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Dual Band HTSC Power Limiter

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Abstract. A new construction of dual band HTSC power limiter is proposed. The device consists of two microstrip bandpass filters. Each filter consists of two quarter-wave resonators which couple through a composite half-wave resonator with HTSC-element. The prototype of the device in the open mode has operation passband of about 10% and 11% with central frequency being equal to 1.48 GHz and 2.03 GHz, the minimum loss in the passband is equal 1.9 dB and 1.7 dB for LF-channel and HF-channel correspondingly. The transfer characteristics of the device were investigated in the case of microwave power level up to 3.15 W.

Keywords: power limiter, microwave, HTSC, microstrip structure.

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Each receiving radio system must contain a device to protect against powerful radio pulses (power limiter). This device protects the active element of the radio receiver (transistor or amplifier) from an external radio pulse, whose power is critical for the active element. Power limiter has two operating modes. When the input signal has low power device works in open mode. In this mode, the device has low loss and a signal passes through it with small loss. The second mode is the closed one. In this mode, the high-power signal is limited to a safe level. Semiconductor protection devices are the most widespread [1]. However, they have some disadvantages. For example, their switching speed is not high enough. Devices based on cyclotron resonance have excellent characteristics [2]. But they require a magnetic field to operate, resulting

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in significant dimensions and weight. In a scientific literature there are described protection devices based on an ability of a high-temperature superconductor (HTSC) to transit from a superconducting state to a normal state when microwave current passes through HTSC. The time of this transition does not exceed ($< 10^{-12}$ s) [3]. Usually HTSC power limiter contains transmission line matched to the tract [3,4]. The operating principle of this type of limiter is to absorb input power in close mode. This can lead to evaporation of a thin layer of HTSC material. In [5–8] the new class of power limiters based on HTSC, in which power limitation occurs due to reflection is presented. Such a device contains three microstrip resonators. The configuration of the outer resonators and the distance between them are chosen in such a way that there is no electromagnetic coupling between the resonators. It occurs due to mutual compensation of inductive and capacitive interactions between outer resonators at the resonant frequencies. The center resonator provides coupling between the outer resonators. This resonator is composite. It contains an insert made of a HTSC-element. In the open mode, the device is a three pole bandpass filter that has low insertion loss. In the closed state, the HTSC-element switches to the normal state and the quality factor of the center resonator drops. As a result, limitation of input power is observed due to strong reflection.

Currently, receivers operating in two operating frequency bands are widespread. They are included in navigation satellite systems, for example, GLONASS, GPS, BeiDou and others. It is obvious that the use of broadband (non-selective) power limiter located at the input of such two-band receiving systems leads to their incorrect operation. When a powerful radio signal falls to an input of such a system at the frequency of one of the operating bands, the power limiter switches to closed mode in both frequency ranges. Of course, for a correct operation such two-band systems, the power limiter must be selective and operates in two working frequency bands that coincide with the operating bands of the entire receiving system.

The two-band HTSC power limiters are known [9]. Such a device consists of two bandpass microstrip filters and two circulators. The resonators in the filters are entirely made from HTSC material. These types of devices are complex because of they consist of two different devices. Circulators lead to an increase in size of the total device. In addition, as studies have shown, the threshold of power limitation (the input power level at which the device switches to limiting mode) is very high.

Our paper presents a design of dual-band HTSC power limiter. The device has two operating frequency bands: a low-frequency channel (LF-channel) and a high-frequency channel (HF-channel). I.e., in open mode the device operates as a dual-band filter and each channel filter has three resonators. The outer resonators are quarter-wave, and the center resonator is composite. A HTSC-element is located in the middle part of the center resonator.

The device under consideration (Fig. 1) consists of two feeding microstrip line *3*, between which there are two bandpass filters (LF-channel filter and a HF-channel filter). Constructions of each channel are identical. The resonators forming the LF-channel have the larger sizes, than the resonators forming the HF-channel. Each channel filter consists of three resonators. The resonators forming the channel filter have the same resonant frequencies. The outer resonators *4* are quarter-wave and short-circuited to the ground. Conductors of these resonators are made of copper. The center resonator is half-wave, it consists of microstrip conductors *5, 6, 7* and HTSC-element *8*, which is placed in middle part of the center resonator. The HTSC-element has the dumbbell form. The copper foils *9* are used to provide galvanic contact between conductors *7* and wide parts of HTSC-element on which a thin silver layers (0.15 μm) were deposited. HTSC-element is fulfilled on a separate substrate *10*.

The overall dimensions of the additional strip conductor *11* and gap between them and the outer resonators, are chosen in such a way, that in the absence of the HTSC-element the outer resonators are tuned so that the inductive and capacitive couplings are mutually compensated. As a result, total coupling coefficient is equal to zero and the outer resonators do not interact with each other, and damping pole is observed at passband frequencies. In this case, the incident

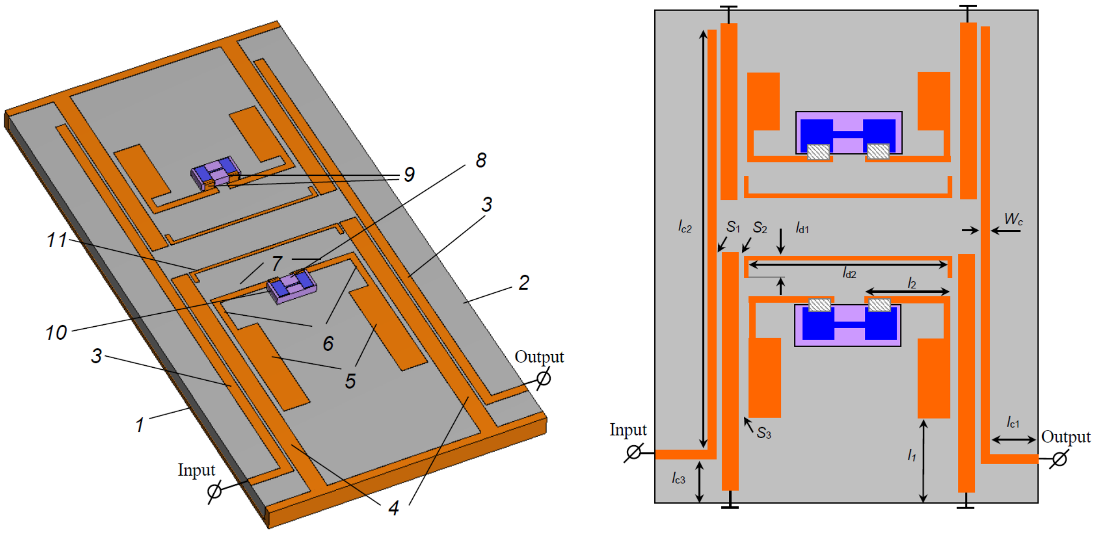

Fig. 1. Left: design of the dual band HTSC power limiter. Right: conductor's pattern and structure parameters of the designed and fabricated device

power is reflected from the input of device. As is known, for a pair of such resonators at any gaps, the inductive interaction always prevails the capacitive one. At the same time these interactions have the opposite sign. Moreover, with increase the spacing between such resonators, capacitive interaction decreases faster than inductive one. In order to the damping pole appears at passband frequencies, it is necessary that the capacitive and inductive interactions are equal modulo. This requires to increase the capacitive interaction of the outer resonators, therefore an element *11* is inset. This additional capacitive interaction is very weak and does not affect the characteristics of the power limiter in the open mode. In the case, when the device is in the closed mode, and the HTSC-element has low conductivity, an additional capacitive interaction compensates the inductive one provided by the middle resonator. As a result, the device limits microwave power.

Using the topology of the dual band HTSC power limiter shown in Fig. 1, a prototype device was manufactured. The following design parameters for LF-channel were obtained: $l_1 = 5.8$ mm, $S_1 = 0.21$ mm, $S_2 = 0.28$ mm, $S_3 = 0.45$ mm, $l_{d1} = 8.6$ mm, $l_{d2} = 1.7$ mm the conductor *5* have next sizes 6.8×1.6 ^{2}, the conductor *6* — 2.2×0.4 mm^2, the conductor *7* — 3.9×0.4 mm^2, the dimension of outer resonators is 17.6×1.0 mm^2. The following design parameters for HF-channel were obtained: $l_1 = 4.91$ mm, $S_1 = 0.21$ mm, $S_2 = 0.32$ mm, $S_3 = 0.31$ mm, $l_{d1} = 2.1$ mm, $l_{d2} = 8.52$ mm the conductor *5* have next sizes 4.0×1.6 mm^2, the conductor *6* — 0.7×0.4 mm^2, the conductor *7* — 4.0×0.4 mm^2, the conductor *7* — 3.9×0.4 mm^2, the dimension of outer resonators is 12.8×1.0 mm^2. The sizes of the feeding microstrip line *3* were $l_{c1} = 1.7$ mm, $l_{c2} = 28$ mm, $w_c = 0.5$ mm. Wide and narrow parts of the HTSC-element were 1.0×0.6 mm^2 and 0.9×0.2 mm^2, respectively. The YBaCuO HTSC film having thickness 150 nm was deposited on the $NdGaO_3$ 0.5 mm substrate. The surface resistance of the film in the normal state was 10 $\Omega/\square$. The HTSC films were produced by technology described elsewhere [10]. The device was cooled with liquid nitrogen. The alumina substrate with a thickness of 0.5 mm ($\varepsilon = 10.8$). Note that the inner dimensions of the device housing are $16.7\times32.0\times6.0$ mm^3.

Bandwidth passband of each channels of the power limiter is defined by electromagnetic coupling between central and outer resonators. This coupling depends on the gap S_3 between the outer resonators, and the inner composite resonator. To increase bandwidth of device the gap S_3 must be reduced. Value of gap S_1 were chosen from the condition of the maximum return losses in the passband to be 15 dB.

In Fig. 2 left the frequency response of the simulated and developed prototype of the device are shown for both cases: superconducting state of the HTSC-element at liquid nitrogen temperature – *1*; and normal state of the HTSC-element at room temperature – *2*. The blue curves are the results of 3D electromagnetic simulation, and the red curves show the measured results. The experimental data were obtained with vector network analyzer R&S ZVA 40.

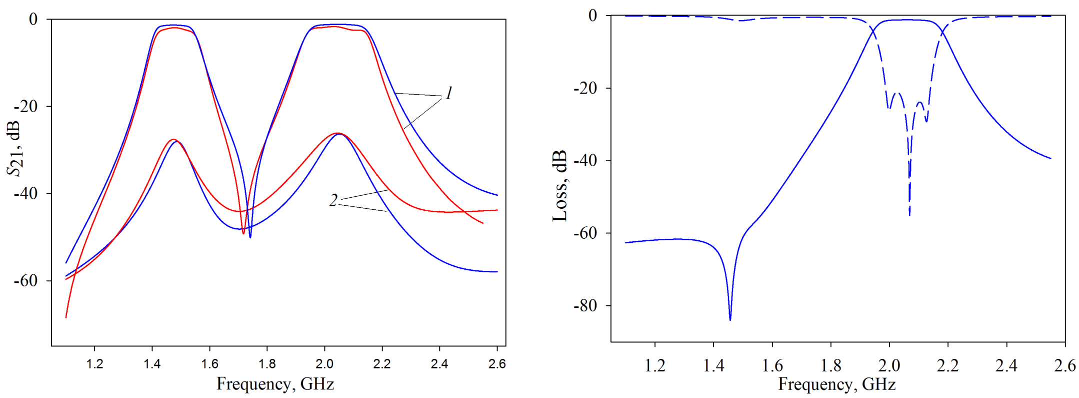

Fig. 2. Left: frequency response of the dual band HTSC power limiter in cases when the HTSC-element is in the superconducting (*1*) and normal state (*2*). The blue curves present for results of electromagnetic simulation; the red curves are experimental data. Right: frequency response of the electromagnetic simulation dual band HTSC power limiter for a case when HTSC-element is absent in the LP-channel. The solid curve is insertion loss; the dashed curve is return loss

It can be seen (Fig. 2) that when the HTSC-element is in the superconducting state, power limiter's fractional width of passbands is about 10% and 11% with central frequency being equal to 1.48 GHz and 2.03 GHz, the minimum loss in the passbands is equal 1.9 dB and 1.7 dB for LF-channel and HF-channel correspondingly. The return loss inside the pass band in this case is less than –15 dB. In the close mode when HTSC-elements pass into the normal state the transmission coefficient decreases by about 28 dB and 26 dB at the operating frequencies, return loss is equal $|S_{11}| = 1$ dB in this case. It means that power of a signal in working bands will be attenuated approximately in four hundred times. At the same time this power limiting is caused by reflection of power. Comparison of the frequency responses obtained by means of 3D electromagnetic simulation and the measured results shows quite good agreement.

Fig. 2 right shows the frequency response of the 3D electromagnetic simulation of dual band HTSC power limiter for a case when HTSC-element is absent in the LP-channel and the HF-channel is in open mode. As we can see damping pole is located at working frequency band of LP-channel. Meanwhile at frequencies HF-channel the passband exists. This means that in the operating frequency band of the LF-channel, the input power is limited, and a significant part of this power is reflected from the input of the device. At the operating frequencies of the HF-channel, the signal passes through device with minimal attenuation.

In Fig. 3 a distribution of microwave current in HTSC power limiter at a central frequency of the HF-channel (2.03 GHz) is shown for two cases: HTSC-element is in superconducting state (left) and in is normal state (right). As we can see, the antinode of microwave current and therefore H-field is located in central part of HTSC-element for open mode. When device is in the closed mode microwave current in an element is practically absent and as a result signal doesn't pass through the device. This is due to the conductivity of HTSC-element in this state is too small and quality factor of the central resonator is very small. As a result, coupling between

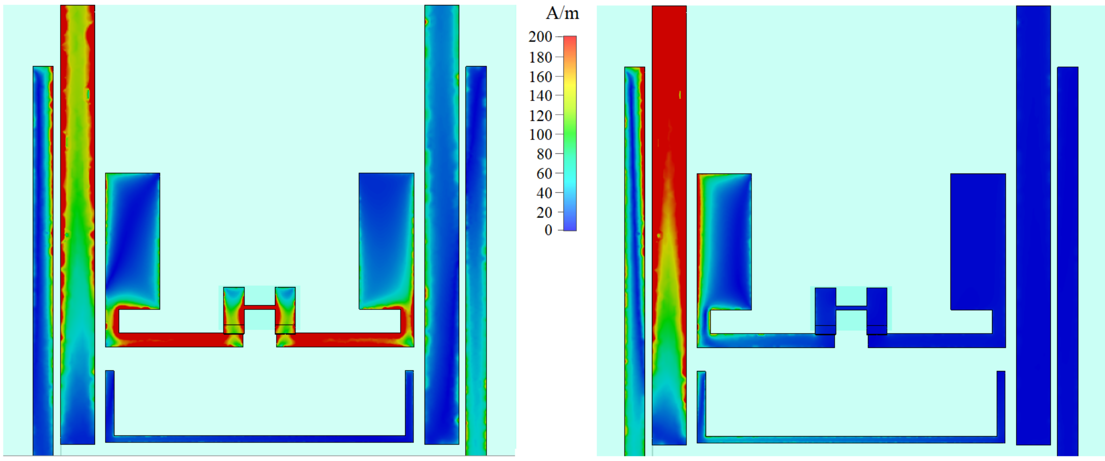

Fig. 3. Distribution of microwave current in HTSC power limiter at a central frequency of the HF-channel (2.03 GHz) for two cases: device in open mode (left) and device in close mode (right)

outer resonators through the center resonator is broken. In this situation the microwave power limitation occurs. The similar situation is observed for LF-channel too.

To determine the value of microwave power switching limiter into the closed mode, it is necessary to carry out measurements its transfer characteristic (Fig. 4). For this purpose, microwave generator R&S SMA100B, power amplifier R&S BBA150 and spectrum analyzer R&S FSW were used. The measurements were carried out at the temperature of liquid nitrogen, at the central frequency of LH-channel (1.48 GHz) and HF-channel (2.03 GHz). In the linear regime the device demonstrates around 1.8 dB insertion loss in both channel. When the input power reaches a critical level P_{in}=13.5 dBm (22.4 mW) drop in P_{out} occurs. The leakage power found to be 7.15 dBm (5.18 mW) and 9.4 dBm (8.7 mW) at the input power about 35 dBm (3.16 W) for LF-channel and HF-channel correspondingly. It means that limitation equals 26 dB in this case. These data are in good agreement with results of the measured device frequency response (see Fig. 2 left).

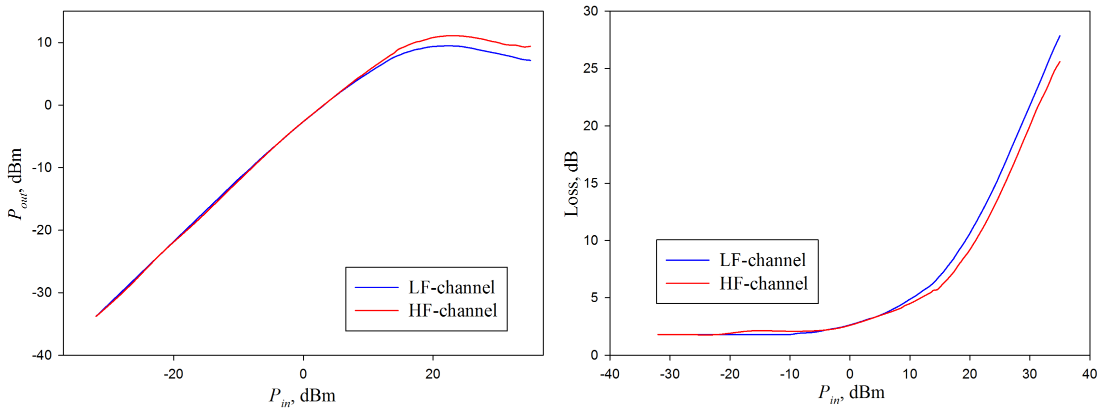

Fig. 4. Left — transfer characteristics of the fabricated device. Right — loss of power limiter versus input power. Blue curves are the results of LF-channel, red curves are the results of HF-channel

A new structure of microwave dual-band HTSC power limiter is presented. The device consists of two microstrip bandpass filters which have two quarter-wave resonators and the third composite one with HTSC-element. The prototype of the device has operation passbands being about 10% and 11% with central frequency being equal to 1.48 GHz and 2.03 GHz, the minimum loss in the passband is equal 1.9 dB and 1.7 dB for LF-channel and HF-channel correspondingly. The transfer characteristics of the device were investigated with microwave power level up to 3.15 W at the central frequencies of LF-channel and HF-channel.

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ВТСП ограничитель мощности с двумя рабочими полосами

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Аннотация. Предложена новая конструкция ВТСП ограничителя мощности с двумя рабочими полосами. Ограничитель содержит два микрополосковых полосно-пропускающих фильтра. Каждый фильтр состоит из двух четвертьволновых резонаторов, которые связаны между собой через составной полуволновый резонатор, содержащий пленку из высокотемпературного сверхпроводника. Макет устройства в открытом режиме имеет ширины рабочих полос пропускания 10% и 11% с центральными частотами 1.48 ГГц и 2.03 ГГц. Минимальные вносимые потери составили 1.9 дБ и 1.7 дБ для НЧ- и ВЧ-каналов соответственно. Передаточные характеристики устройства были исследованы до уровня СВЧ-мощности 3.15 Вт.

Ключевые слова: ограничитель мощности, СВЧ, ВТСП, микрополосковая структура.