

March 5, 1968

W. KRANK ET AL

3,372,352

WAVEGUIDE

Original Filed Sept. 10, 1964

3 Sheets-Sheet 1

Fig. 1

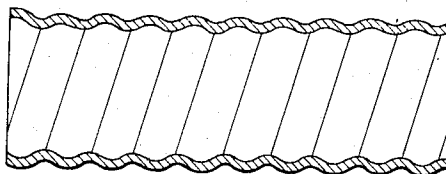


Fig. 2

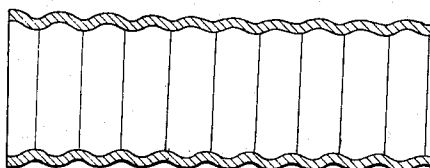
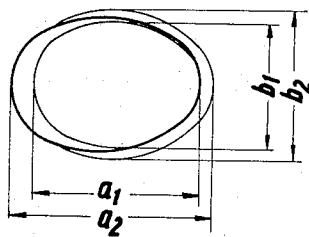


Fig. 3



Inventors:
WOLFGANG KRANK
GÜNTER MÖHRING
BY *Spencer & Kaye*
ATTORNEYS

March 5, 1968

W. KRANK ET AL

3,372,352

WAVEGUIDE

Original Filed Sept. 10, 1964

3 Sheets-Sheet 2

Fig. 4

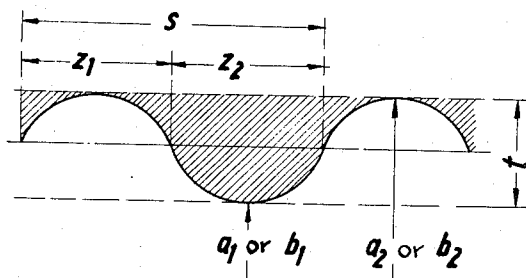


Fig. 5

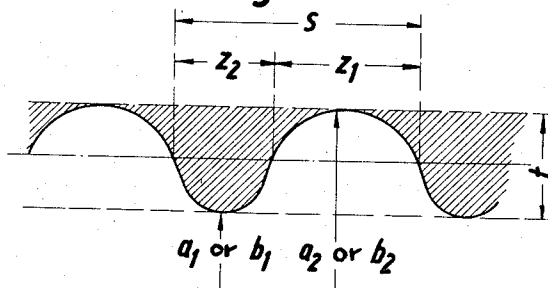
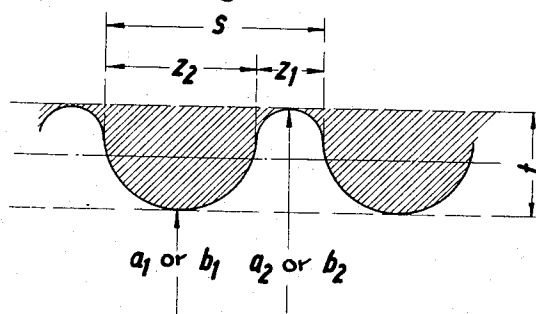


Fig. 6



Inventors:
WOLFGANG KRANK
GUNTER MÖHRING
BY *Spencer & Kaye*
ATTORNEYS

March 5, 1968

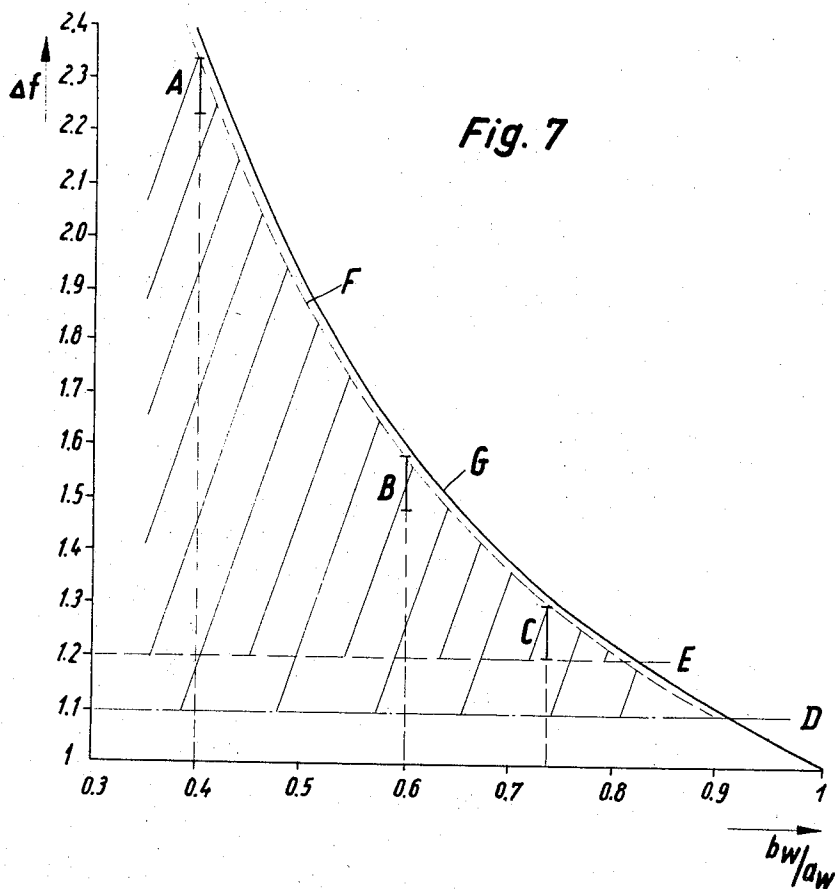
W. KRANK ETAL

3,372,352

WAVEGUIDE

Original Filed Sept. 10, 1964

3 Sheets-Sheet 3



Inventors:
WOLFGANG KRANK
GÜNTHER MÖHRING
BY *Spencer & Kaye*
ATTORNEYS

1

3,372,352

WAVEGUIDE

Wolfgang Krank, Backnang, Wurttemberg, and Günter Möhring, Langenhagen, Hannover, Germany, assignors to Telefunken Patentverwertungs-G.m.b.H., Ulm (Danube), and Hackethal-Draht und Kabel-Werke A.G., Hannover, Germany

Continuation of application Ser. No. 395,532, Sept. 10, 1964. This application July 24, 1967, Ser. No. 655,672
3 Claims. (Cl. 333-95)

ABSTRACT OF THE DISCLOSURE

A waveguide having optimum dimensions and in the form of a flexible hollow conductor for the wideband transmission of linearly polarized electromagnetic waves, the waveguide being in the form of a corrugated metal tube of oval cross section and being dimensioned so that a certain relationship exists between the maximum and minimum dimensions of its major and minor axes, the shape and dimensions of the corrugations, the spacing between two successive corrugation ridges and the corrugation pitch angle.

This application is a continuation of application Ser. No. 395,532, filed Sept. 10, 1964, now abandoned.

The invention relates to a waveguide of optimum dimensions which can be wound on a drum preferably for the wide-band transmission of linearly polarized electromagnetic waves, and which comprises a metal tube of oval cross section welded with a longitudinal seam, wherein the major and minor axes of the oval cross section, which are perpendicular to one another, vary, depending on the corrugations, along the longitudinal axis of the waveguide.

It is known to use waveguides with differing cross-sectional shapes for the transmission of electromagnetic waves of very high frequency. These waveguides generally have circular or rectangular cross section. Smooth waveguides of oval cross section are also known.

For special applications (for example serial feeders of mobile stations) it is often necessary to have a flexible waveguide, that is, a waveguide which can be wound on a drum which permits a satisfactory transmission of linearly polarized electromagnetic waves. A waveguide of oval cross section has recently been proposed for this purpose. It comprises a corrugated metal tube with a longitudinal weld seam. In this case, the transmitted useful wave is a linearly polarized electromagnetic wave, the E-vector of which is perpendicular to the major axis of the oval cross section.

The main object of the present invention is to provide a waveguide of the mentioned kind with optimum dimensions for a predetermined frequency band.

Therefore, starting from a waveguide for the wide-band transmission of linearly polarized electromagnetic waves, which can be wound on a drum and which comprises a corrugated metal tube of oval cross section which is longitudinally welded and in which the major and minor axes of the oval cross section are perpendicular to one another and vary along the longitudinal axis of the waveguide depending on the corrugation, it is proposed according to the invention that the lowest frequency to be transmitted in the given band is about 20% higher than the limit frequency of the useful wave in the waveguide and the first interfering frequency lies above the highest band frequency, and that the relationship between the effective perpendicular axes of the cross section of the oval waveguide satisfy the following conditions:

$$0.4 \leq \frac{b_w}{a_w} \leq \frac{b_1}{a_1} \left[\frac{1 + \frac{b_2}{b_1} + 4K_2 \frac{t_2}{b_1}}{1 + \frac{a_2}{a_1} + 4K_1 \frac{t_1}{a_1}} \right] \leq 0.8$$

2

wherein

a_1 is the major axis of the free cross-sectional area,
 b_1 is the minor axis of the free cross-sectional area,
 a_2 is the maximum major axis due to the corrugations,
 b_2 is the maximum minor axis due to the corrugations,
 K_1 is a corrective factor for finding the effective major axis which depends on the profile of the corrugations,
 K_2 is a corrective factor for finding the effective minor axis which depends on the profile of the corrugations,

$$t_1 = \frac{a_2 - a_1}{2}$$

=depth of corrugations in the direction of the major axis, and

$$t_2 = \frac{b_2 - b_1}{2}$$

=depth of corrugations in the direction of the minor axis.

Additional objects and advantages of the present invention will become apparent upon consideration of the following description when taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic longitudinal sectional view of a waveguide having helical corrugations.

FIGURE 2 is a schematic longitudinal sectional view of a waveguide having a different type of corrugations.

FIGURE 3 is a schematic transverse sectional view of an oval corrugated waveguide.

FIGURE 4 is a schematic cross-sectional view through a portion of a corrugated waveguide wherein the lengths of the ridges is the same as the lengths of the grooves.

FIGURE 5 is a view similar to FIGURE 4 and wherein the lengths of the ridges is less than the lengths of the grooves.

FIGURE 6 is a view similar to the previous two figures but wherein the lengths of the ridges is greater than the lengths of the grooves.

FIGURE 7 is a diagram showing in graphical form some relationships between different properties of elliptical waveguides.

In general, the waveguide is constructed in such a manner that the longitudinally welded metal tube is periodically corrugated, preferably with helical corrugations. Such a periodically corrugated waveguide is illustrated in longitudinal section in FIGURE 1.

For special applications, flexible waveguides are conceivable which are oval in cross section and the corrugations of which do not run helically. A longitudinal section through such a waveguide is illustrated diagrammatically in FIGURE 2.

FIGURE 3 shows a cross section of a corrugated flexible waveguide of oval cross section. In this case, a_1 designates the major axis of the unobstructed cross section, and a_2 the maximum major axis of the oval cross section due to the corrugations of the hollow tubular conductor. The minor axis of the unobstructed cross section is designated by b_1 and the maximum minor axis due to the corrugations is designated by b_2 .

A waveguide constructed according to the invention has optimum dimensions with regard to its flexibility, its attenuation, and/or the bandwidth.

In practice, an oval waveguide of corrugated tube would scarcely be used with a ratio of the effective axes b_w/a_w of less than 0.4. The possible dimensions will be explained below with reference to FIGURE 7. The relative frequency bandwidth, entered on the vertical axis in FIGURE 7, is plotted against the ratio formed from the effective minor axis b_w and the effective major axis a_w . A distance of 20% (corresponding to the broken line E) is assumed as a lower limit to the bandwidth, while the first interfering frequency which occurs is assumed as the upper limit.

This is indicated by the curved full line G in FIGURE 7. It is calculated in accordance with the formula

$$\Delta f = \frac{1}{-0.11 \left(\frac{b_w}{a_w}\right)^2 + 1.14 \left(\frac{b_w}{a_w}\right) - 0.0234}$$

This curve can be modified somewhat for oval waveguides and those resembling an ellipse, the constant value of 0.0234 given in the above formula merely being corrected by adding or subtracting a certain amount. In the practical dimensioning, it is advisable not to go right up to the upper limit (full curved line G) so that no reflection peaks may occur in bent portions of the hollow conductor due to undesired coupling with higher mode waves. A distance of from about 2 to 5% is preferably selected. In FIGURE 7, the broken curve F represents a distance of 2% from the first interfering frequency which occurs. Fundamentally, the lower frequency limit may also be brought more closely to the critical frequency of the useful wave, in which case the attenuation at the lower end of the band rises sharply as a result of the dispersion behavior of the hollow conductor. In FIGURE 7, a value of 10% was assumed for this, represented by the parallel straight line D in phantom lines. If bandwidth Δf of 10% has to be transmitted for example (see FIGURE 7, full vertical line C), then the hollow conductor has the maximum flexibility for a ratio b_w/a_w of 0.75. The waveguide thus dimensioned has not, however, optimum conditions with regard to attenuation. In order to achieve optimum attenuation, a ratio of the effective axes b_w/a_w of 0.4 would have to be selected as shown by the full vertical line A in FIGURE 7. An optimum waveguide with regard to attenuation and flexibility is afforded, if the ratio b_w/a_w amounts to about 0.6 as represented by the vertical line B in FIGURE 7.

If the required relative bandwidth Δf is greater than 10%, then similar ratios of b_w/a_w can be read off from FIGURE 7 in a similar manner.

The corrugations of the hollow conductor may vary in configuration. The corrugation is preferably effected, however, in such a manner that it is periodic.

In a further development of the invention, the corrugations of the hollow conductor are constructed in such a manner that the distance S between two successive ridges satisfies the condition

$$\lambda/10 \leq S \leq \lambda/4$$

and preferably amounts to $\lambda/5$, in which λ designates the mean free wave length in space of the frequency band to be transmitted. In this case, the corrugations are preferably helical.

If the cross section of the waveguide according to the invention is considered, then for each pitch S (see FIGURES 4, 5 and 6), the effect of a capacitive diaphragm is obtained in the vertical plane and that of an inductive diaphragm in the horizontal plane. The frequency characteristics of these two elements are not exactly opposite so that a slight residual reflection occurs at each element. If the pitch is selected of the order of magnitude of $\lambda/4$, however, then the resulting value of the successive disturbance point is at a minimum with regard to the reflection factor of the waveguide. If the pitch S is selected somewhat less than $\lambda/4$ with regard to the wavelength λ , then although the reflection factor will increase somewhat, nevertheless it remains within tolerable limits if the pitch S does not drop below a value of $\lambda/10$. For the dimensioning, this means that if the pitch S lies between $\lambda/10$ and $\lambda/4$, no sharp reflection peaks occur within the frequency band to be transmitted as a result of the residual reflections present. For a satisfactory transmission of a given frequency band, therefore, the corrugation must be effected in such a manner that disturbing reflection peaks lie outside the frequency band. The above condition can also be expressed by the wavelength of the hollow conductor. The specifications for the limits of S are met if

the pitch angle α of the corrugation (FIGURE 1) is between 0 and 60°. In corrugated hollow conductors of oval cross section already produced the pitch angle was preferably 10°.

For particular applications, the corrugation may also be such that the pitch angle α varies continuously between two given values (e.g., -10° and +10°) along the longitudinal axis of the waveguide.

The formula given hereinbefore, according to which the ratio between the effective minor axis b_w and the effective major axis a_w should be between the values 0.4 and 0.8, contains corrective factors K_1 and K_2 as well as the two quantities t_1 and t_2 which represent the depths of the corrugations. According to the invention, the corrective factors K_1 and K_2 lie between the values -0.65 and +0.65. In general, the quantities t_1 and t_2 may be different. For a rough calculation, however, it can be assumed that the depths of the corrugations t_1 and t_2 are approximately equal. For example, the following condition may apply to the depth of the corrugations:

$$t_1, t_2 < 0.2a_1$$

On the basis of the above assumptions, it is possible to distinguish between three distinct forms of corrugations:

The form of corrugation illustrated in FIGURE 4 is constructed in such a manner that the length Z_1 of the ridge is equal to the length Z_2 of the groove of a corrugation ($S=Z_1+Z_2$), in which case the corrective factors K_1 and K_2 have a value of approximately zero. In this figure, t designates the depth of the corrugation as defined above, while S is the pitch. The quantities a_1, b_1, a_2, b_2 represent the corresponding axes of the corrugated hollow conductor.

FIGURE 5 illustrates a further special case of a possible form of corrugation. In this case, the length Z_1 of the ridge is greater than the length Z_2 of the groove of the corrugation, in which case the corrective factors K_1 and K_2 are different from zero and preferably have a value which is greater than zero. The magnitude of the corrective factor depends on the penetration of the field vector of the transmitted wave into the corrugations of the hollow conductor. This means that the corrective factor K_1 or K_2 is dependent not only on the dimensions Z_1, Z_2 and t , but also on the shape of the curvature of the corrugations. With the form of corrugation illustrated in FIGURE 5, the corrective factors are positive.

In the example illustrated in FIGURE 6, the reverse case is assumed in comparison with FIGURE 5. The length Z_1 of the ridge of a corrugation is selected shorter than the length Z_2 of the groove in this case. In this case, too, the corrective factors K_1 and K_2 are different from zero and they are negative. If the curvature of the corrugations is selected different from the example illustrated in FIGURE 6, then modifications are conceivable in which the corrective factors, although different from zero, may have a value greater than zero.

Finally, an example of dimensioning will be given in which the condition is assumed that the relative bandwidth to be transmitted amounts to 20% and optimum flexibility is required. According to FIGURE 7, a ratio of b_w/a_w of 0.676 is obtained for this. If it is assumed that the depth of corrugation t_1 is different from the depth of corrugation t_2 and their ratio (t_1/t_2) has the value 0.9, then, with the corrective factors $K_1=0.03$ and $K_2=0.015$ because of the profile selected, the ratios $b_1/a_1=0.7$ and $b_2/a_2=0.65$ are obtained. If the major axis a_1 , for example, is given, then the dimensions of the waveguide can be calculated on the basis of the formula stated in columns 1 and 2. In an example which was carried out in practice, the pitch S was selected as $\lambda/5$. The corrective factors K_1 and K_2 , which are characteristic for the profile selected, may be determined empirically.

It will be understood that the above description of the present invention is susceptible to various modifications, changes and adaptations, and the same are intended to

be comprehended within the meaning and range of equivalents of the appended claims.

We claim:

1. A waveguide of optimum dimensions in the form of a flexible hollow conductor for the wideband transmission of linearly polarized electromagnetic waves, comprising a corrugated metal tube of oval cross section which is welded longitudinally, said waveguide having corrugations which are periodic and which are selected in such a manner that the disturbing reflection peaks lie outside the frequency band to be transmitted, the major and minor axes of the oval cross section being perpendicular to one another and varying along the longitudinal axis of the waveguide depending on the corrugations, the lowest frequency to be transmitted in the given band being about 20% higher than the limit frequency of the useful wave in the waveguide, and the ratio between the effective perpendicular axes of the oval cross section of the waveguide satisfying the following condition:

$$0.4 \leq \frac{b_w}{a_w} = \frac{b_1}{a_1} \cdot \frac{1 + \frac{b_2}{b_1} + 4K_2 \frac{t_2}{b_1}}{1 + \frac{a_2}{a_1} + 4K_1 \frac{t_1}{a_1}} \leq 0.8$$

in which a_1 is the major axis of the free cross-sectional area;

b_1 is the minor axis of the free cross-sectional area;

a_2 is the maximum major axis due to the corrugations;

b_2 is the maximum minor axis due to the corrugations;

K_1 is a corrective factor for determining the effective major axis which depends on the shape of the profile of the corrugations;

K_2 is a corrective factor for determining the effective minor axis which depends on the shape of the profile of the corrugations;

$$t_1 = \frac{a_2 - a_1}{2}$$

=the depth of the corrugations in the direction of the major axis;

$$t_2 = \frac{b_2 - b_1}{2}$$

=the depth of corrugations in the direction of the minor axis;

and wherein the spacing (S) between two successive ridges of the corrugations satisfying the condition:

$$\lambda/10 \leq S \leq \lambda/4$$

in which λ is the mean free wavelength of the frequency band to be transmitted; and the spacing between two successive ridges of the corrugations being such that $S = \lambda/5$.

2. A waveguide of optimum dimensions in the form of a flexible hollow conductor for the wideband transmission of linearly polarized electromagnetic waves, comprising a corrugated metal tube of oval cross section which is welded longitudinally, said tube being corrugated to have helical corrugations whose pitch angle α is about 10° , the major and minor axes of the oval cross section being perpendicular to one another and varying along the longitudinal axis of the waveguide depending on the corrugations, the lowest frequency to be transmitted in the given band being about 20% higher than the limit frequency of the useful wave in the waveguide, and the ratio between the effective perpendicular axes of the oval cross section of the waveguide satisfying the following condition:

$$0.4 \leq \frac{b_w}{a_w} = \frac{b_1}{a_1} \cdot \frac{1 + \frac{b_2}{b_1} + 4K_2 \frac{t_2}{b_1}}{1 + \frac{a_2}{a_1} + 4K_1 \frac{t_1}{a_1}} \leq 0.8$$

in which a_1 is the major axis of the free cross-sectional area;

b_1 is the minor axis of the free cross-sectional area;

a_2 is the maximum major axis due to the corrugations;

b_2 is the maximum minor axis due to the corrugations;

K_1 is a corrective factor for determining the effective major axis which depends on the shape of the profile of the corrugations;

K_2 is a corrective factor for determining the effective minor axis which depends on the shape of the profile of the corrugations;

$$t_1 = \frac{a_2 - a_1}{2}$$

=the depth of corrugations in the direction of the major axis;

$$t_2 = \frac{b_2 - b_1}{2}$$

=the depth of corrugations in the direction of the minor axis.

3. A waveguide of optimum dimensions, in the form of a flexible hollow conductor for the wideband transmission of linearly polarized electromagnetic waves, comprising a corrugated metal tube of oval cross section which is welded longitudinally, the major and minor axes of the oval cross section being perpendicular to one another and varying along the longitudinal axis of the waveguide depending on the corrugations, the lowest frequency to be transmitted in the given band being about 20% higher than the limit frequency of the useful wave in the waveguide, and the ratio between the effective perpendicular axes of the oval cross section of the waveguide satisfying the following condition:

$$0.4 \leq \frac{b_w}{a_w} = \frac{b_1}{a_1} \cdot \frac{1 + \frac{b_2}{b_1} + 4K_2 \frac{t_2}{b_1}}{1 + \frac{a_2}{a_1} + 4K_1 \frac{t_1}{a_1}} \leq 0.8$$

in which a_1 is the major axis of the free cross-sectional area;

b_1 is the minor axis of the free cross-sectional area;

a_2 is the maximum major axis due to the corrugations;

b_2 is the maximum minor axis due to the corrugations;

K_1 is a corrective factor for determining the effective major axis which depends on the shape of the profile of the corrugations;

K_2 is a corrective factor for determining the effective minor axis which depends on the shape of the profile of the corrugations;

$$t_1 = \frac{a_2 - a_1}{2}$$

=the depth of corrugations in the direction of the major axis;

$$t_2 = \frac{b_2 - b_1}{2}$$

=the depth of corrugations in the direction of the minor axis;

wherein the corrective factors (K_1 and K_2) satisfy the condition:

$$-0.65 < (K_1, K_2) < +0.65$$

and the depth of the corrugations (t_1 and t_2) are substantially equal and satisfy the condition:

$$t_1, t_2 < 0.2a_1$$

the length of the ridges of the corrugations is greater than the length of the grooves of the corrugations, and the corrective factors (K_1 and K_2) are different from zero; said waveguide is dimensioned for optimum flexibility when the relative frequency bandwidth to be transmitted amounts to 20%; and the ratio of the effective

axes of the cross section is 0.676, the ratio of the depths of the corrugations is 0.9, the pitch is $\lambda/5$ and the ratio of the free minor axis (b_1) to the free major axis (a_1) has the value 0.7 with a ratio (b_2/a_2) of the maximum minor axis to the maximum major axis of 0.65.

5

References Cited

UNITED STATES PATENTS

3,200,256 8/1965 Schüttlöffle et al. ----- 333—95

FOREIGN PATENTS

877,692 12/1942 France.
1,113,490 9/1961 Germany.
739,488 11/1955 Great Britain.

OTHER REFERENCES

Southworth: Principles and Applications of Waveguide Transmission, Von Nostrand, 1950, pp. 180-183.

HERMAN KARL SAALBACH, *Primary Examiner*.