TE Clustered-Cavity and Extended Interaction Cavity for Wideband Gyro-Amplifiers

Y. Y. Miao, H. Guo, and V. L. Granatstein

University of Maryland at College Park
Department of Electrical & Computer Engineering
Institute for Research in Electronics & Applied Physics
Abstract: Two newly proposed gyro-device interaction circuits, the $\text{TE}_{0n}$ mode clustered-cavity and extended interaction cavity, have been both theoretically and experimentally studied to demonstrate their performance capability in broadening the bandwidth of high power gyrotron amplifiers.

The results of the HFSS code simulation and cold test experiment show that a joint application of these two kinds of cavities to gyroklystron,
phigtron and the newly suggested gyrotriotron as interaction circuit, could broaden their operation bandwidth up to 3~5% at megawatt power level and millimeter wave frequencies. The simulation and experiments also demonstrate these cavities featuring superior $\text{TE}_{0n}$ mode selectivity, which is of vital importance for high power gyro-amplifier to resolve mode competition problems.

The related technology of constructing the cavities is also presented.
UMCP Phase-Coherent, Harmonic-Multiplying Inverted Gyrotwystron (Phigtron)

**Schematic of Inverted Gyrotwystron (Phigtron)**

<table>
<thead>
<tr>
<th>UMCP Phigtron</th>
<th>frequency</th>
<th>Efficiency</th>
<th>Peak Power</th>
<th>Gain</th>
<th>Bandwidth</th>
<th>Output Mode</th>
<th>Harmonic Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ka output, Ku input</td>
<td>35%</td>
<td>720KW</td>
<td>30dB</td>
<td>0.7%</td>
<td>TE₀₃</td>
<td>2nd</td>
<td></td>
</tr>
</tbody>
</table>
UMCP Harmonic-Doubling Gyro-TWT

(Gyro-TWT prebunching) (Ballistic Bunching) (Gyro-TWT energy extraction)

<table>
<thead>
<tr>
<th>UMCP Gyro-TWT</th>
<th>frequency</th>
<th>Efficiency</th>
<th>Peak Power</th>
<th>Gain</th>
<th>Bandwidth</th>
<th>Output Mode</th>
<th>Harmonic Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ka output, Ku input</td>
<td>12% (unsaturated)</td>
<td>180KW</td>
<td>27dB</td>
<td>3.2%</td>
<td>TE_{03}</td>
<td>2nd</td>
<td></td>
</tr>
</tbody>
</table>
Motivation and Goals

- For coherent millimeter wave application, wide bandwidth (~5%) and high average power are needed.

- Phigtron bandwidth is limited by Q factor of the buncher and output cavities.

- For our gyro-TWT, predicted saturated efficiency is ~25%. One factor of this lower efficiency is due to lack of bunching at the second harmonic of the electron cyclotron frequency.

- Now, we propose a new gyro-device interaction structure; The TE_{0n} mode clustered-cavity which is to be used for broadening the bandwidth of the phigtron and also for enhancing the efficiency of harmonic-multiplying gyro-TWT.
2 or more short TE_{0n} mode cavities, which are closely adjacent but uncoupled, can be used as beam buncher for gyro-amplifiers. Frequency bands of adjacent cavities overlapped. No beam bunching occurring between the cavities of the cluster.

(a). f_1 = f_2 = f_3 = f_4, Q = 1/4 Q_s
(b). f_1 \neq f_2 \neq f_3 \neq f_4
Construction of TE0n Mode Clustered-Cavity
HFSS Simulation of TE Clustered-Cavity

Fig. Transverse field structure of TE Clustered-cavity subunit, resonating in the TE_{031} Mode

Fig. Axial field structure of Clustered-cavity subunit, resonating in the TE_{031} Mode.

Fig. Relative amplitude of electric field along the cavity axis.
An Example of Gyro-Amplifier using TE Clustered-cavities – the Gyrotriotron

- Combined advantages of clustered-cavity gyrokystron and harmonic multiplying Gyro-TWT: high gain, high efficiency, and broad bandwidth
- Mode selective interaction, highly overmoded operation, high power capability.
- Gain of 50dB and bandwidth of 5% are expected, according to the equivalent circuit theory for microwave tube amplifier.
An Example of Clustered-Cavity as Bunching Stage of Gyrotrotttron (3-Stage Harmonic Multiplying Hybrid Gyro-Amplifier)

<table>
<thead>
<tr>
<th>Sub-Cavity No.</th>
<th>Frequency (GHz)</th>
<th>R1 (mm)</th>
<th>R2 (mm)</th>
<th>R3 (mm)</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33.5911</td>
<td>10.57</td>
<td>10.82</td>
<td>15.33</td>
<td>88</td>
</tr>
<tr>
<td>2</td>
<td>34.0368</td>
<td>10.40</td>
<td>10.65</td>
<td>15.08</td>
<td>111</td>
</tr>
<tr>
<td>3</td>
<td>34.3979</td>
<td>10.26</td>
<td>10.51</td>
<td>14.88</td>
<td>137</td>
</tr>
<tr>
<td>4</td>
<td>34.8151</td>
<td>10.10</td>
<td>10.35</td>
<td>14.65</td>
<td>195</td>
</tr>
</tbody>
</table>

Legend:
- Metal
- Lossy Ceramic
- Lossy Honey-Comb
TE0n Mode Extended Interaction Cavity

- Using mode converter/filter structure to get superior mode selectivity with overmoded operation.
- Horn-like configuration to lower Q factor.

Red – uniform waveguide; Yellow – tapered waveguide; Blue – mode converter
Mode Converter/Filter

With \[ \frac{\mu_{0n}}{a} \frac{\mu_{0m}}{b} = K_{c0} \]

\( K_{c0} \) is cutoff wavenumber, \( n \) and \( m \) are integers, \( \mu_{0n} \) and \( \mu_{0m} \) are respectively the \( n \)'th and \( m \)'th roots of the equation: \( J_0(\mu) = 0 \)
The First Resonant Mode of the Extended Interaction Cavity
A High-order Axial Resonant Mode of the Extended Interaction Cavity
Transverse Field Pattern of Extended Interaction Cavity
Resonant Responses of A Ka-band TE Extended Interaction Cavity

Fig. Resonant frequency Vs Q factor. Each resonant mode with same field structure in transverse but different number of axial variations.
Applying TE Clustered-Cavity and Extended Interaction Cavity to Gyro-Amplifiers

(1). Gyrotwystron

(2). Gyrotriotron

(3). Gyroklystron

(4). Inverted Gyrotwystron
   (Phigtron)
Summary

- From HFSS simulation and experiments, superior TE0n mode selectivity of these two kind of cavities has been demonstrated, which is of vital importance in high power gyro-amplifiers to resolve mode competition problems.

- Using TE clustered-cavity as buncher in gyrotriotron, high gain, wide bandwidth and high efficiency can be achieved. Using clustered-cavity as buncher and the extended interaction cavity, as output section, the bandwidth of phigtron can be significantly broadened.

- Also, TE cluster-cavity can be used extensively in other gyro-amplifier, such as gyroklystron and gyrotwystron for broadening operation bandwidth.
ACKNOWLEDGMENT: This work is supported by the DoD MURI for innovative vacuum electronics. Mode converter technology is provided by the Institute of Electronics, Chinese Academy of Science.