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13. ABSTRACT (Maximum 200 words)

This progress report summarizes the work done on "Improved Design Concepts for Millimeter Wave Power Sources," covering the period from March 15, 1992 to March 14, 1993. In the past year, we have designed a phase-locked, harmonic, inverted gyto-twistron, known as the phigtron. The phigtron combines a subharmonic gyro-TWT amplifier input section with a gyroklystron type output cavity. The phigtron is expected to ~~reason~~ research much higher phase-locking gain and wider bandwidth than the two cavity phase-locked gyroklystron oscillator. The efficient and stable of operation of this phase-locked harmonic gyrotron will be obtained through the implementation of mode selective interaction circuits. The proof-of-principle cold test results of such circuitry have recently been obtained indicating that the technical realization of this research concept is feasible. The construction of the phigtron hot test laboratory facility is now actively ~~procding~~. proceeding.

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Final ~~Progress~~ Report

IMPROVED DESIGN CONCEPTS FOR MILLIMETER WAVE POWER SOURCES

AFOSR Grant No. AFOSR-90-0142A

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Contents

Executive Summary

This progress report summarizes the work done on "Improved Design Concepts for Millimeter Wave Power Sources," covering the period from March 15, 1992 to March 14, 1993.

In the past year, we have designed a phase-locked, harmonic, inverted gyro-twistron, known as the phigtron. The phigtron combines a subharmonic gyro-TWT amplifier input section with a gyroklystron type output cavity. The phigtron is expected to reach much higher phase-locking gain and wider bandwidth than the two cavity phase-locked gyroklystron oscillator. The efficient and stable of operation of this phase-locked harmonic gyrotron will be obtained through the implementation of mode selective interaction circuits. The proof-of-principle cold test results of such circuitry have recently been obtained indicating that the technical realization of this research concept is feasible. The construction of the phigtron hot test laboratory facility is now actively proceeding.

1 Design Study of a Phase-Locked, Harmonic, Inverted Gyro-Twistron (Phigtron)

1.1 Summary of the Design

The phigtron is a hybrid gyrotron having an inverted twistron layout with the output cavity operating as a monotron oscillator at the second harmonic of the electron cyclotron frequency. The gyro-TWT mechanism is used with subharmonic injection to prebunch the electron beam during its transport through a mode converter chain, interaction circuit and an isolation, built-in attenuator. The beam current will, therefore, contain harmonic components at the entrance to the oscillator cavity. The phase of the output radiation is thus controlled by an input signal at a lower frequency. The ECRM interaction in the prebunch section, which is one-third of a normal gyro-TWT in length, will occur at the fundamental cyclotron frequency because a uniform magnetic field is applied along the axis extending from the output to the input region. A more detailed block diagram of the gyrotron itself is given in Fig. 1. Figure 2 depicts the internal construction of the tube. Table 1 shows a preliminary estimate of the performance parameters of the tube.

1.2 Unique features of the phigtron

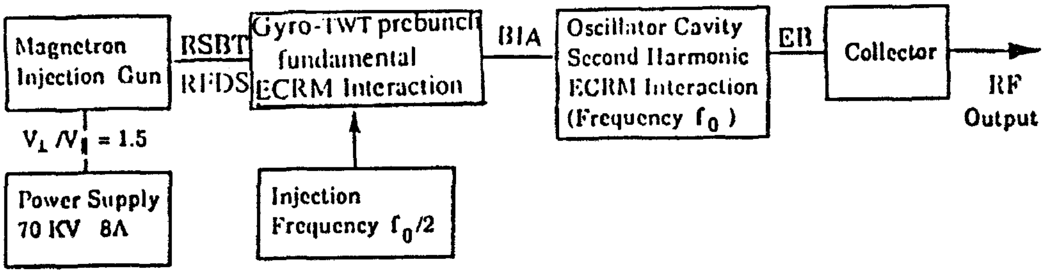
a) The phigtron uses a patented complex cavity[1] that has superior mode selectivity, high power capability, and special rf field profile, resulting in stable, efficient harmonic ECRM operation and high output mode purity (TE_{03}). The TE_{03} mode has low propagation loss and can be efficiently converted into the desired TE_{11} mode for radar and communication systems.

b) A novel, short gyro-TWT, which is free from various kinds of spurious oscillators through the use of a mode selective interaction circuit, is employed as a prebunching section. Thus, a high phase-locking gain is expected.

c) Subharmonic injection and high phase-locking gain make it possible to phase control the 34.5 GHz output radiation of several hundred kilowatts by using a solid state injection source at 17.5 GHz.

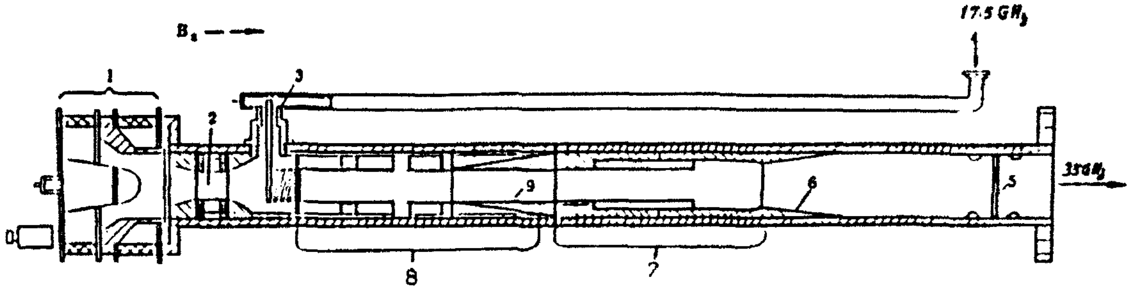
d) A wide bunching bandwidth combined with output microwave filter techniques will offer wideband operating performance.

We plan to apply for a U.S. patent on the phigtron.



RSBT: Radiation Suppressed Beam Tunnel
RFDS: Radiation Free Drift Section
EB: Spent Beam
BIA: Build-in Attenuator

Figure 1. Block diagram of the harmonic phigtron.



1. MIG Gun, 2. Radiation Absorber, 3. Wide-Band Input Coupler, 4. Input Waveguide, 5. Wide Band Output Window, 6. Collector, 7. Complex Cavity, 9 Concentration Attenuator, 8 Beam-Wave Interaction Structure in the shape of a chain of $TE_{01} \rightleftharpoons TE_{02}$ mode ~~convertor~~ converters---TWT prebunching section

Figure 2. Phase-locked, harmonic, inverted gyro-twistron (phigtron) with subharmonic injection.

Table 1. Expected performance of the 35 GHz phigtron.

Output center frequency	35 GHz
Instantaneous bandwidth	3%
Output power	>200 kW
Efficiency	>40%
Gain	50 dB
Harmonic number	2
Output mode	TE_{03}
Magnetic field	6.5 kG (max.), compatible wtih modern permanent magnets (Ne/Fe/B)
Gun type	Magnetron Injection Gun
Gun voltage	60 kV
Gun current	12 A

2 Proof-of-Principal Demonstration of the Mode Selective Circuits for Phase-Controlled Harmonic Gyrotron Oscillators and Amplifiers

The output of the phigtron is a resonant type of mode selective circuit, i.e., the special complex cavity which has been successfully employed in a free running gyrotron oscillator operating at the second harmonic of the electron cyclotron frequency [1]. The non-resonant circuit consists of a mode launcher/input coupler and a converter chain which transforms the TE_{0n} to a TE_{0m} mode. This circuit is incorporated with a non-circular electric mode disk attenuator and an embedded, gradually varying structure which will attenuate all modes. This circuitry was originally designed for a high performance gyro-TWT operating at a higher cyclotron harmonic frequency [2], as shown in Figs. 3, 4 and 5, because of its expected superior ability to suppress spurious mode competition. This nonresonant circuit will be used as the input section of the phigtron. We have performed two sets of cold test experiments to demonstrate the operation mechanism of the mode launcher/input coupler and the mode converter chain circuit separately.

2.1 Preliminary Experimental Results

First, the characteristics of the mode launcher/input coupler, constructed for operation at K_u band frequencies were measured. The electromagnetic radiation energy was transformed from the coaxial TEM mode to the TE_{02} circular waveguide mode through a complex structure implemented with a short coaxial line, a closely wound helix radiator, a cage transition, a vane filter, and a tunable reflector. The reflection and transmission characteristics were measured. A 3 dB bandwidth of about 10% was obtained with the potential for considerable enhancement as shown in Fig. 6 and Table 2. Existence of the TE_{02} mode was demonstrated by an LCD (liquid crystal display) mode pattern which was consistent with theoretical expectations. Second, the mode converter chain circuit was constructed and measured also. A total loss in the mode conversion circuit (without built-in attenuators) of less than 2 dB was obtained within the frequency range of 34 to 37 GHz, approximately reaching the designed requirements.

2.2 Conclusions

Various versions of the mode selective circuit which are all incorporated with near perfect conversions between specific modes have been demonstrated to be viable interaction structures for a series of new phase-controlled harmonic gyrotron devices including gyro-TWT amplifiers, electromagnetically tunable gyro-BWOs and gyro-BWAs, and phase-locked inverted gyro-twistrons with subharmonic injection.

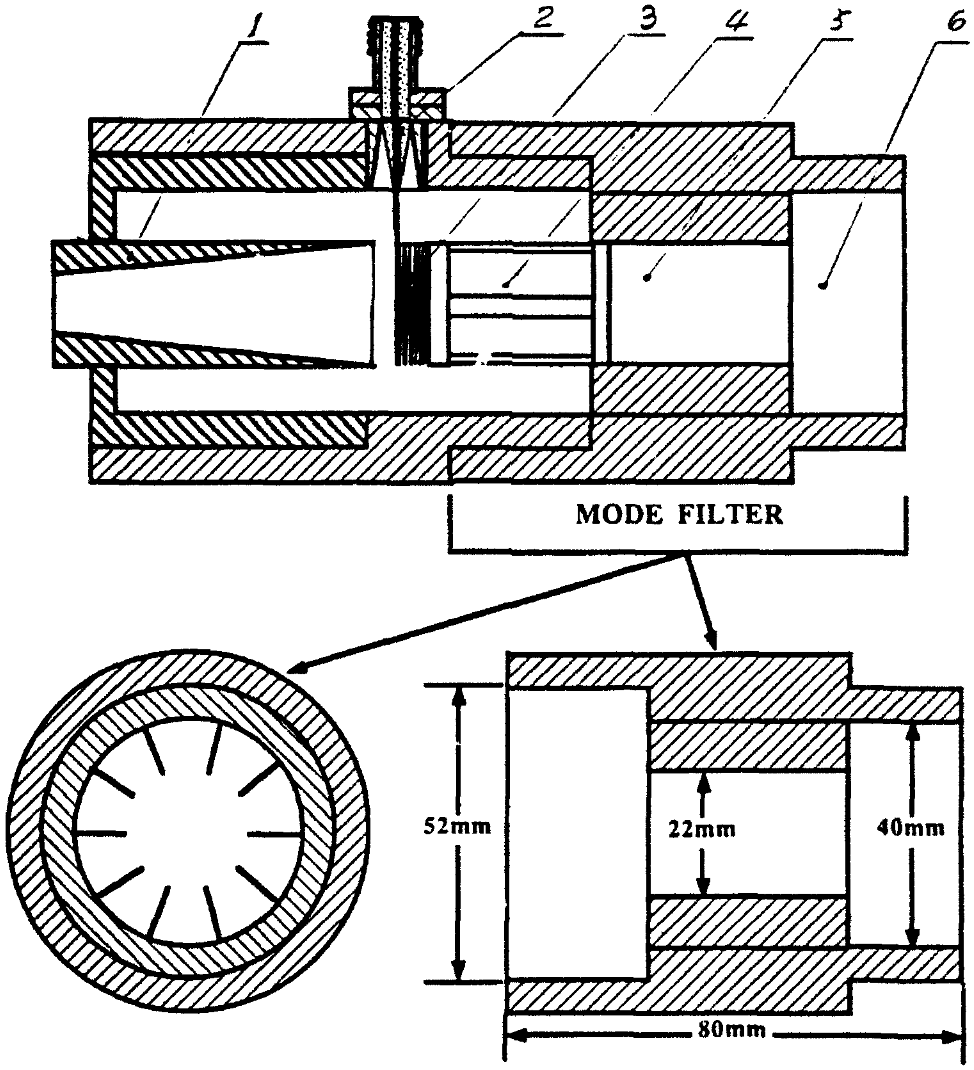


Figure 3. Ku band TE_{02} mode selective input coupler: 1) tuner, 2) coaxial line input, 3) helix radiator, 4) cage transition, 5) vane filter passing TE_{011} mode, 6) TE_{02} mode output.

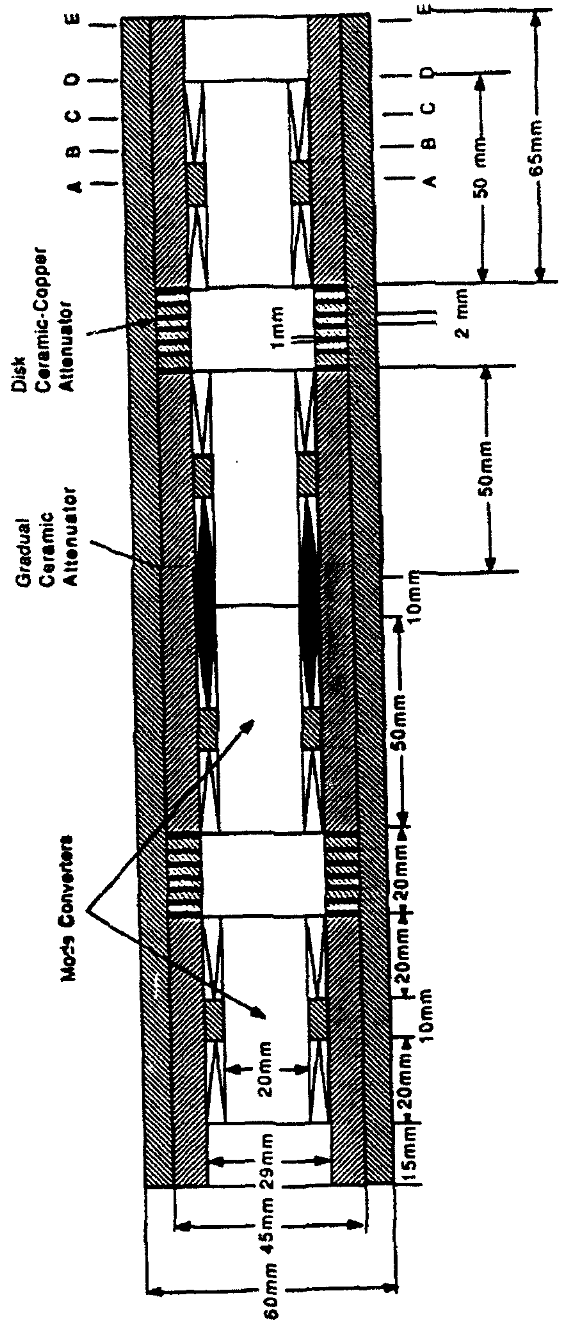


Figure 4. *Ka* band mode selective interaction circuit.

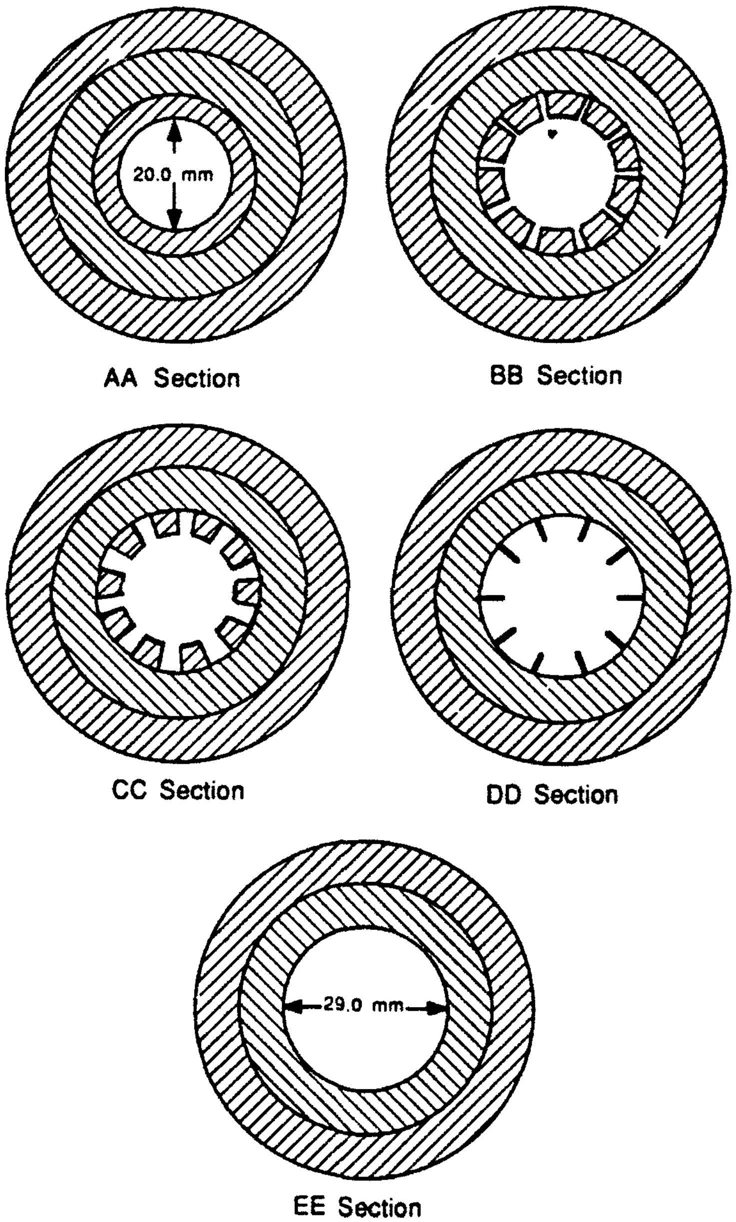


Figure 5. TE_{0n} mode converter cross-sectional view.

Table 2. Mode selective input coupler results.

1. Upper trace (channel 1) : Reflection.
   Lower trace (channel 2) : Transmission.

2. TE_{02} Measured Cutoff Frequency : 16.68 GHz.
   TE_{02} Designed Cutoff Frequency : 16.62 GHz.

3. Maximum reflection in cutoff region.

4. Transmission Bandwidth greater than 900 MHz.

5. Transmission and reflection perfomance are unchanged when a copper/dielectric disk wave-guide (length = 22 mm) is inserted.

6. Points 2 and 5 indicate that the output mode is TE_{02}.

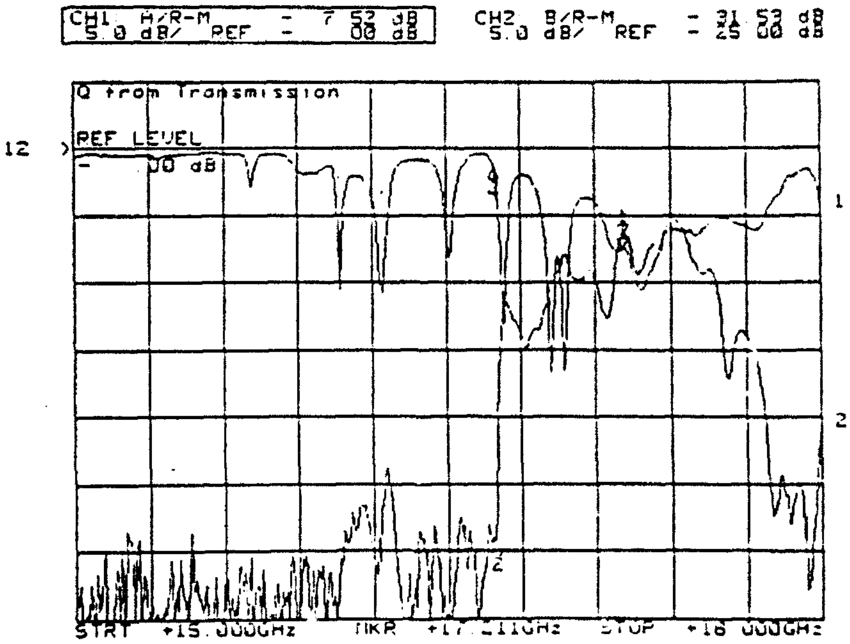


Figure 6. Mode selective input coupler results.

3 References

1. H. Guo, D.S. Wu, G. Liu, Y.G. Miao, S.Z. Qian, and W.Z. Qin, IEEE Trans. on Plasma Sci. **18**, 3, 326-333 (1990).

2. H. Guo, Y. Carmel, B. Levush, T.M. Antonsen, S. Cai, L. Chen, and V.L. Granatstein, IEDM Technical Digest, 783-785, Washington, DC, December 8-11, 1991.

Appendix: Conference Abstracts and Journal Publications Supported by Grant No. AFOSR-90-0142A (in whole or in part)

C1. H. Guo, Y. Carmel, B. Levush, T.M. Antonsen, Jr., S. Cai, L. Chen, and V.L. Granatstein, "Design and Development of a High Performance Gyro-TWT Amplifier Operating at a Cyclotron Harmonic Frequency," Proceedings of the International Electron Devices Meeting, Washington, DC, December 8-11, 1991, pp. 783-785.

C2. H. Guo, J.P. Tate, M. Naiman, B. Levush, T.M. Antonsen, Jr., S.Y. Cai, G.S. Nusinovich, and V.L. Granatstein, "Experimental Study of the Mode Selective Circuits for Phase Controlled Harmonic Gyrotron Oscillators and Amplifiers," paper presented at the Infrared & Millimeter Wave Conference, December 1992.

C3. H. Guo, V.L. Granatstein, J. Tate, Y. Carmel, and B. Levush, "High Performance, Harmonic Gyrotron Devices Implemented with Novel, Mode Selective, Interaction Circuits," Microwave Powe. Tube Conference, Monterrey, CA, May 11-13, 1992.

C4. H. Guo, Y. Carmel, J. Tate, B. Levush, G. Nusinovich, L. Chen, and V.L. Granatstein, "Mode Selective Interaction Circuits and New Compact, Harmonic, Phase-Controlled Gyrotron Devices," 9th International Conference on High Power Particle Beams, Washington, DC, May 25-29, 1992.

C1. DESIGN AND DEVELOPMENT OF A HIGH PERFORMANCE GYRO-TWT AMPLIFIER OPERATING AT A CYCLOTRON HARMONIC FREQUENCY

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ABSTRACT

A 35 GHz, gyro-TWT amplifier designed for operation at the second harmonic of the cyclotron frequency is presented here. It is expected that 200 kW peak output, 15% bandwidth, 40 dB saturated gain, and efficiency of 25% can be obtained. The design may be extended to 94 GHz operation at the fourth cyclotron harmonic. These harmonic gyrotron amplifiers will operate at a magnetic field strength which is compatible with modern permanent magnet technology.

INTRODUCTION

The realization of harmonic, smooth waveguide gyro-TWT amplifiers is often complicated by a severe problem of parasitic backward wave oscillations from the fundamental as well as other harmonics in addition to circuit feedback oscillations of the operating mode resulting from strong reflections at the output end. For example, conventional smooth and tapered wall gyro-TWT amplifiers designed for TE_{02} mode are expected to be subject to a severe problem of oscillations as illustrated in Fig. 1.; the expected spurious oscillations are as follows:

1. Absolute instability at the fundamental cyclotron frequency ($s = 1$) related to the backward branch of the TE_{21} mode.
2. Absolute instability at the second cyclotron harmonic ($s = 2$) related to the backward branch of the TE_{22} mode.
3. Absolute instability at the third cyclotron harmonic ($s = 3$) related to the backward branch of the TE_{13} mode.
4. Parasitic oscillations due to feedback of the operating mode caused by end reflections (e.g. at the output window or collector).

Therefore, gyro-TWT harmonic operation can be realized only if these problems can be effectively solved. Recent impressive results of a second harmonic gyrotron free running oscillator with a special complex cavity [1] inspired us to initiate a research program aimed at demonstrating the feasibility of a second harmonic, wideband, medium power, millimeter wave compact gyro-TWT amplifier for radar and communication. The device is under development (see Fig. 2). The major scientific issues are the development of methods to effectively suppress all the parasitic oscillations in the harmonic gyro traveling wave tube and the techniques to attain wideband and highly efficient operation. In the following we summarize the important design features of the first experimental gyrotron traveling wave amplifier operating at harmonic cyclotron frequency. The expected performance parameters are given in Table 1.

A NOVEL BEAM WAVE INTERACTION STRUCTURE

The interaction circuit is made of a chain of back-to-back mode converters separated by a short section of smooth waveguide (see Fig. 2). Each individual mode converter is shown in Fig. 3. The net result of using this interaction circuit would be that the forward going wave (to be amplified) will periodically change from TE_{02} to TE_{03} and back to TE_{02}. This chain of mode converter allows the hybrid TE_{02}/TE_{03} mode to propagate as if in a constant cross section waveguide. All other TE^* modes and all TM^* modes will have axially varying cutoff wavenumbers shown in Fig. 4 due to the fact that the cross section of the mode converter continuously changes along its axis. The periodic variations of the cutoff frequency of the spurious modes along the axis will spoil the synchronism with the electron beam.

Under these conditions it is expected that the start oscillation current for the spurious modes will increase dramatically. By drastically reducing the problem of mode competition, a large beam current can be maintained in the tube without oscillation. This large beam current will result in a high gain.

A BUILT-IN MATCHING ATTENUATOR

The built-in attenuator (labelled 7 in Fig. 2) is designed for two purposes. The first is to eliminate circuit feedback oscillation induced by end mismatch at the input and output of the interaction structure. The second is to further enhance the beam threshold current of gyro-BWO type oscillation of spurious modes (due to electron feedback) and consequently to be favorable for reliably suppressing various kinds of possible absolute instabilities. The geometry of the attenuator is shown in Fig. 5. It is expected that an excellent match at both sides of the attenuator can be reached because of its cross section gradually varying with the axial distance. Although the attenuator has considerably large attenuation (> 50 dB) to the wave propagating in both forward and backward directions, the design arrangement shown in Fig. 2 still allow normal amplification of input signal. This is because the distance between the input coupler and the attenuator is adjusted to allow a sufficient degree of bunching, and the amplified signal will be induced in the interaction circuit downstream from the attenuator. The built-in attenuator is functionally similar to the sever technique which has been successfully used for the gyro-TWT operating at fundamental cyclotron frequency [2] except that better matching is expected.

A SPECIAL TE_{0n} MODE INPUT COUPLER

The last important feature of our harmonic gyro-TWT design is the wideband input coupler which is depicted in Fig. 6 (see also Fig. 2). This is a helical mode launcher, similar to those used in conventional helix TWTs. The helix wire will be mounted at a radial node of the E_θ field for the TE_{03} mode. Helical couplers of this type are wideband in nature (50% and over) and in our proposed device will excite the desired mode with very high purity.

EXPECTED PERFORMANCE PARAMETERS

The expected performance parameters of the proposed second harmonic amplifier are summarized in Table 1. If successful, the performance of the amplifier will be a major advance in coherent source capabilities in this frequency range. The fact that this harmonic gyrotron is compatible with modern permanent magnet technology will make it an attractive candidate for radar, communication, and commercial applications.

It is expected that the concepts which will be developed during the research can be further extended to higher frequencies. We intend to analyze the feasibility of a fourth harmonic gyro-TWT for 94 GHz operation.

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[1] H. Guo, D.S. Wu, G. Liu, Y.G. Miao, S.Z. Qian, and W.Z. Qin, "Special complex open-cavity and low-magnetic field high power gyrotron," IEEE Trans. on Plasma Science 18, 3 (1990).

[2] K.R. Chu, L.R. Barnett, et al., "Recent developments in gyro-TWT research in NTHU," in Technical Digest of the International Devices Meeting (IEEE, New York, 1990).

* Work supported by AFOSR.

Table 1. Expected performance of the 35 GHz, second harmonic, wide band gyro-TWT amplifier.

Output center frequency	35 GHz
Instantaneous bandwidth	>15% (5.25 GHz)
Output power	> 200 kW (peak), 10 kW (avg.)
Efficiency	> 25%
Gain	50 dB (linear), 40 dB (saturated)
Harmonic number	2
Output mode	TE_{03}
Magnetic field	6.5 kG (max), compatible with with modern permanent magnets (Ne/Fe/B)
Gun type	Magnetron Injection Gun (MIG)
Gun voltage	60 kV
Gun current	14 A

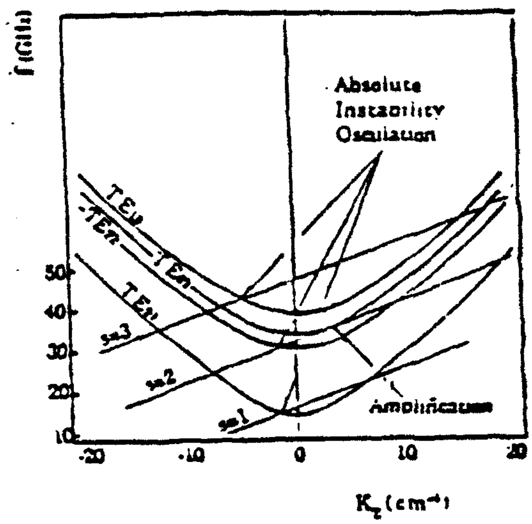
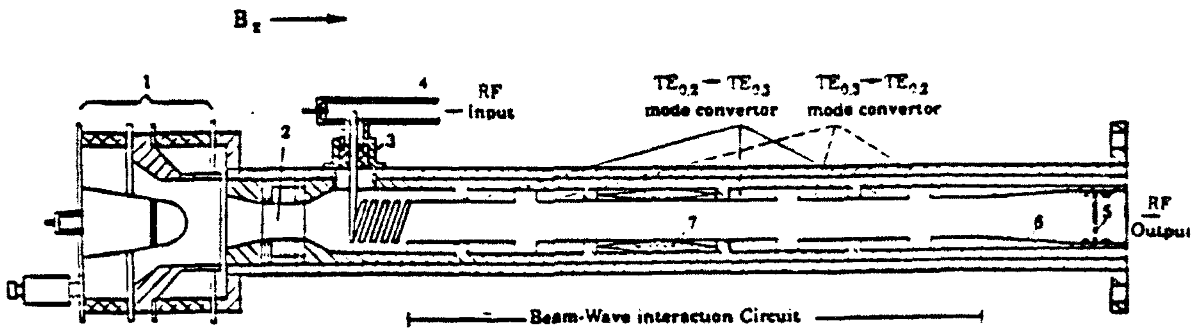


Figure 1: Dispersion curves for the TE_{21}, TE_{22}, TE_{03}, and TE_{13} modes and the beam resonance lines at the fundamental ($s = 1$), second ($s = 2$), and third ($s = 3$) cyclotron harmonic showing the mode competition in harmonic smooth wall gyro-TWTs.



1. MIG Gun. 2. Radiation absorber. 3. Wide Band Input Coupler.
4. Input Waveguide. 5. Wide Band Output Window. 6. Collector.
7. Build-in Attenuator

Figure 2: Wideband harmonic gyro-TWT amplifier.

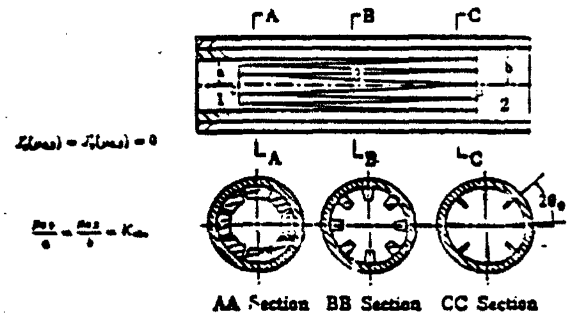


Figure 3. Special mode converter for $TE_{02} \rightleftharpoons TE_{03}$.

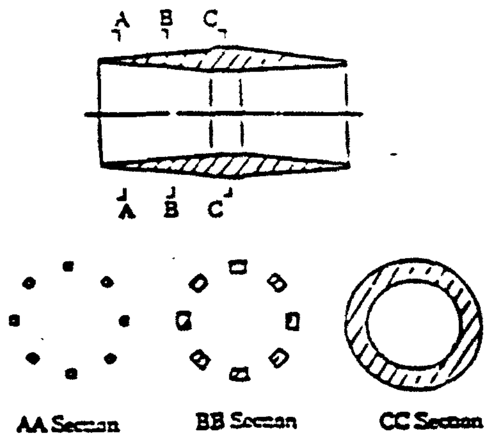


Figure 5. Attenuator for harmonic gyro-TWT amplifier. to be mounted inside of the mode converters.

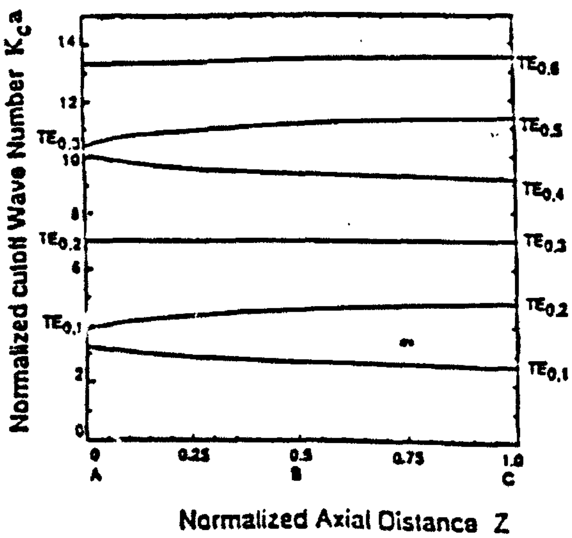


Figure 4. Normalized cutoff wavenumber versus axial distance for our mode converter.

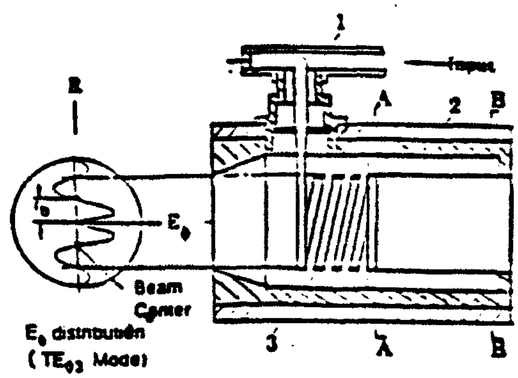


Figure 6: A wideband input coupler for the proposed gyro-TWT amplifier.

Paper prsented at Infrared & Millimeter Wave Conference, Dec. 1992

EXPERIMENTAL STUDY OF THE MODE SELECTIVE CIRCUITS FOR PHASE-CONTROLLED HARMONIC GYROTRON OSCILLATORS AND AMPLIFIERS

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ABSTRACT

The cold test results of the mode selective circuit, which consists of a mode launcher/input coupler and a mode converter chain interaction structure, are presented. This novel circuit is now utilized to develop several kinds of phase-controlled harmonic gyrotrons with high performance.

I. INTRODUCTION

The resonant type of mode selective circuit is the special complex cavity which has been successfully employed for a free running gyrotron oscillator operating at the second harmonic of the electron cyclotron frequency [1]. The non-resonant circuit consists of a mode launcher/input coupler and a converter chain which transforms the TE_{0n} to TE_{0m} mode. This circuit is incorporated with a non-circular electric mode disk attenuator and an embedded, gradually varying structure which will attenuate all modes. This circuitry was originally designed for a high performance gyro-TWT operating at a higher cyclotron harmonic frequency [2], as shown in Figs. 1 and 2, because of its expected superior ability to suppress spurious mode competition. We have performed two sets of cold test experiments to demonstrate the operation mechanism of the mode launcher/input coupler and the mode converter chain circuit separately.

II. PRELIMINARY EXPERIMENTAL RESULTS

First, the characteristics of the mode launcher/input coupler, constructed for operation at K_u band frequencies were measured. The electromagnetic radiation energy was transformed from the coaxial TEM mode to the TE_{02} circular waveguide mode through a complex structure implemented with a short coaxial line, a closely wound helix radiator, a cage transition, a vane filter, and a tunable reflector. The reflection and transmission characteristics were measured. A 3 dB bandwidth of about 10% was obtained with the potential for considerable enhancement. Existence of the TE_{02} mode was demonstrated by an LCD (liquid crystal display) mode pattern which was consistent with theoretical expectations. Second, the mode converter chain circuit was constructed and measured also. A total loss in the mode conversion circuit (without built-in attenuators) of less than 2 dB was obtained within the frequency range of 32 to 38 GHz, approximately reaching the designed requirements.

III. CONCLUSIONS

Various versions of the mode selective circuit which are all incorporated with near perfect conversions between specific modes have been demonstrated to be viable interaction structures for a series of new phase-controlled harmonic gyrotron devices including gyro-TWT amplifiers, electromagnetically tunable gyro-BWOs and gyro-BWAs, and phase-locked inverted gyro-twistrons with subharmonic injection.

Research supported by the DoD Vacuum Electronics Initiative and managed by the Air Force Office of Scientific Research under grant AFOSR-91-0390.

[1] H. Guo, D.S. Wu, G. Liu, Y.G. Miao, S.Z. Qian, and W.Z. Qin, IEEE Trans. on Plasma Sci. **18**, 3, 326-333 (1990).

[2] H. Guo, Y. Carmel, B. Levush, T.M. Antonsen, S. Cai, L. Chen, and V.L. Granatstein, IEDM Technical Digest, 783-785, Washington, DC, December 8-11, 1991.

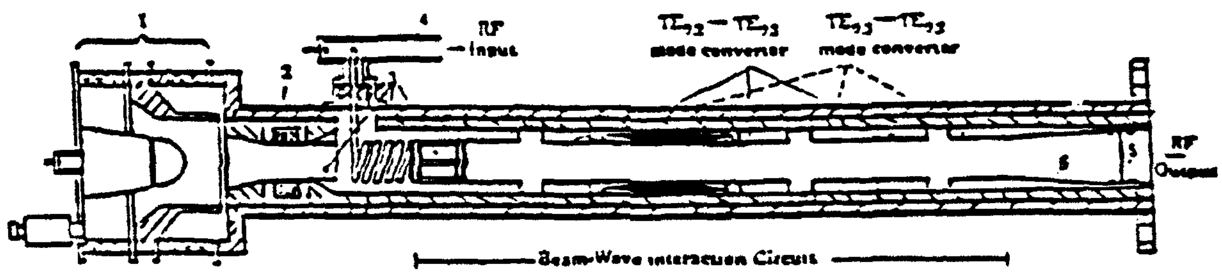

Figure 1. Harmonic gyro-TWT amplifier. 1. MIG Gun. 2. Radiation absorber. 3. Wide-band Input Coupler. 4. Input Waveguide. 5. Wide Band Output Window. 6. Collector. 7. Buncher Attenuator

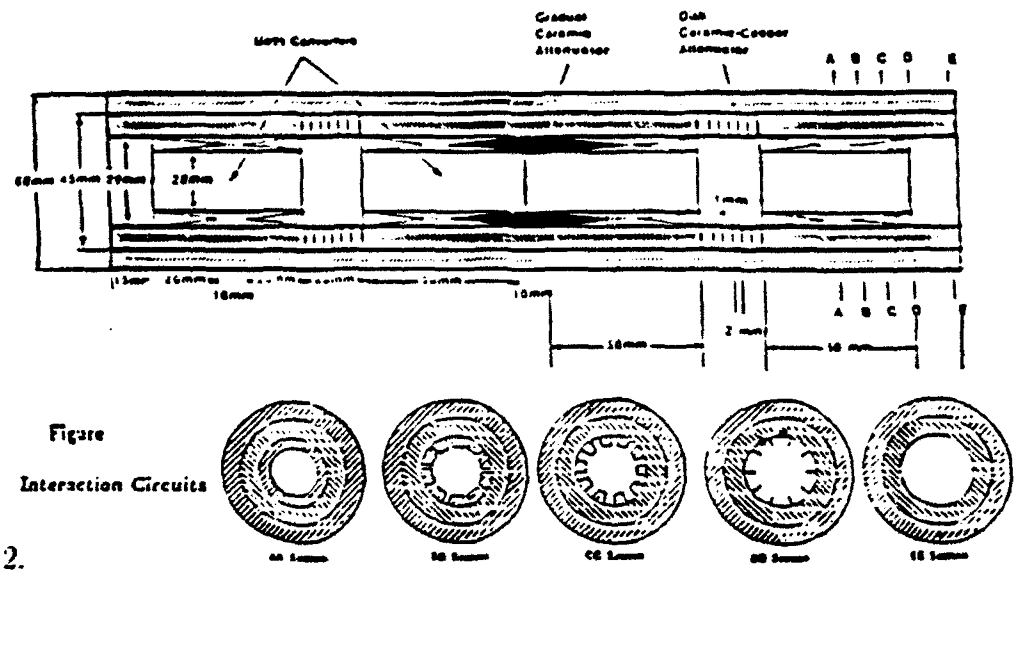

Figure 2.

1993 Microwave Power
Tube Conference

High Performance, Harmonic, Gyrotron Devices Implemented with Novel, Mode Selective, Interaction Circuits

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In order to meet the requirement of modern, millimeter wave radar and communication systems for compact, coherent, high power sources, a series of new, phase-controlled, harmonic gyrotron devices has been conceived including phase-locked gyroklystron oscillators with subharmonic injection, broadband gyro-TWT amplifiers, magnetically tunable gyro-BWAs, and phase-locked inverted gyro-twystron. The realization of high efficiency and stable operation in these devices is to be achieved with various versions of mode selective interaction circuits which utilize conversion between a pair of specific modes. Work has started on the experimental development of a high efficiency, phase-locked harmonic inverted gyro-twystron ('phigtron') and a high power, wideband, harmonic, gyro-TWT amplifier, shown in Figs. 1 and 2. The design performance parameters of each are displayed in Tables 1 and 2, respectively. If successful, either of them will represent a significant advance in coherent source capabilities in the millimeter wave frequency range. The fact that these harmonic gyrotrons are compatible with modern permanent magnet technology make them attractive for defense and commercial applications. From the viewpoint of mode selective technique, this research is based on a 35 GHz, 35% efficient, second harmonic, free running, gyrotron oscillator; its successful operation demonstrates the superior mode selectivity of the interaction circuit to be incorporated in the newly developed, phase-controlled gyrotron oscillators and amplifiers. Also presented in this paper are recently obtained calculations results indicating that various spurious modes will be well suppressed in mode selective harmonic gyrotrons. Finally, we note that our novel mode selective echnique could be applied to megawatt whispering gallery mode gyrotrons both at the fundamental and harmonic cyclotron frequency for solving mode competion problems.

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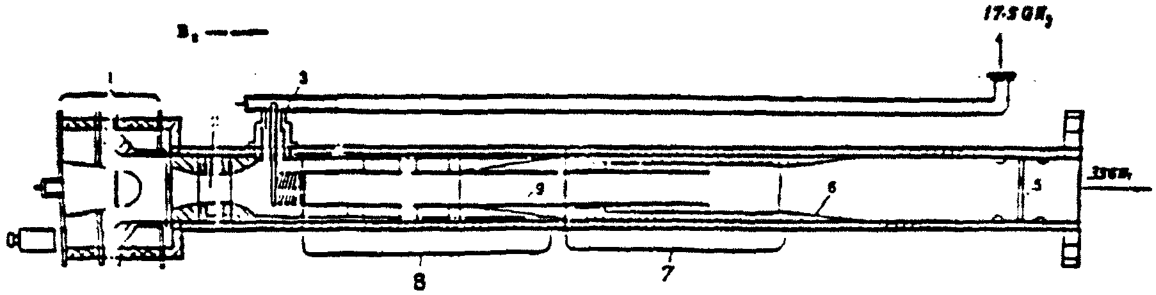
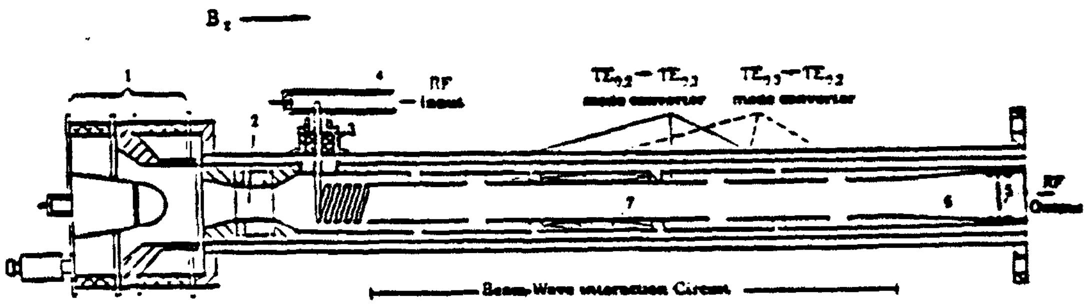


1. MIG Gun. 2. Radiation Absorber. 3. Wide Band Input Coupler. 4. Input Waveguide. 5. Wide Band Output Window. 6. Collector. 7. Complex Cavity. 9. Concentration Attenuator. 8. Beam-Wave Interaction Structure in the shape of a chain of $TE_{01} \rightleftharpoons TE_{02}$ mode convertors—TWT prebunching section

Figure 1: A PHASE-LOCKED, HARMONIC, INVERTED GYRO-TWYSTRON——PHIGTRON



1. MIG Gun. 2. Radiation absorber. 3. Wide band Input Coupler. 4. Input Waveguide. 5. Wide Band Output Window. 6. Collector. 7. Build-in Attenuator

Figure 2: Wideband harmonic gyro-TWT amplifier.

Table 1. Expected performance of the 35 GHz, second harmonic, wide band gyro-TWT amplifier.

Output center frequency	35 GHz
Instantaneous bandwidth	>15% (5.25 GHz)
Output power	> 200 kW (peak), 10 kW (avg.)
Efficiency	> 25%
Gain	30 dB (linear), 40 dB (saturated)
Harmonic number	2
Output mode	TE_{02}
Magnetic field	6.5 kG (max), compatible with with modern permanent magnets (Ne/Fe/B)
Gun type	Magnetron Injection Gun (MIG)
Gun voltage	60 kV
Gun current	14 A

Table 2. Expected performance of the 35 GHz Phigtron.

Output center frequency	35 GHz
Instantaneous bandwidth	2%
Output power	>200 kW
Efficiency	>40%
Gain	50 dB
Harmonic number	2
Output mode	TE_{02}
Magnetic field	6.5 kG (max.), compatible with modern permanent magnets (Ne/Fe/B)
Gun type	Magnetron Injection Gun
Gun voltage	60 kV
Gun current	12 A

C4. Mode Selective Interaction Circuits and New Compact, Harmonic, Phase-Controlled Gyrotron Devices*

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Several types of rf circuits incorporated with perfect conversion between a pair of specific electromagnetic modes are analyzed to have superior mode selectivity for ECRM beam wave interaction, based on a successful *experiment* of a 35 GHz, special complex cavity gyrotron operating at the second harmonic of the cyclotron frequency. By using these mode selective interaction circuits a series of novel, phase-controlled harmonic gyrotron devices operating at millimeter-wave frequencies are proposed including phase-locked gyro-klystron oscillators with subharmonic injection, high power gyro-TWTs, gyro-BWAs, and phase-locked inverted twistrons. A more specific design of the gyro-TWT frequency multiplier is presented, which is currently under development at UMCP.

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