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(54) **Space-filling miniature antennas**

raumfüllende miniaturantennen

antennes miniatures de remplissage d'espace

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Description

Object of the Invention

[0001] The present invention generally refers to a new family of antennas of reduced size based on an innovative geometry, the geometry of the curves named as Space-Filling Curves (SFC). An antenna is said to be a small antenna (a miniature antenna) when it can be fitted in a small space compared to the operating wavelength. More precisely, the radiansphere is taken as the reference for classifying an antenna as being small. The radiansphere is an imaginary sphere of radius equal to the operating wavelength divided by two times π; an antenna is said to be small in terms of the wavelength when it can be fitted inside said radiansphere.

[0002] WO-A- 97/06578 discusses fractal antennas, resonators and loading elements. WO-A-99/27608 relates to a cylindrical conformable antenna on a planar substrate.

[0003] A novel geometry, the geometry of Space-Filling Curves (SFC) is defined in the present invention and it is used to shape a part of an antenna. By means of this novel technique, the size of the antenna can be reduced with respect to prior art, or alternatively, given a fixed size the antenna can operate at a lower frequency with respect to a conventional antenna of the same size.

[0004] The invention is applicable to the field of the telecommunications and more concretely to the design of antennas with reduced size.

Background and Summary of the Invention

[0005] The fundamental limits on small antennas were theoretically established by H.Wheeler and L.J.Chu in the middle 1940's. They basically stated that a small antenna has a high quality factor (Q) because of the large reactive energy stored in the antenna vicinity compared to the radiated power. Such a high quality factor yields a narrow bandwidth; in fact, the fundamental derived in such theory imposes a maximum bandwidth given a specific size of a small antenna.

[0006] Related to this phenomenon, it is also known that a small antenna features a large input reactance (either capacitive or inductive) that usually has to be compensated with an external matching/loading circuit or structure. It also means that it is difficult to pack a resonant antenna into a space which is small in terms of the wavelength at resonance. Other characteristics of a small antenna are its small radiating resistance and its low efficiency.

[0007] Searching for structures that can efficiently radiate from a small space has an enormous commercial interest, especially in the environment of mobile communication devices (cellular telephony, cellular pagers, portable computers and data handlers, to name a few examples), where the size and weight of the portable equipments need to be small. According to R.C.Hansen (R.C.Hansen, "Fundamental Limitations on Antennas," Proc.IEEE, vol. 69, no.2, February 1981), the performance of a small antenna depends on its ability to efficiently use the small available space inside the imaginary radiansphere surrounding the antenna.

[0008] In the present invention, a novel set of geometries named Space-Filling Curves (hereafter SFC) are introduced for the design and construction of small monopole antennas that improve the performance of other classical antennas described in the prior art (such as linear monopoles, dipoles and circular or rectangular loops).

[0009] The invention is defined in the independent claims. Some embodiments thereof are defined in the dependent claims.

[0010] Some of the geometries described in the present invention are inspired in the geometries studied already in the XIX century by several mathematicians such as Giusepe Peano and David Hilbert. In all said cases the curves were studied from the mathematical point of view but were never used for any practical engineering application.

[0011] The dimension (D) is often used to characterize highly complex geometrical curves and structures such as those described in the present invention. There exist many different mathematical definitions of dimension but in the present document the box-counting dimension (which is well-known to those skilled in mathematics theory) is used to characterize a family of designs. The box-cocuting dimension is computed as the slope of the straight portion of a log-log graph. Said straigh portion is substantially defined as a straight segment over at least an octave of scales on the horizontal axis of the log-log graphe. Those skilled in mathematics theory will notice that optionally, an Iterated Function System (IFS), a Multireduction Copy Machine (MRCM) or a Networked Multireduction Copy Machine (NMRCM) algorithm can be used to construct some space-filling curves as those described in the present document; however, the curves constructed using an IFS or MRCM are not within the scope of the claims.

[0012] The key point is shaping part of the antenna (for example the arms of a dipole, the arm of a monopole, the perimeter of the patch of a patch antenna, the slot in a slot antenna, the loop perimeter in a loop antenna, the horn cross-section in a horn antenna, or the reflector perimeter in a reflector antenna) as a space-filling curve, that is, a curve that is large in terms of physical length but small in terms of the area in which the curve can be included. More precisely, the following definition is taken in this document for a space-filling curve: a curve composed by at least ten segments which are connected in such a way that each segment forms an angle with their neighbours, that is, no pair of adjacent segments defines a larger straight segment, and wherein the curve can be optionally periodic along a fixed straight direction of space if and only if the period is defined by a non-periodic curve composed by at least ten connected segments and no pair of said adjacent and connected segments defines a straight longer segment. Also, whatever the design of such SFC is, it can never intersect with itself at any point except the initial and final point (that is, the whole curve can be arranged as a closed curve or loop, but none of the parts of the curve can become a closed loop). A space-filling curve can be fitted over a flat or curved surface, and due to the angles between segments, the physical length of the curve is always larger than that of any straight line that can be fitted in the same area (surface) as said space-filling curve. Additionally, to properly shape the structure of a miniature antenna according to the present invention, the segments of the SFC curves must be shorter than a tenth of the free-space operating wavelength.

[0013] Depending on the shaping procedure and curve geometry, some infinite length SFC can be theoretically designed to feature a Haussdorf dimension larger than their topological-dimension. That is, in terms of the classical Euclidean geometry, it is usually understood that a curve is always a one-dimension object; however when the curve is highly convoluted and its physical length is very large, the curve tends to fill parts of the surface which supports it; in that case the Haussdorf dimension can be computed over the curve (or at least an approximation of it by means of the box-counting algorithm) resulting in a number larger than unity. Such theoretical infinite curves can not be physically constructed, but they can be approached with SFC designs. The curves 8 and 17 described in Figure 2 and Figure 5 are some examples of such SFC, that approach an ideal infinite curve featuring a dimension D = 2.

[0014] The advantage of using SFC curves in the physical shaping of the antenna is two-fold:

(a) Given a particular operating frequency or wavelength said SFC antenna can be reduced in size with respect to prior art.
(b) Given the physical size of the SFC antenna, said SFC antenna can be operated at a lower frequency (a longer wavelength) than prior art.

Brief Description of the Drawings

[0015]

Figure 1 shows some particular cases of non-claimed SFC curves. From an initial curve (2), other curves (1), (3) and (4) with more than 10 connected segments are formed. This particular family of curves are named hereafter SZ curves.

Figure 2 shows a comparison between two prior art meandering lines and two non-claimed SFC periodic curves, constructed from the SZ curve of figure 1.

Figure 3 shows a particular configuration of an SFC antenna not within the scope of the claims, but merely shown for the purpose of informing the public. It consists on tree different configurations of a dipole wherein each of the two arms is fully shaped as an SFC curve (1).

Figure 4 shows other particular cases of SFC antennas. They consist of monopole antennas.

Figure 5 shows an example of an SFC slot antenna (not claimed) where the slot is shaped as the non-claimed SFC in figure 1.

Figure 6 shows another set of SFC curves (15-20) inspired on the Hilbert curve and hereafter named as Hilbert curves. A standard, non-SFC curve is shown in (14) for comparison.

Figure 7 shows another example of an SFC slot antenna (not claimed) based on the (non-claimed) SFC curve (17) in figure 6.

Figure 8 shows another set of SFC curves (24, 25, 26, 27) hereafter known as ZZ curves not claimed. A conventional squared zigzag curve (23) is shown for comparison.

Figure 9 shows a loop antenna based on curve (25) in a wire configuration (top). Below, the loop antenna 29 is printed over a dielectric substrate (10).

Figure 10 shows a non-claimed slot loop antenna based on the SFC (25) in figure 8.

Figure 11 shows a non-claimed patch antenna wherein the patch perimeter is shaped according to SFC (25).

Figure 12 shows a non-claimed aperture antenna wherein the aperture (33) is practiced on a conducting or superconducting structure (31), said aperture being shaped with SFC (25).

Figure 13 shows a non-claimed patch antenna with an aperture on the patch based on SFC (25).

Figure 14 shows another particular example of a family of non-claimed SFC curves (41, 42, 43) based on the Giusepe Peano curve. A non-SFC curve formed with only 9 segments is shown for comparison.

Figure 15 shows a non-claimed patch antenna with an SFC slot based on the non-claimed SFC (41).

Figure 16 shows a non-claimed wave-guide slot antenna wherein a rectangular waveguide (47) has one of its walls slotted with the non-claimed SFC curve (41).

Figure 17 shows a non-claimed horn antenna, wherein the aperture and cross-section of the horn is shaped after SFC (25).

Figure 18 shows a reflector of a non-claimed reflector antenna wherein the perimeter of said reflector is shaped as SFC (25) .

Figure 19 shows a family of non-claimed SFC curves (51, 52, 53) based on the Giusepe Peano curve. A non-SFC curve formed with only nine segments is shown for comparison (50).

Figure 20 shows another family of non-claimed SFC curves (55, 56, 57, 58). A non-SFC curve (54) constructed with only five segments is shown for comparison.

Figure 21 shows two examples of SFC loops (59, 60) constructed with SFC (57).

Figure 22 shows a family of SFC curves (61, 62, 63, 64) named here as HilbertZZ curves.

Figure 23 shows a family of non-claimed SFC curves (66, 67, 68) named here as Peanodec curves. A non-SFC curve (65) constructed with only nine segments is shown for comparison.

Figure 24 shows a family of non-claimed SFC curves (70, 71, 72) named here as Peanoinc curves. A non-SFC curve (69) constructed with only nine segments is shown for comparison.

Figure 25 shows a family of non-claimed SFC curves (73, 74, 75) named here as PeanoZZ curves. A non-SFC curve (23) constructed with only nine segments is shown for comparison.

Only monopole antennas are claimed, and any other antennas shown in the drawings are merely shown as general information to the public.

Detailed Description of the Preferred Embodiments

[0016] Figure 1 and Figure 2 show some examples of SFC curves not within the scope of the claims. Drawings (1), (3) and (4) in Figure 1 show three examples of SFC curves named SZ curves. A curve that is not an SFC since it is only composed of 6 segments is shown in drawing (2) for comparison. The drawings (7) and (8) in Figure 2 show another two particular examples of SFC curves, formed from the periodic repetition of a motive including the SFC curve (1). It is important noticing the substantial difference between these examples of SFC curves and some examples of periodic, meandering and not SFC curves such as those in drawings (5) and (6) in Figure 2. Although curves (5) and (6) are composed by more than 10 segments, they can be substantially considered periodic along a straight direction (horizontal direction) and the motive that defines a period or repetition cell is constructed with less than 10 segments (the period in drawing (5) includes only four segments, while the period of the curve (6) comprises nine segments) which contradicts the definition of SFC curve introduced in the present invention. SFC curves are substantially more complex and pack a longer length in a smaller space; this fact in conjunction with the fact that each segment composing and SFC curve is electrically short (shorter than a tenth of the free-space operating wavelength as claimed in this invention) play a key role in reducing the antenna size. Also, the class of folding mechanisms used to obtain the particular SFC curves described in the present invention are important in the design of miniature antennas.

[0017] Figure 3 illustrates a non-claimed SFC antenna. The three drawings display different configurations of the same basic dipole. A two-arm antenna dipole is constructed comprising two conducting or superconducting parts, each part shaped as an SFC curve. For the sake of clarity but without loss of generality, a particular case of non-claimed SFC curve (the SZ curve (1) of Figure 1) has been chosen here; other SFC curves as for instance, those described in Fig. 21 could be used instead. The two closest tips of the two arms form the input terminals (9) of the dipole. The terminals (9) have been drawn as conducting or superconducting circles, but as it is clear to those skilled in the art, such terminals could be shaped following any other pattern as long as they are kept small in terms of the operating wavelength. Also, the arms of the dipoles can be rotated and folded in different ways to finely modify the input impedance or the radiation properties of the antenna such as, for instance, polarization. Another non-claimed SFC dipole is also shown in Figure 3, where the conducting or superconducting SFC arms are printed over a dielectric substrate (10); this method is particularly convenient in terms of cost and mechanical robustness when the SFC curve is long. Any of the well-known printed circuit fabrication techniques can be applied to pattern the SFC curve over the dielectric substrate. Said dielectric substrate can be for instance a glass-fibre board, a teflon based substrate (such as Cuclad®) or other standard radiofrequency and microwave substrates (as for instance Rogers 4003® or Kapton®). The dielectric substrate can even be a portion of a window glass if the antenna is to be mounted in a motor vehicle such as a car, a train or an air-plane, to transmit or receive radio, TV, cellular telephone (GSM 900, GSM 1800, UMTS) or other communication services electromagnetic waves. Of course, a balun network can be connected or integrated at the input terminals of the dipole to balance the current distribution among the two dipole arms.

[0018] A preferred embodiment of an SFC antenna is a monopole configuration as shown in Figure 4. In this case one of the dipole arms is substituted by a conducting or superconducting counterpoise or ground plane (12). A handheld telephone case, or even a part of the metallic structure of a car, train or can act as such a ground counterpoise. The ground and the monopole arm (here the arm is represented with non-claimed SFC curve (1), but other SFC curve could be taken instead insofar as they fall under the definition of claim 1) are excited as usual in prior art monopoles by means of, for instance, a transmission line (11). Said transmission line is formed by two conductors, one of the conductors is connected to the ground counterpoise while the other is connected to a point of the SFC conducting or superconducting structure. In the drawings of Figure 4, a coaxial cable (11) has been taken as a particular case of transmission line, but it is clear to any skilled in the art that other transmission lines (such as for instance a microstrip arm) could be used to excite the monopole. Optionally, and following the scheme described in Figure 3, the SFC curve can be printed over a dielectric substrate (10).

[0019] Another non-claimed configuration of an SFC antenna is a slot antenna as shown, for instance in Figures 5, 7 and 10 (the curves in figures 5 and 7 are not within the scope of the claims). In Figure 5, two connected SFC curves (following the pattern (1) of Figure 1) form a slot or gap impressed over a conducting or superconducting sheet (13). Such sheet can be, for instance, a sheet over a dielectric substrate in a printed circuit board configuration, a transparent conductive film such as those deposited over a glass window to protect the interior of a car from heating infrared radiation, or can even be part of the metallic structure of a handheld telephone, a car, train, boat or airplane. The exciting scheme can be any of the well known in conventional slot antennas and it does not become an essential part of the present invention. In all said three figures, a coaxial cable (11) has been used to excite the antenna, with one of the conductors connected to one side of the conducting sheet and the other one connected at the other side of the sheet across the slot. A microstrip transmission line could be used, for instance, instead of the coaxial cable.

[0020] To illustrate that several modifications of the antenna that can be done based on the same principle , a similar example is shown in Figure 7, where another curve (the curve (17) from the Hilbert family) is taken instead. Notice that neither in Figure 5, nor in Figure 7 the slot reaches the borders of the conducting sheet, but in another embodiment the slot can be also designed to reach the boundary of said sheet, breaking said sheet in two separate conducting sheets.

[0021] Figure 10 describes another (non-claimed) possible embodiment of a slot SFC antenna. It is also an slot antenna in a closed loop configuration. The loop is constructed for instance by connecting four SFC gaps following the pattern of SFC (25) in Figure 8 (it is clear that other SFC curves could be used instead). The resulting closed loop determines the boundary of a conducting or superconducting island surrounded by a conducting or superconducting sheet. The slot can be excited by means of any of the well-known conventional techniques; for instance a coaxial cable (11) can be used, connecting one of the outside conductor to the conducting outer sheet and the inner conductor to the inside conducting island surrounded by the SFC gap. Again, such sheet can be, for example, a sheet over a dielectric substrate in a printed circuit board configuration, a transparent conductive film such as those deposited over a glass window to protect the interior of a car from heating infrared radiation, or can even be part of the metallic structure of a handheld telephone, a car, train, boat or air-plane. The slot can be even formed by the gap between two close but not coplanar conducting island and conducting sheet; this can be physically implemented for instance by mounting the inner conducting island over a surface of the optional dielectric substrate, and the surrounding conductor over the opposite surface of said substrate.

[0022] The slot configuration is not, of course, the only way of implementing an SFC loop antenna. A closed SFC curve made of a superconducting or conducting material can be used to implement a wire SFC loop antenna as shown in another non-claimed embodiment as that of Figure 9, which features a curve not as defined in claim 1. In this case, a portion of the curve is broken such as the two resulting ends of the curve form the input terminals (9) of the loop. Optionally, the loop can be printed also over a dielectric substrate (10). In case a dielectric substrate is used, a dielectric antenna can be also constructed by etching a dielectric SFC pattern over said substrate, being the dielectric permitivity of said dielectric pattern higher than that of said substrate.

[0023] Another non-claimed configuration is shown in Figure 11. It consists of a patch antenna, with the conducting or superconducting patch (30) featuring an SFC perimeter (the particular case of SFC (25) has been used here but it is clear that other SFC curves could be used instead). The perimeter of the patch is the essential part of the invention here, being the rest of the antenna conformed, for example, as other conventional patch antennas: the patch antenna comprises a conducting or superconducting ground-plane (31) or ground counterpoise, and the conducting or superconducting patch which is parallel to said ground-plane or ground-counterpoise. The spacing between the patch and the ground is typically below (but not restricted to) a quarter wavelength. Optionally, a low-loss dielectric substrate (10) (such as glass-fibre, a teflon substrate such as Cuclad® or other commercial materials such as Rogers® 4003) can be placed between said patch and ground counterpoise. The antenna feeding scheme can be taken to be any of the well-known schemes used in prior art patch antennas, for instance: a coaxial cable with the outer conductor connected to the ground-plane and the inner conductor connected to the patch at the desired input resistance point (of course the typical modifications including a capacitive gap on the patch around the coaxial connecting point or a capacitive plate connected to the inner conductor of the coaxial placed at a distance parallel to the patch, and so on can be used as well); a microstrip transmission line sharing the same ground-plane as the antenna with the strip capacitively coupled to the patch and located at a distance below the patch, or in another embodiment with the strip placed below the ground-plane and coupled to the patch through an slot, and even a microstrip transmission line with the strip co-planar to the patch. All these mechanisms are well known from prior art and do not constitute an essential part of the present invention.

[0024] Other non-claimed configurations of SFC antennas based also on the patch configuration are disclosed in Figure 13 and Figure 15 (however, the specific curve illustrated in figure 15 is not within the scope of the claims. They consist of a conventional patch antenna with a polygonal patch (30) (squared, triangular, pentagonal, hexagonal, rectangular, or even circular, to name just a few examples), with an SFC curve shaping a gap on the patch. Such an SFC line can form an slot or spur-line (44) over the patch (as seen in Figure 15) contributing this way in reducing the antenna size and introducing new resonant frequencies for a multiband operation, or in another preferred embodiment the SFC curve (such as (25) defines the perimeter of an aperture (33) on the patch (30) (Figure 13). Such an aperture contributes significantly to reduce the first resonant frequency of the patch with respect to the solid patch case, which significantly contributes to reducing the antenna size. Said two configurations, the non-claimed SFC slot and the non-claimed SFC aperture cases can of course be use also with SFC perimeter patch antennas as for instance the one (30) described in Figure 11.

[0025] At this point it becomes clear to those skilled in the art that the same SFC geometric principle can be applied in an innovative way to all the well known, prior art configurations. More examples are given in Figures 12, 16, 17 and 18 (however, the specific curve of figure 16 is not within the scope of the claims).

[0026] Figure 12 illustrates another non-claimed configuration of an SFC antenna. It consists of an aperture antenna, said aperture being characterized by its SFC perimeter, said aperture being impressed over a conducting ground-plane or ground-counterpoise (34), said ground-plane of ground-counterpoise consisting, for example, of a wall of a waveguide or cavity resonator or a part of the structure of a motor vehicle (such as a car, a lorry, an airplane or a tank). The aperture can be fed by any of the conventional techniques such as a coaxial cable (11), or a planar microstrip or strip-line transmission line, to name a few.

[0027] Figure 16 shows another non-claimed configuration where the non-claimed SFC curves (41) are slotted over a wall of a waveguide (47) of arbitrary cross-section. This way and slotted waveguide array can be formed, with the advantage of the size compressing properties of the SFC curves.

[0028] Figure 17 depicts another non-claimed configuration, in this case a horn antenna (48) where the cross-section of the antenna is an SFC curve (25). In this case, the benefit comes not only from the size reduction property of SFC geometries, but also from the broadband behavior that can be achieved by shaping the horn cross-section. Primitive versions of these techniques have been already developed in the form of Ridge horn antennas. In said prior art cases, a single squared tooth introduced in at least two opposite walls of the horn is used to increase the bandwidth of the antenna. The richer scale structure of an SFC curve further contributes to a bandwidth enhancement with respect to prior art.

[0029] Figure 18 describes another typical configuration of antenna, a reflector antenna (49), with the newly disclosed approach of shaping the reflector perimeter with an SFC curve. The reflector can be either flat or curve, depending on the application or feeding scheme (in for instance a reflectarray configuration the SFC reflectors will preferably be flat, while in focus fed dish reflectors the surface bounded by the SFC curve will preferably be curved approaching a parabolic surface). Also, within the spirit of SFC reflecting surfaces, Frequency Selective Surfaces (FSS) can be also constructed by means of SFC curves; in this case the SFC are used to shape the repetitive pattern over the FSS. In said FSS configuration, the SFC elements are used in an advantageous way with respect to prior art because the reduced size of the SFC patterns allows a closer spacing between said elements. A similar advantage is obtained when the SFC elements are used in an antenna array in an antenna reflectarray.

Claims

1. A monopole antenna, said monopole antenna comprising a radiating arm and a ground plane (12), said radiating arm being excited by a transmission line (11),
wherein said radiating arm is shaped as a space-filling curve (59-60),
wherein said space-filling curve is composed by at least ten connected segments forming a non-periodic portion of said curve, wherein:

- each of said segments is shorter than a tenth of the operating free-space wave length of the antenna;
- said segments are spatially arranged in such a way that none of said segments form, together with an adjacent segment, a longer straight segment;
- said segments are connected in such a way that each segment forms an angle with its neighbours;
- none of said segments intersect with another of said segments except at the ends of the curve, whereby said space-filling curve intersects itself at its beginning and end so that said space-filling curve forms a closed loop;
- each pair of adjacent segments of said curve

forms a corner; and

- wherein, if said curve is periodic along a fixed straight direction of space, the corresponding period is defined by the non-periodic portion composed by at least ten connected segments, none of said connected segments forming, together with an adjacent segment, a straight longer segment;

said space-filling curve being a curve that features a box-counting dimension larger than one;
wherein said curve is not self-similar

2. An antenna according to claim 1, said antenna having a size so that said antenna fits within a sphere having a radius equal to the operating wavelength of the antenna divided by 2π.

3. An antenna according to any of the preceding claims, wherein said at least ten connected segments composing the space-filling curve (25) are straight segments.

4. An antenna according to claim 1, wherein said corners are curved.

5. An antenna according to claim 1, wherein said corners are rounded or smoothed otherwise.

6. An antenna according to any of the preceding claims, wherein said space-filling curve is printed over a dielectric substrate.

7. An antenna according to any of the preceding claims, wherein the space-filling curve is shaped as a Hilbert curve.

8. An antenna according to any of claims 1-6, wherein the space-filling curve is shaped as a HilbertZZ curve (61, 62, 63, 64).

9. An antenna according to any of claims 1-6, wherein the space-filling curve is shaped as a Peano curve.

10. An antenna according to any of the preceding claims, wherein said space-filling curve (25) is fitted over a curved surface.

11. An antenna according to any of claims 1-9, wherein said space-filling curve (25) is fitted over a flat surface.

12. An antenna according to any of the preceding claims, wherein the antenna is arranged to cover at least one of the following telecommunication services: GSM900, GSM1800, UMTS.

13. An antenna according to any of the preceding claims, having an operating wavelength corresponding to the operating wavelength of a cellular telephone system.

14. An antenna according to any of the preceding claims, said antenna comprising a ground-plane which is a metallic structure within a handheld telephone.

15. An antenna according to any of the preceding claims, said antenna being arranged in a device for mobile communication.

16. An antenna according to claim 15, wherein said antenna is mounted on a cellular telephone.

17. An antenna according to any of the preceding claims, wherein said space-filling curve is not periodic along a straight line.

18. An antenna according to any of the preceding claims, including a network between a radiating element and an input connector of the antenna, said network being a matching network, an impedance transformer network, or a balun network.

19. An antenna according to any of the preceding claims, said antenna being configured for multiband operation.

20. A set of antennas comprising a plurality of antennas according to any of the previous claims, wherein most of said antennas are arranged to be fed with a signal at a given frequency, forming an array of antennas, wherein
at least two antennas of said plurality of antennas are arranged to operate at different frequencies to give coverage to different communications services ; and
wherein said antennas are arranged to be simultaneously fed by means of a distribution or diplexer network.

21. A device for mobile communication, provided with an antenna according to any of claims 1-19, or with a set of antennas according to claim 20.

22. A device according to claim 21, said device being a handheld telephone.

23. A device according to claim 21, wherein a case of said handheld telephone acts as the ground plane of the antenna.

24. A method of producing a mobile communication device having a reduced size, wherein the method comprises incorporating, as an antenna for the device, an antenna according to any of claims 1-19 or a set of antennas according to claim 20.

Patentansprüche

1. Eine Monopolantenne, besagte Monopolantenne bestehend aus einem strahlenförmigen Arm und einer Bodenplatte (12), besagter strahlenförmiger Arm, der von einer Stromleitung erregt wird (11), wobei der genannte strahlenförmige Arm als raumfüllende Kurve geformt ist (59-60),
wobei die genannte raumfüllende Kurve aus zumindest zehn miteinander verbundenen Segmenten zusammengesetzt ist, die einen nicht periodischen Teil der genannten Kurve bilden, wobei:

   - jedes der genannten Segmente kürzer als ein Zehntel der Betriebs-Freiraumwellenlänge der Antenne ist;
   - die genannten Segmente solchermaßen flächendeckend angeordnet sind, dass keines der jeweiligen Segmente zusammen mit einem benachbarten Segment ein längeres gerades Segment bildet;
   - die genannten Segmente solchermaßen miteinander verbunden sind, dass jedes Segment mit seinen benachbarten Segmenten einen Winkel bildet;
   - keines der genannten Segmente eines der anderen Segmente schneidet, außer am Ende der Kurve, wobei sich die besagte raumfüllende Kurve am Anfang und Ende selbst überschneidet, sodass diese raumfüllende Kurve eine geschossene Schleife bildet;
   - jedes Paar nebeneinanderliegender Segmente besagter Kurve bildet eine Ecke; und
   - wobei, wenn besagte Kurve periodisch entlang einer festgelegten geraden Raumrichtung verläuft, die entsprechende Periode von dem nicht periodischen Teil bestimmt wird, der aus mindestens zehn miteinander verbundenen Segmenten besteht, keines der besagten miteinander verbundenen Segmente zusammen mit einem benachbarten Segment ein gerades, längeres Segment bildet;

   besagte raumfüllende Kurve ist eine Kurve mit einem Box-Counting-Maß größer als Eins,
   wobei besagte Kurve nicht selbstähnlich ist.

2. Eine Antenne nach Anspruch 1, besagte Antenne ist so bemessen, dass sie mit einem Radius, der gleich der operierenden Wellenlänge der Antenne geteilt durch 2π ist, in eine Sphäre passt.

3. Eine Antenne nach jedem der vorhergehenden Ansprüche, wobei die besagten mindestens zehn miteinander verbundenen Segmente, welche die raumfüllende Kurve bilden (25), gerade Segmente sind.

4. Eine Antenne nach Anspruch 1, wobei besagte Ecken kurvenförmig sind.

5. Eine Antenne nach Anspruch 1, wobei besagte Ecken gerundet oder auf andere Weise geglättet sind.

6. Eine Antenne nach jedem der vorhergehenden Ansprüche, wobei besagte raumfüllende Kurve auf ein dielektrisches Untergrundmaterial gedruckt wird.

7. Eine Antenne nach jedem der vorhergehenden Ansprüche, wobei die raumfüllende Kurve als Hilbert-Kurve geformt ist.

8. Eine Antenne nach jedem der Ansprüche 1-6, wobei die raumfüllende Kurve als HilbertZZ-Kurve geformt ist (61, 62, 63, 64).

9. Eine Antenne nach jedem der Ansprüche 1-6, wobei die raumfüllende Kurve als Peano-Kurve geformt ist.

10. Eine Antenne nach jedem der vorhergehenden Ansprüche, wobei die besagte raumfüllende Kurve (25) auf einer gewölbten Oberfläche montiert ist.

11. Eine Antenne nach jedem der Ansprüche 1-9, wobei die besagte raumfüllende Kurve (25) auf einer ebenen Oberfläche montiert ist.

12. Eine Antenne nach jedem der vorhergehenden Ansprüche, wobei die Antenne so ausgerichtet ist, dass sie zumindest einen der folgenden Telekommunikationsdienste abdeckt: GSM900, GSM1800, UMTS.

13. Eine Antenne nach jedem der vorhergehenden Ansprüche, mit einer operierenden Wellenlänge, die der operierenden Wellenlänge eines Mobilfunksystems entspricht.

14. Eine Antenne nach jedem der vorhergehenden Ansprüche, besagte Antenne beinhaltet eine Massefläche, die eine metallische Struktur in einem Mobiltelefon ist.

15. Eine Antenne nach jedem der vorhergehenden Ansprüche, besagte Antenne wird in einem Gerät für mobile Kommunikation montiert.

16. Eine Antenne nach Anspruch 15, wobei besagte Antenne an einem Mobiltelefon montiert ist.

17. Eine Antenne nach jedem der vorhergehenden Ansprüche, wobei besagte raumfüllende Kurve nicht periodisch entlang einer gerade Linie verläuft.

18. Eine Antenne nach jedem der vorhergehenden Ansprüche, einschließlich eines Netzwerks zwischen einem Strahlerelement und einer Eingangssteckverbindung besagter Antenne, wobei besagtes Netz-

werk ein Anpassnetzwerk, ein Impedanzwandler-Netzwerk oder ein Balun-Netzwerk ist.

19. Eine Antenne nach jedem der vorhergehenden Ansprüche, besagte Antenne ist für Mehrbandbetrieb konfiguriert.

20. Ein Antennen-Satz, bestehend aus einer Vielzahl Antennen nach jedem der vorhergehenden Ansprüche, wobei die meisten der besagten Antennen so angeordnet sind, dass sie mit einem Signal bei einer vorgegebenen Frequenz gespeist werden können, und zumindest zwei der besagten Vielzahl Antennen so angeordnet sind, dass sie auf anderen Frequenzen funktionieren, um verschiedene Kommunikationsdienste abzudecken; und wobei besagte Antennen so angeordnet sind, dass sie gleichzeitig von einem Verteiler- oder Diplexer-Netzwerk gespeist werden können.

21. Ein Gerät für mobile Kommunikation, ausgestattet mit einer Antenne nach jedem der der Ansprüche 1-19, oder mit einem Antennen-Satz nach Anspruch 20.

22. Ein Gerät nach Anspruch 21, wobei besagtes Gerät ein tragbares Telefon ist.

23. Ein Gerät nach Anspruch 21, wobei das Gehäuse besagten tragbaren Telefons als Massefläche der Antenne dient.

24. Eine Methode zur Herstellung eines mobilen Kommunikationsgerätes mit einer geringeren Größe, wobei die Methode eine Antenne für das Gerät, eine Antenne nach jedem der Ansprüche 1-19 oder ein Antennen-Satz nach Anspruch 20 beinhaltet.

Revendications

1. Une antenne monopôle, ladite antenne monopôle comprenant un bras rayonnant et un plan de projection horizontal (12), ledit bras rayonnant étant excité par une ligne de transmission (11),
où ledit bras rayonnant a la forme d'une courbe de remplissage de l'espace (59-60),
où ladite courbe de remplissage de l'espace comporte au moins dix segments raccordés composant une portion non périodique de ladite courbe, où :

- chacun de ces segments est plus court qu'un dixième de la longueur d'onde à espace libre opérationnelle de l'antenne ;
- lesdits segments sont disposés dans l'espace de telle manière qu'aucun de ces segments ne forme, avec un segment adjacent, un segment droit plus long ;
- lesdits segments sont raccordés de telle manière que chaque segment forme un angle avec ses voisins ;
- aucun de ces segments ne se croise avec un autre de ces segments, sauf aux extrémités de la courbe où ladite courbe de remplissage de l'espace se croise elle-même à son commencement et termine en faisant que ladite courbe de remplissage de l'espace forme une boucle fermée;
- chaque paire de segments adjacents de ladite courbe forme un coin ; et
- où, si ladite courbe est périodique le long d'une direction droite fixe d'espace, la période correspondante est définie par la portion non-périodique composée d'au moins dix segments raccordés, aucun de ces segments raccordés ne formant, avec un segment adjacent, un segment droit plus long ;

ladite courbe de remplissage de l'espace étant une courbe qui représente une dimension de comptage de boîtes (box-counting) supérieure à un,
où ladite courbe n'est pas auto-similaire.

2. Une antenne conformément à la revendication 1, ladite antenne ayant une taille telle que ladite antenne se loge dans une sphère ayant un rayon égal à la longueur d'onde opérationnelle de l'antenne divisée par 2π.

3. Une antenne conformément à l'une quelconque des revendications précédentes, où lesdits au moins dix segments raccordés composant la courbe de remplissage de l'espace (25) sont des segments droits.

4. Une antenne conformément à la revendication 1, où lesdits coins sont courbes.

5. Une antenne conformément à la revendication 1, où lesdits coins sont arrondis ou bien adoucis.

6. Une antenne conformément à l'une quelconque des revendications précédentes, où ladite courbe de remplissage de l'espace est imprimée sur un substrat diélectrique.

7. Une antenne conformément à l'une quelconque des revendications précédentes, où la courbe de remplissage de l'espace a la forme d'une courbe Hilbert.

8. Une antenne conformément à l'une quelconque des revendications 1-6, où la courbe de remplissage de l'espace a la forme d'une courbe HilbertZZ (61, 62, 63, 64).

9. Une antenne conformément à l'une quelconque des revendications 1-6, où la courbe de remplissage de l'espace a la forme d'une courbe Peano.

10. Une antenne conformément à l'une quelconque des revendications précédentes, où ladite courbe de remplissage de l'espace (25) est ajustée à une surface courbe.

11. Une antenne conformément à l'une quelconque des revendications 1-9, où ladite courbe de remplissage de l'espace (25) est ajustée à une surface plate.

12. Une antenne conformément à l'une quelconque des revendications précédentes, où l'antenne est prévue pour couvrir au moins l'un des services de télécommunication suivants : GSM900, GSM1800, UMTS.

13. Antenne conformément à l'une quelconque des revendications précédentes, ayant une longueur d'onde opérationnelle correspondant à la longueur d'onde opérationnelle d'un système de téléphone portable.

14. Une antenne conformément à l'une quelconque des revendications précédentes, ladite antenne comprenant un plan de masse qui est une structure métallique dans un téléphone portable.

15. Une antenne conformément à l'une quelconque des revendications précédentes, ladite antenne étant contenue dans un dispositif pour la communication mobile.

16. Une antenne conformément à la revendication 15, où ladite antenne est montée sur un téléphone portable.

17. Une antenne conformément à l'une quelconque des revendications précédentes, où ladite courbe de remplissage de l'espace n'est pas périodique le long d'une ligne droite.

18. Une antenne conformément à l'une quelconque des revendications précédentes, comprenant un réseau entre un élément rayonnant et un connecteur d'entrée de l'antenne, ledit réseau étant un réseau d'adaptation, un réseau transformateur d'impédance, ou un réseau Balun.

19. Une antenne conformément à l'une quelconque des revendications précédentes, ladite antenne étant configurée pour un fonctionnement multi-bande.

20. Un jeu d'antennes comprenant une pluralité d'antennes conformément à l'une quelconque des revendications précédentes, où la plupart de ces antennes sont prévues pour être alimentées avec un signal d'une fréquence donnée, formant un système d'antennes, où au moins deux antennes de ladite pluralité d'antennes sont prévues pour fonctionner à différentes fréquences pour couvrir différents services de communication ; et
où lesdites antennes sont prévues pour être simultanément alimentées au moyen d'une distribution ou d'un réseau diplexeur.

21. Un dispositif pour la communication mobile, muni d'une antenne conformément à l'une quelconque des revendications 1-19, ou d'un jeu d'antennes conformément à la revendication 20.

22. Un dispositif conformément à la revendication 21, ledit dispositif étant un téléphone portable.

23. Un dispositif conformément à la revendication 21, où un boîtier dudit téléphone portable sert de plan de masse à l'antenne.

24. Un méthode pour fabriquer un dispositif de communication mobile ayant des dimensions réduites, où la méthode comprend l'incorporation, comme antenne pour le dispositif, d'une antenne conformément à l'une quelconque des revendications 1-19 ou un jeu d'antennes conformément à la revendication 20.

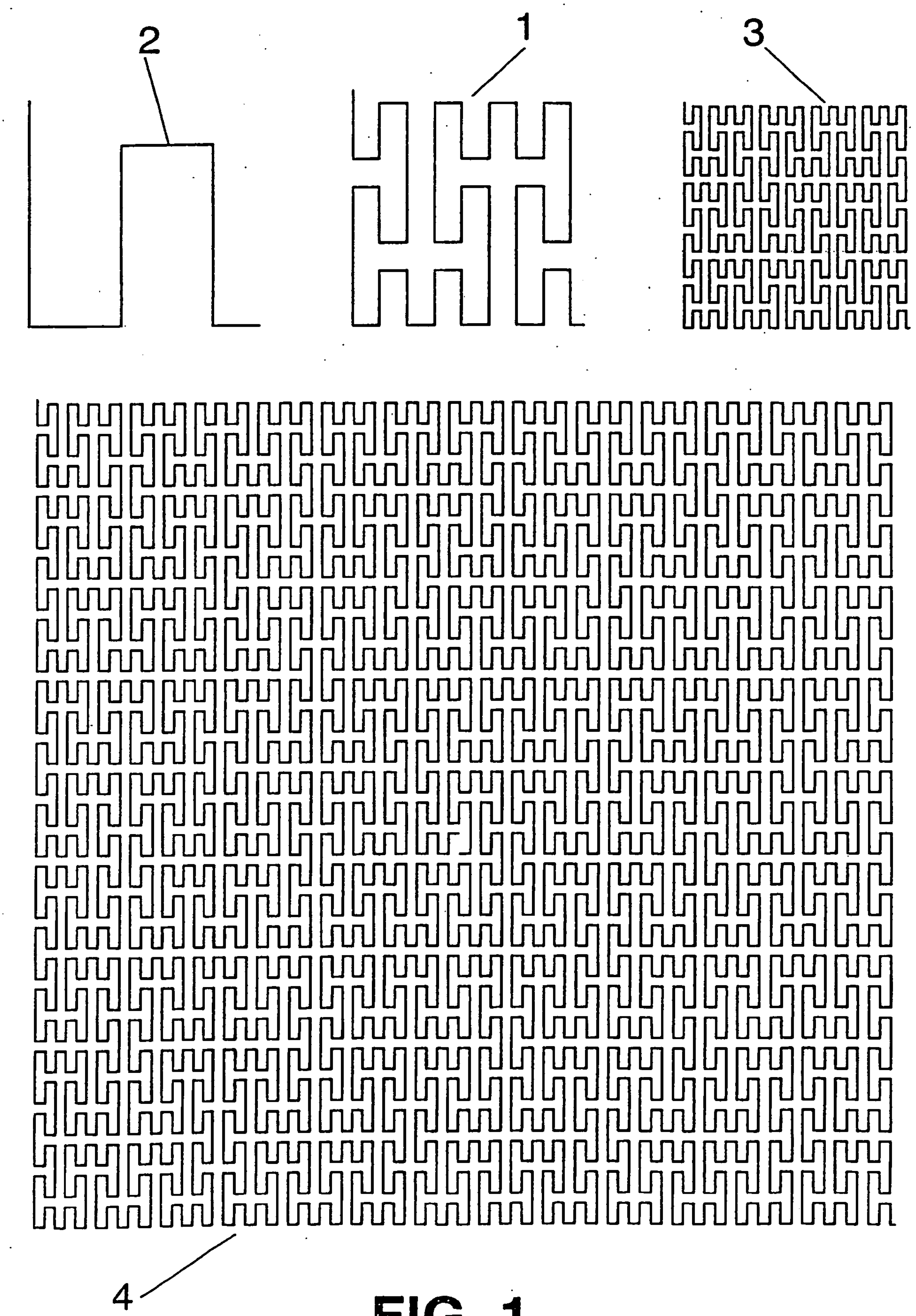

FIG. 1

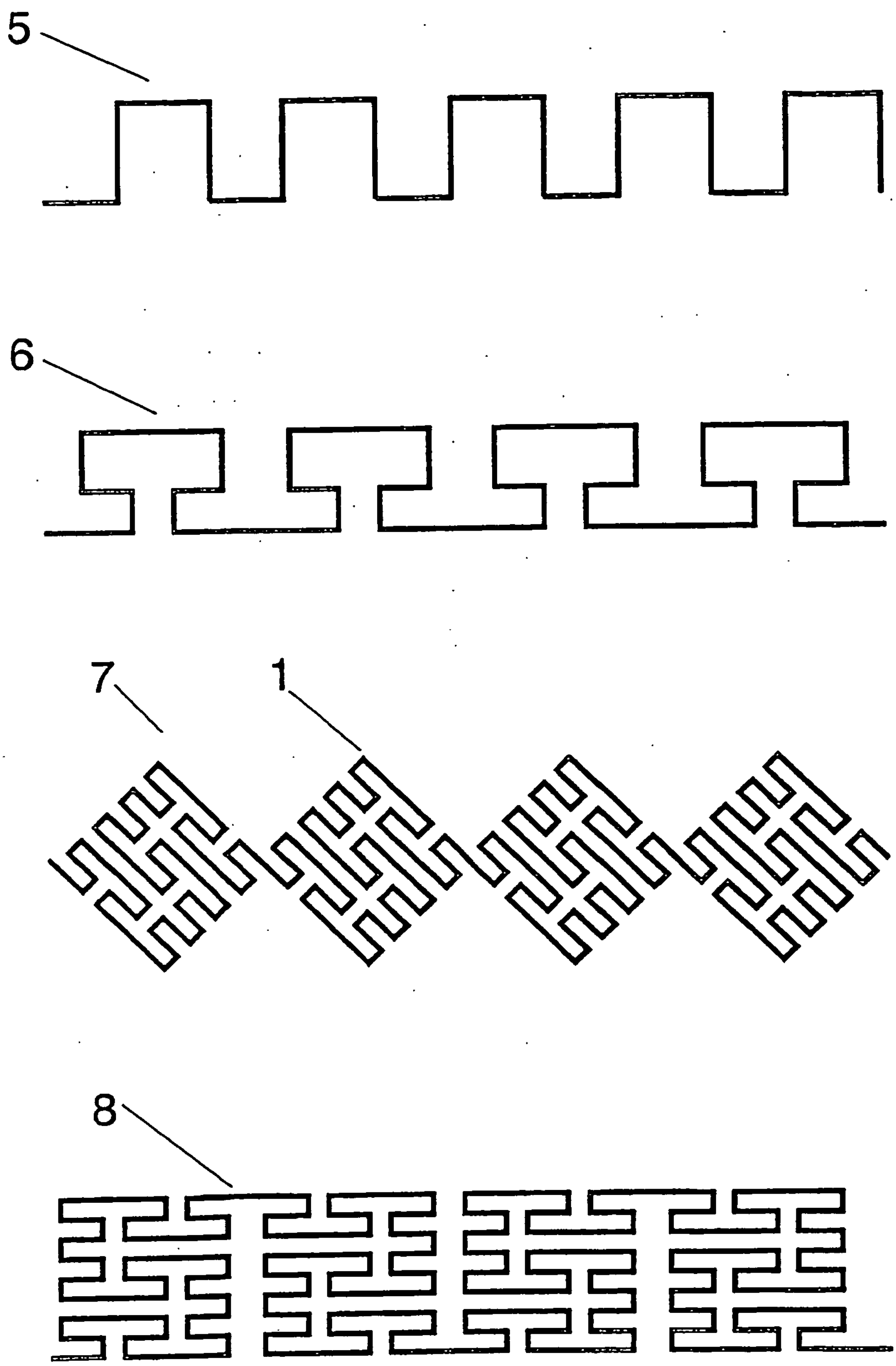

FIG. 2

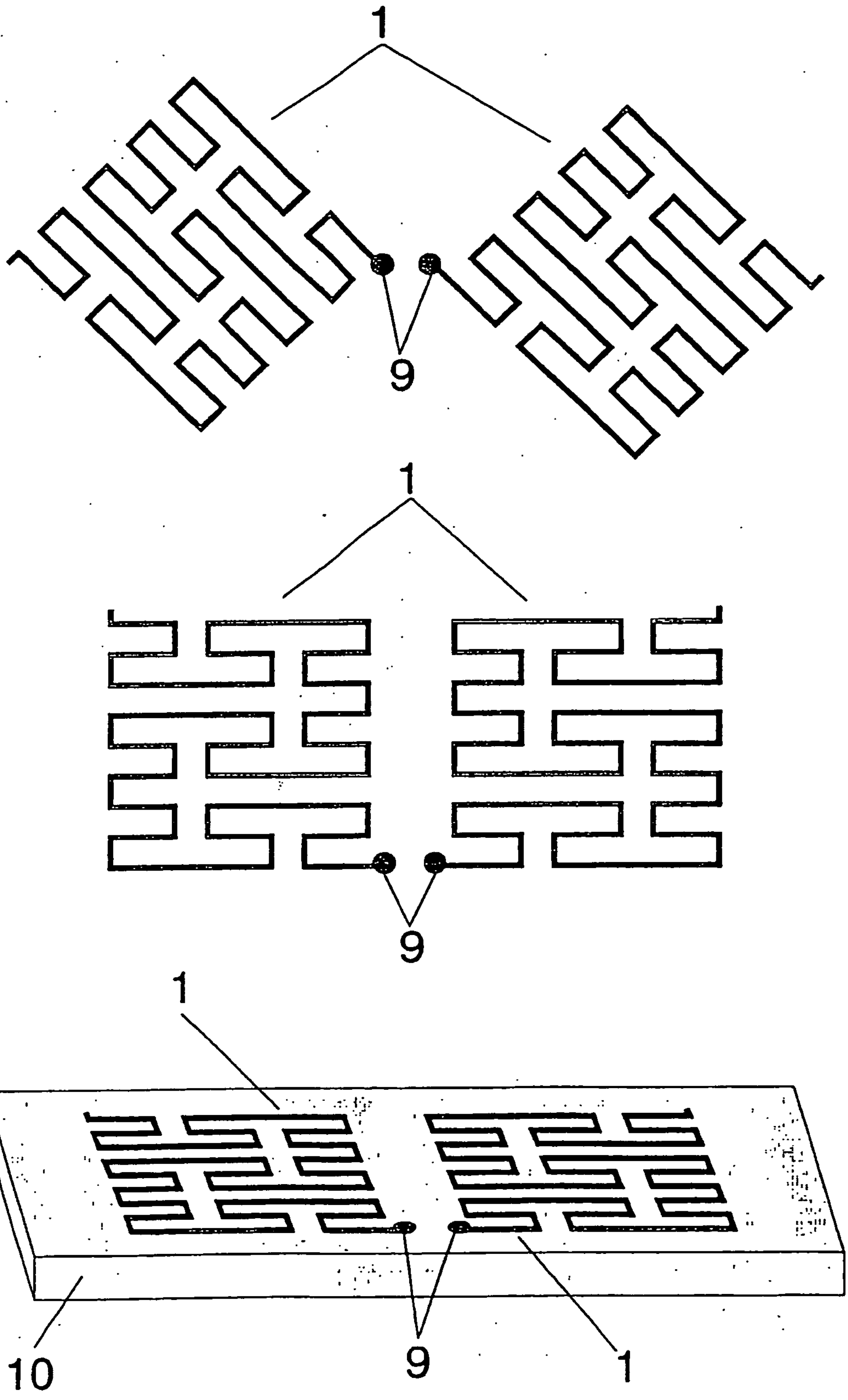

FIG. 3

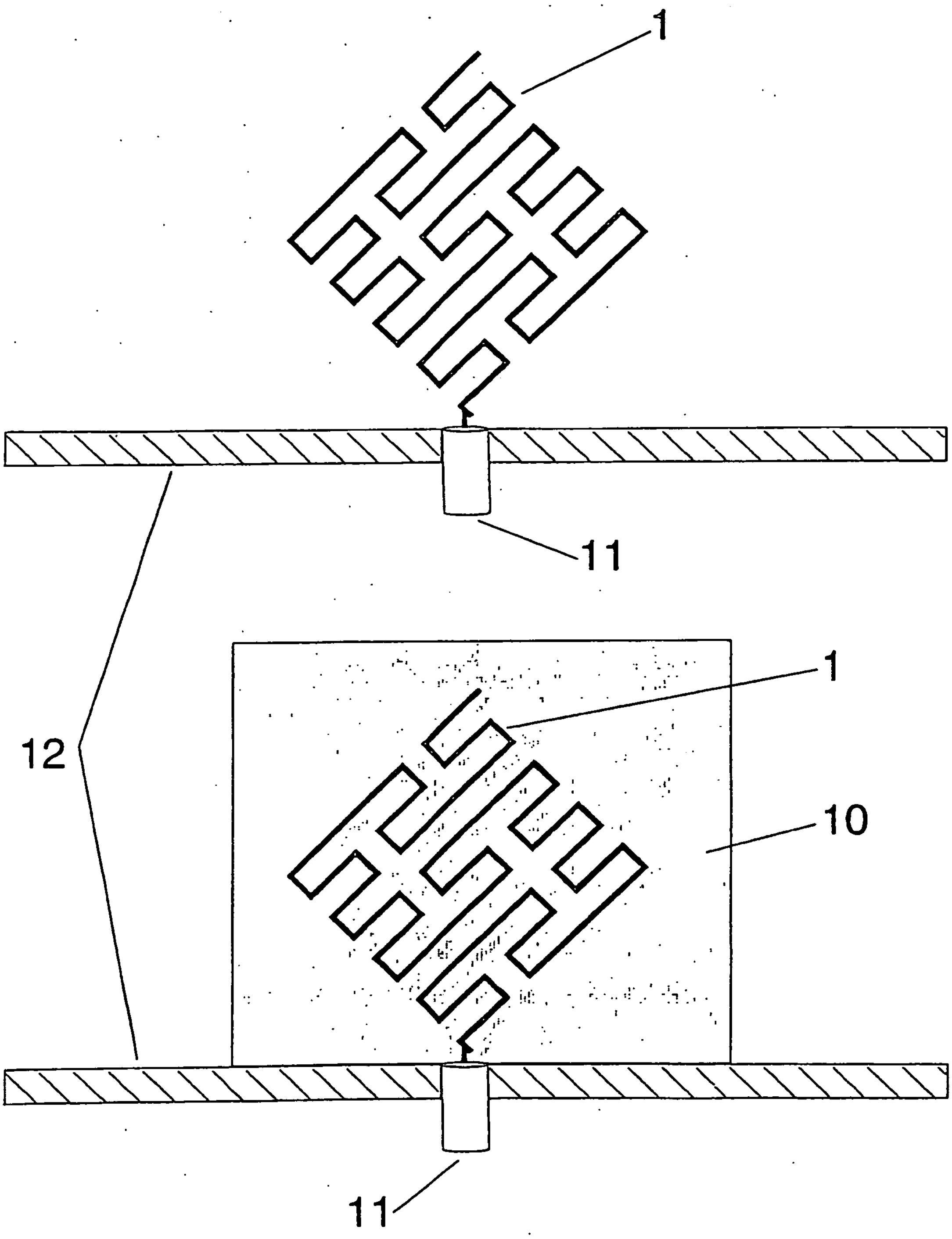

FIG. 4

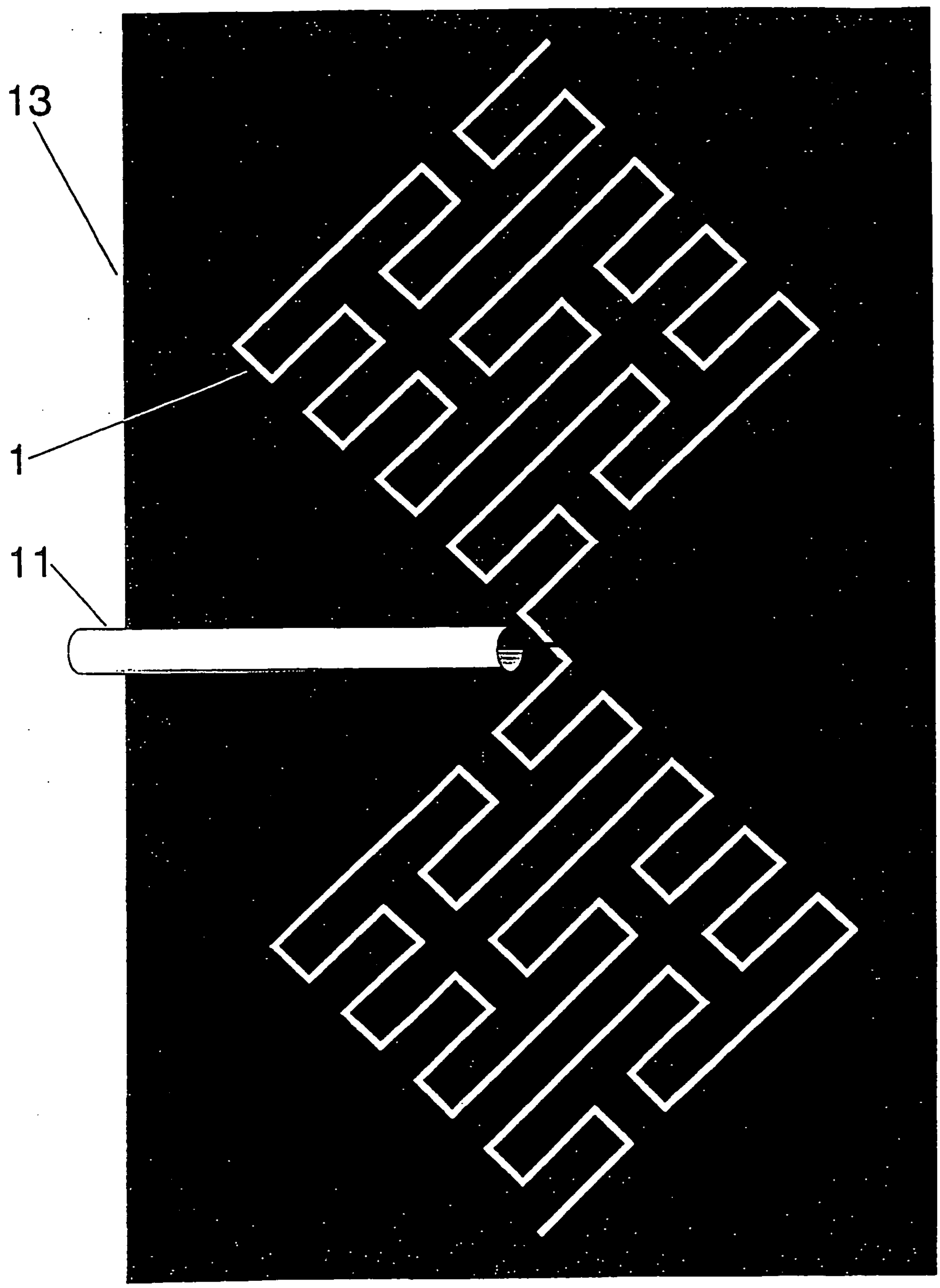

FIG. 5

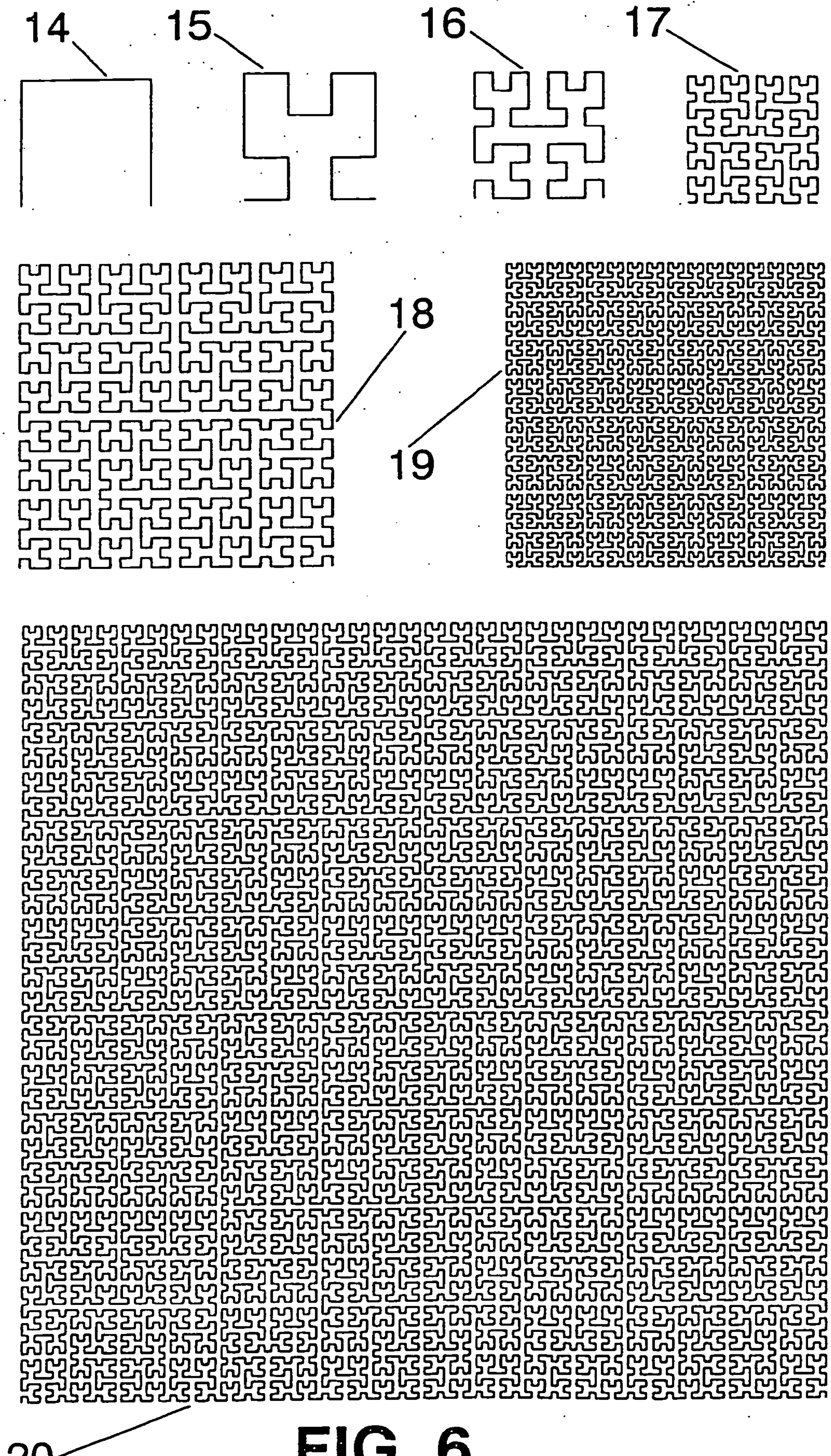

FIG. 6

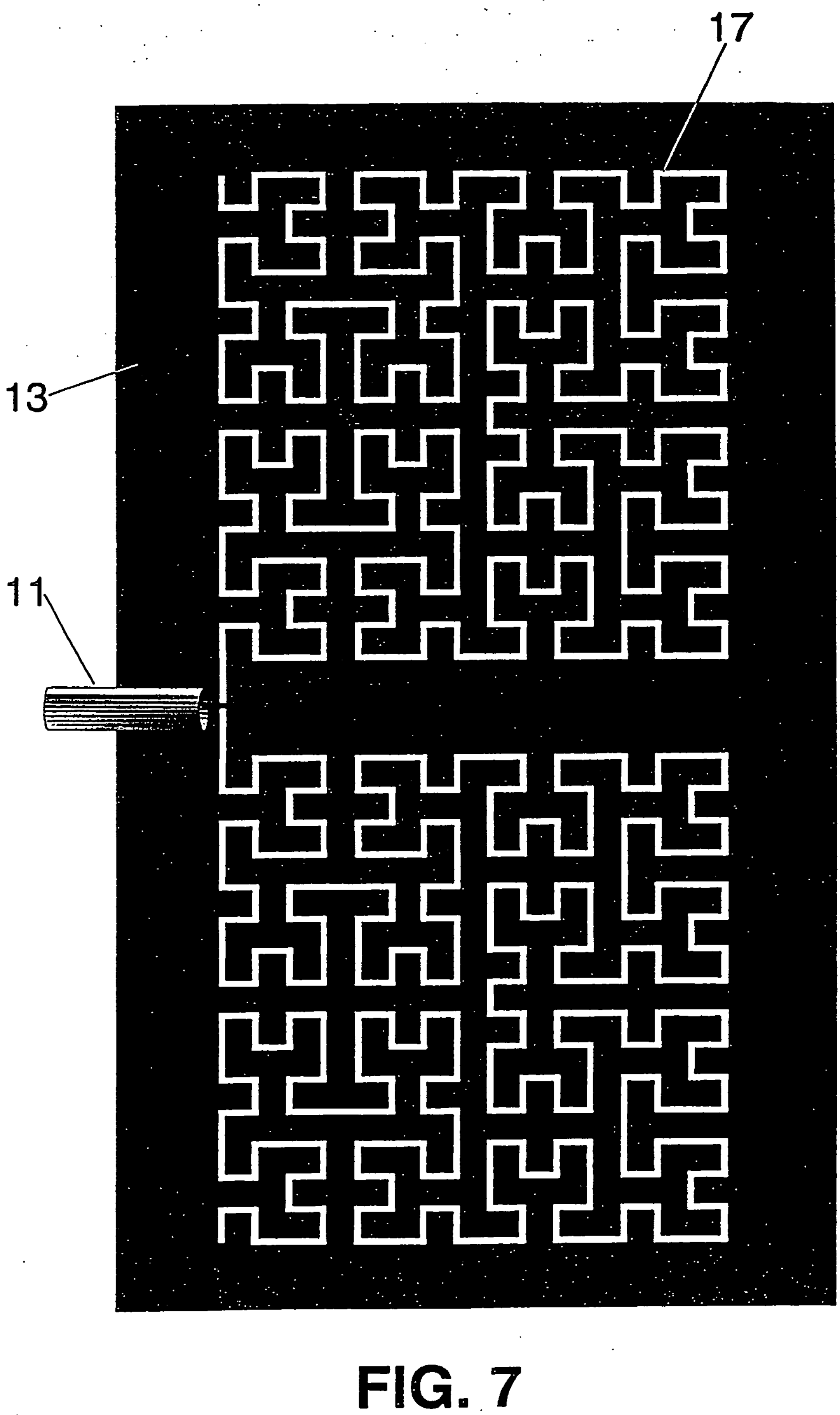

FIG. 7

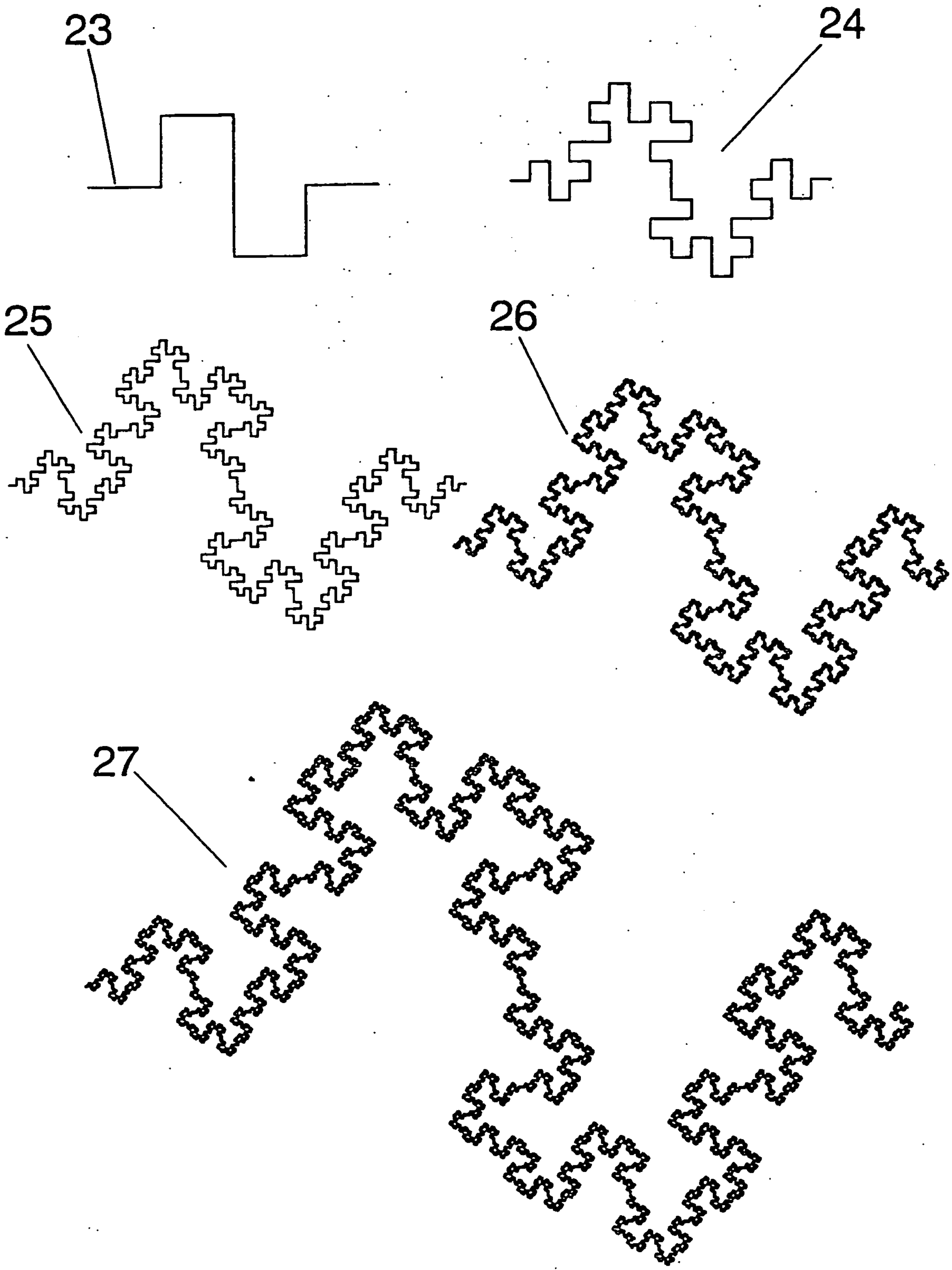

FIG. 8

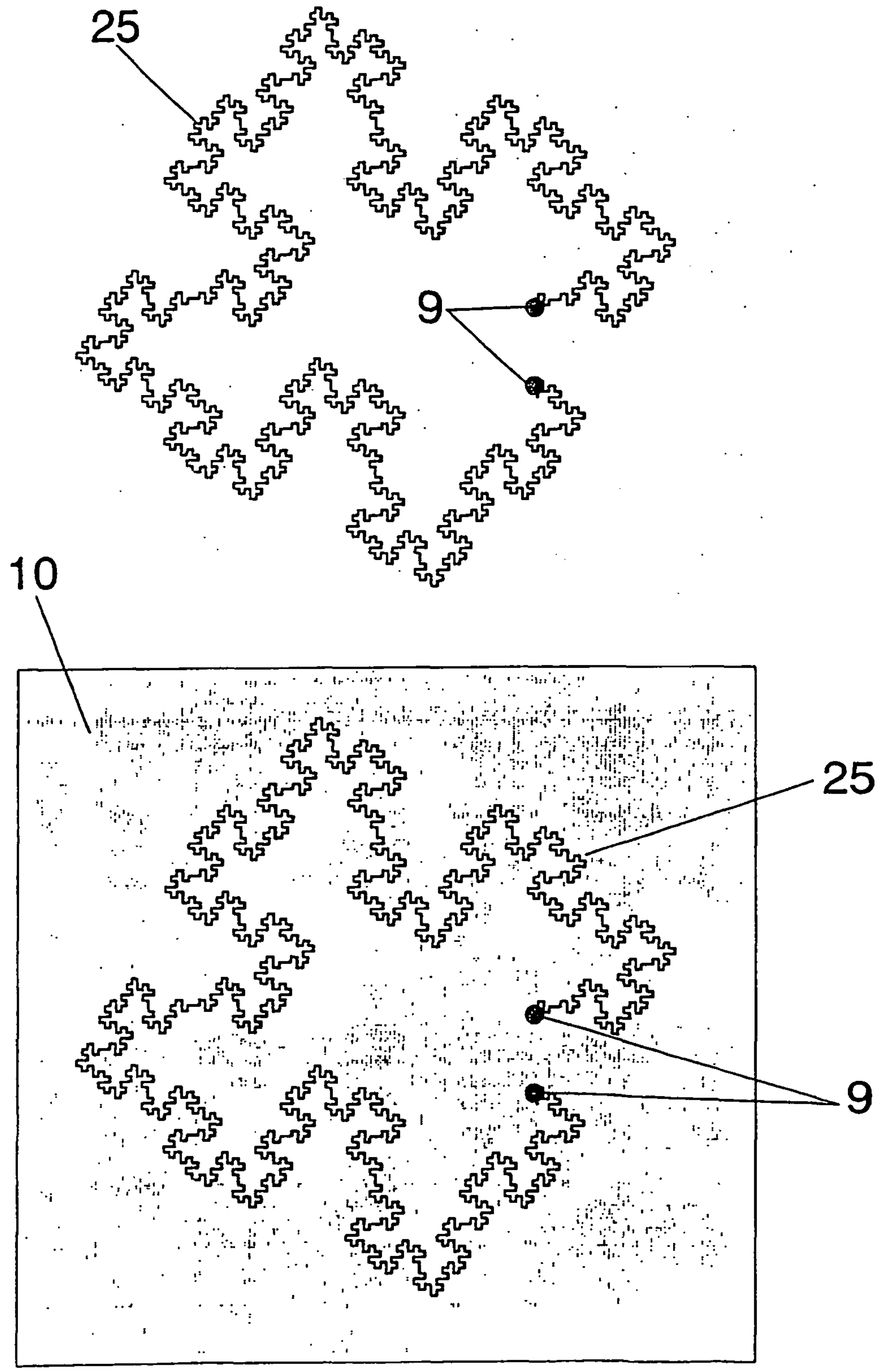

FIG. 9

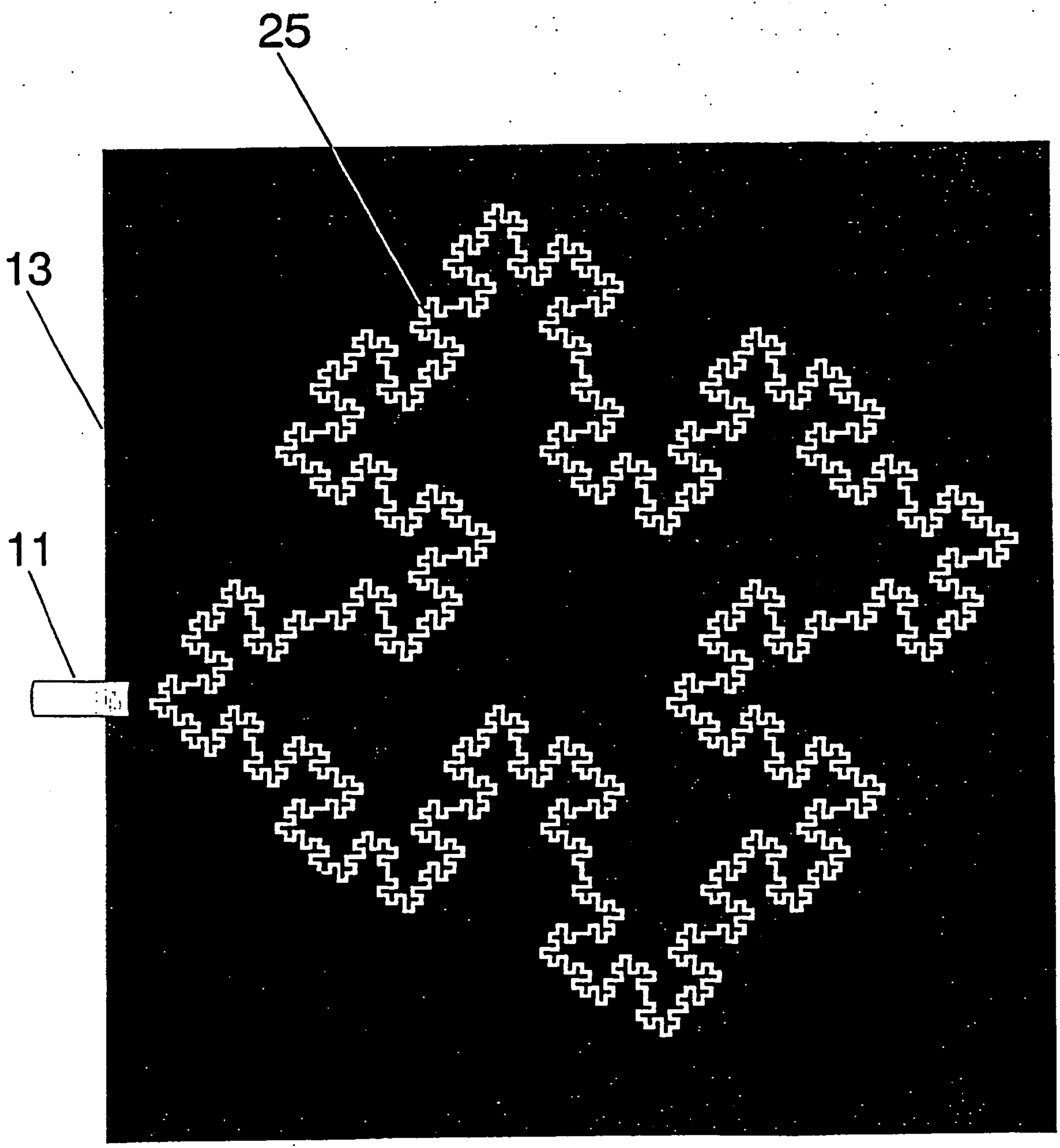

FIG. 10

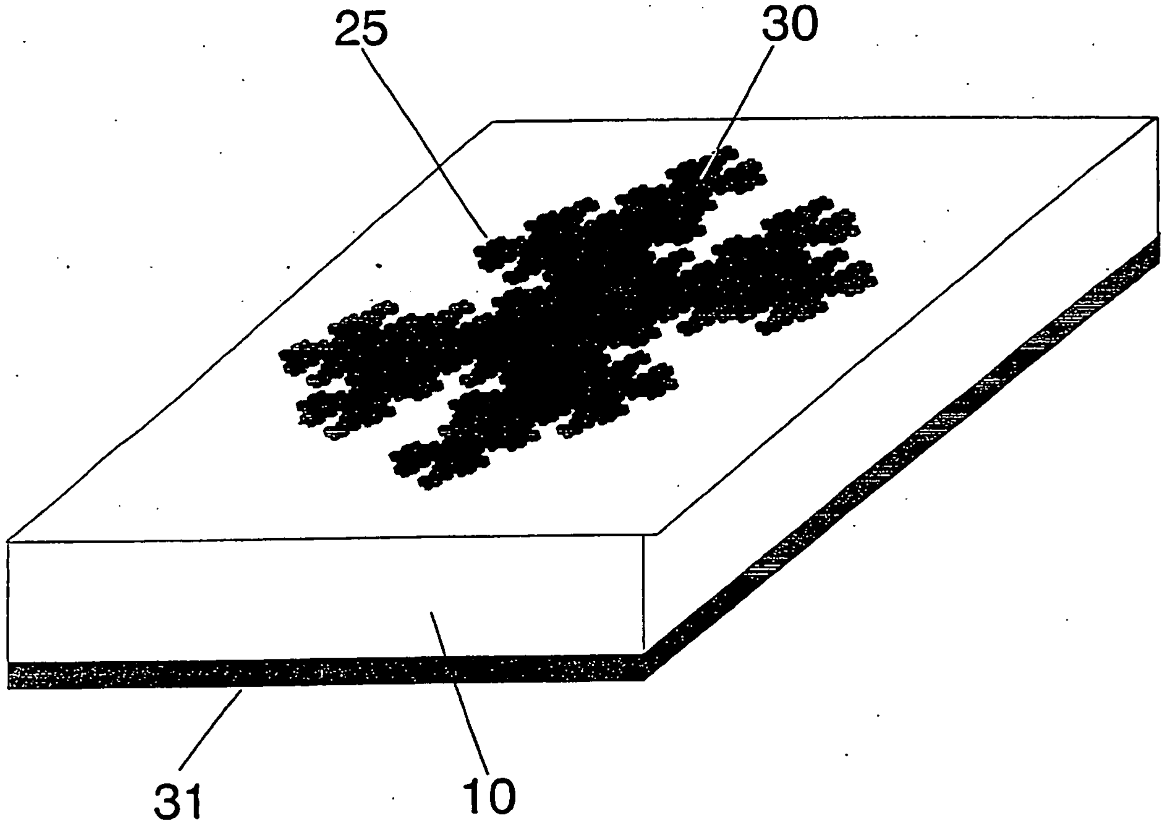

FIG. 11

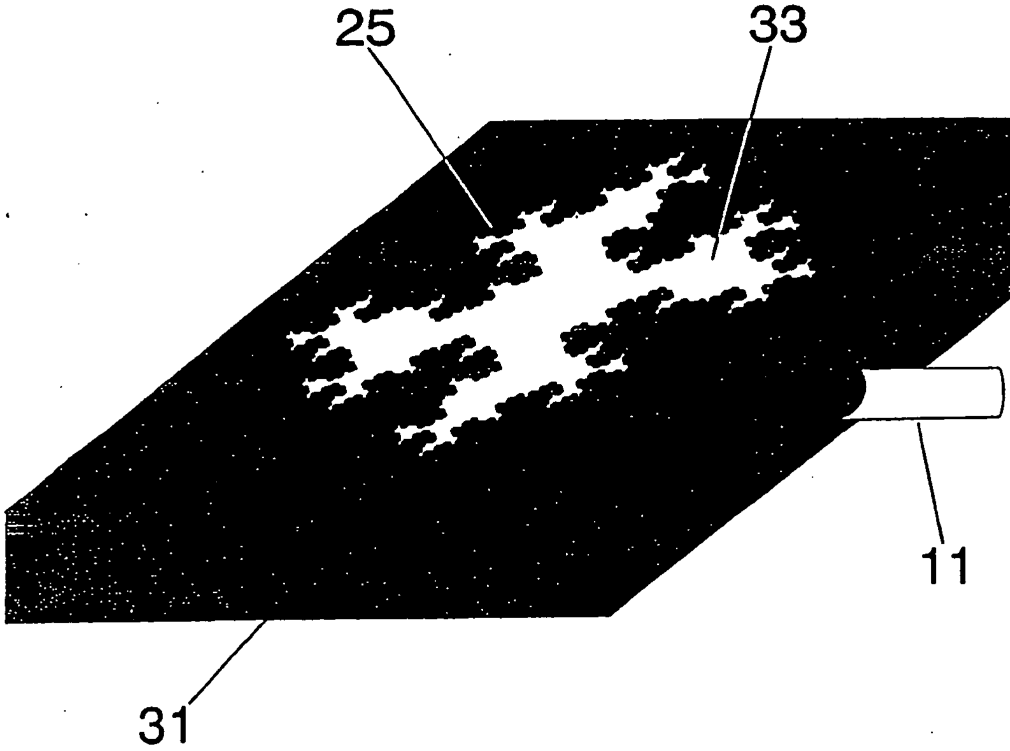

FIG. 12

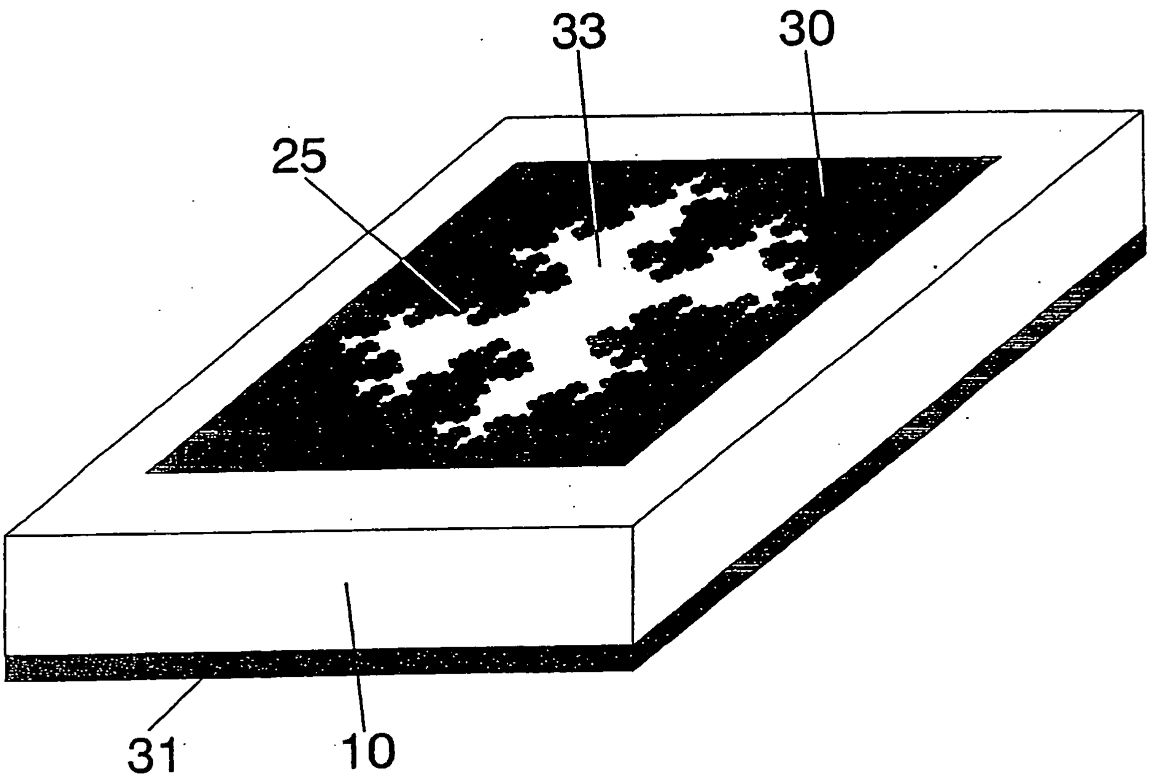

FIG. 13

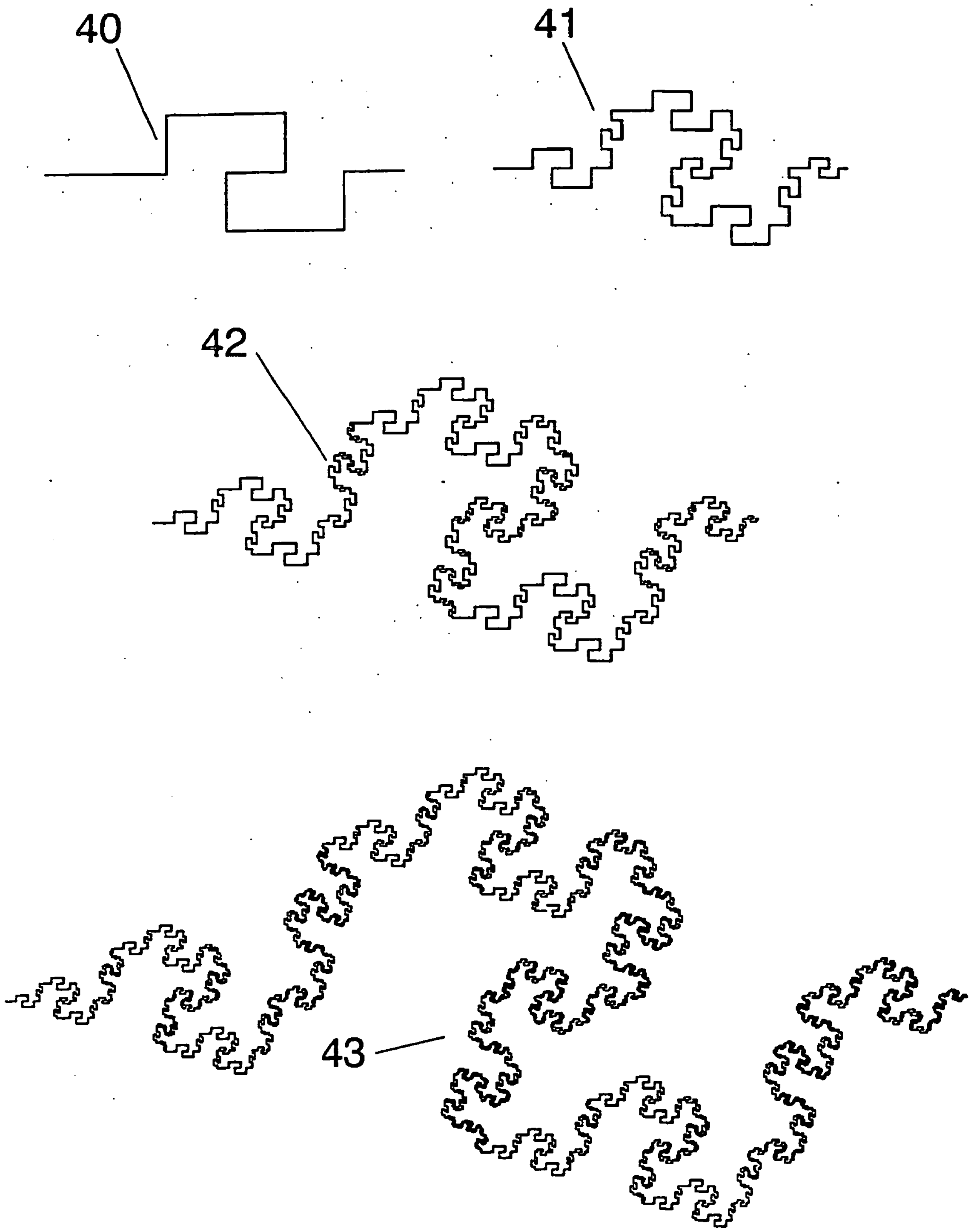

FIG. 14

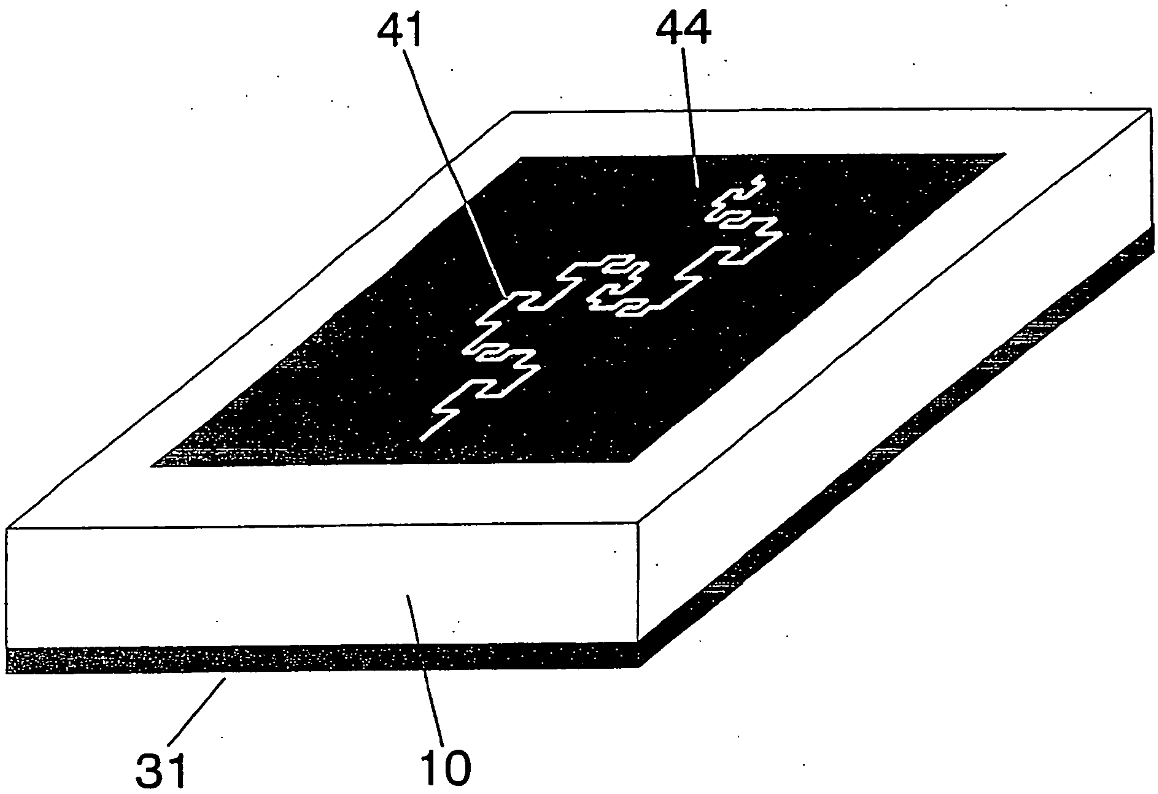

FIG. 15

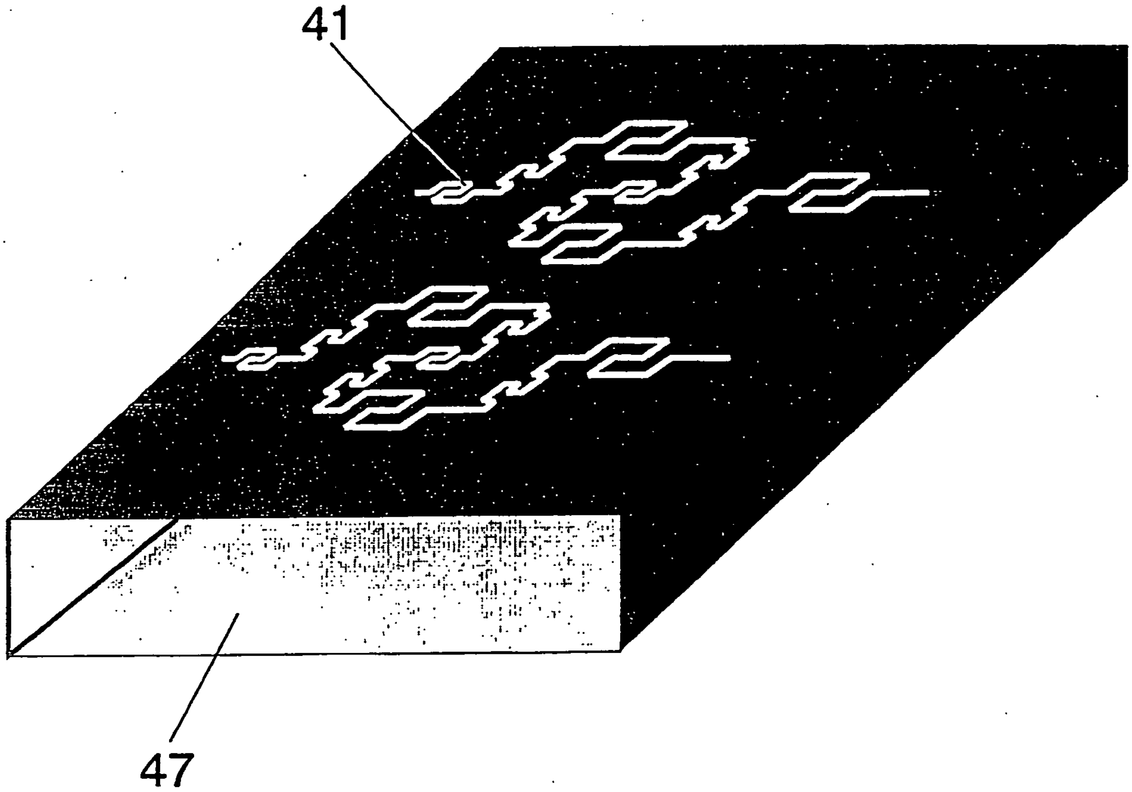

FIG. 16

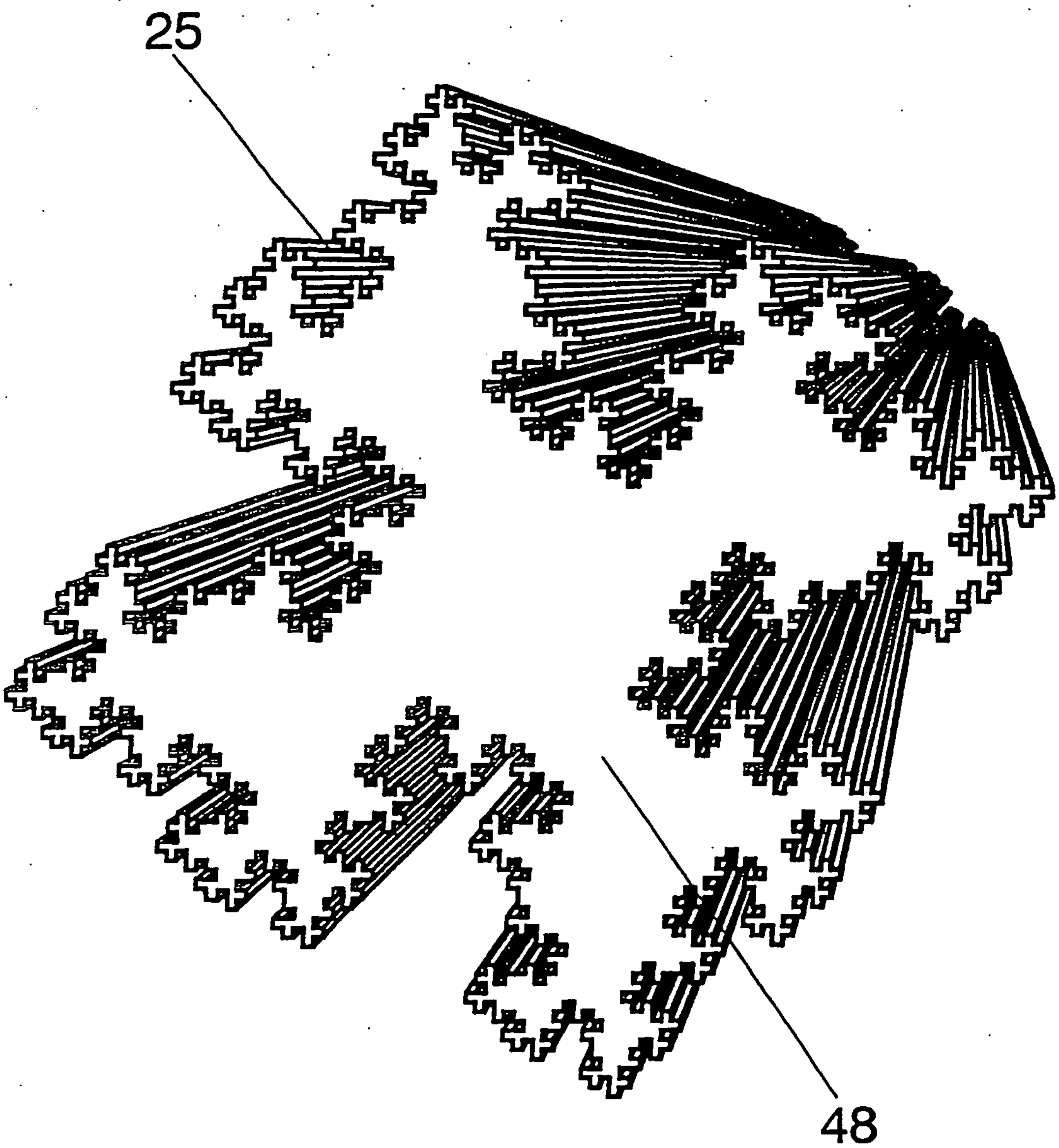

FIG. 17

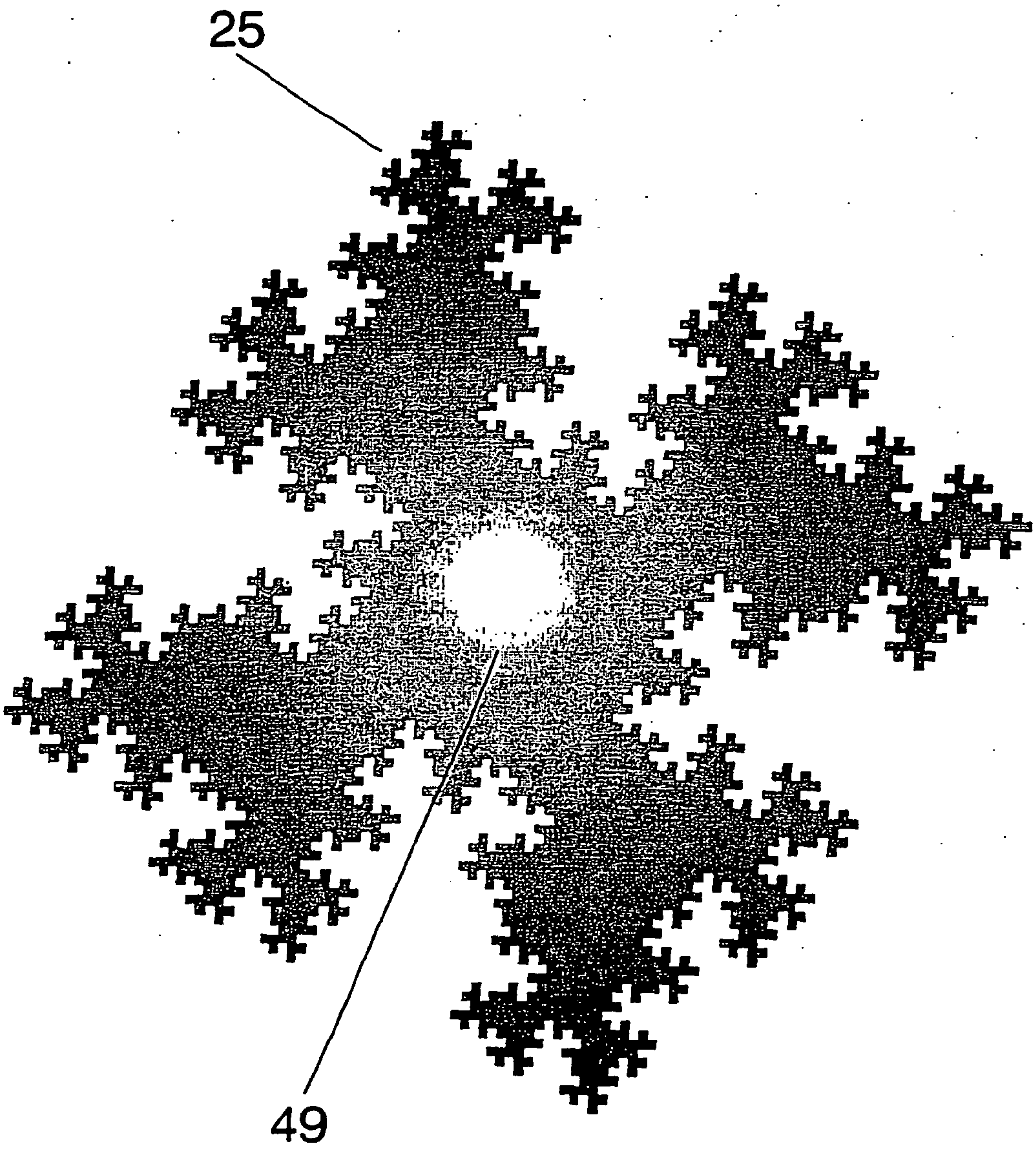

FIG. 18

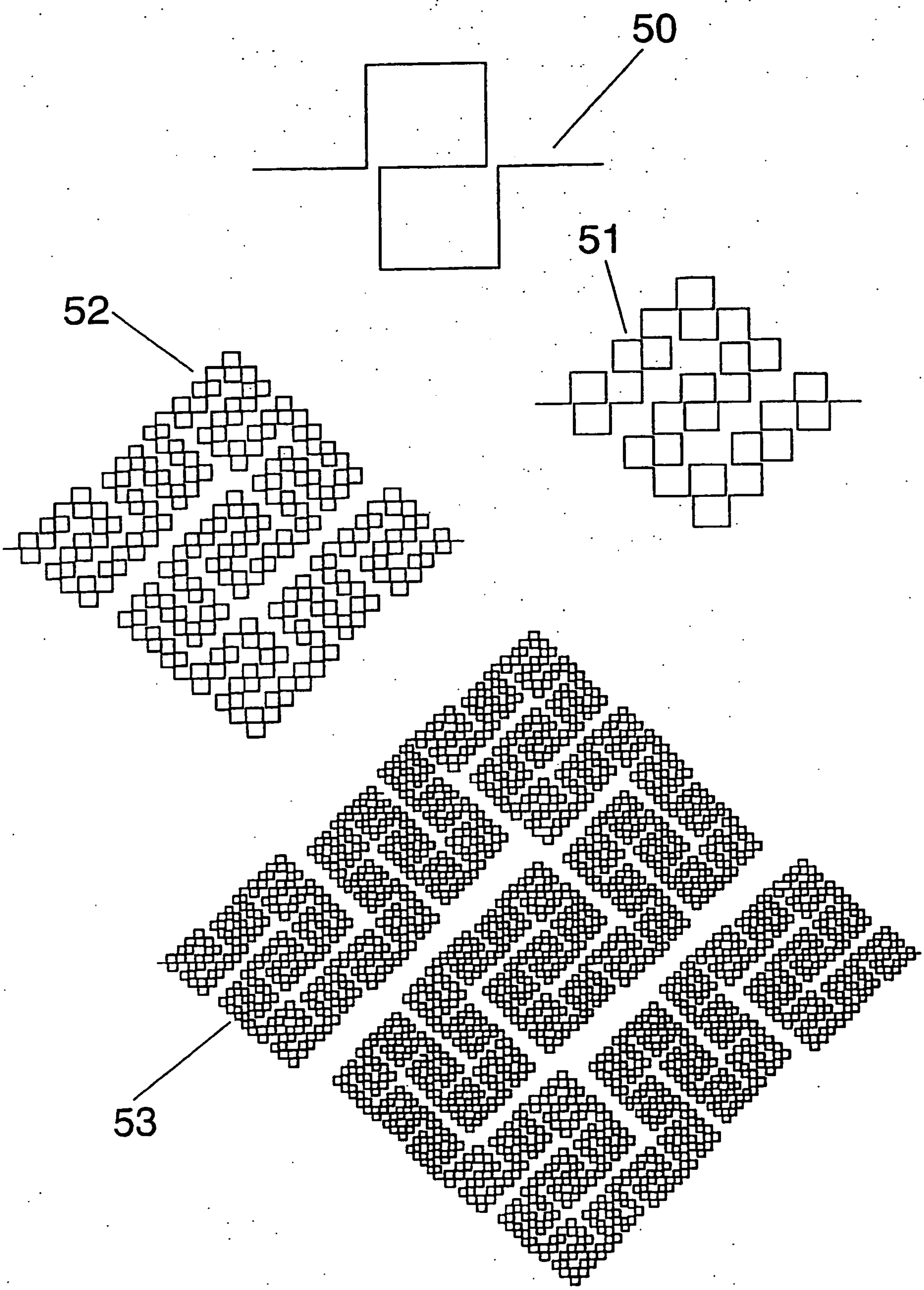

FIG. 19

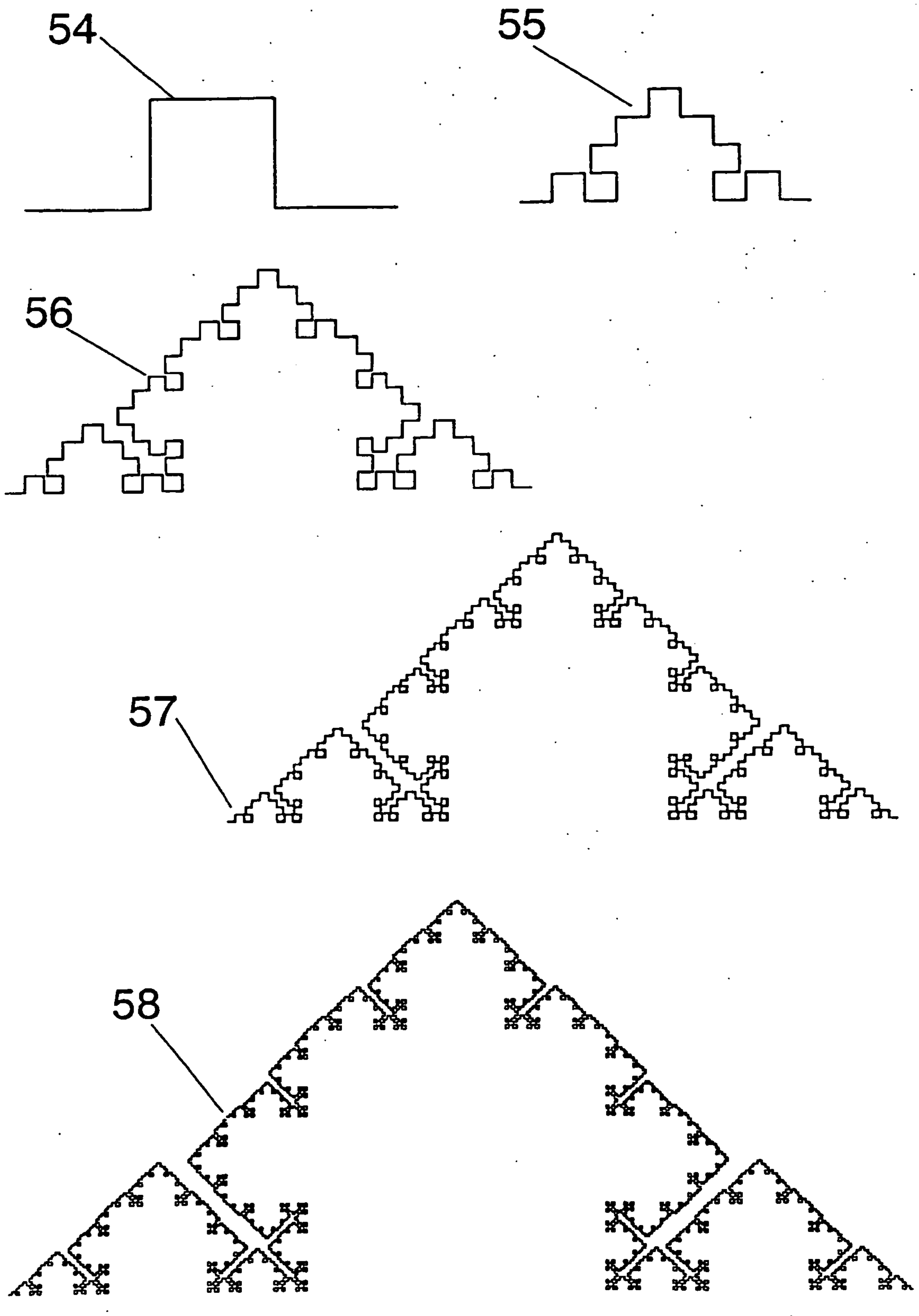

FIG. 20

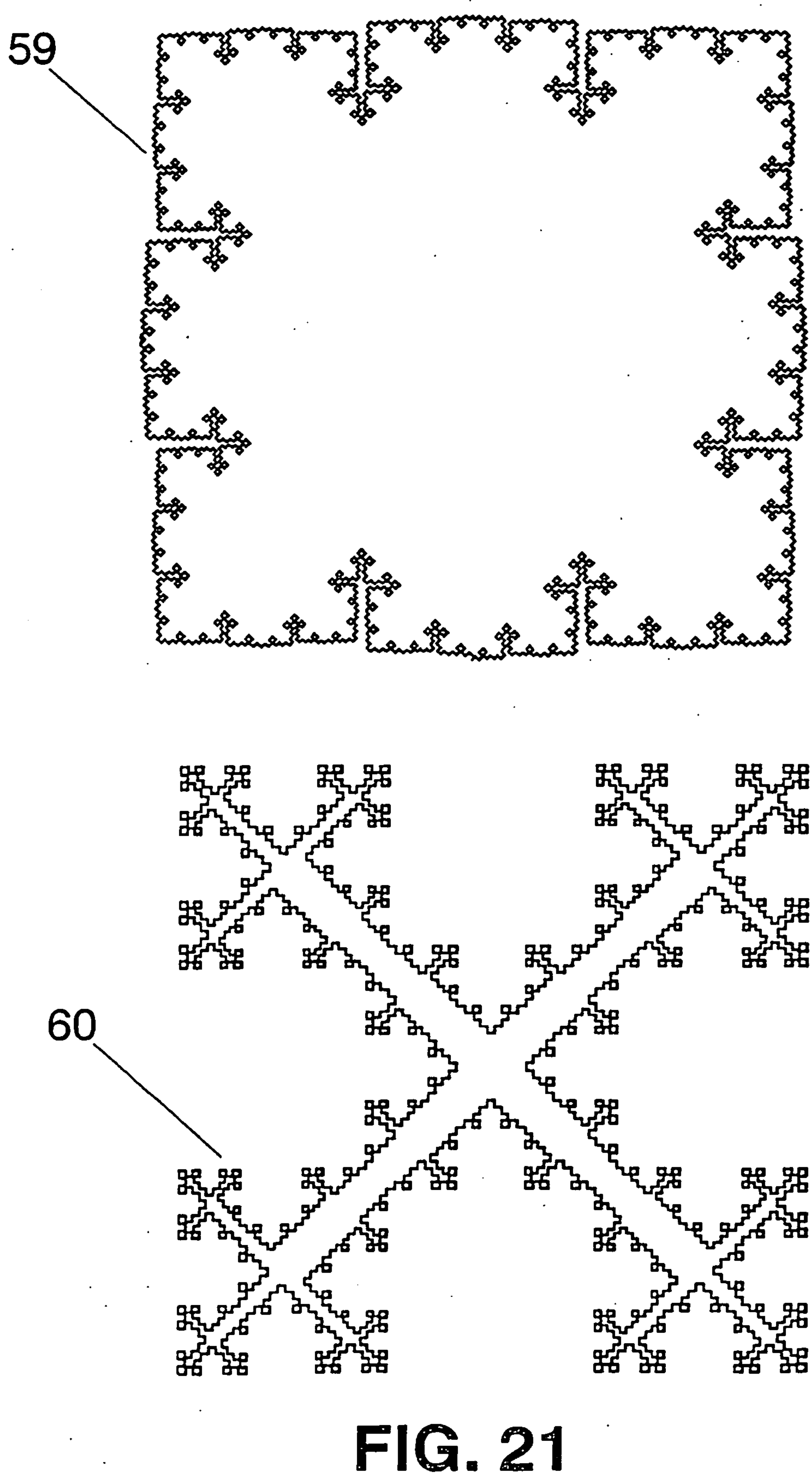

FIG. 21

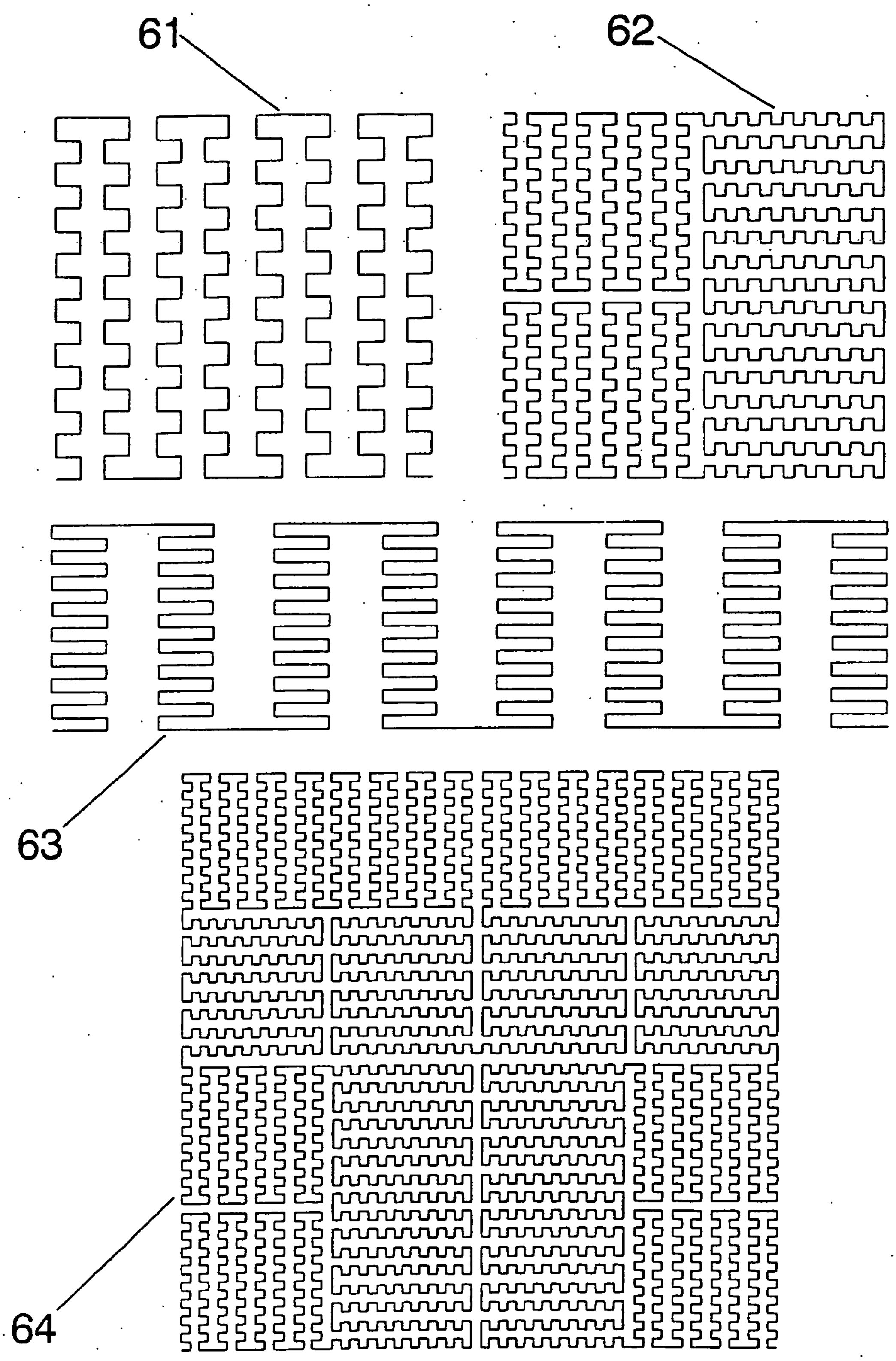

FIG. 22

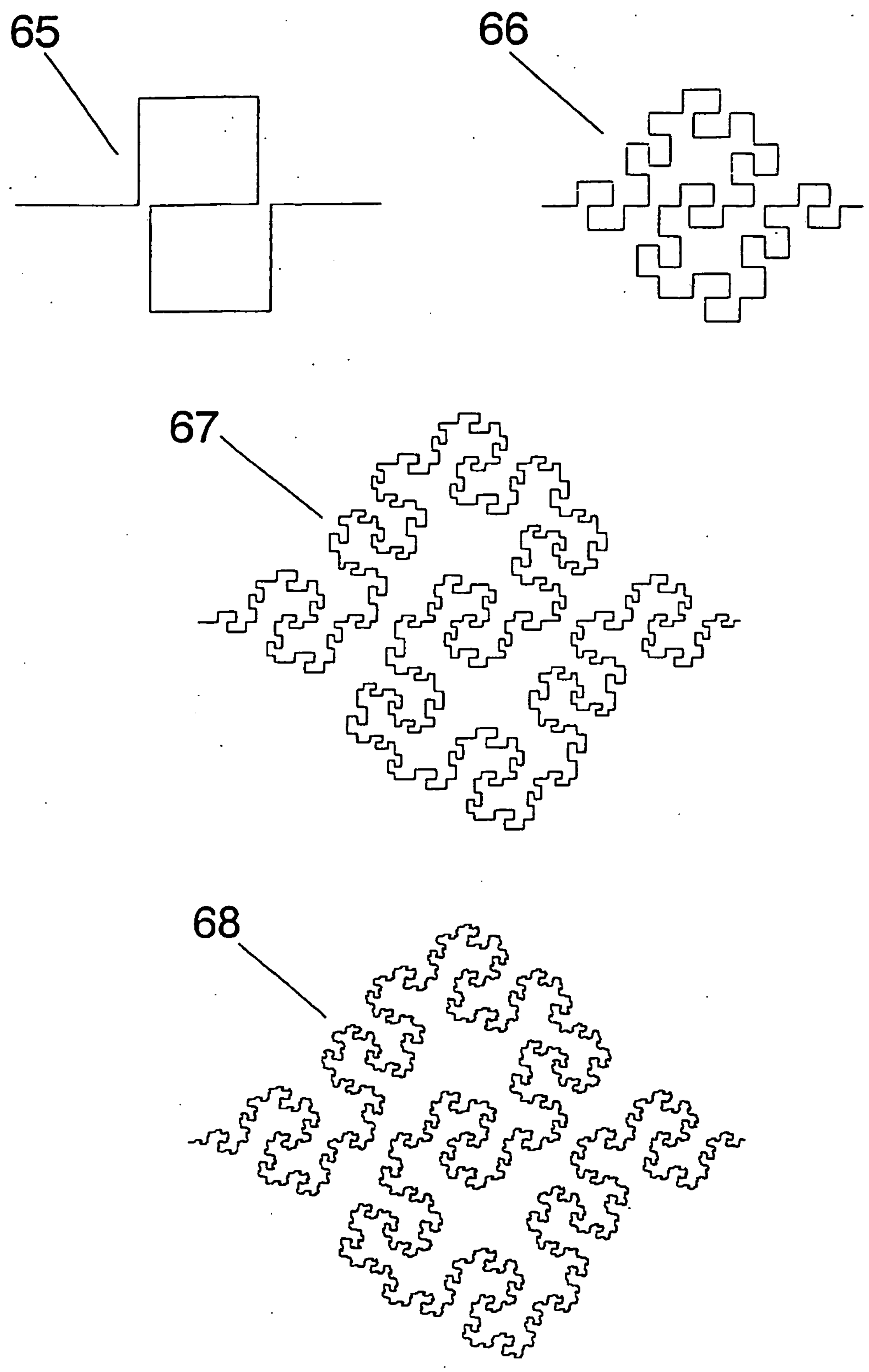

FIG. 23

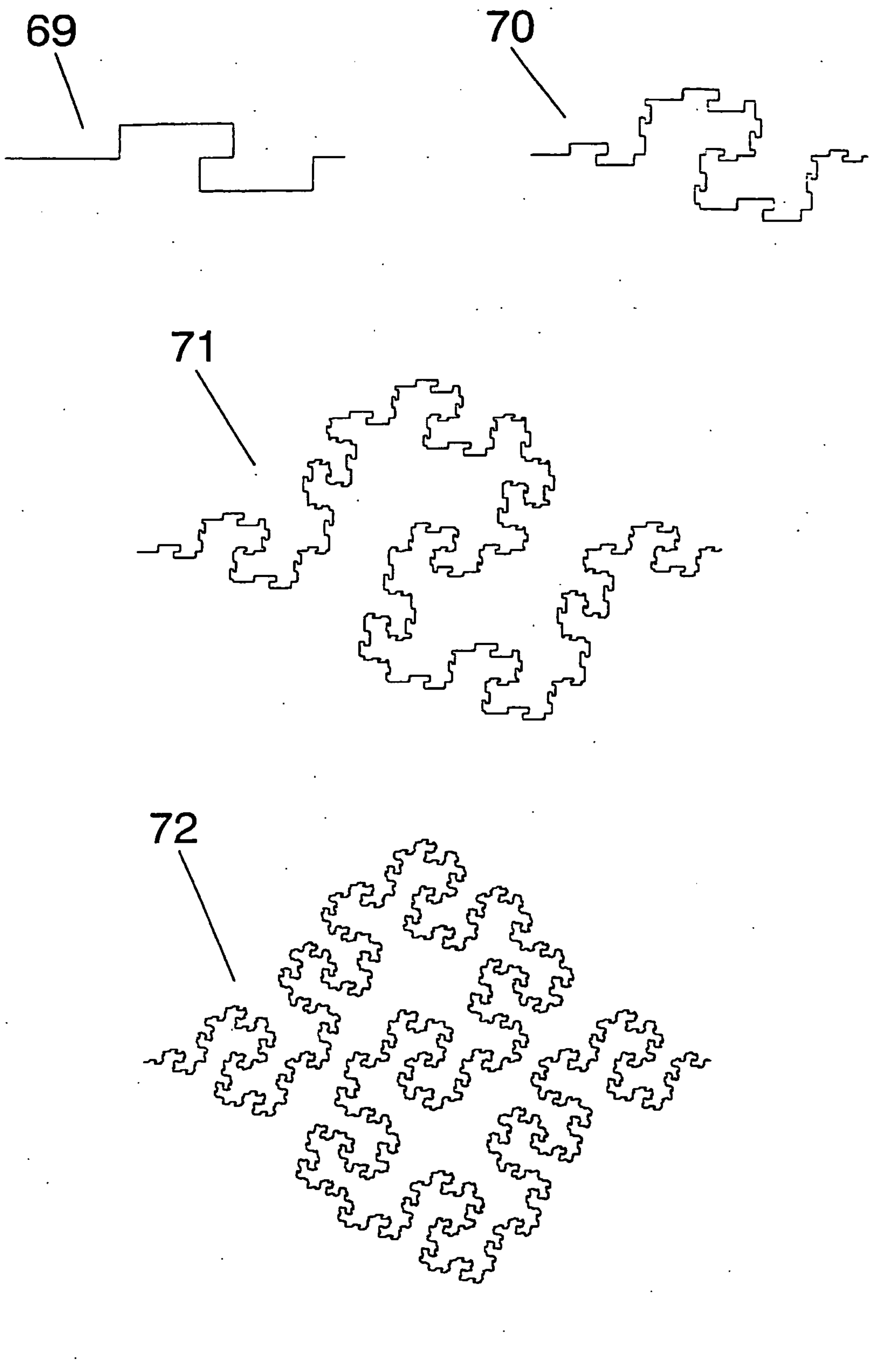

FIG. 24

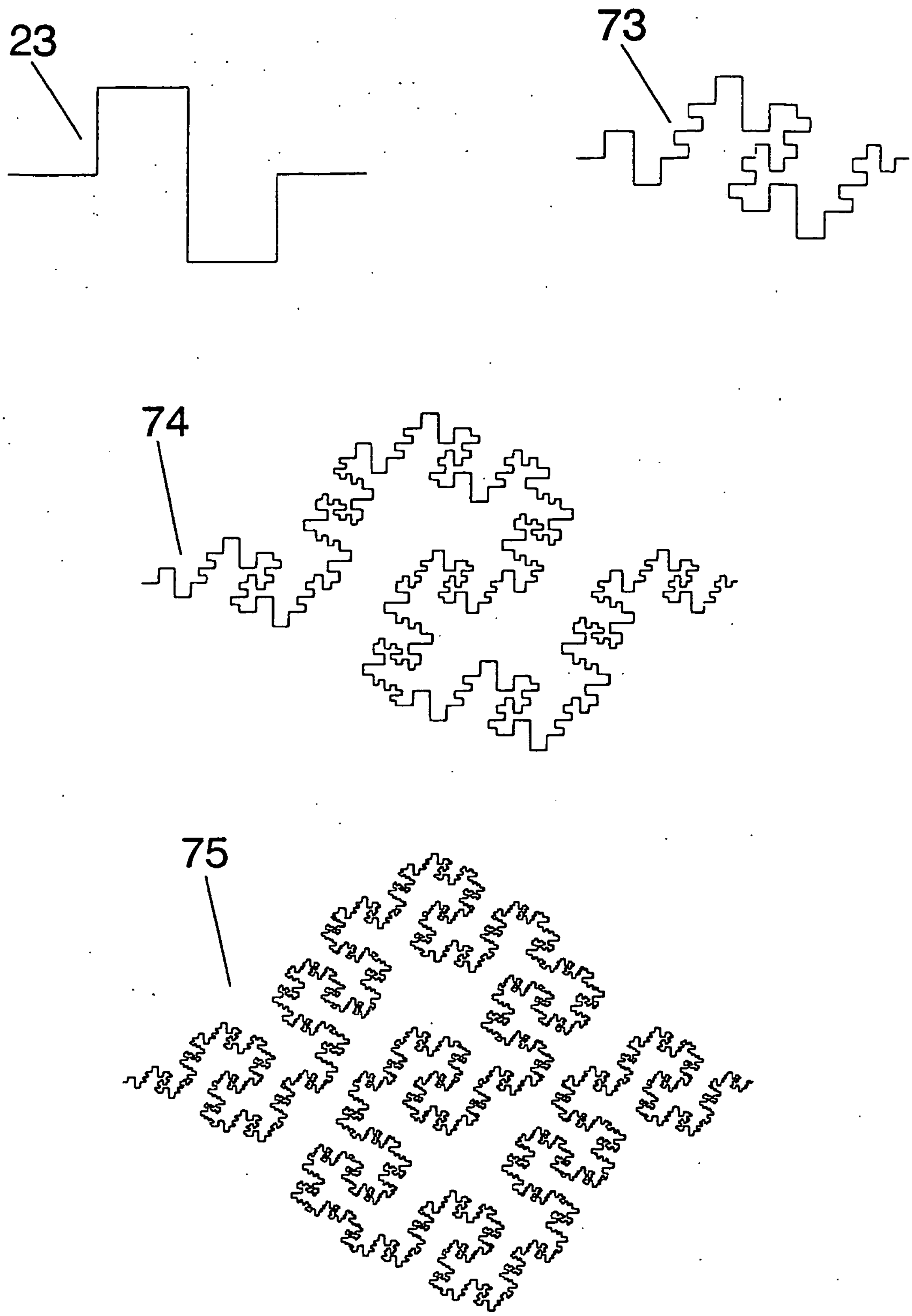

FIG. 25

REFERENCES CITED IN THE DESCRIPTION

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- **R.C.HANSEN.** Fundamental Limitations on Antennas. *Proc.IEEE,* February 1981, vol. 69 (2 **[0007]**