# Design and Operation of a 100 kW CW X-Band Klystron for Spacecraft Communications

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**Abstract:** *A 7.19 GHz klystron producing 100 kW CW of output power over 90 MHz of bandwidth has been designed and three klystrons manufactured for use in a new JPL / NASA transmitter for spacecraft communications. The klystron was fully characterized including its phase pushing figures.*

**Keywords:** klystron; phase pushing figure

## Introduction
The NASA Deep Space Network plans to augment the capability of existing 70M antennas with arrays of 34M antennas. In order to achieve the same effective radiated power as the 70M systems the 34m antennas require an amplifier with a power output four times higher than the current 20KW systems. It was additionally desired to cover both the near Earth and deep space communications bands with the same amplifier. A 100 kW CW solenoid focused klystron has been developed to meet this need. Three of these klystrons have been successfully manufactured, fully characterized and delivered.

## Design
The design of the klystron is similar to the 250 kW CW, 8.56 GHz klystron that is currently used in NASA's Goldstone Solar System Radar (GSSR). The principal differences are a lower operating frequency, a two times wider usable bandpass, a more stringent gain slope variation of 0.05 dB/MHz maximum and the ability to operate in a lower power mode to cover the near Earth communications band. These requirements were met through careful tuning and placement of the cavities using both 1D and 2.5 D large signal simulations.

A fundamental challenge for this project was the focusing and transport of the intense electron beam. With a CW beam power density of ~3.8 MW/cm$^2$ required to achieve the 100 kW of output power, good focusing was critical to avoid possible damage to the RF circuit. Xgun steady-state ray tracing simulations and TESLA simulations show that the beam is well focused with modest scallop under both DC and full RF output power conditions. Here, the electron gun is configured as a diode and uses an M-type cathode with a modest average current density loading of 2.3 A/cm$^2$. Confined flow focusing has also been used.

The rf circuit consists of six cavities: the first three are stagger tuned to achieve the required bandwidth, the next two are inductively tuned for efficiency and the last is the output cavity for power extraction. Cavity dimensions were determined by simulation with HFSS. Each cavity has a thin metal diaphragm that provides ~150 MHz of total trim tuning. The input and output cavities are further coupled to waveguides through inductive irises. The input waveguide transitions to a type N connector while the output waveguide tapers to a thick alumina ceramic window for the greatest bandpass and operating stress margin possible.

## Operation
Figure 1 shows a photograph of the klystron installed into its solenoid. The electron gun is at the bottom of the photograph and is not visible while the collector is pointing upwards and is also not visible. A cylinder is installed around the collector and is bolted to the output polepiece to provide support during antenna rotation. Table I summarizes the measured basic operating parameters while Fig. 2 shows the instantaneous bandpass for one of the units. The other two units had similar performance. As can be seen, over 100 kW of output power was achieved across the required 90 MHz operating band with a maximum gain variation at the low band edge of 0.04 dB/ MHz. A reasonable flatness was achieved by tuning for a wider 1 dB bandwidth than was required. While the full bandwidth could not be measured due to a mode in the calorimetric load used for testing it is estimated to be about 115 MHz. Stable operation into a 1.2:1 output mismatch was also demonstrated across the full bandpass. While the bandpass could be tilted and the output power suppressed or enhanced depending upon the phase of the mismatch, over 100 kW of power could be achieved through adjustment of the beam voltage and drive power. A further achievement was the good beam transmission of 99.9% under DC conditions and 99.2% under full RF output power conditions at the high band edge which corresponded to the lowest beam transmission frequency.

Additional characterization of the klystron at NASA's Goldstone Facility included the careful measurement of all of the fundamental phase pushing factors at the center frequency and at two operating output power levels. A data acquisition program was developed which monitored and captured not only the basic phase data but also fluctuations in half a dozen other parameters that could have a significant impact upon the measured phase such as beam voltage and coolant temperature variations. While one parameter was varied in a controlled manner, the contribution of these other variations could then be subtracted from the measured data which was then smoothed and fit with a least squares fit line to obtain the given pushing factor. Figure 3 shows one example of the fitting of the data for variations in the body coolant temperature while Table II summarizes all of the pushing factors found. Very good fit lines were obtained for the beam voltage, body coolant temperature and drive power data while the heater voltage and solenoid current were less well fit; those variations were small and difficult to measure so those pushing figures should be considered approximate.

**Figure 1.** Photograph of the klystron.

**Table I.** Nominal Operating Parameters

| Parameter | Value |
|---|---|
| Frequency | 7190 MHz |
| Power | 110 kW |
| Gain | 47 dB |
| Bandwidth | > 90 MHz |
| Beam Voltage | 38.5 kV |
| Beam Current | 7.9 A |

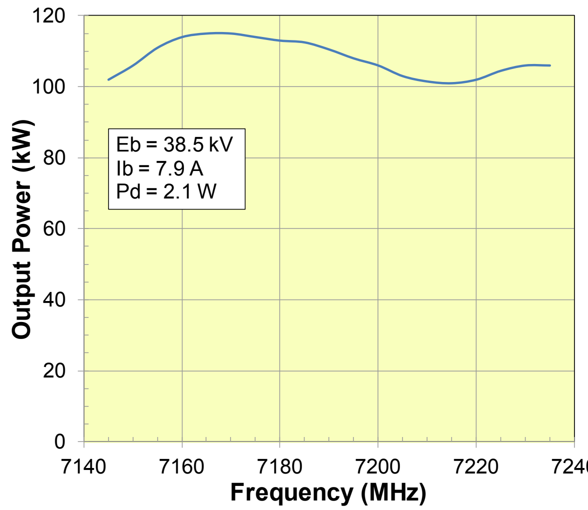


**Figure 2.** Measured instantaneous bandpass.

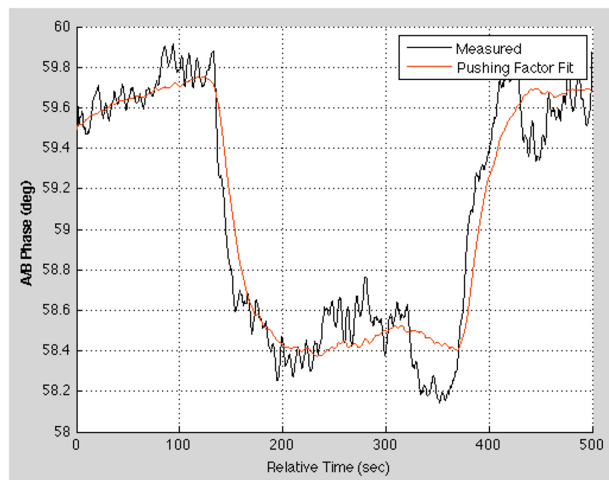


**Figure 3.** Measured phase variation and fit line for changes in body coolant temperature.

**Table II.** Measured Phase Pushing Figures

| Parameter | Value |
|---|---|
| Beam Voltage | 30.5°/kV |
| Drive Power | -4.4°/dB |
| Coolant Temperature | -0.6°/°C |
| Solenoid Current | 0.14°/% |
| Heater Voltage | -0.6°/V |