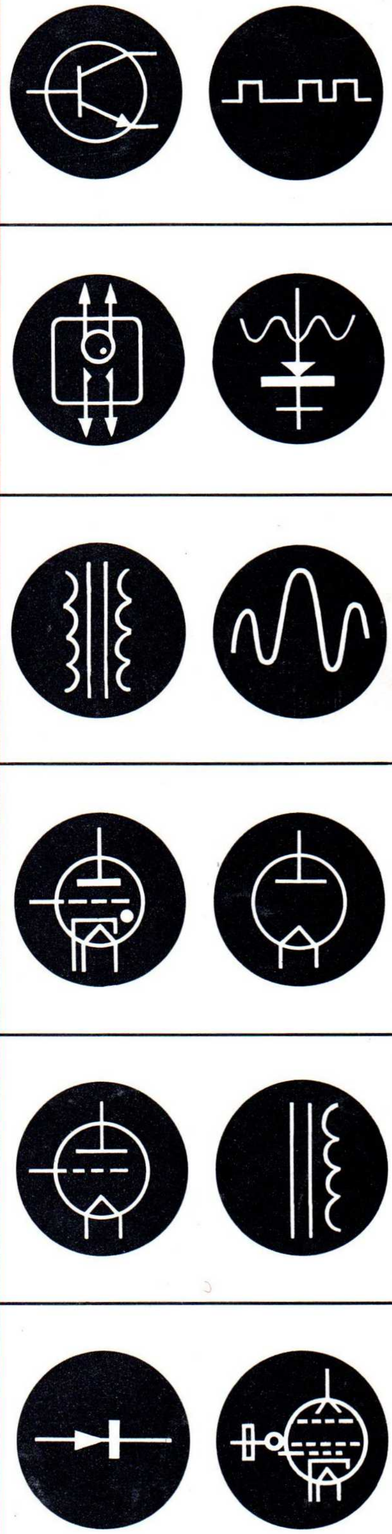
# ADD RAYTHEON RELIABILITY TO EVERY STEP OF YOUR DESIGN



RAYTHEON COMPANY

WALTHAM, MASSACHUSETTS

RAYTHEON

ADD RAYTHEON RELIABILITY

For nearest
Raytheon Sales Office
see last page of insert.

# of the many semiconductor sources

some are **GERMANIUM** houses

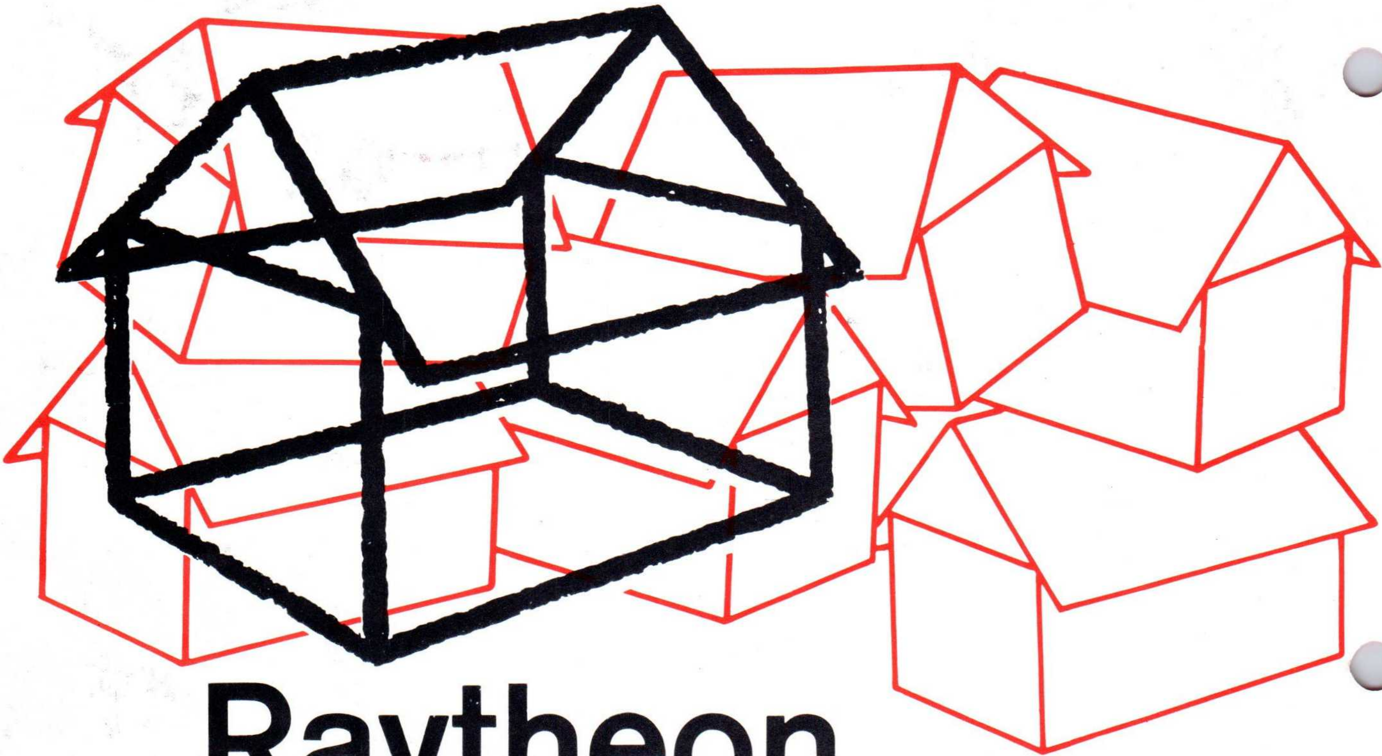
some are **SILICON** houses

some are **DIODE** houses

some are **RECTIFIER** houses

some are **TRANSISTOR** houses

some are **CIRCUIT PACKAGING** houses



# Raytheon

## is all of these in one

**plus** *proven advances in* **RELIABILITY PROCEDURES**
*mechanized production for* **PRODUCT QUALITY**
*extensive engineering for* **APPLICATIONS ASSISTANCE**

There's a Raytheon semiconductor for your application. For information on all Raytheon semiconductor products, call your nearest Raytheon Sales Office. For a copy of our Short Form Catalog, *circle 200 on Reader Service Card.*

SILICON AND GERMANIUM DIODES AND TRANSISTORS · SILICON RECTIFIERS · CIRCUIT-PAKS

RAYTHEON

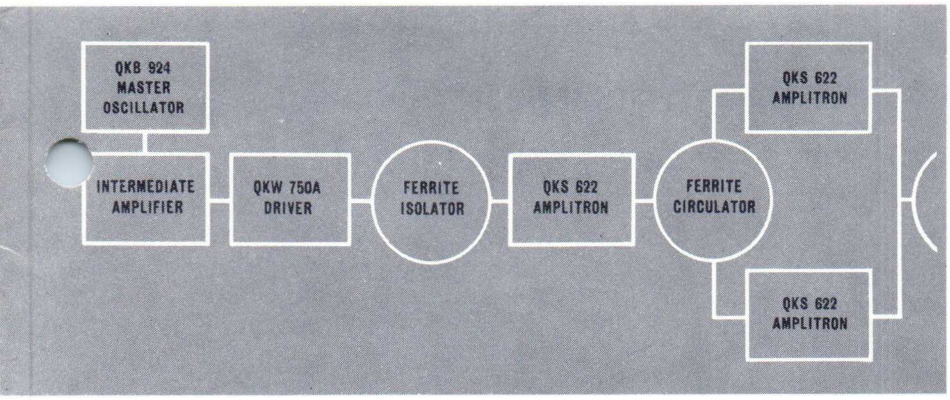
RAYTHEON COMPANY

SEMICONDUCTOR DIVISION

For nearest
Raytheon Sales Office
see last page of insert.

ADD RAYTHEON RELIABILITY

# New microwave tubes for broadband, high-power S-band MOPA chains

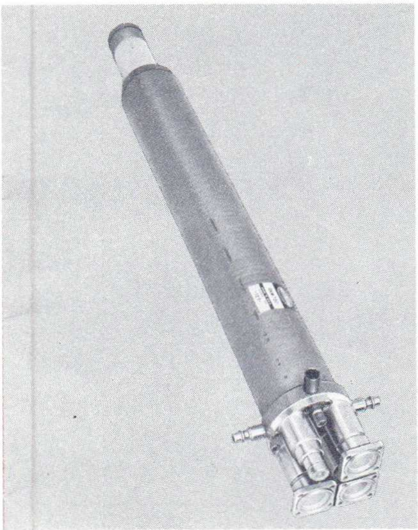



The new tubes described on this page make possible highly efficient master oscillator-power amplifier chains with bandwidths of 7%, peak powers of 6 megawatts and average powers of 30 kilowatts.

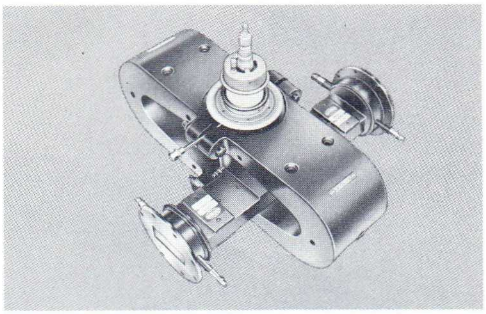
A new concept in master oscillators permits the precise determination and stabilization of frequency. Thus, the MOPA chain is ideally suited to high-duty-cycle, frequency diversity applications employing fully coherent MTI, pulse compression and pulse-to-pulse frequency shift.

Tubes with similar performance characteristics are also available for MOPA operation in other frequency bands. For complete technical details on this new microwave technique and comprehensive brochure, write to Microwave and Power Tube Division, Raytheon Company, Waltham 54, Massachusetts.

***QKW 750A TWT*** has 20 db nominal gain and 100 kw nominal peak power to drive Amplitrons in MOPA chains. Duty cycle is .015 for pulsed operation over the 2,900 to 3,100 Mc range. A similar tube, the QKW 782, covers the 2,700 to 2,900 Mc range. *Circle 201 on Reader Service Card.*



***QKB 924 BWO*** is the master oscillator. This tube in conjunction with an external delay line feedback, provides an extremely stable frequency signal over the 2,700 to 3,200 Mc range. Tubes with similar characteristics are available through X-band. *Circle 202 on Reader Service Card.*

***Two QKS 622 pulsed type Amplitrons**** in parallel operation produce 6 megawatts of power output over the 2,900 to 3,100 Mc range at efficiencies of 75% to 80% and duty cycles as high as .005. The QKS 783 is a similar Amplitron that covers the 2,700 to 2,900 Mc range. *Circle 203 on Reader Service Card.*

**Raytheon trademark*

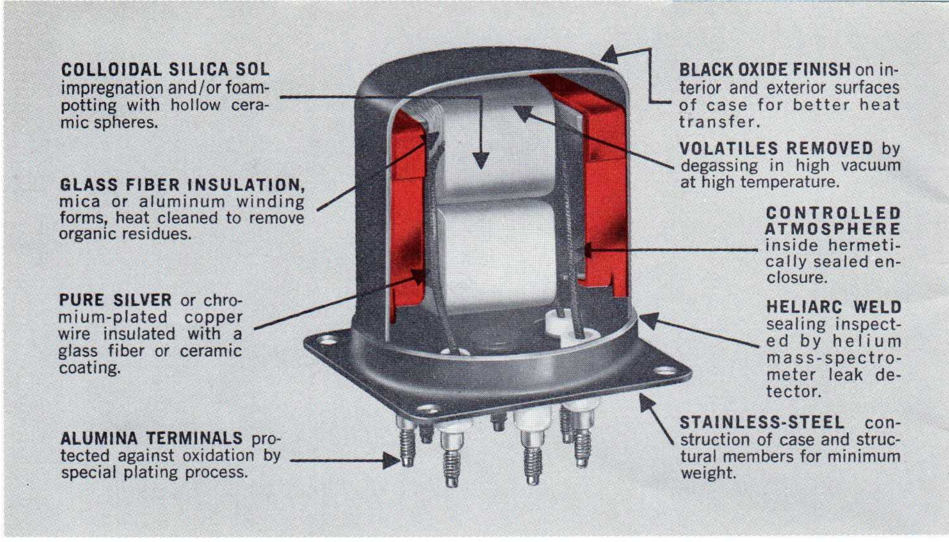
see P.IRE 3-61-346A

RAYTHEON COMPANY

RAYTHEON

MICROWAVE AND POWER TUBE DIVISION

ADD RAYTHEON RELIABILITY




*Circle 205 on Reader Service Card.*

## High Power CW X-Band Circulators

Raytheon's Special Microwave Device Operations announces a new line of high-power ferrite X-band circulators which may also be used as isolators in conjunction with suitable auxiliary loads.

The typical unit illustrated is the model CXH2 covering 10.0 to 10.6 kMc with a continuous power rating of 10 kilowatts. Isolation is 20 db minimum, insertion loss is 0.25 db maximum and VSWR is 1.15.

Used as an isolator, the unit will handle continuous power levels up to 10 kilowatts with a front-to-back ratio of 60:1.

For complete details on this and other significant developments in microwave ferrite devices, please write to Special Microwave Device Operations, Raytheon Company, Waltham Industrial Park, Waltham 54, Massachusetts.

High power X-band circulator CXH2.
*Circle 204 on Reader Service Card.*

## New Raytheon transformer will resist nose cone temperatures to 1,100°F

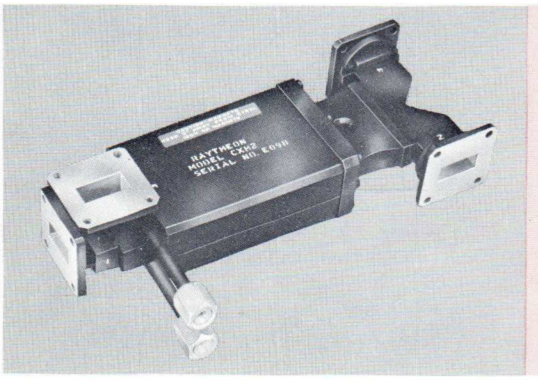
Raytheon is now building transformers capable of withstanding temperatures such as those encountered in a re-entering missile's red-hot nose cone.

The unit pictured above resists temperatures up to 1,100°F which is 700 degrees higher than units presently in use. The goal for units now under construction at Raytheon is a minimum operation time of 2,000 hours with an internal temperature 200 degrees above the ambient of 900 degrees.

To accomplish this, Raytheon has developed new construction techniques and high-temperature resisting wire and insulating materials.

For further information on high-temperature transformers please write, stating your specific requirements, to Magnetics Operations, Raytheon Company, Microwave & Power Tube Division, Waltham 54, Massachusetts.

For nearest Raytheon Sales Office see last page of insert.



**Typical Specifications • MODEL CXH2**

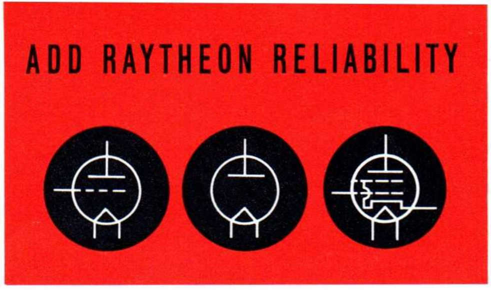
| | |
|---|---|
| Frequency | 10.0–10.6 kMc |
| Power | 10kW (cw) |
| Isolation | 20 db min. |
| Insertion loss | 0.25 db max. |
| VSWR | 1.15 |
| Length | 9 3/16 in. |
| Flanges | UG 39/U |
| Waveguide | RG 52/U |
| Weight | Less than 4 lbs. |
| Water cooled | |

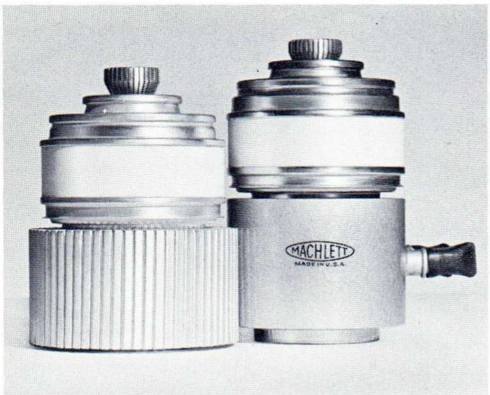
RAYTHEON

RAYTHEON COMPANY

MICROWAVE AND POWER TUBE DIVISION


*UHF Planar Triodes* for communications, radar, and missile application. Special types available include: quick warm up (12 sec. cathode heating) . . . 7.5 amp pulse current . . . grid pulsed power (2kW to 3000 megacycles). *Circle 206 on Reader Service Card.*



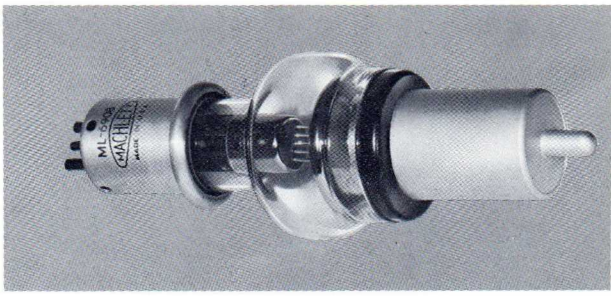




*Hard Pulse Modulator Tubes* for high power radar systems, precise pulse shaping, high repetition rate, coded signaling. From the industry's strongest line: shielded grid triodes (unipotential oxide cathode, output powers to 3.5Mw); high power triodes (pulse powers to 20 Mw; hold-off ratings to 100kV in production to 350kV in development). *Circle 208 on Reader Service Card.*

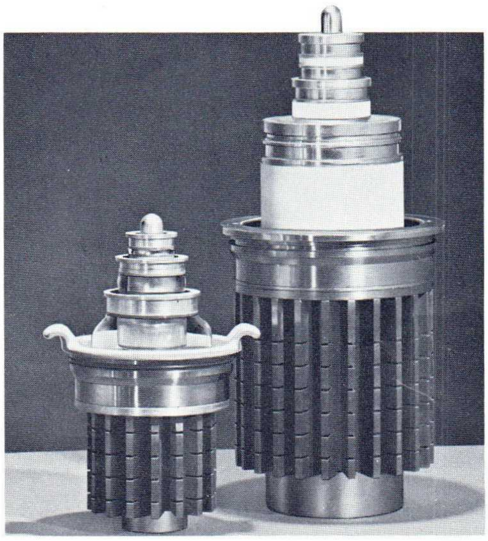
## Electron tube specialist with major capabilities in these fields . . .

The Machlett Laboratories Inc., a pioneer in the art of high power electronics, offers significant advances in these specialized areas of electron tube design and manufacture . . .

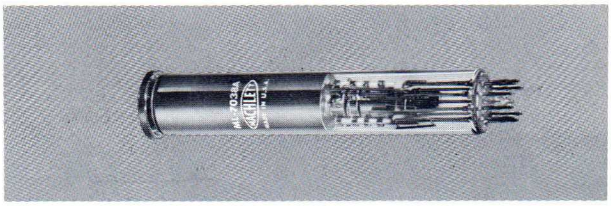
Technical data and product line brochures on request.



*High Vacuum Rectifier Tubes* for hold-off diode application, high voltage power supplies. 110kV-10 amps, air insulated; 150kV-10 amps, oil insulated. *Circle 209 on Reader Service Card.*



*High Power Triodes* for communications, industrial heating, pulse modulation. Water and vapor cooled tubes to 400kW CW output. Ceramic, coaxial-terminal construction; lightweight F-A-C tubes, low, medium and high mu. *Circle 207 on Reader Service Card.*



*TV Camera and Specialized CR Tubes* – Vidicons: for ultraviolet sensitive response... low light level . . . near infrared. Scan conversion tube: S/N ratio of 100:1, rf separation not required. *Circle 210 on Reader Service Card.*

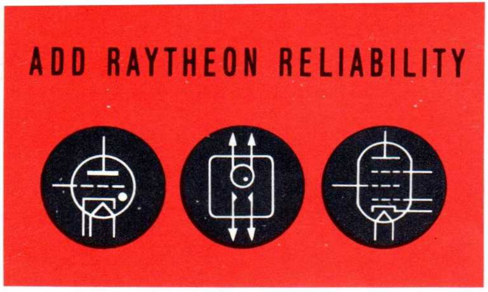
For nearest Sales Office see last page of insert.

THE MACHLETT LABORATORIES, INC.

MACHLETT

SPRINGDALE, CONNECTICUT

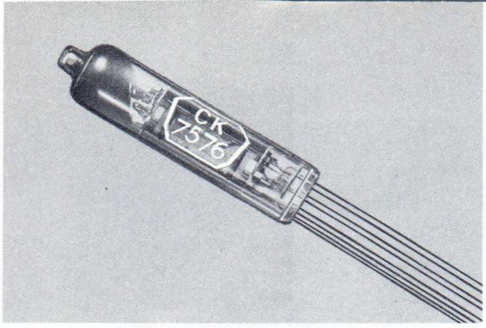
SUBSIDIARY OF RAYTHEON COMPANY




# A reputation for reliability

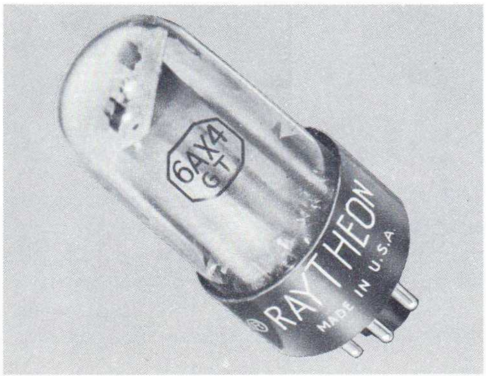
## Raytheon's complete line of components for industrial and military applications

Choose the most reliable electronic components available. Precision-produced by the Industrial Components Division, this broad line encompasses practically every electronic circuit requirement from electron tubes to the most advanced and sophisticated innovations in electronic components. Full technical data can be obtained by writing to: Industrial Components Division, Raytheon Company, 55 Chapel Street, Newton 58, Massachusetts.




***Subminiature Tubes***

Raytheon, leading manufacturer of subminiature tubes, maintains an unprecedented program of quality control. Outstanding features of Raytheon subminiature tubes include: reduced vibration output, superior characteristic uniformity, reduced microphonic output, controlled operation time, tightened characteristic limits, greater resistance to shock and fatigue. *Circle 213 on Reader Service Card.*

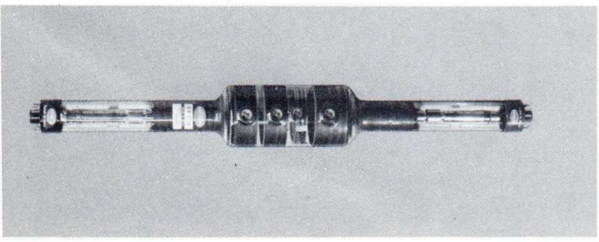



***Receiving Tubes***

Innovations in grid manufacturing techniques and advanced quality control methods result in higher performance and dependability in receiving tubes for radio, TV, high-fidelity, and mobile communications. *Circle 214 on Reader Service Card.*

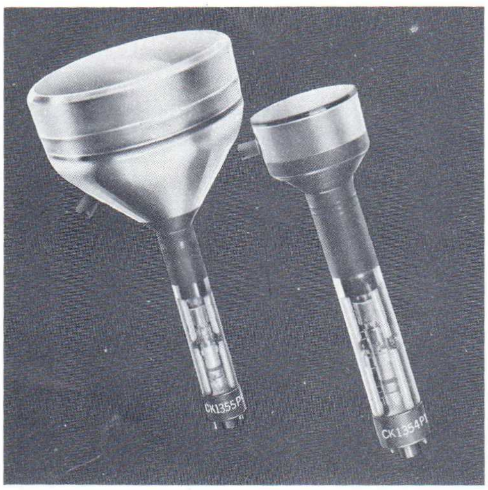

***Noise Modules***

Wide band noise source modules are small, rugged, and require low power. They permit the successful design of extremely compact, portable test equipment and systems capable of reliable operation over wide extremes of shock, vibration, and temperature. *Circle 215 on Reader Service Card.*



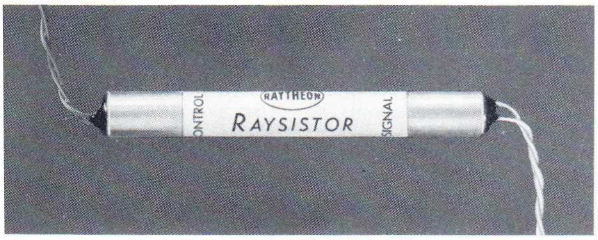
***Storage Tubes***

The advanced design features of Raytheon recording storage tubes offer designers of radar systems many new application possibilities. A full line of single- and dual-gun types enable the design of unique circuits for scan conversion, retention, and signal integration. *Circle 211 on Reader Service Card.*




***Cathode Ray Display Devices***

Printer, infrared stimulable, and high-altitude CRT's like the CK1354 and CK1355 illustrated, are representative of Raytheon's advanced development techniques in cathode ray display devices. Many types—oscillographs, radar indicators, video recorders, and flying spot scanners are available for industrial and military applications. *Circle 216 on Reader Service Card.*




***Raysistors***

Raysistor control devices are electro-optical components designed to operate efficiently as relays, potentiometers, choppers, commutators, and high voltage controls. No mechanical parts mean long trouble-free operation in many circuit applications. *Circle 212 on Reader Service Card.*

For nearest Raytheon Sales Office see last page of insert.

RAYTHEON

RAYTHEON COMPANY

INDUSTRIAL COMPONENTS DIVISION

FOR MORE INFORMATION

Postage
Will be Paid
by
Addressee

No
Postage Stamp
Necessary
If Mailed in the
United States

**BUSINESS REPLY MAIL**

FIRST CLASS PERMIT No. 35308 WALTHAM, MASS.

**RAYTHEON COMPANY**

**TECHNICAL INFORMATION SERVICE**

**138 RIVER STREET**

**WALTHAM 54, MASS.**

# Use this convenient Reader Service Card

*Send data on items circled.*

| | | | | | |
|---|---|---|---|---|---|
| 200 | 201 | 202 | 203 | 204 | 205 |
| 206 | 207 | 208 | 209 | 210 | 211 |
| 212 | 213 | 214 | 215 | 216 | 217 |
| 218 | 219 | 220 | 221 | 222 | 223 |
| 224 | 225 | 226 | 227 | 228 | 229 |

▶ 230 **Circle for name of Raytheon Distributor nearest you.**

Name____________________ Title____________________

Company____________________

Street Address____________________

City____________________ State____________________

Products Manufactured____________________

☐ Send representative.

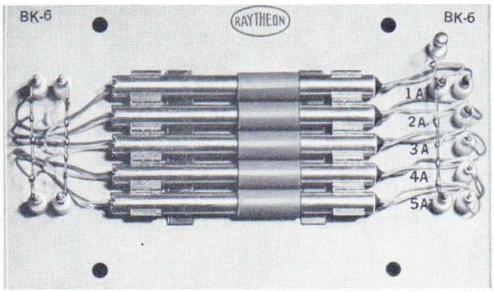
For nearest
Raytheon Sales Office
see last page of insert.

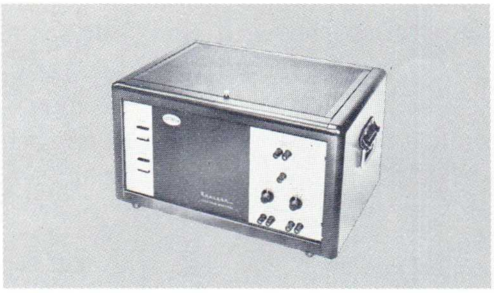

***Low Power Industrial and Transmitting Tubes***

Popular rectifier, series regulator, and transmitting types featuring greater efficiency and reliability are available. Tubes are outstanding for their higher voltages, higher power, and higher temperature handling capabilities. *Circle 217 on Reader Service Card.*

***Filters***

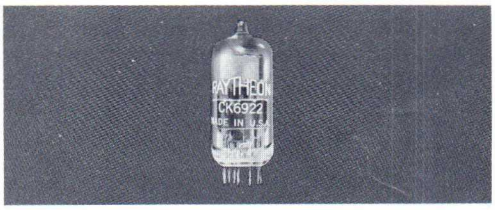
For multiple narrow band filter channel applications, Raytheon magnetostriction rod filters are more rugged, weigh less, take less space and are more precise than other types available. Single filter and arrays are available in both stock and custom designs. *Circle 218 on Reader Service Card.*



***Rayspan Spectrum Analyzers***

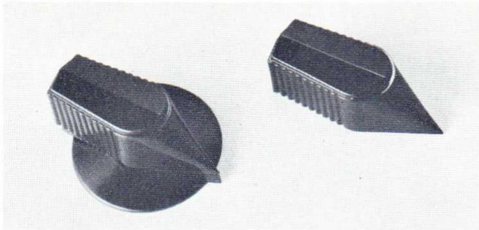
Utilizing a unique magnetostriction filter application, Rayspan Spectrum Analyzers provide the outstanding features of high speed, high resolution, and high sensitivity. Operating over a wide frequency range they enable the analysis of pulses and transients and distinguish weak signals. *Circle 219 on Reader Service Card.*




***Miniature Tubes***

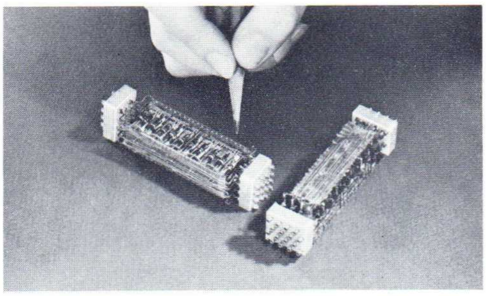
Raytheon miniature tubes are reliable and rugged. Their advanced electrical and mechanical construction features assure long life and trouble-free operation under the most adverse environmental conditions. Frame grid miniature types provide exceptionally high gain and low noise. *Circle 220 on Reader Service Card.*

**ADD RAYTHEON RELIABILITY**



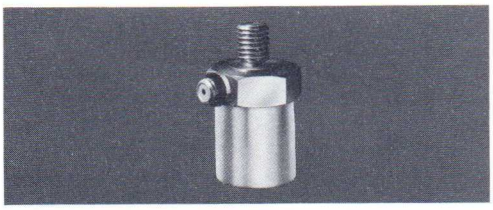
***Control Knobs and Panel Hardware***

For equipment that deserves the precision-engineered look, Raytheon offers the most complete line of matching control knobs to MS91528B plus panel hardware such as knob and shaft locks, test jacks, and panel fasteners. *Circle 221 on Reader Service Card.*



***Weld-Pak Circuit Modules***

Raytheon Weld-Pak circuit modules contain more than 100 components and 300 welds in each cubic inch. A full line of standard computer logic modules, as well as complete custom-design service is available. Raytheon also provides a complete line of Weld-Pak neon, incandescent, and thyratron light indicator packages. *Circle 222 on Reader Service Card.*



***Accelerometers***

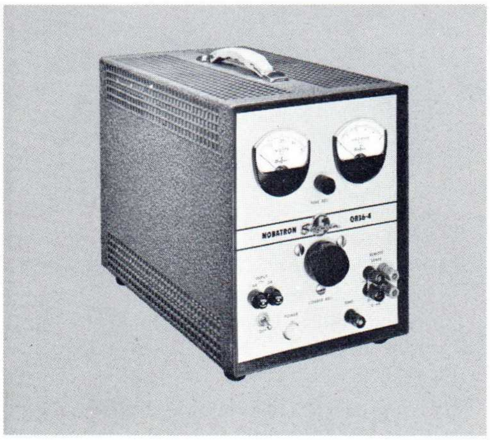
The EM900 piezoelectric accelerometer illustrated, is a general purpose type. It accurately measures shock up to 100,000 G's and vibration up to 10,000 cps with no measurable hysteresis and is operable in ambient temperatures ranging from 100° below zero F to 500° above zero F. *Circle 223 on Reader Service Card.*

RAYTHEON COMPANY

RAYTHEON

INDUSTRIAL COMPONENTS DIVISION

ADD RAYTHEON RELIABILITY



***New portable*** fully transistorized d-c power supply. QR36-4AP regulates 0 to 36 vdc output voltage to ± (0.02% + 1mv) against combined line or load variations. Fully metered. Front panel terminals for remote sensing. *Circle 224 on Reader Service Card.*

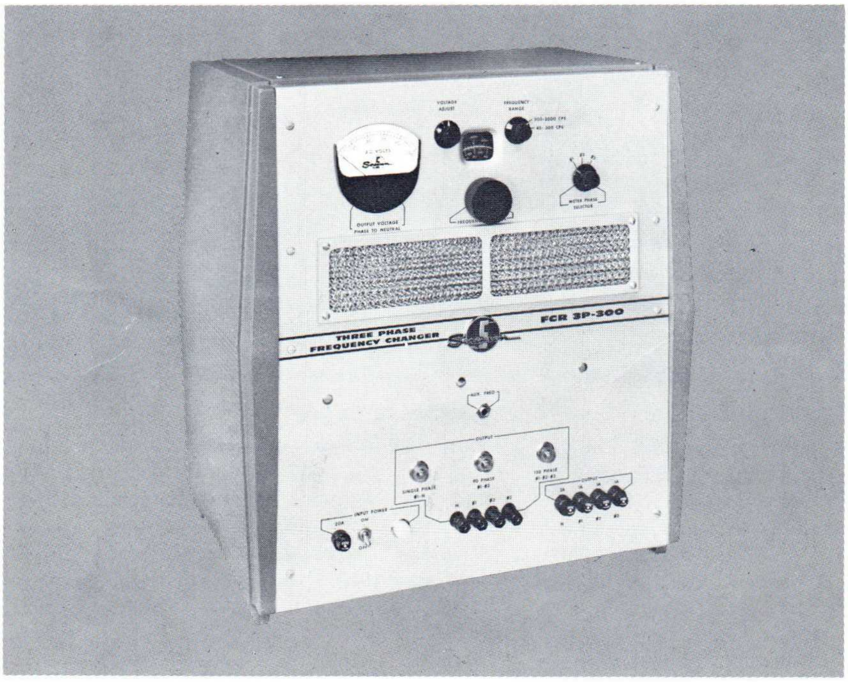

***New portable high-voltage supply*** Model 230-6P has unusually versatile controls, unusually complete protective features for a unit of its size. Rated: 0-30,000 vdc, at 0-6 ma. Reversible polarity. "Coarse" and "Fine" front-panel voltage adjustments. *Circle 225 on Reader Service Card.*

***New wide-range three-phase*** frequency changer, Model FCR3P300, supplies up to 300 volt-amperes, three-phase, at any frequency in the range 45 to 2000 cps. Low distortion. Also rated at 200 VA two-phase or 300 VA single-phase. *Circle 226 on Reader Service Card.*

# Three new models added to Sorensen line of off-the-shelf controlled power units

. . . just a sample of the more-than-400 Sorensen models . . . including regulated d-c power supplies, a-c voltage regulators, voltage regulating transformers, high-voltage d-c power supplies, high-voltage a-c and d-c testers, and miniature component-type inverters, converters, and d-c supplies. Request your copy of the new 1961 Sorensen "Power Supply Handbook and Catalog" from Sorensen & Company, Richards Avenue, South Norwalk, Conn.

For nearest
Sales Office
see last page of insert.




Sorensen

SUBSIDIARY OF RAYTHEON COMPANY

SORENSEN & COMPANY, INC.

SOUTH NORWALK, CONNECTICUT

ADD RAYTHEON RELIABILITY

# Analog-Digital converter handles 5 million information samples/second

Faster than any other available, Raytheon's new A-D converter provides up to 5 million independent 8-bit words per second.

The machine's twenty-five nanosecond aperture time allows digitizing of pulses less than one-half microsecond in width.

About the size of an office typewriter, the A-D converter offers industry and government a basic solid-state tool which significantly extends the state of the art.

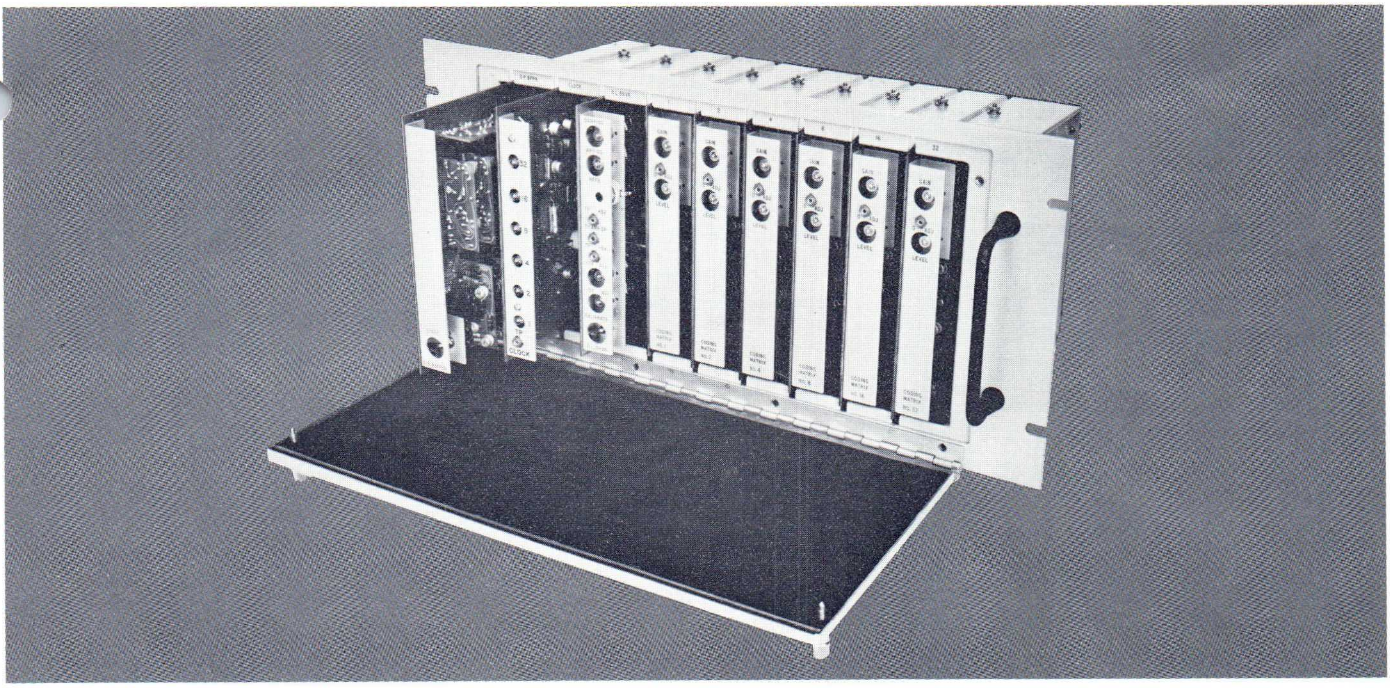
The machine lends itself readily to system integration because its flexible design allows acceptance of variable input as well as wide variations in output format and logic.

With multiplexed input, its applications encompass any product or process requiring continuous or intermittent digitizing of analog voltages in any form.

For complete specifications please write Communications and Data Processing Operations, Raytheon Company, 225 Crescent St., Waltham, Massachusetts.

For nearest Raytheon Sales Office see last page of insert.

Analog-Digital Converter, about the size of an office typewriter, is readily integrated in data handling systems. *Circle 227 on Reader Service Card.*



RAYTHEON COMPANY

EQUIPMENT DIVISION

RAYTHEON

ADD RAYTHEON RELIABILITY

# Power, protection, regulation . . . all three in one transformer!

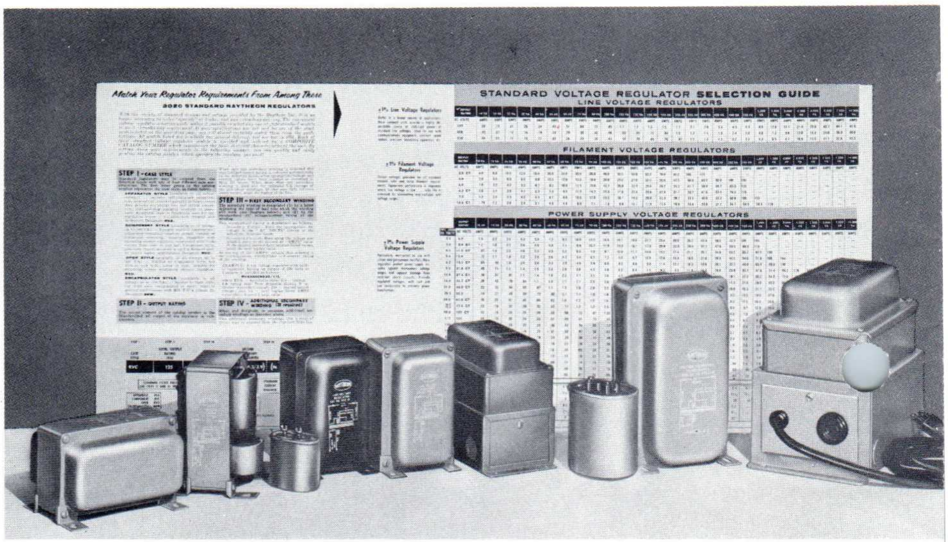
**Series 2020 Voltage Regulating Transformers cost less than ordinary transformers plus associated regulating circuitry.**

Is the transformer in your power supply merely supplying power or does it *regulate voltage* and *protect circuits,* too?

Raytheon's Series 2020 Voltage Regulating Transformers perform all *three* functions. They (1) provide the specified voltage and current from 10 VA to 10,000 VA, (2) stabilize voltage within ± 1% and (3) protect tubes and delicate semiconductor rectifiers against power surges as well as internal and external short circuits.

These versatile "magnetic regulators" are extremely compact and inexpensive, too—take less space and cost less than ordinary transformers plus associated regulating circuitry.

Send for convenient Raytheon Selection Guide and Power Supply Design Data that helps you match your requirements from 2,020 standard units. Commercial Apparatus & Systems Division, Raytheon Company, Keeler Avenue, South Norwalk, Conn.




***Series 2020 magnetic regulators*** are available in a wide range of models and styles. Convenient selection guide lets you choose from 2020 different units. *Circle 228 on Reader Service Card.*


***New low-cost regulated dc power packages.*** These compact "RD" units are available in 132 different ready-to-operate models for standard 19-inch rack installation, 3 to 1,000 volts, 50 to 3,000 watts in 20 voltage steps and 7 power ratings. DC output is isolated and filtered with a ripple reduction to within 0.5 to 1.0% depending on model. *Circle 229 on Reader Service Card.*

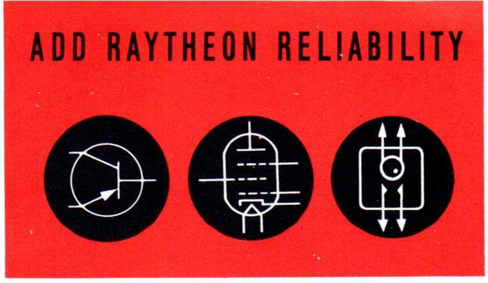
For nearest Raytheon Sales Office see last page of insert.

RAYTHEON

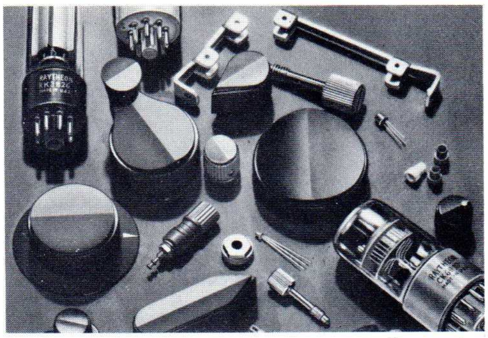
RAYTHEON COMPANY

COMMERCIAL APPARATUS AND SYSTEMS DIVISION

For nearest
Raytheon Sales Office
see last page of insert.




# RAYTHEON DISTRIBUTORS in 57 cities offer immediate delivery of RAYTHEON RELIABLE COMPONENTS . . . at no penalty in price



*If no Raytheon Distributor* is listed for your area, we will be pleased to send you the name of the Distributor nearest you. *Circle 230 on Reader Service Card.*

## *Raytheon Distributors in your area include:*

**ALABAMA**
Birmingham
Forbes Distributing Company
AL 1-4104
MG Electrical Equipment Company
FAirfax 2-0449
Mobile
Forbes Electronic Distributors, Inc.
HE 2-7661

**ARIZONA**
Phoenix
Radio Specialties & Appl. Corp.
AL 8-6121
Tucson
Standard Radio Parts, Inc.
MA 3-4326

**CALIFORNIA**
Burbank
Valley Electronic Supply Co.
VIctoria 9-3944
Glendale
R. V. Weatherford Co.
VIctoria 9-2471
Hollywood
Hollywood Radio & Electronics, Inc.
HO 4-8321
Inglewood
Newark Electronics Company
ORchard 4-8440
ORegon 8-0441
Los Angeles
Federated Purchaser
BRadshaw 2-8771
Graybar Electric Company
ANgelus 3-7282
Kierulff Electronics, Inc.
RIchmond 8-2444
Oakland
Brill Electronics
TE 2-6100
Elmar Electronics
TEmplar 4-3311
Palo Alto
Zack Electronics
DA 6-5432
San Diego
Radio Parts Company
BE 9-9361
San Francisco
Fortune Electronics
UN 1-2434
Santa Ana
Airtronic Sales, Inc.
KImberly 5-9441
Santa Monica
Santa Monica Radio Parts Corp.
EXbrook 3-8231

**COLORADO**
Denver
Ward Terry Company
AMherst 6-3181

**CONNECTICUT**
East Haven
J. V. Electronics
HObart 9-1310

**DISTRICT OF COLUMBIA**
Electronic Industrial Sales, Inc.
HUdson 3-5200

**FLORIDA**
Miami
East Coast Radio & Television Co.
FRanklin 1-4636
Electronic Equipment Co., Inc.
NEwton 5-0421
West Palm Beach
Goddard Distributors, Inc.
TEmple 3-5701

**ILLINOIS**
Chicago
Allied Radio Corporation
HAymarket 1-6800
Newark Electronics Corp.
STate 2-2944

**INDIANA**
Indianapolis
Graham Electronics Supply Inc.
MElrose 4-8486

**LOUISIANA**
New Orleans
Columbia Radio and Supply Co.
TW 7-0111

**MARYLAND**
Baltimore
Wholesale Radio Parts Co., Inc.
MUlberry 5-2134

**MASSACHUSETTS**
Boston
Cramer Electronics, Inc.
COpley 7-4700
DeMambro Radio Supply Co., Inc.
AL 4-9000
Graybar Electric Co.
HUbbard 2-9320
Lafayette Radio Corp. of Mass.
HUbbard 2-7850
Cambridge
Electrical Supply Corp.
UNiversity 4-6300

**MICHIGAN**
Ann Arbor
Wedemeyer Electronic Supply Co.
NOrmandy 2-4457
Detroit
Ferguson Electronics, Inc.
UN 1-6700

**MISSISSIPPI**
Jackson
Ellington Radio, Inc.
FL 3-2769

**MISSOURI**
Kansas City
Burstein-Applebee Company
BAltimore 1-1155
St. Louis
Graybar Electric Company
JEfferson 1-4700

**NEW HAMPSHIRE**
Concord
Evans Radio
CApital 5-3358

**NEW JERSEY**
Camden
General Radio Supply Co.
WO 4-8560 (in Phila.: WA 2-7037)
Mountainside
Federated Purchaser Inc.
AD 8-8200

**NEW YORK**
Binghamton
Stack Industrial Electronics, Inc.
RA 3-6326
Buffalo
Genesee Radio & Parts Co., Inc.
DElaware 9661
Wehle Electronics Inc.
TL 4-3270
Elmira
Stack Industrial Electronics, Inc.
RE 3-6513
Ithaca
Stack Industrial Electronics, Inc.
IThaca 2-3221
Mineola, Long Island
Arrow Electronics, Inc.
PIoneer 6-8686
New York City
H. L. Dalis, Inc.
EMpire 1-1100
Milo Electronics Corporation
BEekman 3-2980
Sun Radio & Electronics Co., Inc.
ORegon 5-8600
Terminal-Hudson Electronics, Inc.
CHelsea 3-5200

**OHIO**
Cincinnati
United Radio Inc.
CHerry 1-6530
Cleveland
Main Line Cleveland, Inc.
EXpress 1-4944
Pioneer Electronic Supply Co.
SUperior 1-9411
Columbus
Buckeye Electronic Distributors, Inc.
CA 8-3265
Dayton
Srepco, Inc.
BAldwin 4-3871

**OKLAHOMA**
Tulsa
S & S Radio Supply
LU 2-7173

**OREGON**
Portland
Lou Johnson Company, Inc.
CApital 2-9551

**PENNSYLVANIA**
Philadelphia
Almo Radio Company
WAlnut 2-5918
Radio Electric Service Co.
WAlnut 5-5840
Pittsburgh
Marks Parts Company
FAirfax 1-3700
Reading
The George D. Barbey Co., Inc.
FR 6-7451

**TENNESSEE**
Knoxville
Bondurant Brothers Company
3-9144

**TEXAS**
Dallas
Graybar Electric Company
RIverside 2-6451
Houston
Busacker Electronic Equipment Co.
JAckson 6-4661
Harrison Equipment Company
CApitol 4-9131

**UTAH**
Salt Lake City
Standard Supply Company
EL 5-2971

**VIRGINIA**
Norfolk
Priest Electronics
MA 7-4534

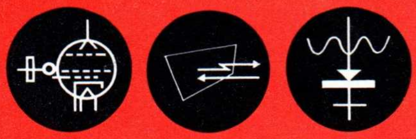
**WASHINGTON**
Seattle
Western Electronic Company
AT 4-0200

**WEST VIRGINIA**
Bluefield
Meyers Electronics, Inc.
DAvenport 5-9151

**WISCONSIN**
Milwaukee
Electronic Enterprises, Inc.
GR 6-4144

RAYTHEON COMPANY
RAYTHEON
DISTRIBUTOR PRODUCTS DIVISION

**ADD RAYTHEON RELIABILITY**



## For complete information on Raytheon products see your nearest Raytheon Sales Office listed below

**CALIFORNIA**
225 N. Van Ness Ave.
Hawthorne, Calif.
PLymouth 7-3151

486 El Camino Real
Redwood City, Calif.
EMerson 9-5566

**COLORADO**
1422 Hancock St.
Colorado Springs, Colo.
MElrose 3-3846
(Microwave Communications only)

**CONNECTICUT**
Richards Ave.
South Norwalk, Conn.
TEmple 8-6571
(Sorensen & Co. Headquarters)

1063 Hope Street
Springdale, Conn.
FIreside 8-7511
(Machlett Laboratories, Inc. Headquarters)

**DISTRICT OF COLUMBIA**
1000 16th St., N. W.
Washington, D. C.
MEtropolitan 8-5205
(Semiconductors only)

**FLORIDA**
1612 E. Colonial Drive
Orlando, Fla.
GArden 3-0518

**GEORGIA**
3110 Maple Drive, N. E.
Atlanta, Ga.
231-3350

**ILLINOIS**
510 N. Dearborn St.
Chicago, Ill.
MIchigan 2-5316
(Machlett Laboratories only)

9501 Grand Ave.
Franklin Park, Ill.
NAtional 5-4000

**INDIANA**
3599 S. East St.
Indianapolis, Ind.
STate 4-4318
(Distributor Sales only)

**IOWA**
Box 397
Strawberry Point, Iowa
WEst 3-2244
(Microwave Communications only)

**LOUISIANA**
4032 Thalia St.
New Orleans, La.
JAckson 2-7611
(Microwave Communications only)

**MARYLAND**
100 Roesler Rd.
Glen Burnie, Md.
SOuthfield 1-0450

**MASSACHUSETTS**
Spencer Laboratory
Wayside Ave.
Burlington, Mass.
BRowning 2-9600
(Microwave and Power Tube Div. Headquarters)

215 First Ave.
Needham Heights, Mass.
HIllcrest 4-6700
(Semiconductor Division Headquarters)

55 Chapel St.
Newton, Mass.
BIgelow 4-7500
(Industrial Components Division Headquarters)

1415 Providence Turnpike
Norwood, Mass.
NOrwood 7-6700
(Commercial Apparatus & Systems Division Headquarters)

225 Crescent St.
Waltham, Mass.
TWinbrook 9-8400
(Communications & Data Processing Operations Headquarters)

130 Second Ave.
Waltham Industrial Park
Waltham, Mass.
TWinbrook 9-8080
(Special Microwave Devices Operations Headquarters)

190 Willow St.
Waltham, Mass.
TWinbrook 9-8400
(Magnetics Operations Headquarters)

411 Providence Turnpike
Westwood, Mass.
DAvis 6-7700
(Distributor Products Division Headquarters)

**MICHIGAN**
New Center Bldg.
7430 Second Ave.
Detroit, Mich.
TRinity 3-5330

**MINNESOTA**
6121 Excelsior Blvd.
Minneapolis, Minn.
WEst 9-2988
(Distributor Sales only)

**MISSOURI**
P.O. Box 917
Kansas City, Mo.
SHerwood 1-1560
(Transformers only)

**MISSOURI** (cont.)
111 S. Bemiston Ave.
Clayton 5, Mo.
PArk View 7-5133
(Distributor Sales only)

**NEW JERSEY**
210 Sylvan Ave.
Englewood Cliffs, N. J.
LOwell 7-4911

1500 Kings Highway
Haddonfield, N. J.
HAzel 8-2499

**NEW YORK**
Manhattan
WIsconsin 7-6400

2360 James St.
Syracuse, N. Y.
HOward 3-9141

**NORTH CAROLINA**
1402 E. Morehead St.
Charlotte, N. C.
FRanklin 5-2914
(Distributor Sales only)

**OHIO**
3076 W. 117th St.
Cleveland, Ohio
WInton 1-7716

333 W. First St.
Dayton, Ohio
BAldwin 3-8128
(Semiconductors only)

**OKLAHOMA**
2611 E. 41st St.
Tulsa, Okla.
RIverside 2-4784
(Distributor Sales only)

**PENNSYLVANIA**
1125 Old York Rd.
Abington, Pa.
TUrner 6-7500
(Distributor Sales only)

408½ Beaver St.
Sewickley, Pa.
SEwickley 3700
(Distributor Sales only)

**TEXAS**
Lee Park Bldg.
3511 Hall St.
Dallas, Texas
LAkeside 6-7921

**CANADA**
Raytheon Canada Limited
Waterloo, Ontario
SHerwood 5-6831

**OVERSEAS**
International Sales & Service
100 River Street
Waltham 54, Mass.
TWinbrook 9-8400

RAYTHEON

RAYTHEON COMPANY

WALTHAM, MASSACHUSETTS

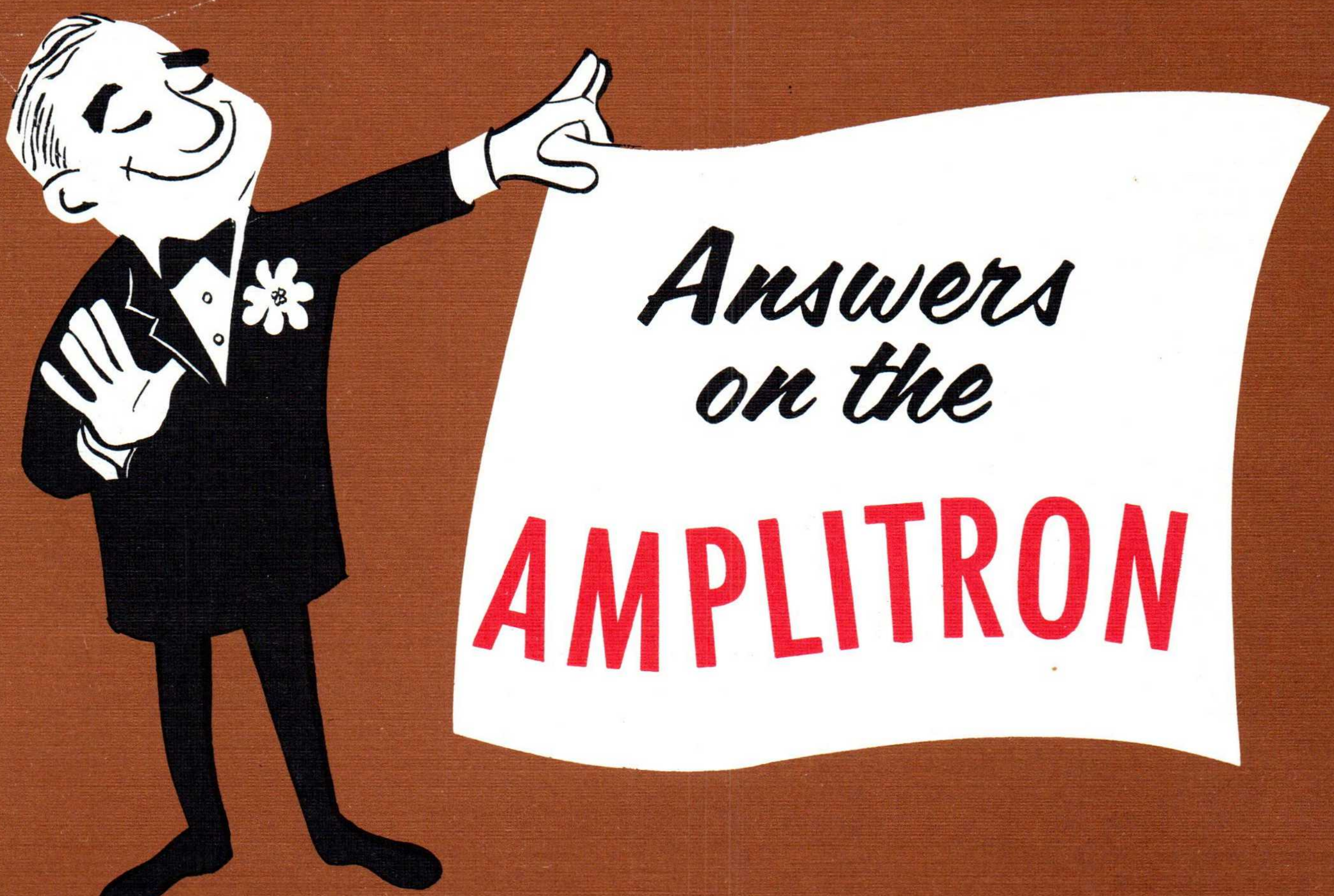
A-2233

PRINTED U.S.A.

T.P.D. 8.

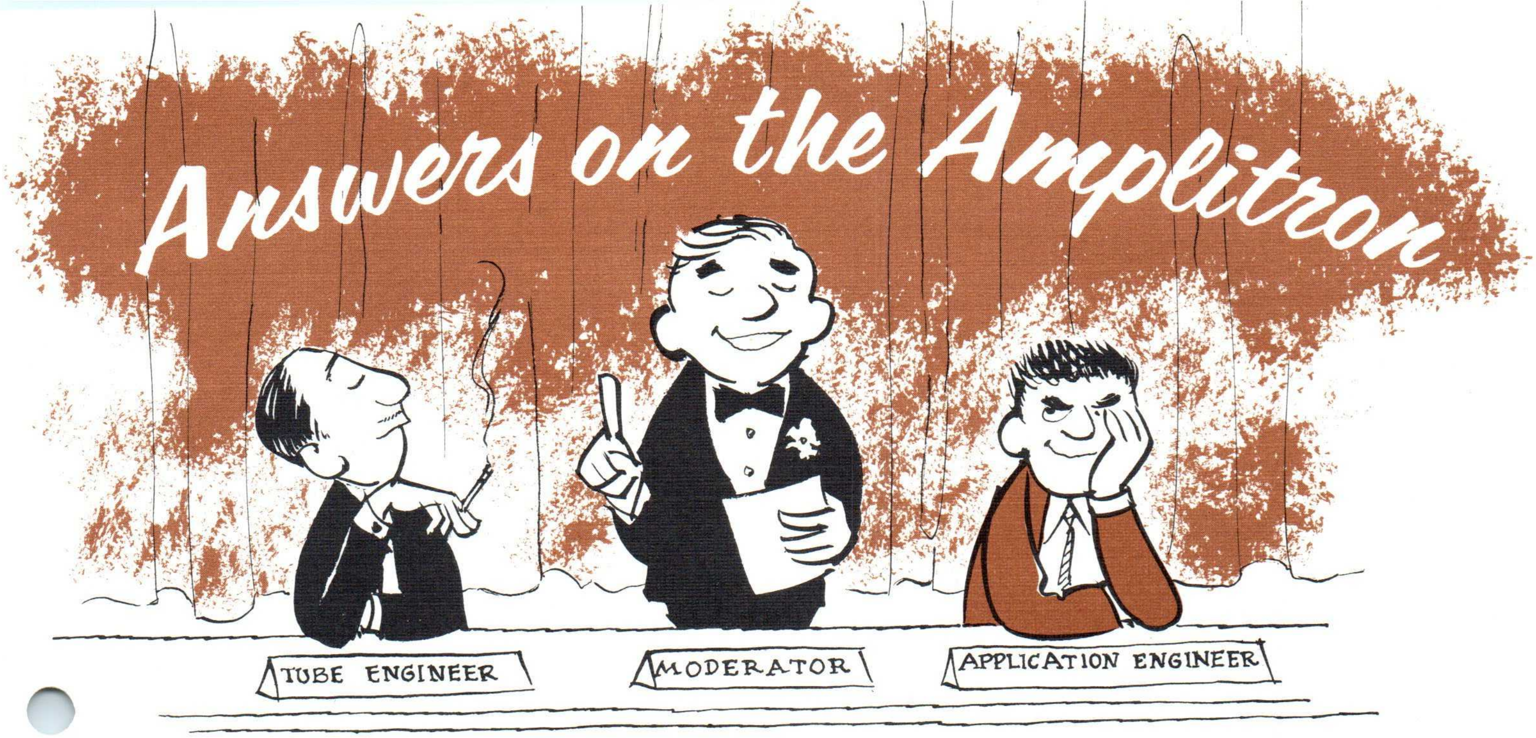
RAYTHEON






RAYTHEON MANUFACTURING COMPANY
MICROWAVE AND POWER TUBE DIVISION
WALTHAM 54, MASSACHUSETTS

# Answers on the Amplitron




*Moderator*

"As the leading designer and manufacturer of microwave tubes in the United States, Raytheon Manufacturing Company maintains a maximum effort to provide systems designers with the most advanced tube types, so that the full performance demanded in modern systems can be realized. The Amplitron,* a compact, highly efficient, microwave tube, capable of handling high peak and average powers, is one of the results of such constant effort.

The purpose of this meeting is primarily to present the latest application information on the Amplitron* to the system designer. One of Raytheon's Tube Application Engineers will begin the program with a discussion of the properties and use of the tube. He will be followed by a Tube Design Engineer who will discuss the nature of the tube itself. These engineers will then answer any questions concerning the Amplitron* and its application that you, Mr. System Designer, wish to ask at that time."

*Application Engineer*

"In general, the Amplitron* can be described as a new type of crossed field vacuum tube which combines high power output, high efficiency, frequency flexibility, relatively low input voltages, and excellent phase stability, with simple, compact, mechanical construction. When suitably driven, the device operates over a frequency band which is nominally ten percent, producing output signal levels in the megawatt region with a nominal power gain of 10 db.

Inherent high efficiency, as high or higher than that of a magnetron, makes the Amplitron* ideally suited for intermediate and final stages in amplifier chains. Figure 1 illustrates the external construction of a typical Amplitron.* The physical similarities to a conventional magnetron oscillator are obvious. Aside from the waveguide (or coaxial) coupling required, the size, weight, and appearance of an Amplitron* are generally comparable to the corresponding features of a magnetron operating at the same wavelength and power level.

For purpose of simplification, the Amplitron* may be considered as a short, lossless length of active

* Raytheon Trademark

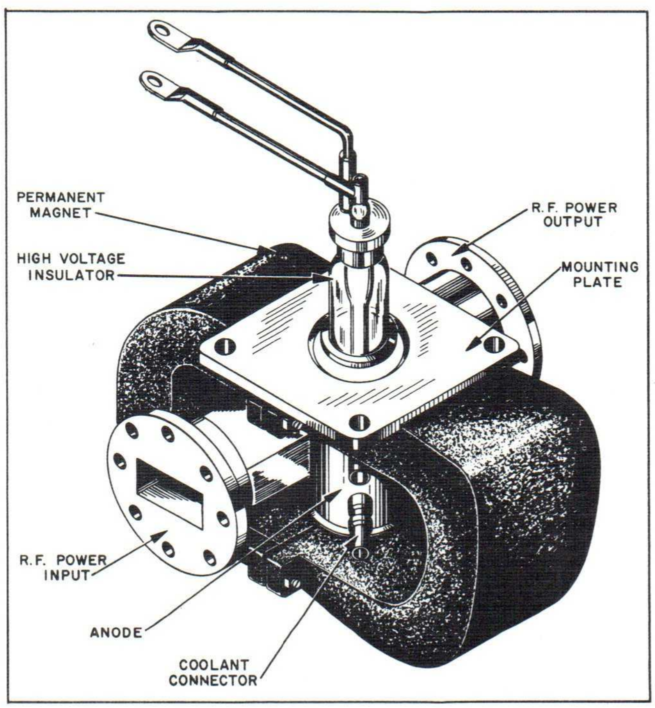



**Figure 1**

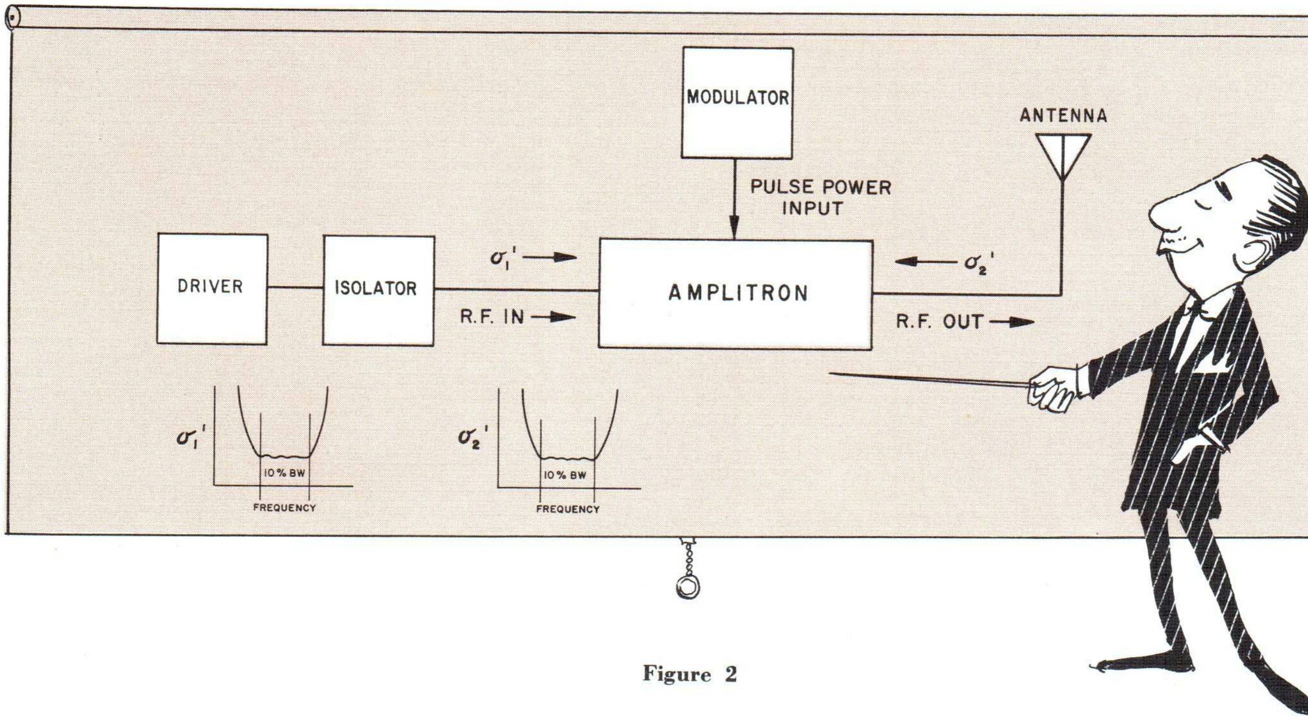



**Figure 2**

transmission line which has certain electrical properties. See Figure 2. This transmission line however, has the ability to transform energy from an external DC (or pulsed) power source into R. F. energy, and thus produce power gains in the order of 10 db or higher with relatively high efficiency (50 to 65%). Gain is defined as $\frac{\text{RF out}}{\text{RF in}}$, and efficiency as $\frac{\text{RF out} - \text{RF in}}{\text{Modulator Power in}} \times 100$.

Since the Amplitron* behaves as a lossless transmission line in either the forward or reverse direction, it is possible to perform duplexing at the input side of the device. Reflected energy from the target will be relatively unaffected by the tube. Because of this same lossless property it is generally necessary to provide isolation between the driver and the Amplitron* to protect the driver tube and to prevent regenerative feedback oscillation of the Amplitron.*

In order to discuss possible applications for the Amplitron,* it is perhaps advisable at this time to list the properties of the tube in its present state.

The following characteristics therefore are presented for your consideration.

1. Bandwidth ten percent.
2. High peak power.
3. High efficiency.
4. Short or long pulse width capability.
5. Very low phase pushing figure.
6. Simple mechanical construction, adapted to all the standard production techniques for magnetrons.
7. Only a moderate operating potential required.
8. No lead shielding usually required.
9. No heater power usually required for preheat or operate.
10. Excellent pulse stability.

The Amplitron* is intended for use in pulsed radars, or frequency diversity systems, where its role is to obtain a high level output signal, and to reproduce faithfully the frequency and phase of the R.F. input. Where increased ranged and improved overall performance for an existing radar system are required, the Amplitron* is an ideal solution. The Amplitron* is a power package that can usually be added to existing radar systems with little modification to the original equipment. Figure 3 illustrates this increased radar coverage.

* Raytheon Trademark

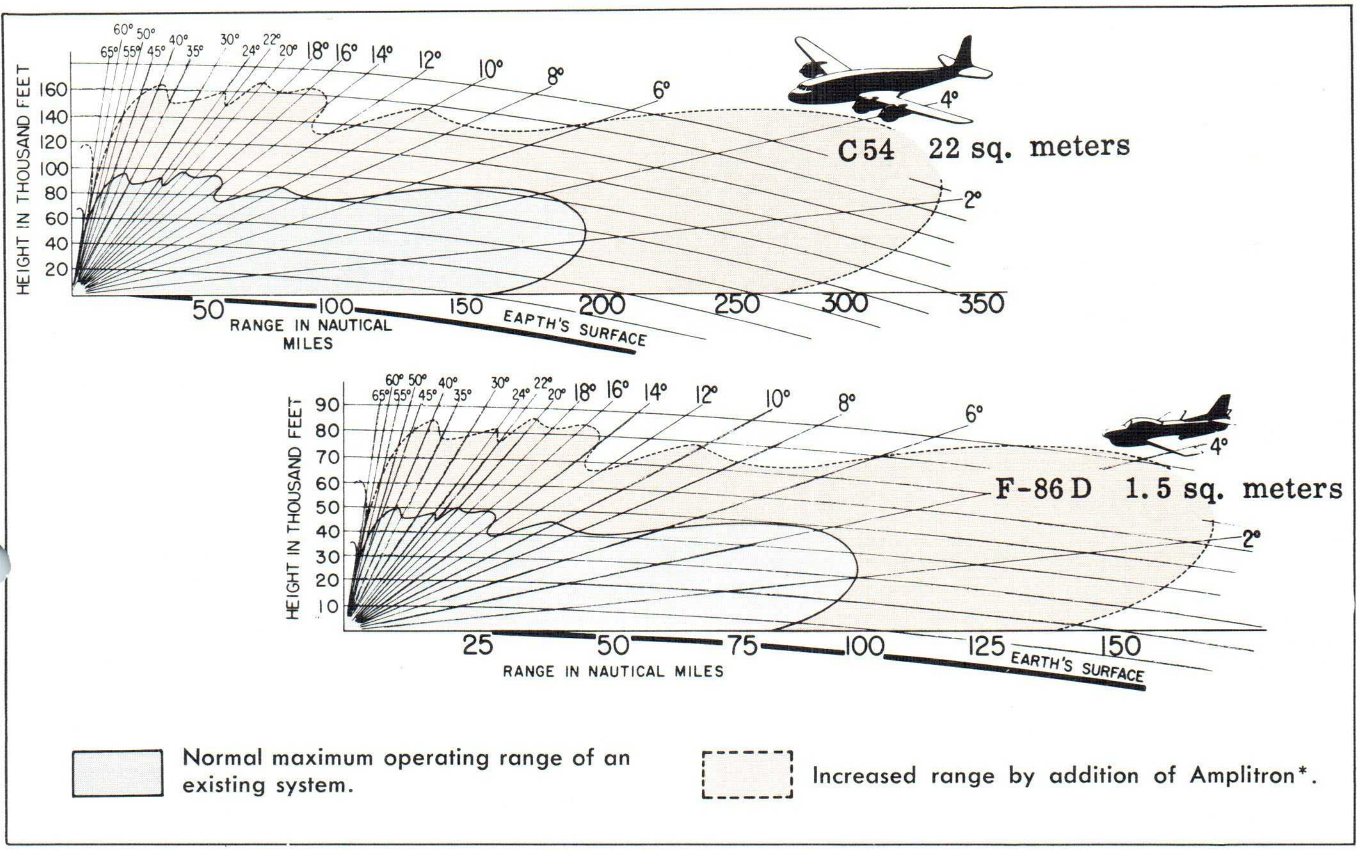



**Figure 3**

Using the bi-directional properties of the Amplitron,* it may be possible to duplex on the input side and use the existing radar duplexing equipment. This duplexing arrangement allows the duplexer to operate at the power level of the original R.F. device, even though the system is operating effectively at a transmitted peak power level ten or more times greater than the power level of the original driver. Figure 4 is a schematic showing how such duplexing can be accomplished."

*Tube Design Engineer*

"You have heard the general characteristics of the Amplitron* described and what it can do for a radar transmitter. Now let us examine the internal circuit of the device so that we may understand more fully why the Amplitron* has these characteristics.

* Raytheon Trademark

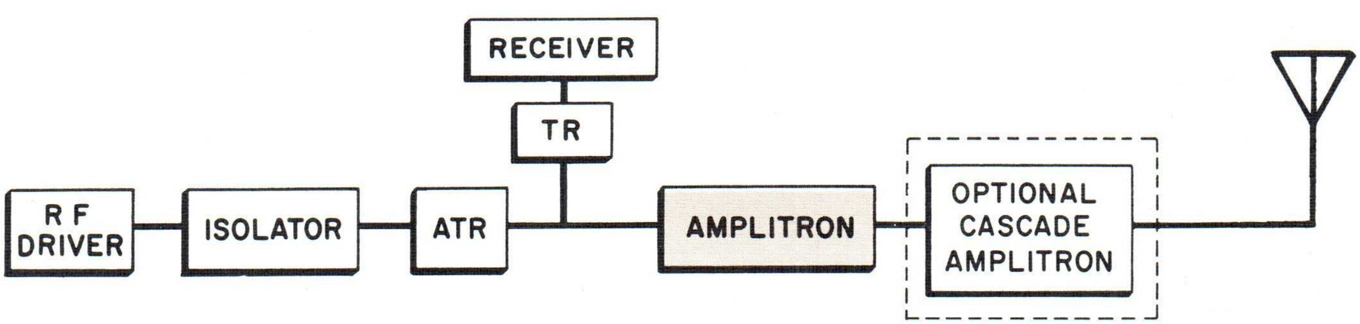



**Figure 4**

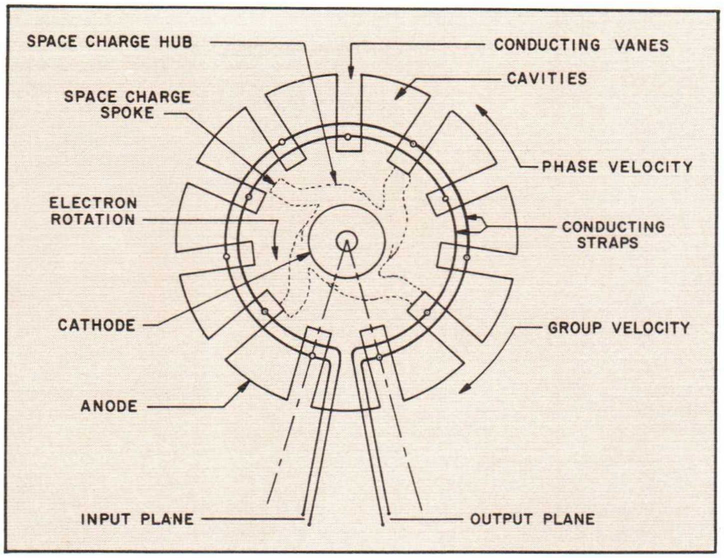



**Figure 5**

Figure 5 shows the internal structure of the Amplitron.* You will note that it resembles a multi-cavity strapped magnetron, in which a number of vanes form cavities which are connected in turn by conducting straps. A continuous, cylindrical, cathode is employed, as in the magnetron, which produces a rotating multiple velocity space charge in the interaction space between cathode and vane tips.

The circuit employed in the Amplitron* supports so-called "backward waves." For energy traveling along the anode circuit from input to output, there is an apparent rate of progression of phase fronts which travels in the opposite direction adjacent to the vane tips. This rate of progression is termed the phase velocity as distinguished from the group or true energy velocity. If the rotating space charge is made to travel with the same direction and speed as this apparent progression of phase fronts, electrons will become bunched into spokes extending from the space charge hub of the cathode to the vane tips. Each time these spokes traverse a gap between vanes, the R.F. fields in that gap will be phased so as to extract energy from the electrons in the spokes. The interchange of energy as in the conventional multi-cavity magnetron is accomplished in the following manner. The D.C. field between cathode and anode imparts kinetic and potential energy and accounts for the increase in R.F. energy. The entire process is manifested by D.C. anode current which results when the electrons, having given up most of their energy, reach the anode.

In a magnetron oscillator a high Q re-entrant network is employed in order to obtain load stability, but the re-entrancy of the circuit imposes restrictions on its frequency of operation. A traveling wave progressing around the closed network must experience during a single transit an integral number of R.F. cycles. This condition is met at only the discrete frequencies of the high Q resonances.

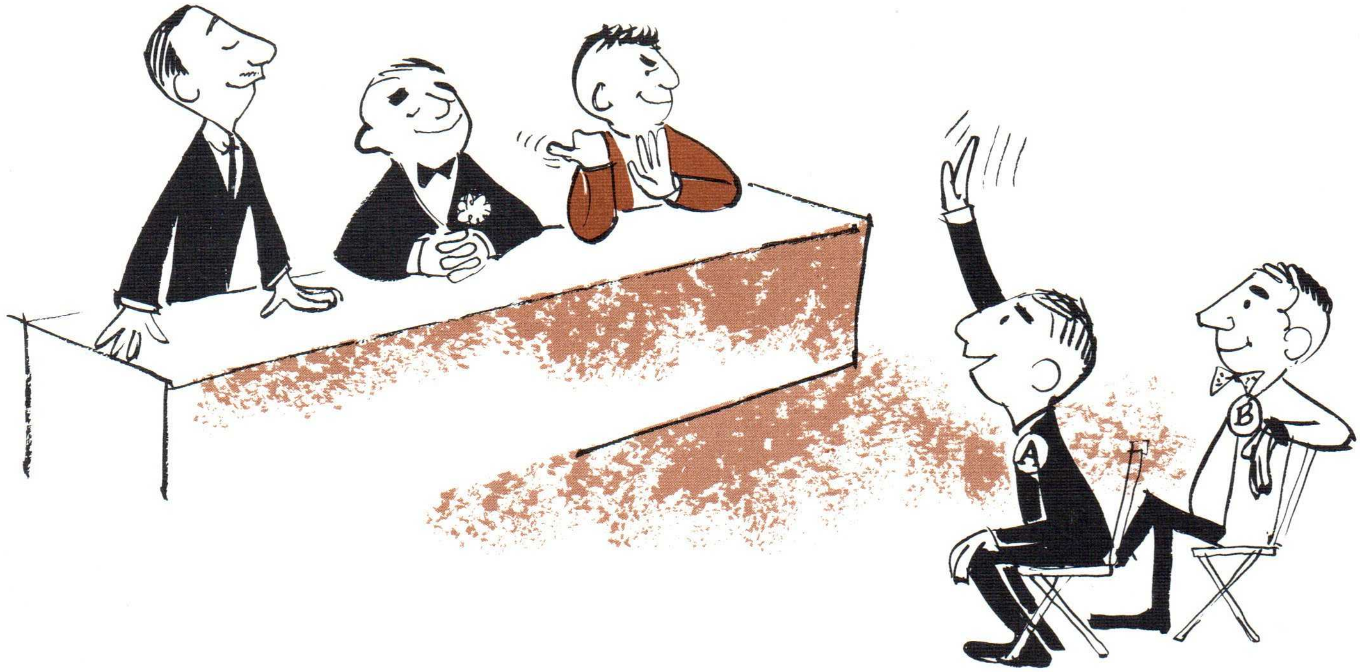
In the Amplitron,* the circuit is not re-entrant, and it is matched in the operating band, eliminating frequency determination due to circuit resonances. Because the electron interaction space is re-entrant, however, the re-entrant phase of the space charge spokes must still be reckoned with. Although re-entrancy precisely in phase with the input R.F. signal can, strictly speaking, be satisfied only at one frequency in the band, operating is possible with large phase differences (in the order of 90°) between the spoke and the R.F. field. In this way, operation is obtained over a broad frequency range. In practice, operating bands of ten percent or more are achievable.

In the Amplitron,* the driving signal will control the frequency and phase of the output. It should be noted in the cases of the magnetron oscillator and the Amplitron,* that the multiple velocity electron stream arising from the continuous cathode eliminates any precise frequency determination due to electron velocity.

A significant advantage of the matched circuit is the resulting low R.F. voltage along the anode network. Pulse stability (freedom from internal arcing) in magnetrons and Amplitrons* is directly related to the magnitude of the R.F. field. In the Amplitron,* which has relatively low R.F. voltage in comparison with the magnetron, the improvement in pulse stability is readily discernible. The relatively low R.F. voltage also contributes to the high efficiency of the tube.

Phase stability can also be expected to be very good in the new device. Such stability can be attributed to the fact that R.F. energy transfer in the Amplitron* is primarily through the circuit, very little being carried by the beam."

* Raytheon Trademark




*Moderator*

"Now that the Application Engineer and Tube Design Engineer have presented a brief summary of their particular phases of the Amplitron,* specific questions by the System Designers will be answered by the appropriate engineer."

Q. *System Designer "A"*

"Will the Amplitron* amplify amplitude modulated signals?"

A. *Application Engineer*

"No. The Amplitron* is essentially a constant efficiency device and consequently its output level is proportional to the D.C. pulsed power input. As a result the output level of the Amplitron* is relatively independent of the R.F. input level. This insensitivity to drive level tends to preserve constant output in a multi-stage amplifier chain."

Q. *System Designer "B"*

"Why is isolation required in most cases between the Amplitron* and its driver?"

A. *Tube Engineer*

"Although the Amplitron* possesses a mechanism for cancelling any reverse directed power which it generates itself, it does not damp out appreciably reverse directed power which is reflected from a mismatch at its output. Unless isolation is provided between the driver and the Amplitron* when the Amplitron* is operated into a mismatched load, the driver will see a very high VSWR depending upon the gain of the Amplitron,* and the amount of mismatch in the load."

Q. *System Designer "B"*

"Are ferrite isolators available for isolation purposes?"

A. *Application Engineer*

"Yes. Isolators are available at most frequencies in the microwave region. The Components Department of the Raytheon Equipment Engineering Division, manufactures ferrite isolators which are ideal for this application."

Q. *System Designer "A"*

"Are any mechanical or electrical adjustments required for operation over the ten percent frequency range?"

A. *Tube Engineer*

"No mechanical adjustments are required when pulsed power is supplied from a line type modulator. It should be expected that the microwave environment in which the Amplitron* is placed will affect the operation because of the lossless property of the Amplitron* and the high power levels involved. In addition, the operating voltage and/or current must change slightly as the operating frequency is varied. This change occurs automatically when using a line type modulator, and essentially constant R.F. power output (power variations are less than 1 db) results over the entire operating frequency band. (The operating band is not defined by 3db points.) With other forms of power supplies, some degree of current regulation is required as the driver frequency is varied."

* Raytheon Trademark

Q. *System Designer "A"*

"What is the gain of the Amplitron*?"

A. *Application Engineer*

"The Amplitron* is not a constant gain device. Its effective gain varies with operating power level and has a mean value near 10 db. The effective gain decreases with increasing power level and increases with decreasing power level."

Q. *System Designer "B"*

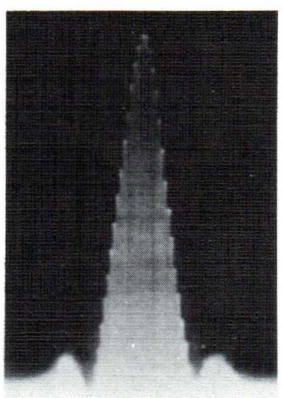
"What can you tell us about the efficiency of the Amplitron*?"

A. *Application Engineer*

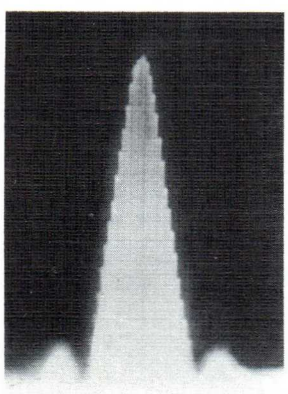
"The efficiency of the Amplitron* is one of its outstanding features. Amplitron* efficiency is defined as R.F. power output minus R.F. power input, divided by modulator power input. Efficiencies above sixty percent are common. Carefully measured efficiencies from seventy to eighty percent and high power output have been achieved simultaneously. The system engineer will recognize that the efficiency of the final amplifier is a primary factor in determining the physical size and weight of the modulator. The high efficiency inherent in the Amplitron* also means that less equipment would be required to cool the anode of the final stage."

Q. *System Designer "A"*

"Is the Amplitron* sensitive to pulse shape and power supply ripple?"



Driver Input Spectrum



Amplitron Output Spectrum

**Figure 6**

A. *Tube Engineer*

"The Amplitron* has an inherently low phase pushing figure. Phase pushing indicates a dependency of the R.F. output phase on the amount of current flowing through the Amplitron.* Values of the order of 0.5° phase change per one percent change in anode current are obtained. As a result, both spectrum reproduction and MTI operation are excellent." See Figure 6.

Q. *System Designer "A"*

"What about the effect of load variations on Amplitron* performance?"

A. *Application Engineer*

"Under variable load conditions the quality of the output spectrum remains unchanged regardless of phase position and output mismatch up to a VSWR of 2.0, providing, of course, that the driver source is adequately isolated."

Q. *System Designer "B"*

"Is the Amplitron* susceptible to changes in pulse voltage, magnetic field, heater power, etc.?"

A. *Application Engineer*

"The Amplitron* is not critically dependent upon magnetic field, anode voltage, anode current, load conditions, or frequency."

Q. *System Designer "A"*

"What do you mean by 'no heater power required'?"

A. *Tube Engineer*

"Extensive tests have indicated that some Amplitrons* require no heater power at all. This eliminates the need for costly heater power supplies and their associated circuitry."

* Raytheon Trademark

Q. *System Designer "A"*

"What are the operating voltage requirements of the Amplitron*?"

A. *Tube Engineer*

"The input impedance of the Amplitron* is comparable to that of the magnetron. Its operating voltages are moderately low."

Q. *System Designer "B"*

"Is the Amplitron* sensitive to voltage rise time?"

A. *Application Engineer*

"The Amplitron* will operate at considerably faster voltage rise times than the magnetron. The time required for the Amplitron* to build up to its full operating power is very short since operation does not have to build up from noise."

Q. *System Designer "A"*

"At what pulse widths can the Amplitron* be operated?"

A. *Application Engineer*

"The values vary with operating level and design frequency. Values up to 20 microseconds have been used successfully with no limit apparent. CW operation has also been demonstrated."

Q. *System Designer "B"*

"How do the physical characteristics of the Amplitron* compare with those of the magnetron?"

A. *Tube Engineer*

"The Amplitron* possesses the magnetron characteristic of compactness, and is therefore very desirable for airborne or other applications requiring light weight."

Q. *System Designer "A"*

"Is there a proper sequence for applying DC power and RF drive to the Amplitron*?"

A. *Application Engineer*

"The R.F. drive must coincide with or overlap the Amplitron* current pulse. In the absence of RF drive, the Amplitron* produces spurious signals of considerable bandwidth and power."

Q. *System Designer "A"*

"What type of tubes are used to drive the Amplitron*?"

A. *Application Engineer*

"Any type of tube can be used to drive an Amplitron,* although the resulting composite microwave circuit must be designed for the tubes involved."

* Raytheon Trademark

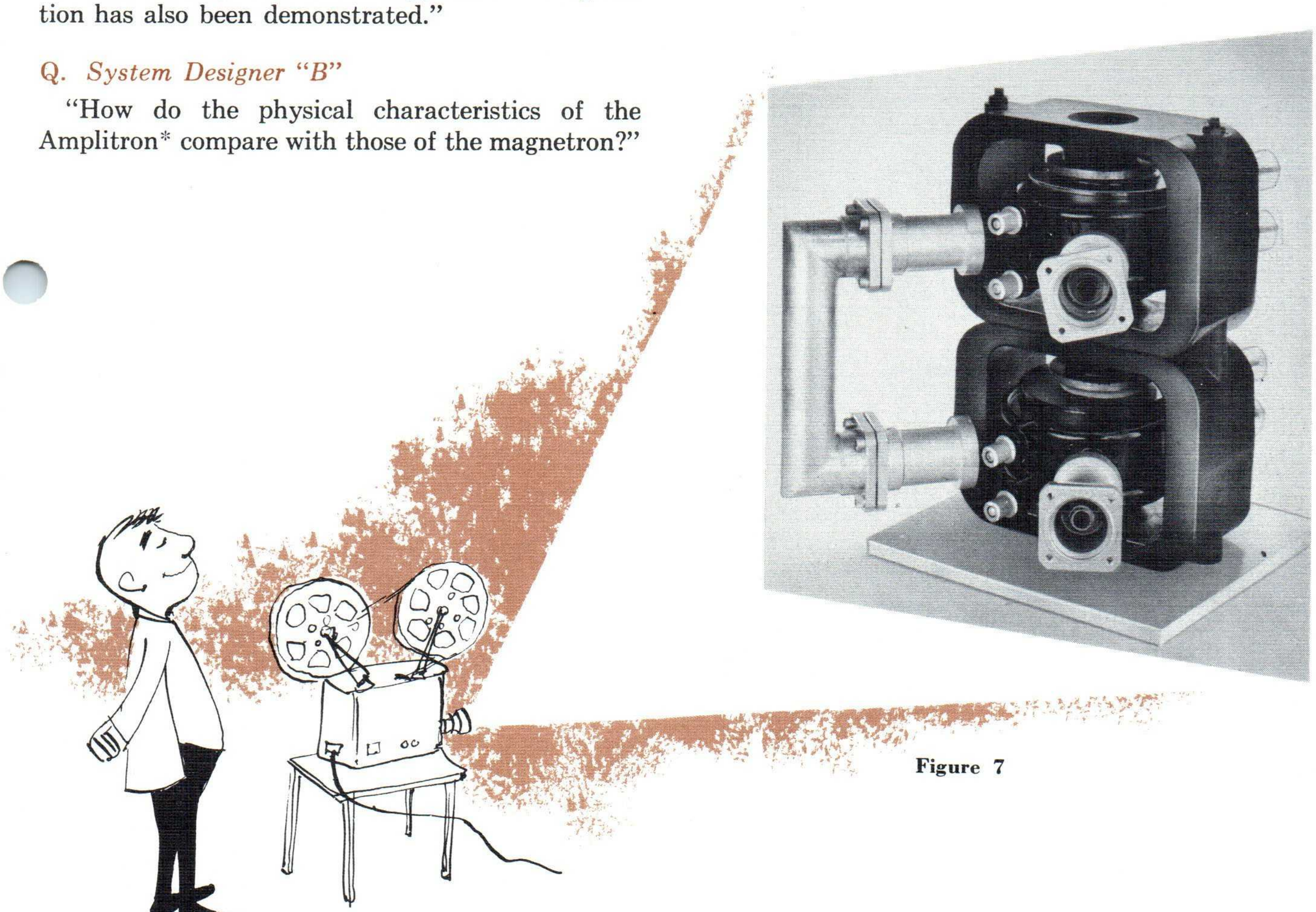


**Figure 7**

Q. *System Designer "B"*

"Is there any advantage in operating an Amplitron* at low gain, say in the order of 3 db?"

A. *Tube Engineer*

"The fact that all the input power appears at the output of the Amplitron* and therefore is not wasted, suggests the possibility of using Amplitrons* at relatively low gains. For example, the paralleling of two tubes is often used as a device to double the power. It may be desirable also to operate two Amplitrons* in cascade to produce increased power although the gain of the second tube may be as little as 3db. Extremely high efficiencies can be obtained through high drive and low gain operation. Efficiencies under these conditions may be seventy percent or higher." See Figure 7.

Q. *System Designer "A"*

"What tube types are now available from Raytheon?"

A. *Application Engineer*

"At present there are nine types of Amplitrons* either available or under study and development. All are classified with the exception of type QK653 which operates in the frequency range of 1250 to 1350 Mc. Information on this type is available in published form. Information on the various classified types can be furnished upon proper clearance from the appropriate Military Agency. Requests for tubes should be directed to Power Tube Sales Office, Microwave and Power Tube Division, Raytheon Manufacturing Company, Waltham, Mass."

*Moderator*

"We have attempted in this meeting to present information concerning the nature and application of Raytheon's newest tube type, the Amplitron.* To recapitulate, the use of an Amplitron* final stage makes possible the attainment of new levels of power output with very high efficiencies. Faithful reproduction of input spectrum over a ten percent band of frequencies can also be expected from this type of final stage. The Amplitron* in this capacity represents a universally desired advance in the microwave tube art.

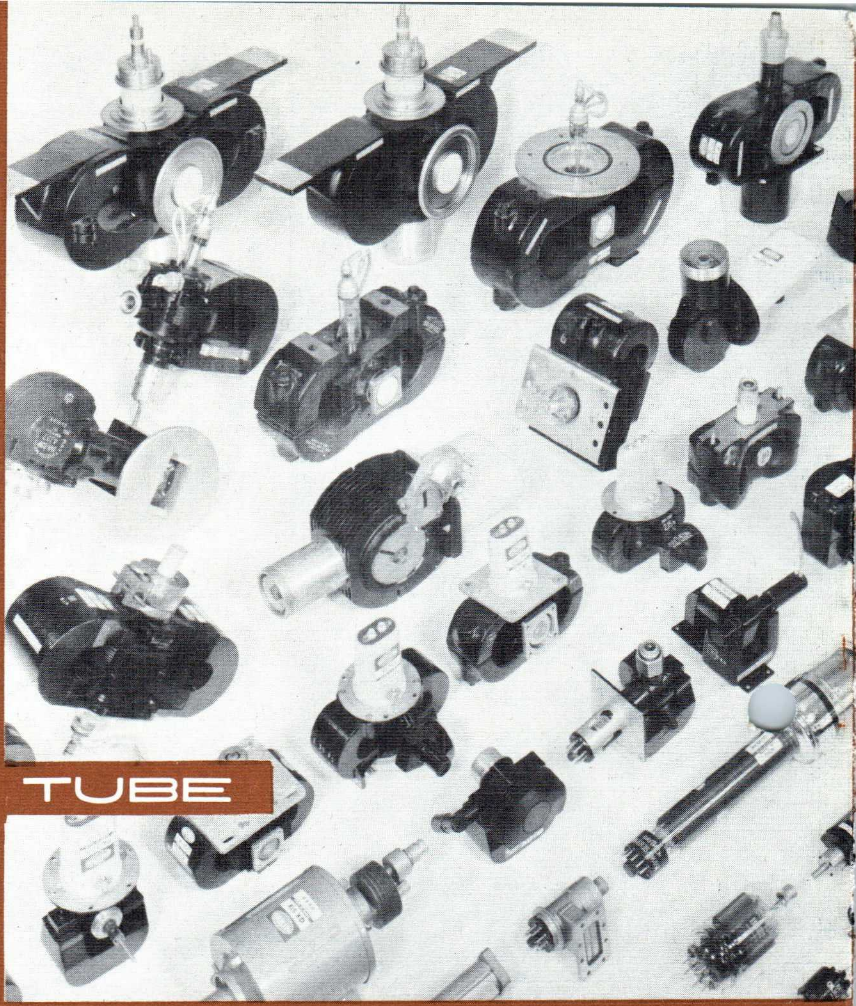
Amplitrons have been produced which deliver more than ten megawatts of peak power. At L band or lower frequencies the Amplitron* should be capable of producing hundreds of kilowatts of average power efficiently. Experimental evidence indicates that Amplitrons* can be made for operation at any frequency at which microwave tubes are normally employed.

We realize that systems designers and engineers will want and need more information concerning this device than has been discussed in this meeting. Requests for such information should be forwarded to the Applications Engineering Department, Microwave and Power Tube Division, Raytheon Manufacturing Company, Waltham, Mass. In cases where the information requested is of a classified nature, instructions concerning the procedure for obtaining proper clearance will be furnished promptly."

* Raytheon Trademark




Printed in U.S.A.



*Inquire about*

ANY MICROWAVE TUBE

Our application engineers are ready to assist you in selecting the proper microwave tube for your particular requirement. Consolidated tube data sheets will be furnished upon request to the Sales Department, Microwave and Power Tube Division, Raytheon Manufacturing Company, Waltham 54, Massachusetts.

RAYTHEON

RAYTHEON MANUFACTURING COMPANY
MICROWAVE AND POWER TUBE DIVISION
WALTHAM 54, MASSACHUSETTS

T.P.D.



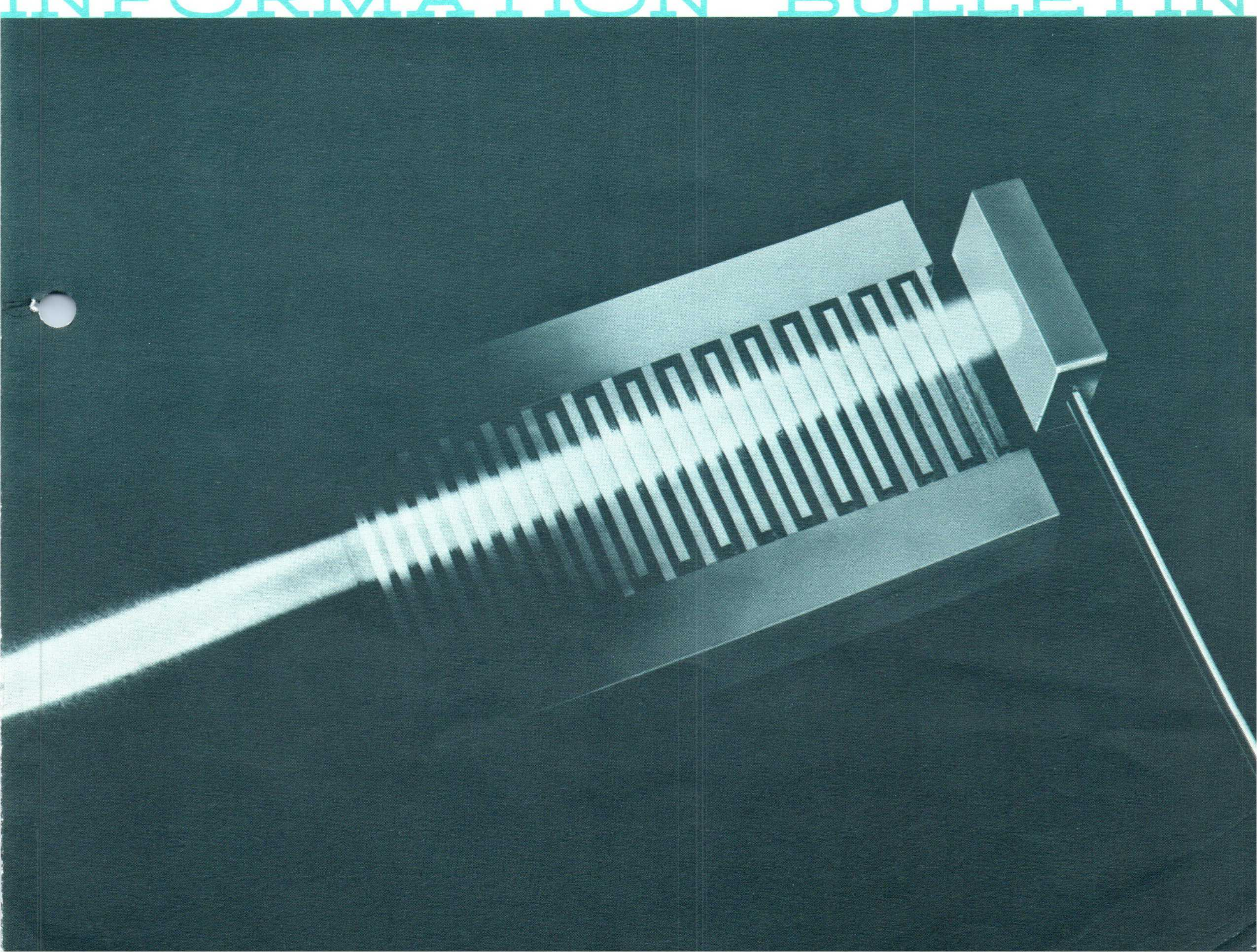
Att Mr. Langford/Smith

RAYTHEON

MICROWAVE AND
POWER TUBE DIVISION

# "Beam Miser"
## INCREASES EFFICIENCY IN CROSSED-FIELD DEVICES

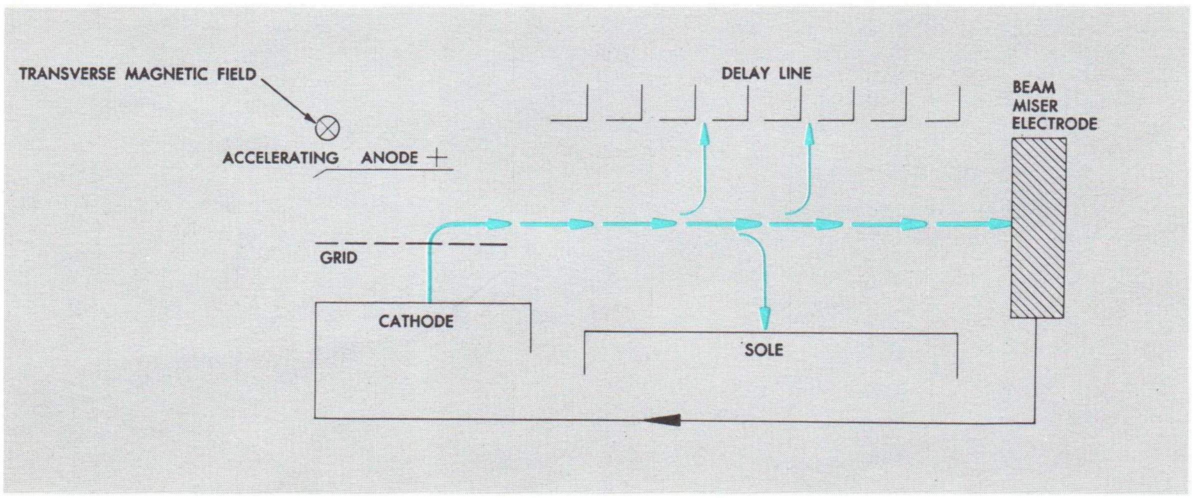
INFORMATION BULLETIN



# 'Beam Miser' is Raytheon's newe in crossed-field oscillator an design . . .

**The "Beam Miser" is a unique type of depressed collector and circuit permitting significant increases in bandwidth, power, and/or efficiency, with no additional electrodes or other changes in tube configuration or application.**

The "Beam Miser" concept yields some of the advantages of a reentrant electron beam in crossed-field tubes. This is done by collecting a portion of the spent beam at cathode potential and returning it to the cathode by a conductor inside the tube. The schematic below indicates this function in a general crossed-field beam-type tube.



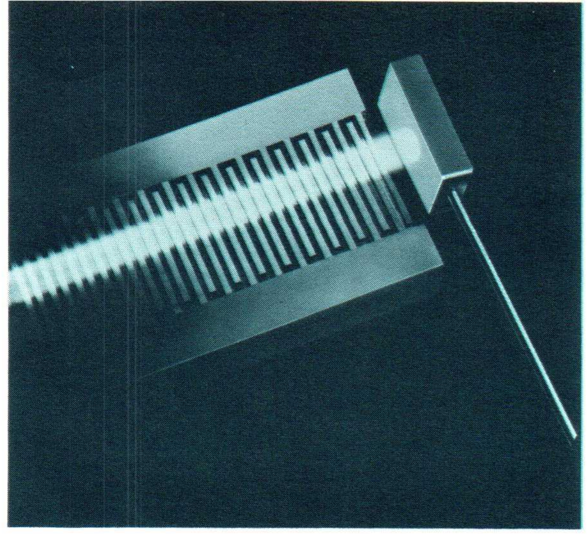

schematic of "Beam Miser"

A "Beam Miser" has been designed into an existing M-BWO and was capable of intercepting as much as 40% of the total beam current under operating conditions. The return of this intercepted beam current to the cathode effectively increases the total beam current for a given anode current as supplied by the external power supply.

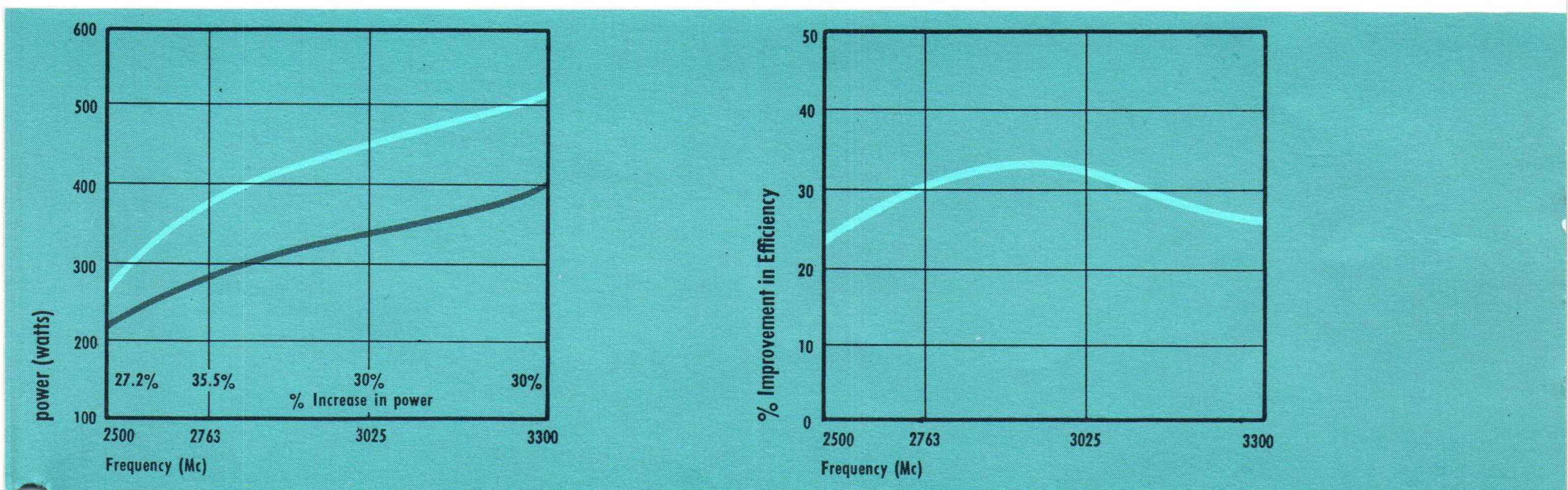
The "Beam Miser" permits higher power output for a given power input, or alternatively, less power input for a given power output. A tube with a "Beam Miser" requires no external mechanical changes or additional electrical input connectors, and is directly replaceable in the same socket as a standard tube not having a "Beam Miser".

# est advance

# d amplifier



The charts below show performance of an experimental "Beam Miser" in a QKA625 type M-BWO, comparing power output and efficiency obtained with and without the "Beam Miser", with no change in heater or other parameters and no additional electrodes:




"Beam Miser" Anode Tuning

Similar results have been obtained with other crossed field tubes. It can be seen that use of the "Beam-Miser" permits a large power increase. The increase in bandwidth at a given power level is evident

Preliminary results have shown no deterioration of performance of signal quality, and no spurious signals have been observed. Further work will undoubtedly provide greater improvements in power and efficiency.

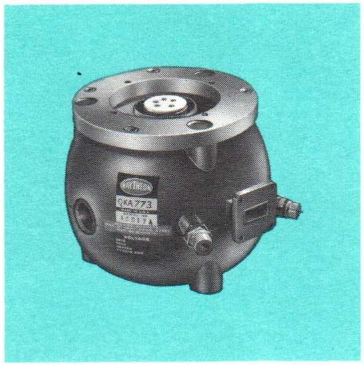
The "Beam Miser" is applicable to Crossed-Field Amplifiers (CFA's) as well as oscillators, and should be of considerable interest to those concerned with this type of tube. Amplifiers are expected to show even more dramatic results than those obtained with oscillators. For example, it is probable the "Beam Miser" will be a very important tool in extending the present three-db bandwidth of CFA's.

Raytheon is actively engaged in a considerable number of development programs for M-BWO's and CFA's covering the entire range from VHF through K-band. The "Beam Miser" is applicable to any of these. Eventually, as the "Beam Miser" is incorporated into Raytheon tubes, it will result in significantly higher power ratings, wider bandwidths, and higher power at low frequencies with smaller tubes.

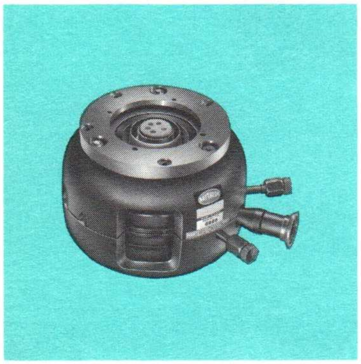
**For further information with reference to specific tube types, you are invited to contact your nearest Raytheon sales office, listed on the back page of this bulletin.**

RAYTHEON

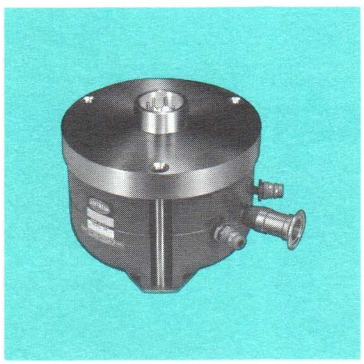
MICROWAVE AND POWER TUBE DIVISION



The M-type backward wave oscillator, introduced more than eight years ago, has been perfected by Raytheon and is now being economically mass produced. A complete and compatible line of these tubes is now in production or development covering the active spectrum, UHF through K-band.



These tubes are small, light, ruggedized, of metal and ceramic construction, with complete mechanical and electrical interchangeability across the spectrum. They have low spurious signal output, no frequency discontinuities into a mis-matched load, and consistent and reliable operation with the highest power and thermal stability of any comparable tube in the industry.



Only three M-type BWO's are shown here. However, many variations of these tubes are in production and are immediately available. These variations are classified at present. Information on classified tubes will be supplied promptly, upon receipt of proper security clearance.


RAYTHEON COMPANY

RAYTHEON

MICROWAVE AND POWER TUBE DIVISION

## REGIONAL SALES OFFICES

**NEW ENGLAND AREA AND UPPER NEW YORK STATE**
Spencer Laboratory
Wayside Avenue
Burlington, Massachusetts
BRowning 2-9600

**NEW YORK AREA**
210 Sylvan Avenue
Englewood Cliffs, New Jersey
LOwell 7-4911
(New York City) WIsconsin 7-6400

**WEST COAST AREA**
225 North Van Ness
Hawthorne, California
PLymouth 7-3151

**WASHINGTON**
The Solar Building, Suite 601
1000 Sixteenth Street, N.W.
Washington 6, D. C.
MEtropolitan 8-5205

**SOUTH ATLANTIC AREA**
100 Roesler Road
Glen Burnie, Maryland
SOuthfield 1-0450

**MID-WEST AREA**
9501 Grand Avenue
Franklin Park, Illinois
NAtional 5-4000

**RAYTHEON CANADA LTD.**
400 Phillips Street
Waterloo, Ontario
SHerwood 5-6831

**DAYTON**
333 W. First Street
Room 455
Dayton 2, Ohio
BAldwin 3-8128



5M-7-61-WEA

Printed in U.S.A.

A compatible line of high power voltage-tunable BWO's that feature extremely high speed electronic tuning over a half-octave bandwidth, and are capable of being amplitude and/or frequency modulated at rates exceeding 10 megacycles per second. Narrow-band tuning or modulation may be accomplished by varying the sole voltage; full band tuning or modulation by varying the delay line voltage.

| Tube No. | Frequency (MHz) | Power (Watts) (Min.) | Delay Line Voltage (V) | Delay Line Current (Ma) | Accelerator Voltage (V) | Sole Voltage (—V) | Grid Voltage (—V) | Output Couples To | Weight (lb.) | Size (Inches) Dia. | Size (Inches) Height |
|---|---|---|---|---|---|---|---|---|---|---|---|
| QKA1250 | 1000-1400 | 200 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | RG/44U | 28 | 7.5 | 5.1 |
| QKA1251 | 1300-1850 | 200 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | RG/44U | 28 | 7.5 | 5.1 |
| QKA1252 | 1800-2550 | 200 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | RG/44U | 28 | 7.5 | 5.1 |
| QKA1253 | 2500-3550 | 180 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | RG/44U | 25 | 7.5 | 5.1 |
| QKA1254 | 3500-4850 | 180 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | RG/44U | 25 | 7.5 | 5.1 |
| QKA1255 | 4800-6550 | 165 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | DR-19 | 17 | 6.6 | 4.0 |
| QKA1256 | 6500-8550 | 150 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | DR-19 | 17 | 6.6 | 4.0 |
| QKA1257 | 8500-11000 | 150 | 2300-4000 | 300 | 900-1900 | 900-3400 | 100-700 | DR-19 | 17 | 6.6 | 4.0 |
| QKA1250-1 | 1000-1400 | 400 | 2300-4000 | 500 | 900-2000 | 900-3400 | 100-700 | RG/44U | 28 | 7.5 | 5.1 |
| QKA659 | 3250-4450 | 180 | 2200-4800 | 300 | 1000-2100 | 1100 | 250 | RG/44U | 25 | 7.5 | 5.5 |
| QKA773 | 8450-11000 | 150 | 2300-5200 | 300 | 1000-2150 | 1600 | 600 | RG/52U | 20 | 7.0 | 5.9 |

**NOTE:** Many other BWO's, both classified and unclassified, are available for special applications. Contact Raytheon for complete details.

RAYTHEON
TECHNICAL INFORMATION SERVICE

# Technical Information Bulletin

## DESCRIPTION AND USE OF A COMPUTER CONTROLLED TEACHING SYSTEM

BY

Donald L. Bitzer
and
Peter G. Braunfeld

Coordinated Science Laboratory
University of Illinois
Urbana, Illinois

This paper describes a rather unique application for the Raytheon Recording Storage Tubes. The equipment was designed at the Univeristy of Illinois Coordinated Science Laboratory and used Raytheon CK7571/QK685 tubes. The Coordinated Science Laboratory was awarded a tri-agency (military) sponsored contract to develop a teaching machine. The equipment has been successfully designed and has been in use in a limited way - teaching university credit courses.

The Raytheon storage tube is used as the memory in the communication system between the student and the computer - teacher.

# DESCRIPTION AND USE OF A COMPUTER CONTROLLED TEACHING SYSTEM

DONALD L. BITZER and PETER G. BRAUNFELD
Coordinated Science Laboratory
University of Illinois
Urbana, Illinois

ABSTRACT

PLATO, an automatic teaching system, is described. This system uses a single, general purpose digital computer programmed so as to tutor a number of students concurrently. Each student has an electronic keyset for communicating to the central computer and a TV set to view materials selected or written by the computer. Since the students share the digital computer, a more sophisticated set of teaching rules can be programmed than could be instrumented in an economic way at each student station. Moreover, the use of a central computer makes it possible to change the teaching rules by modifying the computer program instead of rebuilding each student site.

Several preliminary studies used two student stations connected to ILLIAC, the University of Illinois digital computer. Data obtained from these studies are discussed from the system-design as well as the educational viewpoint.

## I. INTRODUCTION

The pace at which new information and ideas must be acquired to keep active in a scientific field continues to increase rapidly. As a result, such resources as available study time and adequately prepared teachers must be used as efficiently as possible. For these reasons, there has been much effort to develop automatic teaching devices for the presentation of lesson material. The main objective of the PLATO project at the Coordinated Science Laboratory is to develop a teaching system with a central control element capable of concurrently teaching a variety of subject matters to a large number of students. To this end, we plan to develop a series of systems, each system embodying improvements indicated by experience with the previous systems. This effort differs from the more usual approach where the teaching device is fixed and lesson material is prepared with this particular device in mind.

Because of the numerous changes anticipated during the course of developing the system, the natural choice for the central control element is a high-speed, general-purpose digital computer. The general-purpose computer makes most system changes possible, without necessitating hardware changes, by simply modifying the computer program. Such flexibility is not available in the free-standing machines. In addition, as automatic teaching techniques become more complex, it would become prohibitively expensive to provide the necessary equipment of the free-standing type for each student.

In order to evaluate the system and determine improvements for future system design, we prepared and tested lesson material from several different areas of study. The data reported here come from four sets of lessons, two sets treating computer programming; the other two deal with topics in electrical engineering (electromagnetic theory and network synthesis). Each of the four sets of lessons was prepared by a different person and presented either to high school or college students. Our principal interest here is to determine the data exchange rates between the student and the system. However, the detection of needed improvements in the content and order of presentation of the lesson material was a natural by-product of the studies.

From the data obtained, we find that each student inserts, on the average, from 10 to 15 inputs per minute. Our preliminary studies of these data indicate that about 1,000 students studying 8 different lessons can concurrently use a single central computer which has an add-time of about 10 μsec. and a high speed memory of 32,000 words of 48 bits each.

## II. DESCRIPTION OF THE PLATO SYSTEM

To aid the reader in understanding our data analysis, we furnish a brief description of the PLATO system. A more detailed description can be found in other publications (Ref. 1 and 2).

As already mentioned, the PLATO system uses as its central control element a high speed digital computer. All student stations are connected to the central computer. The computer accepts each student's requests in sequence, but, because of its high speed, all students can be served without noticeable delay. The present PLATO system has two student stations connected to ILLIAC, the University of Illinois general purpose digital computer.

Each student has a keyset and a television set. The keyset, illustrated in Fig. 1, is used by the student to communicate to the central computer. The buttons on the keyset are of two types: (1) character keys: (numerals, letters, and other symbols) used by the student to answer questions, and (2) logic keys ("continue", "reverse", "help", "aha!", "judge", and "erase") used by the student to proceed through the instructional material. Information selected by the computer for display to a student appears on the student's television screen. This information has two sources: (1) a central slide selector, and (2) the student's electronic blackboard. The central slide selector has a capacity of 61 slides with a random access time of less than 1 $\mu$sec. Although a single slide selector is shared by all students, each student has independent access to any slide. Each student has an electronic blackboard on which the central computer can write characters and draw diagrams. Information unique to a student, such as his answer to a question, is written on his own blackboard. The images from the slide selector and blackboard are superimposed on the student's television screen.

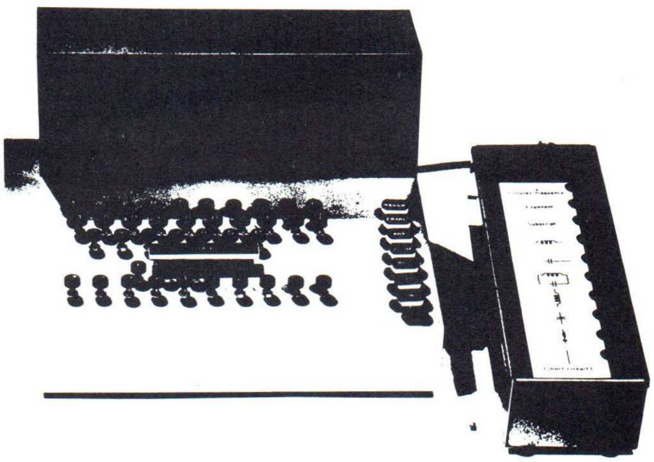


FIG. 1. PICTURE OF STUDENT'S KEYSET

The type of teacher represented by the system depends to a great extent on the teaching rules programmed in the central computer. Fig. 2 shows a diagram of the teaching rules used with the studies reported in this paper. The lesson material is divided into a main sequence and a number of help sequences. The lesson material in the main sequence is written for the better students. In addition to textual material, the main sequence contains questions which the student is required to answer. The material in the help sequences is for the students who need assistance in answering main sequence questions. It typically presents further information and leading questions helpful in finding the correct answer to the main sequence problem.

The student uses the "continue" and "reverse" buttons to move forward and backward through the material. However, when a question is asked by the computer, the student must answer the question correctly before he is allowed to proceed. After inserting the answer to a question, the student pushes the "judge" button and the computer writes "OK" or "NO" next to the answer. If the answer is correct, the student can proceed. If the answer is incorrect, the student can erase his wrong

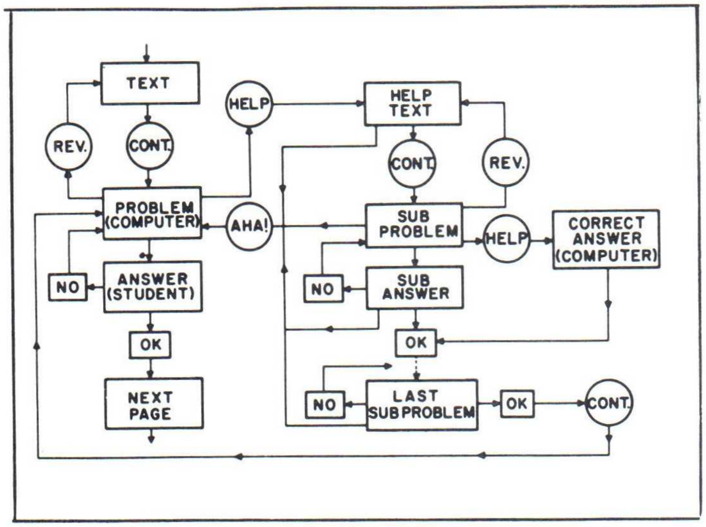



FIG. 2. DIAGRAM OF TEACHING LOGIC

answer and try again, or he can ask to see the help sequence by pushing the button labeled "help." Each question in the main sequence has its own help sequence. In the help sequence, too, the student must answer the questions correctly before he can go on. If he is unable to give the correct answer, he can ask for help again, but because of the limitations of ILLIAC, we were unable to provide help sequences for "help questions." Whenever all the help is exhausted (referred to as help-help) for either a question in the main sequence or a help sequence, the student is so informed and given a choice of returning to the question and trying again or having the computer insert the correct answer. The final button to be discussed is the "aha!" key. This is for the student who has asked for help but due to sudden insight feels no need to complete the help sequence. The "aha" button takes the student from the help sequence back to the question in the main sequence. If, after "aha" the student finds he cannot answer the question, and again asks for help, the computer returns him to his previous position in the help sequence.

If the student pushes an illegal button, such as the "continue" button when a question remains to be answered on a page, the computer activates a buzzer at the student's keyset and records the input as "finger trouble."

## III. THE STUDENT RECORDS

While the students proceed through the lesson material, the computer is keeping detailed records on each student. These student records are essential for evaluating the instructional material as well as for providing information for future system designs. These records are available on two tapes: (1) raw data suitable for re-ingestion into the computer for later extensive processing and (2) sorted data suitable for printing out in a format for easy visual inspection. A sample of a printed student record is shown in Appendix I. The following events and the time that they occurred are recorded:

1. The page on which the student is working
2. The answers submitted and judged by the computer
3. The correctness of the answers
4. The requests for help-help
5. The answers supplied by the computer

In addition, a "finger trouble" number is printed which corresponds to the sum of the number of times the student pushes an illegal button. The results of the processed data are summarized in Table I and Table II of Appendix II. The records do not show student answers which were erased before being judged, though it would be possible to do this. Our experience indicates that this event happens rarely. There is also a slight ambiguity with respect to the use of the "aha!" button, which could only affect the numbers given in the tables in a negligible way.

## IV. EDUCATIONAL ANALYSIS OF THE DATA

The ready availability of a detailed and accurate record of each student's progress through the lesson material is one ofthe most important and useful features of the PLATO system. It means that one can get easily a picture of each student's performance -- in a detail which otherwise would be almost impossible to obtain. Perhaps even more important than this, the human lesson preparer has the feedback from student performance that makes it possible for him to improve his lessons as more and more data become available. Since the raw data making up the student records are kept in the store of the central computer, it is natural and easy to use this same computer to process them in any desired manner. Some, though not all, of the entries in Table II (Appendix II) were automatically generated by the computer. With more experience, we plan to develop further automatic processing routines to sort data and generate statistical parameters.

It is not our intent here to present a detailed discussion of all the data analysis that has been done, but rather, to show, by specific example, what data is readily available in the system and how such data may be interpreted. Table II displays items of interest with respect to sections of four different courses; these are shown in the left-most column of the table and include: (1) ILLIAC programming (7 chapters - complete introductory course); (2) IBM-650 programming (3 chapters); (3) Introduction to Maxwell's Equations (3chapters); (4) Network synthesis (1 chapter). The first of these courses was used mainly with high school students; the remaining three with college students.

The first column of entries labelled "STUDENTS" records the total number of students who took each lesson. The next column, labelled "HELP," records the total number of times that students requested help in the lesson. The numbers in this column divided by the corresponding number of students taking the lesson gives the number of times the average student asked for help. This number is a measure of the difficulty of the main sequence; for, presumably, if the material presented in the main sequence is easy and the questions asked are also easy, students will require "help" only rarely. On the other hand if the material or the questions are hard, "help" will be requested more frequently.

The question of how much "help" should be used on the average by students in a well-written lesson is difficult to answer precisely. It seems reasonable at least to stay away from the extremes: If few students ever need "help," the lesson may be too easy and not sufficiently challenging to the better students. If almost every student needs help on most problems, then it seems that some of the "help" material should be incorporated into the main sequence. Only experience and judgement will resolve questions of this kind, and general rules probably cannot cover all specific cases.

The next column, labelled "HELP-HELP," refers to the number of times a student asked for help when no further help was available. This may occur in two classes of cases, which are not distinguished in the table: (1) the student requests "help" for a question posed in the help-sequence or (2) the student requests "help" for a main-sequence question after completing the help sequence for that question. Thus, the figures in this column are a measure of the effectiveness of the help sequences. For example, the help sequences of the ILLIAC course, Chapter 5 will need revision, since the 15 students taking that chapter requested "help-help" 144 times (for an average of 9.6 per student). It is clear from this that in a large number of cases either the help sequence itself was too difficult for the student, or it did not help him to solve his initial main-sequence problem.

When a student requests "help" and the computer tells him that no further help is available, the student is given two alternatives: (1) he may request the computer to supply him the correct answer to the troublesome question; or (2) he may ask to be presented with the slide containing the problem once again, to see if, by further reflection, he cannot get the answer by himself. The next two columns of Table II show which of these two courses of action students chose. The column "ANSWER (MACHINE)" gives the number of times the machine provided the answer, while the column labelled "ANSWER (STUDENT) shows the number of times the student finally got the right answer by himself. The table shows that in the majority of cases students asked the machine to provide the answer. Nevertheless, a sufficient number of students reconsidered at the brink of getting a computer-supplied answer and struggled through to arrive at their own correct answer to make the inclusion of the possibility of reconsidering important.

The next column shows the total number of wrong answers submitted by student and the column after this shows this number as a percentage of the total number of answers submitted. These numbers are, once again, a measure of the difficulty students are having with the material as a whole. Finally, the last three columns show the maximum, minimum, and average times spent by students on the material. The numbers show that students vary widely in the time spent finishing a lesson.

Finally, it should be remarked that this information is available in much greater detail than indicated by the table. For example, once one has decided that Chapter 5 of the ILLIAC course bears looking into, one can examine the data pertaining to this lesson question by question to determine where the difficulty with the material lies. Such detailed analyses have been performed in a small number of cases, but it would be too tedious to report them here.

## V. ANALYSIS OF RESULTS FOR SYSTEM DESIGN

The student records have provided useful information for the design of future systems. A summary of the information pertaining to system design is contained in Table I of Appendix II. An important but expected result obtained from the student data is that the student requests that require the least amount of computer time occur most frequently.

Both computer speed and memory capacity are important considerations in the system design. From the data thus far obtained it appears that as many as 1,000 students can be taught concurrently by one computer without noticeable delays for any student. In order to calculate the time a student must wait for the computer to accept his request, one must know the distribution of the inputs to the system and the computer execution times required to dispense with each of these inputs. A list summarizing the distribution of the different type of student requests along with the corresponding estimated execution times is given in Fig. 3. The requests are divided into seven groups: "characters", "continue", "reverse", "help", "aha!", "judge", and "erase." Requests in the same group may require different amounts of computer time. For example, the amount of time required to judge a student's answer depends on the judge routine selected for use with that question. Therefore, some of these groups are further divided into three sections, each section requiring a different amount of computer time.

From the list in Fig. 3, the expected value, E(T), and the standard deviation, $\sigma_T$, of the computer execution time can be calculated. The calculations determine that:

$$E(T) = 429 \text{ microseconds}$$

$$\sigma_T = 425 \text{ microseconds}$$

Assuming that the arrival time of the student inputs is Poisson distributed (a reasonable assumption for 1,000 independent student stations), we can determine, E(n), the expected number of student requests not yet completed, and the expected waiting time, E(w), that elapses before the computer will accept a given student request (Ref. 5). Since the computer times are only estimates, we have doubled the calculated values of E(T) and $\sigma_T$, and more than doubled m, the average number of student inputs per unit time as determined from the data. This gives:

$$E(T) = 858 \text{ microseconds}$$

$$\sigma_T = 850 \text{ microseconds}$$

| inputs | o/o of total inputs | estimated computer time to accomodate in μsec. |
|---|---|---|
| cont. | 6.0 | 200 |
| 7.6 o/o | .8 | 600 |
| | .8 | 1500 |
| rev. | .4 | 200 |
| 2.0 o/o | .8 | 600 |
| | .8 | 1500 |
| help | | |
| 2.5 o/o | 2.5 | 300 |
| aha | .1 | 200 |
| .7 o/o | .3 | 600 |
| | .3 | 1500 |
| judge | 8.0 | 300 |
| 16.1 o/o | 6.5 | 1000 |
| | 1.6 | 3000 |
| erase | 1.2 | 200 |
| 4.0 o/o | 1.6 | 600 |
| | 1.2 | 1500 |
| characters | | |
| 67.1 o/o | 67.1 | 300 |

Fig. 3. Summary of Distribution of Student Inputs and Corresponding Computer Execution Times.

$$m = .000333 \text{ requests per microsecond}$$

$$\rho = mE(T) = .29$$

We insert these numbers into the following formulas (Ref. 5):

$$E(n) = \rho + \frac{\rho^2 + m^2\sigma_T^2}{2(1-\rho)} \qquad (1)$$

$$E(w) = \frac{\rho^2 + m^2\rho_T^2}{2m(1-\rho)} \qquad (2)$$

with the results:

$$E(n) = .41$$

$$E(w) = 342 \text{ microseconds}$$

Assuming an exponential distribution, P(T), for the computer execution time, we can compute the probability, P(n), that there exist at least n not yet completed student requests, and the probability, P(w), that a student's request will wait a time w before being accepted by the computer (Ref. 4). The exponential distribution is a reasonable choice since it fits the general shape of the student data, and, similar to our data, has an expected value equal to its standard deviation. The distribution for the computer time is:

$$P(T)\,dT = \frac{1}{E(T)} \exp\left[-\frac{T}{E(T)}\right] dT \qquad (3)$$

This gives for P(n) and P(w)(Ref. 4):

$$P(n) = \rho^n \qquad (4)$$

$$P(w) = \rho \exp\left[-\frac{w(1-\rho)}{E(T)}\right] \qquad (5)$$

For $n = 4$

$P(n) = .0071$

For $w = 100{,}000$ microseconds

$P(w) = .29 \exp[-82.5]$

As is illustrated by the previous calculations, the probability of the student request list becoming long or the student experiencing a noticeable delay is very small. Since the computer is idle $(1-\rho)$ per cent of the time, we find that 1,000 students concurrently using the system still leaves the computer free more than two-thirds of the time.

Memory space for handling 1,000 students is a more severe problem. However, a previous study (Ref. 3) has shown that with proper use of the memory space and by relinquishing one relatively minor feature of the present PLATO teaching logic, 1,000 students can use the system for studying as many as eight different lessons. This assumes that the available computer memory consists of 32,000 words, each forty-eight bits long, and a random access time of about 4 microseconds. In addition, we assume a standard magnetic tape storage unit that requires about 4 milliseconds starting time, and an additional 300 microseconds per word stored. The stored information is divided into four parts.

1. The Control Program for Teaching the Lesson Material (3,000 words)

The present PLATO control program uses about 1500 words of memory.

2. The Information Describing the Lesson Material (12,000 words)

All necessary information for a page currently requires about 7 memory locations. Therefore, to store eight lessons concurrently, each consisting of 200 pages, will require about 12,000 words in the high speed memory.

3. Current Information Describing Each Student's Position in the Lesson Material (16,000 words)

Some of the judging routines permit several variations in an answer. Except for the student's answer replacing the correct or standard answer, the information describing a student's current position is similar to the information describing the lesson material. The present PLATO system keeps all of the previous student information as current. Thus, if a student reverses, he sees his final correct answers exactly as he submitted them to the computer. There is not sufficient space in the high speed memory to store all these old answers for 1,000 students. Sixteen words per student permits several back pages of old answers to be stored. The difference would be noticed only when a student reverses more pages than is stored as current information. In this case we would replace his old answers by standard answers. This variation does not affect the student records which will still record the exact answers.

4. The Student Records (100 to 1,000 words of high speed memory plus magnetic tape unit)

The student requests are immediately stored in the high speed memory in a list about 200 words in length. Whenever the list is full or the computer free, the list is transferred in a block to the magnetic tape unit. To transfer the list requires less than 5 per cent of the computer time (Ref. 3).

## VI. CONCLUSIONS

The detailed student records are essential for evaluating the lesson material, the student's performance, and the system design. From the present data it appears possible to teach concurrently as many as 1,000 students on a high speed digital computer of the kind currently available, and using only about one-third of the computer's time. This suggests the possibility of using an additional memory for the teaching function so that the remaining two-thirds of the computer's time can be used for regular computer operation.


## ACKNOWLEDGEMENTS

The authors wish to thank O. R. Brown, E. C. Jordan and L. D. Fosdick for their help in preparing the lesson material. We also acknowledge the help of Mrs. Julia Berger for preparing the manuscript.

The research reported in this document was made possible by support extended to the University of Illinois Coordinated Science Laboratory jointly by the Department of the Army (Signal Corps), Department of the Navy (Office of Naval Research), and the Department of the Air Force (Office of Scientific Research, Air Research and Development Command) under Signal Corps Contract DA-36-039-SC-85122.


## REFERENCES


1. Bitzer, D. L., Braunfeld, P. G., and Lichtenberger, W. W., "PLATO: An Automatic Teaching Device," I.R.E. Transactions on Education, Volume E-4, Number 4, December, 1961.

2. Bitzer, D. L., Braunfeld, P. G., and Lichtenberger, W. W., "PLATO II: A Multiple-Student, Computer-Controlled, Automatic Teaching Device," Proceedings of the Conference on Application of Digital Computers to Automated Instruction, October 10-12, 1961.

3. Bobotek, H., "Capacity of the PLATO System Using the CSX-1 Computer as the Control

Element," Coordinated Science Laboratory Memorandum, July 30, 1962.

4. Goode, H. H., and Machol, R. E., Control Systems Engineering, McGraw-Hill Book Company, Inc., 1957, pp. 328-343.

5. Kendall, D. G., "Some Problems in the Theory of Queues," J. Royal Statistical Society, Vol. 13, Number 2, pp. 151-185, 1951.

Appendix I

PLATO II: HISTORY OF EVENTS

STUDENT 1, RUN 1, LESSON 1, CHAPTER 6.

| TIME IN MINUTES | PAGE NUMBERS (MAIN) | (HELP) | ANSWER | OK/NO |
|---|---|---|---|---|
| .0 | 1 | | | |
| .1 | 2 | | | |
| .1 | | 100 | | |
| .2 | | | EMORY | OK |
| .3 | | | 87 | OK |
| .4 | | | 71 | NO |
| .5 | | | 710 | OK |
| .5 | | | A | OK |
| .5 | 2 | | | |
| .6 | | | 103 | OK |
| .6 | 3 | | | |
| .8 | | 101 | | |
| .8 | | | L | OK |
| .9 | | | 200 | NO |
| 1.6 | | | 100 | NO |
| 1.7 | NO MORE HELP | | | |
| 1.7 | HELP-HELP GIVEN | | 100F | |
| 1.9 | 3 | | | |
| 2.1 | | | L5 200F | OK |
| 2.1 | | 102 | | |
| 2.2 | | | L | OK |
| 2.3 | | | A | OK |
| 2.4 | | | OLD | OK |
| 2.4 | 3 | | | |
| 2.5 | | | L4 202 | NO |
| 2.9 | | | L4 202F | OK |
| 2.9 | | 103 | | |
| 3.0 | 3 | | | |
| 3.2 | | 103 | | |
| 3.4 | | | EMORY | OK |
| 3.4 | | | 87 | OK |
| 3.5 | | | 710 | OK |
| 3.6 | | | A | OK |
| 3.6 | 3 | | | |
| 3.8 | | 112 | | |
| 3.8 | | 4 | | |
| 3.8 | | 104 | | |
| 3.8 | 3 | | | |
| 4.1 | | 112 | | |
| 4.1 | 4 | | | |
| 4.2 | | 105 | | |
| 4.2 | | 0 | | |

NET FINGER TROUBLE = 9 ERRORS.

| | | no. of students | total inputs | o/o of continue | o/o of reverse | o/o of help | o/o of aha | o/o of judge | o/o of char-acters | o/o of erase | total t(min) for all students | inputs/student/unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ILLIAC Programming | Chpt. 1 | data not available | | | | | | | | | | |
| | " 2 | 15 | 5175 | 9.9 | 2.0 | 1.4 | .7 | 18.5 | 63.0 | 4.5 | 880.5 | 5.[illegible] |
| | " 3 | 11 | 8112 | 4.9 | .9 | .8 | .3 | 14.7 | 75.7 | 2.7 | 668.8 | 12.1 |
| | " 4 | 10 | 6095 | 6.2 | 1.3 | 3.3 | 1.0 | 17.8 | 65.2 | 5.2 | 836.0 | 7.3 |
| | " 5 | 15 | 7314 | 7.2 | 2.7 | 6.1 | .8 | 17.0 | 60.6 | 5.6 | 1164.0 | 6.3 |
| | " 6 | 8 | 4120 | 7.0 | 1.5 | 1.1 | .3 | 17.5 | 69.4 | 3.2 | 354.4 | 11.6 |
| | " 7 | 7 | 3760 | 6.4 | 1.1 | 2.3 | .5 | 19.1 | 66.6 | 4.0 | 396.9 | 9.5 |
| Programming the IBM-650 | Chpt. 1 | 6 | 2070 | 10.8 | 3.3 | .8 | .1 | 12.0 | 71.3 | 1.7 | 124.0 | 16.7 |
| | " 2 | 9 | 3031 | 12.4 | 3.5 | 1.7 | .3 | 14.2 | 65.4 | 2.5 | 283.3 | 10.7 |
| | " 3 | 9 | 5497 | 6.7 | 1.5 | 1.0 | .3 | 14.0 | 74.1 | 2.4 | 310.8 | 17.7 |
| Introduction to Maxwell's Equations | Chpt. 1 | 4 | 976 | 7.7 | 1.0 | 2.8 | 1.5 | 16.1 | 66.0 | 4.9 | 155.6 | 6.3 |
| | " 2 | 6 | 1527 | 6.1 | .9 | 2.1 | 1.7 | 15.5 | 68.6 | 5.1 | 199.8 | 7.6 |
| | " 3 | 6 | 1744 | 5.7 | 1.4 | 3.6 | 2.1 | 18.9 | 61.2 | 7.1 | 379.1 | 4.6 |
| Network Synthesis | Chpt. 1 | 10 | 3357 | 12.6 | 5.1 | 4.1 | 2.1 | 11.7 | 59.9 | 4.5 | 554.0 | 6.1 |
| | total or ave. | 116 | 50778 | 7.6 | 2.0 | 2.5 | .7 | 16.1 | 67.1 | 4.0 | 6307.2 | 8.4 |

Table I. Summary of System Analysis Data

| | | no. of students | help | help-help | answer (machine) | answer (student) | wrong answers | o/o of wrong answers | time max. | time min. | ave. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ILLIAC Programming | Chpt. 1 | | | data not available | | | | | | | |
| | " 2 | 15 | 48 | 13 | 13 | 0 | 234 | 24.4 | 75.5 | 23.5 | 58.7 |
| | " 3 | 11 | 34 | 17 | 16 | 1 | 221 | 18.6 | 91.8 | 38.8 | 60.8 |
| | " 4 | 10 | 102 | 51 | 50 | 1 | 319 | 29.4 | 120.7 | 40.8 | 83.6 |
| | " 5 | 15 | 173 | 144 | 131 | 13 | 406 | 32.6 | 97.9 | 33.9 | 77.6 |
| | " 6 | 8 | 25 | 11 | 11 | 0 | 131 | 18.2 | 88.6 | 26.3 | 44.3 |
| | " 7 | 7 | 52 | 17 | 16 | 1 | 151 | 21.0 | 82.9 | 34.7 | 58.7 |
| Programming the IBM-650 | Chpt. 1 | 6 | 11 | 3 | 3 | 0 | 36 | | 29.8 | 11.3 | 20.7 |
| | " 2 | 9 | 36 | 10 | 6 | 4 | 76 | 16.8 | 40.6 | 15.0 | 31.5 |
| | " 3 | 9 | 42 | 9 | 5 | 4 | 131 | | 54.2 | 20.4 | 34.5 |
| Introduction to Maxwell's Equations | Chpt. 1 | 4 | 25 | 2 | 0 | 2 | 48 | 32.7 | 45.3 | 30.2 | 38.9 |
| | " 2 | 6 | 26 | 3 | 3 | 0 | 78 | 33.1 | 50.3 | 21.1 | 33.3 |
| | " 3 | 6 | 41 | 12 | 10 | 2 | 124 | 37.6 | 68.0 | 59.8 | 65.2 |
| Network Synthesis | Chpt. 1 | 10 | 93 | 23 | 22 | 1 | 150 | 38.2 | | no data | |
| | total or ave. | 116 | 708 | 315 | 286 | 29 | 2105 | 24.8 | | | |

Table II. Summary of Educational Data

"Reprinted with permission from the Proceedings of the National Electronics Conference, 18, 787, 1962."

A Designer's Guide to RAYTHEON

# RECORDING STORAGE TUBES

# Raytheon Recording Storage Tubes Extend Your System Capabilities

A desire to store radar and television displays, to permit viewing over prolonged periods of time, brought about the development of the versatile Recording Storage Tube. Raytheon innovations, initiated in 1947, led to the design of the first Recording Storage Tube with a continuous dynamic range and frequent playback without the loss of stored information. Continued development and improvements in manufacturing techniques brought about both single-gun and dual-gun types which are now used in many radar and industrial applications. Raytheon Recording Storage Tubes are precision devices manufactured under quality standards insured by over a decade of experience in the design and development of cathode ray tubes. These storage tubes are electronic input-electronic output devices and storage is accomplished by electron charge on a dielectric surface.

The unique capabilities of fast writing and long storage, together with fast erase and immediate read-out, make Raytheon Recording Storage Tubes versatile devices for many equipment and system applications. Information can be written and stored by sequential techniques or by random writing. Read-out may use similar techniques because both modes of operation are accomplished by electrostatic or magnetic deflection positioning of the cathode ray beam on the storage assembly. Complete, partial or selective erasure is also possible. These features suggest many applications. A few are described here.


## Scan Conversion

Raytheon Recording Storage Tubes can easily perform the function of converting electronic information available in one form, such as Radar-PPI, to another form, such as television-type scanning. A bright display is therefore possible, and the storage characteristics permit the integration of weak targets and the generation of target trails to indicate the past history of moving targets. Some of the more typical scan conversion applications are:

**Radar — PPI to television-type presentation*

**Radar — PPI to PPI presentation to change scan rates*

**Computer data to PPI presentation for radar simulation*

**Television to Television presentation converting one standard to another*

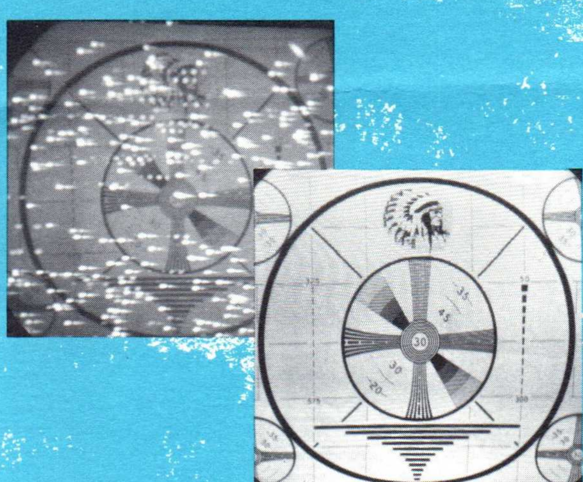

## Stop Motion

For instant storage and immediate read-out of television pictures, Raytheon Recording Storage Tubes feature the fast writing, reading and erasing characteristics necessary for stop motion. Equipment applications in this area include:

**Industrial — Time and motion studies of moving equipment*

**Medical — Stop motion of televised X-ray pictures*

**Editing — Of live television and video tape*



## Integration for Signal-to-Noise Improvement

Since the storage of information is accomplished by the accumulation of charges on a dielectric material, the repetition of input signals can build up or integrate these charges. Noise is generally random and does not repeat itself as frequently as a desired signal. Therefore it is possible to integrate any signal information that is actually below the noise level until it becomes greater than the noise.

## Computers, Data Processing and Storage—

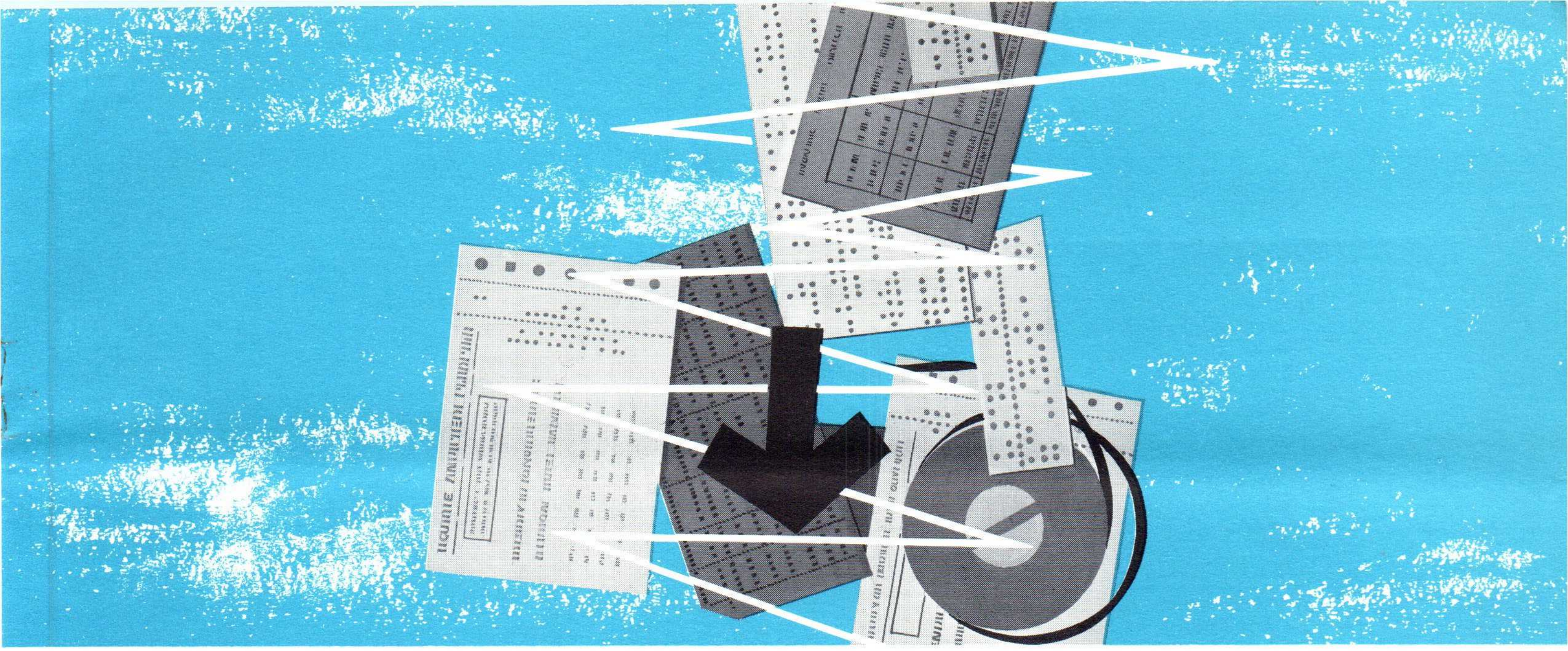
The high resolution capabilities and the wide dynamic range of Raytheon Recording Storage Tubes make it possible to store and process a vast amount of digital or analog information. Over several thousand pieces of information can be stored, integrated and selectively erased. Even new information can be added to stored information as desired. In the higher resolution tubes, such as the CK7702, over one million bits of information can be stored on the storage assembly. Information may be stored for long periods, read-out and erased. Random access to any of the stored information is possible since cathode ray tube scanning techniques are used.

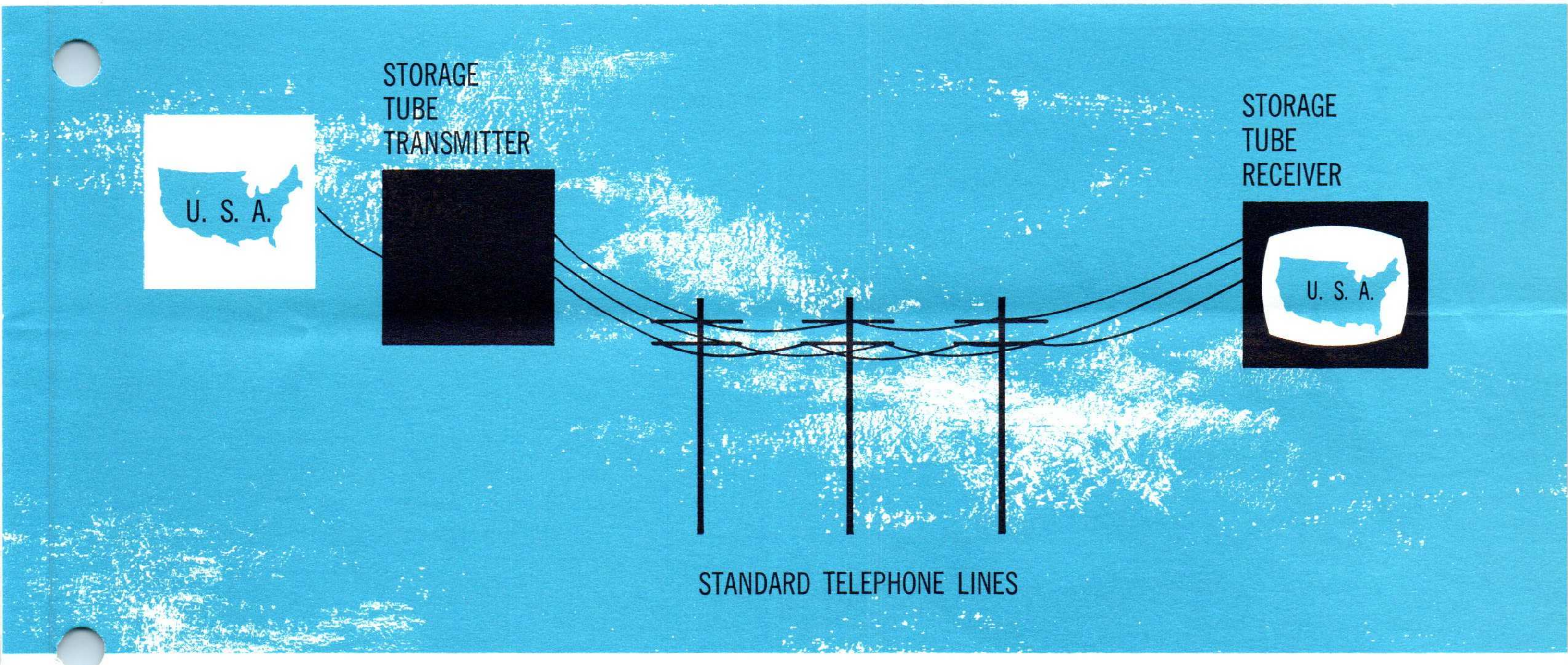
## Slow-Down Video—

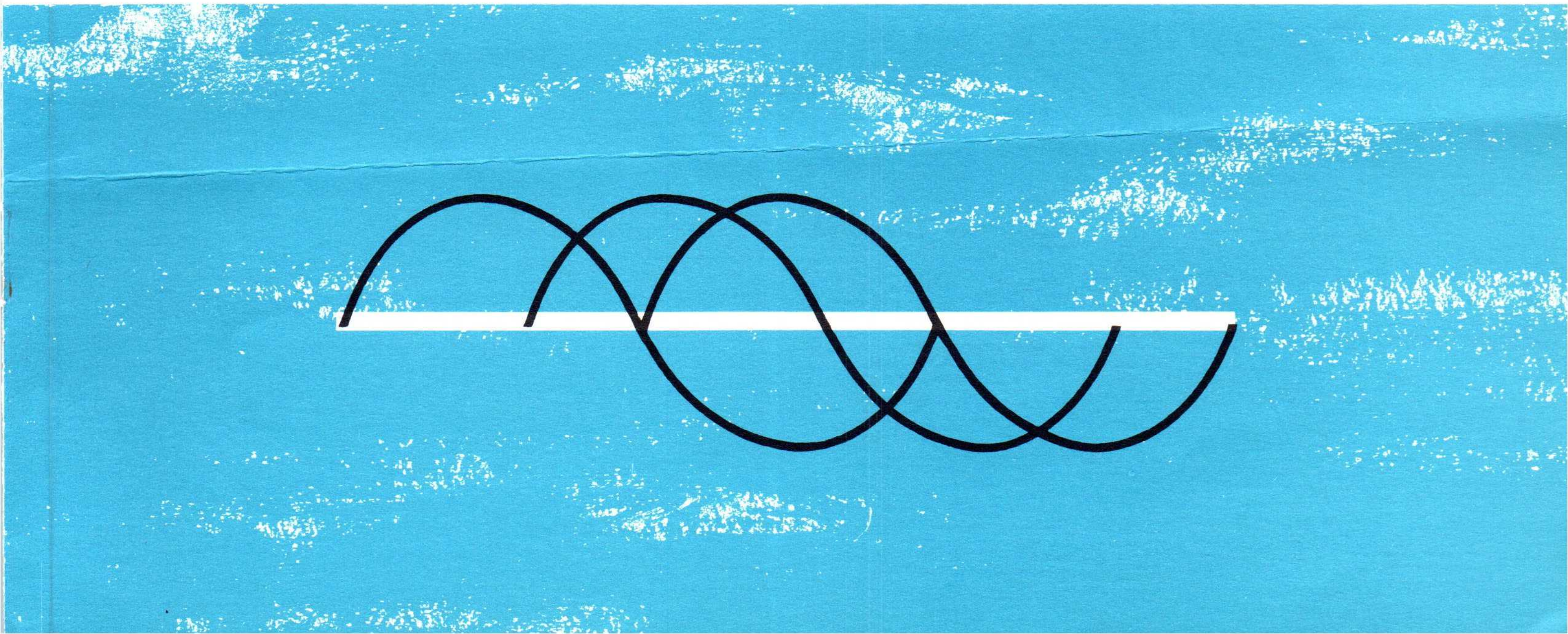
Raytheon Recording Storage Tubes can be used for bandwidth compression. High frequency electronic signals, requiring wide band-pass amplifiers, can be stored and read-out at slow scanning rates to permit transmission over narrow band-pass transmission lines. In this type of system storage tubes are used as the intermediate step in transmisison and receiving. Information that has been slowly written can be read-out at the receiving end at the original high scanning rate and reproduced on a television monitor. The transmission of high quality pictures, or other data, from location to a remote location, using existing transmission media, is accomplished with this system.

## Time Delay or Phase Shift—

Variable time delay of electronic signals can be obtained by use of Raytheon Recording Storage Tubes. The incoming signal can be stored and simultaneously read-out at the desired displacement time on a dual-gun recording storage tube. Variable displacement of the signal pattern, with respect to time or the phase angle, can be attained by changing the read-out scanning position with respect to the writing beam.




STORAGE TUBE TRANSMITTER
U. S. A.
STORAGE TUBE RECEIVER
U. S. A.
STANDARD TELEPHONE LINES



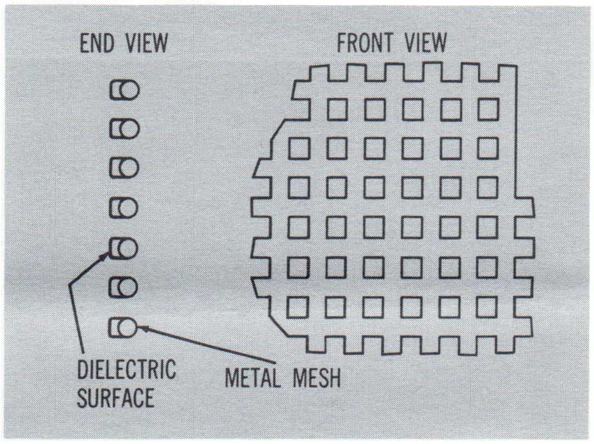



**FIG. 1 — Magnified section of storage screen**

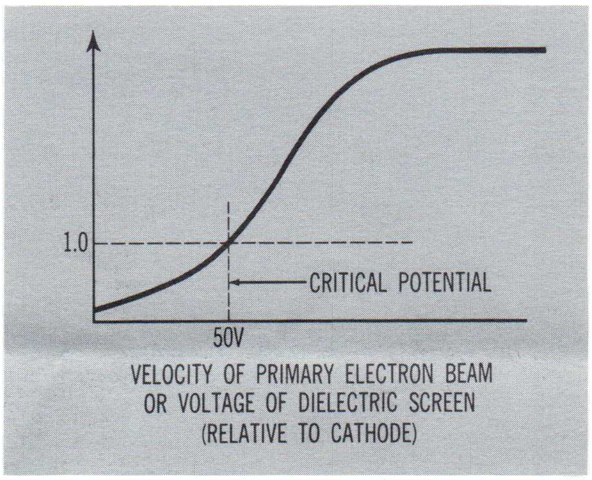



**FIG. 2 — Secondary emission characteristic of recording storage tube dielectric**

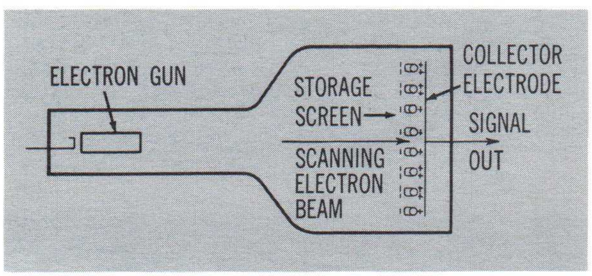



**FIG. 3 — Simplified drawing of single gun tube — reading mode**

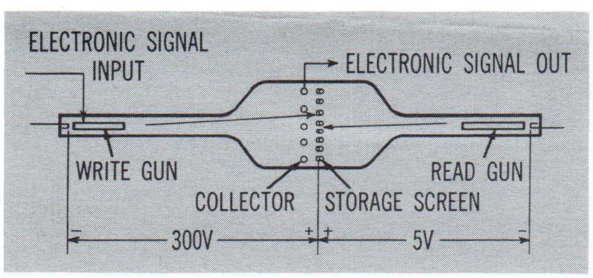



**FIG. 4 — Dual gun recording storage tube — simplified drawing**

# PRINCIPLES OF OPERATION

When an electron beam strikes any material, secondary electrons are emitted. The quantity of secondary electrons emitted is a function of the velocity of the primary electron beam.

The secondary electron emitting surface in the Recording Storage Tube is a dielectric that has been deposited on a metal mesh or screen. Figure 1 illustrates this storage screen mesh. This screen, in the highest resolution types, has more than 2000 cross wires across its diameter.

Figure 2 shows the characteristic curve for secondary to primary emission ratio for the dielectric material used.

Since the velocity of the electron beam will be proportional to the voltage on dielectric material the ordinate of velocity in Figure 2 can be voltage. The crossover, called critical potential, where the secondary to primary ratio is unity occurs at approximately 50 volts.

Using the secondary-emission characteristic shown by Figure 2, the dielectric screen surface can be discreetly charged or discharged as a function of the potential on the metal screen and the position and magnitude of the primary electron beam.

The various modes of operation are described as follows:

**PRIME** This is the basic form of erasure and prepares the storage screen for subsequent writing. It is accomplished by scanning the storage screen dielectric with an unmodulated beam. The storage screen mesh is operated at a voltage below critical potential and since the secondary to primary emission ratio is less than unity the dielectric surface can store electrons and become negatively charged to cathode gun potential. A total prime can be used if complete erasure of old patterns is desired or a partial prime can be used if it is desired to gradually decrease old signals in amplitude (e.g.: to generate target trails in radar). Selective priming of only part of the storage screen can be accomplished by only scanning the area where it is desired to erase previously stored information. Typical storage screen voltage for prime is +20 volts.

**WRITE** "Writing" of the charge pattern is accomplished by modulation of a scanning electron beam and operation at a storage screen voltage that yields a high secondary to primary emission ratio. This is any voltage above critical potential and is nominally 300 volts for fastest writing speeds. Since during the prime mode the dielectric surface was negatively charged, the surface is discreetly discharged towards the positive direction by the writing beam. As the modulated beam scans over the surface varying amounts of secondary electrons depending on the instantaneous beam amplitude are emitted at the surface and the stored pattern is established.

**READ** Once a charge pattern has been written in, it can be read out by scanning the storage screen with an unmodulated beam. The storage screen is operated at 10 to 15 volts. The dielectric surface with its charged pattern is now actually negative with respect to the electron gun cathode. Depending on the charged pattern the electron beam is therefore modulated as it passes through the storage screen to the collector element. See Figure 3. By selecting the proper storage screen voltage the most negative areas of the dielectric (established by the prime mode) can completely cut off the electron beam from the collector and thus the "black" level is established. Various gray shades will appear in any areas where the dielectric is less negative.

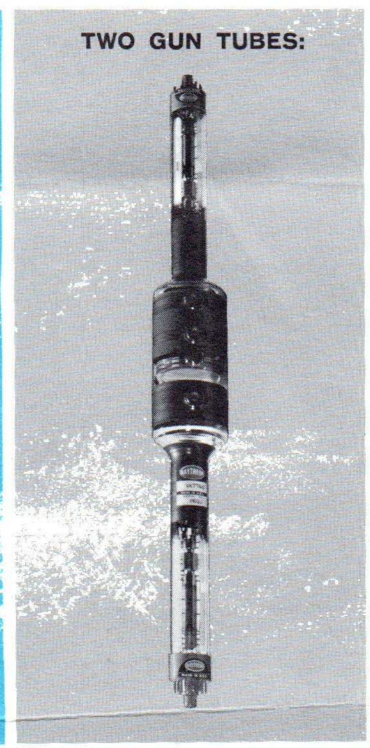
Long storage time with readout is possible because the storage dielectric in the read mode is negative with respect to the gun cathode and therefore the electron beam does not strike the dielectric surface.

Simultaneous Write and Read modes are possible with the use of two electron guns. This is desirable in most scan-conversion applications. Since two independent potentials can be maintained on the storage screen with respect to the two electron gun cathodes, the tube can be truly writing a charge pattern and reading it at the same time. See Figure 4. Partial automatic prime can also be simultaneously obtained with the dual gun tubes.

Since the collector is a metal screen that is scanned across by the writing beam some write information signal appears in the collector output. This can be removed by cancellation techniques or by use of RF modulation of the reading beam. The signal output by the RF method is an RF carrier signal with the charge pattern as amplitude modulation. It can be amplified with usual RF amplifiers and detected for subsequent display. Usual RF frequencies used are 30 mc. or 60 mc.

**ERASE** Where total erasure is needed, it is frequently desirable to operate the tube in the positive erase mode. To accomplish this, the storage screen voltage is set at or above the value used for Write and the storage surface is scanned with an unmodulated electron-beam. This action discharges any stored pattern, bringing the whole storage surface to a uniform equilibrium potential. The tube must then be primed prior to subsequent writing.

## RECORDING STORAGE PRODUCTION TYPES NOW AVAILABLE


**CK7571/QK685**

*High Resolution — 1000 TV lines at 50% modulation per diameter/Magnetic Deflection/Magnetic or electrostatic focus or combination of both with dynamic correction for best uniform resolution/Gray Levels — 5*

**CK6835/QK464A**

*High Resolution — 700 TV lines at 50% modulation per diameter/Magnetic Deflection/Magnetic Focus*

**CK7570/QK411A**

*High Resolution — 400 TV lines at 50% modulation per diameter/Electrostatic Deflection/Electrostatic Focus*

**CK7702**

*Simultaneous write & read/High Resolution — 1200 TV lines per diameter at 50% modulation/Variable automatic prime/Magnetic deflection of both read and write electron beams/Magnetic or electrostatic focus or combination of both with dynamic correction for best uniform resolution.*

# Regional Sales Offices

**NEW ENGLAND**
55 Chapel St.
Newton 58, Mass.
Tel: BIgelow 4-7500

**MID-ATLANTIC**
210 Sylvan Ave.,
Englewood Cliffs, N.J.
Tel: LOwell 7-4911
NYC: WIsconsin 7-6400

1500 Kings Highway
Haddonfield, N.J.
Tel: HAzel 8-1800

2360 James St.,
Syracuse, N.Y.
Tel: HOward 3-9141

**SOUTH ATLANTIC**
100 Roesler Rd.,
Glen Burnie, Md.
Tel: SOuthfield 1-0450

1612 East Colonial Drive,
Orlando, Florida
Tel: GArden 3-0518

**WEST CENTRAL**
9501 Grand Ave.,
Franklin Park, Ill.
Tel: NAtional 5-4000

3511 Hall Street
Dallas, Texas
Tel: LAkeside 6-7921

**WESTERN**
225 North Van Ness Ave.,
Hawthorne, California
Tel: PLymouth 7-3151

**GOVERNMENT SALES**
333 West First St.,
Dayton 2, Ohio
Tel: BAldwin 3-8128

1000 Sixteenth St., N.W.,
Washington 6, D.C.
Tel: MEtropolitan 8-5205

**CANADA**
Raytheon Canada, Ltd.
400 Philips St.,
Waterloo, Ontario, Canada

**IN EUROPE**
Raytheon-Elsi, AG
Zug, Switzerland
Tel: 042/44414

**IN ALL OTHER AREAS OF THE WORLD**
Raytheon Company
International Sales & Service
Lexington 73, Mass.
Tel: VOlunteer 2-6600

RAYTHEON INDUSTRIAL COMPONENTS DIVISION
Newton, Massachusetts

SP 1079

Printed In U. S. A.

RAYTHEON
TECHNICAL INFORMATION SERVICE

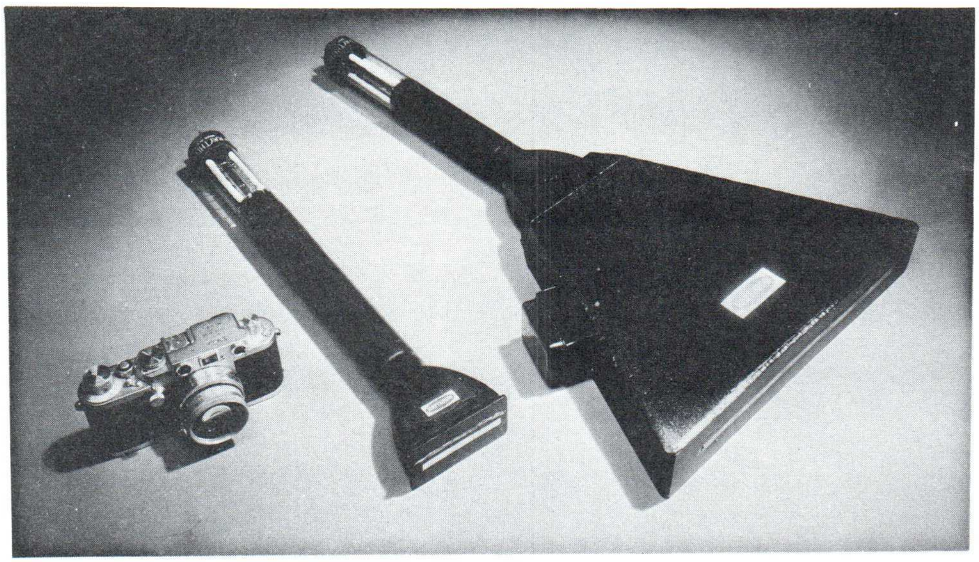
# Information Release

TRD

(30)

## Electrostatic Printer Tubes

New Raytheon electrostatic printer tubes translate electronic signals into printed words and pictures on paper. These high resolution, high speed tubes can print 20,000 characters per second or more than 10,000 lines of non-repetitive computer output information per minute.



This translation process was pioneered and developed by A.B. Dick. Known as Videograph, the process can read and translate binary pulses directly from a computer, magnetic tape, paper tape, or punched cards and print the translation on paper or display it on a cathode ray tube. The system can be adapted for high speed scanning and direct reproduction or transmission of graphic materials. Furthermore, pictures of moving objects which pass in front of a specially adapted tv camera can be instantaneously printed out.

The heart of any such system is a printer tube. Raytheon currently has four types available. Custom modifications are possible for other application.

The CK1366/QV130 has a single row of printing elements and can print a strip to 2-3/4" wide, ideal for mailing labels.

The CK1367/QV131 is similar to the 1366 in printing width. This type has 40 rows of printing elements. The increased number of elements permits complete conversion on one horizontal scan resulting in faster printing.

The CK1368/QV132 has a single row of printing elements capable of printing a strip up to 8-5/8" wide, excellent for standard size sheet paper printing.

The CK1369/QV133 is similar to the 1368 in printing width. This type has the 40 rows of printing elements.

Resembling flattened tv cathode ray picture tubes, each has an array of wires (up to 86,000 in 8-5/8") projecting through both sides of the face plate of the tube. The electron beam gives the combination of wires a negative charge, forming the desired letter or picture. In a printing system this charge is transferred to a paper passing across the wire array at the front of the tube. When the paper is passed through positively charged powered ink, the words or pictures appear. Treatment of the paper sets the printing, thereby making hard copy.

Whether used in in-plant or remote operations, printer tubes fill a need where speed and quality of reproduction have hindered procedures. Inventory reports can be sent from branch warehouse to central offices without waiting for excessive tabulation and duplication. Locations of freight cars can be determined when tv cameras in marshalling yards flash the pictures of moving cars back to the printer for instantaneous continuous tone printing. Freight branch operations can transmit waybills, bills of lading, etc. from office to office. News photos can be transmitted and printed in a fraction of the time present methods require.

All four of these new Raytheon tubes employ medium persistence green fluorescent stripes for locating the beam on the matrix wires and have magnetic deflection and focusing. The deflection angle is 40 degrees. The above types are available to customers' specifications within 60 days. Application engineering services are available.

Prices in <u>sample</u> <u>quantities</u> are as follows:

CK1366/QV130 . . . . . . . $ 2,000
CK1367/QV131 . . . . . . . $ 3,000
CK1368/QV132 . . . . . . . $ 8,000
CK1369/QV133 . . . . . . . $10,000

The above prices are net and subject to change without notice. Quantity prices will be supplied on inquiry.

# # #

(3)

Please return to Langford-Smith

# The Handling and Storage of
# MAGNETRONS

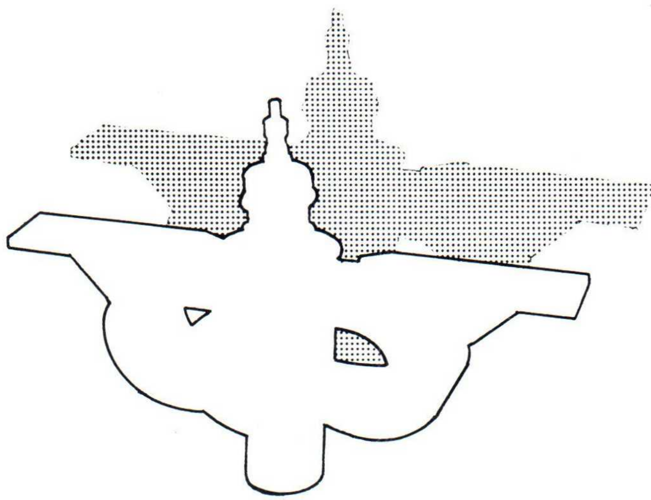

RAYTHEON

**Prepared by:**

**Magnetron Application Engineering Sect.**
**Raytheon Manufacturing Company**
**Microwave and Power Tube Operations**
**Waltham, Massachusetts**

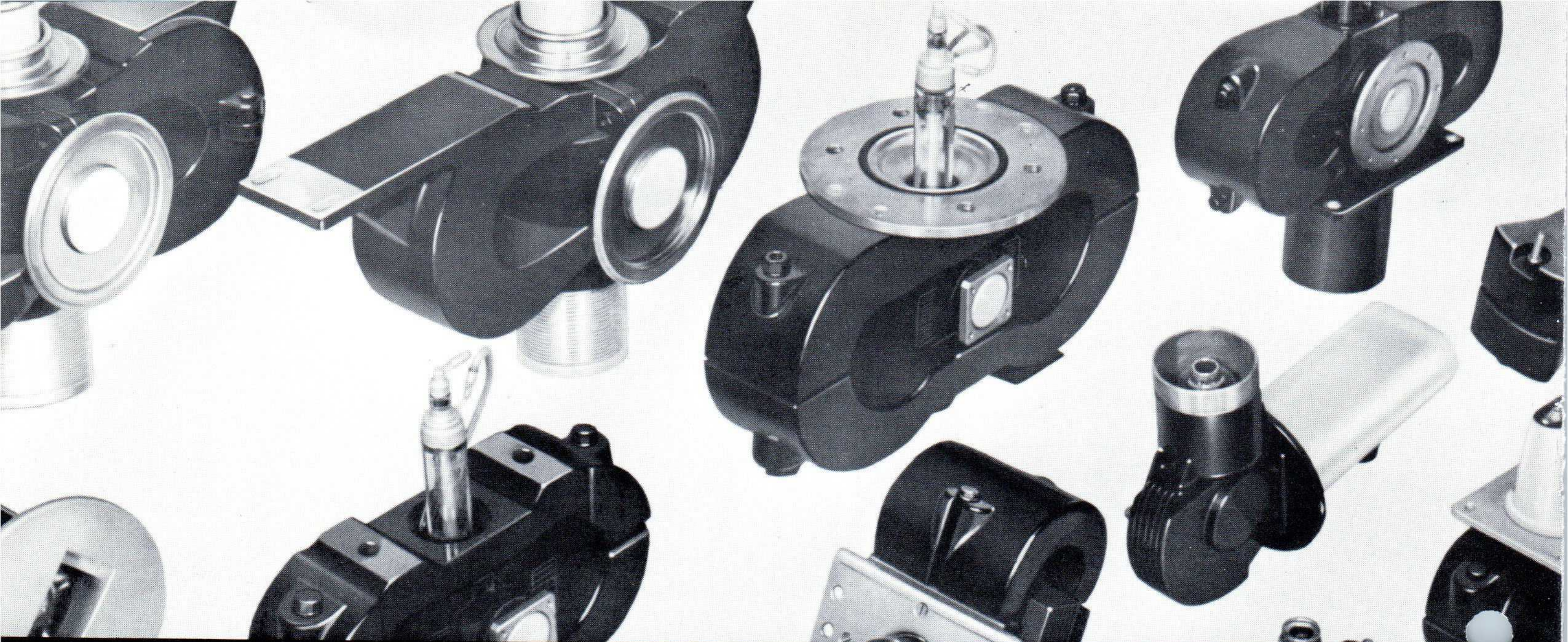
# The Handling and Storage of

# MAGNETRONS

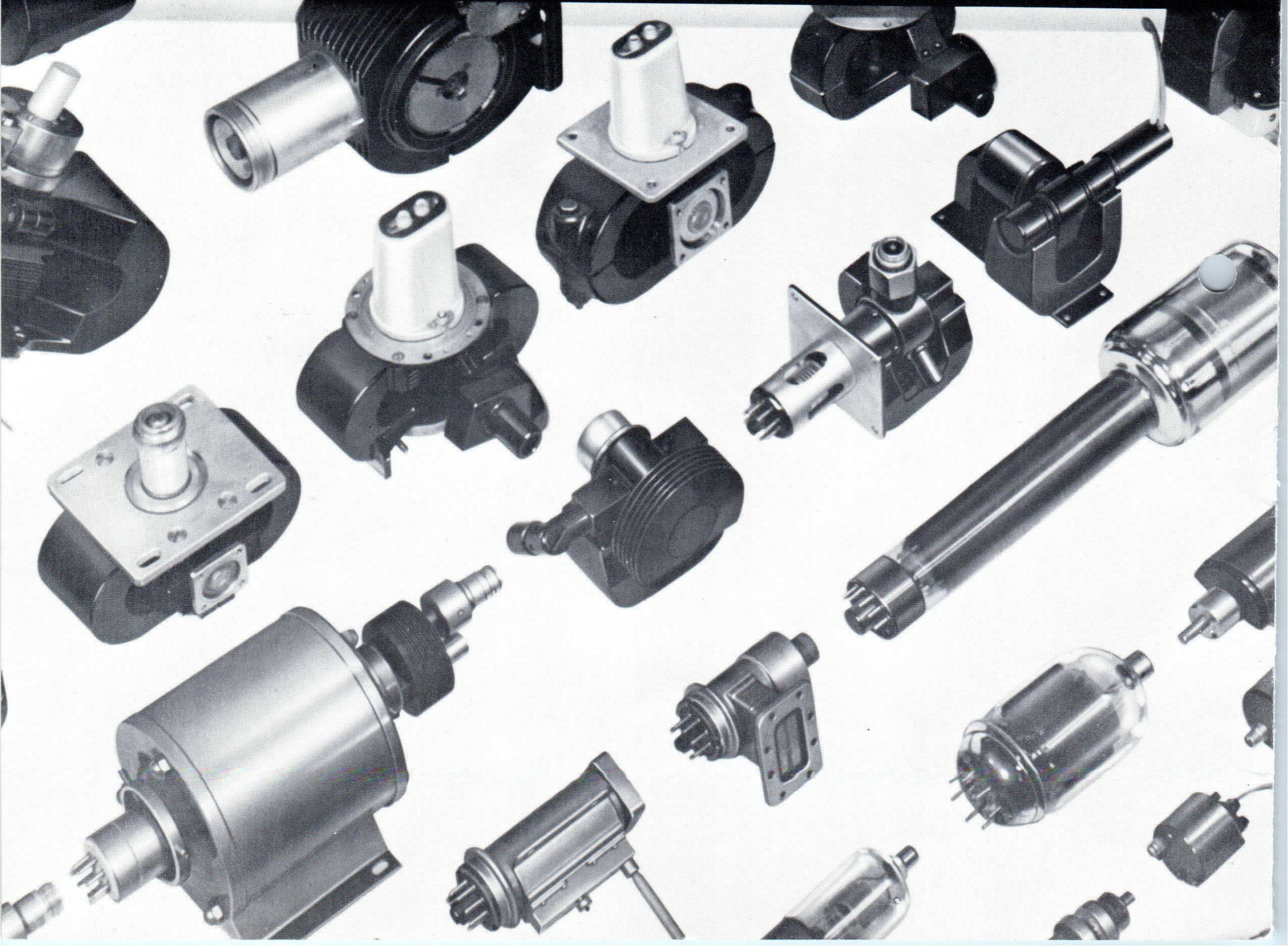


Prepared by

Magnetron Application Engineering Sect.
Raytheon Manufacturing Company
Microwave and Power Tube Operations
Waltham, Massachusetts



*Raytheon - World's Largest Manufacturer of Magnetrons and Klystrons*



# The Handling and Storage of Magnetrons

PHYSICAL HANDLING is always a potential source of magnetron damage. The Microwave and Power Tube Division of the Raytheon Manufacturing Company has therefore prepared this discussion of magnetron handling precautions. It is intended to serve as a guide to personnel at Military Supply Depots, and to anyone who may be required to prepare a magnetron for system installation or future shipment.

The magnetron is an electron tube capable of generating high power output radio frequencies in a radar application. It serves as the very heart of most radar equipments. Damage as a result of poor handling to this component prior to installation will render the radar system useless. Therefore, from the standpoint of radar reliability and cost, the importance of careful magnetron handling cannot be over-emphasized. Some of the larger and more recently developed magnetrons actually cost more than a new automobile.

Certain precautions have been taken by the tube manufacturer in the design of a magnetron shipping container to insure proper tube protection during transportation and storage. Supply depot personnel, however, probably feel that magnetron shipping containers were designed explicitly to make their lives miserable. Although some of these shipping containers are large, bulky and appear to be out of proportion when compared to the size of the product contained, they were specifically designed in that manner with the following considerations in mind:

1. The magnetron needs protection against excessive vibration and mechanical shock which might be encountered during transportation. Shipping containers for light weight magnetrons, therefore, generally incorporate two individual cardboard boxes, one inside the other and separated by a resilient material. See figure 1. The magnetron is located within the inner box and the resilient material serves as a shock absorber. For the larger types of magnetrons the cardboard boxes are replaced by heavy wooden crates with the inner section separated from the outer by rubberized horse

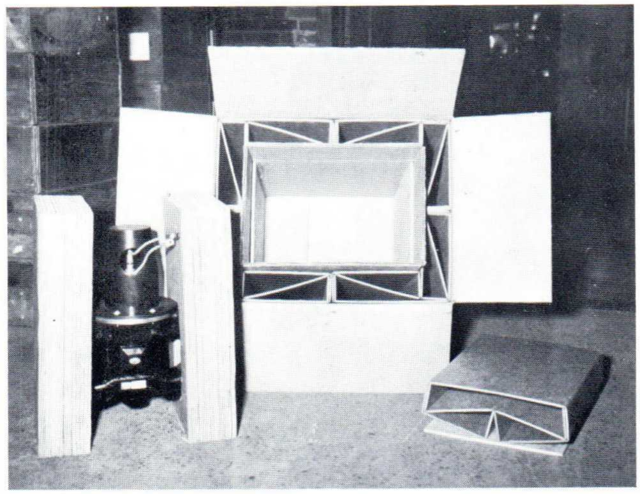


Figure 1

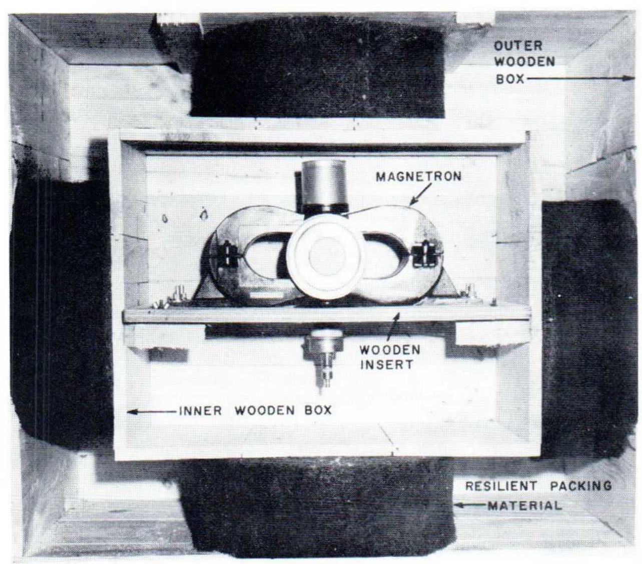



Figure 2

hair pads. (See figure 2.) Even without the magnetron, this large shipping container often weighs as much as 200 pounds. A caution label such as shown in figure 3 is attached to the outside of each shipping box containing a magnetron.

2. The magnetic properties of magnetrons must be protected at all times. Most magnetrons manufactured today are of the integral magnet type, so called because a permanent magnet which is energized and carefully calibrated at the factory is actually a part of the tube structure. Proper spacing is a prime factor in preventing the interaction of magnetic fields between two such tubes during storage. For those magnetrons which are not packed in a magnetically shielded container, a caution label, such as shown in figure 4, is used. When a requirement is established which specifies shipment by air, a caution label, such as shown in figure 5, is attached to the box.

It is realized that a temptation exists with those working in supply depots or other storage areas to conserve space by discarding the outer shipping box and storing only the inner box containing the magnetron. THIS MUST NEVER BE DONE, since interaction of the magnetic fields could weaken tube magnets and thereby reduce magnetron per-


Figure 3


Figure 4

formance in a radar transmitter. An additional danger arises when the magnetron is shipped from one location to another, even for very short distances, without the protective shock absorbing pads. Each magnetron should be retained in both its inner and outer shipping container until the tube is required for immediate system installation.

For those Air Force Bases or Naval Air Stations which may not have a satisfactory shock mounted dolly or cart for transportation of the very heavy magnetrons, a temporary shock absorbing cart can be made by using one of the large wooden containers. With only the wooden covers removed and with the rubberized horse hair padding intact, a

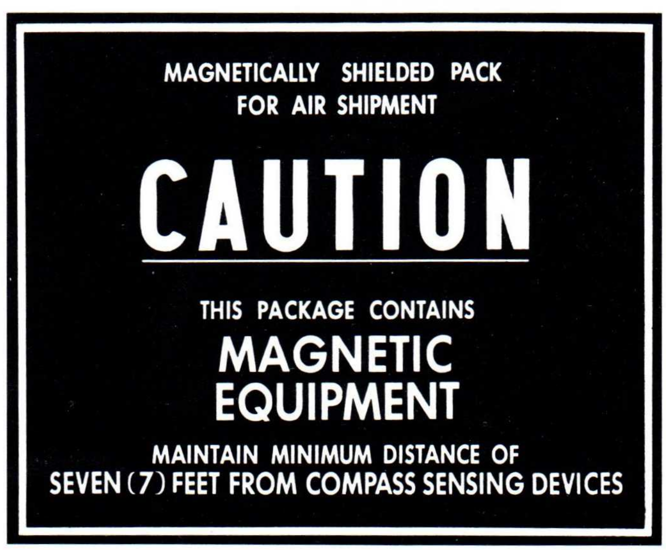



Figure 5

set of wheels can be added to the outer box to form a cart. Many aborted aircraft missions, resulting from magnetron failure due to improper handling prior to installation, can be prevented by this simple procedure.

For fixed radar installations, where a spare magnetron is usually kept in the vicinity of the transmitter, a protective storage receptacle is a necessity. This need can easily be filled by a shipping container, both inner and outer boxes, with the covers removed. Shipboard installations present a particularly dangerous environment for magnetron storage because of the steel decks and bulkheads. Wooden storage racks designed to provide proper magnetron spacing from magnetic materials is perhaps the only practical solution for shipboard applications.

Unnecessary jarring of the magnetron should be avoided. When it is necessary to transfer the magnetron from its crate to the radar transmitter, extreme care should be exercised in making certain that the magnetron parts normally protected by the shipping container are not struck against any objects during handling.

Some of the large magnetrons presently used in field radars weigh in the vicinity of 70 to 80 pounds. (See figure 6.) Because of the awkward position in which they are mounted, it is recommended that two men perform the task of removing this type tube from the shipping container. While an integral magnet type magnetron may give the appearance of massiveness and great structural strength, the internal structure is in reality some-

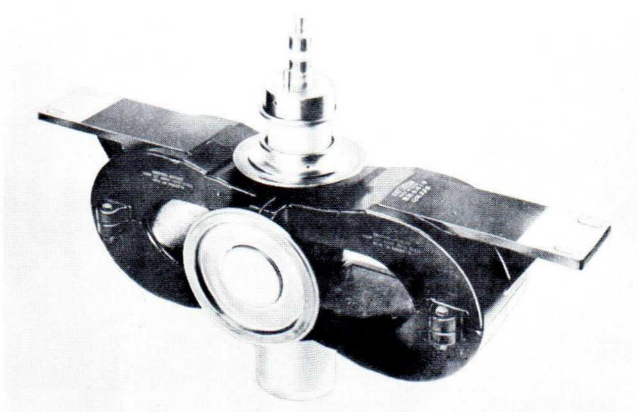


Figure 6

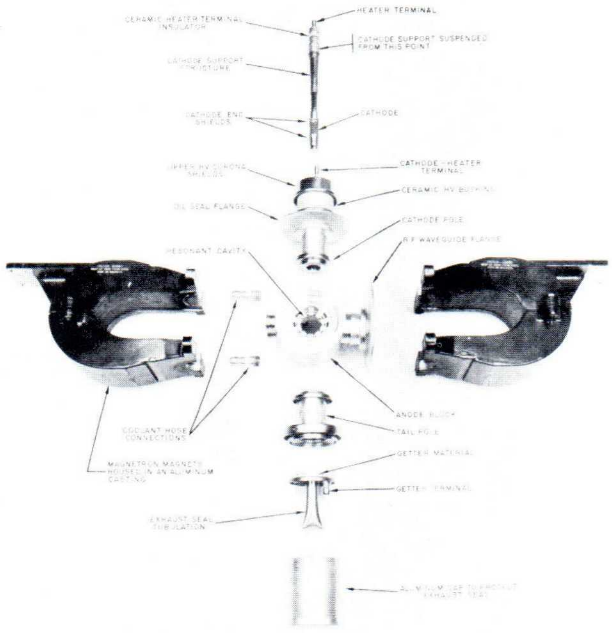



Figure 7

what delicate and involves critical alignment of the parts. (See the exploded view in figure 7 and the cut-away view in figure 8.) In the course of careless handling, a shock imparted to the heater terminal could move the cathode off center thereby destroying tube performance. It is only necessary to move this cathode a few thousandths of an inch within the magnetron cavity to result in permanent damage. In the case of magnetrons containing glass parts, a slight mechanical shock could easily fracture the glass and destroy the tube. (See figure 9.)

Shipping guards or dust covers are commonly used to protect the magnetron high-voltage bushing and r.f output section thereby preventing damage to these parts during transit, storage, and handling. These dust covers should be removed during the course of installation, but always replaced if the magnetron is to be repacked for storage or shipment to another location.

Those magnetrons referred to as the integral magnet type MUST BE KEPT AWAY FROM FERROMAGNETIC ARTICLES such as steel tools, table tops, floors, etc. Each tube of this type will have a warning label on the magnet to indicate the minimum proximity permissible for ferromagnetic materials. (See figure 10.) Although the mag-

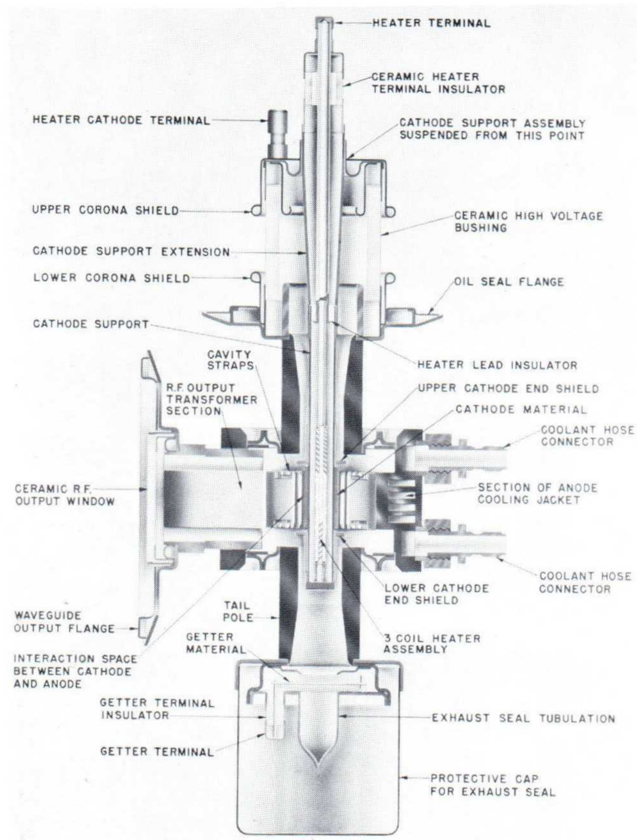



Figure 8

nets have been stabilized prior to shipment, they can be de-magnetized by severe mechanical shock or proximity to ferromagnetic materials. *These magnets must never be removed* or *loosened.* They were energized at the factory to a level which permits optimum magnetron operating performance and any alterations will reduce, if not destroy, tube operation. Whenever possible non-magnetic tools should be used during installation and mounting. Steel tools used in the vicinity of a magnetron can cause de-magnetization and if the magnet contains a field strong enough to attract a tool, the hand of the man holding the tool could be injured.

If the magnetron anode block is surrounded by a cooling jacket and water has been used as a coolant, do not store the tube in a freezing environment unless certain that all water has been removed from the jacket. Permitting water to freeze within the jacket of a magnetron will result in severe physical distortion with probable loss of the tube.

It should be remembered that any magnetron, either liquid or forced air cooled, which has been

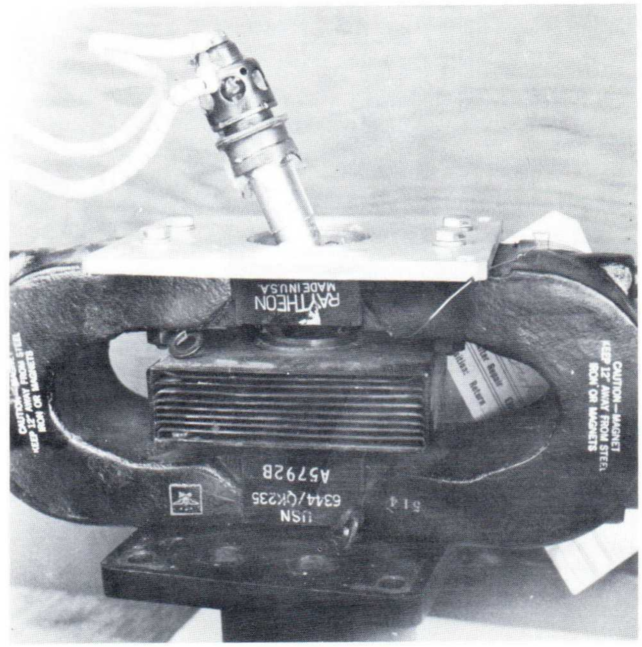


Figure 9

**CAUTION - MAGNETS**
**KEEP 12" AWAY FROM STEEL**
**IRON OR MAGNETS**

Figure 10

stored in a freezing environment, may accumulate frost. This frost or moisture must be wiped off with a clean dry rag from the insulated portions (either glass or ceramic) before any attempt is made to install such a tube in the radar transmitter. For those cases where moisture might accumulate in an area not readily accessible, it can only be recommended that the tube be permitted to thoroughly dry in a warm atmosphere.

Some magnetrons, such as the one shown in figure 6, require the high-voltage cathode bushing to be immersed in an insulating medium such as oil. This oil must be kept free from dirt and moisture. Only that grade of oil specified by the equipment manufacturer should be used. The pulse voltage applied to the magnetron cathode bushing of these tubes is normally in the vicinity of 75,000 volts. Contaminated oil will contribute to failure of such tubes.

If for any reason it is found necessary to clean foreign matter from some surface of the magnetron, STEEL WOOL SHOULD NEVER BE USED. A fine grade of sandpaper or crocus cloth will be adequate and will eliminate the dangerous possibility of steel particles adhering to insulating portions of the tube because of the strong magnetic field.

Nothing must be written upon ceramic portions of the magnetron for any reason. (See figure 11.) A graphite pencil mark, for example, would cause an arc path under normal operating potentials along the surface of the ceramic and the resulting damage would be irreparable.


Figure 11

As a final precaution, whenever it is found necessary to ship a magnetron from one location to another or return it to the manufacturer as an exhibit, it is imperative that the magnetron be properly packed in both the inner and outer shipping container. A large magnetron must be securely bolted to the wooden insert to avoid the damage shown in figure 12. No useful information can be obtained from magnetrons improperly packed and damaged during transit.

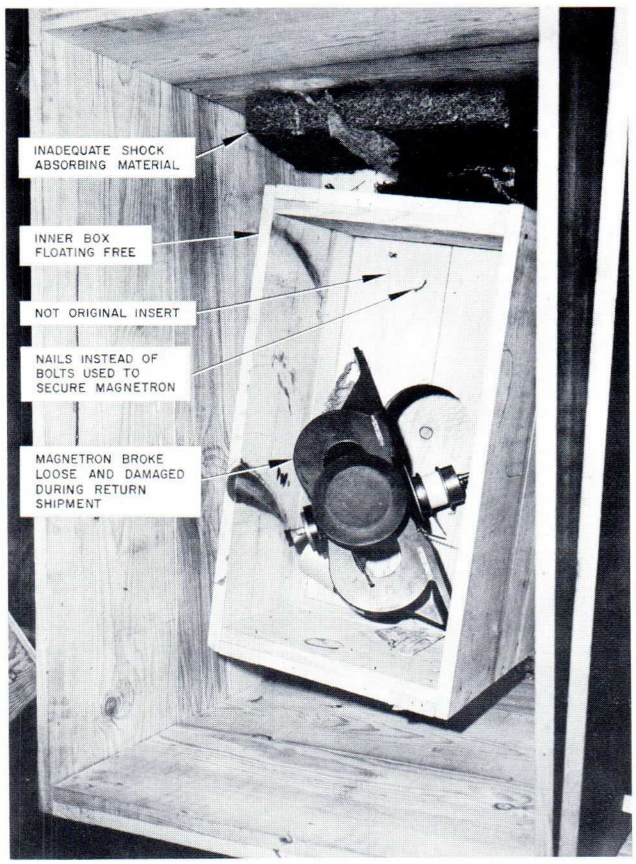



Figure 12

Figure 13 illustrates damage to the magnetron tuning mechanism incurred during installation. This same damage is possible during transit when the packing bolts are not securely fastened.

All papers submitted with the magnetrons to describe its history of performance, hours of life accumulated, and reason discontinued from service must be enclosed with each tube returned to the manufacturer for analysis. If these failure exhibits are not carefully handled and properly packed with a

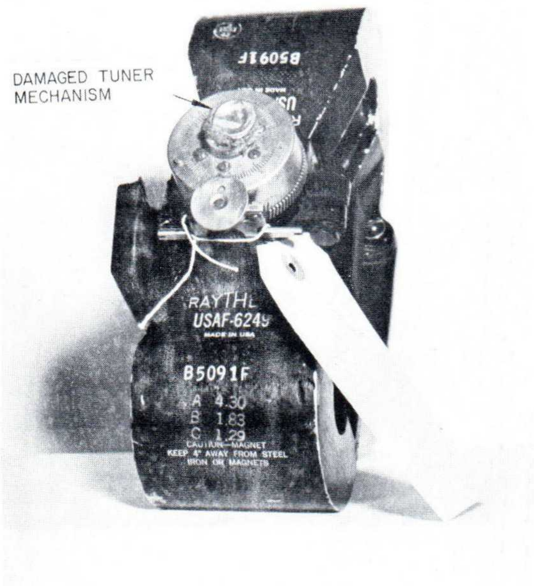



Figure 13

copy of the failure causes attached, the exhibit will contribute little or nothing to an engineering analysis. Unless this simple procedure is followed, the tube manufacturer cannot properly evaluate the problem and the problem will probably continue unchecked.

Packing and returning magnetrons to the manufacturer in the manner illustrated by figures 14 and 15 will only serve to impede proper analysis.

Figure 14

During a recent field study conducted by magnetron engineers, it was discovered that the majority of problems pertaining to physical handling and storage of the magnetron seemed to be the result of misunderstanding and lack of sufficient information. It is hoped that this article may help to overcome this problem. Raytheon feels certain that personnel responsible for the physical handling and storage of a magnetron in a field environment will exercise more caution once the dangers involved are made known to them.

There are, no doubt, many details concerning magnetron handling which this article has not covered. In an effort to compile a more complete article on the subject, Raytheon wishes to extend aɪɪ invitation to all those actively concerned, to forward suggestions to the Magnetron Application Engineering Section

RAYTHEON MANUFACTURING COMPANY
MICROWAVE AND POWER TUBE OPERATIONS
WALTHAM 54, MASSACHUSETTS

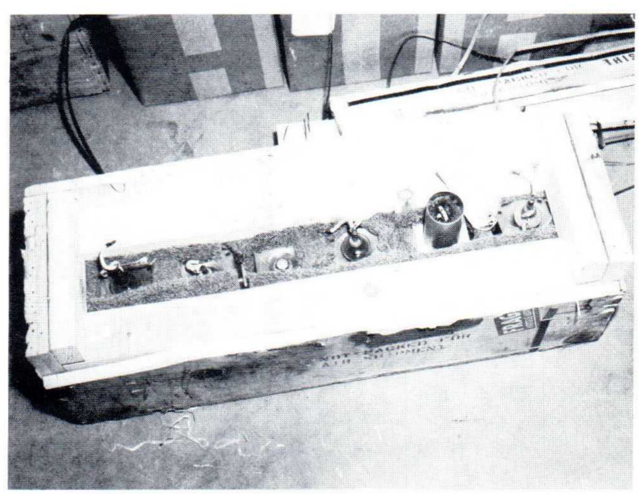


Figure 15

# Now Available

**NEW CONSOLIDATED DATA BOOKLET**

**for RAYTHEON Magnetrons, Klystrons, Backward Wave Oscillators and Special Purpose Tubes.**


**ALSO**

**A New Concept in Microwave Tubes**

**THE**

## AMPLITRON - STABILOTRON

Our application engineers are ready to assist you in selecting the proper microwave tube for your particular requirement. The above data sheets will be furnished upon request to the Sales Department, Microwave and Power Tube Operations, Raytheon Manufacturing Company, Waltham 54, Massachusetts.

# Laboratory TWT Uses Tunnel Cathode

## *Cold Cathode in S-Band Tube Has Hollow Electron Beam That Is Shaped and Pre-Focused During Fabrication*

**Experimental traveling wave tube** employs a heatless tunnel cathode. Here, the pipelike tube is inspected by Hans-Joachim Krahn, a member of the scientific team that developed the tube at Raytheon.

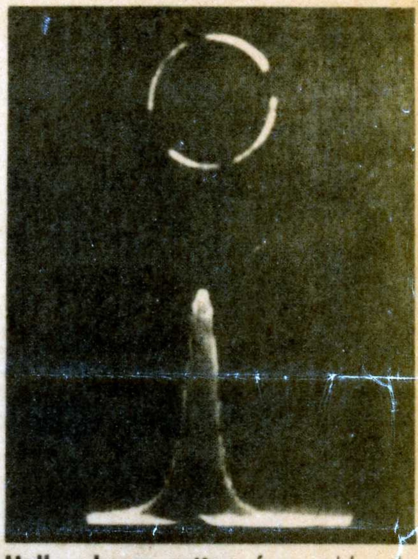
AN EXPERIMENTAL 2 to 4-Gc traveling-wave tube employs a heatless tunnel cathode.

The S-band tube, which was designed at Raytheon Co.'s Spencer Lab., Burlington, Mass., has a semiconductor tunnel cathode made of aluminum, aluminum oxide and gold.

The cathode forms a beam having a hollow-circle cross-section for efficiency. The hollow-beam emission current has been measured at 100 $\mu$amp when pulsed at a 500-$\mu$sec rate with a 5 per cent duty cycle.

The cold-cathode TWT's electron beam is shaped and pre-focused during fabrication. This is done with masks while depositing layers of vaporized semiconducting materials onto the cathode.

Raytheon said that, although cold cathodes are fairly well established as an electron emission technique, they had never before been applied as substitutes for the heated cathode in a TWT.



**Hollow beam pattern** from cold cathode in experimental traveling-wave tube is shaped and pre-focused during fabrication. Spectrum analyzer screen shows waveform of incident signal and amplified signals.

Raytheon said a marketable product may be several years away based on the present level of development activity.

Further development is expected to lead to a fast-starting TWT that could be useful in space applications, remote communications relay stations, military radar and data-transmission systems.

### Tunnel Cathode Performance

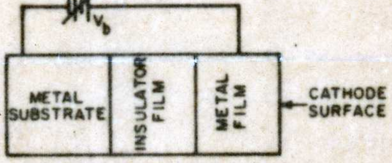
Tunnel cathodes have distinct advantages over hot or thermionic cathodes, according to Dr. Glenn Wade, assistant general manager of Raytheon's Research Div. These advantages include high current densities, low temperature operation, low-noise beams and instant starting. Space-charge-limited operation should also be possible, he said.

Dr. Wade explained that, although considerable progress has been made in designing practical tunnel cathodes, their ultimate performance depends on more knowledge of cathode materials and their energy structure. Other requirements are: better control of the tunnel process, uniformly smooth surfaces and uniform properties over the cathode area, cathode films free of pinholes, and for low-noise emission, uniform work function over emitting surface. ■ ■

### What Are Tunnel Cathodes?

**The tunnel cathode is a metal-insulator-metal sandwich, as shown in the drawing. Electrons tunnel from the metal substrate and appear in the metal film as hot electrons. Some of the hot electrons have sufficient energy to pass over the cathode surface barrier into the vacuum.[1] In the drawing, a temperature of 0 K is assumed for simplicity.**

**Electrons in the metal substrate occupy energy levels up to fermi level $F_1$; those in the metal film, up to fermi level $F_2$. $F_2$ has been shifted down with respect to $F_1$ by the battery voltage across the insulator. Since the insulator is a thin film, electrons can tunnel through it into the metal film. The battery voltage exceeds the height of the vacuum barrier and some of the tunneling electrons arrive with energies higher than the vacuum**




**level. If the mean free path for the hot electrons is large enough compared to the thickness of the metal film, emission into the vacuum can occur. Electrons arriving at the cathode surface with energies lower than the vacuum level eventually fall to below $F_2$ and are conducted away through the battery, to constitute a circulating current.**

**Reference**

1. C. A. Mead, "Operation of Tunnel Emissive Devices," *Journal Applied Physics*, Vol. XXXII, No. 4, April, 1961.

file Raytheon

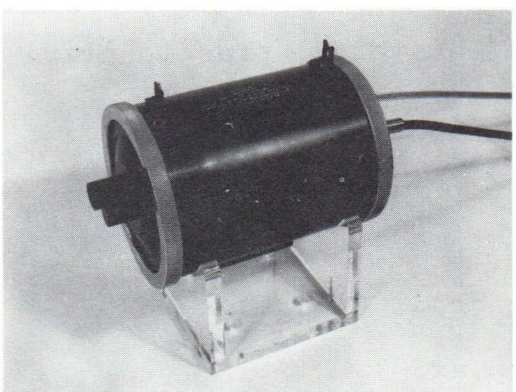
EEV
Mr Langford-Smith

LTP-100

Revised August 1961

# laser technical proposal





RAYTHEON

**RAYTHEON COMPANY**

**Special Microwave Devices Operation**

Waltham Industrial Park Waltham 54, Massachusetts

# SPECIFICATIONS

## 1. Laser Head

Laser Material: Corundum (Ruby) doped with 0.05% Chromium

Ruby Size: 2.5" long - 0.25" diameter

Flash Tube: Special FX1 suitable for normal use up to 400 joules. (Edgerton, Germeshausen & Grier, Inc.)

Laser Threshold: 100 joules (nominal)

Trigger Output: BNC Connector

Principal Pump Wavelengths: 5000 - 6000 Angstroms

Output Wavelength: 6943 Angstroms

Output Pulses: See Text

Output Beamwidth: See Text

Output Bandwidth: See Text

Head Size: Approx. 8" long, 5" diameter, plus mounting block

Weight: 11 lbs. approx.

## 2. Power Supply

Input: 115V, 60 cps

Reservoit Capacity: 400 microfarads

Charging Voltage: 2,000 volts max.

Mater: 4" - 2 KV FSD

Charging Time: 15 seconds (nominal) (See Text)

Remote Operation: Jack provided on front panel

Approximate Size: 35"$^{H}$ x 24"$^{W}$ x 22"$^{D}$ Console with casters

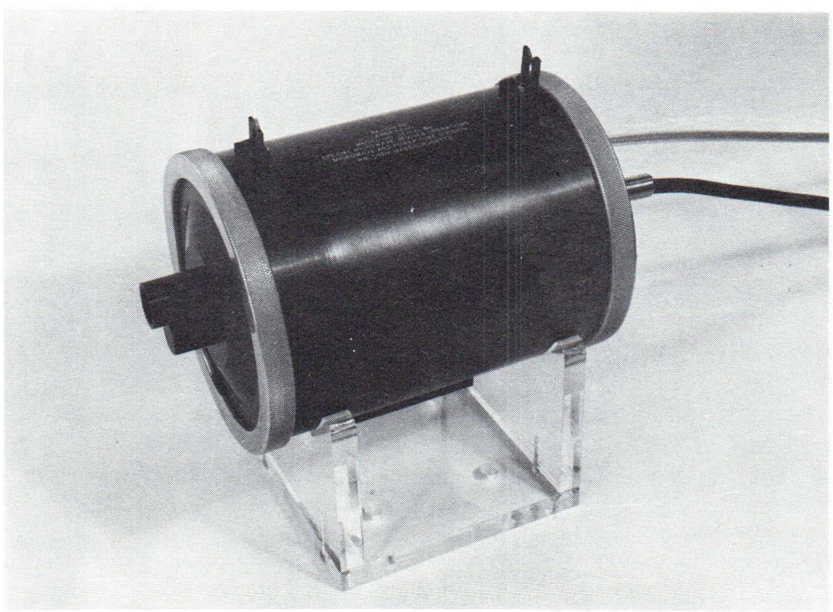
Weight: 350 lbs. approx.

THE RAYTHEON LASER

We are able to offer an experimental laser similar to the Raytheon design described recently in the national magazines. This would consist of two components, namely a laser head and a power supply.

Laser Head

This comprises a ruby rod and a single xenon flash tube, mounted in an optical enclosure, together with a trigger output circuit. The ruby rod and flash tube are mounted along the foci of a polished cavity of elliptical cross-section thus ensuring that all the light emitted by the flash tube is incident on the ruby rod. This improved optical design permits laser action to be obtained with less than one-tenth the flash tube energy previously required.



RAYTHEON LASER HEAD

Figure 1

One end of the ruby rod is made totally reflecting by silvering and the other end is partially reflecting. Multiple reflections within the rod, whose ends are optically flat and parallel, enable laser action to build up. The light is emitted from the partially silvered end of the rod in a narrow beam.

A BNC connector supplies a trigger signal when the flash tube is triggered. This enables the output pulses to be studied using an oscilloscope and a suitable optical detector.

Power Supply

The power supply contains a bank of condensers which are charged to a voltage determined by the setting of a control on the front panel. This voltage is indicated on a meter also located on the front panel. In this manner it is possible to vary the amount of energy supplied to the flash tube and to determine the threshold energy for laser action.

Minimum charging time depends on the desired energy level, the threshold voltage of the flash tube (at least 500 volts), and the voltage on the capacitor bank as determined by the variac control setting. The nominal value of 15 seconds charging time given in the specifications allows time for cooling between flashes. It is possible to flash the laser in more rapid sequence, limited only by the actual charging time as seen by the meter. This can be as short as 8 or 10 seconds. However, rapid flashing heats the flash tube and ruby, causing an increase of threshold.

## Operation of the Laser

Light from the flash tube having wavelengths in the vicinity of 4100 and 5600 Angstrom Units excites, respectively, electrons from the ground state to the $^4F_1$ and $^4F_2$ states. From these excited states the electrons fall back to the ground state by one of two processes. One means is by emitting a photon at 4100 or 5600 Angstrom Units and the other is by first falling to the $^2E$ state, by radiationless phonon transition, and then emitting a photon at 6943 Angstroms. The second process is the one which makes laser action possible.

The first step of phonon emission is non-radiative and merely serves to heat the ruby. This transition takes place in 0.1 microseconds. The spontaneous photon emission at 6943 Angstrom units takes 5 milliseconds and it is this bottleneck which causes over-population of the $^2E$ state.

Laser action occurs due to multiple reflections between the end faces of the ruby rod in a manner somewhat analogous to the commencement of oscillations in a microwave tube cavity. Please refer to Figure 3.

## Laser Output

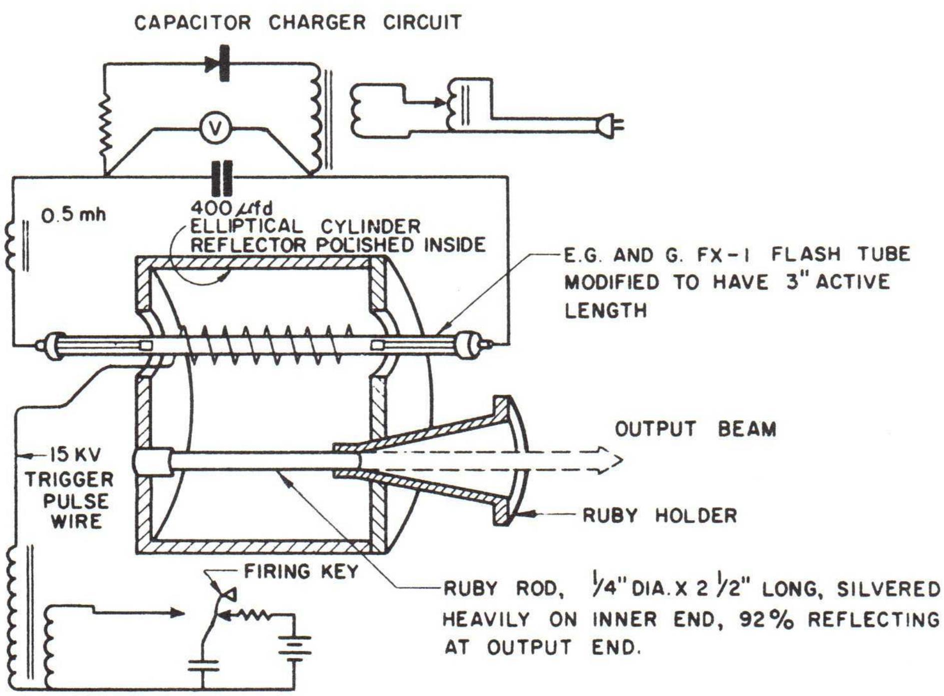
The output from the laser commences approximately 400 microseconds after the flash tube is triggered and lasts for a similar period. The output pulse consists of a series of peaks and is strongly dependent on the pump energy.

With pump energy just above the threshold required for laser action, the output consists of a series of pulses spaced approximately 5 microseconds apart (See Figure 4).

RAYTHEON LASER POWER SUPPLY

Figure 2

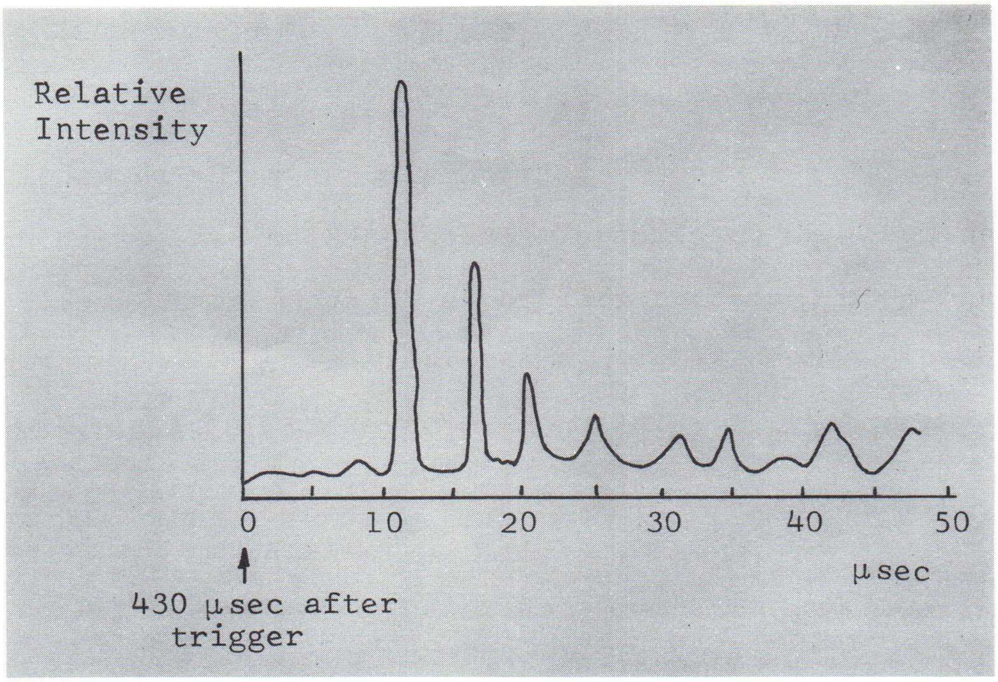
---




**STIMULATED EMISSION:** Chromium atoms in the ruby rod are excited to higher energy levels by a pulse of light from the flash tube. The chromium atoms returning to the ground state emit coherent light.

LASER SCHEMATIC

Figure 3




PUMP POWER JUST ABOVE THRESHOLD

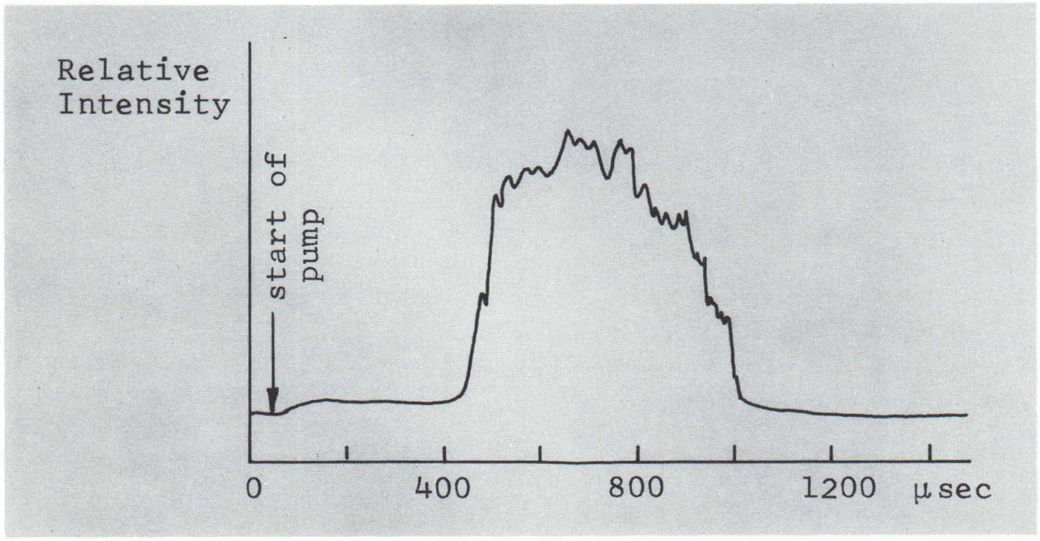
Figure 4

The width of the individual spikes has been measured as 0.5 microseconds but may be shorter since the time constant of the optical detection system could have been the limiting factor in this measurement. Simple theoretical considerations indicate that the pulse rise time may be of the order of $10^{-9}$ seconds. One possible explanation for these spikes is that the pump over-populates the level in the ruby, whereupon laser action commences but this then depletes that level more rapidly than the pump can supply energy.

If the pump energy is considerably greater than the threshold, more spikes appear and these eventually overlap and form a more continuous pulse of light output as indicated in Figure 5.

The beam-width of the laser has been measured as 1/30th of a degree when operating just above the threshold for laser action. No conclusive measurements of beam-width have been made when operating well above the threshold level.

Using a Fabry-Perot interferometer the bandwidth of a typical ruby rod was found to be 0.06 $cm^{-1}$ (0.03 Angstroms).




PUMP POWER WELL ABOVE THRESHOLD
Figure 5

Laser output was measured with an RCA 7102 Photomultiplier Tube, .020" dia. pinhole and a Baird-Atomic Filter for 6943 Angstroms. (Pinhole located at Photomultiplier Tube.)

Due to the nature of the laser output discussed above and the difficulty in measuring optical power, it is not possible to estimate the output power with any accuracy. From expected conversion efficiencies, it is estimated that the total output pulse would contain energy of the order of one joule.

It is realized that more precise specifications would be desirable but the present state of the laser art is such that we believe this unit represents a valuable tool for further experiments in either the operation or application of a laser. The laser head is constructed in such a way that the ruby rod may be replaced readily, thus enabling other materials to be evaluated. Similarly, the xenon flash tube may be easily replaced should this be necessary at any time. The use of a single xenon flash tube makes such replacement relatively inexpensive.

## Safety Precautions

While the physiological effects of the laser beam are not yet known, great care should be taken to prevent the beam entering the eye since this might cause permanent blindness.

It should be noted that the sensitivity of the eye at 6943 Angstroms is only one two hundredth of the sensitivity at the center of the visible spectrum, even so, the output appears as a brilliant spot when displayed on a white screen. A further indication of its brilliance is that it can be detected with a photomultiplier through a pad of 40 sheets of ordinary writing paper.

In view of this great intensity, it would be wise to avoid allowing the beam to fall on any part of the body until the physiological effects are better understood. IN PARTICULAR, THE OUTPUT FACE OF THE RUBY ROD SHOULD NEVER BE VIEWED WITHOUT FIRST DISCONNECTING THE CAPACITOR BANK FROM THE FLASH TUBE.

## Specifications

1. Laser Head -- Model LH-1

   Laser Material: Corundum (Ruby) doped with 0.05% Chromium

   Ruby Size: 2.5" long - 0.25" diameter

   Flash Tube: Special FX1 suitable for normal use up to 400 joules (Edgerton, Germeshausen & Grier, Inc.)

   Laser Threshold: 100 joules (nominal)

   Trigger Output: BNC Connector

   Principal Pump Wavelengths: 5000 - 6000 Angstroms

   Output Wavelength: 6943 Angstroms

   Output Pulses: See Text

   Output Beam-width: See Text

   Output Bandwidth: See Text

   Head Size: Approx. 8" long, 5" diameter, plus mounting block

   Weight: 11 lbs. approx.

2. Power Supply--Model LPS-1

   Input: 115V, 60 cps

   Reservoir Capacity: 400 microfarads

   Charging Voltage: 2,000 volts max.

   Meter: 4" - 2 KV FSD

   Charging Time: 15 seconds (nominal) (See Text)

   Remote Operation: Jack provided on front panel

   Approximate Size: $35''^{H}$ x $24''^{W}$ x $22''^{D}$ Console with casters

   Weight: 350 lbs. approx.

Price

Laser head, ruby, flash tube, power supply and interconnecting cables and remote control switch . . . $5,850

Delivery

Immediate from stock, subject to prior sale.

Refer all inquiries to:

Raytheon Company
Special Microwave Devices Operation
130 Second Avenue
Waltham 54, Massachusetts
Attn.: R. Burke
Tel: TWinbrook 9-8080

Additional flash tubes and rubies of various dopings will be quoted on request.

## RAYTHEON SALES OFFICES

CHICAGO, Illinois
9501 Grand Avenue
Tel: NAtional 5-4000
Contact: William Widugiris

GLEN BURNIE, Maryland
100 Roesler Road
Tel: SO 1-0450
Contact: Dick Devlin

HAWTHORNE, California
225 North Van Ness Avenue
Tel: PL 7-3151
Contact: John Frame

ENGLEWOOD, New Jersey
210 Sylvan Avenue
Tel: (New Jersey) LO 7-4911
(New York) WI 7-6400
Contact: John Stabile

WALTHAM, Massachusetts
130 Second Avenue
Tel: TW 9-8080
Contact: Robert Rigel

RAYTHEON

## RAYTHEON COMPANY

**Special Microwave Devices Operation**

Waltham 54, Massachusetts

Telephone TWinbrook 9-8080

3M 8-61

Printed in U.S.A.

RAYTHEON


# *Introducing*

**a new concept in**

**MICROWAVE TUBES**

T.P.D. (9)

SALES & SERVICE IN THE UNITED KINGDOM:-
B. & K. LABORATORIES LTD.
4 TILNEY ST., PARK LANE, LONDON, W.1., ENGLAND.
TELEPHONE: GROSVENOR 4567

# THE
# AMPLITRON AND STABILOTRON

# A NEW

## Broad Band microwave component

As the state of the art of microwave tube design has advanced over the years systems designers have been able to produce radar equipment having greater and greater capability for both military and commercial application. In certain areas, however, the types of tubes available have imposed a limit which has prevented these designers from realizing the full performance demanded in modern systems concepts. As the leading designer and builder of microwave tubes in the United States, Raytheon has maintained a maximum effort to present a solution to these limits. The result of this effort has been the development of a new class of crossed field microwave tube useful either as a broad band high power amplifier or, with appropriate external circuitry, as a highly stable self excited oscillator. This basic device has been named the PLATINOTRON but is becoming more widely known by the terms AMPLITRON or STABILOTRON depending upon the application considered.

The platinotron may be used as a compact, highly efficient, broad band amplifier capable of handling high peak or average powers. In this role the tube is referred to as the "AMPLITRON."*

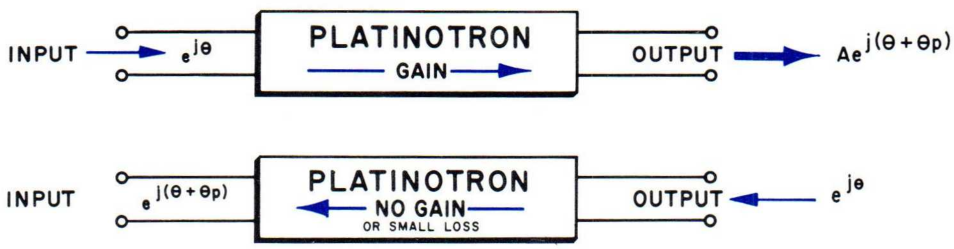
Suitable feedback and stabilizing components enable the platinotron to be used as a frequency stabilized, self-excited oscillator that operates with high efficiency, and high power output. When used in this capacity, the tube with its external components is called a "STABILOTRON."*

*Trademark

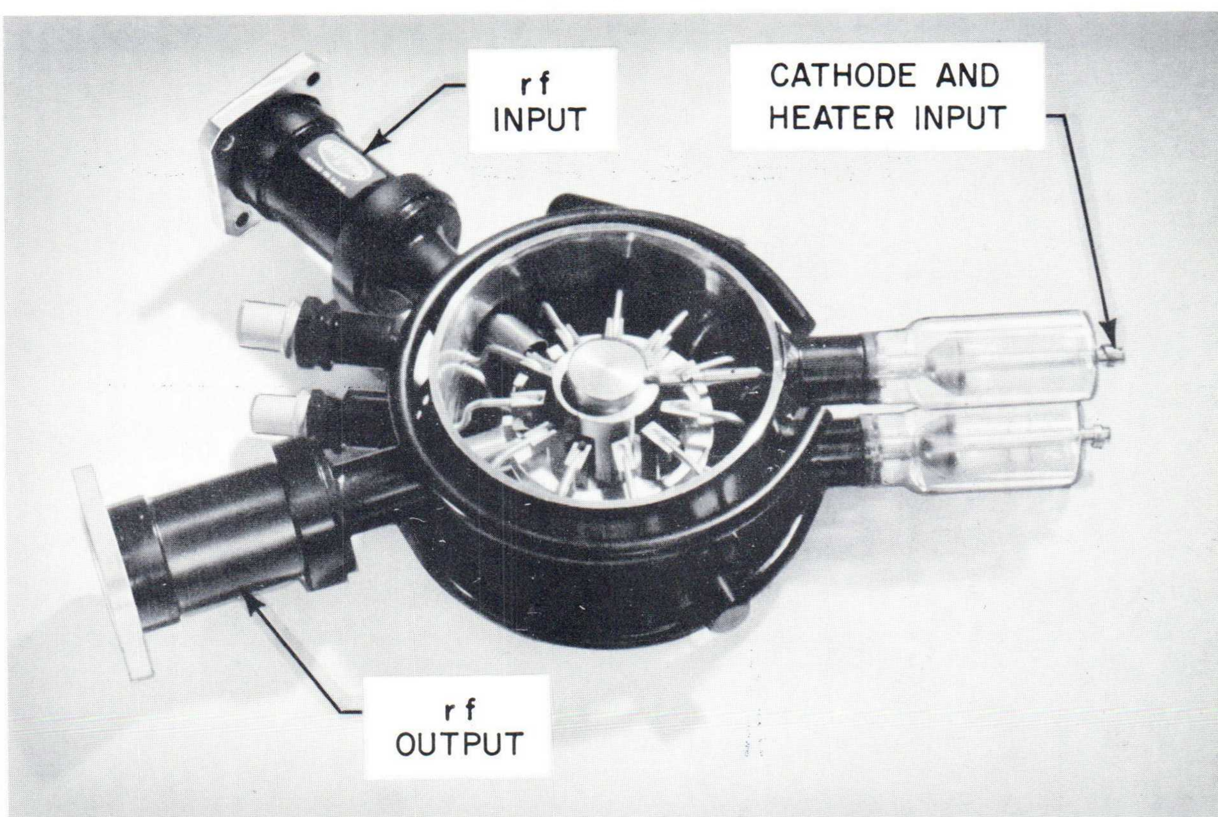
RAYTHEON

*Excellence in Electronics*

# Characteristics of THE BASIC TUBE as a circuit element




The bi-directional properties of the tube are shown above. If rf energy is fed into the Input connection of the tube, it appears in amplified form at the Output connection. If rf energy is fed into the Output connection, it appears with no gain and little or no loss at the Input connection.

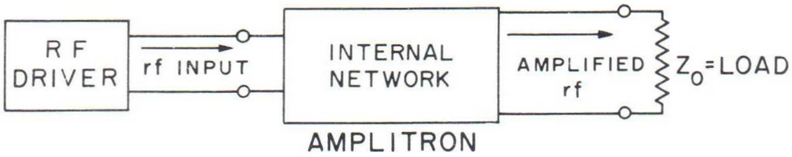



The physical appearance of the L-Band tube (with an anode cover removed).

# THE BASIC TUBE

## . . . used as an amplifier

### THE AMPLITRON




The term "Amplitron"* has been given to the use of the tube as a saturated amplifier.

The properties of the Amplitron are:

BROAD BAND
A nominal 10% bandwidth is obtainable with no decrease in output power or efficiency.

HIGH POWER
Peak power in the range of several megawatts. The electrical properties of the platinotron indicate that it is ideally suited for producing high values of either peak or average power.

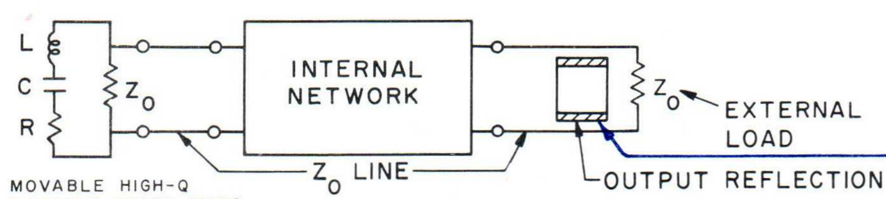
HIGH EFFICIENCY
Values from 50-75% across the tuning range.

SHORT OR LONG PULSE WIDTHS
With the Amplitron it is possible to use pulse widths up to 20 microseconds in duration.

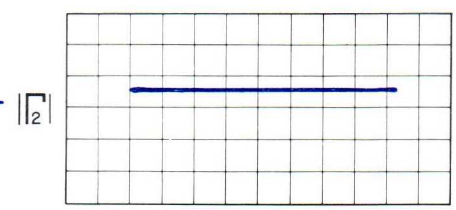
VERY LOW PHASE PUSHING
Phase pushing of the Amplitron is approximately 1/10 that of other high power amplifiers. Thus the power supply regulation and modulator pulse shape are not critical elements in the performance of the Amplitron.

## . . . used as a self-excited stabilized oscillator

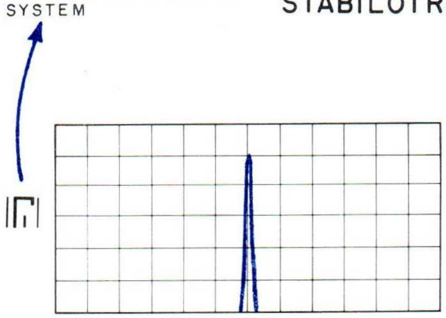
### THE STABILOTRON




STABILOTRON BASIC SCHEMATIC




REFL. COEF. OF OUTPUT MISMATCH




REFL. COEF. OF HI-Q. STABILIZING SYSTEM

The "Stabilotron" consists of (1) a platinotron (2) a high-Q tunable stabilizing system, and (3) a feedback reflection or mismatch in the output circuit of the platinotron.

These components comprise a feedback network which will oscillate when:

| | | Conditions for oscillation |
|---|---|---|
| (1) | $|\Gamma_1|\,|\Gamma_2|$ (Gain) $\geq 1$ | AMPLITUDE |
| (2) | around-the-loop phase shift is $= 2\pi n$, n = any integer | PHASE |

SIMPLE MECHANICAL CONSTRUCTION

The mechanical properties of the Amplitron are readily adapted to all the standard production techniques for magnetrons.

ONE COMMON POWER SUPPLY

When used in conjunction with a driver operating at a comparable anode voltage, both an Amplitron and its driver may be operated satisfactorily from the same power supply and modulator.

REPRODUCTION OF RF INPUT SIGNAL

Conditions such as pulse shape distortion, load variations, heater power changes, power supply modulation, or rf frequency changes, have very little effect on the reproduction of the rf input signal.

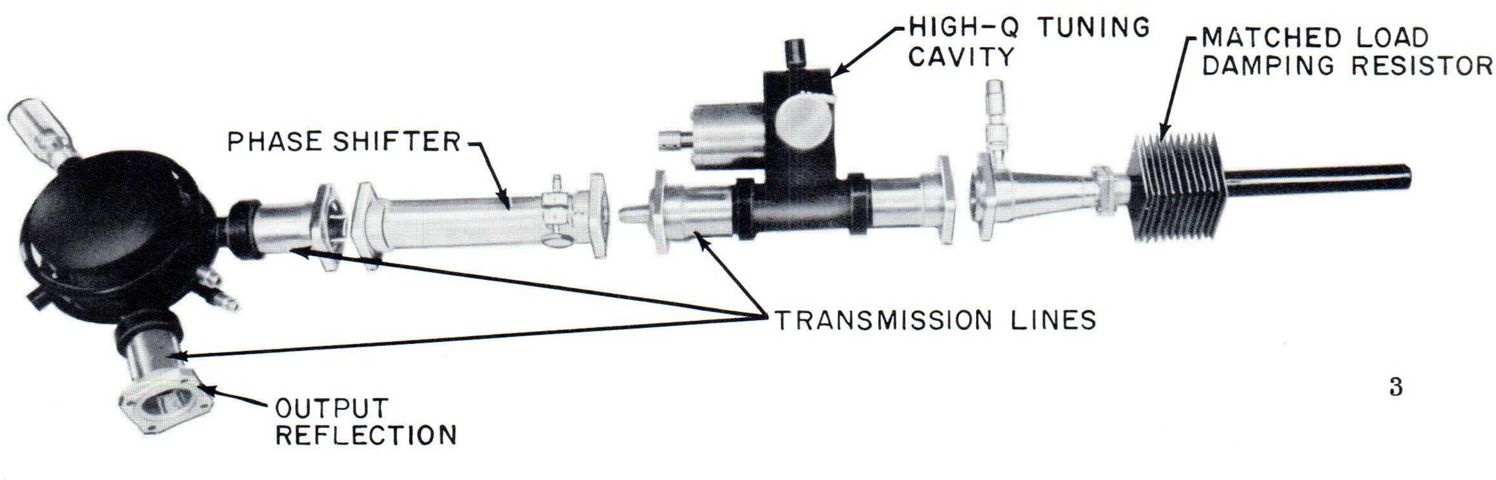
OTHER ADVANTAGES

Only a small permanent magnet is required with the Amplitron. The Amplitron requires no electromagnets, lead shieldings, or well regulated power supplies nor does it require relatively high operating voltages.

## TYPICAL OPERATING VALUES

| | | 5J26 MAGNETRON | QK434 STABILOTRON | QK520 AMPLITRON |
|---|---|---|---|---|
| Pulling Figure | Mc/sec. | 2.5 | .5 | .... |
| Pushing Figure | Kc/sec/Amp. | 50-100 | 1-4 | .... |
| Peak Operating Current | Amperes | 46 | 37 | 35 |
| Operating Potential | Kilovolts | 28 | 36 | 40 |
| Typical Efficiency | % | 42 | 48 | 50-75 |
| Peak Power Output | Kilowatts | 550 | 600 | .... |
| Gauss Line Discontinuities | | Present | Absent | Absent |
| Spectrum Sensitivity To Heater Power | | Yes | Heater off during operation | |
| Tuning Range | Mc/sec. | 1220-1350 | 1250-1350 | 1225-1350 |
| Phase Stability | Degrees/Amp. | .... | .... | 1 |
| Power Gain | Decibels | .... | .... | 5-20 Depending on rf drive level |
| Relative Time Jitter | μ Milliseconds | ≃ 15 | ≃ 4 | .... |
| Magnetic Field | Gausses | 1400 | 1100 | 1325 |

Part of the signal that is amplified through the platinotron is reflected by the feedback mismatch in the output circuit of the platinotron and travels through the tube back to the stabilizing system. The stabilizing system re-reflects only the energy that is at the resonant frequency of the stabilizing cavity and absorbs the energy that is not at the resonant frequency of the cavity. Thus the Stabilotron will oscillate only at the frequency of the high-Q tunable cavity. With overall efficiencies ranging from 45-60% the Stabilotron has such great frequency stability that it removes many of the objections to using a self-excited oscillator as the source of transmitted power in high quality radar systems. When phase pushing of a chain amplifier composed of available tubes is examined, it may be found that the use of a Stabilotron will actually produce a superior radar.

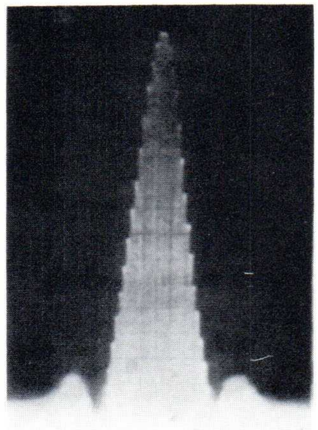


# *Further details* on the AM

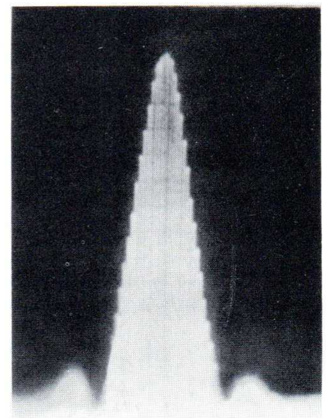
## showing the faithful reproduc

The properties of the Amplitron are:

1. Tuning range normally 10%
2. High peak power in the range of several megawatts
3. High efficiency with values of 50-75% across the tuning range
4. Short or long pulse widths up to 20 microseconds in duration
5. Very low phase pushing approximately 1/10 that of other high power amplifiers
6. Simple mechanical construction adapted to all the standard production techniques for magnetrons
7. One common power supply for both an Amplitron and its driver
8. Only a moderate operating potential required
9. No lead shielding required
10. No electromagnets required
11. No critical power supply or pulse shape



Driver Input Spectrum

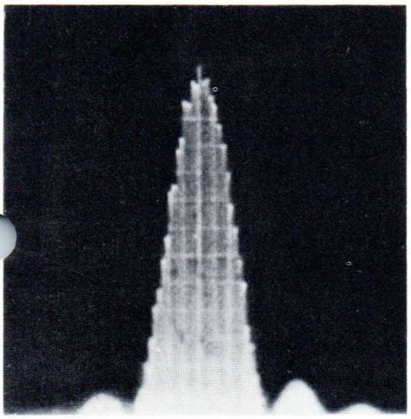


Amplitron Output Spectrum

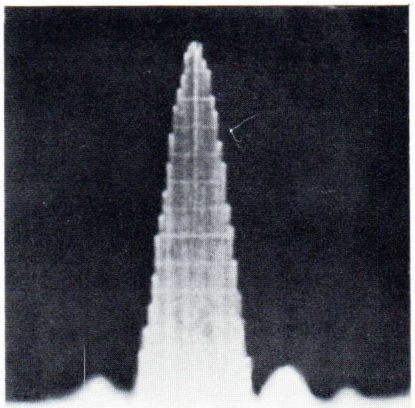
**RF Peak Power Input — 100 kilowatts**
**RF Peak Power Output — 1050 kilowatts**
**Power Gain — 10.2 decibels**
**Efficiency — 57%**
**Frequency — 1340 mc/sec.**
**Pulse width — 5 microseconds**

# PLITRON

## tion of driver input spectrum.

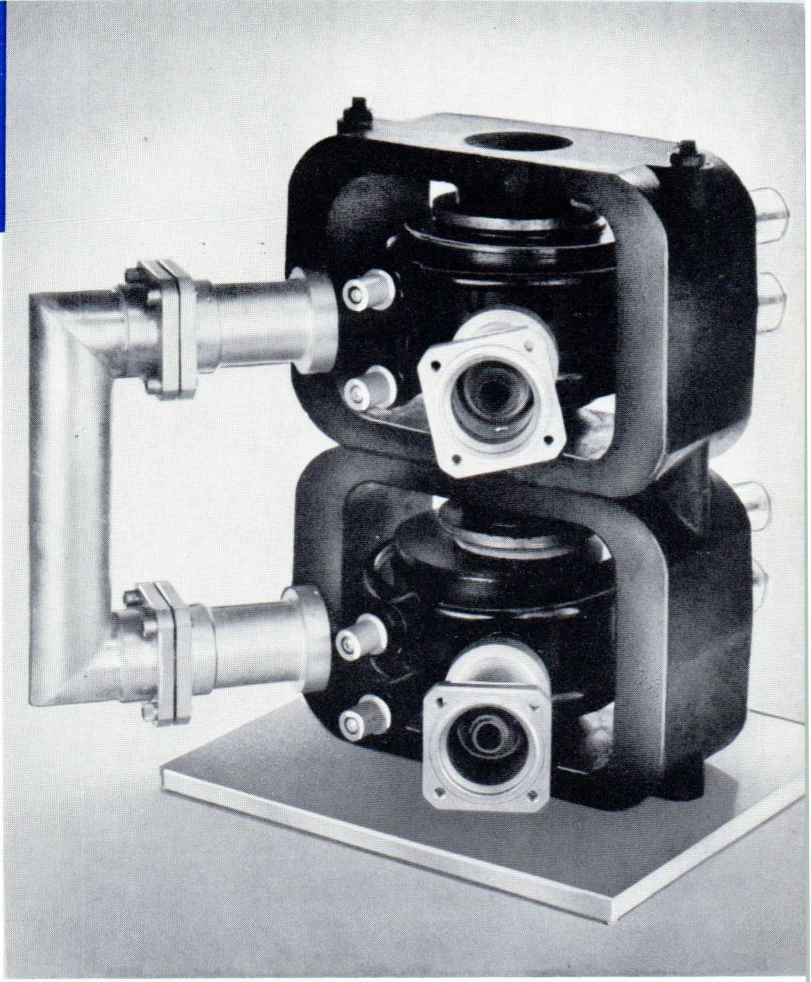


Driver Input Spectrum

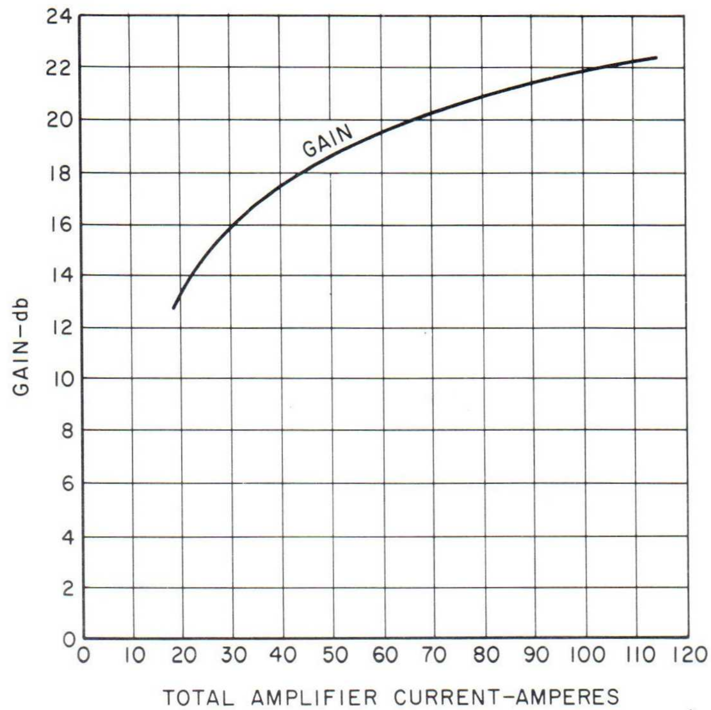


Amplitron Output Spectrum

**RF Peak Power Input — 90 kilowatts**
**RF Peak Power Output — 900 kilowatts**
**Power Gain — 10.0 decibels**
**Efficiency — 58%**
**Frequency — 1275 mc/sec.**
**Pulse width — 5 microseconds**



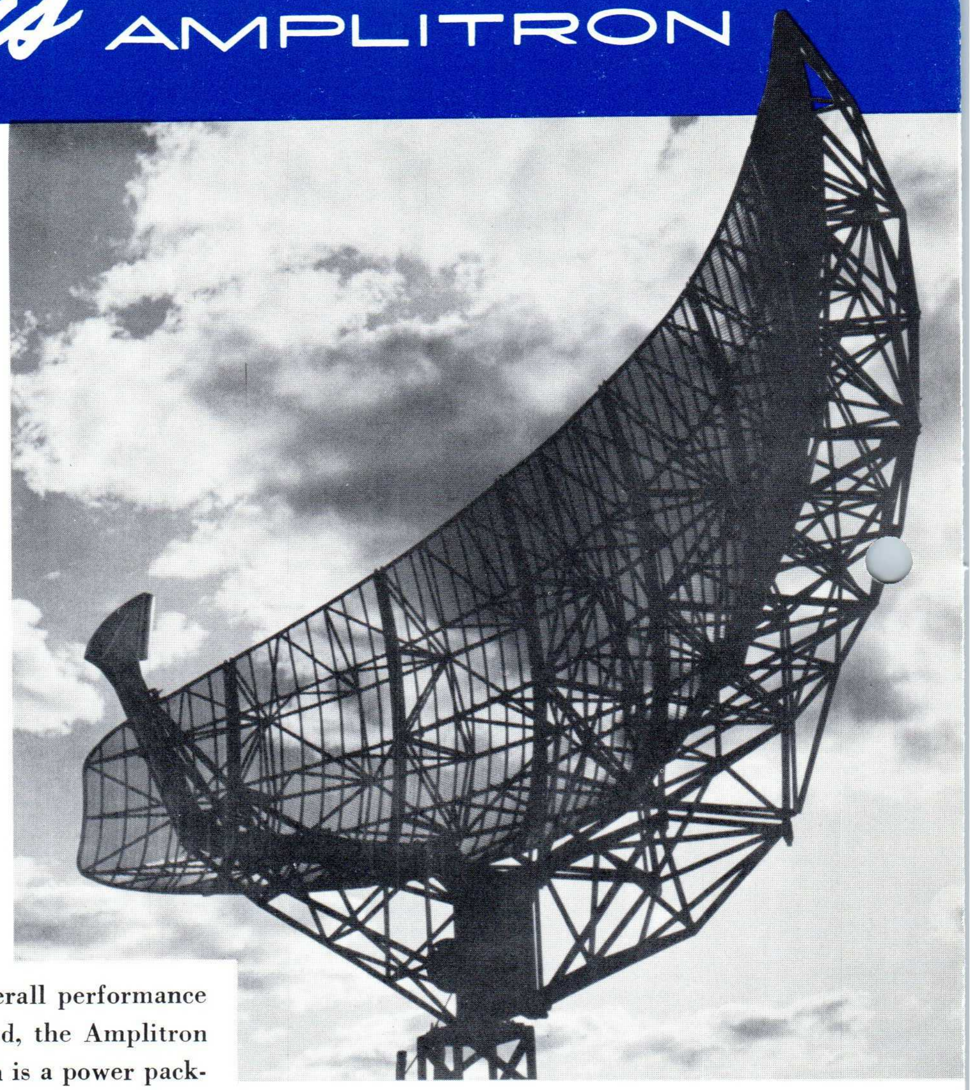
Two Cascade L-Band Amplitrons.




Successful cascade of Amplitrons for high gain applications is shown above. The limiting feature of cascade operation has been self-oscillations due to high gain and incidental mismatches. Raytheon's recent developments with high power L-Band ferrite isolators will speed the achievement of higher-gain cascade systems.

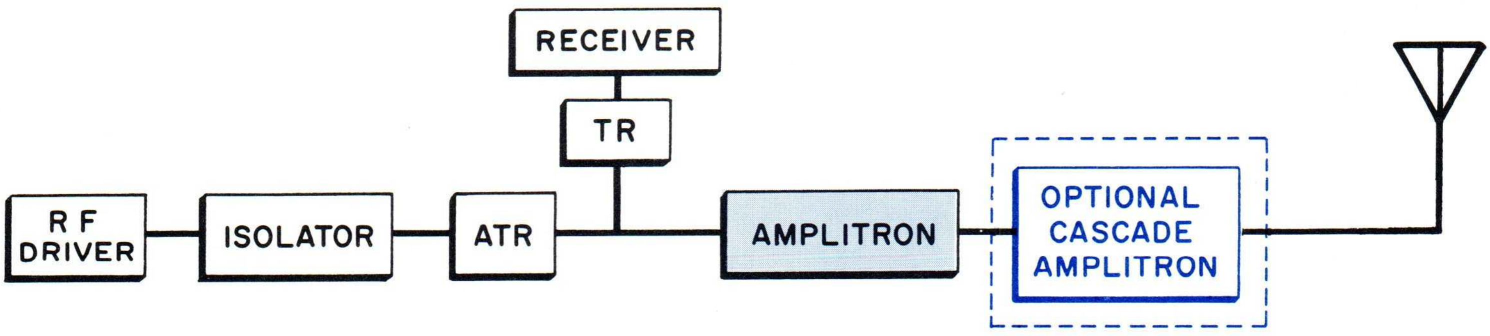
# *Applications* of the AMPLITRON

## a "power pack" for search radar systems



Where increased range and improved overall performance for existing search radar systems is required, the Amplitron represents an ideal solution. The Amplitron is a power package that usually can be added to existing radar systems with little modification of the original equipment.

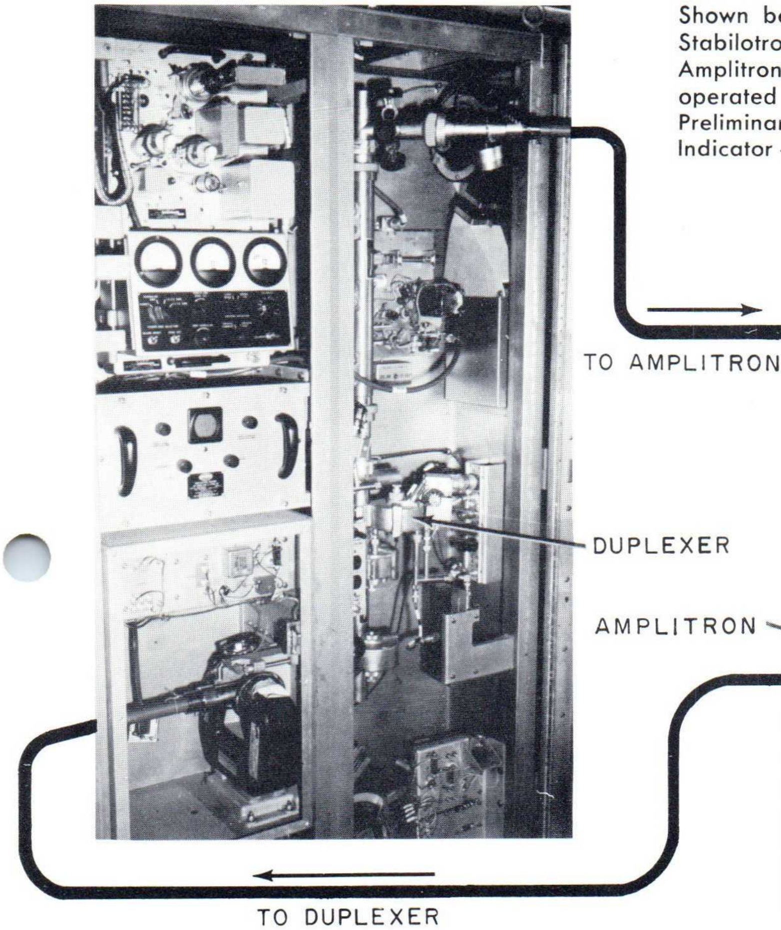
Using the bi-directional properties of the Amplitron, it is possible to duplex on its input side, and use the existing radar duplexing equipment. This arrangement allows the duplexer to operate at the power level of the original rf driver, even though the system is effectively operating at a transmitted peak power level ten or more times greater than the power level of the original rf driver.

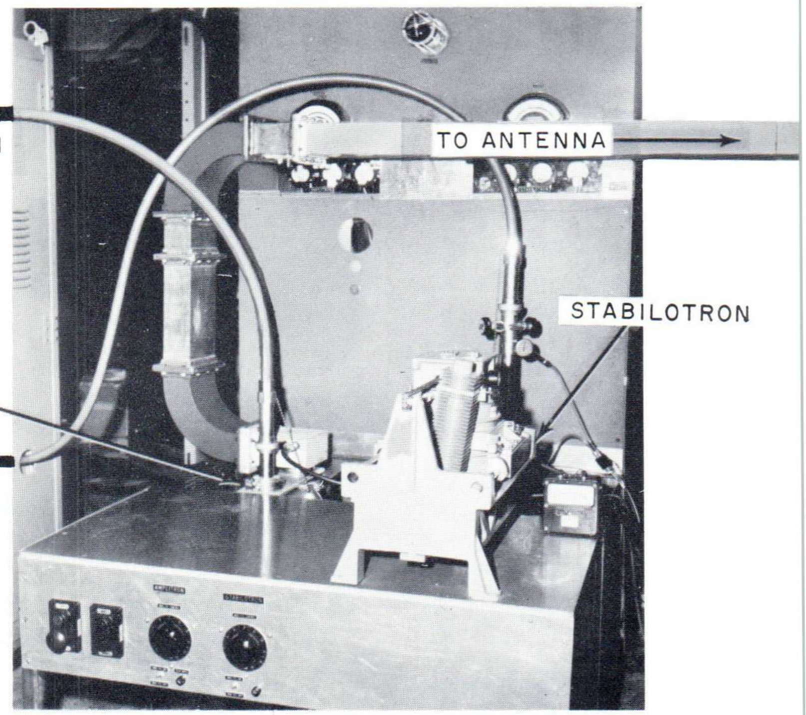





Schematic illustrating how a high-level Amplitron may be used with a low-level duplexer.

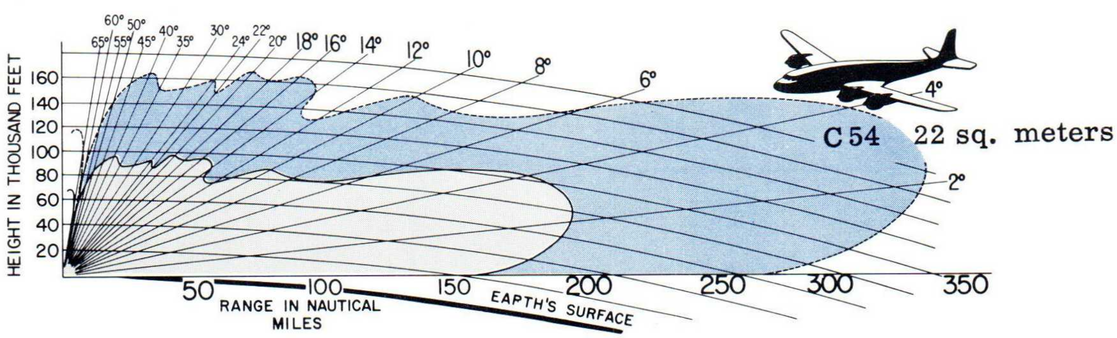
Shown below is a long range search radar set with a Stabilotron substituted for the original rf driver and an Amplitron inserted after the duplexer. Both tubes were operated from one external power supply and modulator. Preliminary tests indicate excellent MTI — Moving Target Indicator — characteristics and vastly increased range.

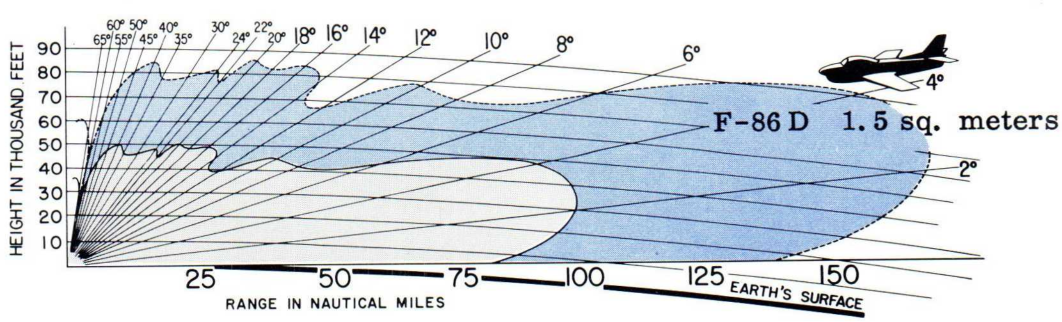



# INCREASED RADAR COVERAGE

Performance of a long range search radar system at present and with a proposed high power Amplitron that will be available in the near future.




Equipment (adapted) with Raytheon High Gain Antenna scanning at 6 rpm.

Equipment (adapted) with Proposed Amplitron to increase peak power to 4 megawatts and with Raytheon High Gain Antenna scanning at 6 rpm.

# STABILOTRON *Characteristics*

Examination of search radar performance leads to an investigation of the individual units that comprise the basic radar set. Some of the present rf transmitters display characteristics that put a limit on the available system performance.

The Stabilotron enables the systems engineer to think in terms of the following greatly improved transmitter characteristics:

A HIGH QUALITY SPECTRUM with pulses up to 20 microseconds in duration.

A HIGH QUALITY SPECTRUM under a variety of conditions involving (a) load variation (b) heater power changes (c) pulse shape distortions.

A HIGH QUALITY SPECTRUM throughout a tuning range normally 8-10% in extent.

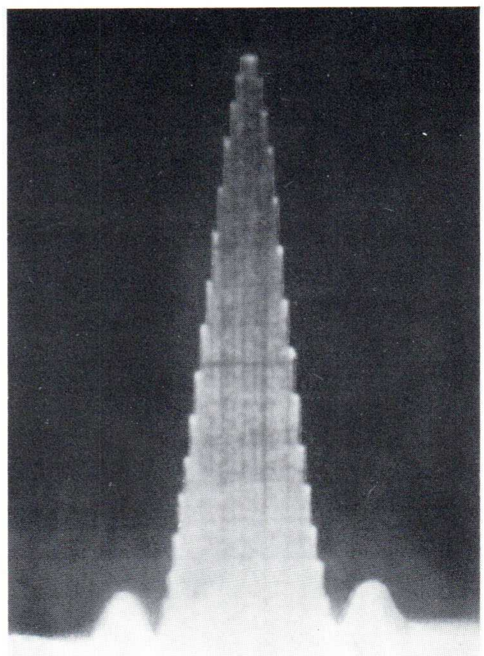
A PULLING FIGURE better than that of the conventional magnetron by a factor of 5 to 10.

OVERALL EFFICIENCIES ranging from 45-60% across the tuning range.

Because of the Stabilotron's relatively small pulling figure, its performance is LESS SUBJECT TO "LONG LINES EFFECT" than is the magnetron. For this reason the Stabilotron can be operated into transmission lines four times longer than those possible with magnetrons before frequency instability (long lines effect) becomes noticeable.

A DYNAMIC PUSHING FIGURE improvement from 10 to 50 depending upon the magnetron used for comparison.

"GAUSS LINE DISCONTINUITIES" associated with some magnetrons ARE COMPLETELY ABSENT with the Stabilotron. Incremental changes in the magnetic field, heater power, operating point or frequency have caused magnetrons to enter unstable operating regions on the performance chart. These unstable regions, sometimes quite near the normal operating point, are unsuitable for radar operation. It normally requires a careful operator to adjust the magnetron until it is out of these unstable regions; thus, the freedom from "gauss line discontinuities" associated with the Stabilotron is a highly desirable feature for field application.



A typical spectrum is shown above. The Stabilotron has operated with a 3, 5, 7, and 17 microsecond pulse duration. An excellent spectrum of almost theoretical bandwidth was obtained at each pulse width.

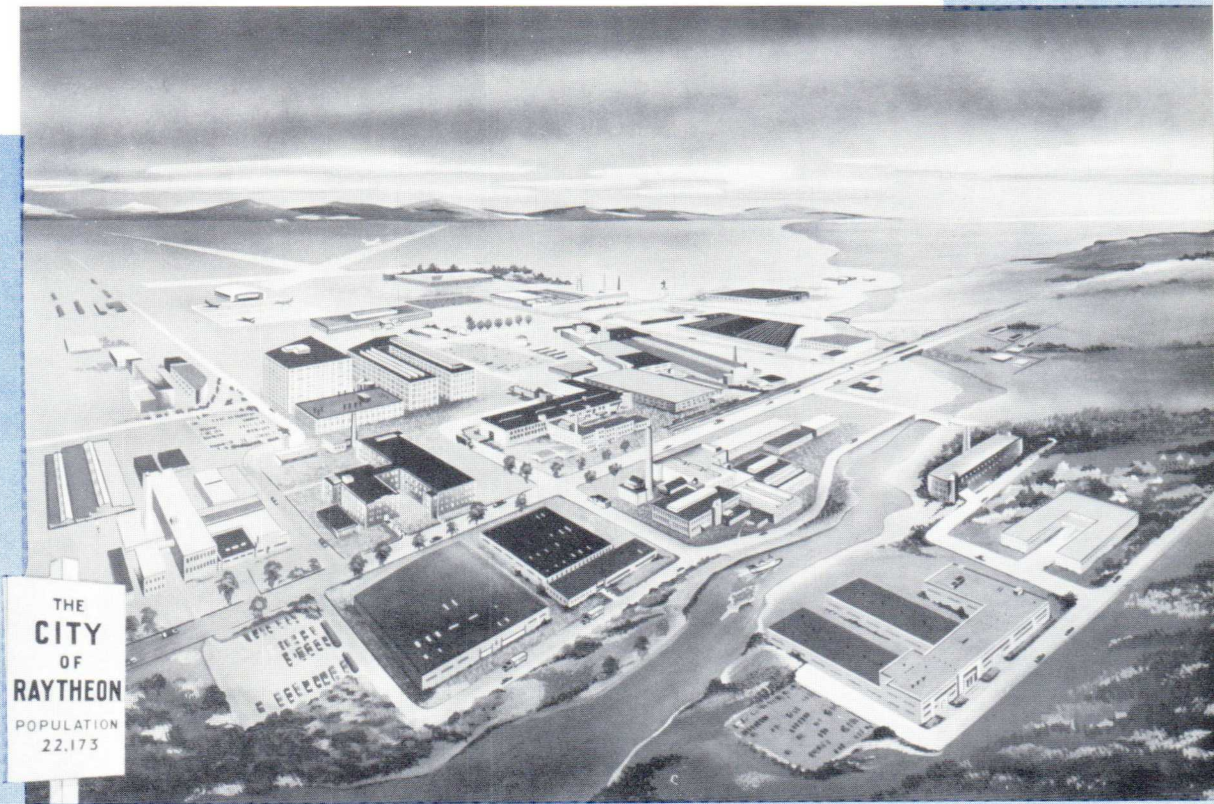
# *Availability*

The Amplitron described in this report is nominally a 1.5 megawatt L-Band tube, but other Amplitrons at S-Band have produced as much as 4.5 megawatts of peak power. At L-Band or lower frequencies the Amplitron should be capable of being designed to produce hundreds of kilowatts of average power efficiently.

Experimental evidence indicates there are no limitations to the frequency of amplitron operation.

Stabilotrons have been operated at L-Band, S-Band, and C-Band frequencies. Used with a search radar system for more than two years, the L-Band Stabilotron has yielded performance unattainable by comparable magnetrons.

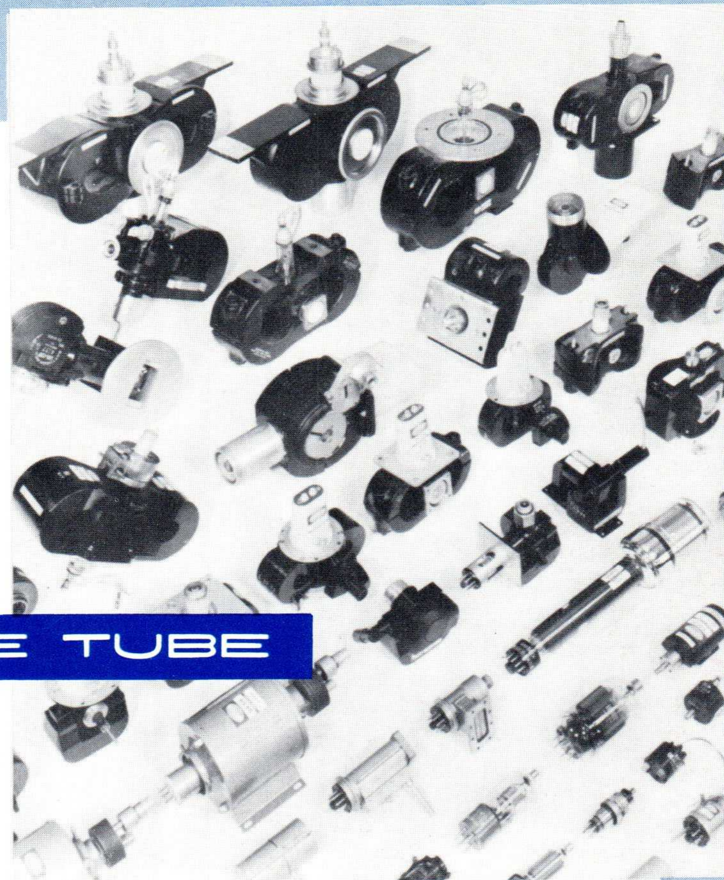
Information as to availability or development of an Amplitron, Stabilotron, or the combination of both for your particular application is available from the Sales Department, Microwave and Power Tube Operations, Waltham, Mass.




Pictured here are the principal buildings of the Raytheon Manufacturing Company as they would appear if consolidated in one location. From these many plants across the nation come complete microwave systems, whose universal acceptance has earned for Raytheon an eminent position among the world's leading manufacturers.

RAYTHEON

Printed in U.S.A.



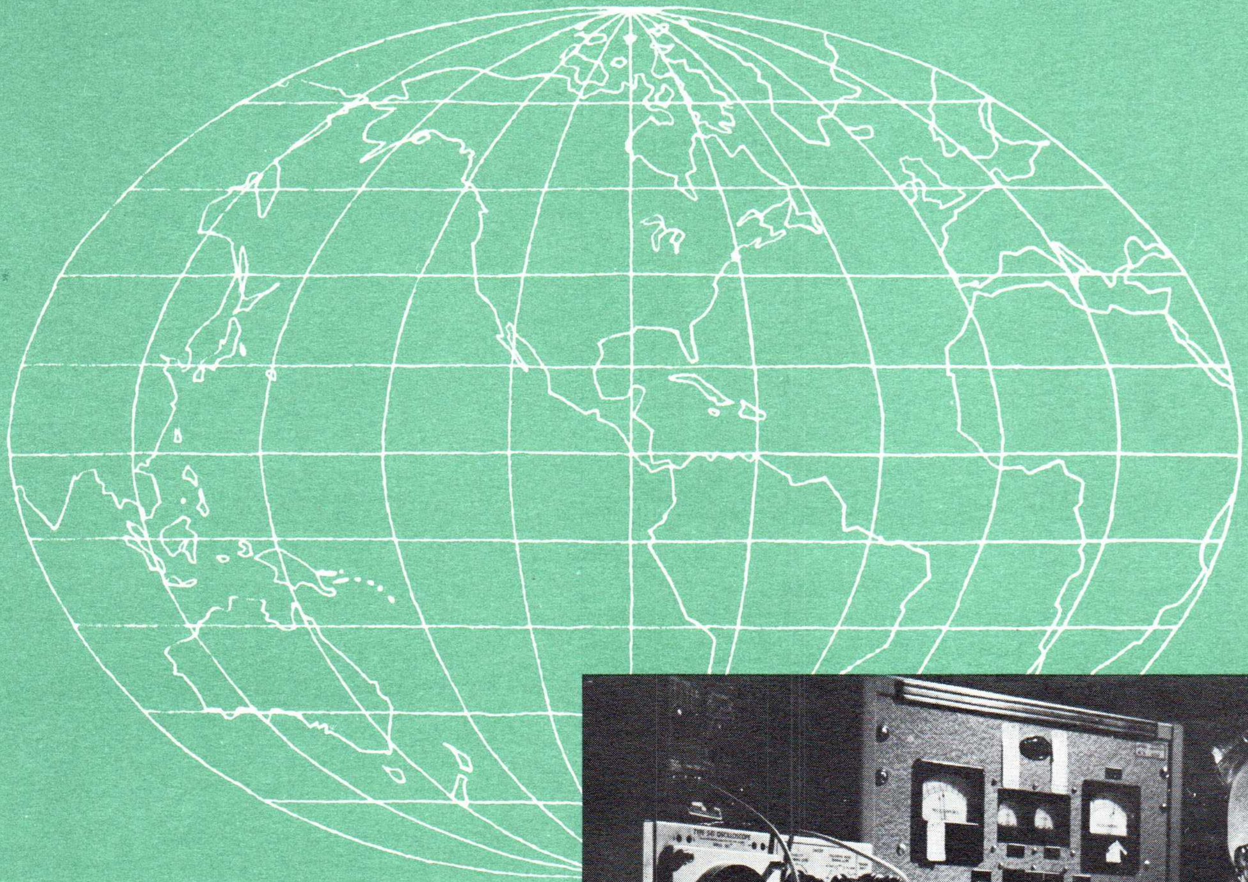
*Inquire about*

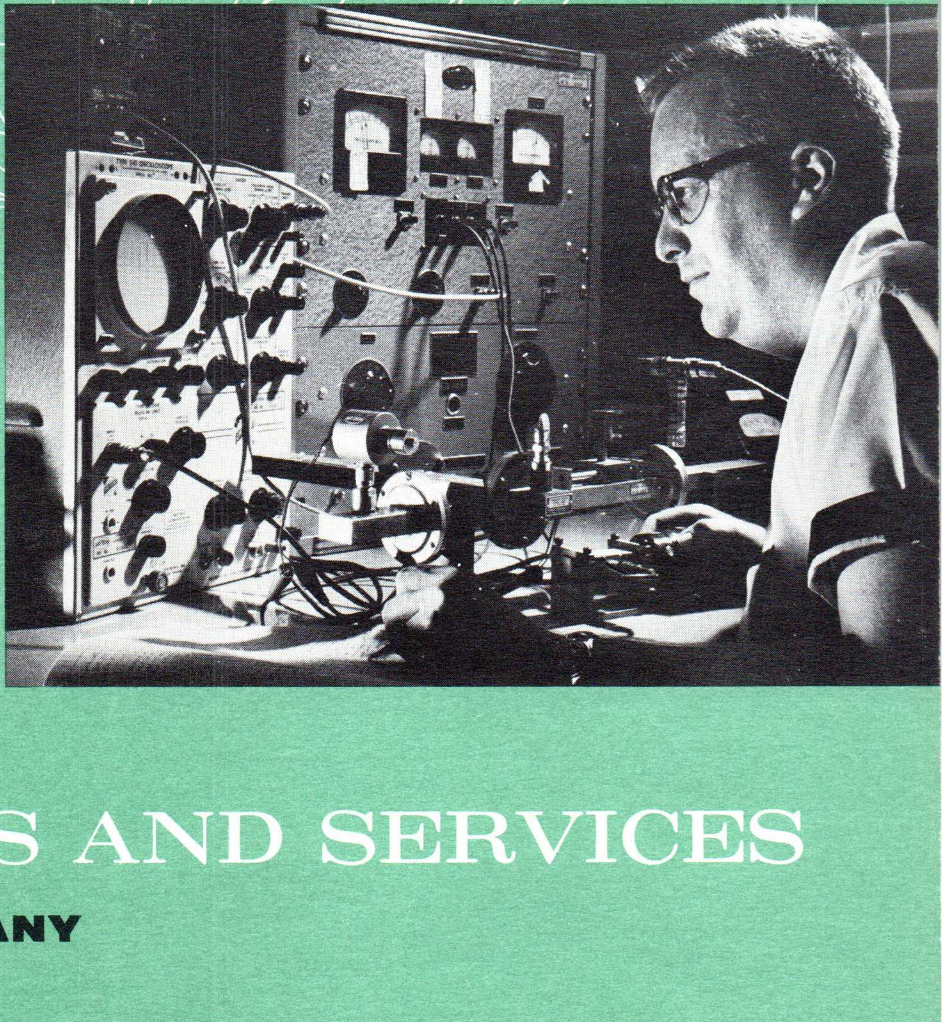
## ANY MICROWAVE TUBE

Our application engineers are ready to assist you in selecting the proper microwave tube for your particular requirement. Consolidated tube data sheets will be furnished upon request to the Sales Department, Microwave and Power Tube Operations, Raytheon Manufacturing Company, Waltham 54, Massachusetts.

RAYTHEON

**RAYTHEON MANUFACTURING COMPANY**
MICROWAVE AND POWER TUBE OPERATIONS
WALTHAM 54, MASSACHUSETTS





RAYTHEON

# PRODUCTS AND SERVICES

**RAYTHEON COMPANY**

RAYTHEON

# PRODUCTS AND SERVICES

## . . . by divisions

### COMMERCIAL APPARATUS AND SYSTEMS DIVISION

1 1415 Providence Highway, Norwood, Massachusetts
NOrwood 7-4440

Commercial Marine Operations
Marine Product Operations
Magnetics Operations
Sorensen Operations

This division manufactures and markets a number of established commercial product lines. These include marine radar, "Fathometer"® depth sounders, and other navigational aids, precision welding equipment, electronic ovens, ultrasonic impact grinders, magnetic components, and the Sorensen line of precision power supplies and voltage regulators.

Among the more recent additions are citizens band radiotelephones, portable depth sounders, and laboratory equipment for research and development.

### DISTRIBUTOR PRODUCTS DIVISION

2 411 Providence Turnpike, Westwood, Massachusetts
DAvis 6-7700

This division complements the marketing programs of several manufacturing divisions by marketing all Raytheon products sold through distributor channels.

Delivery is expedited by the revolutionary "Unimarket" automated distribution system which makes possible 24-hour delivery practically anywhere in the U.S.A.

### ELECTRONIC SERVICES DIVISION

3 Second and South Avenues, Burlington, Massachusetts
BRowning 2-9300

This division provides integrated world-wide product and customer support for both government and commercial business. It provides service capability in 90 strategic locations. This capability is made up of a field engineering force, service shops, and repair depots.

The headquarters at Burlington provides training for company and customer personnel, technical service publications, and the company's centralized replacement parts department.

### EQUIPMENT DIVISION

4 1089 Washington Street, West Newton 65, Massachusetts
DEcatur 2-7700

Airborne Equipment Operations
Communications and Data Processing Operations
Santa Barbara Operations
Submarine Signal Operations
Surface Radar and Navigation Operations

This division designs, produces, and markets a broad range of electronic equipments and systems for government and industry. Radar and related devices, including data processing equipment, are the leading product categories. Typical projects include airborne navigation and bombing radars; air traffic control and storm detector radars; and military search, precision tracking, and weapon control radars. Related products include countermeasures equipment, microwave relay and communications systems, and altimeters.

To complement radar techniques for fire control, missile guidance, and other military purposes, intensive development work is being done on infrared systems.

Underwater sound, another major field, is represented by sonar equipment and complete ASW weapons systems.

### INDUSTRIAL COMPONENTS DIVISION

5 55 Chapel Street, Newton 58, Massachusetts
BIgelow 4-7500

Industrial Tube Operations
Receiving Tube Operations
Industrial Cathode-Ray Tube Operations
Electromechanical Components Operations

One of the oldest and largest manufacturers of special-purpose tubes, this division produces tubes for industrial and military applications including computers, telephone equipment, industrial controls, military and commercial aircraft, and more than 25 U.S. missiles. Included in the line are many highly specialized types such as decade counter and storage tubes.

The Receiving Tube Operations, located at Quincy, Mass., manufactures receiving tubes primarily for entertainment use. Principal applications are in TV and radio receivers (including automobile radios) and in high-fidelity music systems. These tubes are sold direct to original equipment manufacturers and also through the Distributor Products Division to distributors who supply the dealer replacement market.

In addition to tubes the division produces other components such as magnetostriction filters, control knobs, and panel hardware, as well as ultra-compact welded assemblies of electronic components and circuitry which are contributing to the Polaris missile project and other programs.

### MACHLETT LABORATORIES, INC.
### (A subsidiary of Raytheon)

6 Springdale, Connecticut
Stamford, FIreside 8-7511

Machlett, the oldest name in the commercial production of x-ray tubes in the United States, is the largest producer of medical and industrial x-ray tubes and x-ray "valves" of all types.

Machlett has also risen to prominence as a supplier of special-purpose electron tubes. Included in this latter category are: high-power triodes for heavy-duty industrial electronics and nearly all phases of high-power commercial broadcasting; "hard" modulator tubes for high-power radar use; high-vacuum diodes for air pollution control and particle recovery; television camera tubes for closed-circuit TV and commercial broadcasting; storage and scan-conversion tubes; and UHF planar triodes for a variety of microwave applications.

## MICROWAVE AND POWER TUBE DIVISION

7

Foundry Avenue, Waltham 54, Massachusetts
TWinbrook 9-8400

Established in 1942 to develop and manufacture microwave tubes for military radars, this division is the world's largest producer of magnetron tubes and a leading producer of reflex klystrons. Recent pioneering is reflected in the Amplitron, which was originated at Raytheon, and in a line of backward-wave oscillators and traveling-wave tubes. These and many other types find application in radars, beacons, missiles, test equipment, communications, and electronic heating.

In addition to tubes the division offers three related product lines: ceramic devices, which embody production techniques used in the manufacture of high-power tubes; microwave ferrite devices, which are closely associated with microwave tubes in the design of advanced radar systems; and infrared detectors of advanced design.

## MISSILE SYSTEMS DIVISION

8

520 Winter Street, Waltham 54, Massachusetts
TWinbrook 9-8000

Prime contractor for the U.S. Navy's air-to-air Sparrow III missile system as well as weapon systems manager for the U.S. Army's ground-to-air Hawk, this division, now the largest in the company, has pioneered in guided missiles since 1944. Sparrow III is operational with the U.S. Sixth and Seventh Fleets. Hawk, also in production and soon to become operational, is the only available ground-based antiaircraft missile effective against low-level sneak attack. Recently Hawk achieved the first intercept and destruction of one missile by another.

Missile system elements and components are produced in division production plants in Lowell, Mass.; Andover, Mass.; and Bristol, Tenn. Components developed and now in production for these systems are available for other government end-use.

Developments for these and other forward-looking defense and space programs are coordinated by the Bedford, Mass., division laboratories.

## RAYTHEON CANADA, LTD.

9

Waterloo, Ontario
SHerwood 5-6831

This division designs, produces, and markets electronic equipment for government and industry in Canada, and also special items for the U.S. Products include video and data-handling portions of radar systems, radar simulators, bright displays, and spectrum analyzers, as well as complete radar systems.

Raytheon Canada also serves as Canadian distributor for Raytheon products.

## RAYTHEON EUROPE

10

452 Pleasant Street, Watertown 72, Massachusetts
BIgelow 4-7500

Raytheon Europe markets Raytheon products through Raytheon AG and Sorensen Ard AG, as indicated below, in the British Isles, Continental Europe, the Near East, and North African countries which border on the Mediterranean and Red Sea.

Raytheon AG, with headquarters in Zug, Switzerland, markets equipment and systems such as radar, communications, and marine products.

Sorensen Ard AG, with manufacturing facilities in Zurich, Switzerland, markets Raytheon and Sorensen apparatus for industrial and laboratory use.

The marketing of components is directed by Raytheon Europe.

Raytheon Europe is also responsible for the manufacture of systems, equipment, and components by Raytheon's European subsidiaries and licensees.

## RESEARCH DIVISION

11

Seyon Street, Waltham 54, Massachusetts
TWinbrook 9-8400

Both independent research projects and work in support of scientific developments by other divisions are carried out by this group. Primary efforts include theoretical and experimental studies in materials, basic and solid-state physics, physical electronics, and microwave tubes.

Several Raytheon products have been conceived, developed, and produced within this division. Ferrite microwave devices now constitute a product line of the Microwave and Power Tube Division; Pyrographite and plastic high-temperature insulating materials as well as reinforced plastic components are being produced and marketed by the Research Division.

## SEMICONDUCTOR DIVISION

12

215 First Avenue, Needham Heights, Massachusetts
HIllcrest 4-6700

First in the electronics industry to mass-produce and market junction transistors, this division manufactures a complete line of semiconductor devices for such varied uses as computers, missiles, communications systems, home radios, radars, and hearing aids.

Products include germanium and silicon transistors, germanium and silicon diodes, and silicon rectifiers, as well as packaged circuit modules containing semiconductor devices.

RAYTHEON

# PRODUCTS AND SERVICES INDEX

This comprehensive list of Raytheon products includes catalogue items, products available only on a custom basis, and products supplied only to the government or to military contractors under government authorization when required.

Following each listing is a key number indicating the manufacturing division (see numbered list of divisions on preceding pages). An additional key number "2" indicates that the product is also marketed by the Distributor Products Division (see below).

## PRODUCT INQUIRIES

COMMERCIAL. If the product listing is keyed only to the manufacturing division, inquiries regarding specifications and prices should be directed to that division.

Products handled by the Distributor Products Division are indicated by the additional key number "2". In addition to handling all distributor business, this division encourages original equipment manufacturers to take advantage of the fast service provided by local distributors supplied through the "Unimarket" automated distribution system. In keeping with this policy, distributor prices and factory prices are equalized up to certain quantities. Information regarding quantities, prices, and local distributors as well as product specifications may be obtained by direct inquiry to the Distributor Products Division.

GOVERNMENT. Please direct all inquiries regarding products and capabilities to:

Government Contracts Office
Raytheon Company
Stanley Avenue
Watertown 72, Massachusetts
TWinbrook 9-8400, ext. 3640

EUROPE. Please direct inquiries as indicated in the listing for Raytheon Europe (Division "10") on the preceding page.

OTHER INQUIRIES. Writers, editors, publishers, educators, students, and others who are *not* writing as prospective customers should direct all inquiries concerning Raytheon activities and products to:

Office of Public Relations
Raytheon Company
103 River Street
Waltham 54, Massachusetts
TWinbrook 9-8400, ext. 3863

| PRODUCTS | DIVISION |
|---|---|
| Accelerometers, missile | 8 |
| Altimeters, military | 4 |
| Amplifiers, magnetic | 1 |
| Analyzers, spectrum | 1 |
| Antennas: | |
| marine | 1 |
| microwave and UHF | 4 |
| Anti-submarine warfare systems | 4 |
| Battery chargers, telephone | 1 |
| Beacons, radar | 4 |
| Binding posts | 5, 2 |
| Bright display equipment, radar | 4, 9 |
| Broadcast equipment — *see* Relays, microwave; Tubes | |
| Ceramic products: | |
| flanges, insulators, bushings, cylinders, diode mounts, etc. | 7 |
| Chokes | 1 |
| Circuit packages (modular component assemblies) | 5, 12, 2 |
| Clips, fuse and resistor | 5, 2 |
| Coils | 1 |
| Communications equipment: | |
| citizens band and marine | 1, 2 |
| microwave relay, underwater, infrared, coding, decoding, multiplexing, communication zone indicators (COZI), military pack sets | 4 |
| Components, electrical: | |
| standard, printed-circuit, and subminiature test jacks; binding posts; fuse and resistor clips | 5, 2 |
| Components, electronic — *see* Tubes, Magnetic components, Ferrite microwave devices, etc. | |
| Components, mechanical: | |
| terminal board brackets, handles, control knobs | 5, 2 |
| Computer components: | |
| logic assemblies, magnetic shift registers, switching assemblies. *Also see* Semiconductor products, Tubes, Data processing equipment | 5 |
| Computers, special-purpose military | 4, 8, 9 |
| Control knobs | 5, 2 |

| PRODUCTS | DIVISION |
|---|---|
| Control systems, special-purpose military | 4, 8 |
| Converters: | |
| power | 1 |
| radar scan | 4, 9 |
| Countermeasures and counter-countermeasures equipment | 4, 8 |
| Counter tubes, decade and radiation | 5, 2 |
| Data processing equipment | 4, 8 |
| Delay lines | 1, 5 |
| Depth sounders — *see* Marine Products | |
| Detectors — *see* Gas detectors, Tubes, Semiconductor products | |
| Diathermy units, microwave | 1 |
| Diodes: | |
| germanium and silicon | 12, 2 |
| vacuum and gas — *see* Tubes | |
| tunnel (Esaki) | 12, 2 |
| Direction-finders, marine | 1 |
| Display equipment, bright-screen | 4, 9 |
| Electrical components — *see* Components, electrical | |
| Electron tubes — *see* Tubes | |
| Electronic (microwave) ovens | 1 |
| Electronic services | 3 |
| Electrostatic: | |
| generators | 1 |
| precipitators | 1 |
| Encapsulated component assemblies | 5, 12, 2 |
| Esaki (tunnel) diodes | 12, 2 |
| "Fathometer"® depth sounders: | |
| for commercial craft | 1 |
| for pleasure craft | 1, 2 |
| Ferrite microwave devices: | |
| isolators, circulators, switches, amplitude modulators, etc. | 7 |
| Field Engineering | 3 |
| Filters: | |
| magnetic | 1 |
| magnetostrictive | 5 |
| Fire-control systems, infrared and radar | 4, 8 |
| Fish finders — *see* Marine Products | |
| Flowmeters, acoustic | 4 |
| Fluorochemical transformers | 1 |

| PRODUCTS | DIVISION |
|---|---|
| Gas (fume) detectors, marine | 1 |
| Generators: | |
| electrostatic | 1 |
| microwave power | 1 |
| microwave signal | 8 |
| noise, wide-band | 1 |
| Guidance and control systems, missile | 4, 8 |
| Gyros, miniature airborne | 8 |
| Hardware — *see* Components, mechanical | |
| Heating equipment, microwave: | |
| ovens and components, diathermy units, special industrial, laboratory generators | 1 |
| High-temperature materials: | |
| plastic (ablative) | 11 |
| Pyrographite and related materials | 11 |
| insulated wire | 5 |
| Impact grinders, ultrasonic | 1 |
| Industrial equipment — *see especially* Heating, Ultrasonics, Relays, microwave; Power supplies, Welding, Tubes | |
| Infrared — *see* Tubes, Guidance and control systems, Fire-control systems, Scanners, Viewers | |
| Instrumentation systems | 4, 8 |
| Insulation testers | 1 |
| Insulators — *see* Ceramic products | 7 |
| Inverters, power | 1 |
| Jacks, test | 5, 2 |
| Knobs, control | 5, 2 |
| Lamps, panel | 2 |
| Liquid treatment units (sonic oscillators) | 1 |
| Machine tools, ultrasonic (impact grinders) | 1 |
| Magnetic components: | |
| transformers, (fluorochemical, pulse, etc.), filters, coils, chokes, magnetic amplifiers, inductors, spectrum analyzers | 1 |
| delay lines, shift registers, magnetostrictive filters. *Also see* Power supplies | 5 |
| Magnetizers | 1 |

RAYTHEON

# PRODUCTS AND SERVICES INDEX *continued*

RAYTHEON

**RAYTHEON COMPANY**
**WALTHAM, MASSACHUSETTS**

Printed in U.S.A. Form 0105

RAYTHEON

TECHNICAL INFORMATION SERVICE

# Technical Information Bulletin

RAYTHEON COMPANY

INDUSTRIAL COMPONENTS DIVISION

RECORDING STORAGE TUBES - STORAGE SCREEN MODULATION WRITING MODE

PRINCIPLES OF OPERATION

When an electron beam strikes any material, secondary electrons are emitted. The quantity of secondary electrons emitted is a function of the velocity of the primary electron beam and the characteristics of the material.

The secondary electron emitting surface in the Recording Storage Tube is a dielectric that has been deposited on a metal mesh or screen. Figure 1 illustrates this storage screen mesh. This screen, in the highest resolution types, has more than 2000 cross wires across its diameter.

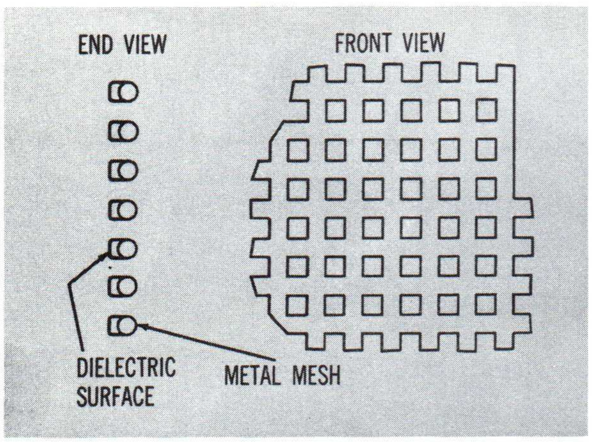



FIG. 1 — Magnified section of storage screen

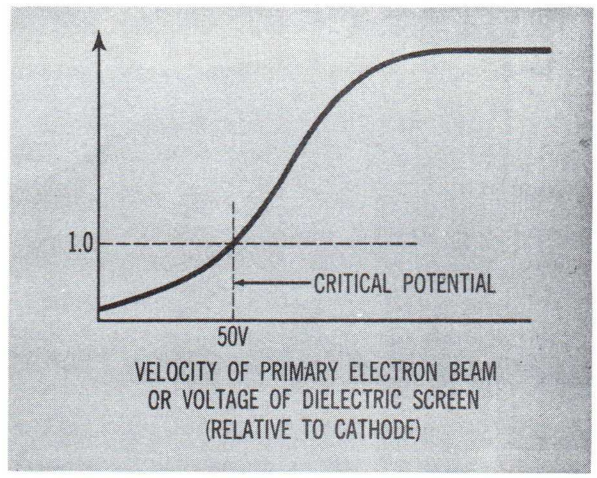



FIG. 2 — Secondary emission characteristic of recording storage tube dielectric

Figure 2 shows the characteristic curve for secondary to primary emission ratio for the dielectric material used.

Since the velocity of the electron beam will be proportional to the voltage on dielectric material, the abscissa of velocity in Figure 2 can be voltage. The crossover, called critical potential, where the secondary to primary ratio is unity occurs at approximately 50 volts.

Using the secondary-emission characteristic shown by Figure 2, the dielectric screen surface can be discretely charged or discharged as a function of the potential on the metal screen and the position and magnitude of the primary electron beam.

The various modes of operation are described as follows:

ERASE: To prepare the storage screen for subsequent writing in this type of operation, it is necessary to remove all electron charge from the surface of the dielectric. This is accomplished by scanning the storage screen dielectric in the area to be erased with an unmodulated electron beam. The storage screen mesh is operated at a voltage well above critical potential and normally at the same potential as the decelerator screen. Since the secondary to primary emission ratio is greater than unity at this high potential, the dielectric surface becomes completely discharged of any electrons that may be stored on its surface. In this erase mode, the potential of the dielectric surface becomes equal to the potential on the metal portion of the storage screen mesh and, therefore, there is no voltage existing across the dielectric.

PRIME: This mode of operation may or may not be necessary, depending on the type of written information to be stored. If the information to be stored is available in a continuous type of information, such as a television scan, it is not required. However, if it is in the form of randomly written character or symbol storage, it may be required.

Priming is accomplished by scanning the storage screen dielectric with an unmodulated beam and the storage screen mesh is operated at a voltage well below critical potential. Since the secondary to primary emission ratio is less than unity, the dielectric surface can store electrons and become negatively charged uniformly to electron-gun cathode potential. Typical storage screen voltage for prime with this type of operation is +10 volts.

WRITE: "Writing" of the charge pattern is accomplished by modulation of the storage screen element with the information to be written. Simultaneously, a continuous electron beam is deflected and positioned to store the information on the dielectric. The static or dc potential on the storage screen is the same dc value as that used in the prime mode described above and the reading mode described below. If a writing video voltage of 5 volts is applied to the storage screen in this writing process, (for a total instantaneous voltage of 15 volts) the dielectric surface will be more negatively charged at the particular position where the electron beam dwells. The dielectric surface can be charged to cathode potential, because, as in prime mode described above, the secondary to primary emission ratio is less than unity. In this writing mode, the surface of the dielectric can be discretely charged more negatively as determined by the position of the electron beam at any particular instant. A complete charged pattern can therefore be established on the dielectric.

READ: Once a charged pattern has been written in, it can be read out by scanning the storage screen with an unmodulated beam. The storage screen metal is operated at 10 volts nominally. The dielectric surface with its electron charged pattern is now actually negative with respect to the electron gun cathode, except in those areas where no information has been written. In these areas the cathode to dielectric potential is zero. Depending on the charged pattern, the electron beam is modulated as it passes through the storage screen holes to the collector. See Figure 3.

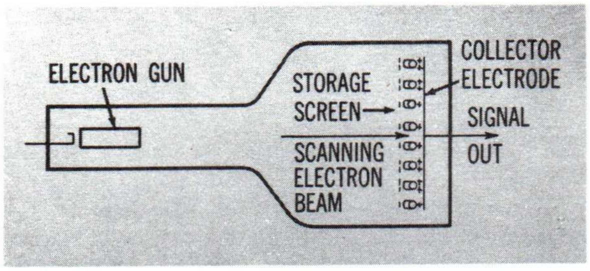



FIG. 3 — Simplified drawing of single gun tube — reading mode

By operation in the writing mode with large video signals on the storage screen, the most negative areas that are established on the dielectric can completely cut off the electron beam from the collector and thus the maximum signal-level of written information is established. Various grey shades will appear in any areas where the dielectric is less negative. The output signal at the collector is amplified, and can be used for further processing or displayed on a cathode ray tube.

Long storage time is possible because the storage dielectric in the read mode is negative with respect to the electron gun cathode and, therefore, the electron beam does not strike the dielectric surface.

Extremely good position registration between written and read-out information is possible in this operation of the Recording Storage Tube. The information that is stored on the dielectric is accomplished at essentially the same electron beam velocities that exist during the read-out mode. There is, therefore, essentially identical electron beam paths between the writing and reading modes and no apparent shift in position or time reference.

## Scan-Conversion Using Storage Tubes

This is a re-issue of a previous bulletin. The information is current and of value now as a refresher.

The term "scan-conversion" has recently gotten the connotation of converting PPI radar information into a constant brightness television-type display using a dual-gun storage tube. This is, of course, the F.A.A. application and, in addition, is of interest to many branches of the Service. Scan-conversion is broader than this, however. Another form is "slow-down video", where a television-type picture is converted into a low-frequency signal which can be passed over telephone lines and then reconverted into a display. Conversion of sonar information into a pictorial display with read-out in television fashion, is again another form of scan-conversion. Then again, it is frequently desirable to take information and speed it up in time or convert it into higher frequency data. These examples are only a few of the possible scan-converter applications for storage tubes.

The fundamental link between these differing applications is the desire to take a certain type of information, record it in a storage device, and then read it out in a different form or time sequence than that used in recording it. The input information to the storage device may be a picture written-in in the form of radial lines, in the form of a spiral pattern, in the form of television lines, or in the form of discrete dots fed to the storage device from a computer with the location of these dots being indicative of the location of radar objects. The output is read using a different scan type or speed.

A single-gun tube can be used for scan-conversion if it is possible to use time-sequencing of writing, reading, and erasing/priming. In the dual-gun versions, simultaneous reading, writing and erasing of information can be accomplished readily.

The question as to whether a specific application should use a single-gun storage tube or a dual-gun storage tube is frequently difficult to resolve. Where there is ample time such that writing can be accomplished and then reading can be begun later, a single-gun storage tube may prove to be the least expensive approach to scan-conversion. This is frequently the case in "slow-down" video applications where it is desired to transmit only a single picture over the telephone lines once every few minutes. It is more obvious that, where it is desirable to simultaneously write new information while old information is continuously being read-out in television form, such as in the F.A.A. Bright Display application, a dual-gun storage tube is called for.

Some of the important criteria to study in discussing whether a single-gun or a dual-gun storage tube should be used for a specific application are as follows:

1. In applications where very substantially different scan speeds are used for writing and reading, although a single-gun storage tube may be possible from the standpoint of sufficient time available between writing and reading, it is possible that a dual-gun storage tube may be required because of deflection yoke limitations. That is, a deflection yoke designed for very slow, linear scans may be incapable of deflecting fast enough for a television-type read-out scan. In addition, it is difficult to design deflection circuitry that will pass good, linear scans for both fast and slow scanning speeds. With a dual-gun storage tube, completely independent deflection coils and deflection circuitry can be used for writing and reading. It must be noted, on the other hand, that with the dual-gun storage tube, two deflection coils and two sets of deflection circuitry are needed - thus this approach may be more expensive than using a single-gun tube.

2. Many applications require extreme precision of reproducibility of the pattern written into storage. For example, if it is necessary to determine the range of a radar target very precisely or read out from the stored display, any errors occurring in scan linearity or positional accuracy may be very serious. In a dual-gun system, two deflection circuits are used. In addition, there are two electron guns - each of which may have inherent errors in beam-positioning. With a single-gun storage tube, errors caused by the electron gun or by deflection circuitry are frequently self-canceling since the same gun is used for writing and reading. Thus better "tracking" or accuracy is frequently obtained using a single-gun storage tube. (For optimum tracking, a special mode of operating a single-gun storage tube, called "storage-screen modulation", will normally be used. Information concerning this mode of operation will be made available in a future Product Information Bulletin).

3. Where it is desirable to continuously add new information to a written pattern, and especially where it is desirable to fade gradually the old information so that moving the targets will appear as a bright dot with a fading trail behind it, the dual-gun storage tube is ideally suited inasmuch as gradual erase can be accomplished by simply setting the collector voltage of the storage screen such that it is only slightly more positive than the read-gun cathode voltage. On the other hand, a single-gun storage tube can be operated such that this same effect of target trails is obtainable. This can be done where sufficient dead time is available in the over-all writing-reading-erasing cycle such that the tube can be periodically switched into a "partial prime" mode with a complete scan of the storage surface while the tube is in that mode.

Many more applications involving scan-conversion could be discussed with specific recommendations given for each application, but such a discussion would be relatively fruitless inasmuch as the requirements of an individual system may make necessary a specific solution to the problem of scan-conversion. It is, therefore, advisable for any potential user of storage tubes to discuss their application in detail with a qualified expert in the field before deciding exactly how they will design their system. For this reason, we advise that our sales engineers contact the storage tube product specialist or an engineer in the Storage Tube Department whenever a customer is in doubt as to the usefulness of a recording storage tube in his application or whether the single-gun or dual-gun version is best suited to the task.

A. S. Luftman

RAYTHEON technical information
Excellence in Electronics
BULLETIN



June 1958

ENG — 1

T.P.D.

(7)

# THE "AMPLITRON"

The "Amplitron", developed by Raytheon is a new microwave device. It offers high operating efficiency (50-70%), simple construction, nominal gain, light weight, and relatively low operating voltage for the power involved. It can serve as an r.f. power booster for pulsed radars now in existence, or as the high power stage of radars under development.

The "Amplitron" requires no electrical or mechanical adjustments to operate over its bandwidth when operated in conventional line type radar modulators. When added to an existing system therefore, the radar frequency may be fixed or variable within this range. When used in moving target indicator (MTI) radars, the "Amplitron" introduces little change in the frequency spectrum produced by the radar. Anode current or voltage variations have very little effect on the total phase shift. This results in low phase pushing, and excellent input spectrum reproduction under ripple and slow rise time pulse conditions.

The "Amplitron" is a two-way device. R.F. energy introduced at the input terminal is amplified at the output, while a received signal passes back through the "Amplitron" with essentially no attenuation. This makes duplexing possible at the "Amplitron" input. In most cases therefore the duplexer serving the radar to which the "Amplitron" is added can be used without modification.

MTI application of the "Amplitron" is discussed in an article by Mr. Thomas A. Weil of Raytheon's Equipment Engineering Laboratory.

Additional information concerning this device may be obtained by contacting the Raytheon Manufacturing Company, Power Tube Division, Application Engineering Department, Waltham, Mass.

## APPLYING THE AMPLITRON AND STABILOTRON TO MTI RADAR SYSTEMS

The Amplitron is a basically new type of microwave amplifier offering compactness, high power, high efficiency, coherent operation, and wide bandwidth. A typical L band Amplitron is shown in Figure 1. This tube provides 10 db of

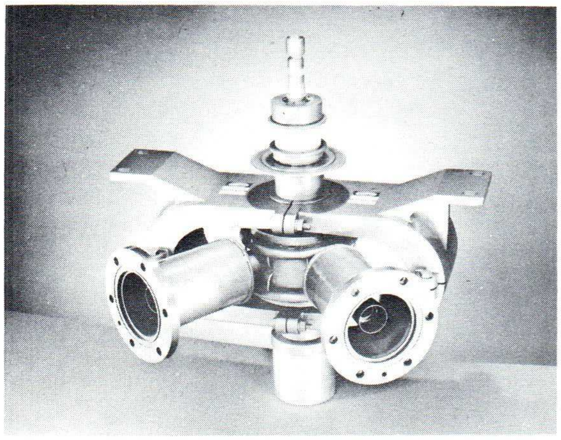


Fig. 1 L Band Amplitron.

gain from 1250 to 1350 megacycles and a peak power output of 4 megawatts. This frequency range is covered without tuning of any sort, so that it can serve as the high power stage of radars in development or as an effective RF power booster for radars already in existence. Typical Amplitron efficiency is 60 percent. Amplitron stability is given in terms of a phase pushing figure, which states how much the phase delay through the Amplitron changes for a given change in anode current.

The same basic device can also be used as a stabilized oscillator, called a Stabilotron, by the addition of suitable feedback and a stabilizing cavity, as shown in Figure 2. This Stabilotron

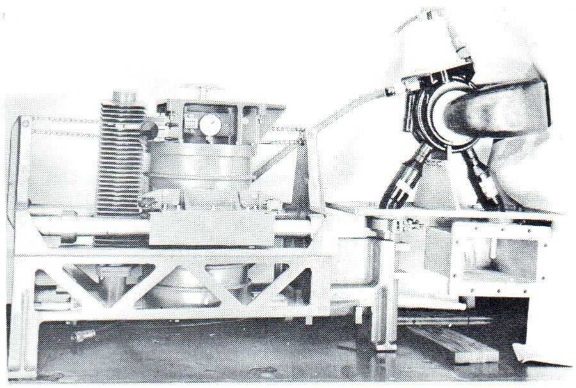


Fig. 2. L Band Stabilotron.

provides a peak power output of 600 kilowatts over its tuning range of 1250 to 1350 megacycles. Its stability is indicated in terms of a pushing figure, which states how much the output frequency will shift for a given change in anode current.

## MTI Systems

To see how much frequency variation is tolerable in a Stabilotron or how much phase variation is tolerable in an Amplitron when one or both of these are to become part of a radar transmitter, we must examine how a modern coherent MTI (Moving Target Indicator) system extracts its information from the received signals. The term coherent, as used here, indicates that the system will make use of the phase information in the received signal rather than the amplitude information; this type of system is now the most common type, and this paper will be limited to such systems. These systems are basically as shown in Figure 3.

### Pulsed Amplifier System

In the first system shown, the transmitted pulse consists of an amplified sample of the continuously running reference oscillator. The output of the phase detector will be a pulse at the time when the echo signal is received; and the amplitude of the pulse will depend on the exact phase angle of the reference oscillator at which the received signal begins to return. This system thus measures the time required for an echo to be received, in terms of cycles of the reference oscillator, but is concerned only with the fractional part of a cycle beyond an integral number of cycles. The phase detector output

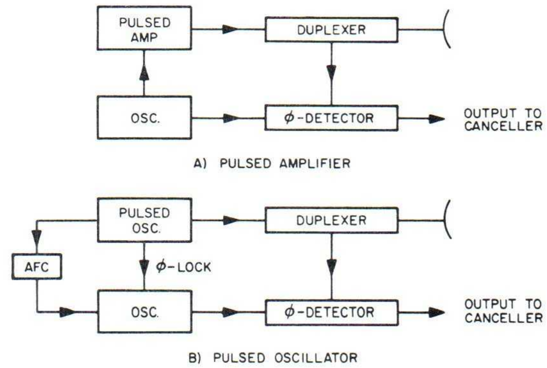



Fig. 3. Basic Coherent MTI Systems.

would change from maximum to minimum, for example, if the target moved a distance of a quarter of a wavelength toward or away from the radar; how this information is used will be shown later. It can be seen that this system is extremely sensitive to target motion, but it is therefore also very sensitive to any accidental variations taking place within the radar system. Since the amplifier shown is usually a chain of amplifier stages, there are many places for accidental variations to enter.

### Pulsed Oscillator System

The second system shown is actually much more common. Here another oscillator such as a magnetron or a Stabilotron is pulsed to produce the transmitter signal. In order for the phase information in the echo to be significant, this pulsed oscillator must bear a known phase relationship to the reference oscillator against which the echo will be compared. This is usually done by automatically controlling the frequency of the pulsed and reference oscillators to be the same and then phase locking the reference oscillator to the pulsed oscillator each time the transmitted pulse is produced. The result is then closely the same as if a sample of the reference oscillator had been amplified and transmitted.

### STALO, COHO

In practice, superheterodyne systems can be made much more stable and sensitive and are commonly used. The two basic systems just described are actually used as superheterodyne systems as shown in Figure 4. The STALO is a

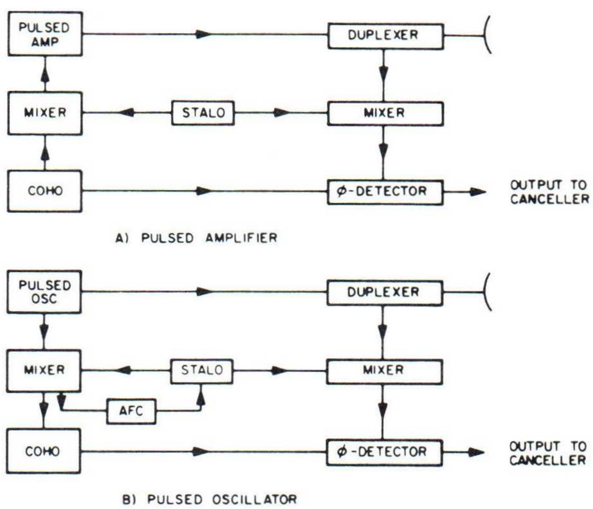



Fig. 4. Superheterodyne Coherent MTI Systems

stable local oscillator which, via the mixers, converts signals from RF to IF or vice versa. The COHO is a coherent (or reference) oscillator at IF, which, together with the STALO, provides the reference frequency in terms of which the time for echo returns is measured. In the pulsed oscillator system, the Automatic Frequency Control is applied to the STALO and the phase locking is more suitably applied to the COHO.

## Phase Detector

We may now look at the phase detector characteristic, as shown in Figure 5. The output of the phase detector depends on the phase angle between the reference signal and the received signal, as shown; it is convenient to think of vector diagrams as also shown, in which the phase detector output depends on the amplitude of the received signal vector component which lies along the reference vector. Three cases are shown: a strong fixed target, a moving target, and both together (occurring at the same range). The successive pulses out of the phase detector in each case will be as shown. In cases where a moving target is present, the phase detector output varies at the doppler frequency rate, as determined by the number of cycles of the reference oscillator by which the echo return time changes per second. The problem is to detect relatively weak moving targets in the presence

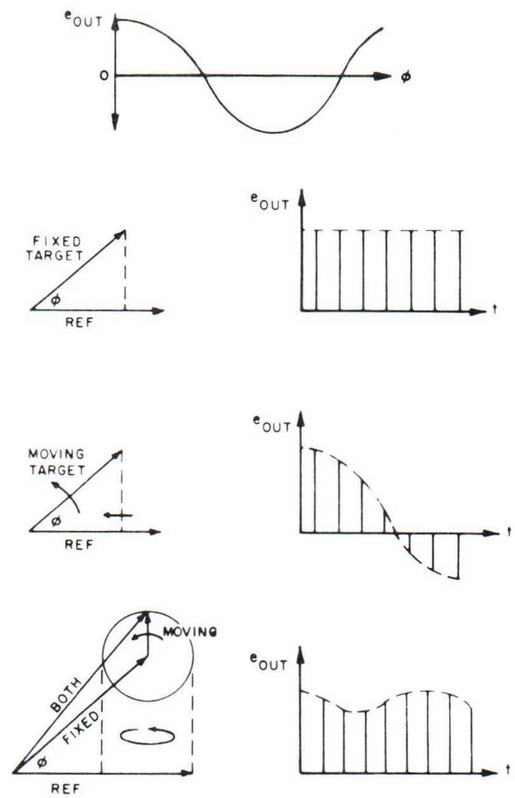



Fig. 5. Phase Detector Characteristic and Outputs from Fixed and Moving Targets.

of strong fixed targets which may occur at the same range, such as when an airplane flies over a city. The difficulty is that any instabilities in the radar system will modulate the phase angle of strong fixed targets exactly as if a moving target were also present, and the receiver will think that a moving target is present.

## Canceller

In an actual system the output of the phase detector is fed to a unit called a canceller, in which steady values of phase detector output at any range are rejected and the variations are retained. The overall performance of the system is described in terms of how well fixed targets are cancelled; these fixed targets are often called "clutter" because of their effect on a PPI presentation. The amount of residual variation left after cancellation of strong clutter is called "uncancelled residue". If the uncancelled residue is 40 db smaller than the maximum phase detector output, then this is called 40 db "cancellation ratio". This also means that a 40 db weaker moving target in the presence of the fixed target would cause the same amount of variation in the phase detector output. In order for the system to detect a moving target in the presence of the strong fixed target, however, the moving target must override the uncancelled residue by some noticeable amount, in the same way that an ordinary signal must override receiver noise level to be detectable with sufficient certainty, the ratio of the strength of this barely discernable moving target to the strength of the fixed target which has been cancelled has come to be called "sub-clutter visibility", and is the true measure of performance of an MTI system.

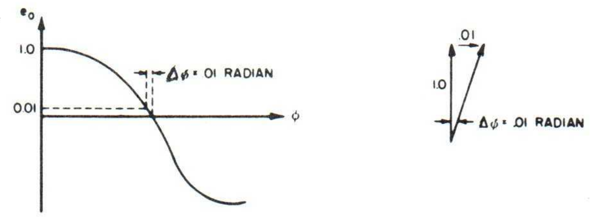



Fig. 6. Phase Change for Output of .01 of Maximum.

## Desired Performance

Before stability requirements can be established on the transmitter, the desired overall performance must be specified. It turns out that antenna scanning generally limits the obtainable cancellation ratio to something of the order of 30 or 40 db for practical MTI radar systems; and since the antenna must scan, this is an unavoidable limitation. But if antenna scanning is to be the only limitation, then the transmitter must be an order of magnitude more stable than this; that is, with the antenna not scanning, the transmitter must be sufficiently stable to permit obtaining 40 to 50 db cancellation ratio. For ease of calculation, it will be assumed for the moment that the allowable limitation on system cancellation ratio due to transmitter instabilities has been specified as 40 db, which is a voltage cancellation ratio of 100 to 1.

## Transmitter Instabilities

Since the transmitter basically serves merely to sample the target echo return time at regular intervals, and since the return time is measured in cycles of the reference oscillator, the way in which transmitter instabilities enter the problem is not immediately obvious. However, since moving targets are detected as doppler frequency variations in the phase detector output, then anything which causes the phase detector output to vary from pulse to pulse will be interpreted as a moving target. In order to obtain 40 db cancellation ratio for strong fixed targets, instabilities must not cause the phase detector output to vary by more than .01 of full output, as shown in Figure 6. At the point of maximum phase detector sensitivity to small changes, an output of .01 of maximum will be caused by a .01 radian change in phase, or 0.57 degrees.

## Pulse-to-Pulse Phase Changes

In the case of a pulsed amplifier transmitter, any change in the time it takes the signal to travel through the amplifier contributes directly to the time it takes for the echo to be received; it becomes clear that the time delay or phase delay of the pulsed amplifier must remain constant within 0.57 degrees of one RF cycle from pulse to pulse, if 40 db cancellation ratio is to be achieved. Whether this is difficult or not depends on the phase modulation sensitivity of the amplifier, as will be discussed later.

## Pulse-to-Pulse Frequency Changes

In the case of a pulsed oscillator transmitter, the automatic frequency control system insures that the STALO will follow changes in the pulsed oscillator frequency, but only on the average. Slow variations in transmitted frequency due to temperature drift, for example, will be followed by the STALO, but rapid variations in frequency from pulse to pulse such as would be caused by modulator ripple will not be followed. The COHO is phase locked to the pulsed oscillator on every pulse, but it is locked only in phase and not in frequency; after the transmitted pulse is over the locking ends and the COHO will continue to run at its own resonant frequency, which may be slightly different from that of the phase locking pulse. As a result, when the echo pulse is received, the slight difference in frequency will cause the output of the phase detector to vary during the pulse length, as the received phase angle gradually gets ahead of or behind the phase angle of the COHO, as shown in Figure 7. Since the COHO was locked to the tail end of the pulse, there will be no error at the tail, but the front end will be off by the phase angle resulting from the frequency difference times the pulse length; and averaged over the pulse length this

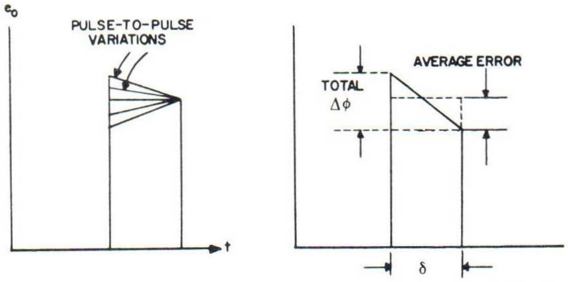


Fig. 7. Effect of Pulse-to-Pulse Frequency Variations on Phase Detector Output.

is equivalent to a fixed phase error of half this much. Thus, for 40 db cancellation ratio, the transmitted frequency of the pulsed oscillator must be steady within $.01/\pi \times \delta$ cycles per second. For a 2 microsecond pulse, for example, this would require the pulsed oscillator frequency to be stable within 1.6 kc, even though, for example, the carrier frequency may be 1300 megacycles. This is a short term stability of 1 part in $10^6$. Whether this is difficult or not depends on the frequency modulation sensitivity of the pulsed oscillator, as will be discussed later.

In practice, the bandwidth of the phase detector is usually tailored to the pulse width and steep waveforms as shown do not appear; however, these waveforms are useful for explanatory purposes, and the amplitude of the actual waveforms will correspond to the average amplitudes of the pulses shown here.

## Frequency Domain Approach

It is interesting to study the MTI stability problem also in the frequency domain. The spectrum of a pulsed transmitter is shown in Figure 8; it is a line spectrum, the lines being spaced

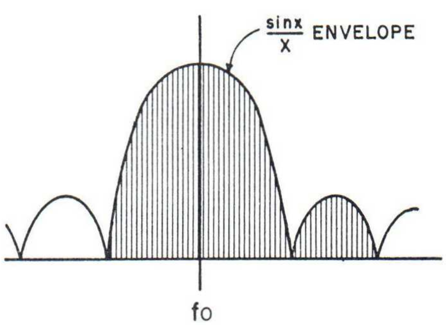


Fig. 8. Spectrum of Pulsed Transmitter

by the pulse repetition rate. The echo from a fixed target will be exactly the same, but the echo from a moving target will be very slightly shifted in frequency; the problem is to detect the moving target in the presence of a strong fixed target, as shown in Figure 9. Anything

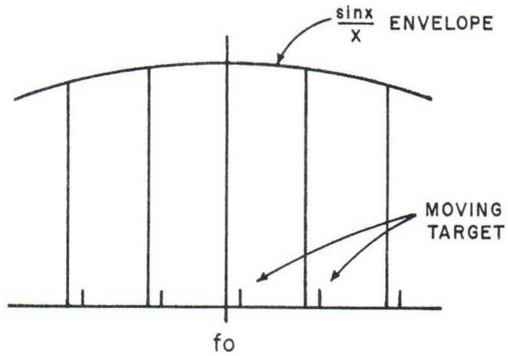


Fig. 9. Spectra of Fixed and Moving Targets.

which will cause fixed targets alone to have this same spectrum picture will deceive the receiver into thinking a moving target is also present. If a pulsed amplifier transmitter is phase modulated, sidebands will appear around each spectrum line, and the amplitude of the sidebands are, for small modulation index, just equal to half the modulation index itself. The modulation index for frequency modulation or phase modulation is given by

$$m = \Delta f/f_m = \Delta\phi.$$

The phase detector will respond to both the upper and lower sidebands, so that for 40 db cancellation ratio the two sidebands together must be no greater than a 40 db weaker moving target, or .01 as strong as the main spectrum lines of the fixed target. Since $m = \Delta\phi$, this again results in the requirement that the phase modulation of the pulsed amplifier be no greater than .01 radian.

This frequency domain approach is not easily extended to the pulsed oscillator case, because of the phase locking of the COHO which takes place on each pulse. Since phase errors due to pulsed oscillator frequency error can only accumulate for one pulse length, a reasonable estimate may be made by interpreting $f_m$ as $1/\delta$, where $\delta$ is the pulse width. The result of requiring $\Delta f/f_m = .01$ for 40 db cancellation ratio then gives $\Delta f = .01/2\pi\delta$, which is very close to the result previously obtained. The stability requirement on the STALO, it can easily be seen, is much more severe because phase errors due to frequency modulation of the STALO can accumulate from the time the pulse is transmitted until the echo is received.

## Amplitude Modulation

At this point a word should be said about variations in the amplitude of successive transmitted pulses. It is true that AM of this sort would also produce sidebands around the transmitted spectrum lines; but it is assumed that the receiver, which is interested only in phase information, will have a limiter preceding the phase detector. In practice, by the time the other stability requirements on the transmitter are met, the AM is usually very small; and the receiver generally uses a limiter anyway, for dynamic range reasons. Without a limiter, 1% AM would cause a 1% variation in phase detector output and would limit the obtainable cancellation ratio to 40 db.

## Combination Systems

A pulsed oscillator system may also be used followed by a pulsed amplifier. The usual stability requirements will apply to the pulsed oscillator, but if the locked COHO, which must be included in pulsed oscillator systems, is locked to the transmitted pulse sampled after the amplifier, then any phase variations from pulse to pulse in the amplifier will automatically be taken into account by the locked COHO. If the COHO is locked to a sample of the transmitted pulse before the amplifier, then the usual stability requirements will still apply to the amplifier.

Another interesting combination system can also be considered. As described above, a locked COHO will allow for pulse-to-pulse phase variations in an amplifier, and there is no reason why a locked COHO cannot be used with a basic pulsed amplifier system even without a pulsed oscillator as shown in Figure 10.

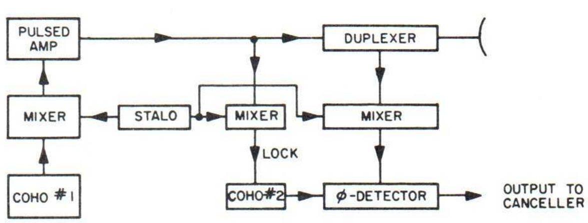



Fig. 10. Pulsed Amplifier Plus Locked COHO.

This system retains all the features of the pulsed amplifier system of Figure 4 but is now insensitive (at least to a first order) to phase variations from pulse to pulse in the amplifier. Whether this system is worthwhile or not depends on the cost and difficulty of making a good locked COHO compared with that of preventing phase modulation in the pulsed amplifier transmitter.

## Further Transmitter Instabilities

In addition to pulse-to-pulse frequency or phase variations, there are other undesirable effects which may appear in transmitters for MTI systems: intra-pulse modulation, time jitter, and pulse width jitter, as described below.

## Intra-Pulse Variations

In a pulsed amplifier transmitter, variations in phase delay may also take place during the pulse length. These intra-pulse variations will be reproduced on reception, but since the bandwidth of the receiver is tailored to the pulse width, the receiver will not follow these variations. Instead, the phase detector output will be the average of what it would be if it could follow the variations. If these variations are large, the maximum output available from the phase detector will be reduced, as shown in Figure 11. This

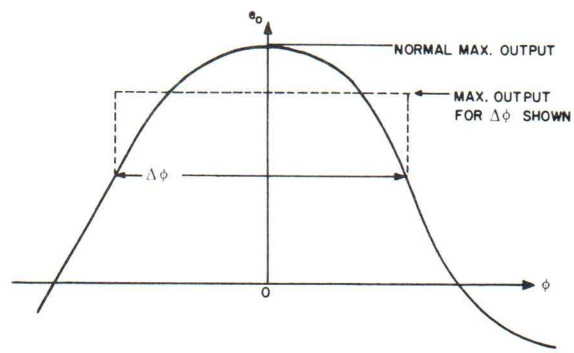



Fig. 11. Reduction in Output Resulting from Intra-Pulse Phase Variation.

will cause a loss in system sensitivity which should be minimized by keeping the intra-pulse phase variation below 1 radian. If the intra-pulse phase variation is a linear change during the pulse length, then it is equivalent to a shift in transmitted frequency of $\Delta\phi/2\pi\delta$ cycles per second, where $\Delta\phi$ is expressed in radians; that is, a slightly mistuned STALO in a pulsed oscillator system will also cause a loss of sensitivity by causing a phase change during the received pulse length. Even if the STALO is exactly tuned to the average pulsed oscillator frequency, a large enough frequency change during the transmitted pulse can again cause loss of sensitivity. If the frequency change is linear during the pulse, the resulting phase change will be parabolic; in any case, the total phase change, sometimes called phase runout, should be held to approximately one radian or less. This can be expressed approximately as $2\pi\Delta f\delta<1$, where $\Delta f$ is now the intra-pulse frequency change.

## Time Jitter

Time jitter in an MTI system must also be held within tight limits. The canceller which follows the phase detector will only cancel signals that do not vary in amplitude or in time of appearance. A delay line canceller works by storing the echo returns from one pulse and subtracting them from the returns from the next pulse; and if the second pulse is a little late, as shown in Figure 12, two spikes will be left over.

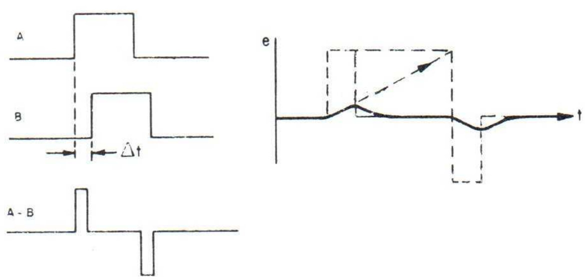



Fig. 12. Effect of Time Jitter on Cancellation.

Actually, the bandwidth of the canceller is tailored to the pulse width, so that the canceller output will not build up to full amplitude in such a small fraction of a pulse width; it is more likely, in fact, to be headed toward full output in about one pulse width, so that the voltage amplitude which does build up will be proportional to the amount of pulse misalignment. The uncancelled residue which will result, therefore, will be equal to the time jitter divided by the pulse width. A factor of two should probably be included to cover the fact that there is misalignment at both the beginning and end of the pulse. This means, for example, that time jitter in the firing time of the modulator and pulsed transmitter must be held within .01 microsecond in a system using a 2 microsecond pulse in order to permit 40 db cancellation ratio.

## Pulse Width Jitter

Pulse width jitter may also occur, and in a similar fashion will result in imperfect cancellation. Pulse width jitter could be caused, for example, by a variation in the amplitude of the pulse modulator output from pulse to pulse, together with a non-linear load such as a magnetron, Stabilotron, or Amplitron; a higher amplitude of modulator pulse will cause the non-linear load to fire sooner during the rise and turn off later during the fall of the modulator pulse. Pulse width jitter must be held within the same limits as time jitter; however, the requirements on phase or frequency stability usually require lower modulator ripple than pulse width jitter does, so that pulse width jitter is seldom a major limitation on cancellation ratio.

## Summary of Instabilities

The preceding stability requirements are tabulated in Figure 13 in a form which will permit calculating the cancellation ratio (in db) to which the system will be limited by each of the instabilities listed.

1. LIMITATIONS ON MTI CANCELLATION RATIO DUE TO TRANSMITTER
   - A. FM OR PHASE MODULATION
     - PULSED OSCILLATOR: $-20 \log \pi \Delta f \delta$
     - PULSED AMPLIFIER: $-20 \log \Delta \phi$
     - PULSED AMPLIFIER PLUS LOCKED COHO: ——
   - B. TIME JITTER: $-20 \log 2 \Delta t / \delta$
   - C. PULSE WIDTH JITTER: $-20 \log \Delta t / \delta$
2. INTRA-PULSE FREQUENCY OR PHASE CHANGE LIMITS TO AVOID LOSS OF SENSITIVITY:
   - PULSED OSCILLATOR: $2\pi \Delta f \delta < 1$
   - PULSED AMPLIFIER: $\Delta \phi < 1$

Fig. 13. Summary of Transmitter Instabilities.

Based on Figure 13, some interesting generalizations may now be made:

1. The time jitter limitation becomes harder to meet in short pulse systems.

2. The pulse-to-pulse frequency stability required of a pulsed oscillator becomes harder to meet in high carrier frequency and long pulse systems; so does the intra-pulse frequency stability requirement.

3. The pulse-to-pulse phase stability required of a pulsed amplifier is independent of the carrier frequency and the pulse length; so is the intra-pulse phase stability requirement.

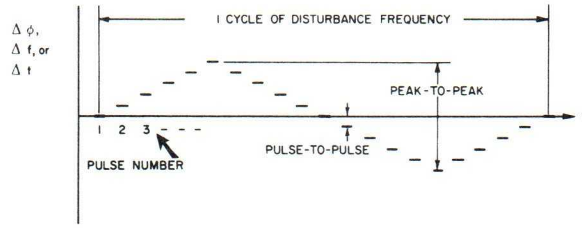



Fig. 14. Comparison of Peak-to-Peak and Pulse-to-Pulse Instabilities.

## Effect of Disturbance Frequency

So far, pulse-to-pulse instabilities have been discussed on the basis of any single pair of pulses. In an actual group of pulses, as shown in Figure 14, the peak-to-peak variation may exceed the pulse-to-pulse variation, and the variations will be occurring at one or a combination of modulation or "disturbance" frequencies, such as 120 cycle ripple. Whether the pulse-to-pulse, peak-to-peak, or some rms value of the instabilities is significant depends on the kind of canceller actually used and its sensitivity to the particular disturbance frequencies. It would be most conservative for the transmitter design to be based on holding the peak-to-peak values of the instabilities within the limits given in Figure 13; if more accurate allowances are needed, Figure 15 will provide a guide in any particular case. The canceller frequency responses shown are various compromises aimed toward rejecting fixed or very slowly moving targets, which consist of frequencies at or near the pulse repetition rate, and yet responding with full sensitivity to all moving targets.

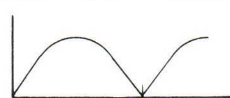
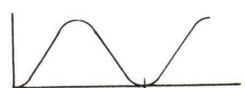
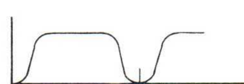
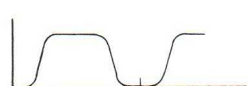
| SIGNAL CANCELLER: | NUMBER OF PULSES COMPARED: | SYSTEM SENSITIVITY TO DIFFERENT DISTURBANCE FREQUENCIES: | THIS RESULTS BECAUSE THE CANCELLER OUTPUT DEPENDS UPON: |
|---|---|---|---|
| DELAY LINE CANCELLER: | 2 |   | MAGNITUDE OF PULSE-TO-PULSE VARIATIONS. |
| 2 DELAY LINE 3 PULSE CANCELLER | 3 |   | MAGNITUDE OF VARIATIONS IN A+C−2B. |
| DELAY LINE CANCELLER WITH FEEDBACK | SEVERAL |   | MAGNITUDE OF VARIATIONS AVERAGED OVER SEVERAL PULSES. |
| RANGE GATE FILTER SYSTEM | USUALLY PRR TIMES TIME ON TARGET |   | TOTAL RMS VARIATION AFTER LOW FREQUENCIES ARE REMOVED |

Fig. 15. Signal Canceller Frequency Sensitivities.

| TUBE TYPE | TYPICAL JITTER MICROSECONDS | TYPICAL SENSITIVITY | STABILITY VS LINE TYPE MODULATOR POWER SUPPLY RIPPLE |
|---|---|---|---|
| MAGNETRON | .001 TO .050 | $\frac{\Delta f}{f} = .001 \text{ TO } .003 \left(\frac{\Delta I}{I}\right)$ | $\frac{\Delta I}{I} = 2 \frac{\Delta E_{DC}}{E_{DC}}$ |
| STABILOTRON | .002 | $\frac{\Delta f}{f} = .0004 \frac{\Delta I}{I}$ | $\frac{\Delta I}{I} = 2 \frac{\Delta E_{DC}}{E_{DC}}$ |
| AMPLITRON | .001 DRIVEN | $\Delta\phi = 0.4°$ FOR 1% $\Delta I/I$ | $\frac{\Delta I}{I} = 2 \frac{\Delta E_{DC}}{E_{DC}}$ |
| KLYSTRON | 0 AS AMP | $\frac{\Delta \phi}{\phi} = -\frac{1}{2}\frac{\Delta E}{E}$ $\phi \approx 5\lambda$ <br> $\Delta\phi = 9°$ FOR 1% $\Delta E/E$ | $\frac{\Delta E}{E} = 0.8 \frac{\Delta E_{DC}}{E_{DC}}$ |
| TWT | 0 AS AMP | $\frac{\Delta \phi}{\phi} = -\frac{1}{3}\frac{\Delta E}{E}$ $\phi \approx 10\lambda$ <br> $\Delta\phi = 12°$ FOR 1% $\Delta E/E$ | $\frac{\Delta E}{E} = 0.8 \frac{\Delta E_{DC}}{E_{DC}}$ |
| TRIODE | 0 AS AMP | $\Delta\phi = 0.5°$ FOR 1% $\Delta I/I$ | $\frac{\Delta I}{I} = 1.0 \frac{\Delta E_{DC}}{E_{DC}}$ |
| TETRODE | 0 AS AMP | $\Delta\phi = 0°$ TO $0.5°$ FOR 1% $\Delta I/I$ | $\frac{\Delta I}{I} = 1.0 \frac{\Delta E_{DC}}{E_{DC}}$ |

Fig. 16. Tube Modulation Sensitivities and Relationships to Modulator Ripple.

## Modulation Sensitivities of Tubes

In order to calculate tolerable modulator ripple and tolerable intra-pulse voltage or current variation, two more relationships must be known: frequency or phase pushing versus anode current or anode voltage; and by what factor anode current or voltage varies compared with modulator ripple. These relationships are given in Figure 16. It can be seen that the Stabilotron is an order of magnitude less sensitive than a magnetron to anode current variations, and that Amplitrons, Triodes, and Tetrodes are an order of magnitude less sensitive than klystrons and TWT's. The relationships to ripple in a line type modulator are based on the fact that for small changes in load impedance a line type modulator delivers constant power, so that a 1 percent increase in modulator DC voltage will force a 2 percent increase in load power, even if the load impedance changes as a result. Thus, even though the volt-ampere characteristic of a crossed-field device such as a magnetron, Stabilotron, or Amplitron is very steep, a 1 percent increase in modulator DC voltage will only cause a 2 percent increase in the anode current of a crossed-field type load. The factor for three-halves-power drift-tube devices is 0.8, and for linear class C amplifiers it is 1.0, as shown. Hard tube modulators cannot be generalized; the factors will depend on the dynamic internal impedance of the hard tube modulator compared with the dynamic impedance of the load.

## Examples of Stability Calculations

Specific examples can now be calculated, based on Figures 13, 15, and 16.

### Example 1

Pulsed Stabilotron Oscillator and Amplitron amplifier.

Frequency: 1300 mc.

Pulse length: 2 microseconds.

PRR: 360 pps

Required system cancellation ratio: 40 db.

Assume that any one transmitter instability must permit 50 db cancellation ratio.

A. Tolerable pulse to pulse frequency change: (Stabilotron stage)

$$\pi \, \Delta f \, \delta = .003 \text{ (50 db)}$$

$$\Delta f = \frac{.003}{\pi \times 2 \times 10^{-6}} = 480 \text{ cps max.}$$

Tolerable modulator ripple: (Stabilotron stage)

$$\% \frac{\Delta I}{I} = \frac{\Delta f}{f} \frac{100}{.0004} = \frac{480 \times 100}{1.3 \times 10^{9} \times 4 \times 10^{-4}} = 0.1\%$$

$$\% \frac{\Delta E_{DC}}{E_{DC}} = \frac{1}{2} \frac{\Delta I}{I} = .05\% \text{ ripple.}$$

If the modulator power supply is 60 cycle three phase full wave rectified, then the ripple will be 360 cps and will be ignored by the canceler. Any 60, 120, or high frequency ripple must be held to this .05% limit, however.

B. Tolerable time jitter: (both stages)

$$2\Delta t / \delta = .003$$

$$\Delta t = \frac{.003\delta}{2} = .0015 \times 2 \times 10^{-6} = .003 \text{ microseconds}$$

C. Tolerable intra-pulse FM: (Stabilotron stage)

$$2\pi \, \Delta f \, \delta < 1$$

$$\Delta f = \frac{1}{2\pi\delta} = \frac{1}{4\pi \times 10^{-6}} = 80 \text{ KC.}$$

Tolerable current ripple during the pulse:

$$\% \frac{\Delta I}{I} = \frac{\Delta f}{f} \frac{100}{.0004} = \frac{8 \times 10^{-4} \times 100}{1.3 \times 10^{9} \times 4 \times 10^{-4}} = 15\%$$

D. Pulse to pulse phase change: (Amplitron stage)

Allowed for by locked coho.

E. Intrapulse phase change:

$$\Delta\phi < 1 \text{ radian or } 57^\circ$$

$$\Delta\phi = 0.4^\circ \text{ for } 1\% \; \Delta I/I$$

20% $\Delta I/I$ produces only 8° change.

In this example, use of a Stabilotron rather than a magnetron permits levels of modulator ripple and intra-pulse current ripple that can more easily be achieved in practice. The amplitron serves to boost the system power by 10 db without imposing any severe requirements on its high power modulator.

Example 2

Pulsed amplifier chain of TWT's driving an Amplitron output stage.

Frequency: not important.

Pulse length: 4 μsec.

PRR: Several to be used.

Required system cancellation ratio: 40 db

Again, assume any one transmitter instability must permit 50 db cancellation ratio.

A. Tolerable pulse-to-pulse phase change:

$$\Delta\phi = .003 \text{ radian or } 0.17 \text{ degrees.}$$

Assume 0.1° tolerable per stage.

Tolerable Amplitron modulator ripple:

$$\% \frac{\Delta E_{DC}}{E_{DC}} = \frac{1}{2} \frac{\Delta I}{I} = \frac{1}{2} \frac{0.1}{0.4} = 0.12\%$$

Tolerable TWT modulator ripple:

$$\% \frac{E_{DC}}{E_{DC}} = \frac{1}{0.8} \frac{\Delta I}{I} = \frac{1}{0.8} \times \frac{0.1}{12.0} = 0.01\%$$

B. Tolerable time jitter:

$$2 \Delta t / \delta = .003$$

$$\Delta t = \frac{.003\delta}{2} = \frac{.003 \times 4 \times 10^{-6}}{2} = .006 \text{ microseconds.}$$

C. Tolerable intra-pulse phase change:

$$\Delta\phi < 1 \text{ radian or } 57^\circ$$

Amplitron intra-pulse current variation:

As before, even 20% $\frac{\Delta I}{I}$ produces only 8° change.

TWT intra-pulse voltage variation:

$\Delta\phi = 12°$ for 1% $\Delta E/E$.

$\frac{\Delta E}{E}$ must be held to less than 5% during the pulse for less than 60° $\Delta\phi$.

In this example the use of an Amplitron as the high power stage or stages increases the transmitter power significantly without placing any severe requirements on the high power modulator.

Measured Results

A breadboard model and a prototype system using a pulsed 1300 megacycle Stabilotron oscillator transmitter have been built and tested. Measured stability was as follows:

Time jitter: less than .002 microseconds; this was the limit of the measuring equipment.

Pulse-to-pulse frequency stability: less than 1 kc peak to peak; this was the limit of the measuring equipment.

Intra-pulse frequency stability: approximately 10 kc.

A demonstration Stabilotron-Amplitron system and a similar Magnetron-Amplitron system have also been tested. Although the modulator for the Amplitron had about 1 percent ripple, no deterioration of system MTI characteristics was detectable when the Amplitron was used to boost the system power output to about 4 megawatts.

A production model of an Amplitron booster stage to be added to existing radars is now being designed and should be in service in 1959. Several other systems using Amplitrons or Stabilotrons, some of them classified, are now in development. In each of these cases and in others to which Amplitrons and Stabilotrons may be applied, the transmitter and modulator stability requirements have been or may be calculated by the methods that have been discussed here.

Bibliography

Brown, W.C., "The Stabilotron: Performance Characteristics and Circuit Analysis". Raytheon Manufacturing Company Internal Memorandum, Microwave and Power Tube Operations, Waltham, Mass. October 1954, Unclassified

Brown, W.C., "Final Engineering Report, Magnetron Study Project; Volume I: Design and Development of the Platinotron, Amplitron, and Stabilotron", Signal Corps Contract No. DA-36-039-sc-56644, December 1955, Unclassified.

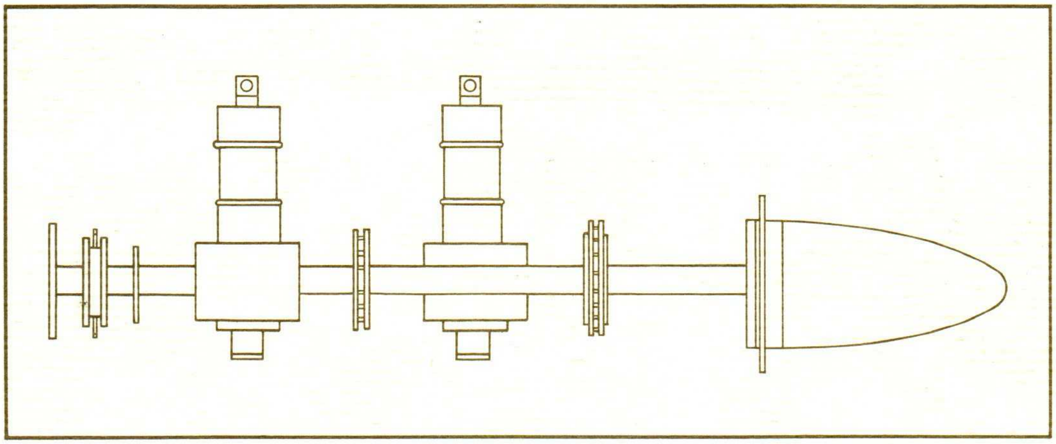
Brown, W.C., "Platinotron Increases Search Radar Range", Electronics, August 1957.

Brown, W.C., "Description and Operating Characteristics of the Platinotron- A New Microwave Tube Device", Proceedings of the IRE, September 1957.

# THE 425 KILOWATT SUPER POWER AMPLITRON

RAYTHEON

a state-of-the-art development



# Raytheon's 425 kw Super Power Amplitron-

*what it is . . .*

*how it has advanced the state-of-the-art . . .*

*where it may be used . . .*

The conventional Amplitron is recognized as the most efficient microwave power generator ever developed. It is a continuous-cathode crossed-field device used primarily to amplify signals at the output stages of microwave systems. Outstanding features of the Amplitron are conservation of primary power, compactness, low phase shift (and phase sensitivity), bandwidth on the order of 10%, gain or 10 db or more, low operating potential, and heater-less operation for many applications.

The Super Power Amplitron* employs a new, efficient method of removing dissipated power to effect a many-fold increase in rf power. At the same time, this tube maintains the desirable features of the conventional Amplitron. The combination of 425 kilowatts and 72% efficiency obtained simultaneously from this tube represents the highest CW power and efficiency ever obtained at 10 cms. The impact of this breakthrough on the rate of progress in microwave power generation is shown in the chart on Power Trends.

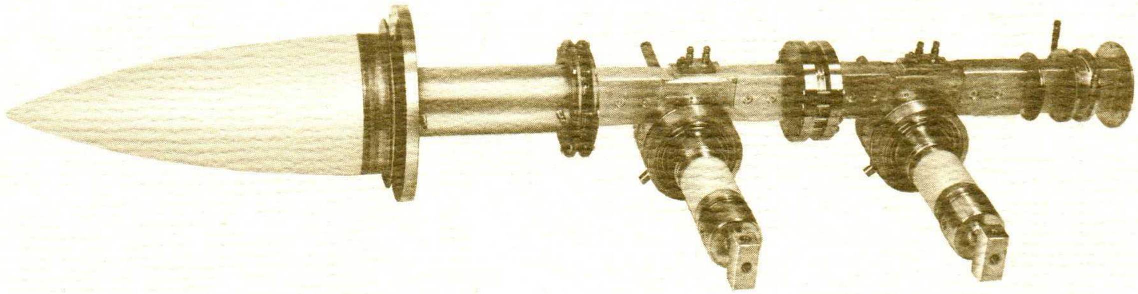
The Super Power Amplitron embodies several other advances in the state-of-the-art. For example, it employs a long-life, pure metal cathode which remains at room temperature under either start or operate conditions. In addition, the ogival-shaped ceramic output window solves the problem of handling large amounts of microwave power in waveguides by radiating directly into the antenna or load. The output configuration also can be designed to be used in conjunction with conventional waveguides.

The large amounts of efficiently-generated power made available by the new Super Power Amplitron development may be used to upgrade conventional applications of microwave power. Equally important, new types of applications for microwaves are made possible by the new power levels. For instance, high power microwave energy can be focused to produce a region of high energy density for heating and producing selective changes in plasmas and other materials. Also, because microwave energy can be focused and very easily and quickly controlled, it can be considered for use in industrial continuous flow processes.

Raytheon is now expending considerable effort to refine its present Super Power developments to make available devices suitable for an extremely wide range of general applications. We would be pleased to work with you on any of your application possibilities for super power at the present power levels. Or, let us assist you in planning future products and processes utilizing the even higher power levels that will be available soon.

* Developed by Raytheon under Government sponsorship.


**A FACILITY FOR TESTING developmental models of Super Power Amplitrons is located at Raytheon's Spencer Laboratory, Burlington, Massachusetts. The test facility occupies the 26,000-square-foot section at the upper right.**



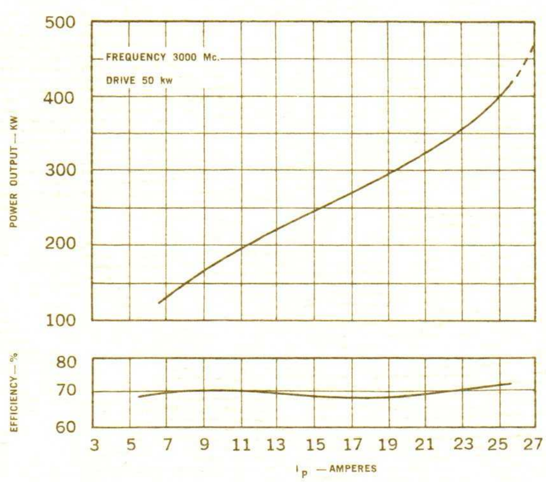
## SUPER POWER AMPLITRON
### Preliminary Characteristics

| | |
|---|---|
| Frequency | 3000 mc |
| Power (cw) | 425 kw |
| Efficiency | 72% |
| Gain | 10 db |
| Anode Voltage | 22 kv |
| Cooling | Water |
| Length | 71″ |
| Weight with Magnets | 400 lbs. |
| Output Configuration | Integral radiating horn |
| Output Window | Ceramic radome |

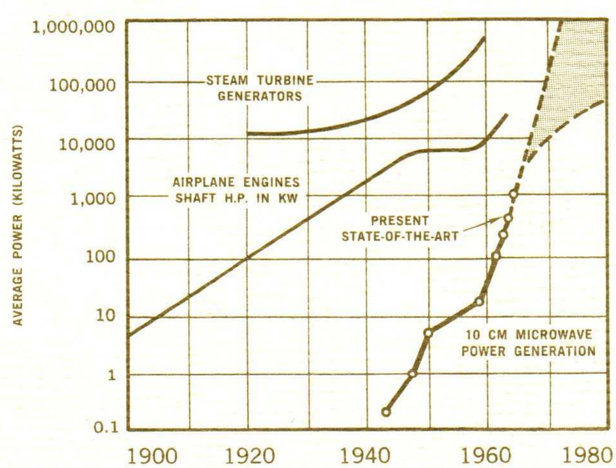
## DRIVER-OSCILLATOR
### Preliminary Characteristics

| | |
|---|---|
| Frequency | 2600-3100 mc (preset) |
| Power (cw) | 20-100 kw |
| Efficiency | 55% |
| Anode Voltage | 22 kv |
| Cooling | Water |
| Length | 24″ |
| Weight with Magnets | 130 lbs. |
| Output Configuration | S-band waveguide |

## SUPER POWER AMPLITRON
### Performance Characteristics




## Progress of Power Generation with Time



## RAYTHEON REGIONAL OFFICES

**NEW ENGLAND AREA AND UPPER NEW YORK STATE**
Spencer Laboratory, Wayside Avenue, Burlington, Massachusetts, BRowning 2-9600

**NEW YORK AREA**
210 Sylvan Avenue, Englewood Cliffs, New Jersey, LOwell 7-4911 (New York City, Wisconsin 7-6400)

**WEST COAST AREA**
12701 South Van Ness Avenue, Hawthorne, California, PLymouth 7-3151

**WASHINGTON**
The Solar Building, Suite 601, 1000 Sixteenth Street, N.W., Washington 6, D.C., MEtropolitan 8-5205

**SOUTH ATLANTIC AREA**
100 Roesler Road, Glen Burnie, Maryland, SOuthfield 1-0450

**MID-WEST AREA**
9501 Grand Avenue, Franklin Park, Illinois, NAtional 5-4000

**DAYTON**
333 W. First Street, Room 455, Dayton 2, Ohio, BAldwin 3-8128

**CANADA**
Raytheon Canada Limited, Waterloo, Ontario, SHerwood 5-6831

**EUROPE**
Raytheon-Elsi S.p.A., Via Villagrazia, 79, Palermo, Italy, Telephone 235531/2/3

**OTHER AREAS OF THE WORLD**
Raytheon Company, International Sales & Service, Lexington 73, Massachusetts, U.S.A., VOlunteer 2-6600

RAYTHEON

RAYTHEON COMPANY

MICROWAVE AND POWER TUBE DIVISION

Printed in U. S. A.

5M-8-63-WEA