PROCEEDINGS OF ISAP '92, SAPPORO, JAPAN

An Experimental Investigation of Superconducting Microstrip Antenna Feeding Methods

M.A. Richard[1], K.B. Bhasin[2], and P.C. Claspy[1]

[1]Department of Electrical Engineering and Applied Physics
Case Western Reserve University
Cleveland, OH 44106, USA

[2]National Aeronautics and Space Administration
Lewis Research Center
Cleveland, OH 44135, USA

ABSTRACT: The high permittivity associated with substrates that are typically used for high-temperature superconductors (HTS) cause the edge impedance of microstrip patches to be very high, causing difficulty in matching a patch to a microstrip transmission line. In this paper, feeding techniques for K and Ka-band superconducting microstrip antennas are examined. Superconducting microstrip antennas that are directly coupled, gap coupled, or electromagnetically coupled to a microstrip transmission line have been designed and fabricated on lanthanum aluminate substrates using a YBCO high-temperature superconducting thin film. Measurements from these antennas, including input impedance, bandwidth, patterns, and efficiencies are presented. Although each antenna configuration has its advantages, electromagnetic coupling allows the flexibility of using a low permittivity substrate for the microstrip patch while using HTS for the feed network.

INTRODUCTION: The recent discovery of the ceramic high-temperature superconductors (HTS) has generated much speculation into their use in microwave antennas systems. Experimental investigations of passive microwave devices such as delay-lines, resonators, and filters at X-band frequencies have shown that HTS provides a substantial loss reduction over identical circuits fabricated with metals (gold, silver, or copper)[1]. Analytical work by Dinger [2] has shown that the an 100-element linear HTS antenna may experience an 8 to 10 dB improvement in gain over an identical antenna made with normal metals. One problem associated with the use of HTS for microstrip antennas, however, is the substrate material. The ceramic HTS compounds can presently be grown successfully only on high-permittivity substrates such as lanthanum aluminate (ϵ_r=23) or magnesium oxide (ϵ_r=9.6). Although these material allow the miniaturization of the feed network, it also causes difficulty in matching the transmission line impedance to the edge impedance of the patch. To overcome these difficulties and use HTS effectively in microstrip antennas, we have designed and fabricated antennas with several different feeding methods. The experimental performance of these antennas are compared. Measurements at cryogenic temperatures were performed by placing the antennas in a closed-cycle gas refrigerator capped with a polyethylene radome [3]. The input impedances, efficiencies, and far-field patterns were measured for the antennas.

DIRECT-COUPLED ANTENNA: A four-element array of rectangular microstrip patches is shown in Fig. 1a. The substrate is 254 μm thick lanthanum aluminate, while each patch is 825 μm long by 1650 μm wide. The feedpoint is inset 28% to obtain a input impedance of approximately 200 ohms. Matching to this point is done by

a 2.8 μm wide 100 ohm microstrip line serving as a quarterwave transformer between the patch and the 50 ohm transmission line. The input impedance measurements of this antenna show a relatively poor match at the resonant frequency of 30.6 GHz. Computer simulations of the feed network show that one of the main reasons is the enormous line-width discontinuity at the 100 ohm quarter-wave transformers feeding each patch. Pattern measurements and the efficiency of this antenna relative to an identical gold antenna are shown in Fig. 2 and 3.

GAP-COUPLED ANTENNA: A circular patch gap-coupled to a 50 ohm microstrip line is shown in Fig. 1b. This configuration eliminates the need for the high-impedance matching transformers, but instead depends upon a relatively narrow 15 μm gap between the patch and the feedline for capacitive coupling. The substrate is 254 μm thick lanthanum aluminate, while the patch has a radius of 610 μm. The 100 μm feedline is gap-coupled to the patch via a 15 μm gap. The width of this gap is quite critical; overetching of the gap to 28 μm in the HTS antenna caused significant under-coupling of the patch. An identical antenna patterned with gold and with a 15 μm gap showed an almost perfect match at 26 GHz, but a very narrow (1 %) impedance bandwidth. The efficiency of these antennas were measured using the Wheeler Cap method [3]. The method consists of measuring the input resistance at resonance with and without a radiation shield. For this work an aluminum cap with inner dimensions of 1.25 cm wide and deep by 0.64 cm high was used. The HTS antenna was found to surpass the performance of the metal antenna at temperatures below 70 K, reaching a peak efficiency of 71%. It is reasonable to assume that much of the remaining 26% is lost as surface waves; closed form approximation by Pozar [4] show a surface wave radiation efficiency of about 70% at 25 GHz. The measured patterns and antenna efficiencies are shown in Fig. 3. The patterns show pertubations in the E-plane due to surface wave generation. These findings are consistant with those reported by Schaubert and Yngvesson [5].

ELECTROMAGNETICALLY-COUPLED ANTENNA: A circular patch electromagnetically coupled (EMC) to a 50 ohm microstrip line is shown in Fig. 1c. This configuration reduces the effective dielectric constant that the patch sees, leading to diminished surface wave generation, but because of the high permittivity of the feed line substrate, strong coupling can be achieved between the line and patch. Because the radiative patches are on the top layer, this configuration allows the possibility of integrating active devices or delay lines directly on the feed substrate to make active phased array antenna. This configuration has the aditional advantage of insulating the YBCO from incident thermal radiation, which is a consideration for large arrays. For this work, the feedline is made from HTS deposited on lanthanum aluminate, while the patch is gold deposited on a 127 μm alumina substrate. These antennas have 25 dB return loss at 28.5 GHz, and a relatively wide (3.44 %) impedance bandwidth. The measured return loss and antenna patterns are shown in Fig. 4. The patterns show the pertubations in the E-plane as found in the case of the gap-coupled antennas.

CONCLUSION: Superconducting antenna fed by three seperate methods have been experimentally investigated. All configurations suffer from surface wave losses, and patterns of the single-element gap-coupled and EMC antennas show pertubations in the E-plane patterns due to surface waves. The gap-coupled antenna is simple to fabricate and is easily matched but has a very narrow bandwidth. The EMC antenna configuration poses several advantages including wider bandwidth, thermal insulation, and greater area for integrated components, but has the disadvantage

of increased complexity.

ACKNOWLEDGEMENT: The authors would like to thank Mr. Joe Warner for fabricating the HTS films, and Mr. C. Gilbert for the array design. One author, M.A. Richard, acknowledges support through the Ohio Aerospace Institute Doctoral Fellowship program.

References

1. *IEEE Microwave Theory Tech.*, Special Issue vol. 39, no. 9, Sept. 1991.
2. Robert J. Dinger, "Some Potential Applications of High Temperature Superconductors," *Journal of Superconductivity*, vol. 3, no. 3, pp. 287-296, 1990.
3. M.A. Richard, K.B. Bhasin, C. Gilbert, S. Metzler, and P.C. Claspy, "Measurement Techniques for Ka-Band Microstrip Antennas," *Antenna Measurement Techniques Association Proceedings*, pp. 1.13-1.17, 1991.
3. Wheeler, H.A., "The radiansphere around a small antenna," *Proc. IRE*, vol. 47, pp. 1325-1331. Aug. 1959.
4. Pozar, D.M., "Rigorous closed-form expressions for the surface wave loss of printed antennas," *Electron. Lett.*, 1990, vol. 26, no. 13, pp. 954-956.
5. Daniel H. Schaubert and K. Sigfrid Yngvesson, "Experimental Study of a Microstrip Array on High Permittivity Substrate," *IEEE Trans. Antennas and Propagat.*, vol. AP-34, no. 1, pp. 92-97.

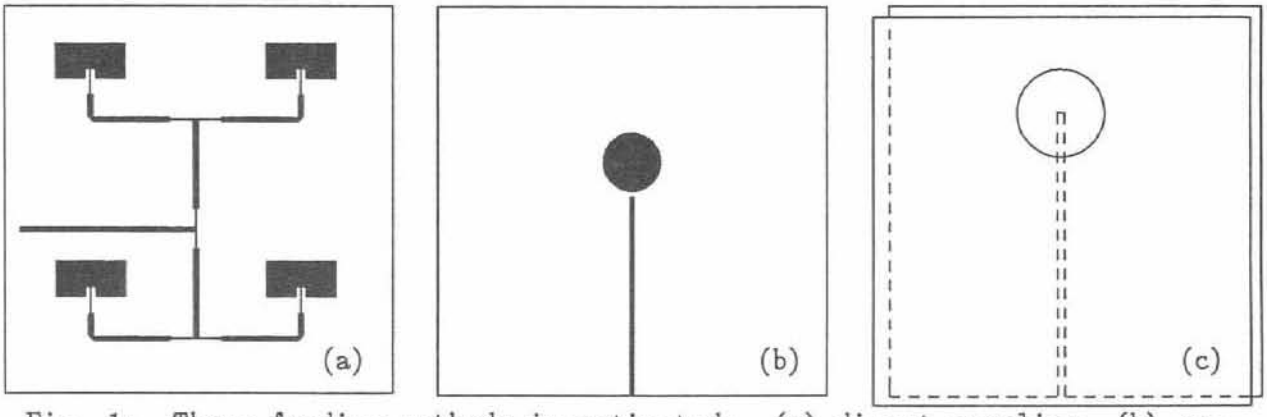

Fig. 1: Three feeding methods investigated: (a) direct-coupling, (b) gap-coupling, and (c) electromagnetic coupling.

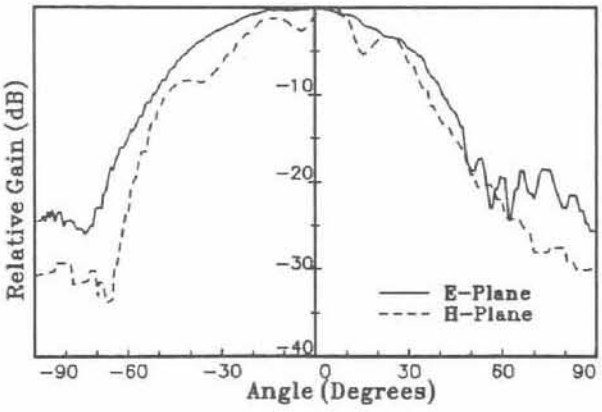

Fig. 2: Measured E- and H-plane patterns of the 4-element array.

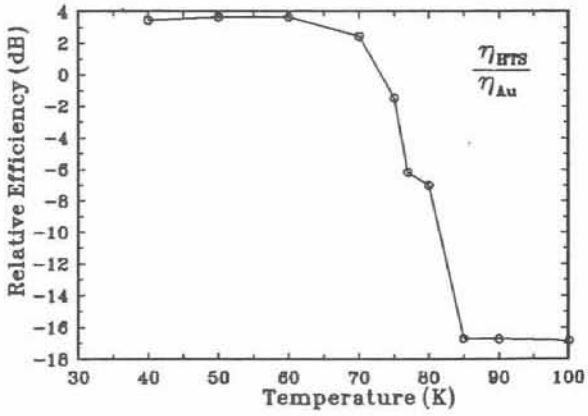

Fig. 3: Efficiency of HTS array relative to the gold array.

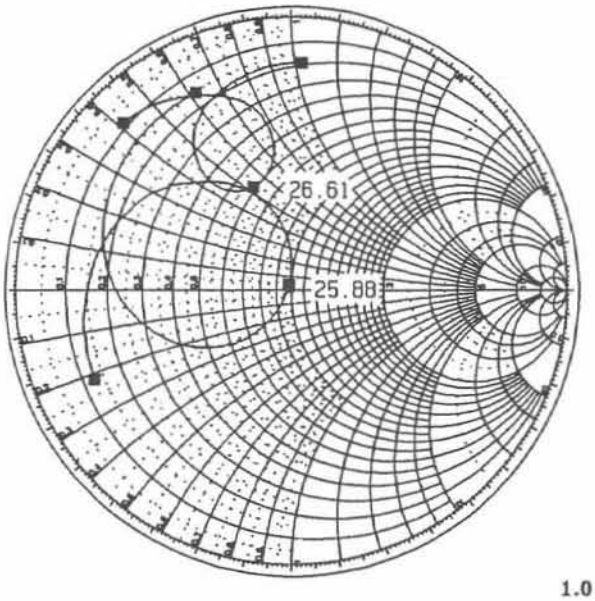

Fig. 4: Input impedance of gap-coupled antennas. The HTS is resonant at 26.61 GHz while the gold antenna is resonant at 25.88 GHz.

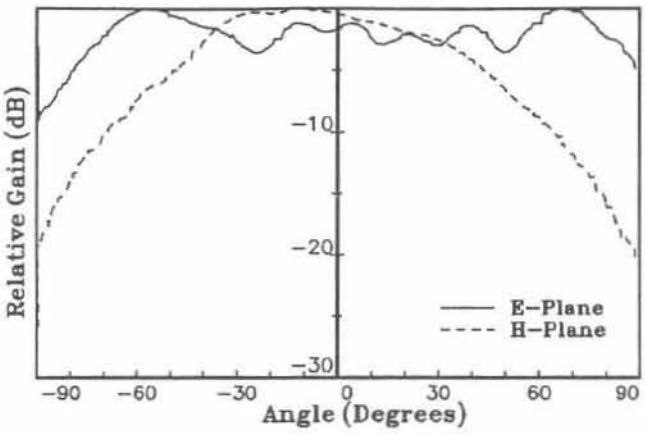

Fig. 5: Measured E- and H-plane patterns of the gap-coupled microstrip antenna.

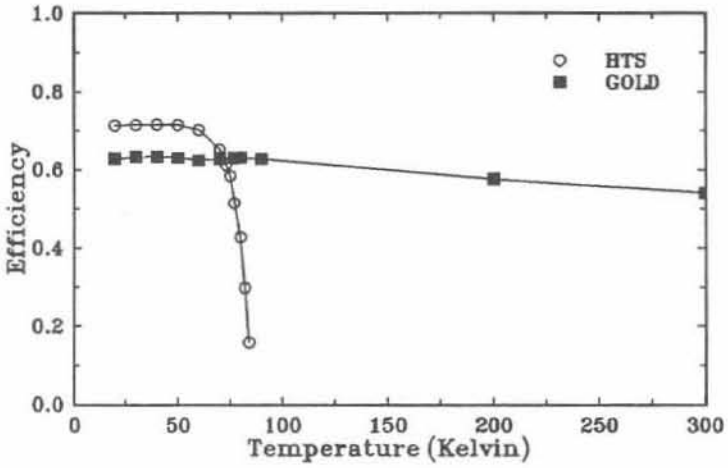

Fig. 6 (right): Measured efficiencies of gold and HTS gap-coupled antennas.

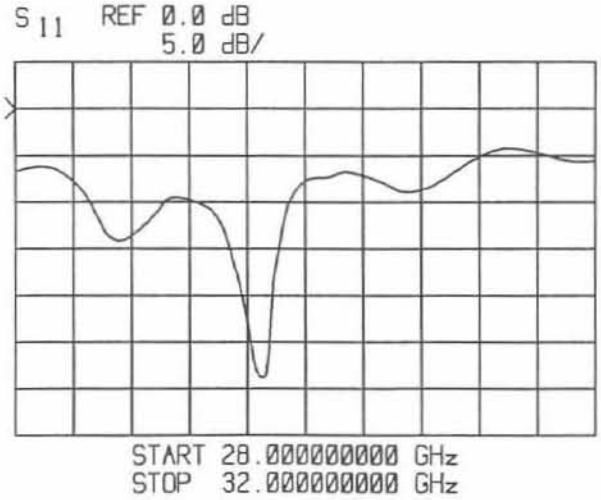

Fig. 7: Return loss of EM-coupled patch. The resonance is at 29.66 GHz.

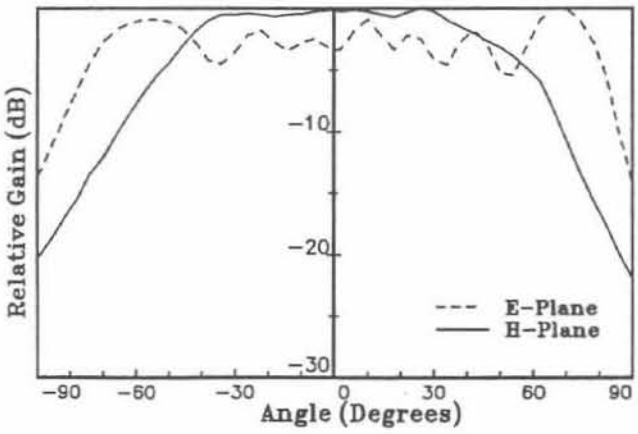

Fig. 8: Measured antenna patterns of EM-coupled patch.