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# Cold Test Results of a Standing Wave Muffin-tin Structure at X-band*

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## Abstract

A muffin-tin structure is chosen to study high gradient acceleration in the millimeter wavelength range. In order to understand the electromagnetic field characteristics, a standing wave structure operating at a frequency around 11.4 GHz was built. Cold test measurements were performed and results are presented. Comparisions with theoretical predictions based on computer simulation are shown.

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## 1. INTRODUCTION

The muffin-tin structure[1] is chosen for development of high gradient (≥ 1 GV/m) acceleration at SLAC. The operating frequency is tentatively chosen around 32 times SLAC frequency (32× 2.856 GHz). The size of accelerating structures in this frequency range is at the millimeter scale. RF measurements of accelerating structures in this frequency range have never been performed. Since it is important to characterize the electromagnetic field of mm-wave accelerating structures, it is necessary to first perform RF measurements at lower frequencies. Those can provide useful information about the field configurations of muffin-tin structures. A standing wave muffin-tin structure was built at an operating frequency (4× 2.856 GHz) in the X-band. Measurement results for the standing wave muffin-tin structure at X-band are presented. Conceptual descriptions of RF measurements in the mm-wave range are described.

There are five full cells and two half cells in the muffin-tin structure. This design is chosen to imitate the field configurations of a $2\pi/3$ mode traveling wave structure[1]. At each end of the muffin-tin structure there is a circular hole of diameter 0.086" drilled through the center. These holes are used to insert RF probes.

## 2. MEASUREMENTS

An E-probe is inserted through a hole for signal detection as shown in Fig. 1. Reflection measurements were first performed to scan the contents of various modes in the frequency domain.

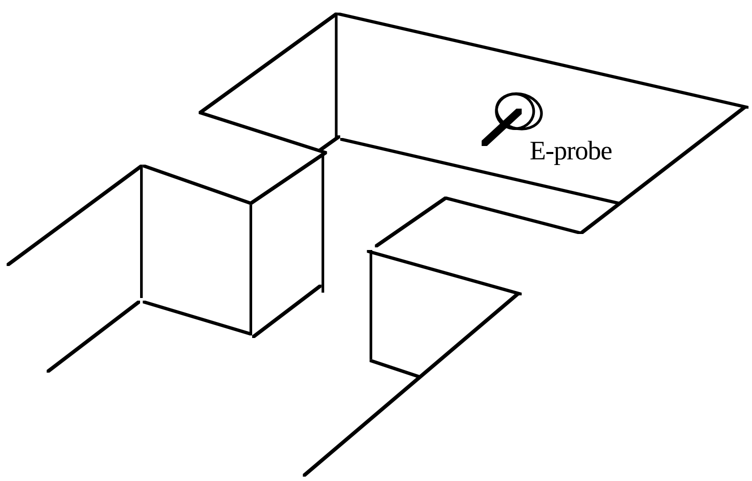
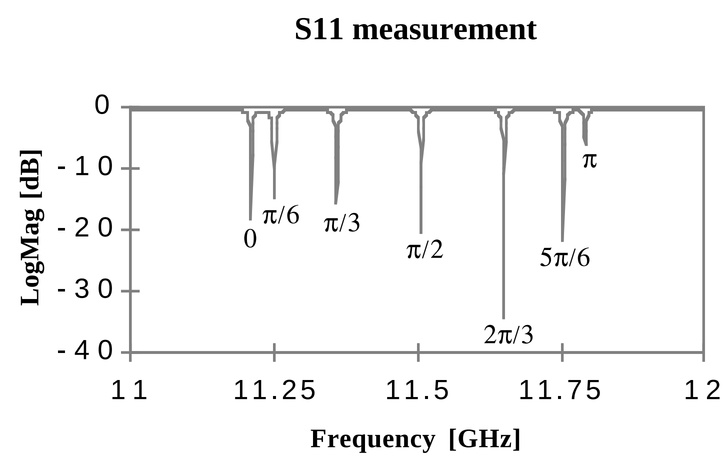



**Fig. 1**: E-probe placement for signal detection.

The reflected signals are given in Figs. 2, 3, and 4. Figure 2 shows the fundamental mode. Each cavity cell can be viewed as an harmonic oscillator. Since there are 7 cells in the structure coupled together through iris openings. Therefore, one expects to observe 7 resonant modes. Each spectral line in Fig. 2 corresponds to one mode. The measured frequency for the 2π/3 mode used for particle acceleration is 11.6475 GHz; the calculated value from MAFIA[2] simulations is 11.5619 GHz.



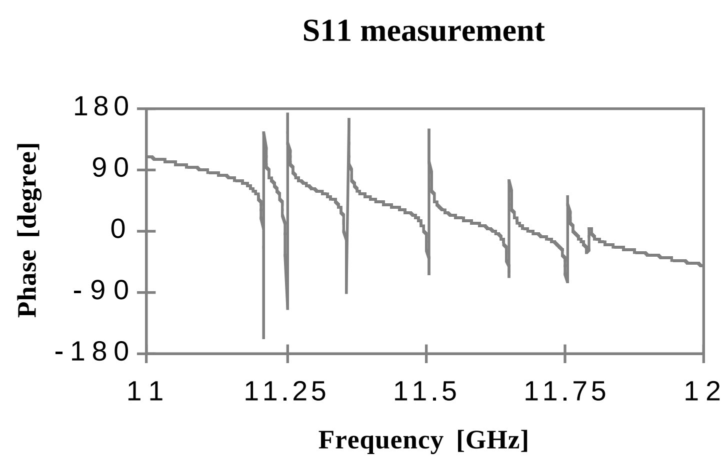




**Fig. 2**: The measured frequency spectrum of reflected signal from 11 to 12 GHz.

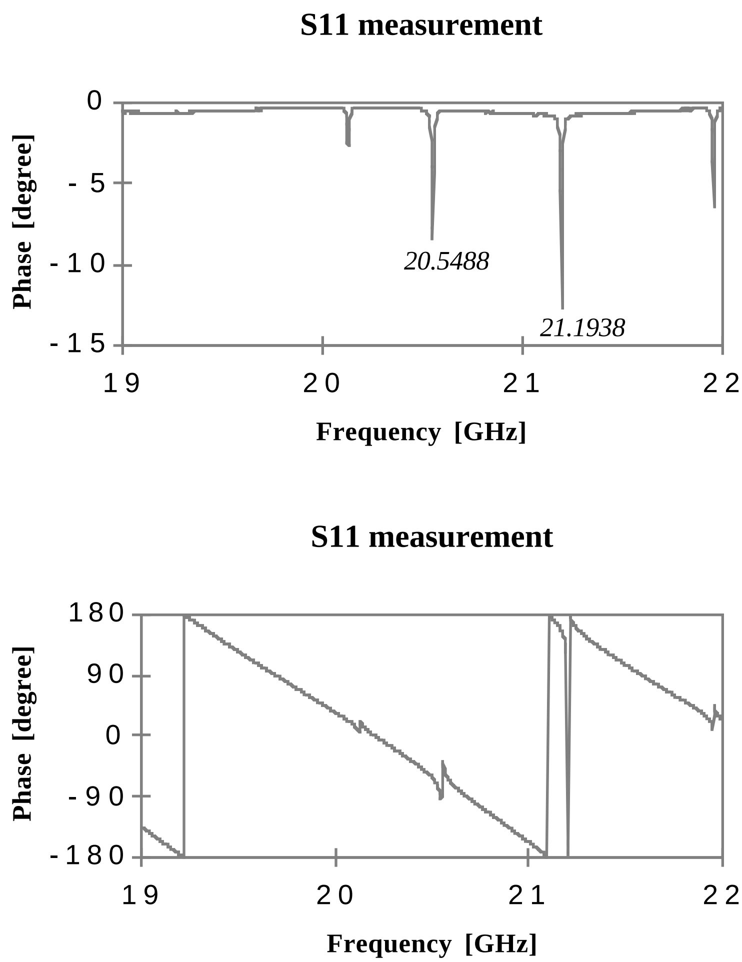



**Fig. 3**: The measured frequency spectrum of reflected signal from 19 to 22 GHz.

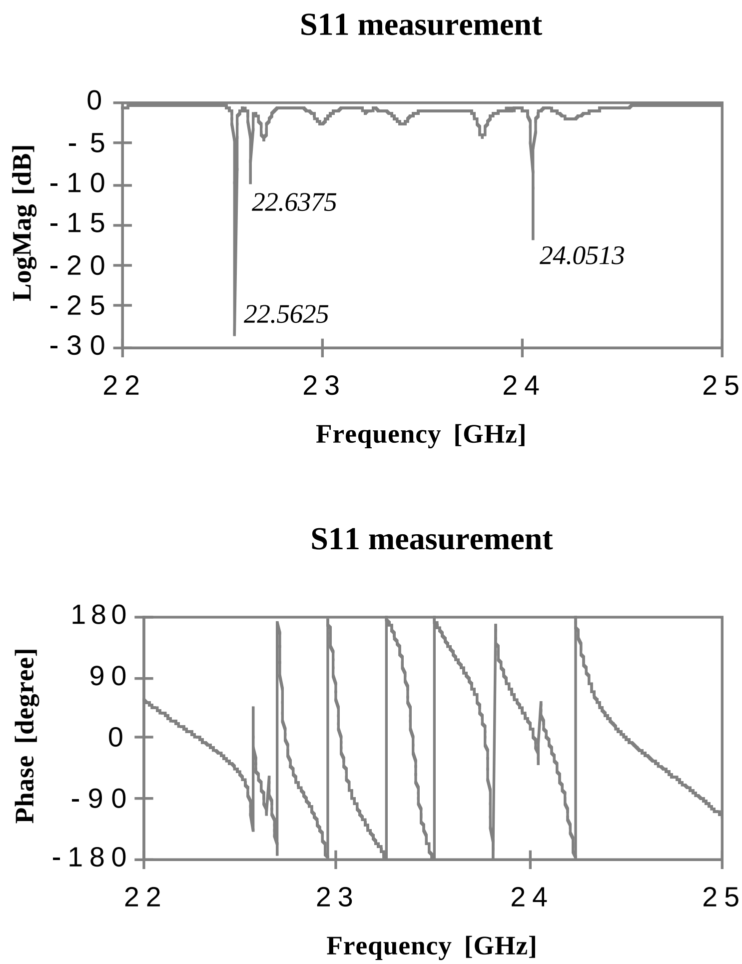



**Fig. 4**: The measured frequency spectrum of reflected signal from 22 to 25 GHz.

The axial field profile was measured by performing bead pull measurements[3, 4] and recording the shift of resonant frequency for the $2\pi/3$ mode. By using a small cylindrical bead made of metal and moving it along the longitudinal axis without transverse offsets, the normalized amplitude of the accelerating field can be measured. The experimental setup is depicted in Fig. 5. The X-band muffin-tin structure has a longitudinal length of 2.07". The measured frequency shift for the $2\pi/3$ mode as a function of the bead position along the longitudinal axis is given in Fig. 6.

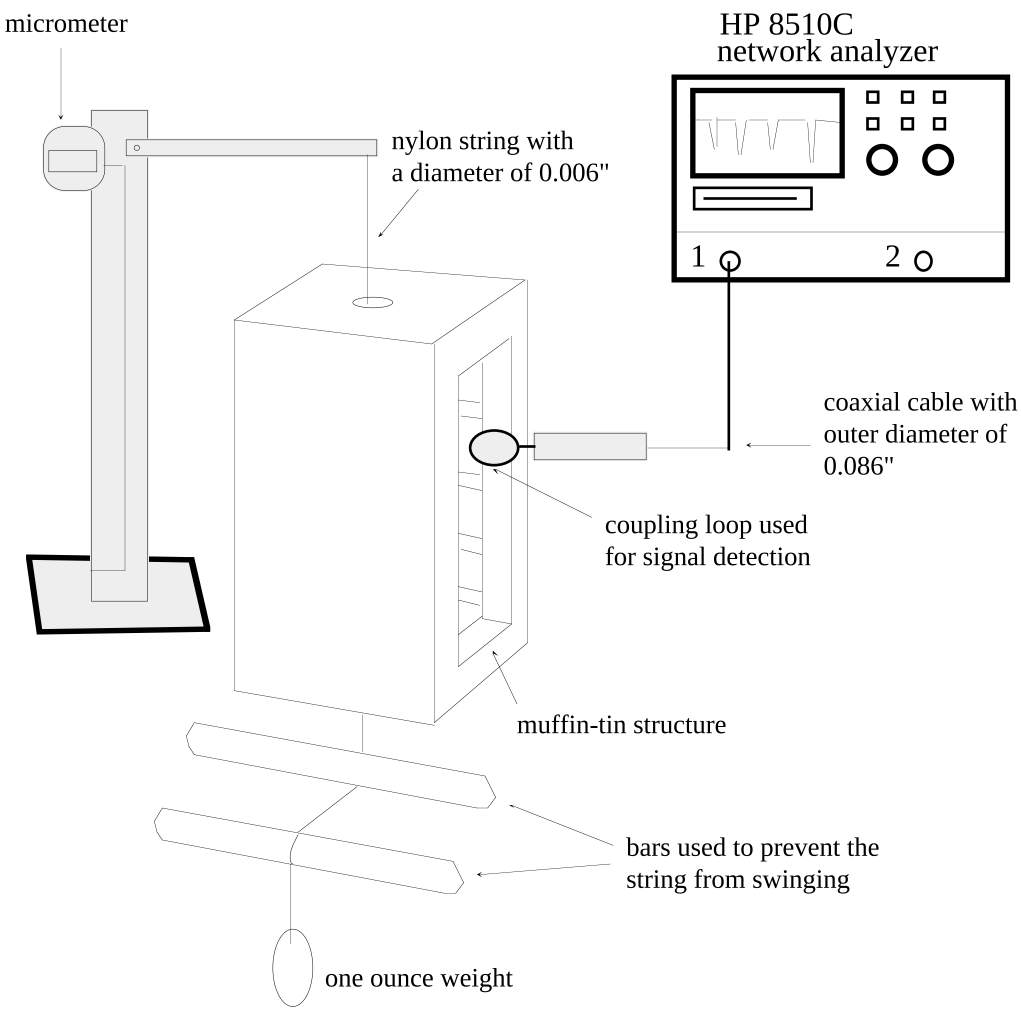



**Fig. 5**: The experimental setup for bead pull measurements.

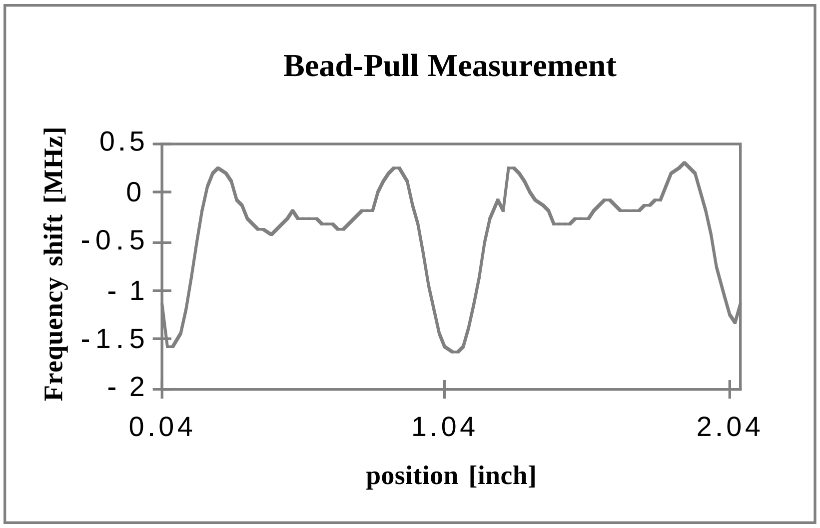



**Fig. 6**: The measured frequency shift for the 2π/3 mode as a function of the bead position along the longitudinal axis. The length of the structure is 2.07".

For conceptual illustration, a simulated field profile for the 2π/3 mode along the longitudinal axis of a structure with 2 oscillation periods is given in Fig. 7. Only the first three space harmonics are used in the calculation.

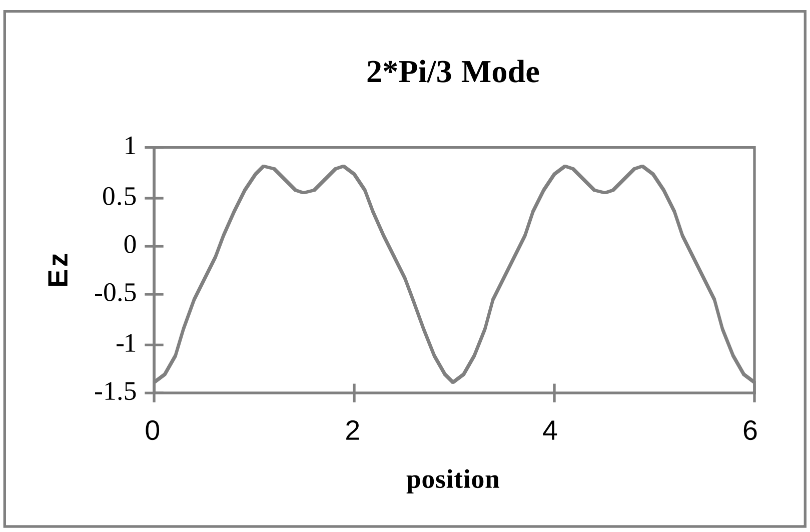



**Fig. 7**: The simulated field profile along the longitudinal axis of a structure with 2 oscillation periods. The units are arbitrary.

The measured results of loaded Q-factor are given in Table 1 and the calculated results for 2π/3 mode from MAFIA[2] simulation are given in Table 2.

| Frequency [GHz] | Loaded Q-factor |
|---|---|
| 11.6475 | 1658 |
| 22.5625 | 1336 |
| 22.6375 | 2317 |
| 24.0505 | 1253 |

**Table 1**: The measured results of frequency and Q-factor for various modes.

| Frequency [GHz] | Unloaded Q-factor | R/Q [Ω] | Shunt Impedance [MΩ] |
|---|---|---|---|
| 11.5619 | 6817 | 127 | 0.87 |
| 22.0781 | 10103 | 9.3 | 0.09 |
| 23.6769 | 11295 | 7.4 | 0.08 |

**Table 2**: The calculated parameters for the 2π/3 mode of X-band muffin-tin structure.

## 3. MEASUREMENT METHODS IN THE MM-WAVE RANGE

By using the nonresonant perturbation measurement[5, 6, 7], one can measure the amplitude and phase of the accelerating field. The information needed is the difference between the unperturbed input reflection coefficient $S_{11}^{u}$ and the perturbed input reflection coefficient $S_{11}^{p}$ with a bead inside the structure. The mathematical expression of this statement is as follows:

$$\Delta S_{11}(z) = S_{11}^{p}(z) - S_{11}^{u}(z) = A|E(z)|^2 e^{-2j\theta_E(z)}$$

where z is the longitudinal coordinate, $\theta_E(z)$ is the phase advance along the longitudinal direction of the structure, E(z) is the accelerating field, and A is a constant which depends on the input power and the bead characteristics. Since a vector network analyzer for millimeter wavelengths is quite expensive, an alternative option depicted in Fig. 8 is being considered for bead pull measurements in the millimeter wavelength range.

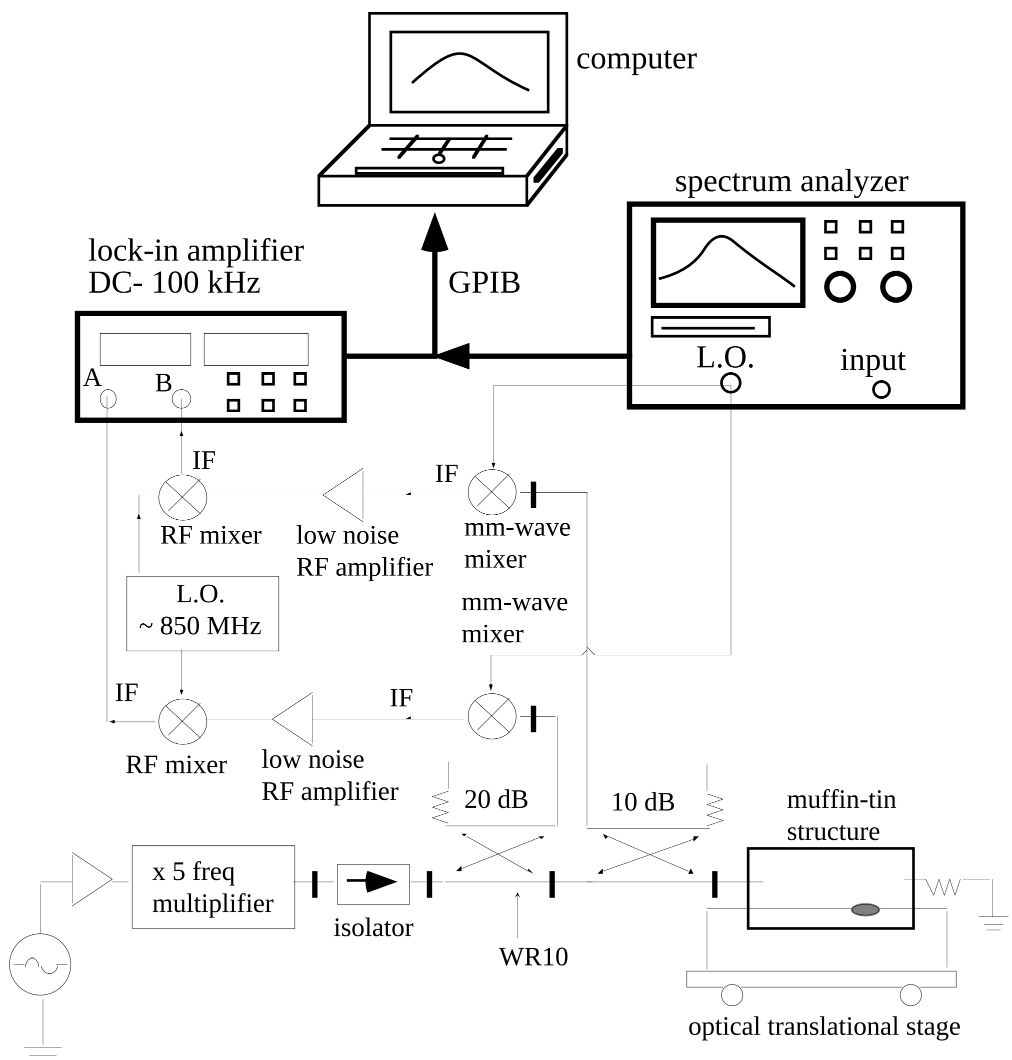



**Fig. 8**: Conceptual block diagram of experimental setup for RF measurements in the millimeter wavelength range.

The operating frequency of the mm-wave muffin-tin structure is around 92 GHz. A HP8673 frequency synthesizer and a 5 times frequency multiplier are used to generated the 92 GHz source signal. The incident signal is monitored through a 20 dB WR10 waveguide coupler. There are two stages of signal mixing occurring after the WR10 coupler. The signal is mixed down to an intermediate frequency around 850 MHz by a HP11970W mm-wave mixer which uses the 18th harmonic of the spectrum analyzer local oscillator. The average conversion loss of the mixer is about 42 dB. The output signal from the mm-wave mixer, after the first mixing stage, goes through a low noise, narrow-band, RF amplifier (center frequency ≈ 850 MHz, bandwidth ≤ 20 MHz). After the low noise RF amplifier, the signal goes to the second mixing stage which mixes the signal down to the audio frequency range (≤ 100 kHz). A lock-in amplifier is used to detect the amplitude and phase of the input signal. The reflected signal follows the same procedures for signal processing. The lock-in amplifier takes the input signal from port A as the reference, then it gives the amplitude and phase of the signal from port B with respect to the reference as the output. Therefore, one can use the source signal as the reference and measure the amplitude and phase of reflected signals with and without the perturbing object in the structure.

To perturb the field inside the mm-wave muffin-tin structure, a small bead is needed. Hollow metallic cylinders with diameters ranging from 25 to 127 μm with an approximate length of 500 μm have been fabricated by sputtering aluminum onto silica optical fibers and nylon surgical thread for bead pull measurements[3]. Further miniturization of metallic beads can be achieved by using this sputtering technique. Because the diameter of the string used in bead pull measurements for the mm-wave muffin-tin structure must not be too large (≤ 25 μm), the string will be fixed on two supporting arms which will be mounted on an optical translational stage. An operator can then move the thin string by shifting the translational stage which provides one micron or better accuracy. This arrangement also avoids breaking the thin string used to support the metallic bead.

Since the source signal will contain different harmonics of the frequency multiplier, care needs to be taken in order to remove them in the signal processing. The nearest spurious harmonic is 22 MHz away from the desired signal (Fig. 9).

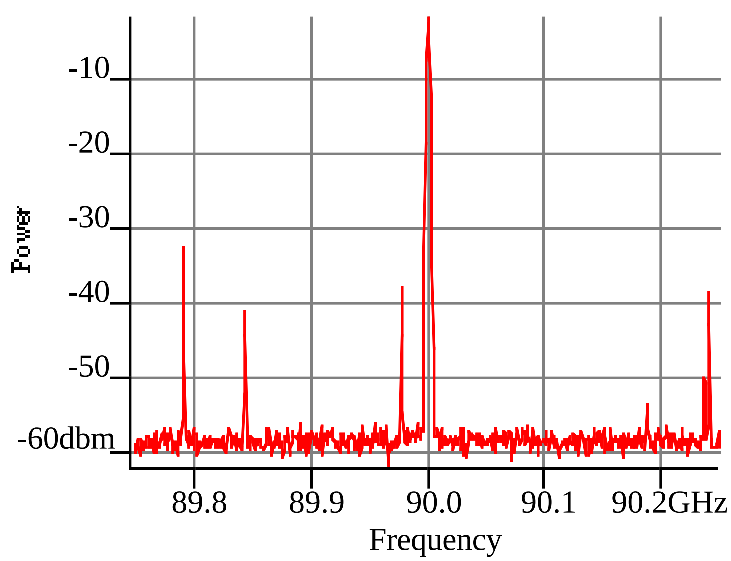



**Fig. 9**: The spectrum of output signal from the frequency multiplier.

## 4. SUMMARY

Results of the measurements of the X-band muffin-tin structure have been presented, however more work needs to be done to improve the accuracy of these preliminary experimental results. An alternative scheme for performing RF measurements for the mm-wave muffin-tin structure without the use of a vector network analyzer has been presented. This work will help develop a better understanding of the properties of mm-wave muffin-tin structures.


## ACKNOWLEDGMENTS

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