

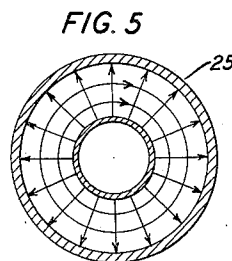
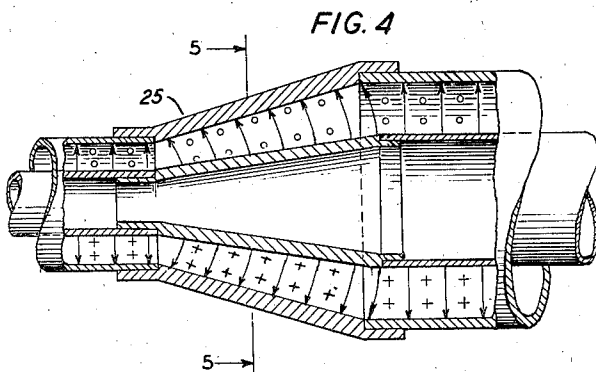
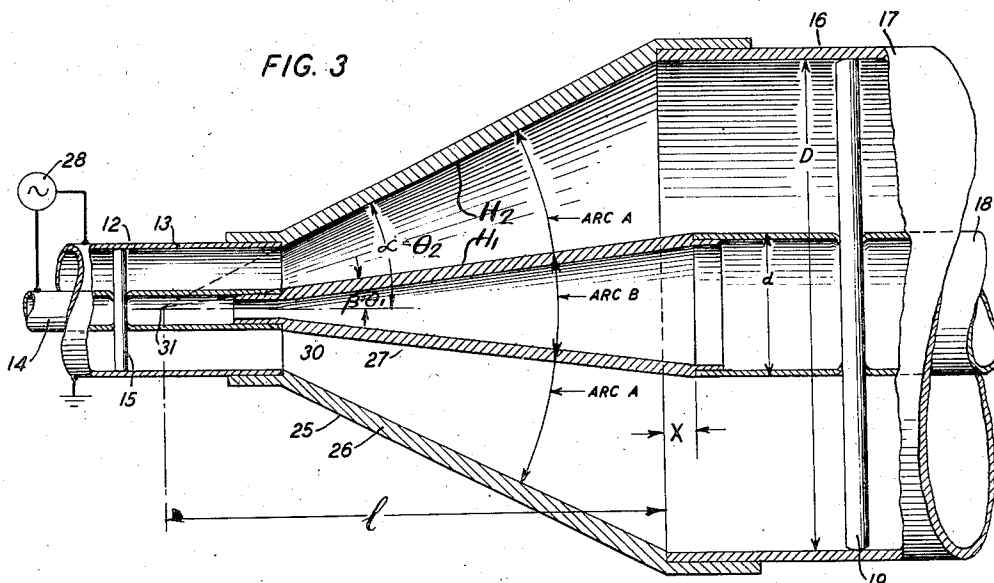
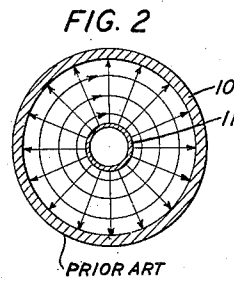
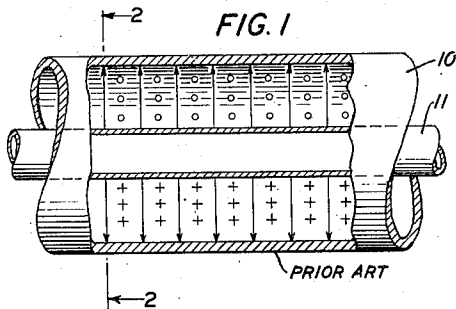
Nov. 16, 1948.

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2,453,759

TAPERED UNION FOR CONCENTRIC CONDUCTOR LINES

Filed Dec. 20, 1943



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2,453,759

TAPERED UNION FOR CONCENTRIC
CONDUCTOR LINES

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Application December 20, 1943, Serial No. 514,948

1 Claim. (Cl. 178—44)

1

This invention relates to a concentric conductor line transmitting signal waves of high frequencies and including at least two sections of different physical sizes, and more particularly to a tapered union for connecting such two sections.

The patent of E. I. Green, No. 1,841,473 granted January 19, 1932, discloses a concentric conductor line comprising two sections of different physical sizes assembled such that the ratio of the internal diameter of each outer conductor to the external diameter of its associated inner conductor is substantially the same so that both line sections have substantially the same impedance. The patent of A. G. Clavier, No. 1,932,448 granted October 31, 1933, discloses two concentric conductor sections of different physical sizes connected by a conical adapter arranged such that, at any point therealong, the ratio of the internal diameter of the outer conductor to the external diameter of the inner conductor is substantially equal to the corresponding ratio of either line section. As a consequence, the characteristic impedance of the conical adapter is substantially equal or matched to that of either line section.

It has been found that the conical adapter tends to vary in effective impedance from point to point with variations in the frequency of the signal waves being transmitted thereover, and that such impedance variation tends to increase with frequency. This tends to introduce an impedance mismatch between the joined line sections and thereby to create reflection effects which tend to introduce loss in the transmitted signals. The impedance variation of the conical adapter, that is, the impedance mismatch between the joined line sections, tends to attain a maximum when the wavelength of the transmitted signal waves tends to approach the physical length of the conical adapter. This mismatch may be important in such uses as making accurate measurements, for example.

The present invention contemplates connecting two concentric conductor sections of different physical sizes, but the same characteristic impedance, by a tapered union whose characteristic impedance from point to point substantially matches that of the individual line sections regardless of the wavelength of the transmitted signals.

The object of the invention is to provide a concentric conductor transmission line of at least two sections of different physical sizes, with a substantially uniform impedance irrespective of the wavelength of the signals transmitted thereover.

In a concentric conductor transmission line comprising at least two sections having different physical sizes and connected by a tapered concentric conductor union as disclosed in the Green patent, supra, a specific embodiment of the

2

present invention comprises a tapered concentric conductor union in which the outer and inner conductors are arranged such that, for a given radius and center, the ratio of the arc extending between two diametrically opposite points on the internal surface of the outer conductor to the arc extending between two diametrically opposite points on the external surface of the inner conductor is substantially equal to the corresponding ratio of diameters of either of the line sections being joined together. As a consequence, the characteristic impedance of the tapered union from point to point is substantially equal to that of either of the two line sections being connected together, regardless of the dimensional relation between the wavelength of the signals and the physical length of the tapered union.

The invention will be readily understood from the following description taken together with the accompanying drawing in which:

Fig. 1 is a partial cross-sectional view of a concentric conductor and graphically illustrates the distribution of the electrostatic and electromagnetic fields intervening between the inner and outer conductors and familiar to the prior art;

Fig. 2 is a cross-sectional view taken along the lines 2—2 in Fig. 1;

Fig. 3 is a partial cross-sectional view of a specific embodiment of the present invention;

Fig. 4 is a partial cross-sectional view similar to Fig. 3 but graphically showing the distribution of the electrostatic and electromagnetic fields in Fig. 3; and

Fig. 5 is a cross-sectional view taken along the line 5—5 of Fig. 4.

In Figs. 1 and 2 an outer conductor 10 is arranged concentrically with an inner conductor 11 such that a certain ratio exists between the inside diameter of the outer conductor and the outside diameter of the inner conductor. According to the Green patent, supra, this ratio provides the assembled outer and inner conductors with a certain characteristic impedance:

$$Z_0 = \frac{138}{\sqrt{K}} \cdot \log_{10} \frac{D}{d} \quad (1)$$

in which Z_0 is the characteristic impedance in ohms, K is the dielectric constant of the insulating material separating the outer and inner conductors, and D is the inside diameter of the outer conductor, and d is the outside diameter of the inner conductor. Hence, with a given dielectric constant K , the characteristic impedance is determined by the ratio

$$\left(\frac{D}{d}\right)$$

In the concentric conductor section of Fig. 1, the average electrostatic field at successive points along the horizontal axis of the line is graphically

represented by the full lines disposed vertically and having arrows on the corresponding ends thereof; and the electromagnetic field at successive points along the horizontal axis of the line is graphically shown by the vertically disposed characters (0) and (+). At a given point along the longitudinal axis of the concentric conductor line, the average electrostatic field may be further represented graphically like the spokes of a wheel, Fig. 2, while the average electromagnetic field may be graphically shown as a plurality of concentric circles, Fig. 2.

A plurality of concentric conductor sections similar to the one shown in Figs. 1 and 2 may be embodied in a concentric conductor transmission system illustrated in Fig. 3. Referring to this figure, concentric conductor section 12 comprises outer conductor 13 and inner conductor 14 spaced concentrically, for example, by insulator 15 as illustrated in the patent of P. H. Smith, No. 2,280,200 granted April 21, 1942; and concentric conductor section 16 includes outer conductor 17 and inner conductor 18 spaced concentrically by insulator 19 in the manner of the Smith patent, supra. It is evident that the two outer conductors 13 and 17 have different inside diameters, and the two inner conductors 14 and 18 have different outside diameters. However, the ratios of the inside diameters of the individual outer conductors 13 and 17 to their associated inner conductors 14 and 18, respectively, are substantially equal so that the individual concentric conductor sections 12 and 16 have substantially the same characteristic impedance as disclosed in Green patent, supra.

Thus, the physical relationship of the outer and inner conductor of the two concentric conductor sections determines the distribution of both the electrostatic and electromagnetic fields therein, and both the latter, in turn, determine the characteristic impedance of the individual concentric conductor sections. Hence, the physical relationship of the outer and inner conductors embodied in the individual concentric conductor sections determines their characteristic impedance.

The concentric conductor sections 12 and 16 are connected by a tapered union 25, Fig. 3, comprising a tapered outer conductor 26 and a tapered inner conductor 27. A suitable wave translating device 28 applied across the outer and inner conductors of the concentric conductor section 12 serves to transmit or receive signal waves of a high order of frequency, including the ultra-high frequency range. Thus, the wave translating device 28, concentric conductor sections 12 and 16, and tapered union 25 comprise a high frequency transmitting or receiving system.

In accordance with a specific embodiment of the present invention, the tapered concentric conductor union 25 is arranged to have a characteristic impedance from point to point, which is substantially equal to that of the individual concentric conductor sections 12 and 16. This is accomplished by designing the tapered union such that, for a given radius and center, the ratio of the length of the arc formed between diametrically opposite points on the internal surface of the tapered outer conductor 26 to the length of the arc formed between diametrically opposite points on the external surface of the tapered inner conductor 27 is substantially equal to the ratio of the inside diameters of either outer conductor 13 or 17 to the outside diameter of the associated

inner conductor 14 or 18. Thus, the characteristic impedance of the tapered union, from point to point, is substantially equal to the characteristic impedance of either concentric conductor section 12 or 16, both of which, as previously pointed out, have substantially the same characteristic impedance.

It will be observed that in any tapered union in which the foregoing geometrical relations obtain, the diameter of the inner tapered conductor 27, in the plane of the larger end of the outer tapered conductor 26, is necessarily smaller than the diameter d of the connected coaxial conductor 18. It is only at some distance X (Fig. 3) beyond that plane that the diameter of the inner tapered conductor becomes equal to the diameter d .

Referring to Fig. 3, the arc A extends between diametrically opposite points on the internal surface of the outer tapered conductor 26; arc B between diametrically opposite points on the external surface of the inner tapered conductor 27; the given radius 30 extends between both arcs A and B and the given point 31 on the horizontal axis of the union 25; and the arc B coincides with a portion of the arc A. As graphically illustrated in Fig. 4, the average electrostatic and electromagnetic fields tends to describe arcs. As such fields determine the impedance of the tapered union, Equation 1 can now be written:

At the bottom of page 286 of S. A. Schelkunoff's textbook entitled "Electromagnetic Waves" published by the D. Van Nostrand Company, Inc. in 1943, mention is made that if two coaxial cones are insulated at their common apex and if an alternating current voltage is maintained between their apices, waves will be generated with electric lines coinciding with meridians and magnetic lines along circles coaxial with the axis.

Let $I(r)$ be the total current in the inner cone, and $V(r)$ the voltage from the inner cone to the outer cone along a meridian.

The voltage is the integral of $rE\theta$ along a meridian and may be expressed as

$$V(r) = \eta e^{-i\theta r} \left(\cot \frac{\theta_1}{2} - \cot \frac{\theta_2}{2} \right)$$

$$I(r) = I(0) e^{-i\theta r}$$

$$Z_0 = \frac{V(r)}{I(r)} = \frac{\eta e^{-i\theta r} \left(\cot \frac{\theta_1}{2} - \cot \frac{\theta_2}{2} \right)}{I(0) e^{-i\theta r}}$$

$$= \frac{\eta}{2\pi} \log \left(\cot \frac{\theta_1}{2} \tan \frac{\theta_2}{2} \right)$$

$$= \frac{\eta}{2\pi} \log \left[\frac{\tan \frac{\theta_2}{2}}{\tan \frac{\theta_1}{2}} \right] \quad (1a)$$

$$= \frac{120\pi \cdot 2.303}{2\pi \cdot \sqrt{K}} \cdot \log_{10} \left[\frac{\tan \frac{\theta_2}{2}}{\tan \frac{\theta_1}{2}} \right]$$

$$= \frac{138}{K} \cdot \log_{10} \left[\frac{\tan \frac{\theta_2}{2}}{\tan \frac{\theta_1}{2}} \right] \quad (1b)$$

which is the exact formula for the characteristic impedance of a tapered section of coaxial conductor.

5

For small angles, the tangent of an angle is approximately equal to the angle in radians so that the following approximation may be made.

$$\begin{aligned}
 Z_0 &= \frac{\eta}{2\pi} \cdot \log \left(\frac{\frac{\theta_2}{2}}{\frac{\theta_1}{2}} \right) = \frac{\eta}{2\pi} \log \left(\frac{\theta_2}{\theta_1} \right) \\
 &= \frac{120\pi}{2\pi} \cdot \frac{2.303}{\sqrt{K}} \cdot \log_{10} \left(\frac{\frac{\theta_2}{2}}{\frac{\theta_1}{2}} \right) \\
 &= \frac{138}{\sqrt{K}} \cdot \log_{10} \left(\frac{\theta_2}{\theta_1} \right) \\
 &= \frac{138}{\sqrt{K}} \cdot \log_{10} \left(\frac{\text{arc length for } \theta_2}{\text{arc length for } \theta_1} \right)
 \end{aligned}$$

where the arcs are measured along the same meridian.

$$Z_0 = \frac{138}{\sqrt{K}} \cdot \log_{10} \frac{\text{Arc } A}{\text{Arc } B} = \frac{138}{\sqrt{K}} \cdot \log_{10} \frac{\angle \alpha}{\angle \beta} \quad (2)$$

Equations 1 and 2 may be written

$$Z_0 = \frac{138}{\sqrt{K}} \cdot \log_{10} \frac{D}{d} = \frac{138}{\sqrt{K}} \cdot \log_{10} \frac{\text{Arc } A}{\text{Arc } B} = \frac{138}{\sqrt{K}} \cdot \log_{10} \frac{\angle \alpha}{\angle \beta} \quad (3)$$

Thus, it is seen when the ratios

$$\left(\frac{D}{d} \right), \left(\frac{\text{Arc } A}{\text{Arc } B} \right), \text{ and } \left(\frac{\angle \alpha}{\angle \beta} \right)$$

are substantially equal, the characteristic impedance of the individual concentric conductor sec-

6

tions 12 and 16 and tapered union 25 are substantially equal.

What is claimed is:

- A microwave transmission line comprising two sections of coaxial conductor line having different physical sizes and arranged to have the same ratio of the inside diameter of the outer conductor to the outside diameter of the inner conductor for both said sections, and a tapered union for connecting said two sections, comprising conically tapered outer and inner conductors extending coaxially in the same direction and proportioned so that the inside surface of the tapered outer conductor and the outside surface of the tapered inner conductor have a common apex, said tapered conductors being further proportioned so that the ratio of the angle formed between the axis of said union and the inside surface of said tapered outer conductor to the angle formed between said axis and the outside surface of said tapered inner conductor is substantially equal to said diametrical ratio of the two coaxial sections being connected, the length of said tapered union being comparable with the wavelength of the microwaves transmitted therethrough.

ALBERT L. ROBINSON.

REFERENCES CITED

- The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,841,473	Green	Jan. 19, 1932
1,932,448	Clavier	Oct. 31, 1933