Nonlinear Microwave Spectrometer for Investigating High-T_c Superconductors

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We describe a nonlinear microwave spectrometer, which can be conveniently used for investigating the harmonic generation at microwave frequencies in high-T_c superconductors. The use of this technique allows highlighting mechanisms responsible for the nonlinear microwave response of high-T_c superconductors as well as measuring specific characteristics of the investigated samples. We report a brief review of the main results obtained.

During long time the main applications of superconductors (SC) at microwave frequencies have concerned the implementation of cavities for particle accelerators; recently the use of SC spreads over a large variety of microwave electronic devices [1]. On the other hand, it has been widely shown that high-T_c SC exposed to intense microwave fields show markedly nonlinear properties. So, the investigation of nonlinear microwave properties of SC has recovered much attention. These studies are of interest in understanding the fundamental physics of the superconductivity and determining parameters for technical applications. In order to improve the quality of devices it is important to know the power level at which the nonlinear effects come in to play. Nonlinear effects manifest through the input power dependence of the microwave surface impedance [2], intermodulation distortion [3], generation of signals at the harmonic frequencies of the driving field [4-8]. The technique of harmonic detection has allowed recognising several mechanisms of nonlinearity [2-7] and measuring specific properties of high-T_c SC [8].

Figure 1 shows the block diagram of the nonlinear spectrometer used for harmonic detection. The basic element of the apparatus is a bimodal cavity oscillating at the two frequencies ω and nω, with n = 2, 3 for the second harmonic (SH) and the third harmonic (TH) detection respectively. The resonance at the fundamental frequency is obtained by inserting a metallic rod into a rectangular copper cavity. The intensity of the magnetic field of the ω-mode varies along the rod as $H(\omega) = H_1\cos(\pi z/2L)$, where L is the length of the rod. The harmonic mode is the TE_{102} mode of the rectangular cavity [9], resonating at 6 GHz, for both SH and TH detection. The sample can be located in a region in which the field distribution is known. To study magnetic properties the sample is located in a region where the fields **H**(ω) and **H**(nω) are maximal and parallel to each other. The fundamental mode of the cavity is fed by a train of microwave pulses, with repetition rate ranging from 1 to 200 pps and pulse width ranging from 1 μs to 1 ms. High input power levels can be used (0.1 - 1 kW) provided that the ratio between the pulse width and the repetition rate does not overcome the value of about 10^{-3}. A low pass filter at the input of the cavity cuts any harmonic content of the oscillator by more than 60 dB. The harmonic signals generated by the sample are filtered by a band pass filter, with more than 60-dB rejection at the fundamental frequency, and are detected by a superheterodyne receiver. The superheterodyne receiver consists of a mixer, a local oscillator at $\omega_L = n\omega + 30$ MHz and an IF amplifier at 30 MHz with 1 MHz bandwidth. It allows detecting a 30 MHz signal whose intensity is proportional to the harmonic power emitted by the sample. The signal is displayed by an oscilloscope and recorded on a personal computer.

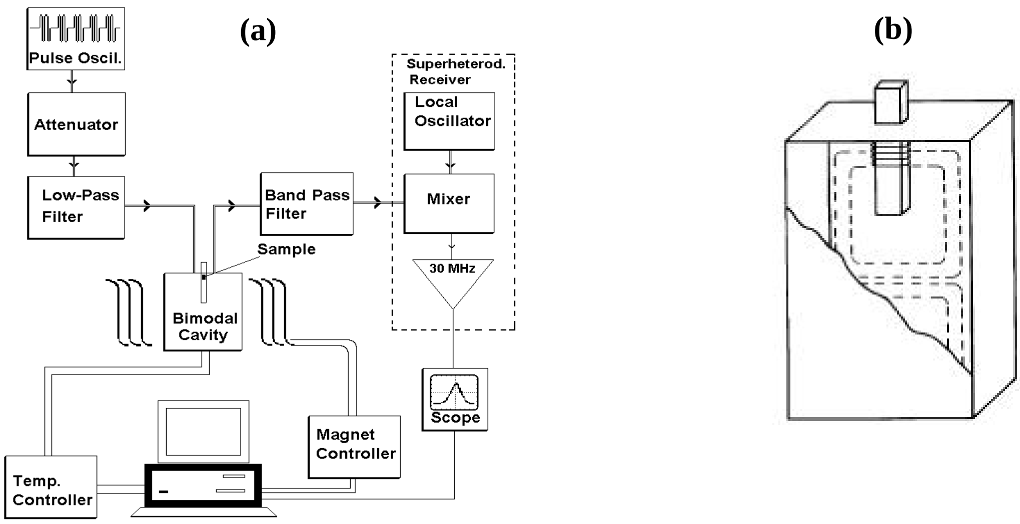

Figure 1(a): Block diagram of the nonlinear microwave spectrometer. **(b)** Bimodal cavity: continuous lines show the magnetic field distribution of fundamental mode, dashed lines that of the harmonic mode.

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The cavity is located between the coils of an electromagnet, which can generate a static field up to 15 kOe. The dc magnetic field can be rotated in a plane containing the magnetic and electric microwave fields over the full range 0-360°. Two additional coils, parallel to the main coils of the magnet and independently fed, are used to reduce the residual field within 0.2 Oe and generate fields of a few oersteds. A cryostat and a temperature controller allow working either at a constant temperature or at temperature varying with a constant rate in the range 4.2 ÷ 300 K.

Since the discovery of high-T_c SC the harmonic emission has been studied in both ceramic and single crystal samples by using the technique above described. The investigation has put out several mechanisms responsible for the nonlinearity. They depend on the temperature, the dc magnetic field and the type of SC. In any case, the nonlinearity is a peculiar property of the superconducting state: both second harmonic and third harmonic signals vanish whenever the samples go into the normal state by increasing either the temperature or the applied field. It has been shown that at low temperatures the nonlinear microwave response is due to extrinsic properties of the superconducting samples such as, *e.g.*, impurities, weak links or flux-line motion. In particular, at low applied fields the harmonic emission has been ascribed to nonlinear processes occurring in weak links [4]. At high fields, when the links are decoupled, the nonlinear response has been ascribed to the distortion of the em wave due to the motion of the fluxons in the critical state [5]. On the contrary, the harmonic emission detected at temperatures close to T_c is related to intrinsic properties of the superconducting state; indeed, it has been ascribed to time modulation of the order parameter by the em field [7].

Figure 2 shows the SH signal intensity as a function of the temperature in samples of ceramic (a) and crystalline (b) $YBa_2Cu_3O_7$. The peak near T_c detected in both the samples can be ascribed to the same mechanism. High quality crystals, in which very few weak links are likely present, exhibit a very weak SH signal at low temperatures.

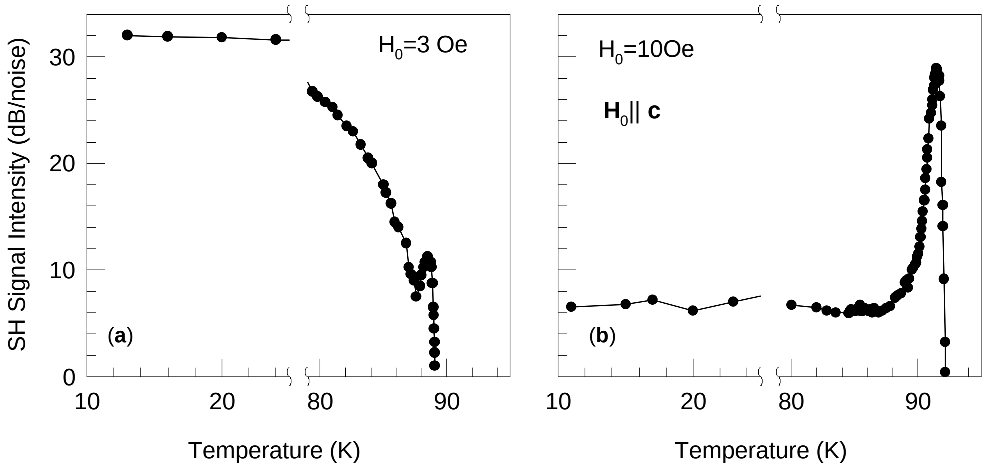

Figure 2: SH signal intensity as a function of the temperature in samples of ceramic (a) and crystalline (b) $YBa_2Cu_3O_7$

The investigation of the harmonic emission, besides to give information on the nonlinearity mechanisms, can be conveniently used for determining specific properties of the investigated samples. Since the harmonic signal vanishes at the superconducting transition, by measuring the intensity of the harmonic signals as a function of the temperature and/or the intensity and the orientation of the magnetic field one can measure the temperature dependence of the upper critical field and its anisotropy [8].

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