



- (51) **International Patent Classification:**
G02B 6/38 (2006.01) *H01P 5/02* (2006.01)
H01P 1/04 (2006.01)
- (21) **International Application Number:**
PCT/GB2017/050308
- (22) **International Filing Date:**
8 February 2017 (08.02.2017)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
1602372.3 10 February 2016 (10.02.2016) GB
16275023.6 10 February 2016 (10.02.2016) EP
- (71) **Applicant:** BAE SYSTEMS PLC [GB/GB]; 6 Carlton Gardens, London SW1Y 5AD (GB).
- (72) **Inventors:** HARPER, Richard John; BAE Systems, Applied Intelligence Laboratories, Great Baddow, Chelmsford Essex CM2 8HN (GB). PLUCINSKI, Thomas, Mark; BAE Systems, Applied Intelligence Laboratories, Great Baddow, Chelmsford Essex CM2 8HN (GB). MCLAREN, Stephen, William; Airbus Defence and Space, Gunnels Wood Road, Stevenage Hertfordshire SG1 2AS (GB).
- (74) **Agent:** BAE SYSTEMS PLC, GROUP IP DEPT; Farnborough Aerospace Centre, Farnborough Hampshire GU14 6YU (GB).

(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

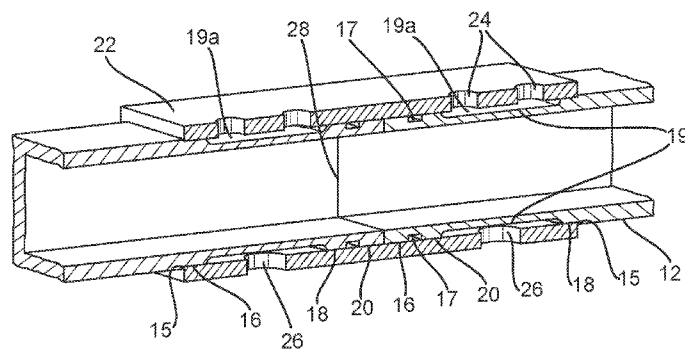
— as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

Published:

— with international search report (Art. 21(3))

(54) **Title:** WAVEGUIDES

Fig. 2



(57) **Abstract:** A waveguide comprising first and second waveguide sections, each waveguide section comprising a main body portion (12) and a connecting portion (14) at its distal end, said first and second waveguide sections being longitudinally aligned to define a conduit therethrough with a butted interface (28) therebetween, the connecting portion of each waveguide section having: (i) a first circumferential ridge (16) on its outer surface located adjacent its distal end, (ii) a second circumferential ridge (18) on its outer surface spaced apart from the first circumferential ridge, and (iii) a third circumferential ridge (20) on its outer surface located between said first and second circumferential ridges, such that a first respective recess (19) is defined between said second and third circumferential ridges and a second respective recess (17) is defined between said first and third circumferential ridges; the waveguide further comprising a sleeve member (22) over said butted interface (28), such that a respective first cavity (19a) is defined between an inner surface of said sleeve member (22) and each said first recess (19) and a respective second cavity is defined between the inner surface of said sleeve member (22) and each said second recess (17), each said first cavity (19a) having a chemical adhesive therein operative to join said first and second waveguide sections together by means of said sleeve member (22).



WAVEGUIDES

This invention relates generally to a waveguide, and a method of manufacturing a waveguide, for use in, for example, communication or radar applications.

Waveguides are generally used for connecting together transmitting and receiving equipment in, for example, communication or radar systems. A waveguide typically comprises a transmission line formed from a hollow conducting tube providing a conduit through which electromagnetic waves are propagated, and may be of any cross-sectional shape, such as, square, rectangular, circular or elliptical, as well as containing single or pairs of opposing ridges.

Regardless of the application in which waveguides are to be used, they are commonly provided with some means of connecting adjacent waveguide sections. The successful connection of waveguides for good Radio Frequency (RF) performance requires that the signals being carried by the waveguides are not significantly reflected, absorbed or distorted by the junction, i.e. the junction offers no appreciable discontinuity to the flow of microwave power. This requires that the internal cross-sections on each side of the junction are well aligned, there is low electrical resistance across the interface and that the point of good contact (i.e. low electrical resistance) occurs at the inside wall of the waveguide, where the electrical currents are generated by the passing signals within.

To this end, various mechanical joints are available, but traditionally, waveguide sections are each provided with flanged ends and connections to components and other discrete waveguide sections are made by using threaded bolts to pull together the flanged ends of the waveguides to form a contacting joint. Flange designs tend to be standardised and, in combination with the above-mentioned fixing bolts, provide the required alignment between waveguides with sufficient mechanical integrity to resist the applied physical forces occurring in service: in a space application, for example, such loads may arise in vibration during launch and differential thermal expansion when in orbit.

- 2 -

In communication systems, where a single waveguide may be carrying high level signals to be transmitted using two or more carrier frequencies, as well as low level received signals, another issue can occur, known as passive intermodulation. Passive intermodulation (PIM) is the generation of interfering signals caused by nonlinearities in the mechanical components of a system, and occurs when two signals mix together (amplitude modulation) to produce sum and difference signals and products within the same band, causing distortion. These effects can occur at waveguide interfaces and a common approach to minimising the effect is to ensure that there is a high contact pressure at the inside wall, usually achieved by providing a raised contact lip around the inside wall so the contact force applied by the fixing bolts is concentrated at this point.

In view of the proven electrical performance of bolted flanges, and similar mechanical joints, together with the reversibility and resultant flexibility thereof, they have long provided the most widely accepted method of joining waveguide sections to each other and/or other interfaces.

However, in modern communication satellites, for example, there can be hundreds or even thousands of waveguide junctions and the resultant mass of flanges and associated fixings can cause significant issues. For instance, the flanges require additional space to be provided at each joint as well as sufficient access to enable the fixing bolts to be tightened. Furthermore, more complex antennas may have many waveguides feeding into them, and in some cases there may be insufficient room for traditional flanged connections.

UK Patent No GB971481 describes a method of joining two waveguide sections together, wherein each waveguide section has, at its connecting end, a respective sleeve section affixed around the waveguide section by means of an adhesive injected into an orifice or 'pocket' formed by complementary recesses in the outer wall of the waveguide section and the inner wall of the sleeve section. Subsequently, the two waveguide sections are joined together at their sleeve section ends by providing a further sleeve member over the butted interface between the sleeve sections, and affixed thereto by means of an adhesive injected into orifices or 'pockets' formed by complementary recesses

- 3 -

in the outer wall of each sleeve section and the inner wall of the sleeve member.

There are a number of issues associated with the above-described method. Firstly, the method described necessitates the use of two sleeve
5 layers, which significantly increases the overall diameter of the resultant waveguide. In many applications, this is simply not acceptable in view of space constraints. Thus, the above-described method is not suitable for many applications. Furthermore, whilst the configuration of the sleeve sections is intended to mitigate the ingress of adhesive into the waveguide joint, this can
10 only be effectively achieved by very careful control of the quantity of adhesive injected into the 'pockets' and/or the use of an adhesive of relatively high viscosity. In the event that even a slight excess of adhesive is injected into the pockets, that excess adhesive will inevitably ooze into the area of the waveguide joint, adversely affecting its RF performance. The alternative or
15 additional requirement that a relatively highly viscous adhesive is used to try and mitigate this possibility, means that there is a severe limitation placed on how thin this layer of adhesive can be made. In applications where RF performance is as critical as minimising the dimensions of the resultant waveguide (due to space restrictions, for example), these issues further restrict
20 the applications in which the described method can be effectively used.

It is an object of aspects of the present invention to address at least some of these issues and, in accordance with a first aspect of the present invention, there is provided a waveguide comprising first and second waveguide sections, each waveguide section comprising a main body portion and a
25 connecting portion at its distal end, said first and second waveguide sections being longitudinally aligned to define a conduit therethrough with a butted interface therebetween, the connecting portion of each waveguide section having: (i) a first circumferential ridge on its outer surface located adjacent its distal end, (ii) a second circumferential ridge on its outer surface spaced apart
30 from the first circumferential ridge, and (iii) a third circumferential ridge on its outer surface located between said first and second circumferential ridges, such that a first respective recess is defined between said second and third

- 4 -

circumferential ridges and a second respective recess is defined between said first and third circumferential ridges; the waveguide further comprising a sleeve member over said butted interface, such that a respective first cavity is defined between an inner surface of said sleeve member and each said first recess and
5 a respective second cavity is defined between the inner surface of said sleeve member and each said second recess, each said first cavity having a chemical adhesive therein operative to join said first and second waveguide sections together by means of said sleeve member.

The provision of the first circumferential ridges or 'dams', i.e. the second
10 cavity, provides an 'overflow' region for receiving any excess adhesive from the first cavity and preventing ingress thereof into the waveguide joint, thereby providing an improved method of joining the waveguide sections without adversely affecting the RF performance of the resultant waveguide, and without the need for additional sleeve members or the use of highly viscous adhesive.

15 In an exemplary embodiment, the outer edges of each first recess may be joined to, or formed integrally with, the second and third circumferential ridges by respective convex (fillet) corners or 'rounds', which have the effect of reducing stress within the waveguide wall, but also of helping to retain the adhesive in the first cavity. An outer edge of each second recess may be joined
20 to, or formed integrally with, the third circumferential ridge by a substantially right-angled corner, thereby providing a substantially vertical side wall, which has the effect of ensuring that any adhesive that escapes from the first cavity is captured into the second cavity. The opposing outer edge of each second recess may also be joined to, or integrally formed with, the first circumferential
25 ridge by a substantially right-angled corner, thereby providing a substantially vertical side wall, which has the effect of preventing any adhesive that has escaped from the first cavity into the second cavity from reaching the butted interface between the first and second waveguide sections.

It will be appreciated that, in a preferred embodiment, the circumferential
30 ridges may define an external diameter of said respective connecting end that substantially matches the inner diameter of said sleeve member. A maximum

- 5 -

distance between said ridges and an inner wall of said sleeve member may, in one exemplary embodiment of the invention, be 0.025mm or less.

The connecting ends of said first and second waveguide sections may be substantially identical, said butted interface may be substantially flat and substantially perpendicular to a waveguide axis defined by said conduit, and
5 said sleeve member may comprise a tubular member configured to surround said butted interface.

The connecting end of said first waveguide section may comprise a male end piece and the connecting end of said second waveguide section may
10 comprise a female end portion including a sleeve portion for receiving said male end portion and aligning said waveguide sections with a choked interface therebetween. The use of a choke design herein may desensitise the electrical performance of the waveguide to the contact conditions and improve PIM performance.

The male end piece may include a recess extending from its distal end of
15 length one quarter of the waveguide wavelength, and the recess, together with a gap between said male and female end pieces of length one quarter of said waveguide wavelength, may thus define said choked interface.

In accordance with another aspect of the present invention, there is provided a
20 method of manufacturing a waveguide comprising the steps of:

providing first and second waveguide sections, each waveguide section comprising a main body portion and a connecting portion at its distal end, the connecting portion of each waveguide section having: (i) a first circumferential
25 ridge on its outer surface located adjacent its distal end, (ii) a second circumferential ridge on its outer surface spaced apart from the first circumferential ridge, and (iii) a third circumferential ridge on its outer surface located between said first and second circumferential ridges, such that a first respective recess is defined between said second and third circumferential
ridges and a second respective recess is defined between said first and third
30 circumferential ridges;

- 6 -

placing said first and second waveguide sections in longitudinal alignment to define a conduit therethrough with a butted interface therebetween;

placing a sleeve member over said butted interface, such that a respective first cavity is defined between an inner surface of said sleeve member and each said first recess and a respective second cavity is defined between the inner
5 surface of said sleeve member and each said second groove; and

introducing, into each said first cavity, a chemical adhesive so as to join said first and second waveguide sections together by means of said sleeve member.

In an exemplary embodiment, the sleeve member may have at least one
10 hole therein, and the method may include the step of injecting said chemical adhesive into said first cavity through said at least one hole.

The method may include the step of applying a preload to said butted interface prior to introducing said chemical adhesive into said first cavity.

The method may include the steps of determining, in respect of a bond-
15 line provided by said chemical adhesive within said first cavity, a maximum strength under shear load, identifying a thickness of said bond-line associated with said determined maximum strength, and providing a first and/or second waveguide section having a connecting end with a recess having a depth substantially matching said thickness.

In accordance with another aspect of the present invention there is
20 provided a waveguide section for use in a method substantially as described above, comprising a main body portion and a connecting portion at its distal end, the connecting portion having: (i) a first circumferential ridge on its outer surface located adjacent its distal end, (ii) a second circumferential ridge on its
25 outer surface spaced apart from the first circumferential ridge, and (iii) a third circumferential ridge on its outer surface located between said first and second circumferential ridges, such that a first respective recess is defined between said second and third circumferential ridges and a second respective recess is defined between said first and third circumferential ridges.

In accordance with yet another aspect of the present invention, there is
30 provided a connecting end for a waveguide section substantially as described

- 7 -

above, comprising a generally tubular member having: (i) a first circumferential ridge on its outer surface located adjacent its distal end, (ii) a second circumferential ridge on its outer surface spaced apart from the first circumferential ridge, and (iii) a third circumferential ridge on its outer surface
5 located between said first and second circumferential ridges, such that a first respective recess is defined between said second and third circumferential ridges and a second respective recess is defined between said first and third circumferential ridges, said connecting end being configured to be affixed to an end of a waveguide section.

10 In accordance with a further aspect of the invention, there is provided a connecting end for a second waveguide section for use in a method substantially as described above with a first waveguide section substantially as described above, wherein said connecting end comprises a sleeve member configured to receive the connecting end of said first waveguide section, said
15 connecting member being configured to be affixed to an end of said second waveguide section.

These and other aspects of the invention will be apparent from the following specific description, in which embodiments of the present invention are described, by way of examples only, and with reference to the
20 accompanying drawings, in which:

Figure 1 is a schematic perspective view of a waveguide section according to a first exemplary embodiment of the present invention;

Figure 2 is a schematic cut-away perspective view of a waveguide according to an exemplary embodiment of the present invention;

25 Figure 3 is a schematic perspective view of a waveguide according to an exemplary embodiment of the present invention illustrating the application of a preload during the manufacturing process;

Figure 4 is a schematic perspective view of a waveguide section according to another exemplary embodiment of the present invention,
30 illustrating a male end piece;

- 8 -

Figure 5 is a schematic cut-away perspective view of a waveguide according to an exemplary embodiment of the present invention;

Figure 6 is a schematic perspective view of a waveguide section according to an exemplary embodiment of the present invention, illustrating a female end piece; and

Figure 7 is a schematic perspective view of a waveguide according to an exemplary embodiment of the present invention illustrating the application of a preload during the manufacturing process.

Referring to Figure 1 of the drawings, a waveguide section 10 according to an exemplary embodiment of the present invention comprises a transmission line formed from a hollow conducting tube of generally rectangular cross-section, providing a conduit through which electromagnetic waves can be propagated, in use. The transmission line comprises two sections: a main body 12 and a connecting end 14. The outer profile of the main body 12 is generally uniform and may be of any known configuration. The connecting end 14 is of the same general cross-sectional shape as the main body 12 and extends concentrically therefrom so as to provide a continuous conduit 13 through the waveguide section, but the overall cross-sectional area of the connecting end 14 is slightly smaller than that of the main body 12 such that there is a small stepped portion 15 where they meet.

Three concentric circumferential ridges (or 'dams') 16, 18, 20 are provided on the outer wall of the connecting end 14. A first dam 16 is located at the distal end of the connecting end 14, i.e. furthest from the main body 12. A second dam 18 is located adjacent the stepped portion 15 between the main body 12 and the connecting end 14. A third dam 20 is provided close to, but spaced apart from, the first dam 16 to define a circumferential groove 17 therebetween. The elongate section of the connecting end 14 between the second and third dams 18, 20 defines a second, wider circumferential groove 19. The ends of the section defining the groove 19 are joined or formed integrally with the second and third dams 18, 20 by respective convex (fillet) corners or so-called rounds 21 which have the effect of reducing stress within the waveguide wall.

- 9 -

In a method, according to an exemplary embodiment of the invention, of manufacturing a waveguide by joining two such waveguide sections together, and referring additionally to Figure 2 of the drawings, a sleeve 22 is employed. The sleeve 22 comprises a rigid tube of generally rectangular cross-section (in this case) defining a channel therethrough that has inner dimensions to closely fit the outer dimensions of the connecting ends 14 of the waveguide sections (but insufficient to accommodate the outer dimensions of the main body 12), such that the connecting ends can be inserted, via the open ends of the channel, into the sleeve 22 until further insertion of the respective waveguide section is prevented when the end of the sleeve 22 hits the stepped portion 15 between the connecting end 14 and the main body 12. It can be particularly seen in Figure 2 of the drawings that the sleeve 22 of a length to accommodate, within its channel, two abutted connecting ends 14 of respective waveguide sections, with the opposing end edges thereof each adjacent to, but not in contact with, a respective stepped portion 15.

The sleeve 22 is provided with holes 24, 26 in the upper and lower walls. More specifically, in this exemplary embodiment, two pairs of holes 24 are provided in the 'upper' wall of the sleeve 22 (in the orientation illustrated) and located such that, two abutted waveguide section connecting ends 14 are positioned within the sleeve channel, each pair of holes 24 is adjacent a respective wide circumferential groove 19 defined between second and third dams 18, 20 of the respective connecting end 14. Indeed, it can be seen that, with the sleeve *in situ* over a pair of abutted connecting ends, pockets 19a are defined between the grooves 19 and the adjacent inner wall of the sleeve 22. In this exemplary embodiment, a pair of single holes 26 is provided in the 'lower' wall of the sleeve 22, each hole 26 once again being located such that, when two abutted connecting ends 14 are positioned within the sleeve channel, each hole 26 is adjacent a respective 'pocket' 19a defined between a circumferential groove 19 and the adjacent inner wall of the sleeve 22.

Thus, in use, a connecting end 14 of a first waveguide section is inserted into the sleeve channel from one end until that end is adjacent to (but not contacting) the stepped portion 15 of the first connecting end 14. A connecting

- 10 -

end 14 of a second waveguide section is inserted into the sleeve channel from the opposite end until that end is adjacent to (but not contacting) the stepped portion 15 of the second connecting end, and the distal ends of the first and second connecting ends are essentially abutted, to create a butted (contact) interface 28.

The holes 24,26 allow adhesive to be injected into the pockets 19a formed between the connecting ends and the adjacent inner wall of the sleeve 22 (as discussed above). The continuous 'pockets' 19a allow the adhesive to flow completely around the waveguide/sleeve interface, and the pocket dimensions (i.e. length and height) can be selected (or adjusted) to optimise the adhesive bond-line thickness and, therefore, overall strength requirement determined/required by the application, as will be discussed in more detail hereinafter. It will be appreciated that the circumferential grooves 19 defining the pockets 19a can, for example, be formed in the respective connecting ends 14 of the waveguide sections by machining the external surface thereof. However, other methods of forming such grooves will be apparent to a person skilled in the art and the present invention is not necessarily intended to be limited in this regard. In an alternative exemplary embodiment, the grooves may additionally or alternatively be formed in the inner wall of the sleeve, and the present invention is, once again, not necessarily intended to be limited in this regard. Furthermore, it will be understood that greater bond strength is likely to be achieved, at least in most cases, if the adhesive is in direct contact with the base materials. Many high performance waveguides are silver plated to minimise loss and, in this case, it is desirable to ensure that the waveguide surfaces forming the pockets 19a are masked, during manufacture, to prevent such plating. There is not thought to be any requirement for the sleeve 22 to be plated, but it may be desirable for the outer surfaces thereof to be coated or otherwise treated, depending on the environment in which it is to be used.

It is essential for good electrical and RF performance of the resultant waveguide that adhesive is prevented from penetrating into the waveguide or significantly across the butted interface 28 between first and second connecting ends. This may be achieved by a) ensuring that the butted waveguide faces

- 11 -

are accurately machined to be flat and perpendicular to the waveguide axis; b) ensuring that the clearance between the inner wall of the sleeve 22 and the outer faces of the dams 16, 18, 20 is small, typically, say, 0.025mm or less; and/or c) applying a preload across the butted interface 28.

5 With particular reference to b) above, the third dam 20 in this exemplary embodiment is intended to prevent adhesive ingress into the waveguide, and the second dam 18 is intended to prevent excess adhesive from escaping through the end of the sleeve 22 and also to assist in improving the alignment of the sleeve on the waveguide. The ends of the section defining the first groove
10 17 are joined to, or formed integrally with, the first and third dams 16,20 by respective right-angled corners, The ends of the section defining the second groove 19 are joined to, or formed integrally with, the second and third dams 18, 20 by respective convex (fillet) corners or so-called 'rounds' 21 which not only have the effect of reducing stress within the waveguide wall, but also of
15 'discouraging' any adhesive therein from escaping at the side edges. Whilst the first groove 17 is narrower (or shorter) than the second groove 19, its substantially vertical side walls have the effect of a) ensuring that any adhesive that escapes from the second groove 19 is captured into the first groove 17, and b) ensuring that any excess adhesive captured in the first groove 17 does not
20 escape into the butted interface region 28.

However, it will be appreciated that the number and precise location on the connecting end 14 of such dams may vary from that depicted and described above, and the present invention is not necessarily intended to be limited in this regard. The acceptable clearance over the dams 16, 18, 20 may, at least to a
25 certain extent, be a function of adhesive viscosity, as will be understood by a person skilled in the art (i.e. the higher the viscosity, the greater can be the acceptable clearance). However, adhesives that have a relatively low viscosity during curing may require the use of additional sealing means, such as 'O' rings or the like, to seal the waveguide off from the adhesive.

30 It will be appreciated from the above that a simple sleeve arrangement of the type described above enables a strong bond-line to be created in a space-saving manner (compared with, for example, flange connections), so as to

- 12 -

connect waveguide sections together in a manner that satisfies the above-described requirement for good mechanical, electrical and RF performance. It will be appreciated that, in order to achieve the required high quality adhesive joints, the surfaces to be adhered should be prepared as specified by the
5 manufacturer of the adhesive being used. Furthermore, and with reference to c) above, for a simple butted junction, it is important to ensure good contact pressure at the interface 28. Thus, a preload may be applied at the interface 28, prior to bonding. Referring to Figure 3 of the drawings, such a preload may be applied by means of a clamp 30, or similar arrangement, configured to be
10 affixed to each of the two waveguide sections being joined, and apply a clamping force that pushes and holds the distal ends together (at the interface 28). In this case, it may be required to provide additional clamping features 32 on the outer surface of the main body 12 of each waveguide section to enable the clamp 30 to be affixed thereto. These features could, for example, be
15 brazed onto, or machined into, the outer walls of the main body 12, depending on the mechanical load requirements. Once the adhesive has been applied and cured, the clamp 30 can be removed.

In alternative exemplary embodiments, the 'sleeve' can be incorporated into one of the waveguide sections so that a male-female geometry is formed.
20 Thus, referring first to Figure 4 of the drawings, a waveguide section having a main body 34 and a male connecting end 36 is illustrated. The connecting end 36 is, in this case, a 'male' end piece and is of similar configuration to that of the connecting end 14 described above and illustrated in Figure 1 of the drawings. Thus, the male end piece comprises a generally rectangular tube having first
25 and third circumferential ridges or 'dams' 38, 42 close to the distal end, the first and third dams 38, 42 being spaced apart to define a relatively narrow groove 39 therebetween. A second dam 40 is provided close to the end adjacent the main body 34, such that a wider groove 41 is defined between the second and third dams 40, 42 as before. A circumferential flange 44 is located behind the
30 second dam 40, immediately adjacent the main body 34.

Referring additionally to Figure 5 of the drawings, the wall of the connecting end 36 is provided with a concentric channel 46 that extends all the

- 13 -

way around the wall and inwardly therethrough from the distal end. The width (the dimension parallel to the waveguide axis) of the channel 46 is equal to one quarter of the guide wavelength, and is therefore dependent on the frequency band of the application. The inner wall of the connecting end 36 is provided with
5 a stepped recess 48 at its distal end.

Referring now to Figure 6 of the drawings, as well as Figure 5, the female end piece 50 comprises an insert portion defining a 'sleeve' 52 comprising an outer wall 54 and a shorter, concentric inner wall 56 with a recess therebetween. The inner dimensions of the outer wall 54 are such that
10 they closely match those of the outer profile of the corresponding male end piece such that the male end piece can be inserted into the female end piece to form a butted interface at 58 (see Figure 5). In this configuration, the inner wall 56 of the female end piece rests within the stepped recess 48 in the inner wall of the male end piece (with a gap 59 therebetween) and there is a discrete gap
15 (depicted generally at 60) at the junction of the internal waveguide wall. It will be appreciated that the length of the gap leading from 60 (or recess 48) is also one quarter of the waveguide wavelength. The male and female end pieces, thus arranged and configured, form a choked-waveguide interface, wherein the discrete gap 60 leads into an RF quarter-wave choke circuit (formed by the gap
20 59 and the channel 46). The choke circuit is designed to minimise reflections from the gap 60 over a required frequency band, as will be familiar to a person skilled in the art, and it will be appreciated that the point of contact is, in this case, at 58. Thus, the circuit is designed so that, at the interface 58, the current crossing is minimised, which desensitises the performance of the junction to the
25 conditions at the junction (which may be advantageous, at least for some applications, when compared with the simpler sleeve design described above with reference to Figures 1 and 2 of the drawings).

As shown in Figures 5 and 6 of the drawings, the outer wall 54 of the sleeve defined by the female end piece is provided with a pair of holes 62 in
30 one wall and a single hole 64 in the opposing wall, wherein the holes 62, 64 are located adjacent the wider groove 41 in the male end piece when it is inserted fully within the sleeve. As before, the number and specific configuration of the

- 14 -

holes 62, 64 may vary and the present invention is not necessarily intended to be limited in this regard.

Cavities or 'pockets' 41a are thus created between the wider grooves 41 in the male end piece and the inner surface of the outer wall of the female end piece sleeve. As before, such pockets 41a can be formed by machining a groove in the outer surface of the male end piece (as shown) or on the inner surface of the female end piece sleeve, or both, and the present invention is not necessarily intended to be limited in this regard. The holes 62, 64 in the outer wall of the female end piece sleeve allow adhesive to be injected into the pockets 41a. The continuous pockets 41a allow the adhesive to flow completely around the interface between the male and female end pieces and, once again, the pocket dimensions can be designed/adjusted to optimise the adhesive bond-line thickness and overall strength requirement determined by the application. As before, the pockets 41a will typically be shallow and designed to maximise the adhesive bond-line strength depending on the adhesive used, and the length of the bond-line can be adjusted to the requirements of the application. Once again, and whilst not clearly shown in Figures 5 and 6, the edges of the wider grooves 41 are joined to, or formed integrally with, the second and third dams 40, 42 by a convex (fillet) corner or 'round' and the edges of the narrower groove defined between the first and third dams 38, 42 are joined to, or formed integrally with, the aforementioned dams for the reasons specified in relation to the embodiment of Figure 2.

It is anticipated that the male and female end pieces can be attached to a standard waveguide using the same or similar methods to those used in the art for connecting flanges thereto. Thus, for example, in the case of a typical aluminium waveguide, the end pieces could be torch brazed onto the waveguide in a manner that will be known to a person skilled in the art.

Once again, and as illustrated schematically in Figure 7 of the drawings, once the male end pieces has been fully inserted into the female end piece, and the surfaces prepared according to the adhesive manufacturer's instructions/specification, a preload may be applied to the assembly in order to ensure good contact pressure at the interface 58 and thereby minimise surface

- 15 -

effects (i.e. oxide layers) upon insertion loss and PIM. Such a preload may be applied by means of a temporary clamp 70 or any other suitable means, as will be apparent to a person skilled in the art.

It will be appreciated that many different types of adhesive may be considered suitable for use in embodiments of the present invention. In some 5 exemplary embodiments, an epoxy paste adhesive (i.e. relatively high viscosity) may be employed. For example, Hysol ® 9395 may be used which is a two-component adhesive system which is non-metallic and cures at ambient temperatures, but has excellent strength properties at temperatures of 10 350°F/177°C and higher. In this case, a BR127 primer can be used to prepare the surfaces to be adhered. However, the adhesive used will be dependent on many factors, including the specific configuration of the end pieces, the material of which the waveguide is made and the application in which the resultant waveguide is to be used. For example, in some exemplary embodiments, such 15 as those using the simple sleeve configuration described above in relation to Figures 1 and 2 of the drawings, an adhesive that cures to a hard resin consistency may be required to ensure that it can maintain the preload applied prior to bonding and maintain good electrical performance.

In all cases, manufacturers of commercially available adhesives usually 20 provide data indicative of the specific bond-line thickness required to give maximum strength under shear load. Thus, the height of the pocket (19a, 41a) can be set to achieve this figure.

It will be appreciated by a person skilled in the art, from the foregoing description, that modifications and variations can be made to the described 25 embodiments without departing from the scope of the invention as defined by the appended claims.

- 16 -

CLAIMS

1. A waveguide comprising first and second waveguide sections, each waveguide section comprising a main body portion (12) and a connecting portion (14) at its distal end, said first and second waveguide sections
5 being longitudinally aligned to define a conduit therethrough with a butted interface (28) therebetween, characterized in that the connecting portion (14) of each waveguide section has: (i) a first circumferential ridge (16) on its outer surface located adjacent its distal end, (ii) a second circumferential ridge (18) on its outer surface spaced apart from the first circumferential ridge, and (iii) a third circumferential ridge (20) on its
10 outer surface located between said first and second circumferential ridges, such that a first respective recess (19) is defined between said second and third circumferential ridges and a second respective recess (17) is defined between said first and third circumferential ridges; and in that the waveguide further comprises a sleeve member (22) over said
15 butted interface (28), such that a respective first cavity (19a) is defined between an inner surface of said sleeve member (22) and each said first recess (19) and a respective second cavity is defined between the inner surface of said sleeve member (22) and each said second recess (17),
20 each said first cavity (19a) having a chemical adhesive therein operative to join said first and second waveguide sections together by means of said sleeve member (22).
2. A waveguide according to claim 1, wherein the outer edges of each first recess (19) are joined to, or formed integrally with, the second and third circumferential ridges (18, 20) by respective convex (fillet) corners (21) or
25 'rounds'.
3. A waveguide according to claim 1 or claim 2, wherein an outer edge of each second recess (17) is joined to, or formed integrally with, the third circumferential ridge (20) by a substantially right-angled corner.
- 30 4. A waveguide according to claim 3, wherein the opposing outer edge of each second recess (17) is joined to, or integrally formed with, the first circumferential ridge (16) by a substantially right-angled corner.

- 17 -

5. A waveguide according to any of the preceding claims, wherein the circumferential ridges (16, 18, 20) define an external diameter of said respective connecting end (14) that substantially matches the inner diameter of said sleeve member (22).
- 5 6. A waveguide according to claim 5, wherein a maximum distance between said ridges and an inner wall of said sleeve member is 0.025mm or less.
7. A waveguide according to any of the preceding claims, wherein the
10 connecting ends (14) of said first and second waveguide sections are substantially identical, said butted interface (28) is substantially flat and substantially perpendicular to a waveguide axis defined by said conduit, and said sleeve member (22) comprises a tubular member configured to surround said butted interface (28).
8. A waveguide according to any of claims 1 to 6, wherein the connecting
15 end of said first waveguide section comprises a male end piece and the connecting end of said second waveguide section comprises a female end portion including a sleeve portion for receiving said male end portion and aligning said waveguide sections with a choked interface therebetween.
- 20 9. A waveguide according to claim 8, wherein the male end piece includes a recess extending from its distal end of length one quarter of the waveguide wavelength, and the recess, together with a gap between said male and female end pieces of length one quarter of said waveguide wavelength, defines said choked interface.
- 25 10. A method of manufacturing a waveguide comprising the steps of:
providing first and second waveguide sections, each waveguide section comprising a main body portion (12) and a connecting portion (14) at its distal end, the connecting portion (14) of each waveguide section having: (i) a first circumferential ridge (16) on its outer surface
30 located adjacent its distal end, (ii) a second circumferential ridge (18) on its outer surface spaced apart from the first circumferential ridge, and (iii)

- 18 -

5 a third circumferential ridge (20) on its outer surface located between said first and second circumferential ridges, such that a first respective recess (19) is defined between said second and third circumferential ridges and a second respective recess (17) is defined between said first and third circumferential ridges;

placing said first and second waveguide sections in longitudinal alignment to define a conduit therethrough with a butted interface (28) therebetween;

10 placing a sleeve member (22) over said butted interface (28), such that a respective first cavity (19a) is defined between an inner surface of said sleeve member (22) and each said first recess (19) and a respective second cavity is defined between the inner surface of said sleeve member (22) and each said second recess (17); and

15 introducing, into each said first cavity, a chemical adhesive so as to join said first and second waveguide sections together by means of said sleeve member (22).

11. A method according to claim 10, wherein the sleeve member (22) has at least one hole (24) therein, and the method includes the step of injecting said chemical adhesive into said first cavity (19a) through said at least one hole (24), and optionally further including the step of applying a preload to said butted interface (28) prior to introducing said chemical adhesive into said first cavity (19a).

12. A method according to claim 10 or claim 11, including the steps of determining, in respect of a bond-line provided by said chemical adhesive within said first cavity (19a), a maximum strength under shear load, identifying a thickness of said bond-line associated with said determined maximum strength, and providing a first and/or second waveguide section having a connecting end with a first recess (19a) having a depth substantially matching said thickness.

13. A waveguide section for use in a method according to any of claims 10 to 12, comprising a main body portion (12) and a connecting portion (14) at

- 19 -

- its distal end, the connecting portion (14) having: (i) a first circumferential ridge (16) on its outer surface located adjacent its distal end, (ii) a second circumferential ridge (18) on its outer surface spaced apart from the first circumferential ridge, and (iii) a third circumferential ridge (20) on its outer surface located between said first and second circumferential ridges, such that a first respective recess (19) is defined between said second and third circumferential ridges and a second respective recess (17) is defined between said first and third circumferential ridges.
- 5
14. A connecting end for a waveguide section according to claim 13, comprising a generally tubular member having: (i) a first circumferential ridge (16) on its outer surface located adjacent its distal end, (ii) a second circumferential ridge (18) on its outer surface spaced apart from the first circumferential ridge, and (iii) a third circumferential ridge (20) on its outer surface located between said first and second circumferential ridges, such that a first respective recess (19) is defined between said second and third circumferential ridges and a second respective recess (17) is defined between said first and third circumferential ridges, said connecting end being configured to be affixed to an end of a waveguide section.
- 10
- 15
15. A connecting end for a second waveguide section for use in a method according to any of claims 10 to 12 with a first waveguide section according to claim 13, wherein said connecting end comprises a sleeve member (22) configured to receive the connecting end of said first waveguide section, said connecting member (14) being configured to be affixed to an end of said second waveguide section.
- 20
- 25

Fig. 1

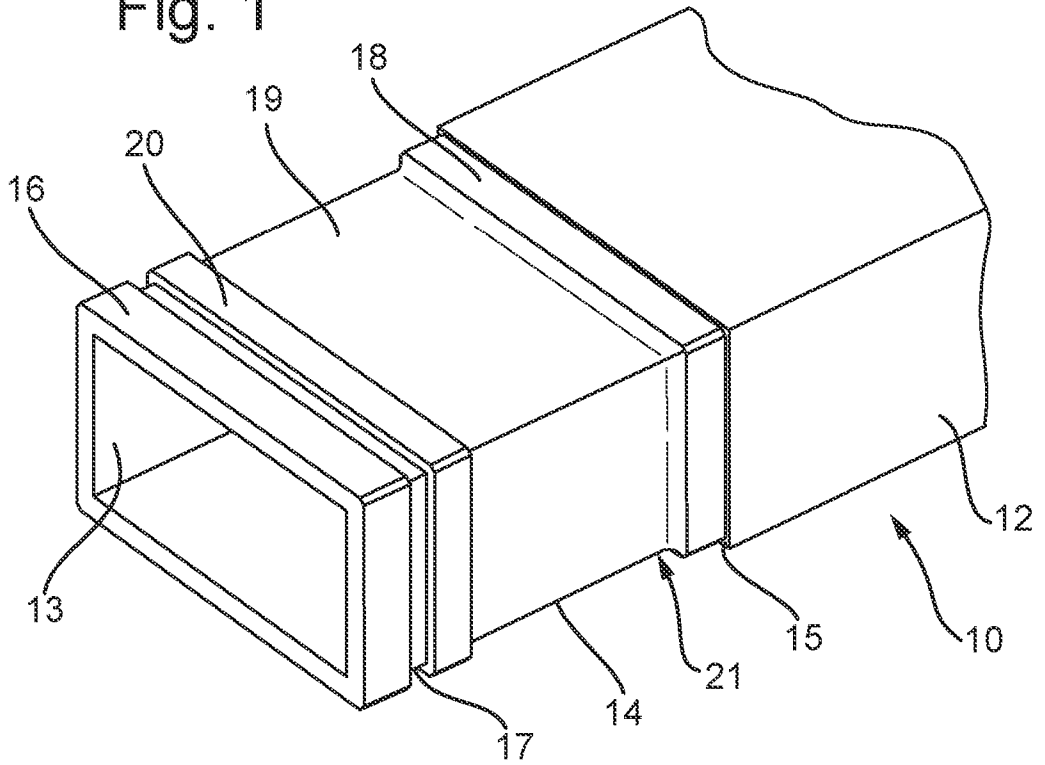


Fig. 2

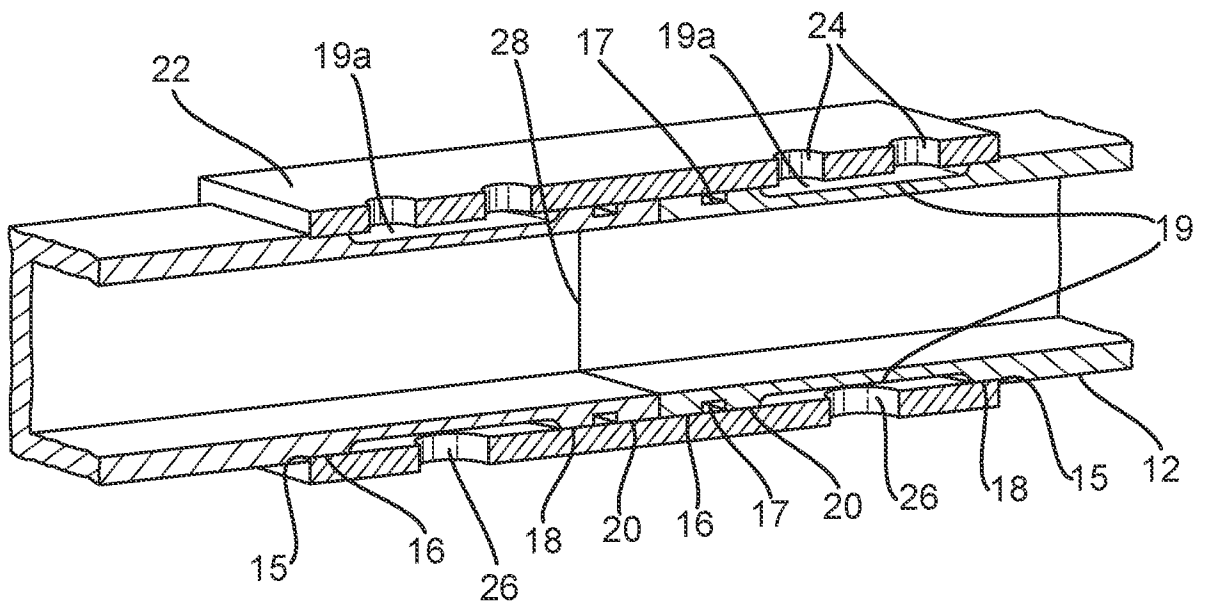


Fig. 3

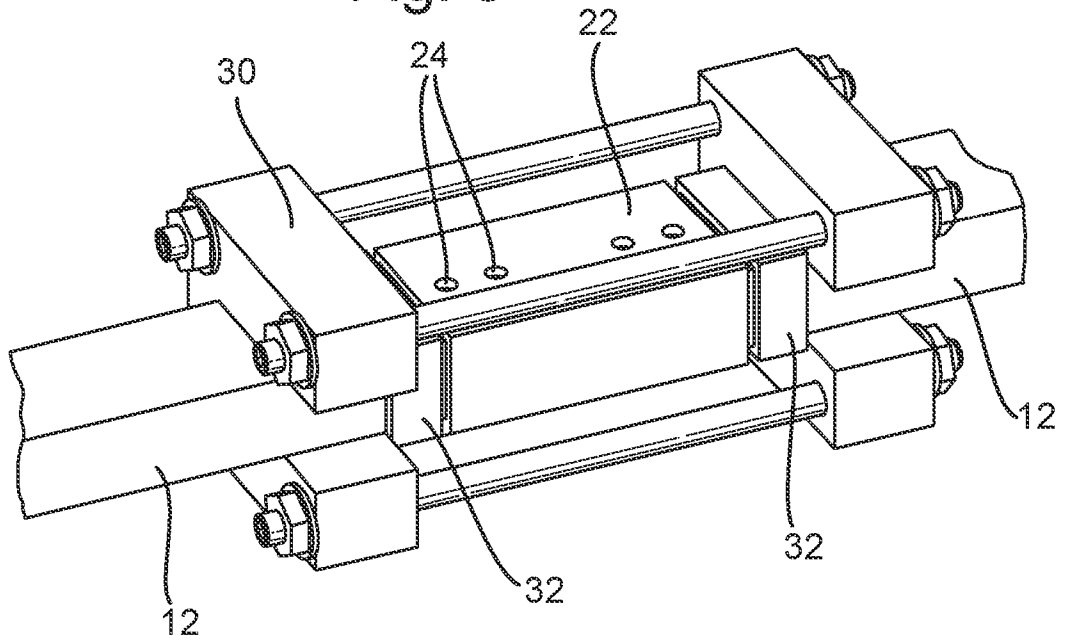


Fig. 4

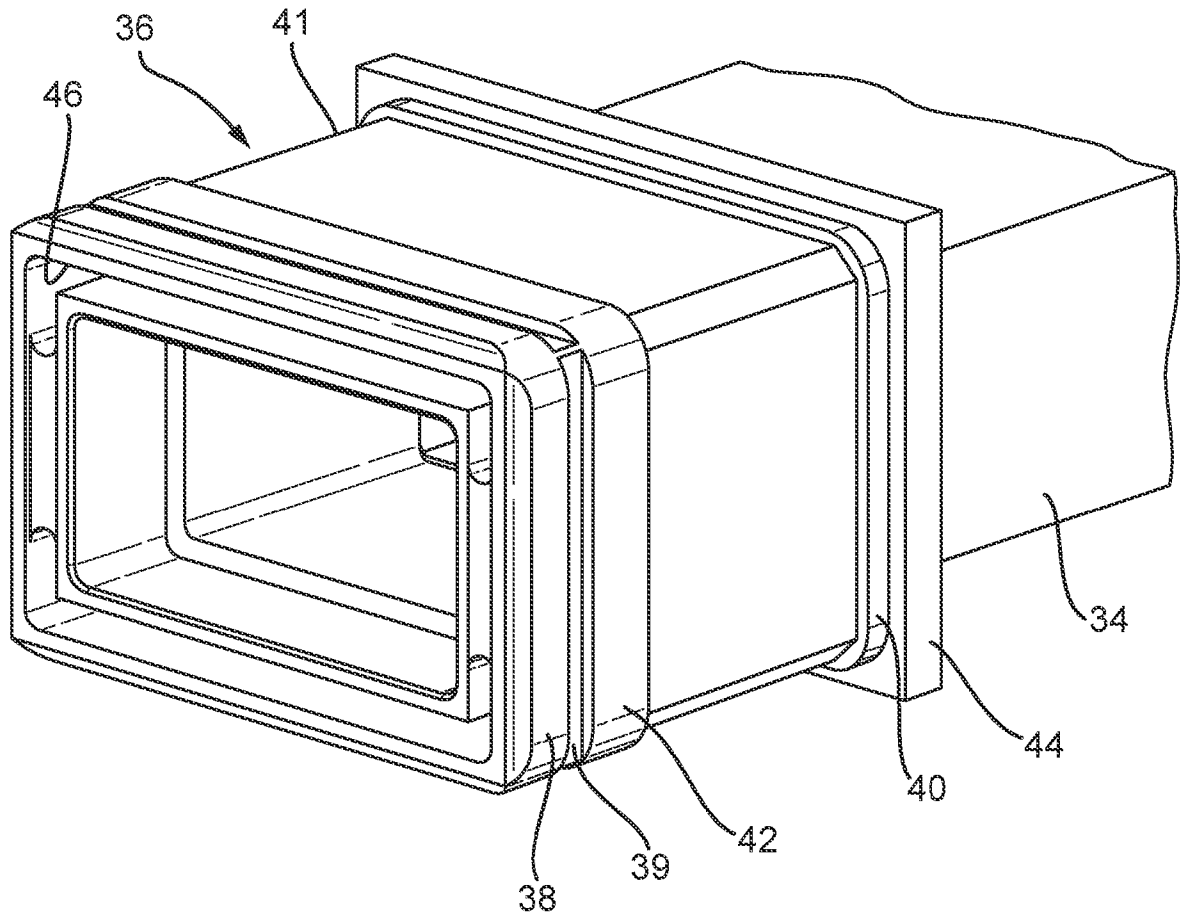


Fig. 5

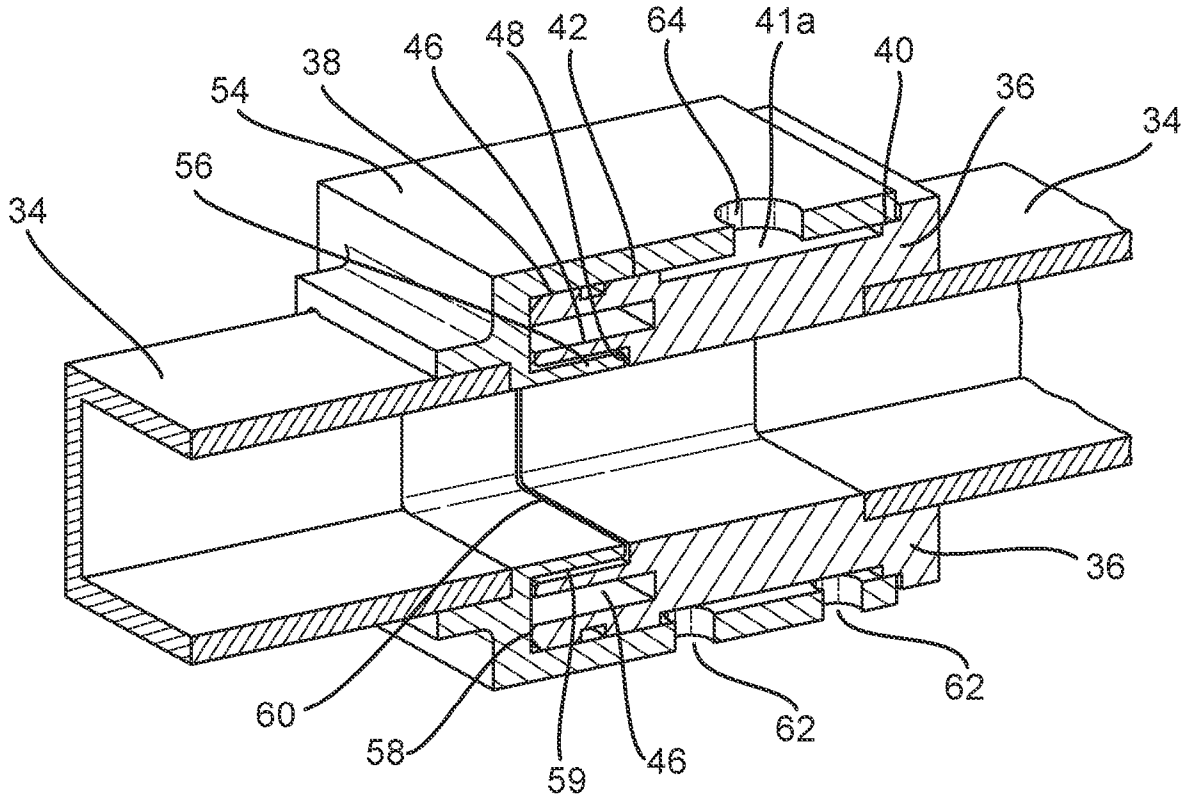


Fig. 6

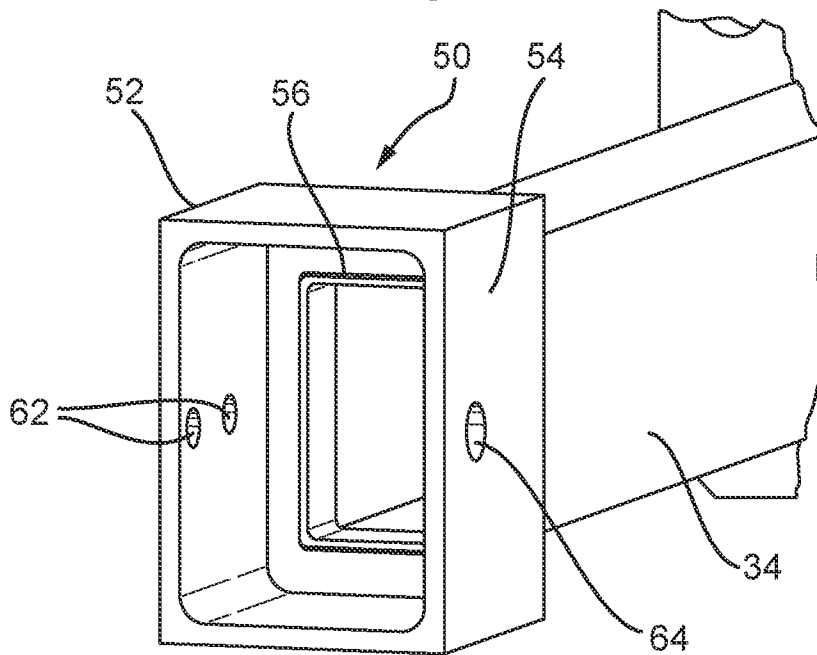
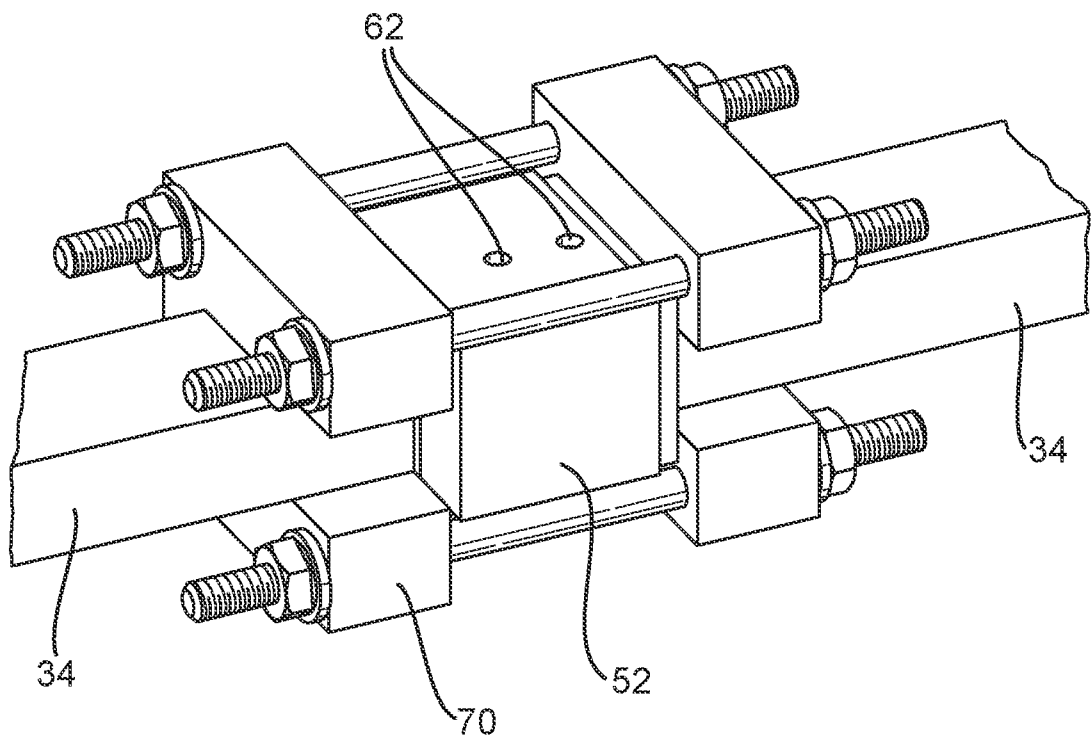


Fig. 7



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2017/050308

A. CLASSIFICATION OF SUBJECT MATTER
 INV. G02B6/38 H01P1/04 H01P5/02
 ADD.
 According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
 Minimum documentation searched (classification system followed by classification symbols)
 G02B H01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 971 481 A (STANDARD TELEPHONES CABLES LTD) 30 September 1964 (1964-09-30)	1-7, 10-15
Y	figure 1 page 1, line 50 - line 57 page 1, line 73 - line 79 -----	8,9
Y	GB 964 530 A (STANDARD TELEPHONES CABLES LTD) 22 July 1964 (1964-07-22) figures 2-3 -----	8
Y	US 3 374 450 A (STEWART ROBERT F) 19 March 1968 (1968-03-19) column 4, line 19 - line 20 -----	9

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

<p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p>	<p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"&" document member of the same patent family</p>
---	---

Date of the actual completion of the international search 4 April 2017	Date of mailing of the international search report 13/04/2017
---	--

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Orignac, Xavier
--	---

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2017/050308

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 971481	A	30-09-1964	NONE

GB 964530	A	22-07-1964	NONE

US 3374450	A	19-03-1968	DE 1541420 B1 29-01-1970
			FR 1500552 A 03-11-1967
			GB 1135258 A 04-12-1968
			US 3374450 A 19-03-1968
