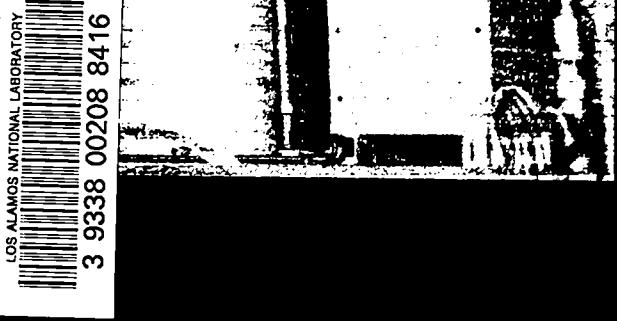


REPRODUCTION
COPY
IS-4 REPORT SECTION

LA-12687-MS
c.3



*High-Power
Microwave-Tube
Transmitters*



Los Alamos
NATIONAL LABORATORY

*Los Alamos National Laboratory is operated by the University of California for the
United States Department of Energy under contract W-7405-ENG-36.*

This work was supported by the US Department of Defense, Army Strategic Defense Command.

*Edited by Robert Graybill, Technical Communication Services,
for Group IS-1
Printing coordination by Guadalupe Archuleta, Group IS-9*

Cover photo: William North installs a klystron in its modulator housing (LANL Photo No. RN90-03 2008).

An Affirmative-Action/Equal-Opportunity Employer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither The Regents of the University of California, the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by The Regents of the University of California, the United States Government, or any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of The Regents of the University of California, the United States Government, or any agency thereof.

LA-12687-MS

UC-000

Issued: January 1994

*High-Power
Microwave-Tube
Transmitters*

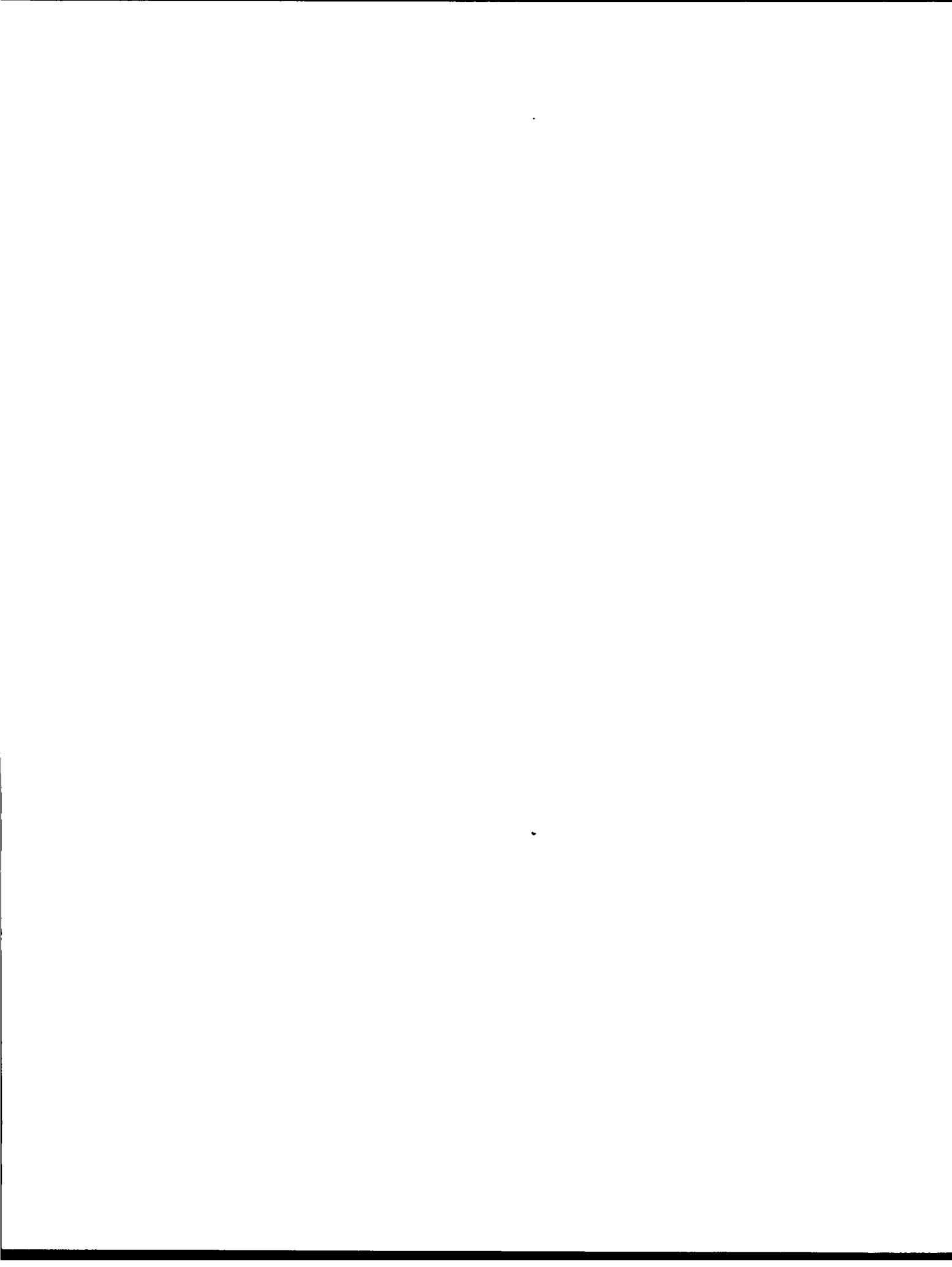
William North



3 9338 00208 8416

Los Alamos
NATIONAL LABORATORY

Los Alamos, New Mexico 87545





LANL Photo No CNS90-2171

Technicians at work on a modulator for a megawatt-class dual-klystron RF station.

*This book is dedicated to
Lawrie Eaton,
leader of the RF Technology Group
of the Accelerator Operations and Technology Division of
Los Alamos National Laboratory.*

*It was his vision that what follows could be of
value to new generations of technologists in this field
(and even the occasional graybeard).
It was at his insistence that the task was undertaken.
If it is of help to anyone, the credit is his.
If it is of no help, the fault is mine.*

Contents

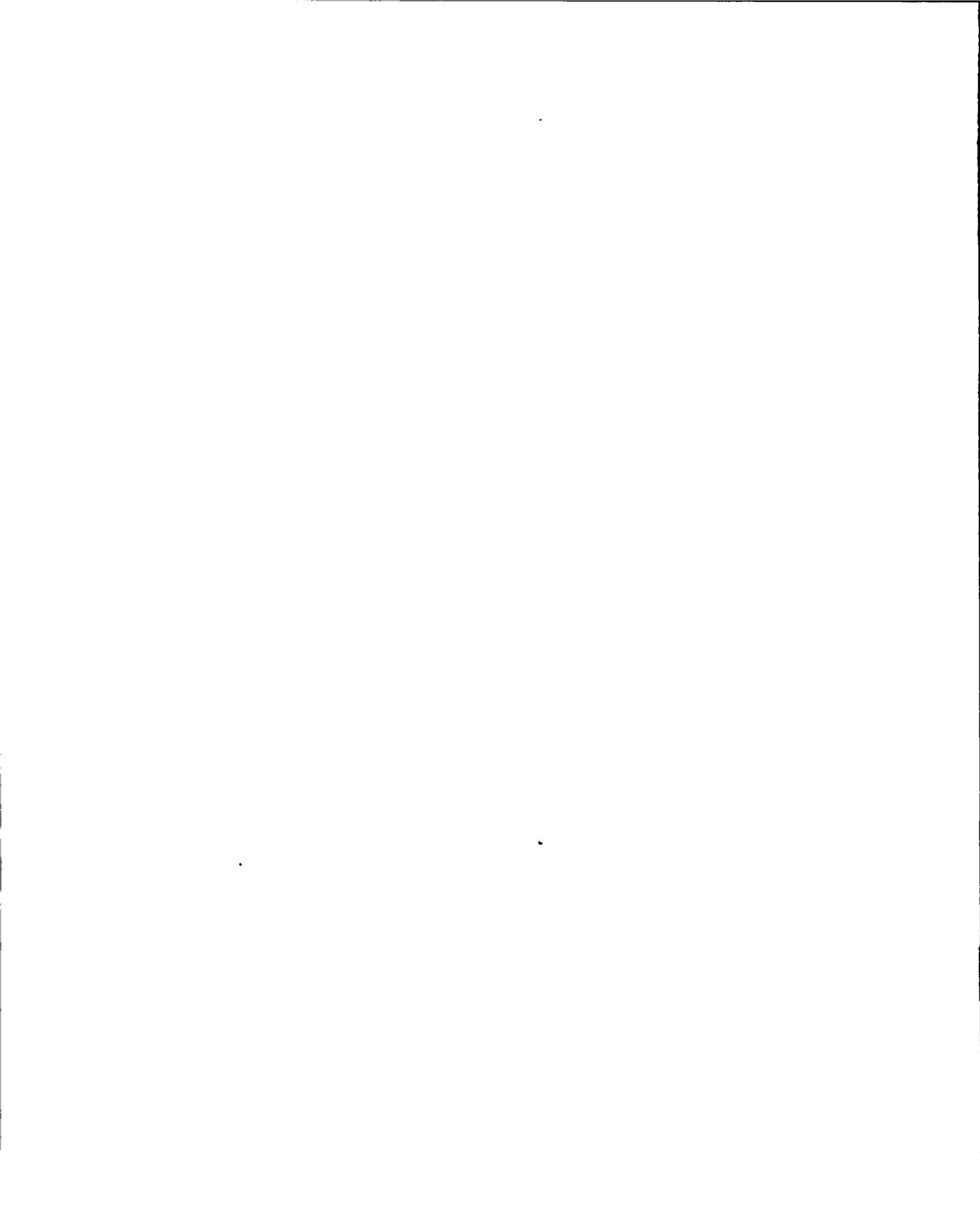
1. Introduction	1
2. The Transmitter	2
2.1 High-power microwave tube	2
2.2 Filament supply	4
2.3 Focus magnet supply	4
2.4 Pulse modulator	5
2.5 Pulsed energy storage	5
2.6 Fault current limiting and charge diversion	6
2.7 Voltage sample	6
2.8 Electronic voltage regulator	6
2.9 High-voltage transformer/rectifier	7
2.10 Step start (or soft start)	7
2.11 Variable voltage device	7
2.12 High-speed contactor or switch-gear	8
2.13 SCR primary controller	8
2.14 Unit substation	8
2.15 Cooling system	10
2.16 Control and monitor	10
3. High-Power Microwave-Tube Transmitter RF Circuit	12
3.1 RF input from the exciter	16
3.2 PIN diode switch	16
3.3 Signal couplers	17
3.4 Ferrite isolator	18
3.5 RF driver amplifier	18
3.6 Another isolator	18
3.7 Another coupler	18
3.8 Power splitter	18
3.9 Waster load	19
3.10 Phase shifter	19
3.11 Time-delay shim	19
3.12 Drive-power-level attenuator(s)	19
3.13 More ferrite isolators	20
3.14 High-power amplifiers	20
3.15 Waveguide arc detector	20
3.16 Forward and reverse couplers	22
3.17 High-power circulator	22
3.18 Output hybrid combiner	22
3.19 Waster power coupler	23
3.20 Waster load	23
3.21 Harmonic filter	23
3.22 Antenna duplexer	24
3.23 Waveguide switch	28
3.24 High-power dummy load	28

4. Transmitter Engineering and the 'ilities'	29
4.1 Reliability	29
4.2 Maintainability	31
4.3 Availability	31
4.4 Electromagnetic susceptibility	32
4.5 Electromagnetic compatibility	33
4.6 Safety	33
4.7 Built-in test equipment.....	39
4.8 Failure modes and effects analysis	40
4.9 Human factors	40
4.10 Configuration control	41
5. And Now a Word From the Sponsor	43
6. What Makes Resistors Hot?	46
7. High-Voltage Insulation	54
8. Pulse Modulators.....	65
8.1 Cathode-controlled electron gun	65
8.2 Modulating anode	66
8.3 Insulated-focus electrode	67
8.4 Intercepting control grid	67
8.5 Shadow-gridded gun	68
8.6 Bonded-grid gun	68
8.7 E-gun considerations	68
9. Cathode Pulsers: Line-Type Modulators	70
9. 1 The line-type pulser	71
9.1.1 The discharge circuit	71
9.1.2 The charging circuit	85
9.1.3 An illustrative example of a line-type modulator	89
9.1.4 The Blumlein discharge circuit	93
9.1.5 The Marx impulse generator	97
9.1.6 Pulse-forming networks	98
9.1.7 Output-pulse transformers	101
9.2 Why do we care about pulse-top flatness?	106
9.3 Modulator output pulse-to-pulse variations	118
9.4 Line-type pulser discharge switches	121
9.4.1 The hydrogen thyratron	121
9.4.2 The ignitron	129
9.4.3 The thyristor	131
9.4.4 The reverse-blocking diode thyristor	134
9.4.5 Spark gaps	134
9.5 Practical system applications of half-control switches	136
9.5.1 The hydrogen thyratron	136
9.5.2 The triode thyristor	137
9.5.3 The diode thyristor.....	142
9.5.4 The ignitron	142
9.5.5 The spark-gap switch.....	143

10. Cathode Pulsers: Hard-Tube Modulators.....	146
10.1 The full-control switch tube	146
10.2 Hard-tube modulator topology	148
10.3 Storage capacitors	155
10.4 Vacuum tubes as switch tubes	161
10.4.1 The 7560 triode switch tube	167
10.4.2 The WL-8461 triode switch tube	170
10.4.3 The ML- 6544 triode switch tube	170
10.4.4 The S94000E and 4CPW1000KB tetrode switch tubes	173
10.4.5 The ML-8549 magnetically beamed triode	179
10.4.6 The ML- 8618 magnetically beamed triode	182
10.4.7 The L-5012 and L-5097 Injectron™ beam-switch tubes	184
10.4.8 The 8454H Crossatron™ switch	186
10.5 Load lines	189
10.6 Pulse fall time of hard-tube modulator	191
10.7 Some practical examples of hard-tube modulators	195
10.7.1 The 200-MW triode (WL-8461) hard-tube modulator	195
10.7.2 An 18-MW hard-tube modulator using the L-5097 beam-switch tube ...	198
11. Modulating-Anode Pulsers	200
11.1 Modulating-anode-pulser topologies	200
11.1.1 Passive pull-up, active pull-down	200
11.1.2 Active pull-up, passive pull-down	201
11.1.3 Active pull-up and pull-down	204
11.1.4 An attempt at simplified amplitude control	205
11.1.5 The grid-catcher type of amplitude control	206
11.1.6 The grid-catcher circuit with potentiometer-type control	207
11.1.7 The gate-catcher type of amplitude control	208
11.1.8 The "quasi-resonant" modulating-anode pulser	210
11.1.9 The modulating-anode power supply/cathode-pulser hybrid	213
11.2 The self-capacitance of modulator decks	215
11.3 Vacuum tubes appropriate for modulating-anode-pulser service	218
11.3.1 The 4PR250C/8248 tetrode	218
11.3.2 The 8960 tetrode	218
11.3.2 The Y-847 triode.....	218
11.3.4 The YU-146 tetrode	219
11.3.5 The TH-5184 tetrode	220
11.3.3 The TH-5188 tetrode	220
11.4 Some representative modulating- anode pulser designs	220
11.4.1 The BMEWS dual-klystron modulator	220
11.4.2 The Millstone Hill radar transmitters	221
11.4.3 Dual-klystron modulating-anode pulser for particle-accelerator RF source.....	224
11.4.4 The modulating-anode pulsers for the MAR-1 radar system	226
11.4.5 The long-range imaging radar transmitter modulating-anode pulsers ...	229
11.4.5 The modulating-anode pulser for the Haystack Auxiliary Radar (HAX)	232
12. Control-Grid Modulators	234
12.1 Grid-modulator topologies	237

12.1.1 Active pull-up, passive pull-down	239
12.1.2 Active pull-up and pull-down grid pulser	241
12.1.3 Single-switch active pull-up and pull-down grid pulser	241
12.1.4 Cascaded solid-state active pull-up and pull down.....	243
12.1.5 Hybrid grid pulser	245
12.1.6 "Inductive-kick" single-switch grid pulser	247
12.2 Transmitter applications of grid pulsers	249
 13. Charge Diverters: the Electronic Crowbar	253
13.1 What happens when an electron gun arcs?	253
13.2 Types of crowbar switches	257
13.3 The nature of surge-limiting resistors.....	261
 14. High-Voltage AC/DC Conversion, or Rectification	263
14.1 Polyphase ac concepts	263
14.2 The three-phase, half-wave rectifier	265
14.3 The three-phase, full-wave (six-pulse) rectifier	267
14.4 The six-phase, full-wave (12-pulse) rectifier	268
14.5 The 12-phase, full-wave, 24-pulse rectifier	271
14.6 Polyphase-rectifier line current	272
14.7 Who cares about harmonic pollution?	277
14.8 Other forms of line pollution	279
 15. Variable-Voltage Devices	282
15.1 The phase-controlled rectifier	282
15.2 The primary SCR controller	284
15.3 The variable autotransformer	288
15.4 The variable-voltage transformer	289
15.5 The step regulator	291
15.6 The induction voltage regulator	292
 16. Electronic Voltage Regulators	295
16.1 Voltage regulators that handle system average current	295
16.2 Voltage regulators that handle system peak current.....	298
16.3 Voltage regulators that do not handle the full microwave-tube beam current	301
16.4 Regulators that must also be modulators	302
 17. Switchgear and Substations	306
17.1 Switchgear	306
17.2 The unit substation	309
 18. Switch-Mode Electronic Power Conditioning.....	311
18.1 Switch-mode dc variable-voltage circuits (dc-to-dc converters)	311
18.2 DC-AC inverters	314
18.3 Voltage-multiplier rectifier circuits	322
18.4 High-voltage dc power supply using a quasi-resonant inverter	326
18.5 The electronic high-frequency power conditioner as applied to a microwave tube	329
18.6 An idea too clever not to share (It's not mine, by the way.)	331

19. Thermal Management.....	334
19.1 Heat transfer by radiation	335
19.2 Heat transfer by conduction in solids	336
19.3 Heat transfer by free, or natural, convection in air	338
19.4 Transfer of heat by forced convection of a cooling fluid	339
19.5 Closed-loop water-cooling systems	342
19.6 Vapor-phase cooling, or convection with state change	347
19.7 Multi-phase cooling	351
20. Transmitter Control, Monitoring, and Interlocking	352
20.1 The relay-logic ladder-network control circuit	352
20.2 A solid-state, serial-control, parallel-indication interlock circuit	355
20.3 Integrated-circuit considerations	362
20.4 The programmable-logic controller	365
20.5 High-speed instrumentation for transmitter monitoring	369
20.6 High-speed crowbar-firing circuits	373
20.7 The pulse "balun"	376
Index	380



HIGH-POWER MICROWAVE-TUBE TRANSMITTERS

by
William North

ABSTRACT

High-Power Microwave-Tube Transmitters describes in detail high-power microwave-tube transmitters and the various subsystems that comprise them. Relying on his long experience as a designer of radar systems and rf stations for particle accelerators, the author also imparts lessons he has learned from his work and opinions he has formed on the transmitter design.