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(54) High power filter, method therein and radio transmitter including the filter

(57) The invention is concerned with a method in high-power superconducting filter of transmission line type. The peak value of the operating voltage and the characteristic impedance of the superconducting filter are chosen in such a way that the peak current is kept

at a sufficiently low value so that non-linear effects induced by a high current density become negligible for a proper operation of the filter. The invention is also concerned with the high-power superconducting filter achieved with the method and a radio transmitter in which such a filter is used.

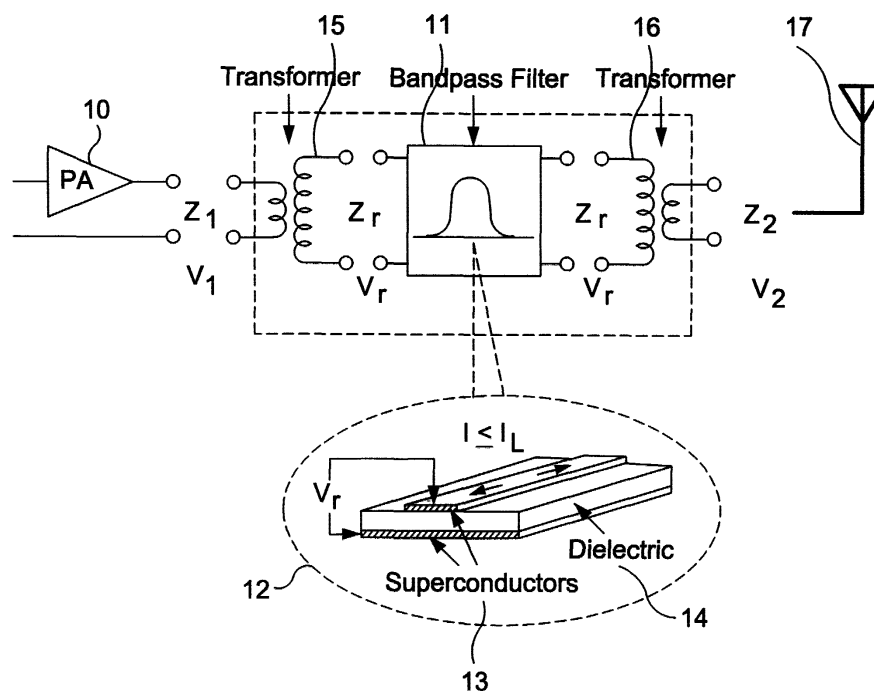


Fig. 2

Description**TECHNICAL FIELD**

5 **[0001]** The invention is concerned with a superconducting filter, a method therein and a radio transmitter including the filter.

BACKGROUND ART

10 **[0002]** A radio transmitter has to transmit desired signals of limited frequency band to an antenna.

[0003] As the available frequency range is restricted, for example due to international agreements and an increasing traffic, the requirements on the receivers and transmitters will also increase so that they only receive resp. generate signals of desired frequencies.

15 **[0004]** A radio transmitter can be considered to consist of a signal processing unit, a frequency generator and modulator and a power amplifier. In the signal processing unit, the information signal is converted to a form suitable for transmission. In the frequency generator consisting of one or more oscillators, a carrier wave is created. The functions of the modulator are partly involved in those of the frequency generator. These functions vary some parameter in the output signal from the frequency generator in accordance with the information signal from the signal processing unit. Finally, the power amplifier increases the signal level to a suitable range.

20 **[0005]** Undesired frequency components are, however, created in the transmitter of various reasons, why filtering is necessary.

[0006] In many instances, it is important that signals from other users do not interfere. For example cellular communication systems might have two or more service providers operating on separate bands within the same geographical area. Also within a single provider's allocated frequency, it is useful to be able to handle multiple signals, as in systems using frequency multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA) and wide-band CDMA (WCDMA). FDMA and TDMA users need filters to divide their allocated frequencies into multiple bands and also CDMA users might have an interest in dividing the frequency range in bands. In such cases, the narrower the bandwidth of the filter, the closer together one may place the channels.

[0007] The size of the filters is also a factor to be taken into consideration.

30 **[0008]** Superconductor (HTS) filters have very deep slopes and low insertion loss, while they also have a small size and low weight making them very suitable in radio frequency (RF) subsystems for high-performance radio communications systems.

[0009] At present, the applications are limited to RF receiver filters for radio base stations while transmitter filter applications are still too difficult to be realized because of the very high power levels that these HTS structures would be required to handle in the transmitters.

35 **[0010]** Transmission lines and waveguides are used to transport electromagnetic energy at microwave frequencies from one point to another in a system without radiation of energy taking place. Basically, as is described in the book "Foundations for microwave engineering" by Robert E. Collin (McGraw-Hill Book Company), transmission lines consist of two or more parallel conductors and will guide nearly a transverse electromagnetic (TEM) wave. The common forms of transmission lines are the two-conductor line, the shielded two-conductor line, and the coaxial line. Another form of transmission line that has come into prominence in recent years is the microwave strip line, which consists of a thin conducting ribbon separated from a wider ground plane by a dielectric sheet or placed between two ground planes to form a shielded structure, as shown in the example of figure 1. The two main advantages obtained with strip lines are the reduction in size and weight and the ability to use printed circuit techniques for the construction of the strip lines and associated components such as bends, junctions, filters, etc. a good introduction to striplines and associated components may be found in a special issue of *IRE Transactions* devoted entirely to this subject. See Special Issue on Microwave Strip Circuits, *IRE Trans.*, vol. MTT-3, March, 1955.

40 **[0011]** An example of a superconducting filter (= stripline resonator) structure is shown in figures 1a and 1b. The stripline (figure 1a) has a center conductor 1, an upper and lower ground plane 2, 3, and a symmetric dielectric 4. The resonator (figure 1b) consists of a length of transmission line 5, patterned by photolithography, one half wavelength long at the fundamental frequency. Overtone resonances occur at all multiples of the fundamental frequency. The resonator is capacitively coupled to the external circuit gaps at the two ends of the stripline. The resonator is fabricated from three separate films on three substrates clamped together in a copper package with RF connections on it. The length of the transmission line is chosen to yield a desired frequency.

55 **[0012]** The main problem is that, with increasing input radio frequency (RF) power, the current density at the edges of, for instance, a superconducting microstripline resonator increases rapidly to such a large value that various non-linear effects, such as intermodulation distortion and harmonic generation, may appear and degrade, therefore, the performance of the filter.

[0013] The non-linear effects in superconductors are of interest both for practical applications and for the study of the fundamental properties of the materials. In a practical application, the designer must know how much power the superconductors can handle and at which power level the non-linear effects become appreciable.

[0014] Attempts have been made to improve the power handling capability of the filters by for example studying the non-linearity dynamic and by improving material properties.

[0015] The article "Nonlinear microwave properties of superconducting Nb microstrip resonators" by M.A. Golosovsky, 1995 The American Physical Society, Physical review B, Volume 51, number 10 handles correlation between material properties of the films and the occurrence of non-linearity. Reference to the articles "Non-linear electrodynamics of superconducting NbN and Nb thin films at microwave frequencies" by C.C. Chin et al., 1992 The American Physical Society, Physical review B, Volume 45, number 9 and "Nonlinearity of Superconducting Transmission line and Microstrip Resonator" by Orest G. vendik et al. IEEE Transactions on microwave theory and techniques, VOL. 45. No2, february 1997 are made with respect to the theory of the non-linear electrodynamics. A model for current distribution in superconductive filters can be found e.g. in "Measurements and Modeling of Linear and Nonlinear Effects in Striplines" by D.E. Oates et al. Journal of Superconductivity, Vol 5, no 4, 1992.

[0016] The earlier solutions to improve power handling capability have however not been able to improve the filters sufficiently to be able to use them in e.g. radio transmitters.

[0017] The object of the invention is to improve the power-handling capability of superconducting filters so as to find new applications for their use.

SUMMARY OF THE INVENTION

[0018] The method of the invention is used in a high-power superconducting filter of transmission line type. It is mainly characterized in that the peak value of the operating voltage and the characteristic impedance of the superconducting filter are chosen in such a way that the peak current is kept at a sufficiently low value so that non-linear effects induced by a high current density become negligible for a proper operation of the filter.

[0019] The method of the invention improves the power handling capacity of superconducting filters. When for any specified (time-averaged) power P that a superconducting filter has to handle linearly, the peak value of the operating voltage V_p and the characteristic impedance Z_r of the superconducting filter are chosen in such a way that the peak current I_p flowing in the superconductors (usually superconducting thin films) in the filter is kept to a sufficiently low value, I_L ($I_p < I_L$) depending on superconducting material and its geometry chosen, so that all non-linear effects induced otherwise by excessively high current density in superconductors become negligible for the proper (linear) operation of the filter. The proper value of V_p (=peak value) can be chosen by using the equation $V_p = 2P/I_L$.

[0020] Furthermore, the characteristic impedance Z_r of the transmission line (e.g. a microstripline) can be chosen by

$$|Z_r| = \frac{V_p}{I_L}$$

which is necessary to keep the peak current I_p in the superconducting thin films at (or below) the proper level of I_L to avoid possible non-linear effects caused by high current density inside the superconductor.

[0021] I_L depends on the superconductive material and its geometry used in the filter. In general, the proper current value of I_L introduced in this invention is an experimentally determined quantity, which depends on the superconductive material used in the filter construction and the geometric size and shape of the superconducting stripline. For instance, the magnetic vortex dynamic properties and the energy gap of the superconductive material play important roles in affecting the value of I_L . The geometric size and shape of the superconducting microstripline may also affect I_L by the local current density and its distribution in the superconductive material. Some detailed discussion on the subject may be found in, for instance, recent book by S.-A. Zhou, published by John Wiley & sons, Inc., New York, 1999.

[0022] The inventor of the invention has introduced a new way of thinking in designing superconducting filters. By releasing the usual requirement of a 50Ω impedance of the input and output port of the filter which existed for component matching reasons, the invention gives the freedom to choose the parameters of the invention in a suitable way.

FIGURES

[0023] Figure 1 is an example of a prior art stripline resonator

[0024] Figure 2 is an example of a filter of the invention

DETAILED DESCRIPTION

[0025] The variation in time of the current and the voltage of the filter of the invention may be described by a waveform, which varies sinusoidally in time, t.

$$I(t) = I_p \sin \omega t$$

$$V(t) = V_p \sin \omega t$$

for a single-tone signal assuming that V and I are in phase. ω is the angular frequency in rad/s. The term V_p is termed the peak voltage and the term I_p is termed the peak current. It is the maximum value, positive and negative, taken by the voltage over the course of one cycle.

[0026] Averages of waveforms give useful information as is explained in the article Electric Circuit Analysis, Principles and Applications, by K.F. Sanders, Emeritus Professor, University of Bristol published in ELECTRONIC SYSTEMS ENGINEERING SERIES, 1992.

[0027] The average of the square of the current waveform $I(t)$, or the means square, is denoted by $\langle I^2 \rangle$ and is calculated from

$$\langle I^2 \rangle = \frac{1}{T} \int_0^T I^2(t) dt$$

where $T = 2\pi/\omega$ is the periodic time.

[0028] The mean square is relevant for the calculation of the average power dissipated in a resistor carrying the current $I(t)$. The instantaneous rate of dissipation of energy in a resistance R is

$$P(t) = RI^2(t)$$

[0029] Thus the average power is equal to

$$P = \langle I^2 \rangle R$$

[0030] A measure of magnitude for a wave form of which the average $\langle I \rangle$ is zero is provided by the root-mean square (RMS) value given by

$$I_{RMS} = (\langle I^2 \rangle)^{1/2}$$

by inserting the expression for $\langle I^2 \rangle$ we get

$$I_{RMS} = \sqrt{\frac{1}{T} \int_0^T I^2(t) dt}$$

and by inserting the expression for $I(t)$ we get

$$I_{RMS} = \sqrt{\frac{\omega}{2\pi} \int_0^{\frac{2\pi}{\omega}} I_p^2 \sin^2 \omega t dt}$$

as $\sin^2 x = \frac{1}{2}(1 - \cos 2x)$, we get

$$I_{RMS} = \sqrt{\frac{\omega}{2\pi} I_p^2 \int_0^{\frac{2\pi}{\omega}} \frac{1}{2}(1 - \cos 2\omega t) dt}$$

which is

$$I_{RMS} = \frac{1}{\sqrt{2}} I_p$$

[0031] Similarly, we can get

$$V_{RMS} = \frac{1}{\sqrt{2}} V_p$$

[0032] The calculation of power bears similarities to the calculations of mean squares in that a product of time-varying functions are involved. In the case of power, these are the voltage $V(t)$ and the current $I(t)$

$$P(t) = V(t)I(t)$$

[0033] When the wave forms are periodic, then the power is also periodic. The average power is given by

$$P = \frac{1}{T} \int_0^T I(t)V(t) dt$$

which by calculation gives

$$P = \frac{\omega}{2\pi} \int_0^{\frac{2\pi}{\omega}} I_p V_p \sin^2 \omega t dt = \frac{\omega}{2\pi} I_p V_p \int_0^{\frac{2\pi}{\omega}} \frac{1}{2}(1 - \cos 2\omega t) dt$$

and finally

$$P = \frac{1}{2} I_p V_p$$

which is the formula used in the invention and which also can be written as

$$P = I_{RMS} V_{RMS}$$

EXAMPLES

[0034] It is supposed that there exist a superconducting microstripline type of filter with a linear power handling capability of 1W with an operating peak voltage of 10V and the characteristic impedance of 50 Ω of its microstripline (resonator). Thus, assuming a sinusoid wave form, the peak current is then 0,2 A.

[0035] A superconducting microstripline type of filter is now designed in accordance with the invention, which is supposed to be capable of handling the time averaged power of $P = 50W$ with sufficiently good linearity. For simplicity, we may let that the geometric sizes (cross sectional area) of the superconducting microstripline (signal line) in our filter is kept the same as that in the above example.

[0036] Thus, since the filter in the above example is supposed to work well with sufficiently good linearity for the peak current value of 0,2 A, we may set $I_L = 0,2$ A in our case, which implies that the peak current I_p in our case (filter) is not allowed to be higher than $I_L = 0,2$ A. Thus, to get the linear power handling capability of $P = 50$ W, the operating peak voltage has to be at least

$$V_p = 2P/I_L = 2 \times 50/0,2 = 500 \text{ V}$$

according to the equation used in the invention, and furthermore the characteristic impedance Z_r of the microstripline in our filter has to be chosen as

$$|Z| = \frac{V_p}{I_L} = \frac{500}{0,2} = 2500 \Omega$$

according to the second equation used in the invention.

[0037] Essentially, the method is to let the high-power superconducting filter be operated at high-voltage and with high impedance transmission line structures so that the peak current (density) in superconductors (usually HTS thin films) of the resonator can be kept sufficiently low to avoid undesired non-linear effects caused otherwise by excessively high current density inside the superconductors.

[0038] In a practical example of the invention, transformers may be used at the input and output sides of the superconducting (bandpass) filter as shown illustratevile in figure 2 in order to raise the operating voltage V_r for the filter and to match the output impedance Z_1 of a power amplifier and the input impedance Z_2 of an antenna. Both the transformers and the filter may be made by superconductors, depending on application. An alternative is to use other types of impedance matching network, such as transmission line matching etc.

[0039] Figure 2 illustrates a part of a radio transmitter of the invention. A power amplifier 10 is used after the signal processing to amplify the radio signal to a power sufficient to be sent to an antenna. A band pass filter 11 is used to filter out undesired frequency components. The filter is a superconducting filter, whose peak voltage and characteristic impedance are chosen in a way so that the peak current does not exceed a certain value. The construction of the filter is indicated in the detailed view of reference number 12. The filter consists of superconductors 13 on both sides of a dielectric 14. The voltage V_r of the filter is the voltage between the superconductors 13. To raise the voltage to a sufficient level transformer 15 may be used at the input of the filter 11 and to match the input impedance of the antenna, transformer 16 may be used at the output of the filter 11. The signal of desired frequency band may then be sent through the antenna 17.

Claims

1. Method in high-power superconducting filter of transmission line type,
characterized in that the peak value of the operating voltage and the characteristic impedance of the superconducting filter are chosen in such a way that the peak current is kept at a sufficiently low value so that non-linear effects induced by a high current density become negligible for a proper operation of the filter.
2. Method of claim 1, **characterized in that** the peak value of the operating voltage V_p is chosen by using the equation

$V_P = 2P/I_L$, where P is the average power that the filter has to handle, and I_L is the current level below which nonlinear effects of the superconductors are negligible.

3. Method of claim 2, **characterized in that** I_L depends on the superconductive material and its geometry used in the filter.

4. Method of claim 1, characterized in that the characteristic impedance Z_r of the filter (e.g. a microstripline) can be chosen by

$$|Z_r| = \frac{V_P}{I_L}$$

5. High-power superconducting filter of transmission line type, **characterized in that** the peak value of the operating voltage and the characteristic impedance of the superconducting filter is chosen in such a way that the peak current is kept at a sufficiently low value so that non-linear effects induced by high current density become negligible for a proper operation of the filter.

6. Filter of claim 5, **characterized in that** the peak value of the operating voltage V_P is chosen by using the equation $V_P = 2P/I_L$ where P is the average power that the filter has to handle, and I_L is the current level below which nonlinear effects of the superconductors are negligible.

7. Filter of claim 5, **characterized in that** the characteristic impedance Z_r of the filter (e.g. a microstripline) can be chosen by

$$|Z_r| = \frac{V_P}{I_L}$$

8. Radio transmitter for transmitting radio signal of desired frequencies consisting of a signal processing unit, a frequency generator/modulator, a power amplifier and a filtering unit for filtering out undesired frequency components, **characterized in that** the filter is a high-power superconducting filter, wherein the peak value of the operating voltage and the characteristic impedance of the superconducting filter is chosen in such a way that the peak current is kept at a sufficiently low value so that non-linear effects induced by a high current density become negligible for a proper operation of the filter.

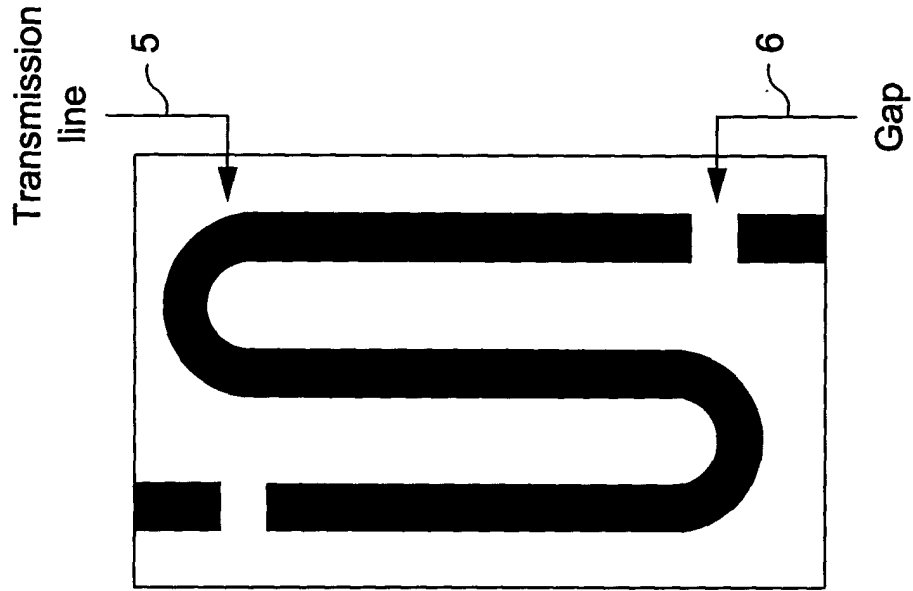


Fig. 1b

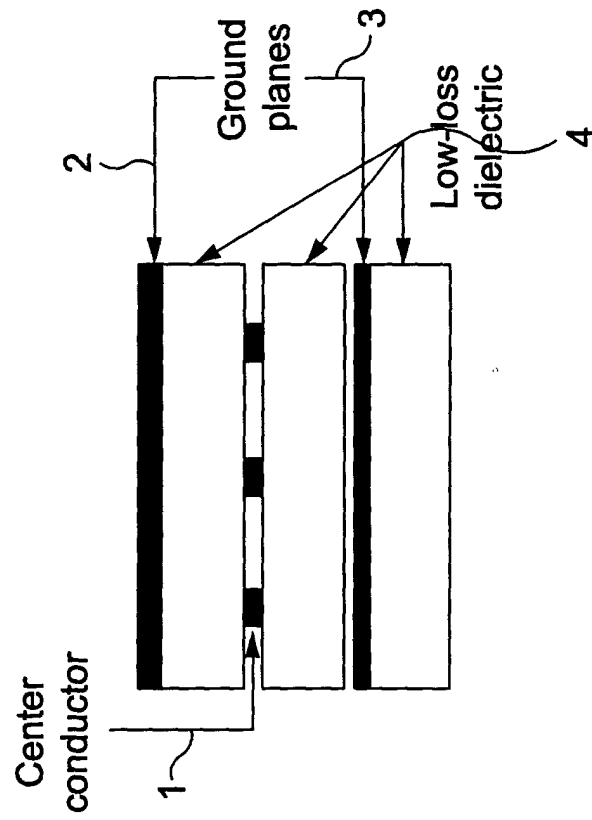


Fig. 1a

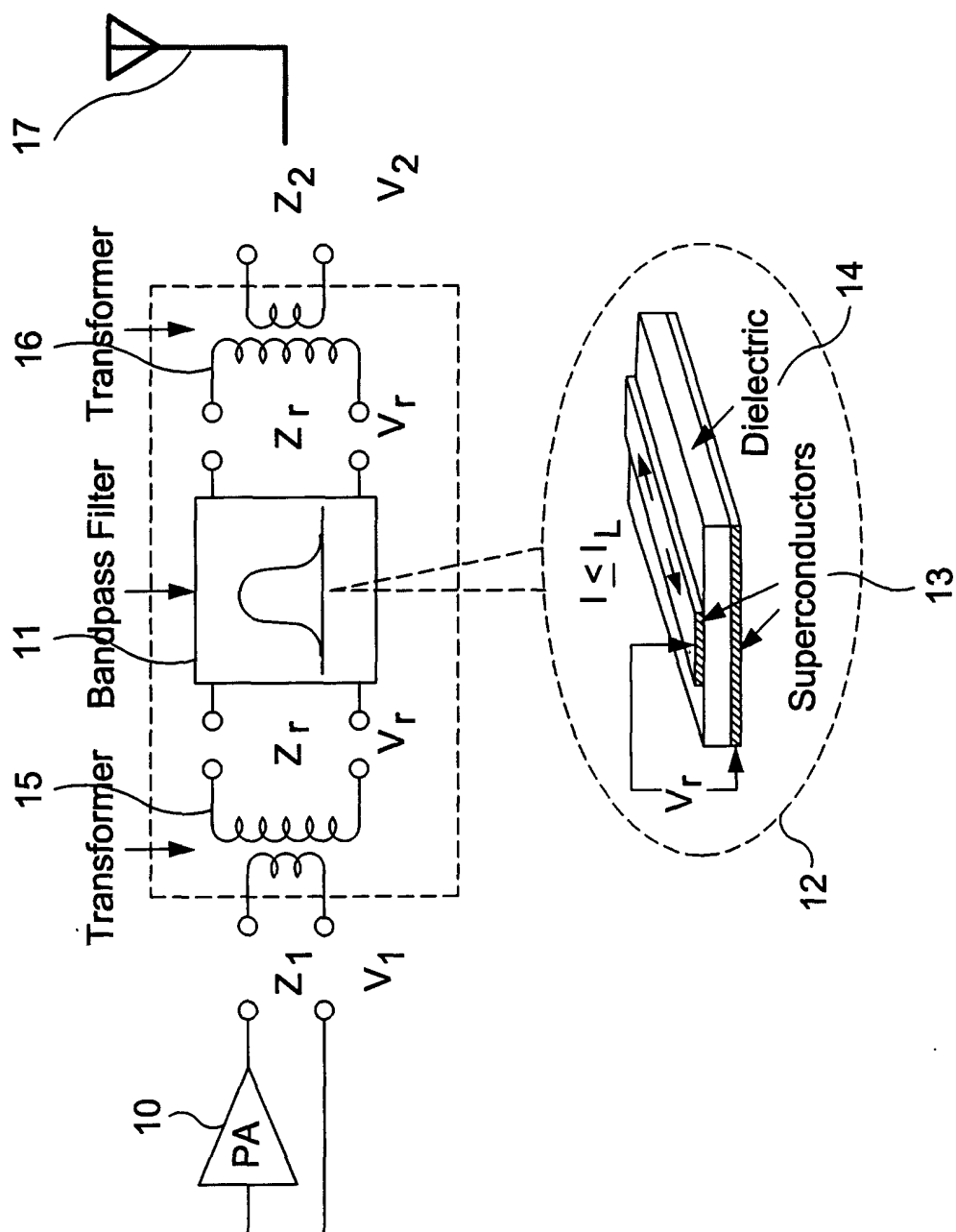


Fig. 2



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 85 0084

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	FATHY A ET AL: "SUPERCONDUCTING NARROW BAND PASS FILTERS FOR ADVANCED MULTIPLEXERS" IEEE MTT-S INTERNATIONAL MICROWAVE SYMPOSIUM DIGEST,US,NEW YORK, IEEE, vol. -, 14 June 1993 (1993-06-14), pages 1277-1280, XP000481230 * page 1279, right-hand column, line 12 - line 26 *	1,5,8	H01P1/203
A	--- J TEMMYO ET AL.: "CHARACTERISTIC IMPEDANCE DESIGN CONSIDERATIONS FOR A HIGH-SPEED SUPERCONDUCTING PACKAGING SYSTEM" IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES., vol. 33, no. 5, May 1985 (1985-05), pages 414-417, XP002147088 IEEE INC. NEW YORK., US ISSN: 0018-9480 * page 416, left-hand column, line 31 - right-hand column, line 26 *	1,5,8	
A	--- Z.-Y. SHEN: "HIGH-TEMPERATURE SUPERCONDUCTING MICROWAVE CIRCUITS" 1994 , ARTECH HOUSE , BOSTON XP002147089 * page 48, line 28 - line 33 * -----	1,5,8	H01P
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 11 September 2000	Examiner Den Otter, A
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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