May 3, 1949. J. B. GEHMAN ET AL 2,469,162

RADIO FREQUENCY DISTRIBUTION TRANSFORMER

Filed Oct. 12, 1946 2 Sheets-Sheet 1

Fig. 1

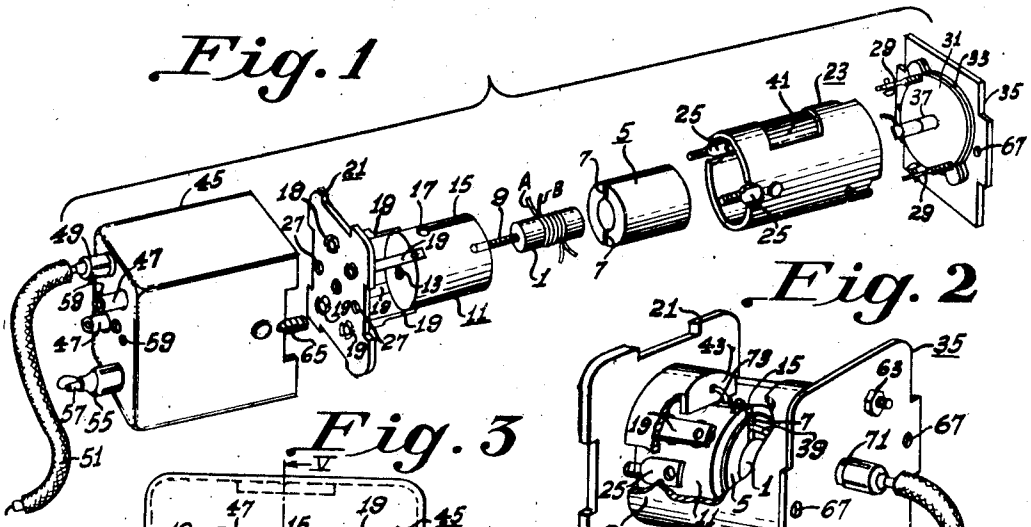


Fig. 2

Fig. 3

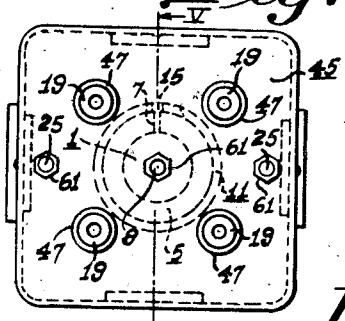


Fig. 5

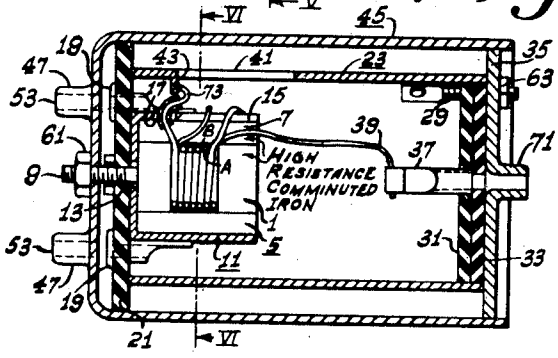


Fig. 4

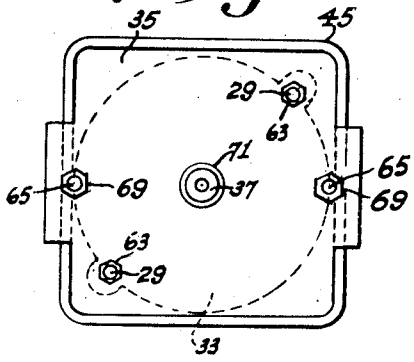
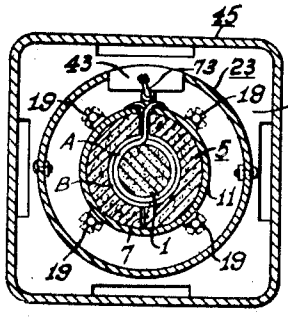


Fig. 6



Inventors
John B. Gehman and
Alfred H. Turner
By C. D. Dusha
Attorney

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RADIO FREQUENCY DISTRIBUTION TRANSFORMER

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Fig. 7



Fig. 11

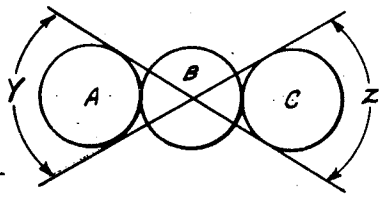


Fig. 10

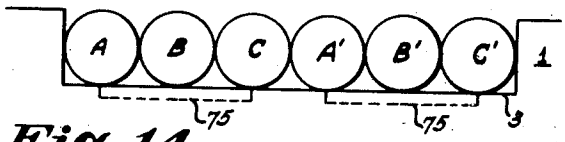


Fig. 14

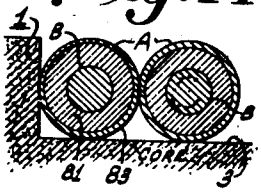


Fig. 8

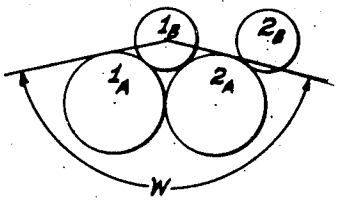


Fig. 9

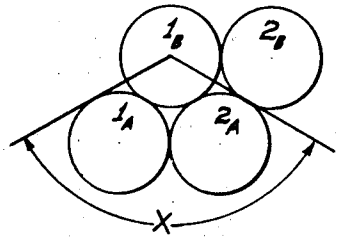


Fig. 12

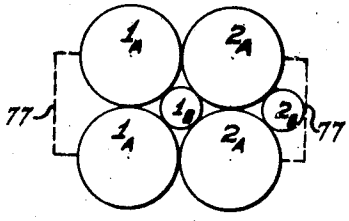


Fig. 13

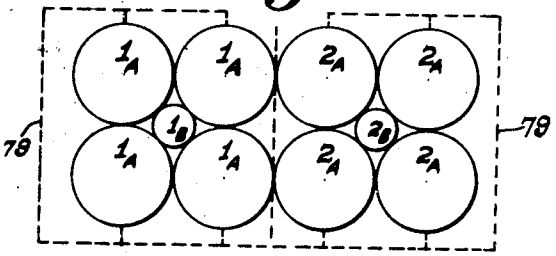


Fig. 15

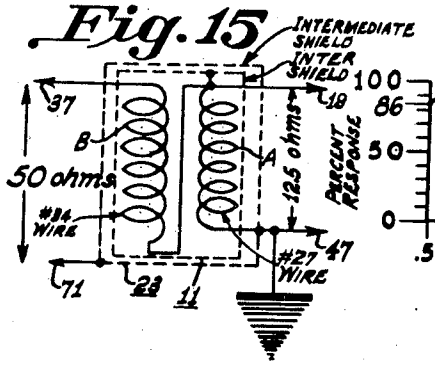
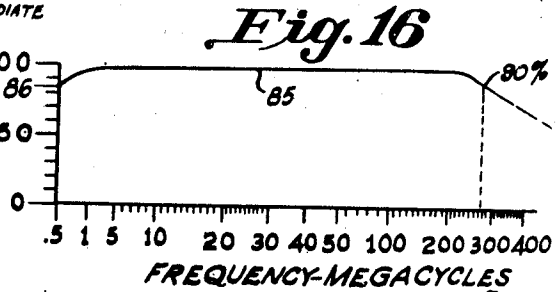


Fig. 16



Inventors
John B. Gehman, and
Alfred H. Turner
By
Attorney

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UNITED STATES PATENT OFFICE

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RADIO-FREQUENCY DISTRIBUTION TRANSFORMER

John B. Gehman, Haddonfield, and Alfred H. Turner, Collingswood, N. J., assignors to Radio Corporation of America, a corporation of Delaware

Application October 12, 1946, Serial No. 702,986

11 Claims. (Cl. 175—359)

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This invention relates generally to radio frequency transformers and more particularly to unique wide frequency band distribution transformers for coupling together sections of coaxial transmission lines.

Modern radio receivers designed for the reception of broadcast, short-wave and television frequency bands require input circuits having substantially uniform response over a frequency band of .5 to the order of 300 megacycles. Since coaxial transmission lines frequently are employed for coupling the antenna to one or more wide band radio receivers, it is essential that distribution transformers providing the required impedance transformation in the antenna distribution circuit respond uniformly over the entire frequency range. Ordinarily the useful frequency range of radio frequency transformers is quite limited due to inductance, distributed capacity and leakage reactance of the windings.

The instant invention comprises a non-resonant transformer utilizing a novel type of winding having extremely high coupling between the primary and secondary portions thereof. The transformer includes a pair of telescoped cylindrical cores which contact and completely surround the windings. The core material is of molded comminuted iron having extremely high permeability, whereby the desired low frequency response of the transformer may be obtained with a minimum number of winding turns. The effective permeability of the core gradually decreases as the frequency increases from .5 to 6 megacycles due to decreasing field penetration within the core. Above 6 megacycles, a much reduced field penetration exists within the core so that the closely coupled windings are effectively surrounded by a metallic shield and the core has no effect upon the coupling or the winding reactance as the frequency is further increased. Due to the low input and output impedances of the coaxial transmission lines, the capacity between the windings and the core does not substantially reduce the transformer frequency response until the operating frequency is of the order of 300 megacycles.

In order to minimize series lead inductance, the connecting leads to the windings are as short as practicable, and consist essentially of concentric metallic shields surrounding the core and windings. By proper proportioning of the shield diameters, desired surge impedance relations and a minimum standing wave ratio may be obtained. The instant invention will be described by reference to a typical transformer for coupling a

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single 50 ohm coaxial line to a distribution circuit comprising four 50 ohm coaxial lines. It should be understood that any other desired impedance transformation may be accomplished in accordance with the invention.

Among the objects of the invention are to provide an improved radio frequency distribution transformer. Another object is to provide an improved wide frequency band distribution transformer for coupling together coaxial transmission lines of a radio frequency distribution network. A further object is to provide an improved radio frequency distribution transformer including an input terminal for a coaxial transmission line and a plurality of output terminals for additional coaxial transmission lines. Another object is to provide an improved radio frequency transformer having substantially uniform response over a frequency range of the order of 500 to 1. An additional object is to provide an improved wide frequency band coaxial line distribution transformer in which the effective inductance is lowered at high frequencies thus changing the transformer resonance to a higher frequency and increasing the cut-off frequency.

A still further object of the invention is to provide a unique radio frequency distribution transformer having extremely closely coupled windings completely enclosed within a high permeability magnetic core and surrounded by a plurality of concentrically disposed shielding elements. Another object of the invention is to provide a novel wide frequency band radio frequency transformer having a plurality of shields surrounding a plurality of windings enclosed within a magnetic core wherein the shields are utilized as direct connections from the transformer terminals to the transformer windings. Another object of this invention is to provide an auto-transformer connection in order to reduce the effective leakage inductance to improve the transformer's high frequency response. An additional object is to provide an improved wide frequency band transformer having substantially constant surge impedance relations over the operating frequency band.

The invention will be described in greater detail by reference to the accompanying drawings of which Figure 1 is an exploded perspective view of a preferred embodiment of the invention; Figure 2 is an assembled, partially cross-sectional, perspective view of said preferred embodiment of the invention; Figure 3 is an output end view of said embodiment of the invention; Figure 4 is an input end view of said embodiment

of the invention; Figure 5 is a cross-sectional, side view taken along the section line V—V of Figure 3; Figure 6 is a cross-sectional view taken along the section line VI—VI of Figure 5; Figure 7 is an enlarged, fragmentary, cross-sectional view of a preferred type of winding suitable for use in said preferred embodiment of the invention; Figure 8 is a schematic diagram illustrating the coupling relations between the two windings of said preferred type of winding; Figure 9 is a diagram illustrating the coupling between the turns of the two windings of a modification of said preferred type of winding; Figure 10 is a fragmentary, cross-sectional view of a second type of winding according to the invention; Figure 11 is a diagram showing the coupling relations between the turns of said second type of winding; Figure 12 is a cross-sectional view of a third type of winding according to the invention; Figure 13 is a cross-sectional view of a fourth type of winding; Figure 14 is a fragmentary, cross-sectional view of a coaxial type of winding according to the invention; Figure 15 is a schematic circuit diagram illustrative of the electrical circuit of the transformer according to the invention; and Figure 16 is a graph illustrative of the frequency response of a typical wide band transformer according to the invention. Similar reference characters are applied to similar elements throughout the drawings.

Referring to Figures 1 to 7, inclusive, of the drawings, a central, "dumbell-shaped" core 1 of molded comminuted magnetic material has a central peripheral slot 3 for receiving a pair of serially connected windings A and B. In a typical embodiment of the invention, the first winding A is a single layer winding of #27 enameled copper wire wound directly on the inner surface of the slot 3. The second winding B also comprises a single layer winding of #34 enameled copper wire wound in the interstices of the larger size winding A. The depth of the lot 3 is sufficient to enclose the two interleaved windings. A split outer cylindrical core 5, also of molded comminuted magnetic material, is fitted over the inner cylindrical core 1 in close contact therewith, and the ends of the two windings are brought out through the slot 7 between the two halves of the outer core 5. One end of the small wire windings B, and both ends of the large wire #27 winding A are brought out through the sides of the slotted outer core 5, and the remaining end of the small (#34 wire) winding B is brought out through one end of the outer core slot. The serially-connected windings comprise an auto-transformer arrangement wherein the primary comprises both windings A and B, and the secondary comprises the larger wire winding A. The inner core 1 includes an axial screw 9 for supporting the core within the transformer structure. The comminuted magnetic material of both cores preferably should be of extremely high permeability material such as RCA #123–11 mix. Such high permeability comminuted cores have relatively high electrical resistance, of the order of several thousand ohms, due to the insulation surrounding each of the comminuated particles.

The two cores, and the windings enclosed therein, are fitted into an inner electrostatic cup shield 11, the supporting screw 9 passing through a clearance aperture 13 in the base thereof. Single opposite ends of the two windings A and B are brought out through a slot 15 in the side of the inner cup shield 11 and are soldered to the

shield 11 at points immediately adjacent to the slot. The remaining end of the larger wire winding A is brought out through the enlarged key-hole end 17 of the slot 15 and is insulated therefrom by a short section of "spaghetti" tubing. The inner cup shield 11 is held between the lugs of four quadrantally disposed tip jacks 19 which are mounted in an insulated strip 21 which contacts the base of the cup shield. The lugs of the tip jacks 19 are soldered to the outer surface of the inner cup shield 11 whereby each of the lugs is directly connected through the shield to opposite ends of the two windings which thus are effectively connected in series to provide an auto-transformer.

An intermediate cylindrical shield 23, having mounting lugs 25 attached thereto, surrounds the inner cup shield 11 and is supported in position by the passage of the mounting lugs 25 through complementary apertures 27 in the insulated strip 21. Similarly, a second pair of mounting lugs 29 attached to the opposite end of the intermediate shield 23 supports a pair of insulated strips 31, 33 and an input ground plate 35. A fifth tip jack 37 is supported in a central aperture of the insulated strip 31 and is connected by a short lead 39 to the remaining end of the small wire winding B.

The intermediate shield 23 includes a window 41 having an inwardly extending lip 43 to which is soldered the remaining end of the larger wire winding A encased in the spaghetti tubing which passes through the key-hole aperture 17 in the side of the inner cup shield 11.

A common ground and outer shield 45 includes on one end thereof four grounding terminals 47 for receiving the grounded conductor terminal 49 of a plurality of flexible coaxial cables 51. The inner terminals of the coaxial cables pass through clearance apertures 53 in each of the grounding cable terminals 47 to permit the inner cable conductor to be inserted into the corresponding output tip jacks 19. If a total of four output coaxial lines are not connected to the transformer, dummy loads comprising a coaxial line connector 55 and a small resistor 57 corresponding to the coaxial line surge impedance, are connected to each of the unused output terminals. The inner assembly comprising the windings, cores, inner and intermediate shields and the insulated and conductive terminal strips are assembled as shown in Figure 2 and are held within the outer shield 45 by the mounting lugs 25 which pass through complementary holes 59 in the outer shield. The ends of the mounting lugs 25 extending through the holes 59 in the outer shield 45 are fitted with nuts 61. Likewise, the ends of the mounting lugs 29 extending through the conductive end plate 35 are fitted with nuts 63, and projecting lugs 65 on the open end of the outer shield 45 pass through apertures 67 in the conductive input ground plate 35 and are fitted with nuts 69.

It will be seen that a common ground connection exists between the input cable terminal 71 and the output cable terminals 47 through both the intermediate and outer shields 23 and 45. The ungrounded input terminal 37 is connected through an extermely short lead 39 to one end of the small wire winding B. The remaining end of the small wire winding B and the opposite end of the large wire winding A are connected together on the immediately adjacent inner cup shield 11 and are directly connected through the lugs 19 of the output tip jacks to provide the four

output ungrounded terminals. The grounded terminal of the large wire winding A is connected through an extremely short lead 73 to the lip 43 of the grounded intermediate shield 23. Thus all transformer winding connections are as short as possible to minimize the lead inductance, thereby extending as far as possible the upper frequency response limits of the device. The diametric proportions of the inner and intermediate shields of the system are selected to provide as closely as possible the desired surge impedance relations in order to minimize the standing-wave-ratio of the device.

The molded comminuted iron cores 1 and 5, being of high permeability material, permit a minimum number of winding turns to be employed for satisfactory response at the .5 megacycle low frequency limit of the useful frequency range. Due to progressively decreasing penetration of the radio frequency field within the core material as the operating frequency is increased, the inductance of the transformer decreases in the frequency range between 1.2 and 6 megacycles. For frequencies above 6 magacycles, the magnetic cores have only a small effect upon the inductance. Due to the low operating impedances of the coaxial lines, the increased distributed capacity between the winding turns and the closely adjacent shields and core elements does not seriously affect the response of the device for frequencies below 250 to 300 megacycles, since the coupling factor is substantially independent of the core characteristics.

In the typical embodiment of the invention described heretofore, the large and small wire windings A and B each comprise seven turns, and the internal diameter of the core slot is of the order of three-sixteenth inch. It has been found that the winding inductance of a single winding is of the order of 15 microhenries at an operating frequency of 1200 kilocycles and that the inductance decreases to about 2.5 microhenries at 6 megacycles. The Q (ratio of reactance to resistance) of the device is of the order of 25 at an operating frequency of 60 megacycles, while the leakage inductance between the windings is less than .2 microhenry at the latter frequency. The efficiency of the transformer over the useful operating frequency range of .5 to 300 megacycles in the device described is due primarily to the extremely close coupling obtained between the two windings and the fact that the coupling factor is not primarily dependent upon the proximity thereto of the magnetic core elements.

In the winding of Figure 7, each of the turns of the smaller wire winding B has an effective coupling angle to the adjacent contacting turns of the larger wire winding A of the order of 170° for the specific winding wire sizes described heretofore. In Figure 8 the turns of the larger wire winding are indicated as 1_A, 2_A, etc., and the turns of the smaller wire winding are indicated as 1_B, 2_B, etc. The effective coupling angle between each smaller wire turn and the adjacent contacting larger wire turns is indicated by the angle W.

Referring to Figure 9, if the wire sizes of the primary and secondary windings are the same, the effective coupling angle X is seen to be considerably smaller than the coupling angle W for the arrangement of Figures 7 and 8.

Figure 10 shows a trifilar winding comprising a parallel-connected double winding A, C, A', C' having a single winding B, B' wound between the parallel-connected turns, the wire sizes of all of the winding turns being the same. The dash lines 75 indicate the parallel connection of the two portions of the double winding A and C. It should be understood that the double winding portions are connected together at their ends. Figure 11 shows the effective coupling angles Y and Z between each turn B and the adjacent double turns A and C, respectively. The total effective coupling angle between the single and double windings, therefore, is Y+Z which in general will exceed the coupling angle X of the winding of Figure 9, but it may be less than the effective coupling angle W of the winding of Figures 7 and 8. The effective coupling angle Y+Z tends to be somewhat larger than is indicated graphically since the turns are coupled on opposite sides instead of adjacently as in the arrangement of Figure 8.

Figure 12 shows a winding arrangement wherein a trifilar three layer winding comprising two parallel-connected large turns 1_A and a single turn 1_B of smaller diameter than the parallel-connected turns provides a 360° coupling angle between the large and small windings. The parallel connection of the large turns 1_A, 2_A, etc., is indicated by the dash lines 77, and said parallel connection may be accomplished at the ends of the large windings.

Figure 13 shows an alternate arrangement wherein four parallel large windings 1_A, 2_A, etc., are coupled through an effective coupling angle of 360° to a single small winding 1_B, 2_B, etc., the wire size of the latter winding being much smaller than that of the primary windings. The parallel connections of the four larger windings are indicated by the dash lines 79. The disadvantage of employing a plurality of parallel connected larger windings to increase the coupling to the smaller winding is that the effective inductance of the larger winding is decreased with each successive parallel-connected winding portion, thereby raising the lower frequency response range of the device. Also the resultant larger winding surface increases the winding distributed capacity and decreases the high frequency response range of the device.

Figure 14 shows a coaxial winding arrangement wherein the smaller inner winding B is enclosed within and coaxial with an outer winding shell A. A flexible layer of insulation 81, such as polystyrene, is interposed between the coaxial conductors, and the outer surface 83 of the outer conductor A is enameled or otherwise insulated to provide insulation between successive turns. The effective coupling angle between the two coaxial windings is 360°.

Figure 15 shows the circuit diagram of the novel transformer described heretofore wherein the input coaxial line impedance of 50 ohms is transformed to an impedance of 12.5 ohms for coupling to four similar 50 ohm output coaxial lines. The auto-transformer arrangement employed includes a common connection from opposite ends of the two windings A and B to the inner cup shield 11, and a common connection to the ungrounded output terminal 19. The input terminal 37 is connected to the remaining end of the small winding B, and the common grounded connection of the input and output circuits is connected to the intermediate shield 23 and to the remaining end of the large winding A. The outer shield 45, not shown, is connected to the intermediate shield 23.

Figure 16 shows a response curve 85 of the typical coupling transformer described in detail heretofore wherein 86 percent response is obtained at

.5 megacycle, a substantially flat characteristic is obtained from 1.5 to 250 megacycles, and 90 percent response is obtained at 275 megacycles. As explained heretofore the response characteristics of transformers of the type described may be varied to provide other desired frequency ranges by varying the number of turns on the primary and secondary windings, by varying the coupling factor between the turns of the windings, and by varying the magnetic core characteristics. It should be emphasized that the characteristics of the magnetic core only affect the low frequency response range of the transformer, since the core does not affect the coupling factor between the adjacently disposed windings, and therefore has no effect upon the high frequency response range.

Thus the invention described comprises an improved wide frequency range coupling transformer for coupling coaxial line distribution networks wherein the useful frequency range is enhanced by extremely close coupling between the windings of an auto-transformer, and a magnetic core extends the low frequency response of the device without substantially affecting the high frequency response characteristics of the device. A variety of different types of windings have been described for providing greater flexibility of design. The novel transformer described may be utilized as a conventional separated primary-secondary type device, but a smaller useful frequency band width results from such an arrangement.

We claim as our invention:

1. A wide frequency band coupling transformer comprising at least two concentric cylindrical shields, a magnetic structure, interleaved windings completely enclosed within said magnetic structure, connections from opposite ends of said windings to the inner one of said shields, a connection from the remaining end of one of said windings to another of said shields, output terminals connected between two of said shields to minimize winding lead inductance effects, and input terminals connected between one of said shields and the remaining end of another of said windings, the separation between said shields being selected to minimize surge impedance discontinuities.

2. A wide frequency band coupling transformer comprising a pair of interleaved insulated windings, a pair of telescoping cylindrical magnetic elements completely surrounding said windings, a first electrostatic shield surrounding and coaxial with said magnetic elements and connected to opposite ends of said windings, a second electrostatic shield surrounding and coaxial with said first shield and connected to the remaining end of one of said windings, a plurality of output connections each connected to said first shield and having a common connection to said second shield, and input connections to the remaining end of the other of said windings and to said common connection.

3. A wide frequency band coupling transformer comprising a central magnetic spool having a pair of interleaved insulated windings thereon in physical contact with said core, a cylindrical outer magnetic structure surrounding and in contact with said spool and said windings, said outer structure having apertures therein for connections to said windings, a first electrostatic shield surrounding and coaxial with said outer magnetic structure and connected to opposite ends of said windings, a second electrostatic

shield surrounding and coaxial with said first shield and having an inwardly extending projection connected to the remaining end of one of said windings, a plurality of output connections connected to said first shield at spaced points on its periphery and having a common grounded connection to said second shield, and input connections to the remaining end of the other of said windings and to said common grounded connection.

4. A wide frequency band coupling transformer comprising a central high resistance comminuted iron magnetic spool having a pair of interleaved insulated windings thereon in physical contact with said core, a cylindrical outer magnetic structure of similar material to said spool surrounding and in contact with said spool and said windings, said outer structure having apertures therein for connections to said windings, a conductive cup partially surrounding and coaxial with said outer magnetic structure and connected to opposite ends of said windings, a conductive cylindrical shield surrounding and coaxial with said cup and having an inwardly extending projection connected to the remaining end of one of said windings, said shield also being electrically connected with said magnetic spool and structure, a plurality of output connections connected to said cup at spaced points on its periphery and having a common grounded connection to said shield, and input connections to the remaining end of the other of said windings and to said common grounded connection.

5. A wide frequency band coupling transformer comprising three concentric cylindrical shields, a pair of telescoped magnetic elements, a pair of interleaved windings completely enclosed within and in physical contact with said pair of telescoped magnetic elements, said elements and windings being partially enclosed by the inner of said shields, connections from opposite ends of said windings to said inner shield, a connection from the remaining end of one of said windings to the intermediate one of said shields, connections between the intermediate and outer ones of said shields, a plurality of output terminals connected between said inner and outer shields, and input terminals connected between said outer shield and the remaining end of the other of said windings, the separation between said shields being selected to minimize surge impedance discontinuities.

6. A wide frequency band coupling transformer for a coaxial transmission system comprising three concentric cylindrical shields, a pair of telescoped cylindrical magnetic elements, a pair of interleaved windings completely enclosed within and in physical contact with said pair of telescoped magnetic elements, said elements and windings being partially enclosed by the inner of said shields, connections from opposite ends of said windings to said inner shield, a connection from the remaining end of one of said windings to the intermediate one of said shields, connections between the intermediate and outer ones of said shields, a plurality of coaxial line output terminals each connected between said inner and outer shields, and a coaxial line input terminal connected between said outer shield and the remaining end of the other of said windings, the separation between said shields being selected to minimize surge impedance discontinuities.

7. A wide frequency band coupling transformer including three concentric cylindrical shields, a pair of telescoped magnetic elements, a pair of concentric windings comprising a helix of co-

axial conductors completely enclosed within and in physical contact with said pair of telescoped magnetic elements, said elements and windings being partially enclosed by the inner of said shields, connections from opposite ends of said windings to said inner shield, a connection from the remaining end of one of said windings to the intermediate one of said shields, connections between the intermediate and outer ones of said shields, a plurality of output terminals connected between said inner and outer shields, and input terminals connected between said outer shield and the remaining end of the other of said windings, the separation between said shields being selected to minimize surge impedance discontinuities.

8. A wide frequency band coupling transformer including three concentric cylindrical shields, a pair of telescoped cylindrical magnetic elements, the inner of said elements having a central peripheral slot for supporting windings, a pair of interleaved windings comprising a first single layer winding and a second single layer winding wound in the interstices of said first winding and of smaller wire diameter than said first winding, said windings being completely enclosed within and in physical contact with said pair of telescoped magnetic elements, said elements and windings being partially enclosed by the inner of said shields, connections from opposite ends of said windings to said inner shield, a connection from the remaining end of one of said windings to the intermediate one of said shields, connections between the intermediate and outer ones of said shields, a plurality of output terminals connected between said inner and outer shields, and input terminals connected between said outer shield and the remaining end of the other of said windings, the separation between said shields being selected to minimize surge impedance discontinuities.

9. A wide frequency band coupling transformer including three concentric cylindrical shields, a pair of telescoped cylindrical magnetic elements, the inner of said elements having a central peripheral slot for supporting windings, a pair of interleaved windings comprising a multilayer winding and a second winding wound in the interstices of said multilayer winding and of smaller wire diameter than said multilayer winding, said windings being completely enclosed within said pair of telescoped magnetic elements, said elements and windings being partially enclosed by the inner of said shields, connections from opposite ends of said windings to said inner shield, a connection from the remaining end of one of said windings to the intermediate one of said shields, connections between the intermediate and outer ones of said shields, a plurality of output terminals connected between said inner and outer shields, and input terminals connected between said outer shield and the remaining end of the other of said windings, the separation between said shields being selected to minimize surge impedance discontinuities.

10. A wide frequency band coupling transformer comprising at least two concentric shields, a magnetic element, a pair of interleaved windings completely enclosed within and in physical contact with said magnetic element, said element and windings being at least partially enclosed by the inner of said shields, connections from both of said windings to one of said shields, a connection from the remaining end of one of said windings to another of said shields, output terminals connected between two of said shields, and input terminals connected between one of said shields and the remaining end of the other of said windings, the separation between said shields being selected to minimize surge impedance discontinuities and the magnetic permeability and field penetration effects of said magnetic elements being so related as to increase the high frequency cut off limits of said transformer thus extending the useful frequency range to the order of 500 to 1.

11. A wide frequency band transformer comprising at least two concentric cylindrical shields, a magnetic structure, interleaved windings completely enclosed within said magnetic structure, connections from one of said windings to the inner one of said shields, connections from said one of said windings to another of said shields, output terminals connected between said shields connected to said one of said windings to minimize winding lead inductance, and input connections to the other of said windings, the separation between said shields being selected to minimize surge impedance discontinuities.

JOHN B. GEHMAN.
ALFRED H. TURNER.

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