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(71) Applicant: **Alcatel- Lucent Shanghai Bell Co., Ltd**
201206 Shanghai (CN)

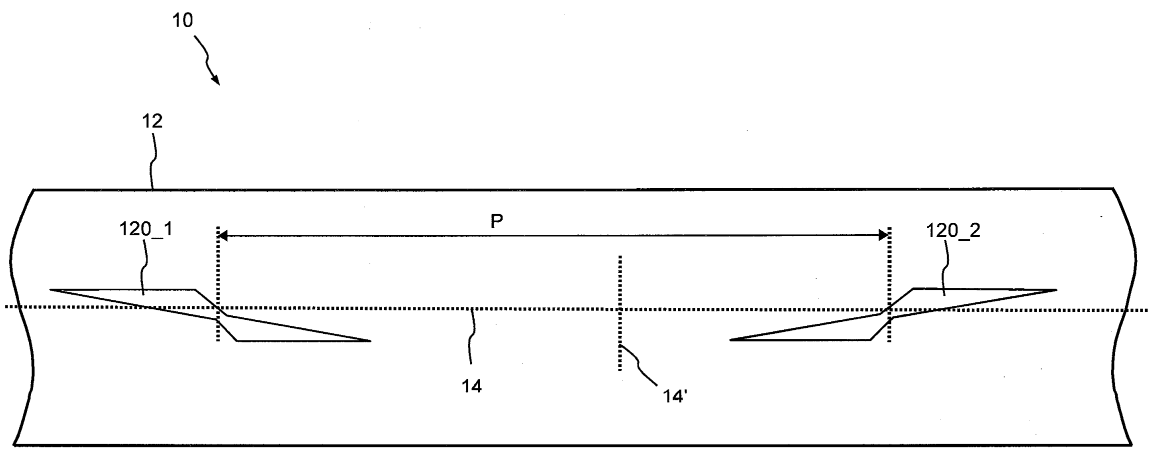
(72) Inventor: **Raya, Moustafa**
30179 Hannover (DE)

(74) Representative: **DREISS Patentanwälte PartG mbB**
Friedrichstrasse 6
70174 Stuttgart (DE)

(54) **Radiating cable and method of manufacturing a radiating cable**

(57) The invention relates to a radiating cable (10) for radiating electromagnetic energy, comprising an outer conductor (12) surrounding a longitudinal axis (14) of the cable (10), wherein the outer conductor (12) comprises a plurality of apertures (120_1, 120_2) arranged along said longitudinal axis (14), wherein a first aperture (120_1; 120_5; 120a) comprises a first shape, and wherein a second aperture (120_2; 120_7) comprises a second shape, wherein said second shape is obtained by applying a transformation to said first shape of said first aperture (120_1), wherein said transformation comprises mirroring said first shape at a second axis (14') which is substantially perpendicular to said longitudinal axis (14).

Fig. 1



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Description

Field of the invention

[0001] The invention relates to a radiating cable for radiating electromagnetic energy. The invention further relates to a method of manufacturing such radiating cable.

Background

[0002] Conventional radiating cables are generally formed from a coaxial cable comprising a conductive core defining the longitudinal axis of the cable and surrounded by an intermediate insulating medium, particularly sheath, of a dielectric material, an outer conductor provided with usually regularly spaced apertures or slots for the passage of electromagnetic radiation, and a protective outer insulating jacket. By virtue of the apertures formed in the outer conductor, a portion of the power flowing in the cable and transmitted from a transmitting source is coupled to the exterior. The cable thus acts as an antenna and the power coupled to the exterior is called the radiated power. Due to their characteristics, radiating cables may be used under conditions in which signals radiated from a point source are attenuated rapidly, e.g. for forming a distributed antenna system.

[0003] Conventional radiating cables functioning as a distributed antenna facilitate e.g. radio communication where the usual free space propagation of electromagnetic waves is hampered, undesired or impossible, for example in tunnels, mines, buildings, alongside tracks or lines and in large complexes like exhibition grounds or airports. Slots in the outer conductor (e.g. formed of copper) allow a controlled portion of the internal RF energy to be radiated into the surrounding environment. Conversely, a signal transmitted near the cable will couple into the slots and will be carried along the cable length. Thus, a radiating cable may be used for both one-way and two-way communication systems.

Summary

[0004] It is an object of the present invention to provide an improved radiating cable which enables to provide a high degree of vertically polarized electromagnetic radiation constituting said radiated power with reduced fading and an improved method of manufacturing such cable.

[0005] According to the present invention, regarding the radiating cable, this object is achieved by said radiating cable comprising an outer conductor surrounding a longitudinal axis of the cable, wherein the outer conductor comprises a plurality of apertures arranged along said longitudinal axis, wherein a first aperture comprises a first shape, and wherein a second aperture comprises a second shape, which is different from the first shape, wherein said second shape is obtained by applying a transformation to said first shape of said first aperture, wherein said transformation comprises mirroring said first shape at a second axis which is substantially perpendicular to said longitudinal axis.

[0006] According to an embodiment, said first aperture with said first shape and said second aperture with said second shape are arranged adjacent to each other along said longitudinal axis, i.e. no further (third) aperture is arranged between said first and second aperture.

[0007] According to a further embodiment, a plurality of aperture groups are distributed along said longitudinal axis. Preferably, a distance between single group elements, i.e. apertures of a same group, is smaller than a distance between adjacent aperture groups. For example, the distance between individual apertures of a same group may be measured between respective center sections of said apertures.

[0008] According to a further embodiment, at least one of said aperture groups comprises said first aperture with said first shape and said second aperture with said second (i.e., mirrored) shape.

[0009] According to a further embodiment, the cable may comprise at least one aperture group which comprises apertures with a same shape each.

[0010] According to a further embodiment, adjacent aperture groups each comprise different aperture shapes per group. I.e. a first aperture group comprises several apertures having a same third shape each, and a second aperture group, which is arranged adjacent to said first aperture group, comprises several apertures having a same fourth shape each, wherein said third shape and said fourth shape are different from each other.

[0011] According to a further embodiment, at least one of said apertures is centrally symmetric, i.e. comprises point symmetry (German: "Punktsymmetrie").

[0012] According to a further embodiment, a shape of at least one of said apertures does not comprise line symmetry, preferably not any line symmetry. I.e., there is no line of symmetry.

[0013] According to a further embodiment, at least one of said apertures is centrally symmetric, but not line symmetric.

[0014] According to a further embodiment, at least one of said apertures comprises a polygonal shape having six edges, i.e. a hexagonal shape, wherein preferably said six edges are connecting adjacent vertices of said hexagonal shape with each other.

[0015] According to a further preferred embodiment, said hexagonal shape is centrally symmetric, but not line symmetric.

[0016] According to a further embodiment, a first angle associated with a first vertex of said hexagonal shape and/or a fourth angle associated with a fourth vertex of said hexagonal shape are acute angles.

[0017] According to a further embodiment, a second angle associated with a second vertex of said hexagonal shape and/or a fifth angle associated with a fifth vertex of said hexagonal shape are larger than 180°.

[0018] According to a further embodiment, a third angle associated with a third vertex of said hexagonal shape and/or a sixth angle associated with a sixth vertex of said hexagonal shape are larger than 90°, but smaller than 180°.

[0019] According to a further embodiment, a distance between a second vertex and a fifth vertex of said hexagonal shape is smaller than a length of any of said six edges, preferably smaller than twenty percent of a length of any of said six edges.

Brief description of the figures

[0020] Further features, aspects and advantages of the present invention are given in the following detailed description with reference to the drawings in which:

Figure 1	schematically depicts a side view of a portion of a radiating cable according to an embodiment,
Figure 2	schematically depicts a side view of a portion of a radiating cable according to a further embodiment,
Figure 3	schematically depicts a side view of a portion of a radiating cable according to a further embodiment,
Figure 4	schematically depicts an aperture according to an embodiment,
Figure 5a, 5b	schematically depict various shapes of apertures according to further embodiments,
Figure 6	schematically depicts an operational scenario of a radiating cable according to an embodiment,
Figure 7a, 7b, 7c, 7d, 7e	schematically depict a coupling loss over a frequency for different polarization types,
Figure 8	schematically depicts a simplified flow-chart of a method according to an embodiment, and
Figure 9a, 9b	schematically depict a longitudinal loss over frequency according to further embodiments.

Description of the embodiments

[0021] Figure 1 schematically depicts a side view of a portion of a radiating cable 10 according to an embodiment. The cable 10 comprises an outer conductor 12 surrounding a longitudinal axis 14 of the cable 10. The cable 10 may comprise one or more inner conductors which are provided radially inwards of said outer conductor 12 and which may be separated from said outer conductor 12 and/or from each other in an electrically isolating fashion by means of insulating means such as dielectric sheaths or other suitable dielectric components. Also, an insulating jacket may be provided on a radial outer surface of said outer conductor 12. Said inner conductor(s) and the insulating jacket are not shown for the sake of clarity.

[0022] According to the embodiments, said outer conductor 12 comprises a plurality of apertures 120_1, 120_2 arranged along said longitudinal axis 14, wherein a first aperture 120_1 comprises a first shape, and wherein a second aperture 120_2 comprises a second shape, wherein said second shape is obtained by applying a transformation to said first shape of said first aperture 120_1, wherein said transformation comprises mirroring said first shape at a second axis 14' which is substantially perpendicular (i.e., allowing a maximum angular deviation from orthogonality between -20° and +20°) to said longitudinal axis 14. In the present example, the second axis 14' is perpendicular to the longitudinal axis 14.

[0023] As is well known in the art, the presence of the apertures 120_1, 120_2 in the outer conductor 12 of the cable 10 enables a portion of electromagnetic energy transported by said cable 10 to be radiated to the exterior of the cable 10 thus e.g. providing functionality for distributed antenna systems. For example, the cable 10 may be designed as a coaxial cable with one inner conductor (not shown), e.g. arranged along the longitudinal axis 14 radially inward of said outer conductor 12.

[0024] According to an embodiment, said first aperture 120_1 with said first shape and said second aperture 120_2 with said second shape are arranged adjacent to each other along said longitudinal axis 14, i.e. no further (third) aperture is arranged between said first and second apertures 120_1, 120_2. According to a further embodiment, a distance between said first and second apertures 120_1, 120_2 comprises a predetermined value P, which preferably depends on a desired operating frequency range of the radiating cable.

[0025] According to a preferred embodiment, the distance P between said first aperture 120_1 with said first shape and said second aperture 120_2 with said second, mirrored, shape is chosen to substantially correspond with half a wavelength of electromagnetic signals that are to be distributed and radiated by said cable. For example, according to an embodiment, if a center frequency of said desired operating frequency range is f1, and lambda1 is the wavelength corresponding to said center frequency f1, then distance P may e.g. be chosen P = lambda1/2.

[0026] According to Applicant's analysis, by choosing the distance P between adjacent, mirrored-shaped apertures to lambda1/2, undesired fading effects may be avoided. It has been shown that the mirroring technique and arranging apertures 120_1, 120_2 with mirrored shapes adjacent to each other inverts the polarity of a distributed current around the respective aperture. The electromagnetic ("E")-fields of adjacent apertures 120_1, 120_2 radiate with same phase and the overlap between the so radiated electromagnetic energy is constructive, thus avoiding the undesired fading.

[0027] According to an embodiment, when "flipping" every second slot (i.e., providing a sequence of apertures 120_1 with the first shape and apertures 120_2 with the second, mirrored, shape) along the cable with P=lambda1/2, fading is minimized at frequency F = n * c / (2 * P), wherein n= {1, 3, 5, 7...}, and c is the speed of light.

[0028] Figure 2 schematically depicts a side view of a portion of a radiating cable 10a according to a further embodiment. A plurality of aperture groups G1, G2 are distributed along said longitudinal axis 14. Preferably, a distance X1 between single group elements, i.e. apertures 120_1, 120_2 of a same group G1, is smaller than a distance P1 between adjacent aperture groups G1, G2. For example, the distance X1, X2 between individual apertures 120_1, 120_2 or 120_3, 120_4 of a same group G1 or G2 may be measured between respective center sections cs of said apertures.

[0029] The first aperture group G1 presently comprises two apertures 120_1, 120_2 the center sections cs of which are spaced apart from each other along the longitudinal axis 14 by the first distance X1. The second aperture group G2 presently comprises also two apertures 120_3, 120_4 the center sections of which are spaced apart from each other along the longitudinal axis 14 by the second distance X2, which may be equal to the first distance X1 or which may be different from said first distance X1.

[0030] Also, within each group, the group members (i.e., apertures of said group) are mirrored with respect to each other at an axis 14' (cf. Fig. 1) substantially perpendicular to the longitudinal axis 14. Presently, group G1 is similar in structure (apart from the different distances P, X1) to the configuration of Fig. 1.

[0031] The configuration depicted by Fig. 2 enables further fading optimization, especially for two or more operating frequencies.

[0032] Figure 3 schematically depicts a side view of a portion of a radiating cable 10b according to a further embodiment, wherein at least one aperture group G3 comprises apertures 120_5, 120_6 with a same shape each. Also, the further depicted aperture group G4 comprises apertures 120_7, 120_8 with a same shape each. Nevertheless, at least two apertures 120_5, 120_7, for example, satisfy the criterion according to the embodiments that a second shape of a second aperture 120_7 is obtained by a transformation from a first shape of a first aperture 120_5, e.g. by mirroring at axis 14', cf. Fig. 1.

[0033] According to a further embodiment, adjacent aperture groups G3, G4 each comprise different aperture shapes per group. I.e. aperture group G3 comprises several apertures 120_5, 120_6 having a same third shape each, and the aperture group G4, which is arranged adjacent to said aperture group G3, comprises several apertures 120_7, 120_8 having a same fourth shape each, wherein said third shape and said fourth shape are different from each other. For example, according to an embodiment, said fourth shape may be derived from said third shape by means of a transformation, e.g. mirroring at the axis 14' (Fig. 1).

[0034] The configuration 10b according to Fig. 3 advantageously minimizes undesired fading for two frequencies F(n), M(k) at the same time, said two frequencies being defined by: F(n) = n * c / (2 * P2), wherein P2 is the longitudinal distance between said aperture groups G3, G4, and M(k) = k * c / X3,
Wherein k= {1, 2, 3...}, wherein X3 is the longitudinal distance between said apertures 120_5, 120_6 of said aperture group G3.

[0035] According to a further embodiment, the distance X4 may be equal to X3 or may be different from X3.

[0036] According to a further embodiment, at least one of the apertures 120_1 1 (Fig. 1) of the radiating cable is centrally symmetric, i.e. comprises point symmetry. According to a further embodiment, a shape of at least one of said apertures 120_1 does not comprise line symmetry, preferably not any line symmetry. According to a further embodiment, at least one of said apertures 120_1 is centrally symmetric, but not line symmetric.

[0037] According to a further preferred embodiment, at least one of said apertures 120a comprises a polygonal shape having six edges, i.e. a hexagonal shape, wherein preferably said six edges are connecting adjacent vertices of said hexagonal shape with each other. Such a configuration is depicted by Fig. 4. The six vertices V1, V2, V3, V4, V5, V6 of the hexagonal shape are connected by six respective edges E1, E2, E3, E4, E5, E6, which are arranged counterclockwise, i.e. in a mathematical positive sense.

[0038] Said shape of the aperture 120a of Fig. 4 also comprises point symmetry, i.e. is centrally symmetric around a point of symmetry SP close to vertices V2, V5, but no line symmetry.

[0039] According to an embodiment, a second vertex V2 and a fifth vertex V5 define a center region around said point of symmetry SP of said aperture 120a, wherein a distance between said second vertex V2 and said fifth vertex V5 is smaller than a length of any of said six edges E1, E2, E3, E4, E5, E6, preferably smaller than 20 percent of a length of any of said six edges E1, E2, E3, E4, E5, E6.

[0040] According to a further embodiment, the first angle $\alpha 1$ and/or said fourth angle $\alpha 4$ are acute angles, i.e. $\alpha 1 < 90°$ and/or $\alpha 4 < 90°$. According to a further embodiment, the second angle $\alpha 2$ and/or said fifth angle $\alpha 5$ are larger than 180°. According to a further embodiment, the third angle $\alpha 3$ and/or the sixth angle $\alpha 6$ are larger than 90°, but smaller than 180°.

[0041] According to a further embodiment, the length of the third and/or sixth edge(s) E3, E6 is smaller than the length of either of the first, second, fourth, or fifth edge E1, E2, E4, E5.

[0042] According to preferred embodiments, geometric parameters of the aperture 120a are chosen as follows:

Total height H34 ranging between 6 mm (millimeter) and 30 mm, preferably between 10 mm and 20 mm. Particularly preferred values are H34=12mm and H34=16mm.

Total length L12 ranging between 60mm and 200mm, preferably between 80mm and 150mm. Particularly preferred values are L12=132mm and L12=90mm.

Leg length w1, w2 ranging between 2mm and 40mm. Particularly preferred values are w1=4mm, w1=25mm, w2=4mm, w2=25mm. Both leg lengths w1, w2 may be equal or, according to further embodiments, different from each other.

Tip length 11, 12 ranging between 10mm and 100mm. Particularly preferred values are 11=62mm, 11=20mm, 12=62mm, 12=20mm. Both tip lengths 11, 12 may be equal or, according to further embodiments, different from each other.

Tip width h1, h2 ranging between 2mm and 20mm. A preferred value is h1=7mm, h2=7mm. Both tip widths h1, h2 may be equal or, according to further embodiments, different from each other.

[0043] Figure 5a, 5b schematically depict various shapes 120', 120" of apertures according to further embodiments. According to some embodiments, the radiating cable may comprise at least one aperture having any of the shapes 120', 120''. The shape variants 120', 120" of Fig. 5a, 5b may also be combined with any of the aforementioned embodiments.

[0044] Figure 6 schematically depicts an operational scenario of the radiating cable 10 together with symbolically depicted dipoles D1, D2, D3, wherein cable 10 is mounted to a wall 300, and wherein first dipole D1 is a radial dipole with respect to cable 10, wherein second dipole D2 is arranged vertically with respect to cable 10, and wherein dipole D3 is arranged parallel with respect to cable 10. Said dipoles D1, D2, D3 illustrate the different polarization orientations also used for obtaining the curves of Fig. 7a, 7b, 7c, 7d, 7e.

[0045] Figures 7a, 7b, 7c, 7d, 7e each schematically depict a coupling loss cl over a frequency f (range from about 0.2 GHz to about 3.0 GHz) for different polarization types of a cable according to the embodiments. Curve c1 denotes vertical polarization, curve c2 denotes radial polarization, and curve c3 denotes parallel polarization.

[0046] Figure 7a depicts said coupling loss cl for a radiating cable (not shown) which comprises a plurality of apertures of the shape depicted by Fig. 4 arranged periodically along the longitudinal axis 14 (Fig. 1) with a longitudinal distance of about 224mm between adjacent apertures, said shape having the following geometric properties: H34=16mm, L12=90mm, w1=w2=25mm, 11=12=20mm, h1=h2=7mm.

[0047] Figure 7b depicts said coupling loss cl for a radiating cable (not shown) which comprises a plurality of apertures of the shape depicted by Fig. 4 arranged periodically along the longitudinal axis 14 (Fig. 1) with a longitudinal distance of about 224mm between adjacent apertures, said shape having the following geometric properties: H34=16mm, L12=90mm, w1=w2=25mm, 11=12=20mm, h1=3.5mm, h2=7mm, i.e., the aperture shape Fig. 7b is based on is slightly asymmetric regarding the tip width h1, h2 as compared to the setting Fig. 7a is based on.

[0048] Figure 7c depicts said coupling loss cl for a radiating cable 10 as depicted by Fig. 1, wherein the apertures 120_1, 120_2 comprise the shape depicted by Fig. 4 and are arranged periodically along the longitudinal axis 14 (Fig. 1) with a longitudinal distance of about 224mm between adjacent apertures 120_1, 120_2, said shape having the following geometric properties: H34=16mm, L12=90mm, w1=w2=25mm, 11=12=20mm, h1=h2=7mm.

[0049] Figure 7d depicts said coupling loss cl for a radiating cable (not shown) which comprises a plurality of apertures of the shape depicted by Fig. 4 arranged group-wise (a group formed by two apertures 120a spaced apart longitudinally by about 112mm), said aperture groups arranged periodically along the longitudinal axis 14 (Fig. 1) with a longitudinal distance of about 350mm between adjacent groups of two apertures each, said shape having the following geometric properties: H34=16mm, L12=90mm, w1=w2=25mm, 11=12=20mm, h1=h2=7mm.

[0050] Figure 7e depicts said coupling loss cl for a radiating cable 10a as depicted by Fig. 2, wherein the apertures 120_1, 120_4 comprise the shape depicted by Fig. 4, and wherein the apertures 120_2, 120_3 comprise a correspondingly mirrored shape as depicted by Fig. 2, wherein X1=X2=112mm, P1=350mm, and H34=16mm (Fig. 4), L12=90mm, w1=w2=25mm, 11=12=20mm, h1=h2=7mm.

[0051] Figure 8 schematically depicts a simplified flow-chart of a method according to an embodiment. The method of manufacturing a radiating cable 10 (Fig. 1) for radiating electromagnetic energy comprises providing 200 an outer conductor 12 (Fig. 1) surrounding a longitudinal axis 14 of the cable 10, wherein the outer conductor 12 comprises a plurality of apertures 120_1, 120_2 arranged along said longitudinal axis 14, wherein a first aperture 120_1 comprises a first shape, and wherein a second aperture 120_2 comprises a second shape, wherein said second shape is obtained by applying a transformation to said first shape of said first aperture 120_1, wherein said transformation comprises mirroring said first shape at a second axis 14' which is substantially perpendicular to said longitudinal axis 14.

[0052] Figure 9a, 9b schematically depict a longitudinal loss 11 (corresponding to the scattering parameter "S12" in dB per 100 meters) over frequency according to further embodiments.

[0053] More specifically, Fig 9a has been obtained by periodically arranging apertures 120a of the shape as depicted by Fig. 4 along the longitudinal axis 14 of a radiating cable with a longitudinal distance of 224mm each, wherein the geometric parameters of the aperture 120a have been chosen as follows: H34=12mm, L12=132mm, w1=w2=4mm, 11=12=62mm, and h1=h2=7mm.

[0054] In contrast, Fig 9b has been obtained by periodically arranging apertures 120a of the shape as depicted by Fig. 4 along the longitudinal axis 14 of a radiating cable with a longitudinal distance of 224mm each, wherein the geometric parameters of the aperture 120a have been chosen as follows: H34=16mm, L12=90mm, w1=w2=25mm, 11=12=20mm, and h1=h2=7mm.

[0055] In the following, various aspects of the above explained embodiments and/or of further embodiments are discussed.

[0056] The radiating cable 10, 10a, 10b according to the embodiments may e.g. be used for providing a leaky coaxial cable (LCX). Advantageously, in long hallways, such like tunnels, corridors and parking places, LCX can be used as a solution for radio communication to achieve homogenously covered areas in spite of the poor RF propagation environment. In case of data transfer between an LCX and a fixed antenna, e.g. on the top of a train (vertically polarized), the radiation from the LCX should be also vertically polarized in order to enable efficiency transfer. Since the antenna on the train can only receive vertically polarized waves, radiation appearing from LCX except for vertical polarization may be considered as losses for this application scenario. Such losses may be avoided by employing the principle according to the embodiments, which enables to provide radiating cables that provided dominant vertically polarized radiation.

[0057] Regarding bandwidth, with growing communication markets and needs, more frequency bands up to e.g. 2.7 GHz are required, for example for services like 2G/3G/4G. In order to have more decoupling of vertical polarization, conventional LCX may require bigger aperture shapes, which result in undesired self-resonance. Due to higher radiation in range of self-resonance frequency, with conventional LCX, a data transmission through the cable gets very poor efficiency and result to stop bands. The spectrum of the harmonic self-resonance can fall in operation bands and result to narrow bandwidth of LCX. This can advantageously be avoided by employing the radiating cable according to the embodiments.

[0058] Also, fading (caused by destructive interference of electromagnetic energy radiated through the apertures of a radiating cable) can be mitigated by employing the embodiments.

[0059] According to Applicant's analysis, by operating an LCX around a specific target frequency, the electrical polarity of two successive (i.e., adjacent) apertures or groups of apertures may get opposite. The opposite polarity on said apertures may result in radiation of opposite electrical field vector directions E1 and E2. The overlap of these vectors E1 and E2 in the central region between the two apertures (not shown) may be destructive due to the opposite phases of these vectors E1 and E2. This is denoted as fading and leads to an LCX suffer from inhomogeneity of covered areas. As stated above, the fading issue can be resolved by applying the principle according to the embodiments.

[0060] Further according to Applicant's analysis, by providing an electrical reflector in a center section SP (Fig. 4) of an aperture 120a of a radiating cable, a part of incident waves traveling in said cable gets reflected. Due to the reflection, the radiation intensity increases. This principle is exploited by the aperture shape according to the embodiment 120a of Fig. 4.

[0061] The aperture shape of Fig. 4 may also be denoted as "twangle slot", because the hexagonal aperture shape may also be considered to be constituted by two triangular apertures overlapping in the center section SP. The comparatively small "waist" section, i.e. the difference vector between vertices V2, V5 of the hexagonal shape advantageously acts as a reflector for electromagnetic waves traveling in a cable 10 comprising said aperture 120a. Due to reflections on said cross point SP the reflected current densify and turn around the edges of the aperture 120a. An opposite electrical polarity appearing from an upper to lower side on said shape according to Fig. 4 results in increased radiation of vertically polarized electrical fields.

[0062] Figures 5a, 5b show apertures according to further embodiments, wherein the aspect of a reflector in a center section of the aperture has been used. These aperture shapes may advantageously also achieve an increased degree of vertical polarization for radiation from a radiating cable. E.g., the combination of two diamond structures, the bottom right aperture shape of Fig. 5b: The cross point acts as an impedance discontinuity and results in dominance of vertical polarization. In the tiled diamond and tiled triangle structures, the maximal discontinuity of impedance in the middle due to maximal opening cause reflections with same behavior like the description above and result to vertical polarization.

[0063] Generally, the aspects according to the embodiments solve the issues of weak vertically polarized radiation of conventional LCX and allow the vertically polarization to dominate over other polarizations.

[0064] Regarding bandwidth of a radiating cable, according to a further embodiment, to overcome a problem of the first harmonic self-resonance falling in used frequency bands, the following solution is presented: The idea is to size the shape of the aperture such that a reactance part of the "antenna-impedance" of the radiating cable 10 is influenced, the reactance part defining the range of resonance. An increase in Fig. 4 of the ratio r=w1/11 or w2/12, respectively, can shift the first harmonic resonance. By increasing said ratio r to a defined value, the second self-resonance gets shifted out of e.g. a frequency range of 2.7 GHz and below, and the first self-resonance stays below 1.7 GHz, whereby a wide use band is attained, see the simulation results of Fig. 9a, 9b (especially the frequency range of 1.7 GHz to 2.7 GHz of Fig. 9b). By keeping both the self-resonance and the first harmonic out of 0.03 GHz to 1 GHz and 1.7 GHz to 2.7 GHz according to an embodiment, this means that an LCX based on the present embodiments may operate broadband mobile radio without influence of self-resonances in that range. The simulation results show how it is possible to shift the self-resonance by changing the ratio r. This solution offer broad bandwidth LCX.

[0065] Regarding fading, the principle according to the embodiments proposes to provide a first aperture 120_1 (Fig. 1) comprising a first shape and a second aperture 120_2 comprising a second shape, wherein said second shape is obtained by applying a transformation to said first shape of said first aperture 120_1, wherein said transformation comprises mirroring said first shape at a second axis 14' (Fig. 1) which is substantially perpendicular to said longitudinal axis 14 of the cable 10. This approach is also denoted as "flipping method", whereby undesired fading may be overcome.

[0066] According to an embodiment, every second aperture 120_2 along the cable 10 may be "flipped", i.e. mirrored at axis 14', (Fig. 1). The flipping or mirroring process, respectively, inverts the polarity of distributed current around the slot during operation of the cable 10. The E-Fields of said adjacent apertures 120_1, 120_2 may then radiate with a same phase (or at least approximately the same phase for a substantial frequency range), and an overlap of the so emitted radiation is constructive, thus exhibiting no fading. According to an embodiment, when flipping (mirroring) every second aperture along a cable with a distance of $P=\lambda/2$ (λ being a considered wavelength), fading gets minimized at frequency $F(n) = n * c / (2*P)$ [equation 1], where n= {1, 3, 5, 7...}.

[0067] According to a further embodiment, an alternative way to minimize fading, which may also be combined with the "flipping method", said alternative way itself, however, not requiring any flipping, is to set a longitudinal distance between two adjacent apertures or groups of apertures as a multiple of a wavelength for the desired frequencies. For example, by setting a distance between two adjacent apertures (not shown) as $P'=\lambda'$. In this case, the polarity of current around the apertures is same when operating at frequency M(k), and the radiations of the respective E-fields are in phase, which follows to minimizing of fading at frequency $M(k)= k*f'=k*c/(P')$ [equation 2], where k= {1, 2, 3...}. Corresponding simulation results are presented by Fig. 7a, 7d.

[0068] According to a further embodiment, it is also possible to optimize a radiating cable for two or more harmonic frequencies; this can be done by providing a group or groups of slots, cf. e.g. Fig. 3. By setting the distance X3, X4 between the "non-flipped" apertures each within one group G3, G4 according to equation 2 above, and by simultaneously setting the distance P2 between two adjacent groups G3, G4 of apertures based on equation 1 above, fading for frequencies M(k) and F(n) may be minimized at the same time (Fig. 3).

[0069] According to further embodiments, it is also possible to use each method only within one group and for two successive groups of apertures. For example by using the flipping process in Fig. 2, for simulation results cf. Fig. 7e, and the "non-flipping method" (cable not depicted, simulation results cf. Fig. 7d).

[0070] To summarize, by employing the principle according to the embodiments, it is possible to overcome the fading problem and to optimize a radiating cable for the required frequencies.

[0071] According to further embodiments, regarding the aspect of dominant vertical polarization: simulations of the "twangle slot", i.e. the aperture shape of Fig. 4 with the various geometric details as given above give evidence of the fact that vertical polarization dominates over the other polarizations beginning from 800MHz (Fig. 7a), where the cable operates in radiating mode. The aperture shape according to the embodiments offers a decoupling level (i.e., difference to the other polarization types) up to ~20dB at higher frequencies, which is a significant benefit for the efficiency of data transfer and also enables to reduce the number of repeaters required for operating a distributed antenna system with radiating cables 10.

[0072] According to further embodiments, it is possible to control the radiated amount of power as well the decoupling level: By increasing the geometric parameter H34 (Fig. 4) of the aperture 120a, the amount of reflections in the center region around the point of symmetry SP can be increased and results in more RF energy being radiated, whereas the decoupling of vertical polarization from the further polarization types decreases.

[0073] As already explained above with reference to Fig. 7b, simulations were also done too for asymmetrical twangle slots (in this context, "asymmetrical" denotes that one or more geometric parameters of the two triangular legs of said aperture 120a (Fig. 4) such as e.g. 11, 12, h1, h2 are not equal). Fig. 7b depicts the coupling loss values cl for the different polarizations. The results confirm that an asymmetrical shape of the aperture 120a (Fig. 4) does not harm the dominance of vertical polarization. Comparing Fig. 7a with 7b shows no influence on dominance also no significant influence on radiation level of coupling loss cl. Only at freq., around 2.6GHz the parallel polarization is greater.

[0074] According to further embodiments, regarding bandwidth, as described above, an increase of the ratio r, i.e. r=w1/l1 or w2/12, cf. Fig. 4, allows to shift the second self resonance out of the use band. By increasing the ratio r from 0.064 to 1.25 (results cf. Fig. 9a vs. 9b) the first harmonic self-resonance peak gets shifted away from 2.25GHz to above 2.8GHz and thus out of the operation band. At the same time, the first resonance remains at 1.5GHz. The simulation results show how it is possible to shift the self-resonance by changing the shape of the aperture 120a according to the embodiments.

[0075] According to further embodiments, regarding fading, a periodical placement of apertures (shape of Fig. 4) with a period of 224mm along the longitudinal axis 14 (Fig. 1), has been examined and a field-simulation was done. As a result, the vertical polarized coupling loss results, cf. curve c1 of Fig. 7a, shows a strong fading as expected around F(1)=600MHz and F(3)=1800MHz.

[0076] When using the flipping or mirroring approach of fig. 1, simulation results show in fig. 7c how the coupling loss c1 for vertical polarization has been improved from 88 dB to 70 dB at 600MHz and from 68 dB to 60dB at 1800MHz, where the other polarizations remain unchanged.

[0077] According to a further embodiment, the simulation results can also prove the "non-flipping method" of fading. Observing fig. 7a shows how the fading of the "non-flipping slots" at 1200 MHz and 2400 MHz have been suppressed. Comparing Fig. 7a with Fig. 7c shows how the coupling loss values cl for vertical polarizations (curves c1) haven been improved from 66dB to 58dB at M(1)=1200MHz and from 72dB to 69dB at M(2)=2400MHz.

[0078] According to a further embodiment, an example of using the "flipping process" double time within one aperture group G1, G2 as well by flipping two successive groups G1, G2 is presented in fig. 3. The associated simulation results of Fig. 7e show how the fading has been suppressed comparing to fig. 7d for the following frequencies: F(1)=400MHz, F(3)=1200MHz, F(5)=2000MHz and F(7)=2800MHz. On the other hand, by using the "non-flipping method" (Fig. 7d), it shows how the fading haven been suppressed by the following frequencies M(1)=800MHz, M(2)=1600MHz and M(3)=2400MHz.

[0079] The principle according to the embodiments advantageously enables to provide an increased usable operating bandwidth especially in a range between 1.7 GHz to 2.7 GHz, with reduced fading.

[0080] The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

[0081] It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

Claims

1. Radiating cable (10) for radiating electromagnetic energy, comprising an outer conductor (12) surrounding a longitudinal axis (14) of the cable (10), wherein the outer conductor (12) comprises a plurality of apertures (120_1, 120_2) arranged along said longitudinal axis (14), wherein a first aperture (120_1; 120_5; 120a) comprises a first shape, and wherein a second aperture (120_2; 120_7) comprises a second shape, wherein said second shape is obtained by applying a transformation to said first shape of said first aperture (120_1), wherein said transformation comprises mirroring said first shape at a second axis (14') which is substantially perpendicular to said longitudinal axis (14).

2. Cable (10) according to claim 1, wherein said first aperture (120_1) with said first shape and said second aperture (120_2) with said second shape are arranged adjacent to each other along said longitudinal axis (14).

3. Cable (10a) according to one of the preceding claims, wherein a plurality of aperture groups (G1, G2) are distributed along said longitudinal axis (14).

4. Cable (10a) according to claim 4, wherein at least one of said aperture groups (G1, G2) comprises said first aperture (120_1) with said first shape and said second aperture (120_2) with said second shape.

5. Cable (10b) according to one of the claims 3 to 4, wherein at least one aperture group (G3, G4) comprises apertures (120_5, 120_6) with a same shape each.

6. Cable (10b) according to claim 5, wherein adjacent aperture groups (G3, G4) each comprise different aperture shapes per group.

7. Cable (10; 10a; 10b) according to one of the preceding claims wherein a shape of at least one of said apertures (120_1, .., 120_8; 120a) is centrally symmetric.

8. Cable (10; 10a; 10b) according to one of the preceding claims wherein a shape of at least one of said apertures (120_1, .., 120_8; 120a) does not comprise line symmetry.

9. Cable (10; 10a; 10b) according to one of the preceding claims wherein at least one of said apertures (120_1, .., 120_8; 120a) comprises a polygonal shape having six edges (E1, E2, E3, E4, E5, E6), e.g. a hexagonal shape.

10. Cable according to claim 9, wherein first angle (α1) associated with a first vertex (V1) of said hexagonal shape and/or a fourth angle (α4) associated with a fourth vertex (V4) of said hexagonal shape are acute angles.

11. Cable according to claim 9 or 10, wherein a second angle (α2) associated with a second vertex (V2) of said hexagonal shape and/or a fifth angle (α5) associated with a fifth vertex (V5) of said hexagonal shape are larger than 180°.

12. Cable according to one of the claims 9 to 11, wherein a third angle (α3) associated with a third vertex (V3) of said hexagonal shape and/or a sixth angle (α6) associated with a sixth vertex (V6) of said hexagonal shape are larger than 90°, but smaller than 180°.

13. Cable according to one of the claims 9 to 12, wherein a distance between a second vertex (V2) and a fifth vertex (V5) of said hexagonal shape is smaller than a length of any of said six edges (E1, E2, E3, E4, E5, E6), preferably smaller than twenty percent of a length of any of said six edges (E1, E2, E3, E4, E5, E6).

14. Cable according to one of the claims 9 to 13, wherein an overall length (L12) of said aperture (120a) measured along said longitudinal axis (14) ranges from about 40mm to about 150mm, wherein said overall length (L12) is preferably about 90mm, and/or wherein an overall width (H34) of said aperture (120a) measured along said second axis (14') ranges from about 8mm to about 20mm, wherein said overall width (H34) is preferably about 16mm.

15. Method of manufacturing a radiating cable (10) for radiating electromagnetic energy, said method comprising: providing (200) an outer conductor (12) surrounding a longitudinal axis (14) of the cable (10), wherein the outer conductor (12) comprises a plurality of apertures (120_1, 120_2) arranged along said longitudinal axis (14), wherein a first aperture (120_1; 120_5) comprises a first shape, and wherein a second aperture (120_2; 120_7) comprises a second shape, wherein said second shape is obtained by applying a transformation to said first shape of said first aperture (120_1), wherein said transformation comprises mirroring said first shape at a second axis (14') which is substantially perpendicular to said longitudinal axis (14).

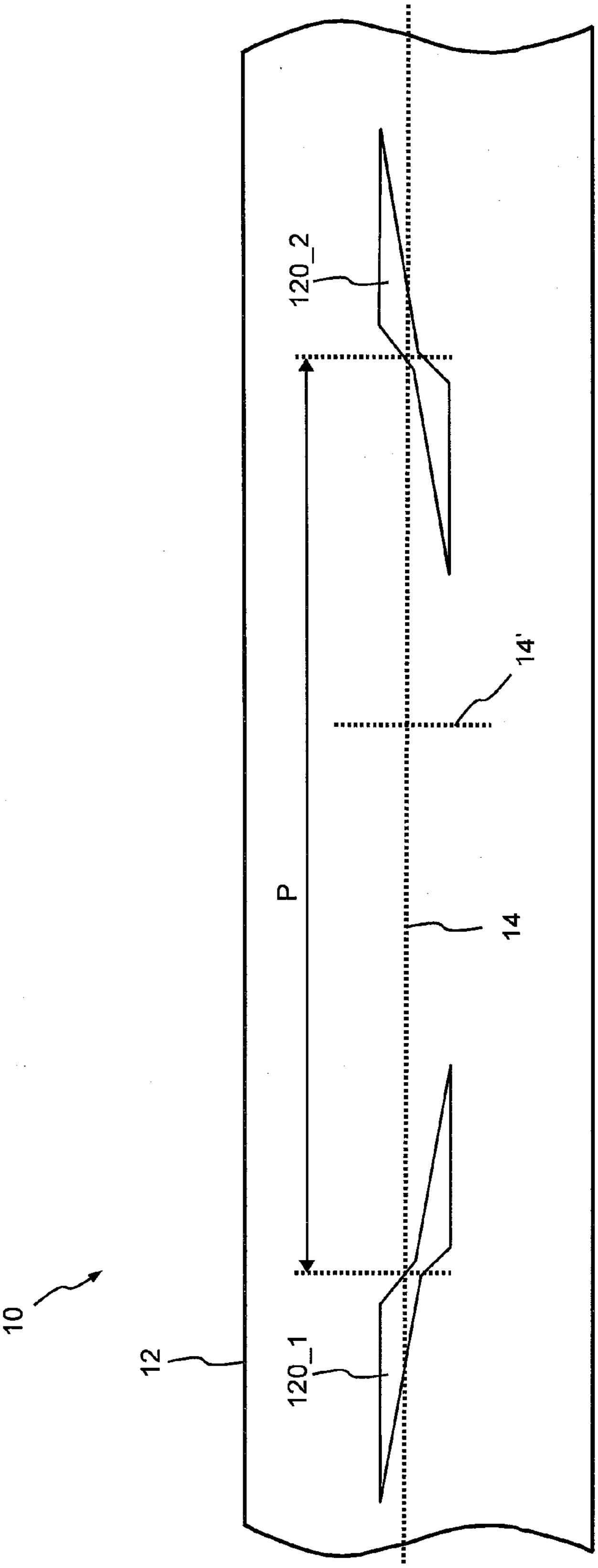


Fig. 1

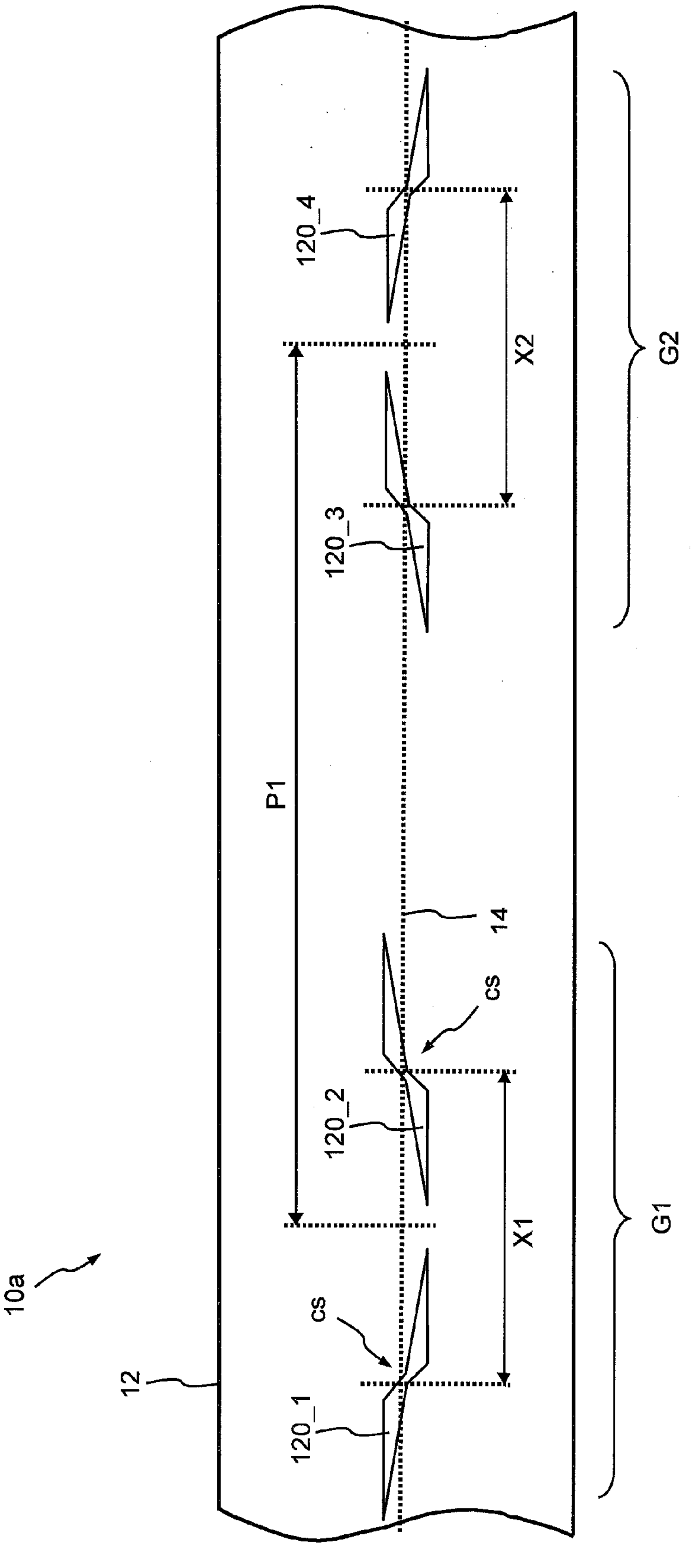


Fig. 2

Fig. 3

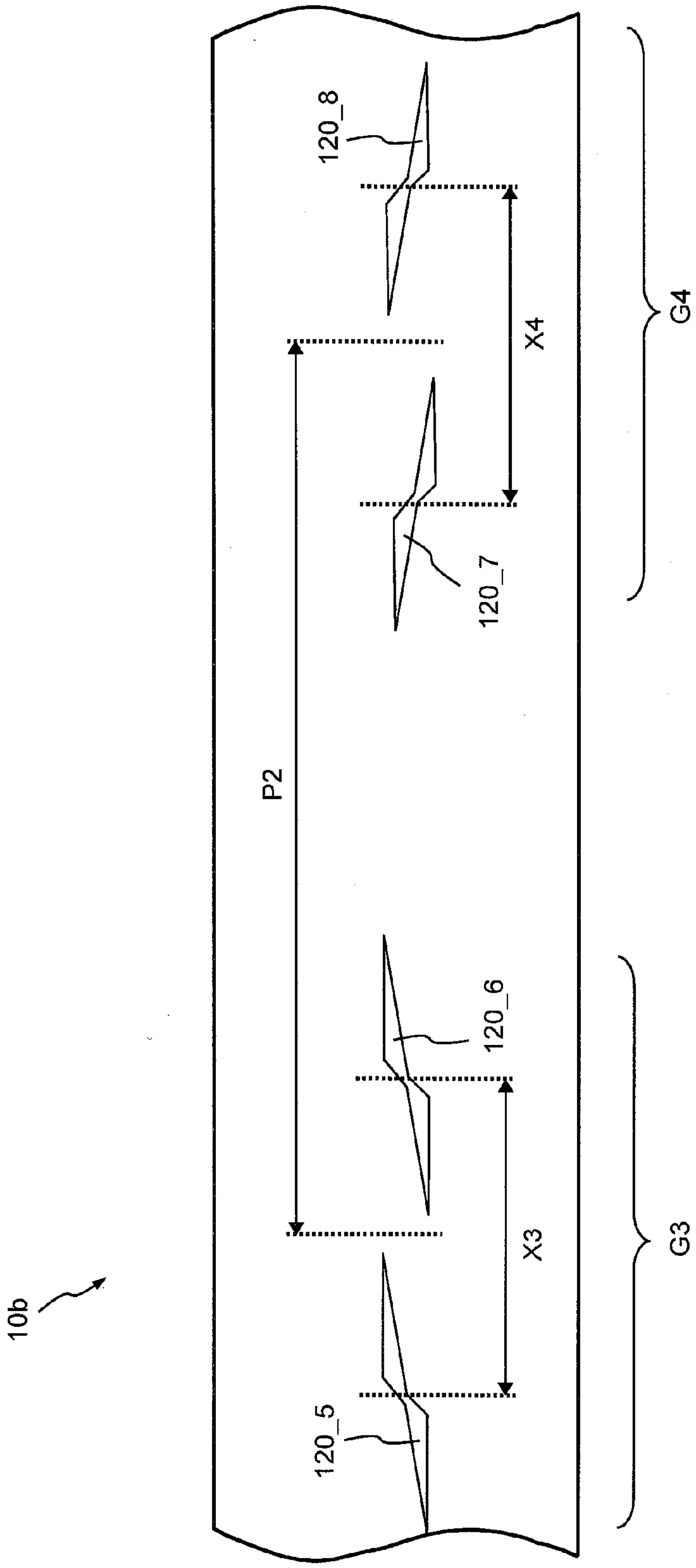


Fig. 4

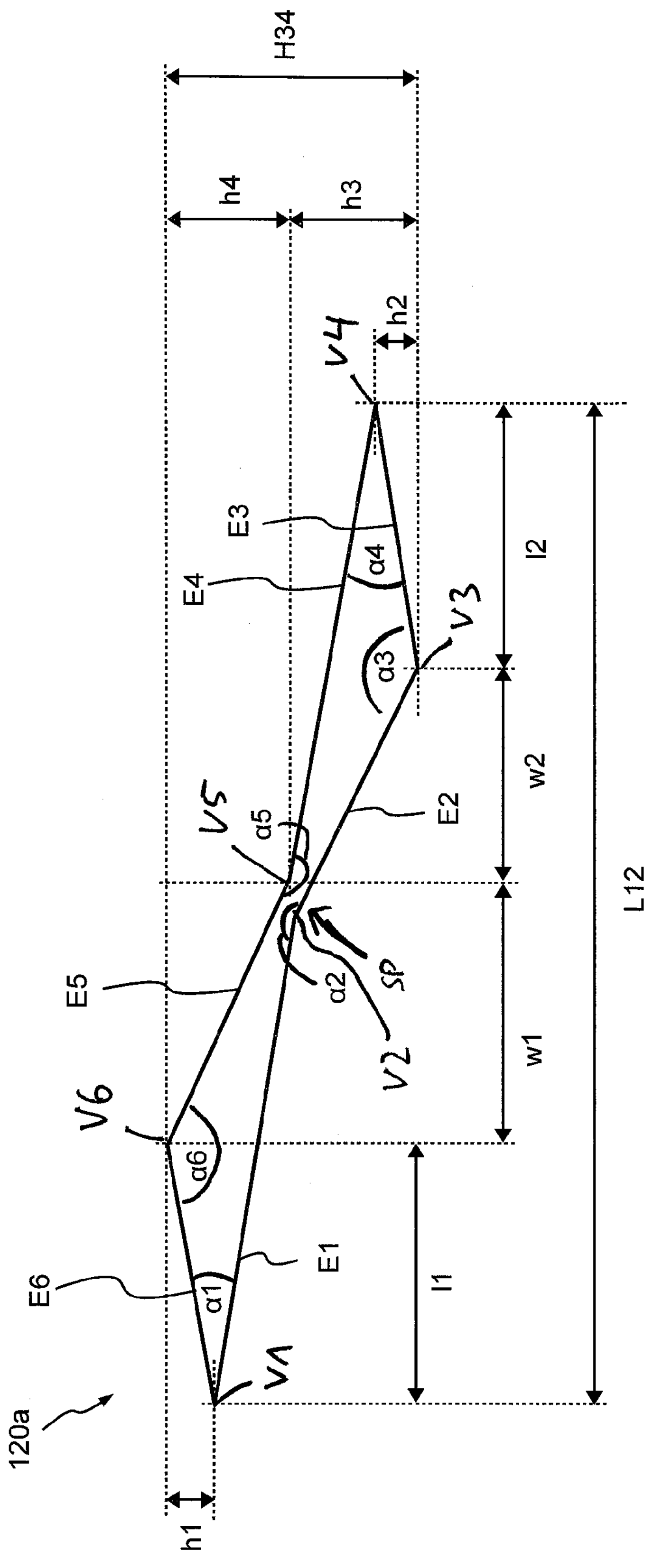

H34
h4
h3
h2
V4
E3
E4
α4
V3
α3
l2
w2
E2
V5
α5
L12
SP
α2
V2
E5
w1
V6
α6
E1
l1
E6
α1
V1
120a
h1

Fig. 5a

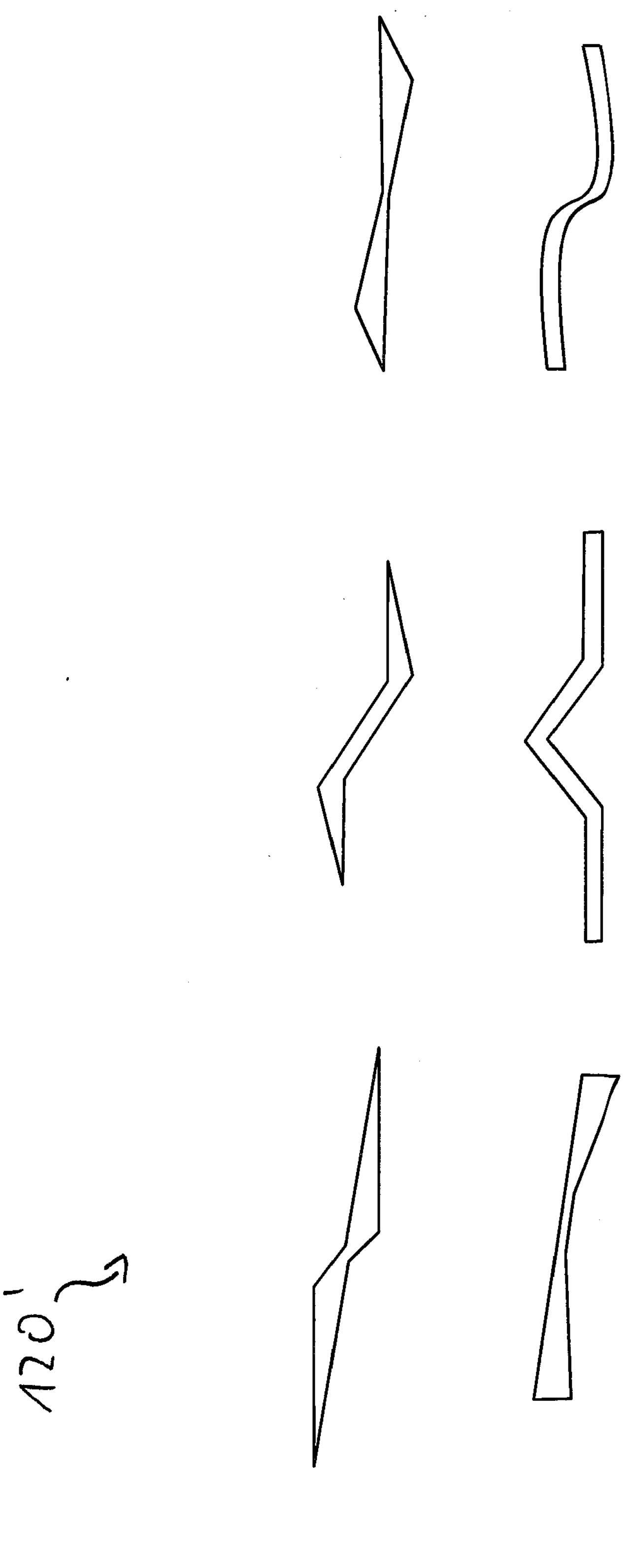


Fig. 5b

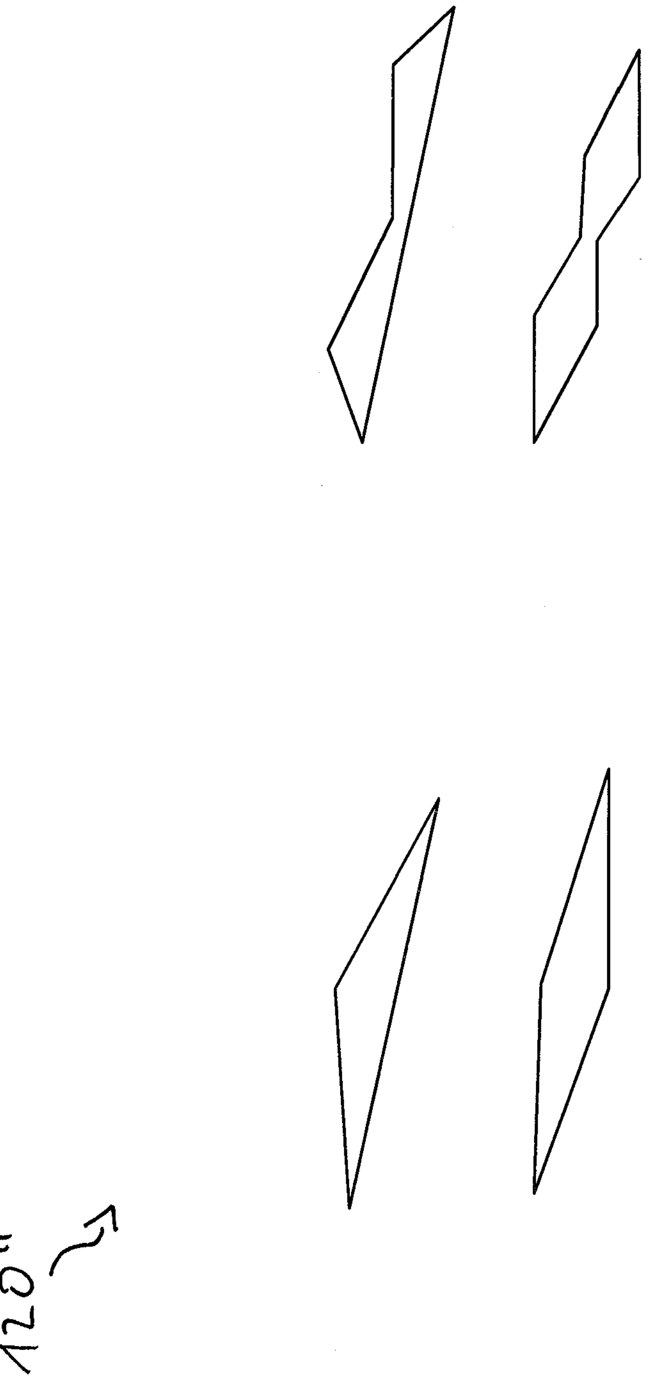


Fig. 6

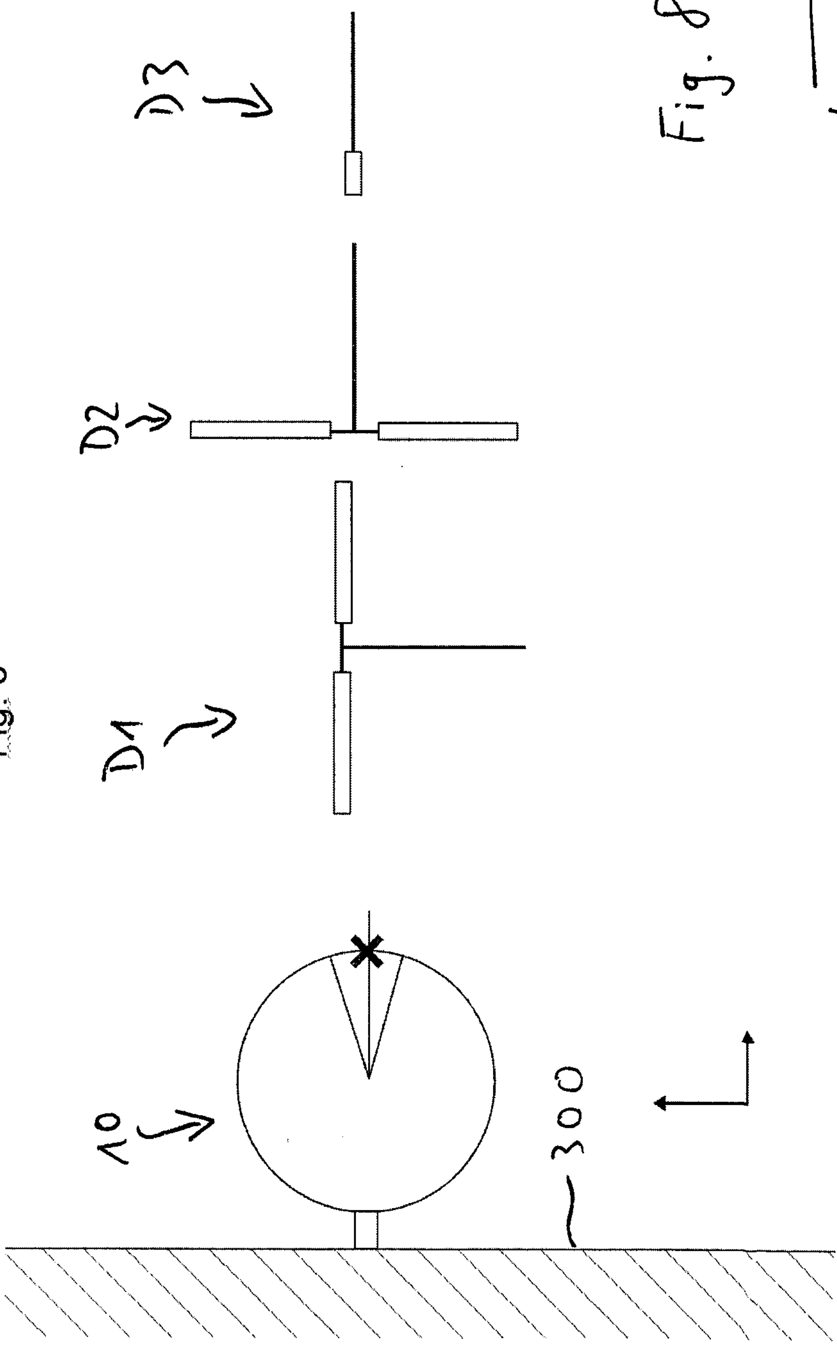


Fig. 8

Fig. 7a

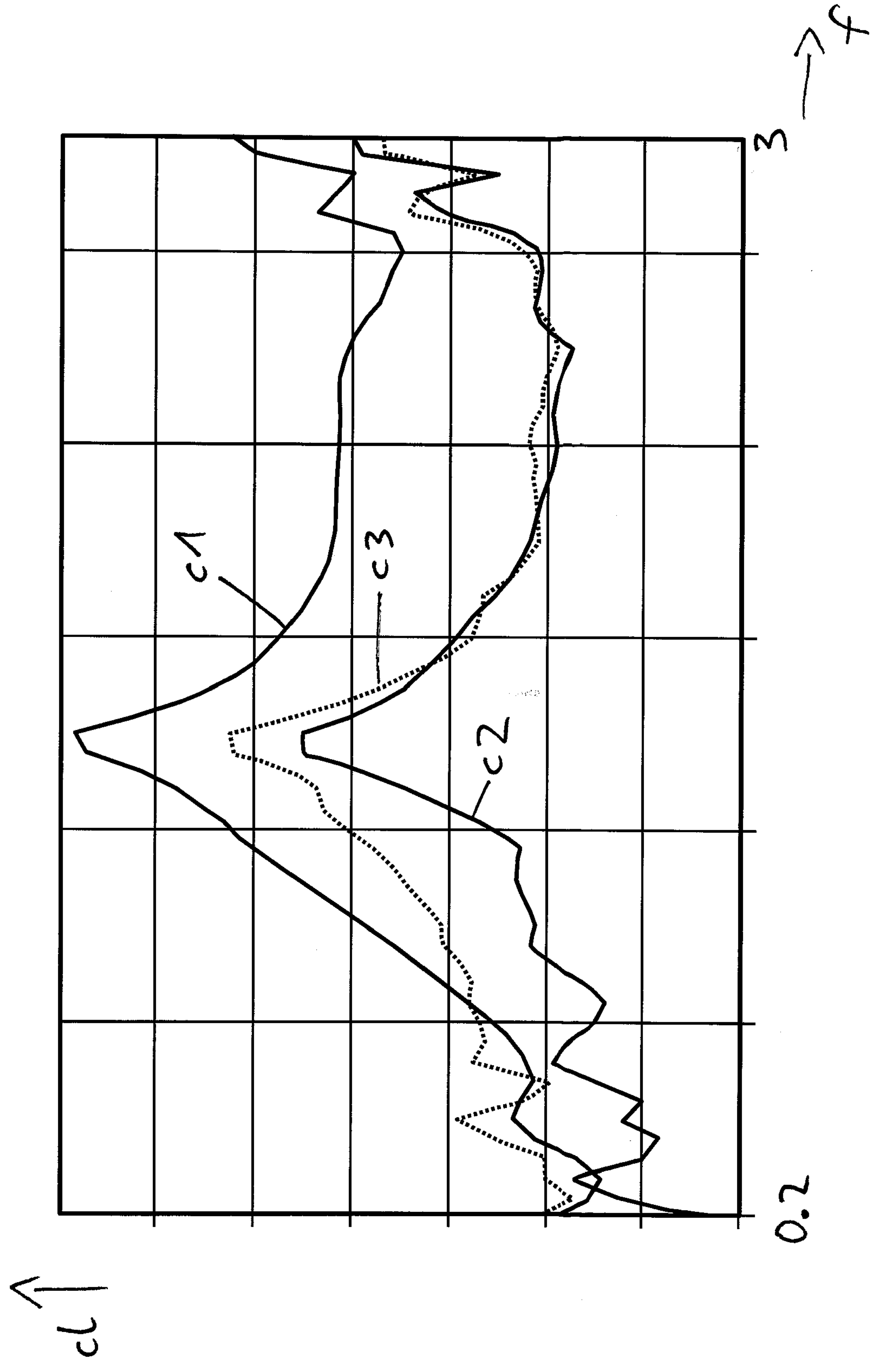


Fig. 7b

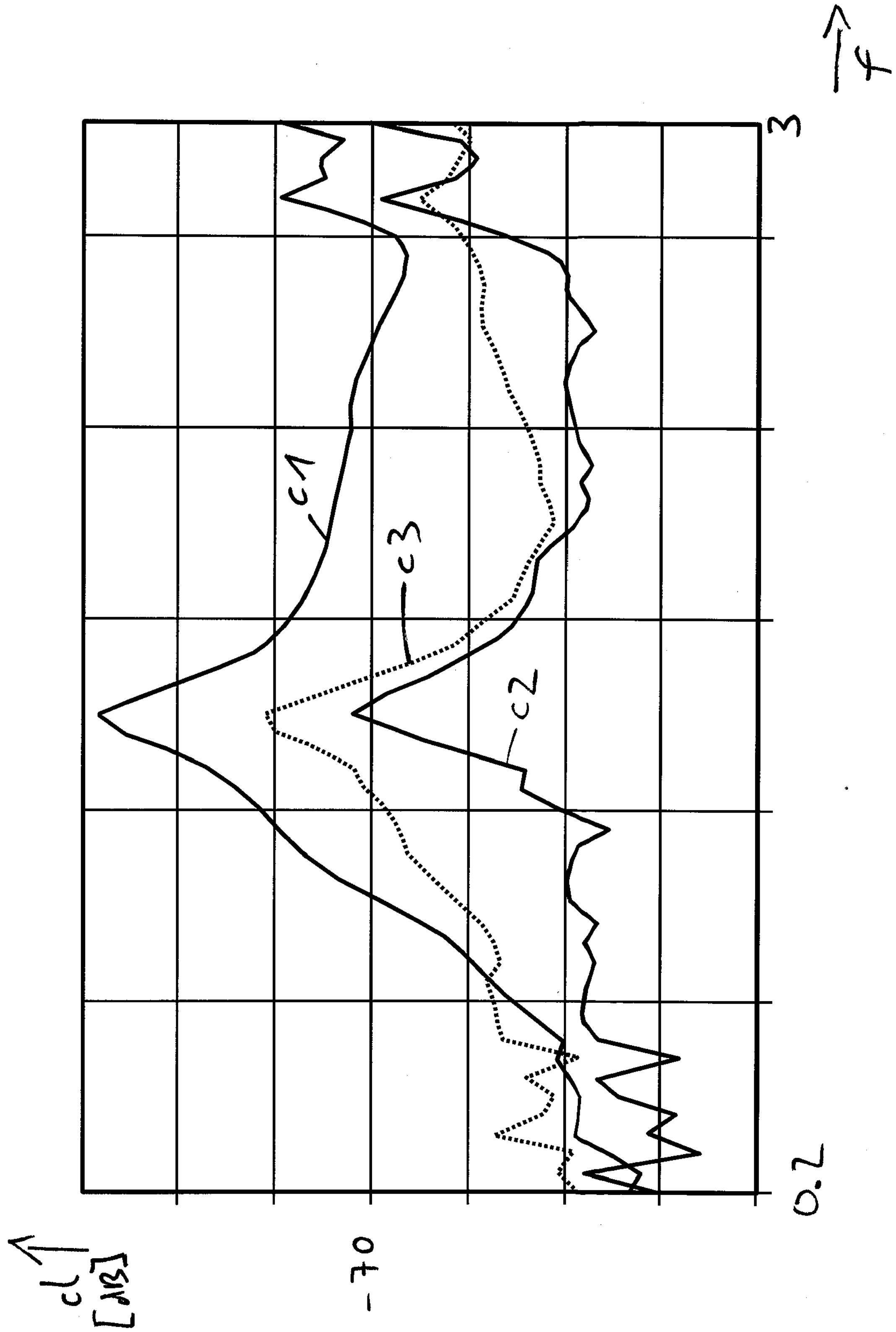


Fig. 7c

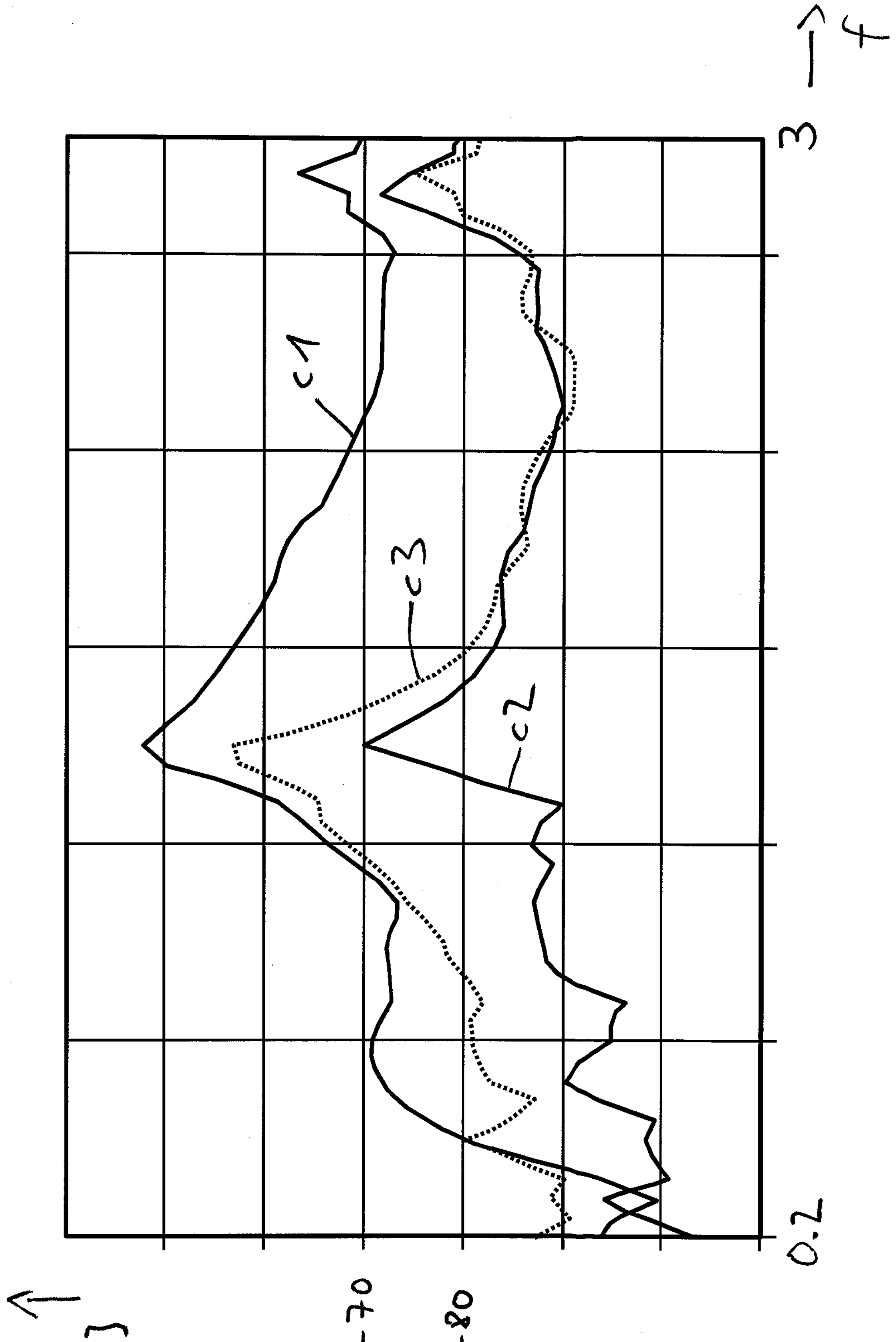


Fig. 7d

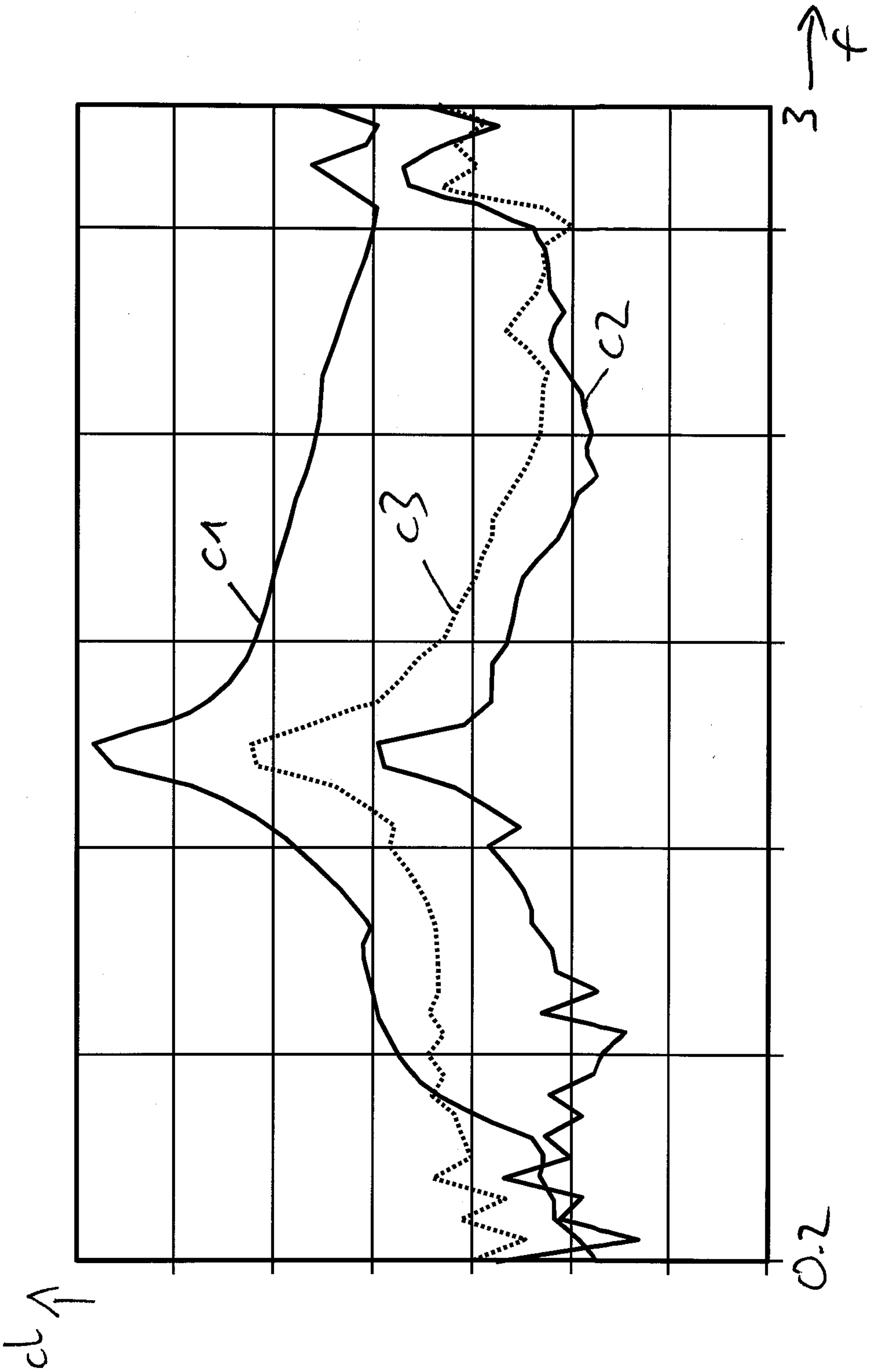
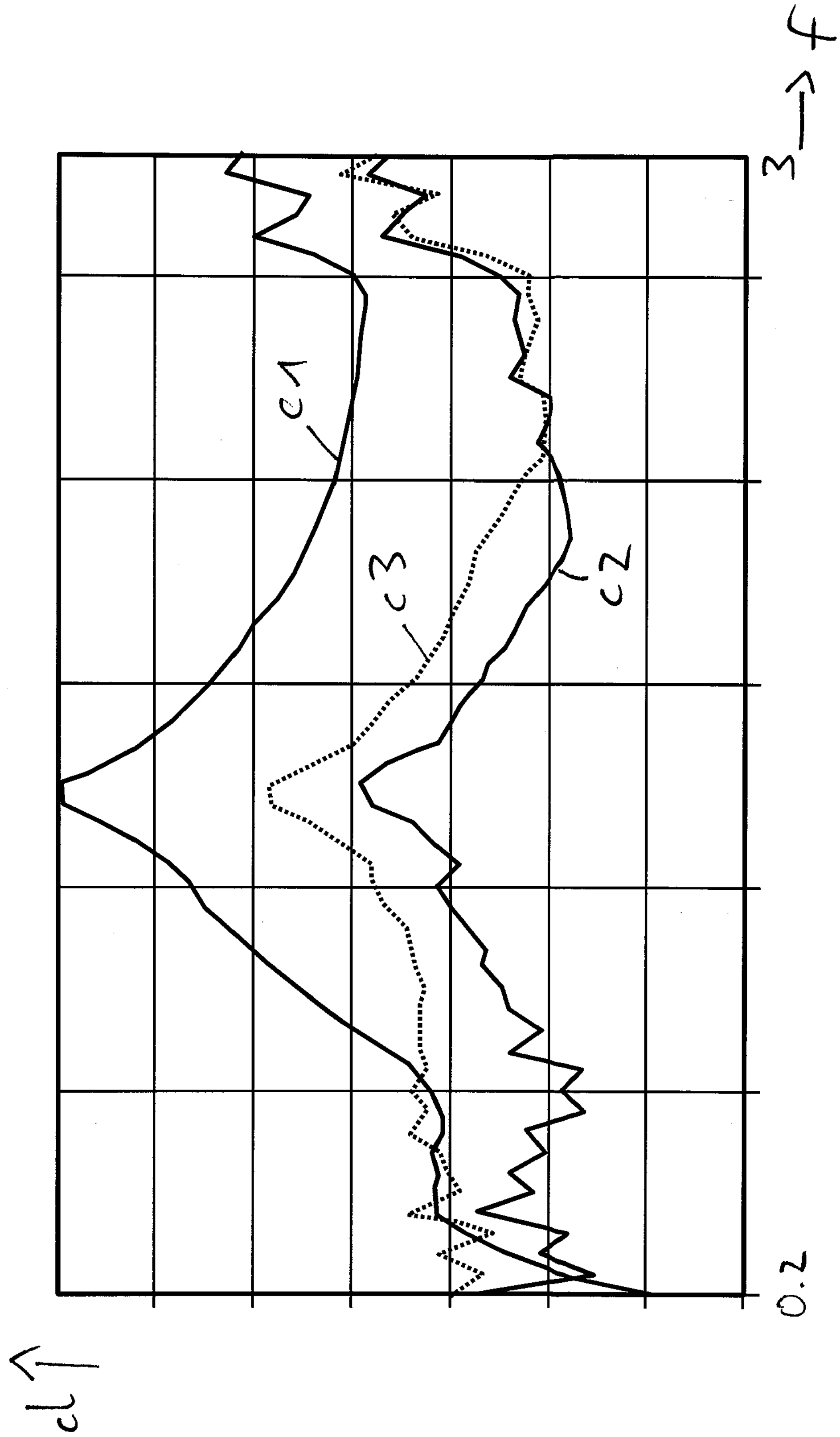


Fig. 7e



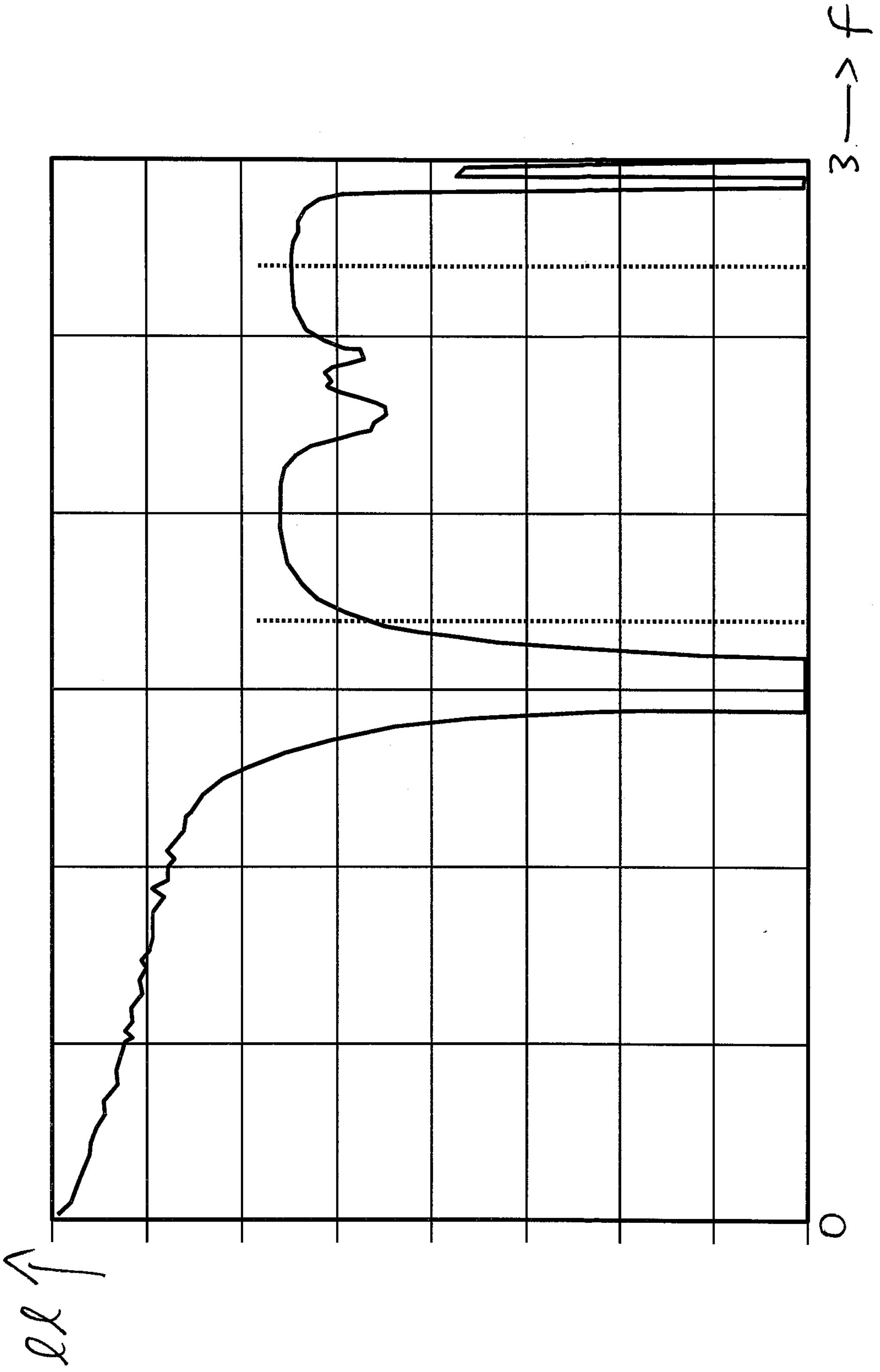
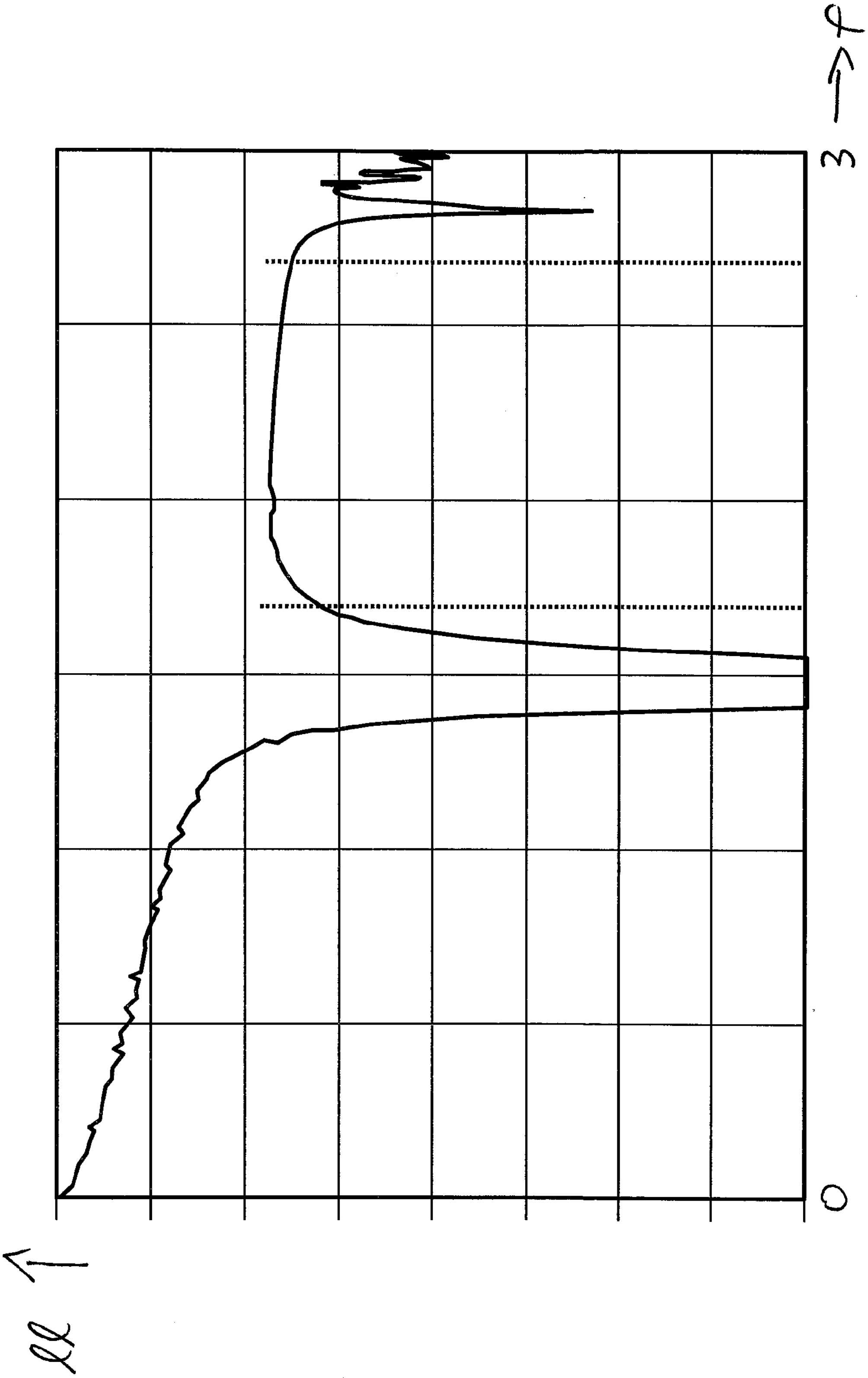


Fig. 9a

Fig. 9b



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EUROPEAN SEARCH REPORT

Application Number
EP 14 19 7835

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The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	28 May 2015	Ribbe, Jonas

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