

# Design of a wideband 140 GHz, 1 kW Gyro-Amplifier

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## Abstract

The design and simulation results for a 140 GHz, 1 kW gyro-amplifier are presented. A bandwidth of over 1 GHz is required at a saturated gain of 50 dB. The operating mode will be the TE<sub>(0,2)</sub> mode and distributed loss is employed to stabilize the circuit. The amplifier will be capable of amplifying short pulses on the nanosecond scale.

## Introduction

A novel, low voltage gyro-amplifier is under development for Dynamic Nuclear Polarization (DNP) enhanced Nuclear Magnetic Resonance (NMR) spectroscopy experiments in the Francis Bitter Magnet Laboratory at the Massachusetts Institute of Technology, Cambridge, MA. In order to increase the Signal-to-Noise Ratio (SNR) of the spectrum, the sample is polarized by millimeter-wave radiation (referred to as simply MMW) introduced into the DNP probe near the electron Larmor frequency and by radio frequency radiation near the nuclear Larmor frequencies. SNR enhancement factors on the order of several hundred are possible using this technique [1-2].

## Amplifier system

The spectroscopy system consists of three major sub-systems: The transceiver that sends low power pulses to the input of the gyro-amplifier and detects the DNP signals, the gyro-amplifier, and the DNP probe system. The transceiver will generate a sequence of 50 to 100 mW phase-controlled nanosecond-scale pulses at 140 GHz. During this sequence, which may last up to 10  $\mu$ s, the gyro-amplifier will actively amplify these short pulses to 1 kW. A novel feature of this amplifier is its low beam power, which makes it difficult to achieve wide bandwidth and high gain.

The gyro-traveling wave tube (gyro-TWT) architecture is preferred over the alternative gyroklystron architecture due to its simpler interaction structure and wide bandwidth capability. The specifications for the gyro-TWT are listed in Table 1.

Table 1: Amplifier Specifications

Parameter	Value
Maximum output power	1 kW peak
Minimum pulse width	1 ns or less
Phase stability	< 1° over a macro pulse
Amplitude stability	< 1% over a macro pulse
Minimum bandwidth	1 GHz
Saturated gain	≥ 50dB

The TE<sub>02</sub> operating mode was chosen for the gyro-amplifier. While lower order modes such as the TE<sub>11</sub> and TE<sub>01</sub> mode are attractive as far as mode competition and coupling are concerned, they also result in much higher heating of the loss-loaded walls and have higher sensitivity to fabrication tolerance.

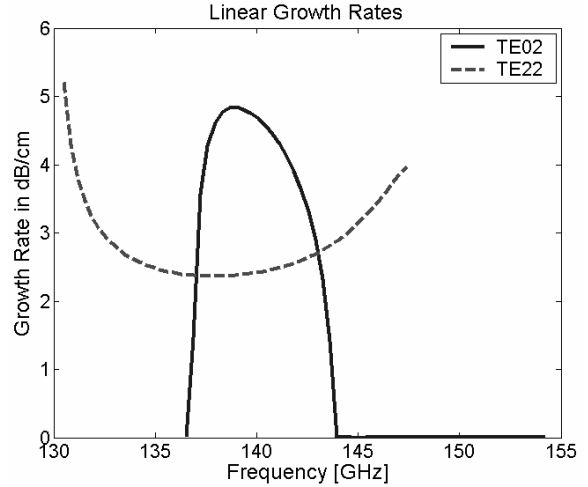


Fig. 1: Linear growth rates for the TE<sub>02</sub> and TE<sub>22</sub> modes.

Table 2: Design Operating Parameters

Beam voltage, $V_0$	30 kV
Beam current, $I_0$	0.5 A
Beam pitch factor, $\alpha$	1.0
Beam radius	0.64 mm
Frequency	140 GHz
Operating mode	TE <sub>02</sub>
Peak magnetic Field	5.05 T

In order to keep the efficiency to a reasonable level, the high beam coupling of the first radial Bessel maximum is necessary. The design operating parameters for the amplifier are shown in Table 2.

Using linear theory code [3-4] for a straight pipe with an electron beam pitch factor of 1.0, a transverse velocity spread of 3% and a 99.5% grazing magnetic field, Fig. 1 was produced showing the growth rates of the TE<sub>02</sub> mode along with the competing TE<sub>22</sub> mode.

The nonlinear, time dependent simulation code MAGY [5] was utilized to design a simple 15 cm long, 2.43 mm radius straight lossy pipe structure. Fig. 2 shows 1 kW output pulses produced for 10 mW square input pulses of various pulse widths. For this simulation, the transverse velocity spread was 5%, the surface resistance was 3.8 ohms, and the magnetic field was 5.04 T. The simulations show over 50 dB of saturated gain and a 3 dB bandwidth of over 1 GHz. This simulation also shows that the bandwidth limits the output pulse width to a minimum value of around 1 ns (FWHM).

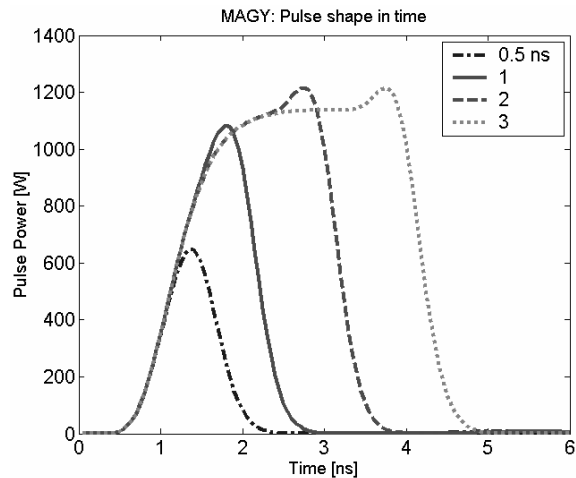


Fig. 2: Output pulses for a 10 mW square input pulse of varying width as predicted by MAGY.

### Superconducting Magnet

A 6.2 T superconducting magnet was acquired from Magnex Scientific, Ltd. The magnet is actively shielded to reduce the stray magnetic fields. The magnet has a 28 cm flat field region with  $\pm 0.5\%$  homogeneity and a 127 mm warm bore. A photo of the magnet is shown in Photo 1.

### Present activities and plans

We are investigating the electron gun that will be needed to produce an electron beam of sufficiently high quality for this amplifier circuit.

The power supply will be required to supply 30 kV at 1 A with a pulse length of up to 20  $\mu$ s. In order to meet the specification on phase stability, the peak-to-peak ripple will have to be 0.1% or better.

There is also interest in the possible use of novel circuit structures to widen the bandwidth and produce pulses with squarer edges.

### References

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Photo 1: A photograph of the 6.2 T superconducting magnet during the nitrogen pre-cool phase.