June 27, 1961 J. R. McDOUGAL 2,990,547

ANTENNA STRUCTURE

Filed July 28, 1959 2 Sheets-Sheet 1

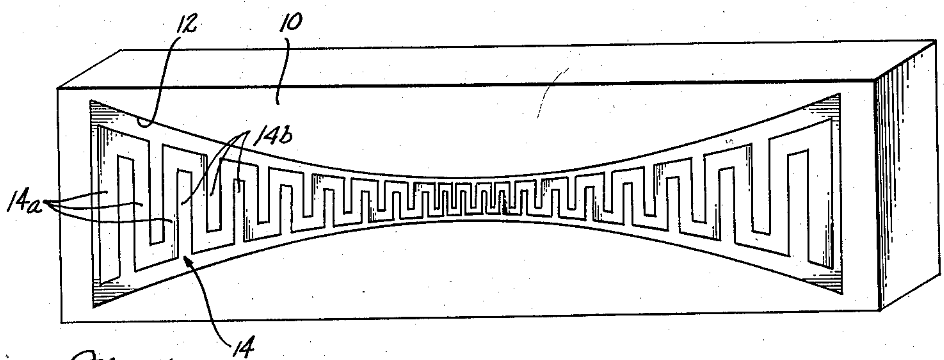

Fig. 1.

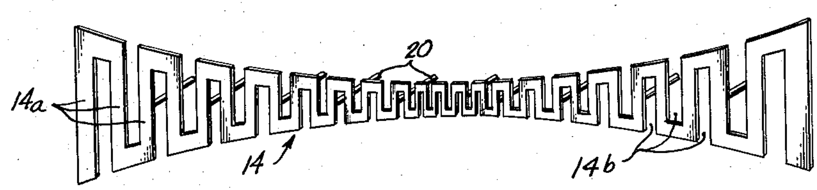

Fig. 2.

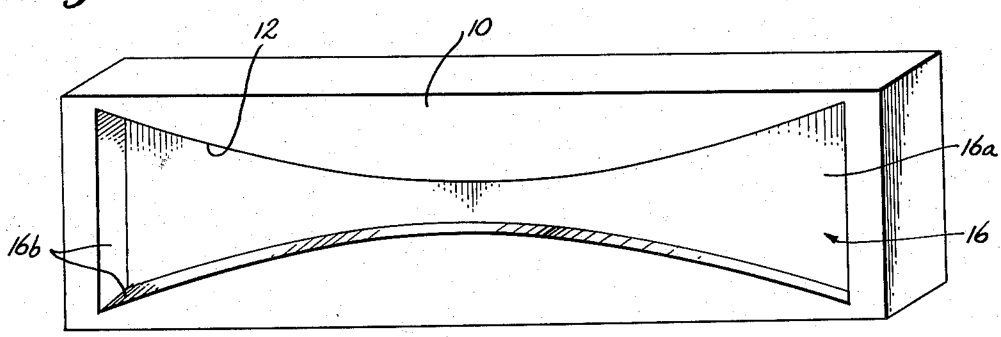

Fig. 3.

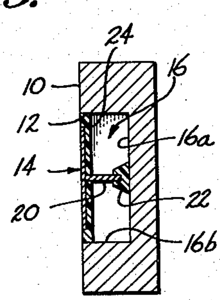

Fig. 4.

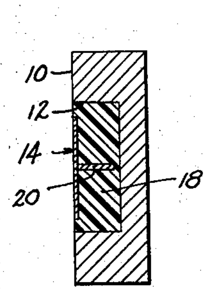

Fig. 5.

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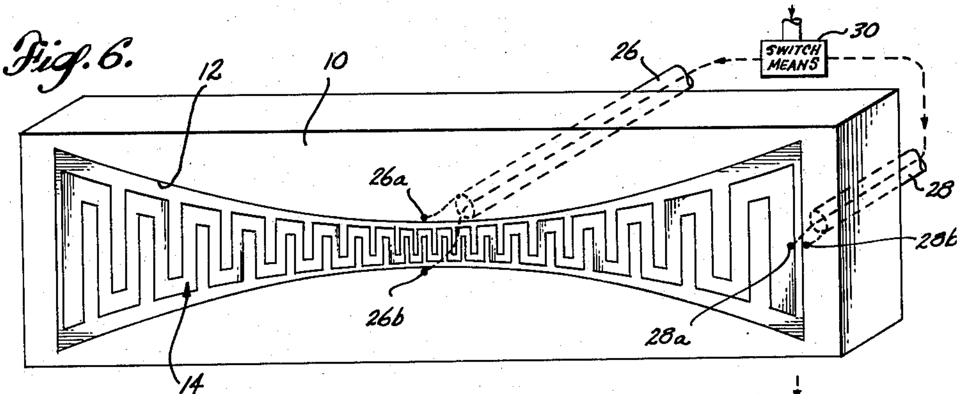

Fig. 6.

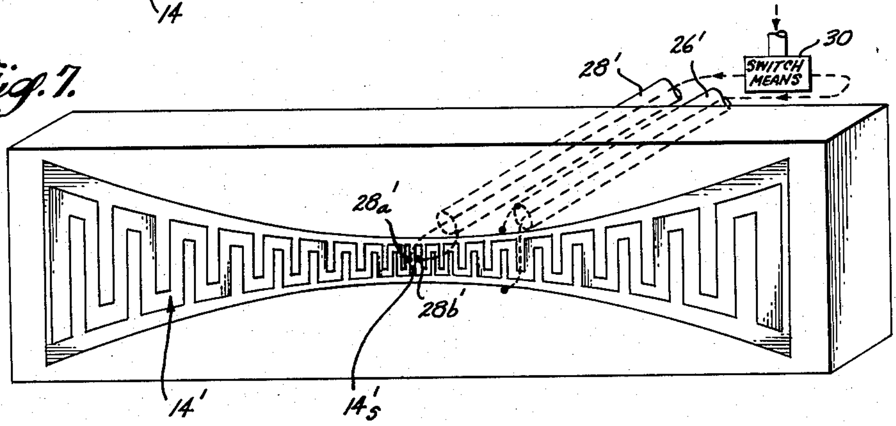

Fig. 7.

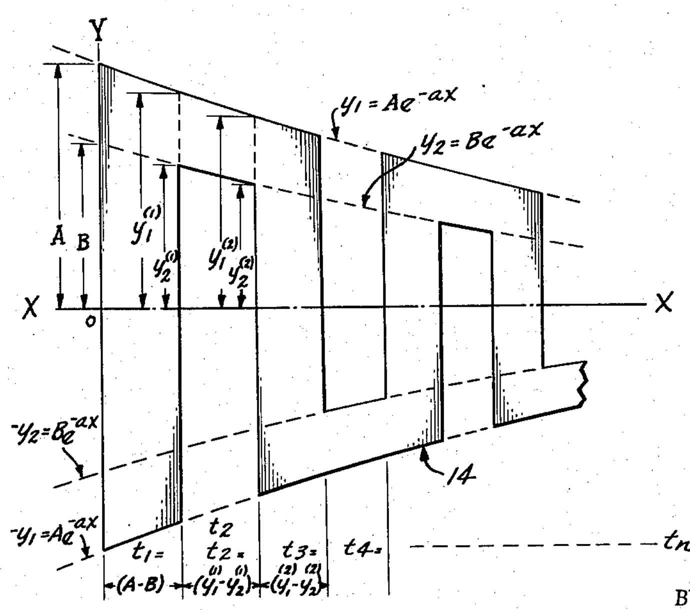

Fig. 8.

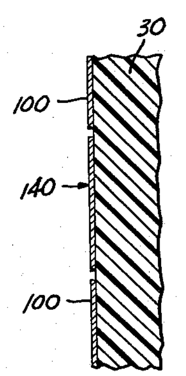

Fig. 9.

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ANTENNA STRUCTURE

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This invention relates to antennas for electromagnetic wave propagation and more particularly concerns a dual dipole flush-mounted antenna structure particularly suited for VHF and UHF operation. The invention is herein illustratively described by reference to the presently preferred form; however, it will be recognized that certain modifications and changes therein with respect to details may be made without departing from the underlying essentials.

While the invention is especially suited for aircraft applications requiring flush-mounted antennas, it has a wide variety of other applications as well. One of its special characteristics is the capacity to operate either with dual polarization or with singular polarization and as a directive radiator in either mode. Another object is to provide such an antenna which may be flush-mounted, which will have a relatively wide band width and which, for its degree of gain or directionality, may be made comparatively small and light in weight.

A further object is to provide a simple antenna of these characteristics which is relatively inexpensive to manufacture and is lent to mass production including production by printed circuit techniques if desired.

Still another object is a flush-mounted antenna suitable for high speed aircraft skin installations which may be relatively shallow in its depth perpendicular to the plane of the skin and which may be made impervious to humidity, temperature, altitude (i.e. atmospheric pressure), sand, dust, etc. In order to achieve the objective of a shallow flush-mounted construction, the novel antenna structure is readily adapted to be dielectrically loaded in an artificial manner which adds inappreciable weight to the structure, this purpose being achievable by artificial dielectric loading using metal elements in a relatively simple arrangement.

Still another object is a relatively versatile antenna which may be energized at any of different feed points as a convenient means to adjust input impedance thereof. By simple switching arrangements the versatility of the antenna as an alternatively dually or singularly polarized device is realized with no structural modifications or adjustments of the antenna itself for either mode of operation.

One feature of the invention resides in the antenna structure combining a conductive radiation surface having an elongated slot therein with a zig-zag conductive element mounted in the slot and presenting a broadside radiation face in substantially coplanar relation to the face of the conductive radiation surface. Either or both the conductive radiation surface and the conductive element may be energized to produce singular polarization of one direction or the other, or dual polarization.

More specifically, the zig-zag conductive element has minimum transverse width between its ends and increases in width exponentially toward both ends, the slot preferably having a similar configuration of somewhat larger outline. Because of its shape, this antenna has been referred to as a bow-tie dual dipole antenna. The successively adjacent and interconnected transverse members of the zig-zag element should be designed with logarithmically increasing thickness and spacing progressing from the point of minimum transverse width toward opposite ends of the zig-zag element.

As a further feature, the slot is backed by a reflective cavity less than a quarter wave length in depth, the same being minimized in depth preferably by the use of artificial dielectric loading achieved by metallic posts projecting from the zig-zag element towards the base of the cavity but not electrical contact with such base.

These and other features, objects and advantages of the invention will become more fully evident from the following description thereof based on the accompanying drawings.

FIGURE 1 is a front perspective view of the antenna.

FIGURE 2 is a front perspective view of the zig-zag element with metal posts for artificial dielectric loading.

FIGURE 3 is a front perspective view of the cavity-backed slotted conductive radiation surface.

FIGURE 4 is a transverse sectional view taken on line 4—4 in FIGURE 1.

FIGURE 5 is a view similar to FIGURE 4, illustrating a modified construction.

FIGURE 6 is a front perspective view illustrating one mode of antenna energization for dually polarized operation.

FIGURE 7 is a front perspective view of the antenna with a different mode of energization for dually polarized operation.

FIGURE 8 is a diagram illustrating the design theory applicable to the zig-zag element.

FIGURE 9 is a transverse sectional view indicating printed circuit or equivalent technique for forming the zig-zag element and the conductive radiation surface slot configuration.

Referring to the first embodiment shown in FIGURES 1 to 4, inclusive, the conductive radiation surface **10** is formed by means which may, in a practical case, comprise a rectangular metal sheet or block or may actually comprise the skin of an aircraft or other conductive support. A slot **12** of elongated proportions is formed in the radiation surface **10** and an elongated zig-zag element **14** is mounted in the slot and presents a broadside radiation face which is substantially in coplanar relation to the surface **10**. This zig-zag element **14** comprises a plurality of transversely extending members **14*a*** which are successively interconnected at alternately opposite ends to define an outline configuration which is contained within the outline of the slot and is marginally spaced inwardly from the edge of the slot on all sides.

Preferably, as later explained in more detail, the optimum results are obtained from this antenna structure when the zig-zag conductive element **14** is of minimum transverse width intermediate its ends (i.e. preferably midway) and increases in width exponentially toward those ends as shown. Moreover, the thickness of and spacing between the successively adjacent transverse members **14a** should be minimum substantially where the transverse width of the element is minimum and should increase logarithmically toward opposite ends of the zig-zag element. While the spacing between the peripheral outline of the zig-zag element and the edges of the slot is not critical, this spacing should be quite small at the ends in order to provide a high capacitive loading on the zig-zag element. The slot preferably has the same exponential taper as the element, although this is not strictly compulsory.

For broadside radiation in one direction, the slot **12** should, in the preferred construction, be backed by a conductive cavity **16** comprising the rear wall **16*a*** and the peripheral side walls **16*b*** which extend around the slot edge. This cavity should have a depth less than a quarter wave length, which in physical dimensions may be minimized by filling the cavity with a dielectric material **18** as shown in FIGURE 5 or, preferably (because of the lesser weight involved), by using an artificial dielectric loading technique involving metal rods or posts **20** mounted on certain of the transverse members **14***a* at intervals along the longitudinal axis of the zig-zag element **14**. These electrically conductive members **20** project from the back side of the zig-zag element toward the cavity surface **16***a*, but do not contact such surface. If desired these posts may be supported by stand-off insulators or dielectric footings **22** secured to the cavity surface **16***a* and may actually serve as a means to physically support the zig-zag element centered in the slot. Preferably, the slot is sealed and the zig-zag element is supported by and embedded in a dielectric panel or sheet **24** which closes the slot. Such an arrangement presents minimum weight and also minimizes the cavity depth so that the antenna structure may be flush mounted in an aircraft skin, for example, and will not project far into the interior of the aircraft. The solid dielectric filling technique shown in FIGURE 5 adds weight but is otherwise satisfactory. In any case, the dielectric material used should be a low-loss dielectric.

The overall length of the zig-zag element should be equal to or slightly less than one-half wave length at the center frequency of the operating band to which it is applied. Various modes of energization for such an antenna structure may be employed. In FIGURE 6 both the slot, or more correctly the surrounding conductive radiation surface in which the slot is formed, and the zig-zag element itself are separately energized in order to form a dual dipole arrangement with dual polarization. The slotted radiation surface is connected to be energized by a coaxial transmission line **26**, one conductor of which is connected to the surface at a point **26***a* and the other conductor of which is connected to the same at a point **26***b*, such points being located at corresponding positions along the length of the slot at opposite sides thereof. Nominally these locations are at the longitudinal midpoint of the slot, but as a matter of practice their position may be shifted along the length of the slot in order to obtain different input impedances suitable for matching the energy source used in different cases. Likewise, the zig-zag element in this example is energized from a coaxial transmission line **28**, one conductor of which is connected to the end transverse member of the zig-zag element at point **28***a* and the other conductor of which is connected to the adjacent point **28***b* of the slot edge, nominally midway between the transverse side of the slot. However, as in the case of the slot itself, impedance match may be achieved by adjusting the position of these connecting points along the end of the structure, i.e. perpendicular to its length. Suitable switching means **30** may be interposed in the transmission lines **26** and **28**, between the antenna structure and the energy source (not shown) in order to connect either or both transmission lines to the respective antenna elements at a given time. In this way it is possible to produce a dually polarized radiation pattern or a singularly polarized radiation pattern with one direction of polarization or the other.

In the modification shown in FIGURE 7 the zig-zag element **14'** is formed in two parts separated at the longitudinal midpoint (i.e. **14**'s). The transmission line **28'** in this instance has one conductor connected to the inner end of one-half of the zig-zag element at point **28'***a* and its other conductor connected to the adjacent inner end of the other half of the zig-zag element at point **28'***b*. In this case the transmission line **26'** is connected to the slotted reflective surface in the same manner as in FIGURE 6.

FIGURE 9 illustrates the application of printed circuit techniques to forming the antenna cavity and the zig-zag element. The zig-zag element in this case is designated **140** and the slotted conductive surface **100**.

Turning now to FIGURE 8, a portion of the zig-zag element **14** is shown, particularly an end portion, to illustrate the theoretical design considerations for optimum performance of the antenna element as a dipole device having the characteristics described. The thickness of the successive transversely extending members **14***a* and the intervening slots **14***b* is designated t with appropriate subscripts to indicate serial relationship. These slots represent dielectric surfaces which intervene between the conductive surfaces represented by the members **14***a*. The distance from the longitudinal center axis x—x transversely to the outside extremities of the slots or gaps formed between successively adjacent elements and also the corresponding outer extremities of the interconnecting portions of conductor which join together successively adjacent elements on either side of an individual slot are designated y with appropriate subscripts and superscripts to designate serial relationship, as shown in the view. The dimensions $t_1, t_2, t_3 \ldots t_n$, are related to the ordinate by the relationship:

$$t_n=(y_1^{(n)}-y_2^{(n)})=(A-B)e^{-axn}$$

where n denotes the numerical order of the surfaces (i.e. conductive or dielectric) as counted from the origin of the coordinate system. The interval t should decrease in logarithmic fashion progressing from the origin (where the origin is at the end of the zig-zag element) as may be demonstrated by solving the above equation for x_n, as follows:

$$x_n=\frac{1}{a}\text{ Log } e\left(\frac{A-B}{t_n}\right);\text{ or } x=\frac{1}{a}\sum_n^0 \text{Log } e\left(\frac{A-B}{t_n}\right)$$

The constants A, B, a, the dielectric constant of the material used in the sheet **24**, the number of intervals t_n, the type of feed selected and the size and shape of the reflecting cavity are all design parameters which in any particular instance will affect the impedance, pattern, power handling capacity and other characteristics of the antenna. The complete zig-zag configuration is obtained by determining the design parameters for one-half of the element, duplicating the curve thus obtained, for the other half, and connecting the two halves together in the center as shown in FIGURES 1 and 2 or with a gap between the two halves as indicated in FIGURE 7.

The y dimensions are defined by the exponential functions indicated in the diagram in FIGURE 8, from which the bow-tie designation is obviously derived.

It has been found that the radiation pattern of such an antenna is essentially independent of frequency over as much as a fifty percent band width variation and that the impedance is such as to be inherently compensated over a thirty percent band width variation, depending upon the standards used, when the backing cavity **16** is approximately 0.08 wave length deep, measured at the center frequency of the band. If the reflecting cavity is omitted, the resulting radiation pattern is, of course, different. It is found as a matter of interest, that the slot **12** should be cut only slightly longer and wider than the zig-zag element and, as previously mentioned, may be although is not necessarily of the same exponential taper. This is another design parameter which is subject to some variation, with consequent effect on the impedance characteristics and radiation characteristics of the device. As previously stated, the gap between the slot and the zig-zag element should be quite narrow at the ends in order to provide capacitive loading to the zig-zag element suitable for proper operation thereof as a dipole.

It should be noted that present-day theories applicable to antenna devices, specifically the "log periodic" theory, do not hold in this case since the dimensions of this antenna structure are such that the interval t_n, in the mid region especially, is so small as to appear almost negligible when compared with wave lengths even at the highest operating frequency of the antenna. A more applicable analysis is obtained by comparison with an array of infinitesimally thin, connected V-shaped elements with an assumed sinusoidal current distribution and with parameters which provide a small interval t_n. This theory indicates end-fire radiation from the zig-zag element at frequencies above and below its operating band of frequencies designed for broadside operation as in the normal mode of operation herein disclosed. Such theory proves to be true in practice, indicating an extended range of usefulness for the antenna.

It should be noted that the optimum operation for broadside radiation from the zig-zag element requires that the currents be essentially in phase along its length. This condition is met in practice by capacitively loading the zig-zag element by use of relatively narrow gaps between its end members and the adjacent end edges of the slot **12**. In general, pattern directivity increases as the number of transverse members **14a** is increased, to the point where it is no longer possible to maintain the in-phase relationship of the currents. It is found that the isotropic pattern directivity or gain of the zig-zag element is approximately 8 decibels when the antenna has optimum design and a cavity depth of approximately 0.08 wave length.

It should also be noted that the zig-zag element may be operated independently in space (i.e., without a surrounding slotted radiation surface), particularly when such element is backed by a reflective cavity and when it is connected for energization in shunt with such a cavity. Under these conditions the zig-zag element has a very workable input impedance.

It is recognized that slot antennas as such are well known in the art.

These and other aspects of the invention will be evident to those skilled in the art based on the foregoing disclosure of the preferred form and mode of operation of the invention.

I claim as my invention:

1. Electromagnetic antenna structure comprising two radiating elements, one a means presenting a conductive radiation surface having an elongated slot therein, and the other a zig-zag conductive element mounted in said slot and presenting a broadside radiation face in substantially coplanar relation to said surface, said zig-zag element having a plurality of members extending transversely to the legnth of said slot and successively interconnected at alternately opposite ends to define an outline configuration contained within the outline of said slot and all portions of which are marginally spaced inwardly from the edge of said slot on all sides, and energy transmission means electrically connected to at least one of said elements to energize said antenna.

2. The anenna structure defined in claim 1, wherein the transverse width of the zig-zag conductive element is minimum intermediate its ends and increases exponentially to its respective ends.

3. The antenna structure defined in claim 2, wherein the thickness of and spacing between the successively adjacent transverse members of the zig-zag element is minimum substantially where the transverse width of the element is minimum, and increases logarithmically toward opposite ends of said element.

4. The antenna structure defined in claim 3, wherein the spacing between the slot and the zig-zag element at the respective ends thereof is relatively small and is materially less than the spacing therebetween at the sides, whereby the zig-zag element has a high capacitive loading producing a broadside radiation pattern.

5. The antenna structure defined in claim 4, and means defining a shallow conductive cavity behind the slot and substantially enclosed on all sides extending around the slot and on the back side extending generally parallel to the slot, said cavity having less than a quarter-wave length depth, transverse to the general plane of the slot.

6. The antenna structure defined in claim 5, further comprising means electrically loading the antenna including conductive rod-like members projecting from selected transverse members of the zig-zag element toward the back side of the cavity but terminating short of making electrical contact therewith, thereby to effect artificial dielectric loading of said cavity.

7. The antenna structure defined in claim 3, wherein the zig-zag element is formed in two parts separated from each other substantially midway between the ends, each part being electrically connected with opposing polarity to the energy transmission means.

8. The antenna structure defined in claim 3, and reflector means comprising a shallow conductive surface mounted behind the slot at less than a quarter-wavelength spacing.

9. The antenna structure defined in claim 8, further comprising means electrically loading the antenna including conductive rod-like members projecting from selected transverse members of the zig-zag element toward the reflector means surface but terminating short of making electrical contact therewith, thereby to effect artificial dielectric loading of said cavity.

10. The antenna structure defined in claim 3, wherein the zig-zag element is energized by the energy transmission means connected to one end thereof and to an adjacent location on the conductive surface element.

11. The antenna structure defined in claim 10, wherein the slotted conductive surface element is also energized by the energy transmission means connected to the same at corresponding locations along the longitudinally extending slot edges, thereby to dually polarize the antenna structure.

12. The antenna structure defined in claim 3, wherein the slotted conductive surface element is energized by the energy transmission means connected to the same at corresponding locations along the longitudinally extending slot edges.

13. Electromagnetic antenna structure comprising two radiating elements, one a means presenting a conductive radiation surface having an elongated slot therein, and the other a zig-zag conductive element mounted in said slot and presenting a broadside radiation face in substantially coplanar relation to said surface, said zig-zag element having a plurality of members extending transversely to the length of said slot and successively interconnected at alternately opposite ends to define an outline configuration contained wholly within the outline of said slot and all portions of which are marginally spaced inwardly from the edge of said slot on all sides, and energy transmission means electrically connected to both of said elements to energize said antenna for dual polarization.

14. The antenna structure defined in claim 13, wherein the zig-zag element is formed in two parts separated from each other substantially midway between the ends, each part being electrically connected with opposing polarity to the energy transmission means, and wherein the slotted conductive surface element is also energized by the energy transmission means connected to the same at corresponding locations along the longitudinally extending slot edges, thereby to dually polarize the antenna structure.

15. Electromagnetic antenna structure comprising two radiating elements, one a means presenting a conductive radiation surface having an elongated slot therein, and the other a relatively thin sheet-like zig-zag conductive element positioned in said slot and presenting a broadside radiation face in substantially coplanar relation to said surface, said zig-zag element having a plurality of members extending transversely to the length of said slot and successively interconnected at alternately opposite ends to define an outline configuration contained wholly within the outline of said slot and all portions of which are marginally spaced inwardly from the edges of said slot on all sides, said slot being occupied by a body of dielectric material across its breadth and width supporting said zig-zag element so positioned therein, and energy transmission means electrically connected to at least one of said elements to energize said antenna.

16. Electromagnetic antenna structure comprising an

elongated zig-zag conductive element having a plurality of members extending transversely of the length of said element and successively interconnected at alternately opposite ends, the transverse width of said element being minimum intermediate its ends and increasing exponentially to its respective ends, and the thickness of and spacing between the successively adjacent transverse members being minimum substantially where the transverse width of the element is minimum and increasing logarithmically toward opposite ends of said element, and means electrically connected to said element for energizing the same.

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