A SOLID STATE DRIVEN, PARASITIC OSCILLATION SUPPRESSED, 17 GHz HIGH GAIN TW KLYSTRON FOR STABLE OPERATION WITH HIGH GRADIENT LINAC STRUCTURES*

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Abstract

The gain of a high power TW relativistic klystron can be increased substantially with the use of a varying phase velocity, large beam aperture, lengthened output structure, designed for asynchronous interaction to control space charge fields and provide near-adiabatic bunch compression during the power extraction process. While this technique enables the replacement of a pulsed vacuum tube driver system with a small, inexpensive solid state RF source, lengthening the output circuit increases the number (and reduces the separation) of the longitudinal mode resonances in the TM_{01} operating band. Thus, the probability of exciting parasitic oscillations is increased, especially when the klystron is operated into a mismatched load or a high Q structure. The prevention of such oscillations, even when in close proximity to the operating frequency, using a technique that is unaffected by the phase or amplitude of reflected signals is described; and test results are presented of a solid state driven, 76dB gain 17GHz TW relativistic klystron recently installed in the linac test facility at the MIT Plasma Science and Fusion Center.

INTRODUCTION

With prior TW relativistic klystrons (TWRKs), the output circuits were designed primarily to extract maximum power from the beam using a short, tapered phase velocity circuit to provide near-synchronous interaction with the peak of the growing TW electric field [1]. In achieving a high gain performance by exploiting the unique ability of a TW circuit to establish a growing electric field gradient that continuously opposes the space charge debunching gradient, the bunch charge centroid must be suitably displaced from the peak of the induced circuit field, and the amplitude of this field must remain substantially greater than the space charge gradients. Since the phase displacement prevents direct interaction with the peak decelerating field, an effective reduction of beam energy for maintaining a high conversion efficiency requires the output structure to be lengthened; and this, in turn, will cause the separation between the increased number of TM_{01} longitudinal mode resonances to be reduced, and the starting current threshold of higher order mode (HOM) instabilities to be lowered.

Unlike the successful suppression of HOM instabilities in TWRK high power output structures by using differential absorption and frequency incoherency techniques [2], the suppression of destabilizing TM_{01} mode oscillations excited within the fundamental operating band presents a unique design challenge. This is especially the case when a high gain klystron is used with a high Q load because the narrow acceptance band can result in a reflection driven klystron oscillation in very close proximity to the operating frequency. An instability of this type was encountered during development of MKIII, a prototype high gain 17GHz TWRK. This tube was tested extensively with the MIT modulator [3] in 2003 and demonstrated stable high power performance with the dual output arms connected to ceramic window water loads having a maximum VSWR of 1.5 (refer Table 1) [4]. Subsequently, the MKIII TWRK was connected via a triple hybrid power divider and a diagnostics network to a 17GHz linac; and, at certain settings of the hybrid phase shifter, RF pulse amplitude instabilities were experienced with simultaneous emission of a 17367MHz signal. Further investigation confirmed this to be a next-nearest-neighbor TM_{01} mode, reflection induced resonance, suggesting that parasitic oscillations of this nature would be avoided if the propagating, longitudinal mode discrete frequencies (typically between $2\pi/3$ and the π cutoff, and having high beam coupling factors) were prevented from reflecting back and being resonantly amplified in the TW output structure.

Table 1: Test Results Obtained with the MKIII TWRK Terminated with Ceramic Window Water Loads

Electron Gun Voltage	545	kV
Collector Current	91	A
Electron Beam Power	50	MW
Drive Frequency	17136	MHz
Drive Pulse Width	100	ns
Drive Cavity Input Power	1.8	W
Output RF Power	25.5	MW
RF Conversion Efficiency	51	%
Saturated Gain	71.5	dB

SUPPRESSION OF TM_{01} INSTABILITIES

The non-availability of 17GHz high peak power recirculators, and issues relating to ferrite lifetime, physical constraints and development costs, discouraged the pursuit of a recirculator solution. Also, resonant cavity filters (attached to the klystron output arms) have limitations in fully discriminating between closely spaced resonances, and the coupling can be altered by the phase of the reflections. The difficulty in isolating a TM_{01} next-nearest-neighbor resonance is clearly indicated in the

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Figure 1A frequency scan of the new high gain klystron showing the typical Q spread constriction between the 2π/3 mode (17144) and the neighboring 17392MHz resonance in the TW output structure.

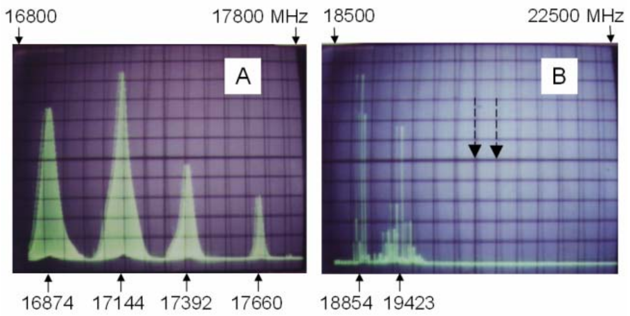


Figure 1: Frequency scans of the new high gain TW structure (designed for the solid state driven klystron). (A) Upper region of the TM_{01} operating band, (B) dipole HOM region indicating suppression of the highly undesirable HEM_{11} modes, at 20460±50MHz (2π/3) and at 20780±50MHz (π).

Simulation findings, confirmed by cold test measurements, indicated that the 2π/3 operating mode would be safely isolated from the TM_{01} higher frequency reflections by using a very sharp cutoff, frequency discriminating circuit in the output arms of the klystron so that, with (say) a short circuit at the output of the frequency discriminator, the power reflected back to the klystron would be attenuated by 25-30dB as the frequency changes from 17200 to only 17300MHz.

Guided by the above specifications, a compact suppression circuit was developed using an array of tapered impedance coupling apertures in the narrow wall of a short length of WR62 waveguide, and eight extraction channels with symmetrically folded and terminated arms, as illustrated in the Figure 2 simulation. A further design objective was that the high power suppression circuit be configured to allow machining as a monolithic assembly, and to enable installation in an existing 12 inch section of rectangular waveguide at the output of the TWRK. Views of the suppression circuits, in a dry hydrogen furnace braze setup and during final assembly, are shown in Figure 3.

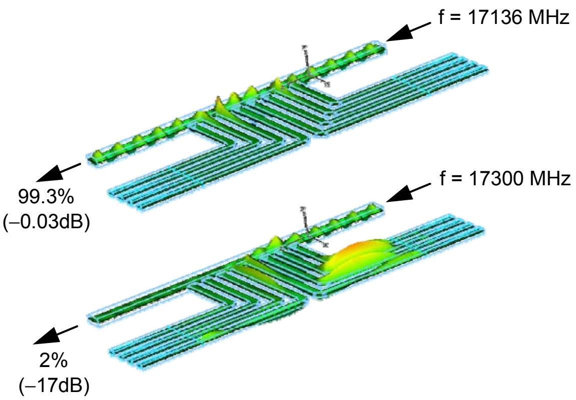


Figure 2: Simulated power transmission characteristics of the TWRK suppression circuit.

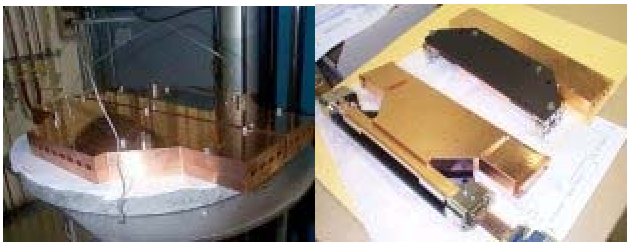
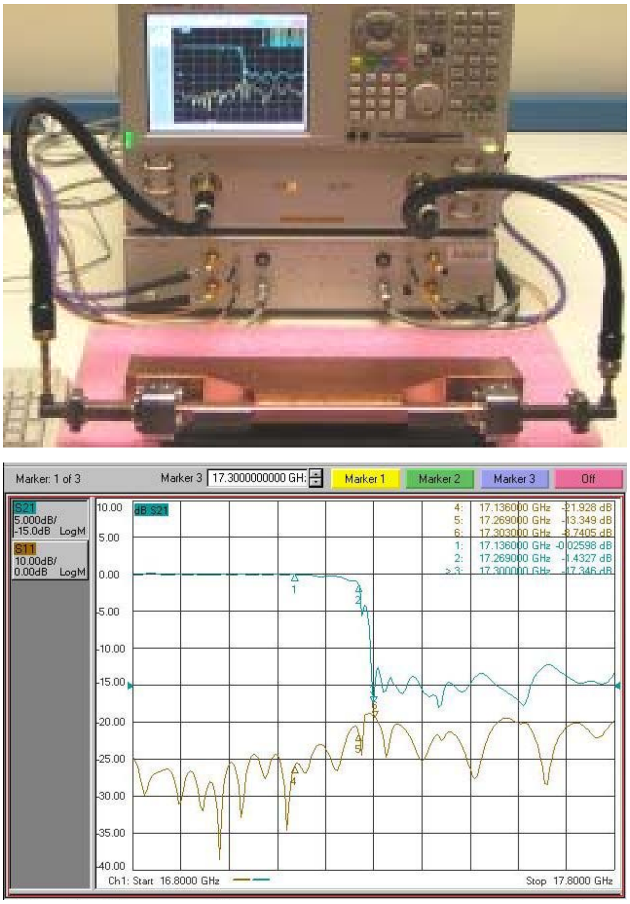


Figure 3: Suppressor assemblies shown during a brazing procedure and after fitting the rigid protection brackets.

Tests performed on the completed suppressor assemblies indicated that the design objectives had been achieved, and cold tests repeated at MIT (refer Figure 4) confirmed that no internal damage had occurred during shipment. Before the new higher gain TWRK was evaluated, the MKIII klystron with a suppressor in each output arm was reconnected to the linac with the same waveguide configuration used when the TM_{01} (17367MHz) instability was encountered; and extensive testing at high power levels demonstrated stable operation without evidence of the parasitic oscillation.



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4:   17.136000 GHz  -21.928 dB
5:   17.269000 GHz  -13.349 dB
6:   17.303000 GHz  -8.7405 dB
1:   17.136000 GHz  -0.02598 dB
2:   17.269000 GHz  -1.4327 dB
> 3: 17.300000 GHz  -17.346 dB
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Figure 4: Typical VNA test setup showing the suppression circuit transmission loss of <1% at 17136MHz, and the 15dB roll-off between 17250 and 17300MHz. (Photograph and measurements courtesy of MIT.)

SOLID STATE DRIVEN KLYSTRON

The 17GHz solid state amplifier (shown in Figure 5A) was specified to have a small signal gain of 30dB minimum, a saturated output power of +39dBm, a maximum pulse repetition frequency of 60Hz and a pulse width range from 0.1 to 1.0µs. The amplifier input pulse was derived from the same pin-diode modulated cw RF source (HP8671B synthesizer) used to excite the existing TWT driver system. To ensure that a minimum input power of 2W would be available at the klystron drive cavity, the drive line losses were limited to 5dB by installing the solid state driver in close proximity to the klystron and pulsed HV modulator. The driver system components, comprising the 30dB gain amplifier mounted on a fan cooled heat sink and a 15V dc power supply, were enclosed in an EMI shielded chassis. Despite the high noise environment and a cascaded RF system gain of 110dB, no pulse jitter or noise related difficulties were encountered during high power operation of the system.

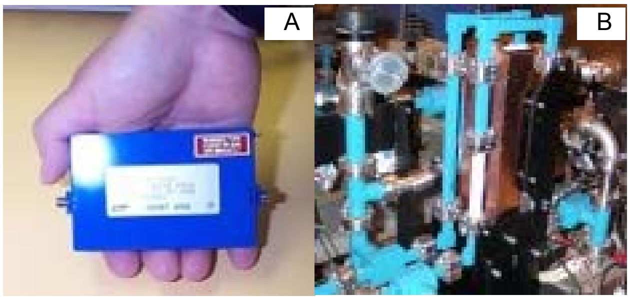

Figure 5: (A) View of the compact +39dBm, 17GHz solid state amplifier. (B) View of vertically mounted suppression circuits inserted into the waveguide network and connected to the TWRK output arms.

The high gain asynchronous TW output structure, comprised ten 2π/3 mode varying phase velocity cavities, including the racetrack shaped dual output cavity; and the RF performance was evaluated with the output arms first terminated with water loads, and then connected via the suppressor circuits and a triple hybrid power controller to the 17GHz linac. (Figure 5B shows how the suppression circuits were integrated into the existing rectangular waveguide system.) High power RF testing of each configuration demonstrated stable oscillation-free performance; and RF waveforms showing the pulse integrity of the driver and high power output pulses of the high gain TWRK are shown in Figures 6A and 6B, respectively.

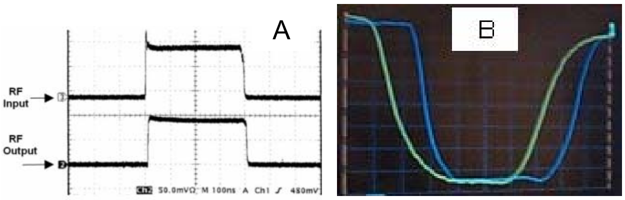

Figure 6: (A) RF waveforms showing the pulse integrity of the 17GHz solid state amplifier. (B) RF power pulse at each output arm of the high gain TWRK. Solid state drive = 510mW. Dual arm output power = 22.3MW.

The transfer curve characteristics of the MKIII and the new high gain TWRK are shown compared in Figure 7.

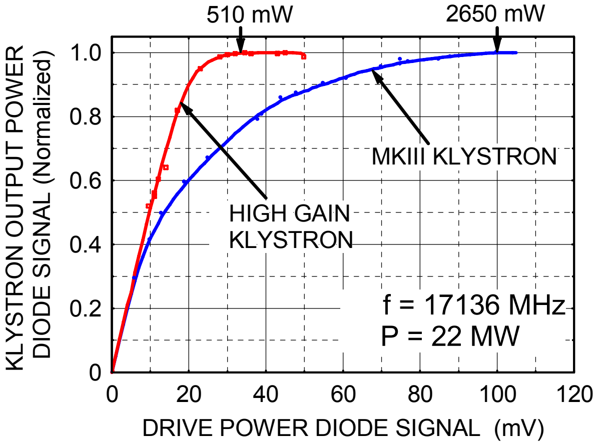

Figure 7: Transfer curve comparison of the MKIII and high gain 17GHz TWRKs.

SUMMARY

- Two 17GHz high gain TW klystrons using compact suppressor assemblies have successfully demonstrated stable high power RF performance operating into a high gradient linear accelerator.
- A high peak power, parasitic oscillation suppressor was developed having a transmission loss of <1% at 17136MHz, and a return loss of 30dB from 17300 to 17800MHz, independent of the reflection phase.
- A 17GHz klystron gain of 76dB was achieved with an asynchronous interaction TW output structure and thereby enabled a small solid state amplifier to be used as a driver.
- A 17GHz solid state driver system has performed exceedingly well (even though installed in a high noise environment alongside a pulsed HV modulator) and has permanently replaced a previously used pulsed TWT driver system.

ACKNOWLEDGEMENTS

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