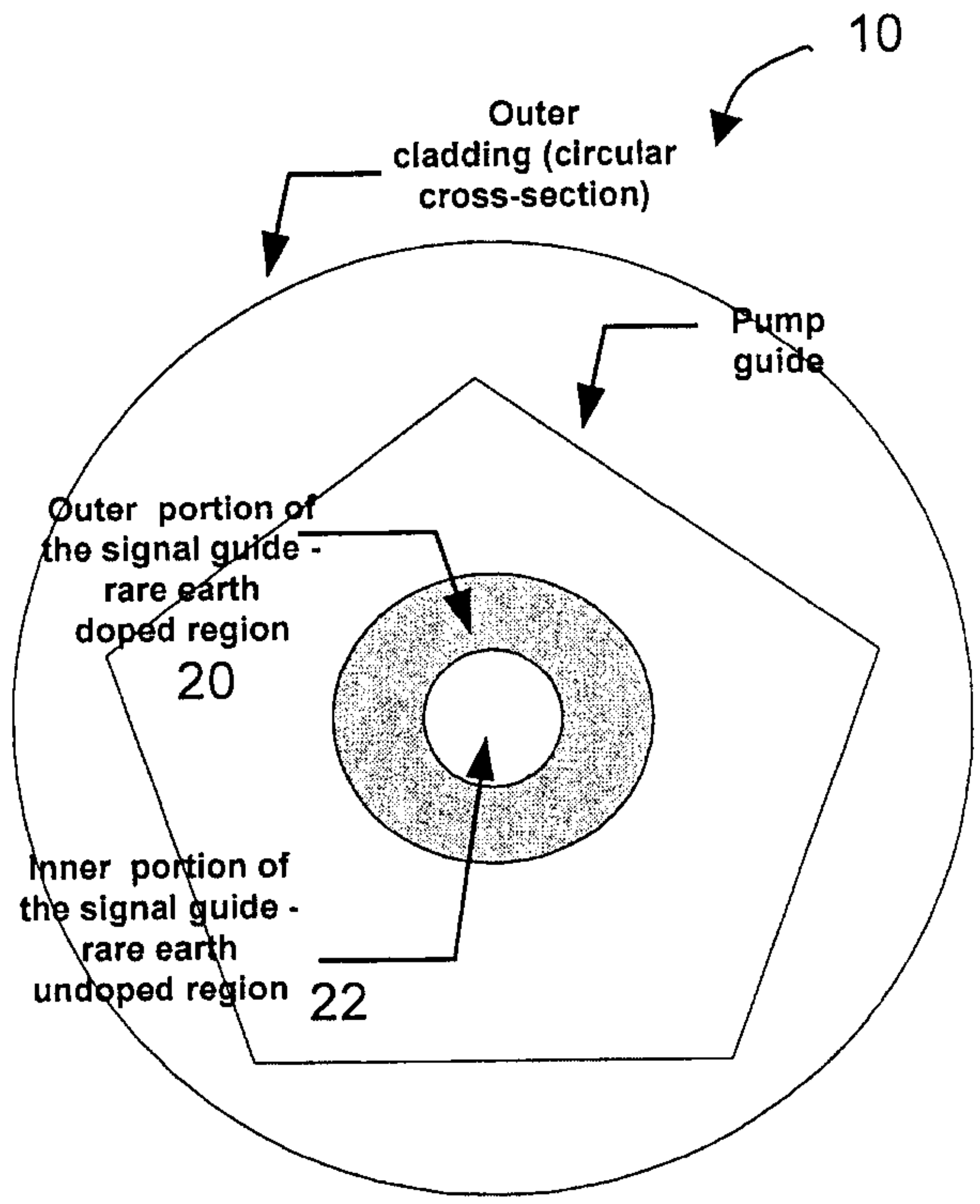


Figure 6B

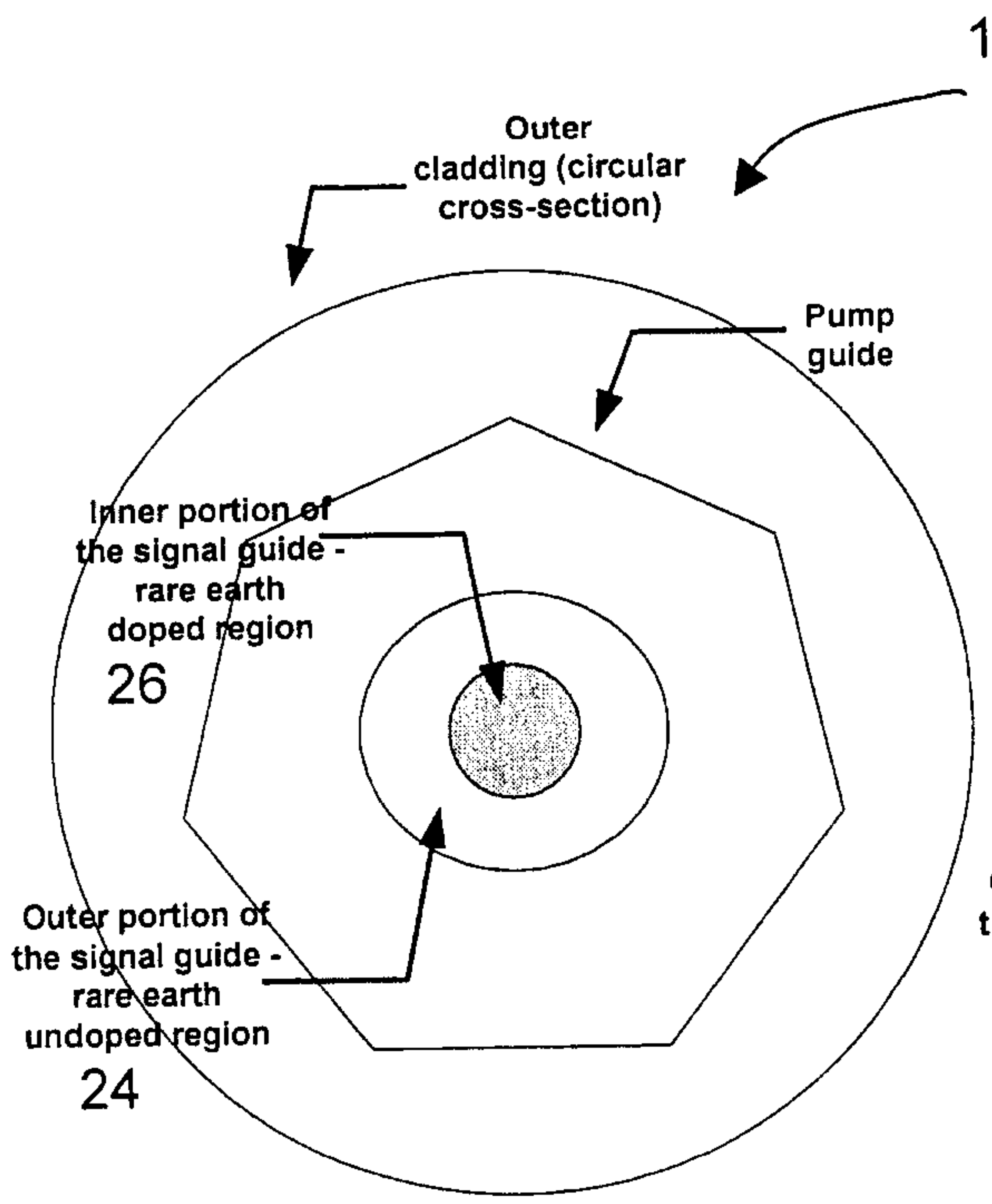


Figure 7A

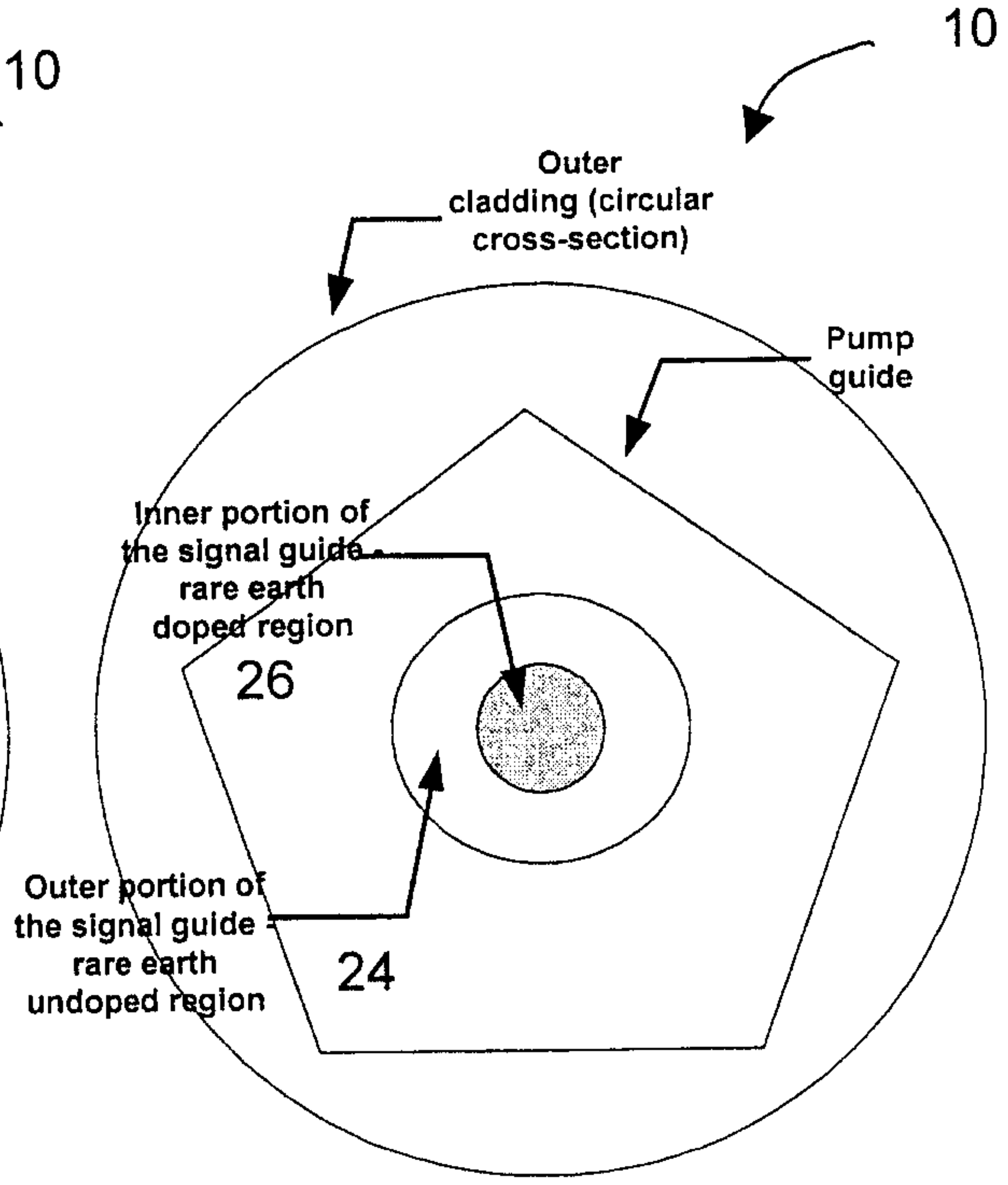


Figure 7B

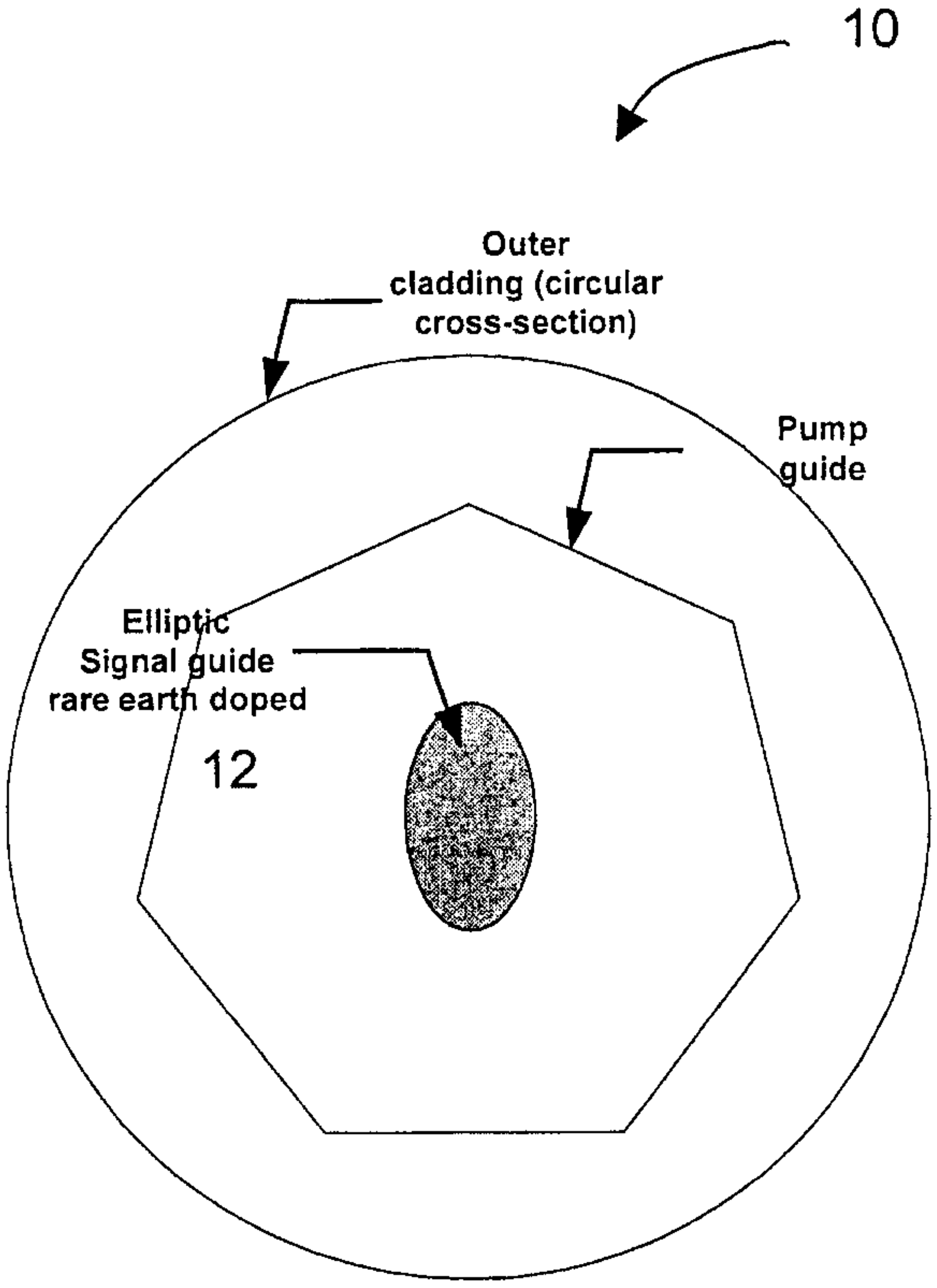


Figure 8A

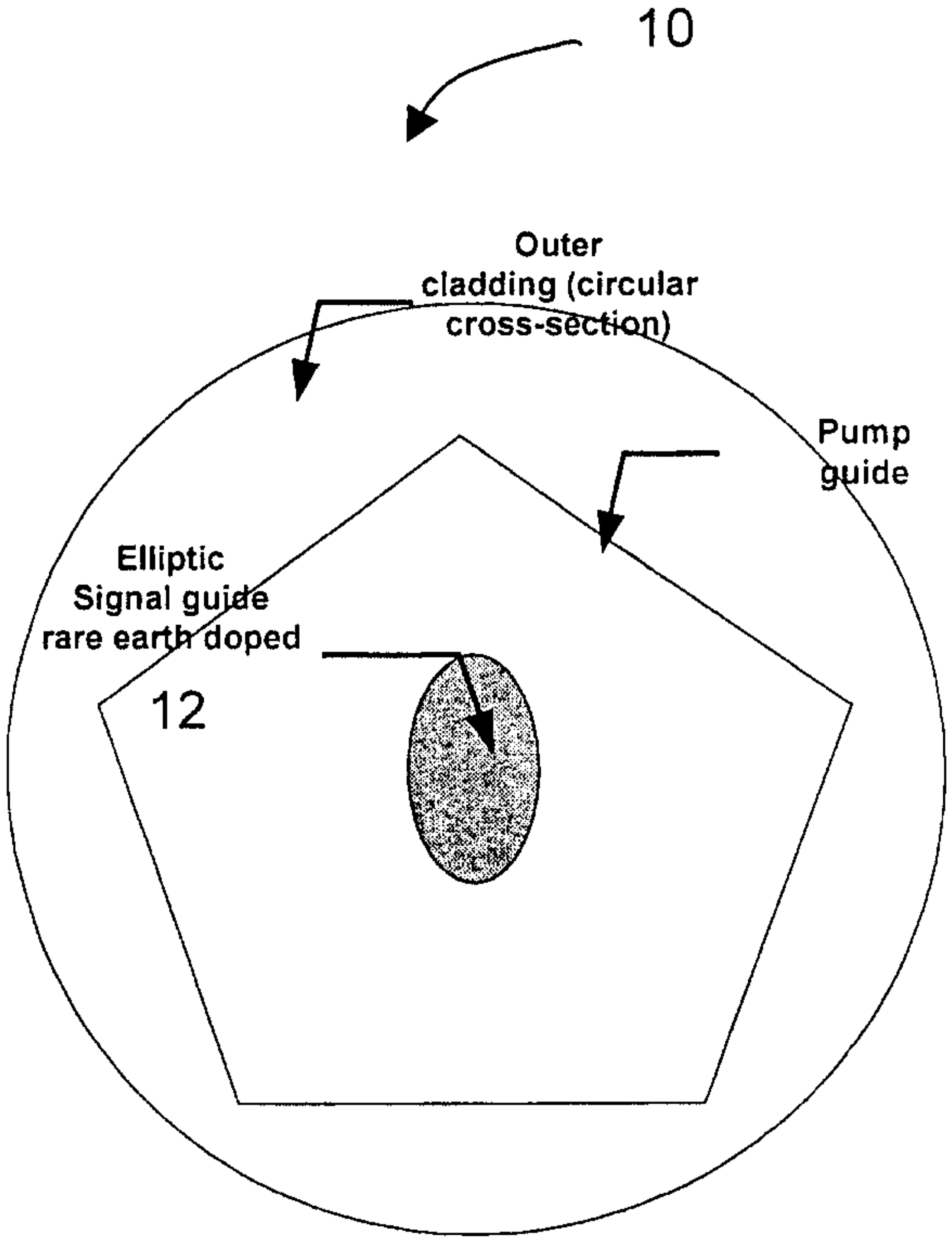
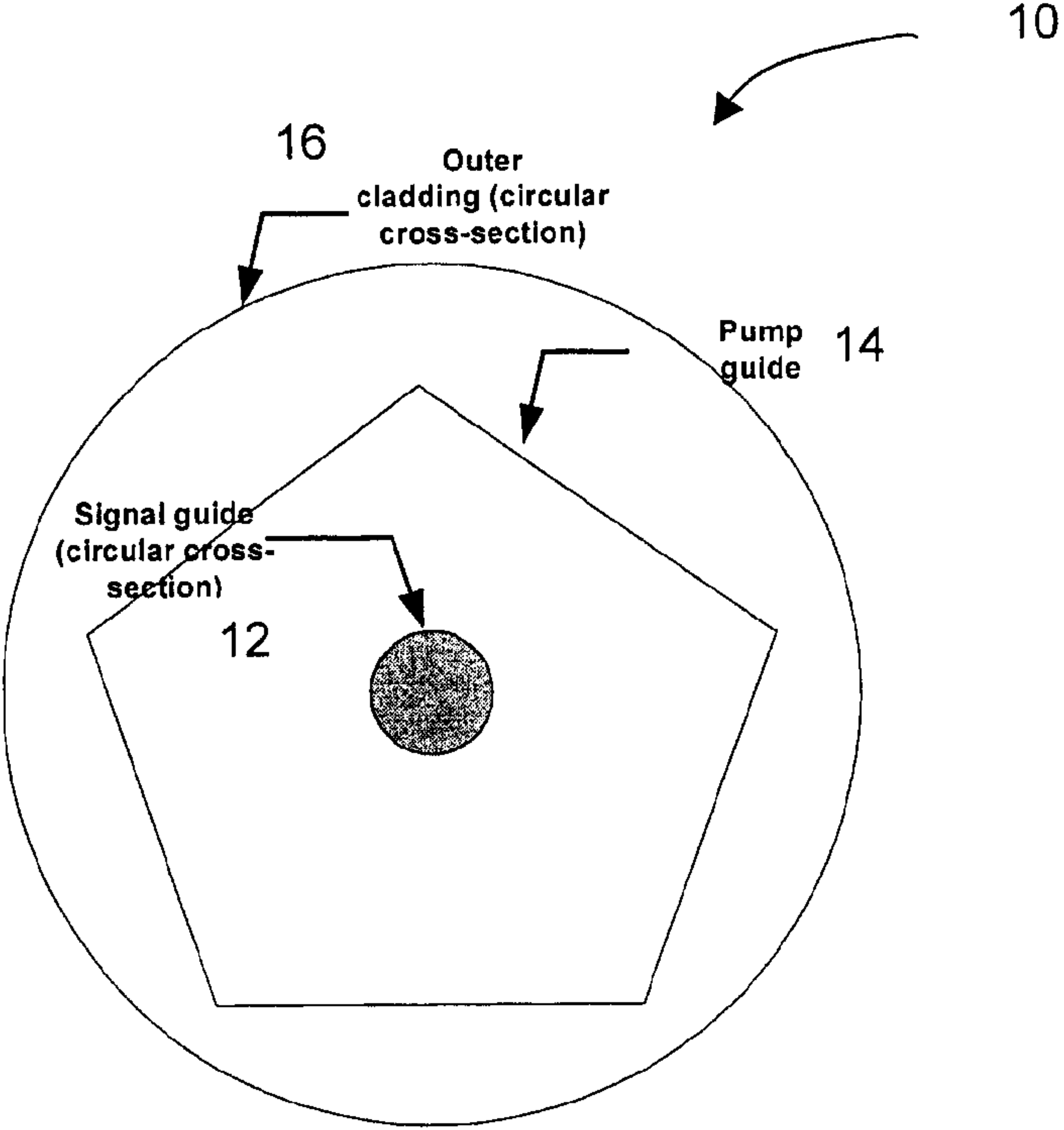


Figure 8B


10
16
Outer cladding (circular cross-section)
Pump guide
14
Signal guide (circular cross-section)
12