MICROWAVE TUBES

RAYTHEON

FEBRUARY 1975

These catalogs provide technical information and reference guides to representative types of unclassified Raytheon microwave tubes. Raytheon has many other commercially available tubes, both classified and unclassified, in addition to those described here. We are also prepared to put our extensive experience to work on the design and manufacture of special tubes to meet particular requirements.

Complete information on the performance, price and availability of all Raytheon microwave tubes and components may be obtained from your nearest regional sales office, listed on the back of this page.

Only unclassified tubes are listed in these catalogs. Information on classified types is available upon receipt of proper security clearance and evidence of need to know.

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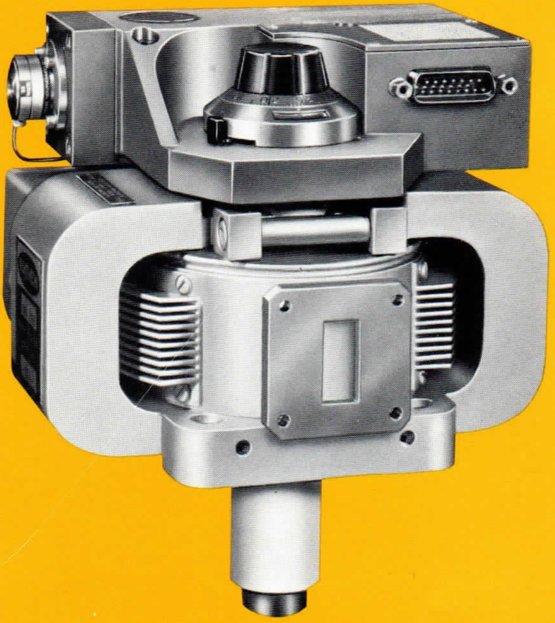
RAYTHEON MAGNETRONS



Raytheon Company has designed and manufactured hundreds of different types of magnetrons, of both conventional and coaxial design. These tubes include pulsed and CW magnetrons in fixed frequency, tunable, and frequency agile versions with peak power levels from 1 kilowatt to 5 megawatts and frequencies from VHF through K-band.

The ratings and descriptions given in the following pages represent only some of the currently available, non-classified types.

If your specific requirements are not found in these listings, please contact your nearest Raytheon Sales Office.

RAYTHEON

Coaxial Magnetrons

The general operation of the conventional magnetron is well understood. This type of tube, used in applications ranging from MTI radars to microwave cooking, still offers the most economical source of r-f power available. The following discussion, however, will concentrate on the newer, less familiar and more sophisticated coaxial magnetrons.

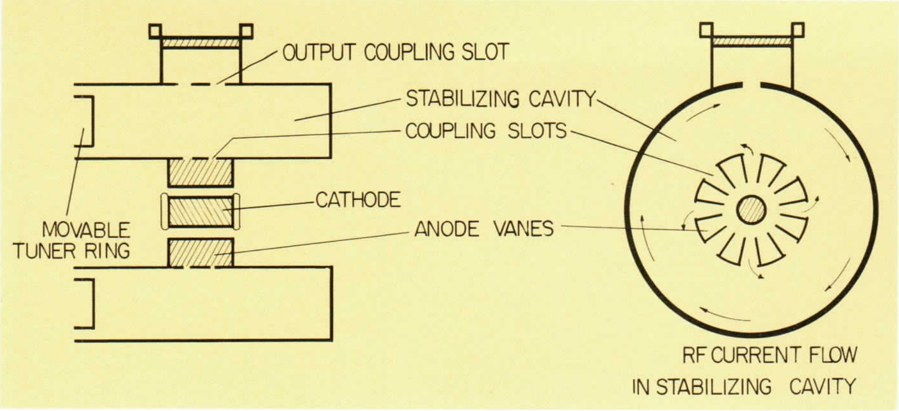


Figure 1 — Cross-Sectional View of Coaxial Magnetron Structure.

Introduction

The unique feature of coaxial magnetrons is a built-in stabilizing cavity that greatly improves frequency stability. Several important secondary effects, such as a better r-f output spectrum, higher efficiency and longer life, are inherent in this design approach. Figure 1 shows how the anode vane structure is coupled through slots in the supporting back wall to the surrounding (or coaxial) stabilizing cavity, and then through a slot in the outer wall of that cavity to the external waveguide load. By proper location of the vane coupling slots, the vane system couples to the desired TE_{011} cavity mode. This arrangement provides mode stability without the use of anode straps, which are one of the causes of low Q's and low efficiency in conventional magnetrons.

Longer life and better reliability result from the use of more vanes than are possible in conventional tubes. At high frequencies, where dimensions of the anode resonant cavities are small, these additional vanes mean larger anode and cathode areas and thus a more conservative tube design.

Conventional tuning is accomplished by moving one end plate of the stabilizing cavity to changes its height. Various tuner drive mechanisms can be furnished.

Pushing

Pushing is the change in operating frequency which results from a change in the anode current of the tube. It is caused by the presence of the electron stream at the vane tips of the anode resonant cavities. This effect is greatly reduced in coaxial magnetrons because the main element determining the frequency is the high-Q cavity, not the low-Q vane system. Pushing figures are typically 1/4 of the values of conventional type magnetrons, low enough so that the r-f output spectrum does not appreciably differ from the Fourier transform of the modulating waveform.

Jitter

One area in which special precautions are necessary with coaxial magnetrons is that of starting characteristics. Because of the time required for oscillation build-up in the high Q pi-mode, excessively fast pulse rise times may lead to misfiring and cause interference from other mode frequencies.

Raytheon tunable coaxial magnetrons can offer the lowest leading edge jitter available in this type of magnetron. This is because of Raytheon's patented mode damping system, which can be applied to any coaxial magnetron design. If low leading edge jitter is a system requirement, such as in MTI radar applications, Raytheon should be contacted regarding this capability.

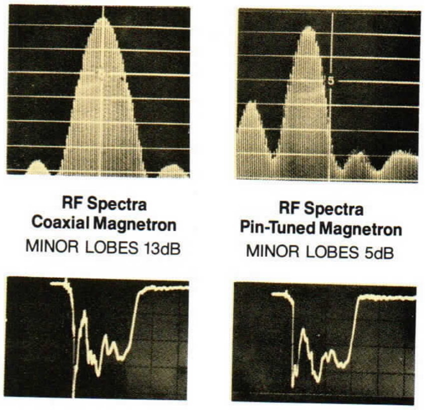
MTI Performance

Coaxial tubes produce about a six-fold improvement of pulse-to-pulse frequency jitter while they introduce about a three-fold increase in time jitter. When MTI improvement factors are computed the net effect is a significant improvement in overall MTI capability. Further improvement of MTI capability can be effected through injection of a low-level (-40 to -50 db) priming signal.

Spectrum Quality

Spectrum Quality of coaxial magnetrons is generally better than that of other tubes. Since it is closely related to the AM and FM occurring in the r-f pulse envelope, the r-f spectrum is improved by the low frequency pushing of the coaxial design. The spectrum bandwith is easily less than 2.0/tp, where tp is the pulse width. Side lobes are at least 9 db below the main lobe. Stability, expressed as a percent of missing pulses due to either arcing or moding, is less than 0.25% for any load phase position. Figure 2 compares spectra of conventional and coaxial magnetrons with a poor pulse shape intentionally applied. For the system designer, greater freedom of pulse shape is a welcome relief.

A typical spectral output from a coaxial magnetron is shown in Figure 3 which shows conformity with the requirements of MIL-STD-469 and also shows the associated modulating pulse.


RF Spectra
Coaxial Magnetron
MINOR LOBES 13dB

RF Spectra
Pin-Tuned Magnetron
MINOR LOBES 5dB

Current Pulses

Figure 2 – Spectrum Quality Comparison.

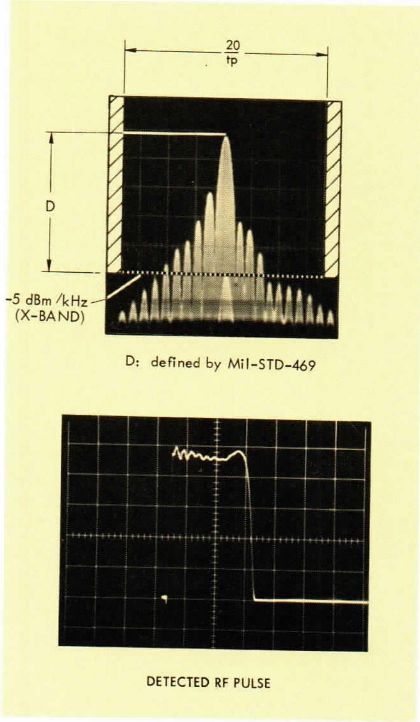


Figure 3 – Typical Spectral Output.

Pulling

Pulling is the frequency change caused by variations in the external load on the magnetron. It is usually specified as the frequency excursion observed when a 1.5 VSWR load is moved through all phase positions. This corresponds to varying reflections from nearby targets or from moving elements in the wave-guide system of the radar. Coaxial magnetrons have typical pulling figures about 1/3 the value common to conventional tubes.

Efficiency

The low circuit losses and high r-f energy storage of the coaxial magnetron permit greater efficiency to be achieved. At both X and Ku bands it is now possible to offer more than 40% efficiency from magnetrons. This can be a significant advantage in new systems, allowing smaller power supplies and cooling systems to be used. For many tube replacement applications, however, the power supplies already exist and have fixed operating points. Also, the antenna or transmission line may not be able to handle increased r-f power. Therefore, the coaxial magnetron may have to be specially decoupled to meet existing system limitations. The result is that the specifications do not always reflect the full capability inherent in the tube.

Pressurization

The output waveguide and the input to the cathode stem are generally pressurized so that standard atmospheric conditions are maintained when high altitude is reached. The permissible range of pressure to be kept in the input and output areas of the tubes is 12 to 45 psia.

Life

Coaxial magnetron life is typically 3 to 5 times greater than conventional magnetrons because the cathode emitting surface and anode vane tip area are much greater. With more anode vanes and larger cathode size, the emission density and vane tip power dissipation are significantly lower, and the effects are seen directly in less arc damage and in better life.

Another significant factor in the longer life of coaxial tubes is the greatly improved pulse stability (arcing, erosion, missing pulses) which comes about as a result of energy storage being primarily in the coaxial cavity, thereby allowing greatly reduced r-f voltages in the electron interaction space.

The result of these characteristics is less system down time, higher reliability, and lower replacement costs.

Frequency Agile Magnetrons

Agile magnetrons offer the radar designer a means of improved radar performance due to reduced scintillation, glint and clutter. Improved ECCM performance is also afforded. Raytheon coaxial magnetrons can be supplied with dither tuning capability. Agile mechanisms can either dither the main broadband tuner about a center frequency (such as the servo tunable electromagnetic actuator type), or can activate a separate agile tuner which is independent of the broadband tuner mechanism. Raytheon's patented "Ring Tuner" is an example of this latter type, and is described below.

The Ring Tuner – The principle of the ring tuner is shown by Figure 4. This is a sketch of a coaxial magnetron cavity with a conventional tuning plunger, either hand-actuated or motor-driven. Note the channel in the outer wall of the cavity. Within this channel is a ring which is severed at two places. Near the output, on both sides of the output coupling slot, the ring is firmly attached to the cavity wall. The recessed ring, however, is free to move from its two free hanging extremities opposite the output slot. A mechanical actuator attached to the free hanging ends of the ring causes the ring to alternately expand and contract, thereby perturbing the resonant frequency of the cavity. The ring is located in a region which is near the peak of the cavity r-f current distribution for every position of the broadband tuner. As a result, the dither tuning range remains virtually constant over a wide frequency band.

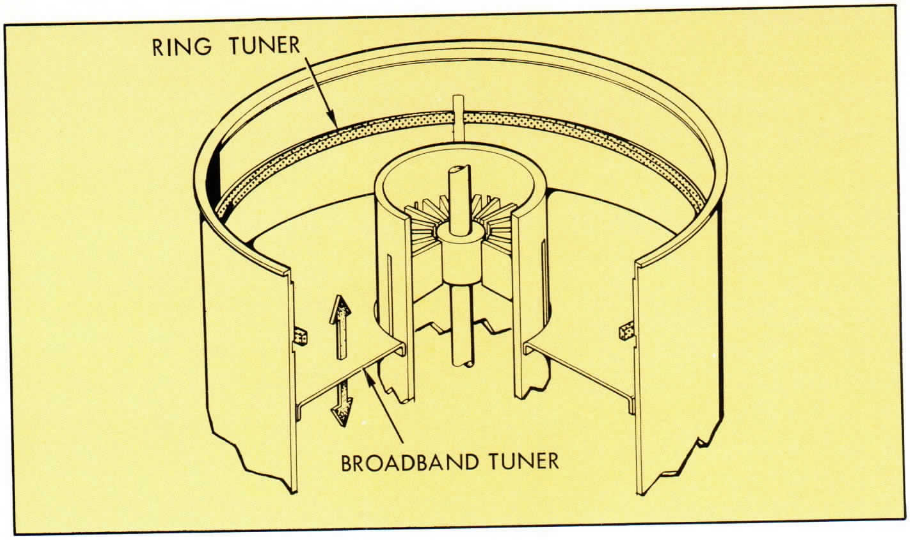


Figure 4—Principle of the Ring Tuner.

A diagram of the ring tuner actuator appears in Figure 5. The prime mover is a compact motor, which imparts, through the rotary motion of its shaft A, a translation of the vertical shaft B. Rocker arm linkages, C, then translate this motion to the horizontal plane and alternately expand and contract the ring.

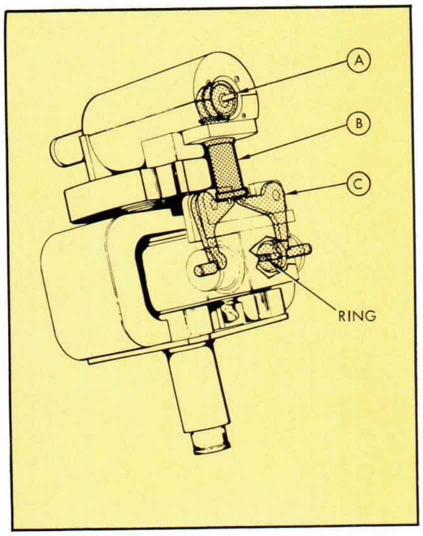


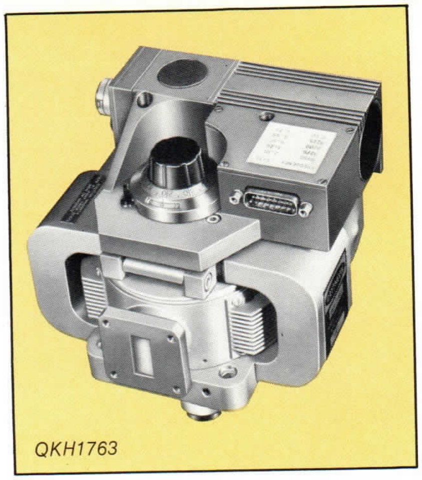
Figure 5—Actuator Mechanism for the Ring Tuner.

Flexible long life bellows assemblies (not shown for simplicity) separate the vacuum region within the tube proper from the external ring actuator system. The bellows are arranged so that the proper load is presented to the actuator assembly at all altitudes which may be encountered in field service.

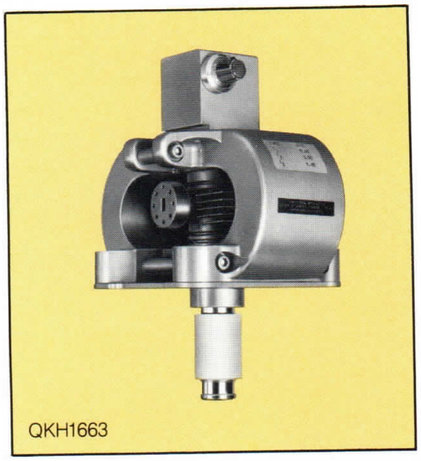
Readout—Both broadband and agile readouts are normally provided for dither tuned tubes. Broadband readout is obtained from a linearized multi-turn potentiometer. Agile readout can be provided by means of a resolver in cases where position readout is desired, or by a motor generator in cases where velocity readout will suffice.

Ring Tuner Reliability—Before selecting a ring-tuned coaxial magnetron for a projected system, the transmitter designer must carefully consider the reliability characteristics of the device. The dither tuner, which commonly operates at 80 to 200 Hz, may be subjected to 720 million cycles over a 1000-hour dither lifetime (which may be 1/2 to 1/3 of the total available tube life). It is obvious that *the dither tuner mechanism must have an operating lifetime commensurate with the expected microwave tube life* in order to avoid field maintenance and repair.

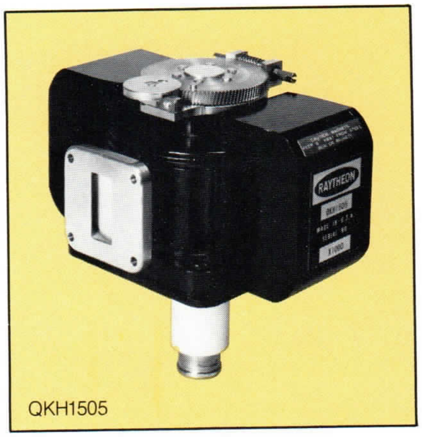
Environmental Capability of the Ring Tuner—Transmitters using ring-tuned magnetrons normally have to satisfy environmental equipment requirements of military aircraft. In certain instances requirements may be considerably more stringent. Raytheon ring-tuned magnetrons are therefore designed for compliance with all appropriate military specifications.



QKH1763



QKH1663



QKH1505

QKH1667

Coaxial Magnetrons

Band	Tube Type	Freq. (GHz)	Peak Power Output* (kW)	Pulse Width (μsec)	Max. Duty Cycle	Anode Voltage (kV)	Peak Anode Current (A)	Code	Weight (lb)
X (I)	**QKH1505**	8.5-9.6	65	0.2-5.0	.001	15	15	MWYB	6.5
	QKH1709****	8.5-9.6	200	0.2-3.0	.001	22	27.5	MWYB	14
	QKH1578/ JAN8855	8.5-9.6	200	0.2-3.0	.0011	22	27.5	MWYB	13
	QKH1512/ JAN8896	8.5-9.6	200	0.2-3.0	.0011	27	25	MWYB	19
	QKH1553	9.245	75	0.2-3.0	.001	15	13.5	FWDB	7.5
	QKH1592/ USAF377A	9.375 ±0.02	70	0.2-3.0	.0011	15	15	FWYB	7
	QKH1665	9.0-9.6	200	0.3-3.0	.001	21.5	27.5	RWYB	17
	QKH1666	9.1-9.5	70	0.3-4.0	.001	15	15	RWYB	13
	QKH1763	9.1-9.5	65	0.3-4.0	.001	15	15	RWYB	13
	QKH1757	9.0-10.0	130	0.2-1.0	.001	18	18	MWYB	13
S (E)	**QKH1667**	2.7-2.9	500-800	0.5-2.5	.0011	29	70	MWJB	95
(F)	**QKH1772**	3.5-3.7	500	0.5-3.0	.001	30	35	MWJB	95
Ku (J)	**QKH1527**	600 MHz 15.5-17.5	95	0.2-2.0	.001	16	16	EWYB	13
	7208B	15.5-17.5	125	0.2-3.0	.001	18	19	MWYB	14
	QKH1526	600 MHz 16.1-16.9	65	0.2-2.0	.001	14	14	EWYB	7.5
	QKH1516	16.6-17.1	35	0.2-2.0	.0008	12	9.5	MWYB	4.3
Ka (K)	**QKH1663**	32.0-33.0	65	0.3	.0008	16.5	16.25	MWYB	13

**Specification minimum value.*

***7008 Replacement.*

Codes:

Tuning	Output	Cooling	Magnet
E Electro-Mech	C Coax	D Conduction	B Permanent integral
F Fixed	W Waveguide	J Forced air/liquid	S Permanent
M Mechanical		Y Forced air	
R Ring			

Conventional Magnetrons

Band	Tube Type	Freq. (MHz)	Peak Power Output* (kW)	Pulse Width (μsec)	Max. Duty Cycle	Anode Voltage (kV)	Peak Anode Current (A)	Code	Weight (lb)
UHF (B)	**RK7547**	406-450	2000	7.0	.0018	55	97	MCZB	220
L (D)	**5J26 (unpackaged)**	1220-1350	400	2.0	.002	30	46	MCYK	20
	RK7484A	1250-1350	2000	3.0	.0012	60	90	MWYB	90
	RK6517	1250-1350	1000	3.0	.0013	53	50	MWYB	90
	QK655	1250-1285	5000	6.0	.0018	71	150	FWZB	110
	QKH942 (10 Hz tun. rate)	1250-1350	5000	6.0	.0018	71	150	IWZB	140
	QK666	1320-1350	5000	6.0	.0018	71	150	FWZB	110
S (G)	**RK6177A (altimeter)**	4268-4350	1 watt CW		1.00	.305	.030	**CXB	1
S (E)	**RK7529**	2700-2850	3500	2.0	.0008	62	115	MWZB	66
	QKH1569	2700-2900	1000	1.0	.001	45	50	MWYB	66
	QKH898	2841-2871	4500	3.0	.001	70	130	MWZB	60
	RK6410A	2750-2860	4500	2.0	.001	70	130	FWZB	57
	RK6406A	2850-2910	1750	2.0	.0007	52	85	FWZB	40
	QKH1528	2900-3100	1000	1.0	.001	45	50	MWYB	66
S (F)	**RK5795**	3100-3500	1000	1.5	.0022	45	45	MWYB	66
	RK6402	3430-3570	700	2.0	.0016	47	50	MWZB	65
	RK8764	3590-3700	1000	1.5	.001	47	50	MWYB	66
S (E)	**RK5586**	2700-2900	800	1.0	.0005	30	70	MCYK	6.5
	RK8798	2700-2900	450	1.0	.001	30	40	MCYK	5.5
	4J35	2700-2740	800	1.0	.0005	28	70	FCYK	5
	4J34	2740-2780	800	1.0	.0005	28	70	FCYK	5
	4J33	2780-2820	800	1.0	.0005	28	70	FCYK	5
	4J32	2820-2860	800	1.0	.0005	28	70	FCYK	5
	4J31	2860-2900	800	1.0	.0005	28	70	FCYK	5
	RK5657	2900-3100	800	1.0	.0005	30	70	MCYK	6.5
S (E)	**2J34**	2700-2740	240	1.0	.002	20	30	FCYA	2.3
	2J33	2740-2780	240	1.0	.002	20	30	FCYA	2.3
	2J32	2780-2820	240	1.0	.002	20	30	FCYA	2.3
	2J31	2820-2860	240	1.0	.002	20	30	FCYA	2.3
	2J30	2860-2900	240	1.0	.002	20	30	FCYA	2.3

**Specification minimum value.*

Codes:

Tuning	**Output**	**Cooling**	**Magnet**
F Fixed	C Coaxial	X Convection	A Separate
I Hydraulic	W Waveguide	Y Forced air	B Permanent integral
M Mechanical		Z Liquid	K Permanent separate

***Electromechanical frequency modulated by a 300 Mz vibrating reed mechanism for use in radar altimeters.*

Conventional Magnetrons

Band	Tube Type	Freq. (MHz)	Peak Power Output* (kW)	Pulse Width (µsec)	Max. Duty Cycle	Anode Voltage (kV)	Peak Anode Current (A)	Code	Weight (lb)
S (F)	**2J70A**	3025-3075	20	1.0	.001	7	8	FCYB	3.7
	2J70B	3025-3075	50	1.0	.001	9	16	FCYB	4
C (G)	**QKH1199**	4900-5100	250	1.0	.001	24	24	MWYB	35
	RK7460	5450-5825	250	0.5	.001	24.5	25	MWYB	35
	RK7156	5450-5825	250	2.0	.001	24.5	24	MWYB	35
	RK6344A	5450-5825	175	2.4	.001	22	22	MWYB	25
	QKH1214	5665-5715	1000	1.0	.001	35	65	MWYB	50
C (H)	**4J59**	6275-6375	180	1.0	.001	18	30	FWYB	11.5
	4J58	6375-6475	180	1.0	.001	18	30	FWYB	11.5
	4J57	6475-6575	180	1.0	.001	18	30	FWYB	11.5
X (I)	**2J50**	8750-8900	40	1.0	.0012	12	12	FWYK	1.3
	RK6002	9230-9404	250	2.0	.001	28	30	FWYB	24
	QKH1374	9300-9320	7	2.0	.002	5.5	4.5	FWYB	3
	RK6959	9330-9420	600	0.5	.0011	33	67	FWYB	45
	QKH1535	9315-9375	20	1.0	.001	7.5	6.5	FWYB	5
	2J55	9345-9405	40	2.0	.001	12	12	FWYB	4
	2J42	9345-9405	7	2.0	.002	5.5	4.5	FWYB	3
	2J42H**	9345-9405	7	2.0	.002	5.5	4.5	FWYB	3
	725A/2J53	9345-9405	40	5.0	.001	12	12	FWYK	1.5
X (I)	**2J51A**	8500-9600	40	3.5	.001	14	14	MWYB	5
	RK6248	8700-8900	1.2	1.0	.045	3.6	0.9	MWYB	6
	7256	9000-9160	40	0.5	.001	14	14	MWYB	5
	QKH1121	9300-9700	7	2.0	.002	5.5	4.5	MWYB	3

**Specification minimum value.*

Codes:

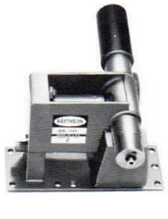
Tuning	Output	Cooling	Magnet
F Fixed	C Coaxial	X Convection	A Separate
I Hydraulic	W Waveguide	Y Forced air	B Permanent integral
M Mechanical		Z Liquid	K Permanent separate

***Designated for jet aircraft environments. Operation to 60,000 feet altitude without pressurization.*


RK7484A


RK5795


RK2J30


QKH1121


QKH1463

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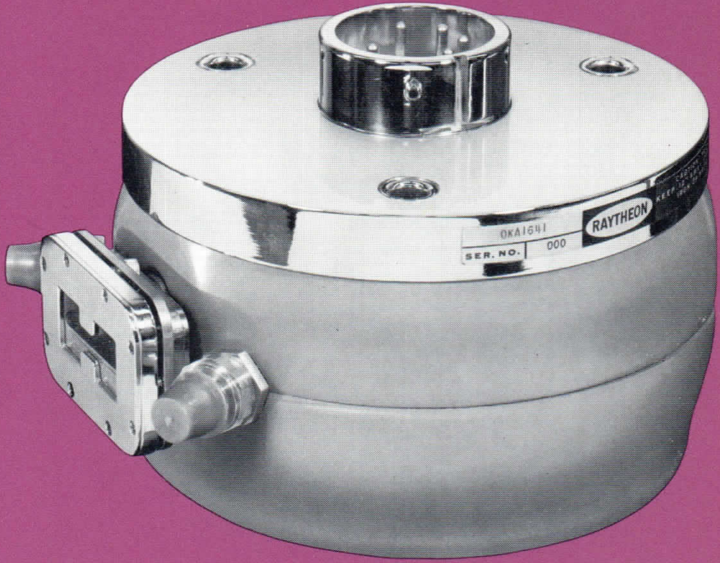
RAYTHEON M-BWO'S



Raytheon Company offers a family of M-BWO's that cover a broad portion of the microwave spectrum. These tubes generate typical CW or average powers up to 500 watts with peak powers of 1000 watts and a typical efficiency of 25 per cent.

Specific operating characteristics of Raytheon M-BWO's can be furnished only upon receipt of proper security clearance and evidence of need to know. Please contact your nearest Raytheon Sales Office for further information.

RAYTHEON

M-Type Backward Wave Oscillators

Introduction

The M-BWO is inherently a voltage tunable crossed-field oscillator. Frequency is determined by the velocity of the electrons, which in turn is related to the electric and magnetic field present. These fundamental relationships reduce to a simple expression as follows:

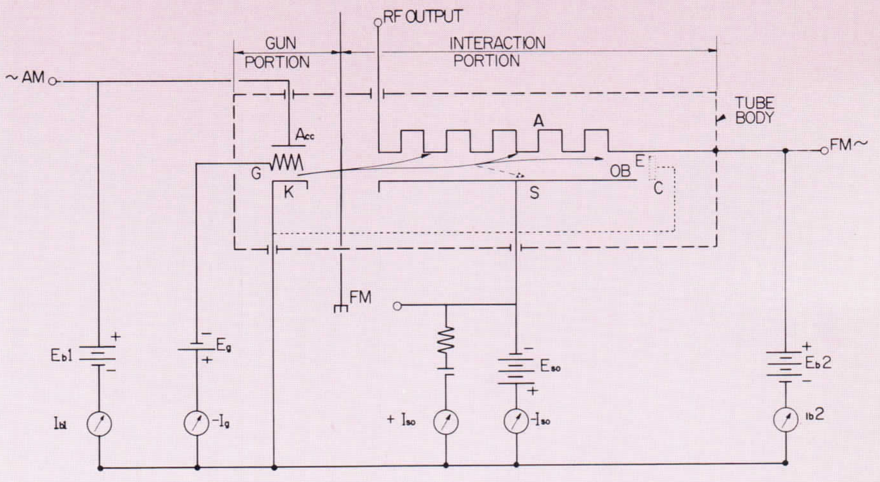
$$\text{Frequency, } F \approx \frac{E}{B}$$

Where E is the voltage between sole and anode, and B is the magnetic field.

A second order effect upon frequency is caused by "beam pushing." $\left(\frac{\Delta F}{\Delta Ib2}\right)$ resulting from variations in beam current.

The cathode, grid and accelerator comprise the "gun" portion of the tube where the beam is initiated, current controlled, and focused for injection into the interaction space. In this space, between the sole and anode (delay line), energy conversion takes place. See Figure 1.

The beam current (and power output) is controlled by the accelerator. The sole to anode voltage controls the output frequency. As a versatile microwave power generator the M-BWO therefore can be pulsed on or off, amplitude modulated (with some attendant FM) and frequency modulated. A dynamic tuning range of 30% is thus provided by an individual tube. A family of current M-BWO's can cover a broad portion of the microwave spectrum; generating typical CW or average powers up to 500 watts with peak powers of 1000 watts and typical efficiency of 25 per cent.



K = Cathode (element to which all voltages are referenced)
G = Grid
Acc = Accelerator
A = Anode or delay line } Frequency Control Elements
S = Sole
OB = Transverse magnetic field
C = Collector (Beam Miser) internally connected
Eb1, Ib1 = Accelerator voltage, current
Eb2, Ib2 = Anode (delay line) voltage current
Eg, Ig = Grid voltage, current (±)
Eso, Iso = Sole voltage, current (±)

FIGURE 1.—MBWO Schematic, Symbols, and Power Supply Requirements.

Dual Mode Operation

Many M-BWO's are designed to have a dual mode capability, i.e. the capability of CW operation and a pulse level of 3 db above the CW level. This is done either over portions of the tuning band or over the entire tuning band, depending on the desired application of the tube. Normally the average power under pulsed conditions is equivalent to that of the CW mode.

Tuning Sensitivity

The dynamic frequency response from the M-BWO dictates consideration of the voltage applied to the controlling tube elements. Power supply ripple or any deliberately applied modulating voltage have the same effect upon output frequency. Typical tuning sensitivity (for standard line tubes) expressed as volts per MHz is as follows:

Frequency Bands	Tuning Sensitivity (Volts/MHz) Sole to Anode
B–C	20
D	7.2
E–F	2.8
G–H	1.4
I	1
J	0.5

Power Output, Frequency and Tuning Voltage

"A Contour Plot," Figure 2 illustrates typical relationships between voltages, frequency and power output when the delay line (anode) current (Ib2) is held constant by adjusting accelerator voltage.

By utilizing the contours of power output and frequency, the typical performance to be expected in this regard may be predicted for a specific tuning voltage or for a sole and/or delay line modulation. A departure from these values is to be expected, of course, if the programming of input conditions causes a departure from the stated value of Ib2.

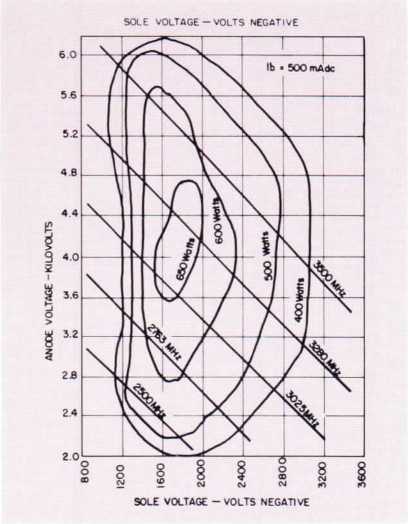


FIGURE 2. – **S-Band MBWO Contour Plot. Power Output, Frequency, Voltage**

Accelerator Control, Beam Current and Power Output

The accelerator is the beam current control electrode. Accelerator voltage Eb1 (or dynamically Δeb1) therefore provides the versatility for amplitude modulation, for turning the tube on or off, for pulsing, or for CW operation. In the sequence of voltages applied to the M-BWO, it should be the last to come on and the first to come off if tube or circuit malfunction occurs.

Typical accelerator characteristics are shown in Figure 3. Useful power output is not generated until a certain current is reached. The current corresponding to this density is called the starting current.

However, in some tubes in the M-BWO family signal emanations, usually in the form of very low level noise, have been detected below the point of fundamental power cut-off.

At zero accelerator voltage these signals are assured of being greater than −60 dbm for all tubes. Pulsing the accelerator is readily achievable. There does not appear to be any limitation on pulse rise time for values less than the beam transit time. Therefore, rise times as short as 0.05 microsecond or less are acceptable. Peak beam current, ib2, and anode dissipation are limiting parameters. Anode dissipation is inter-related with pulse width. The average duty cycle is a consideration but is insufficient in itself in evaluating tube capability. The delay line structure is sensitive to the dissipation energy per pulse.

Pulse width and duty cycle are defined with respect to the current pulse, ib2. The rf pulse will be somewhat narrower, depending upon the starting current.

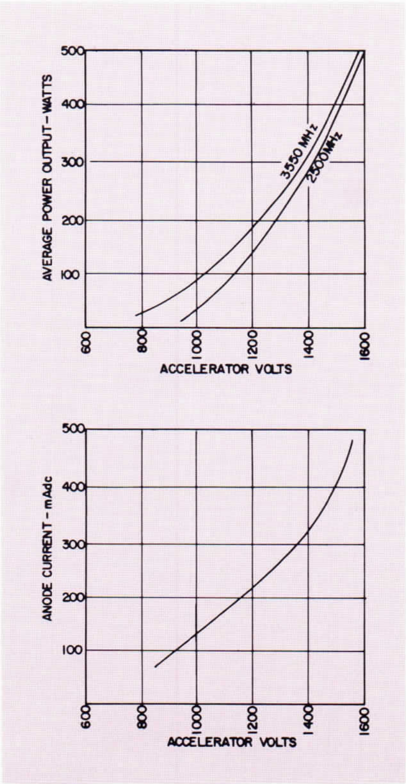


FIGURE 3. —**Typical S-Band MBWO Accelerator Characteristics**

The accelerator voltage may be modulated with frequencies up to 20 MHz or higher to provide an amplitude modulated output. As has been indicated, there is attendant FM due to pushing. The resultant rf spectrum therefore is a combination of FM and AM.

M-BWO Anomalies

The M-BWO, as do most microwave tubes, has certain anomalies which generally do not limit its usefulness but which are characteristics to be considered in application of the device. These are (1) undesired outputs (spurious), (2) regions of discontinuous frequency ("holes" or missing frequency bands), (3) negative resistance characteristics of the sole element (see Power Supply Considerations).

Spurious Signals

The term spurious output refers to an undesired output in the form of line-spectrum signals adjacent to the carrier of an M-type BWO with spurious carrier-frequency spacings that are typically 1.5% of the carrier frequency. The phenomenon is noted in all varieties of M-type backward wave oscillators. In some cases, the amplitude of these spurious signals may approach to within 10 db of the carrier. The spectral line (s) of spurious output may occur on either or both sides of the carrier.

The level of spurious output relative to the carrier, the spurious-carrier ratio is sensitive to the value of beam current.

Missing Frequency Bands or "Holes"

Although M-BWO design and manufacturing experience have established certain rules which minimize the occurence of this anomaly, the phenomena is not sufficiently understood to be completely eliminated in all cases. "Holes" or Missing Frequency Bands, are sudden frequency shifts of a few MHz or less (usually without change of power) as the tuning voltage is varied.

When present, "holes" are discernable primarily under CW operating conditions. It has been observed, however, that if the tuning voltage is modulated to some degree either by ripple or noise frequencies, the "hole" becomes very much less discernable and may disappear. Therefore, in the typical system application where the M-BWO is amplitude and/or frequency modulated, holes "fill-in" and are seldom if ever a significant concern.

Missing Frequency Bands or "holes" may be related to sole current variations as described under Sole Power Supply considerations.

Power Supply Considerations

General

Within the physical limitations imposed upon the equipment designer — weight, size, voltage, etc. — the inherent "voltage tuned" nature of the M-BWO must be kept in mind. If a certain degree of "frequency stability" or RF spectrum shape is required, careful reflection upon the tuning sensitivity is mandatory. Power supply ripple and regulation are key considerations. Regulation should be designed commensurate with the steady state or transient conditions imposed. During accelerator modulation or pulsing, anode power supply regulation is seldom such as to preclude a transient on the tuning voltage.

Overload circuitry which removes the accelerator voltage should have a reaction time sufficient to limit a stored energy discharge of between two and four joules.

All voltages, excluding the filament, may be applied simultaneously or in the conventional sequence, filament, grid, sole and anode and finally the accelerator. Turn off should follow the reverse sequence. In other words, the beam must not be on in the absence of other voltages.

The frequency of the filament supply should be so chosen so as not to excite mechanical resonances of the structure. Usually values of 60 cycles, 400 cycles and 10 kilocycles are acceptable. The tube manufacturer should be consulted. Filament voltage may be applied in two steps or the filament transformer designed with sufficient leakage reactance to limit surge current to 2.5 times the steady state value.

Sole Power Supply

Of special consideration is e design of the sole power supply. The sole element not only draws current from the supply, but may also generate current due to secondary emission. The result may be a negative resistance characteristic which when coupled to the circuit impedance may produce undesired oscillations (sometimes called parasitic oscillations). These undesired oscillations may modulate the sole voltage or introduce voltage discontinuities. Any variation in sole voltage of course tunes the M-BWO, so there may be accompanying anomalies in the rf spectrum. It is good practice, therefore, to observe and measure any transient a. c. variations of sole voltage. M-BWO/power supply interface problems of this sort may be alleviated by selection or trimming of circuit impedance.

Anode Power Supply

Similar transient consideration should also be given the anode supply, particularly if the beam current is to be periodically interrupted or pulsed on and off. The reaction time of typical anode regulation circuits will usually result in rapidly varying transient voltage values at the rise and fall of each pulse. The rf spectrum will respond accordingly.

Power Output and Load VSWR

To obtain correlation with the tube manufacturers' power output data, it is essential that the load VSWR be no greater than 1.1 over the frequency range of interest. Insertion loss should be negligible. These are standard tube specification requirements.

The effect of load VSWR upon M-BWO power output is described in text such as volume II, Crossed Field Devices by Okress, pages 27–29. Here it is shown that load VSWR when combined with tube VSWR, results in a decrease in measured load power by a factor related to the resultant VSWR. A load VSWR of 1.5 will generally reduce load power output by at least 0.5 db (12%). A VSWR of 2.0 increases the reflection to at least 1.0 db (25%).

Measurements of load VSWR must be made directly from the M-BWO flange to include all wave-guide components.

In the process of integrating these tubes into a practical system application, it is inherent that "matched" conditions will not prevail over the broad tuning bandwidths required. The VSWR of the load connected to the M-BWO (which is a summation of interconnections, cabling, and antenna) is a measure of the departure from "matched" conditions. The result to be expected, therefore, is a decrease in actual radiated power.

The specification of radiated power for any equipment should therefore be defined not in absolute value since it may not be accurately measured directly, but related to the M-BWO specification for minimum power output under matched load conditions. In addition, a maximum limit of VSWR and insertion loss should be specified for combined interconnections, cabling, and antenna which are attached to the M-BWO.

RAYTHEON

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RAYTHEON CFA'S

Raytheon Company offers a wide variety of both forward and backward wave crossed field amplifiers with peak power outputs from 100 kilowatts to 5 megawatts and frequencies from L through X-band.

The ratings and descriptions given in the following pages represent only some of the currently available, non-classified types. If your specific requirements are not found in these listings, please contact your nearest Raytheon Sales Office.

RAYTHEON

Crossed Field Amplifiers

Introduction

Raytheon crossed field amplifiers are widely used in military and civilian radar systems. The Amplitron, invented by Raytheon Company, was the original crossed field backward wave amplifier. CFA's have been incorporated into systems from UHF to X-band. Most of these systems utilize high power cathode pulsed CFA's with peak power operation between 100 KW and 5 MW and average power levels up to 20 KW.

The CFA's listed on the following pages are typical of the types manufactured by Raytheon Company. Other types, both classified and unclassified, are available. The reader should contact Raytheon Company for information on CFA's to meet his particular needs.

CFA Categories

There are several distinguishing features of CFA's. CFA's may conveniently be grouped by their mode of operation (forward-wave or backward-wave) and by their electron stream source (injected beam or emitting sole). The first group concerns distinctions of the voltage-frequency behavior of the tube, and the second group concerns the method by which the electron stream is introduced into the interaction region. Both groups can be operated pulsed or CW. The major distinctions between individual tube types are thus heavily intertwined with the end use and the method of application of power to the tube.

Device Selection

The selection of a particular microwave tube type should be made on the basis of its suitability for the requirement. Each system requirement is unique, and very often a specific need dominates and overrides all other considerations in the selection of the most appropriate tube type. The CFA is characterized by low or moderate gain, moderate bandwidth, high efficiency, saturated amplification, small size, low weight, and high perveance. Enhancement of any one feature will invariably degrade another, resulting in a penalty that undercuts its overall suitability. For this reason, the usage of the CFA has been most successful in those applications in which its natural character is essential for the system objective.

The usage of the CFA should be considered as complementary to all other available types rather than, necessarily, a substitute for them. Its most frequent application has been in coherent amplifier configurations in final stages where efficient and multimode performance is required. The driver stages, which are at reduced levels of power, are served best by lower power, higher gain devices such as the linear beam tubes.

Applications

The low gain, high efficiency, small size, and lightweight features of the CFA make it particularly suitable for mobile systems. The size-weight limitations in mobile systems have an impact not only on the size and weight of the tube itself, but, more importantly, on the peripheral equipment. With an efficient final high-power stage, savings accrue to the power supply, the primary fuel quantity, the size and capacity of the cooling system, and the additional incidental power requirements such as filament and solenoid. Advantages further accrue if the system requires multipower modes that can be achieved by omission of pulsing to the final stage and allowing lower level drive power to feed through the final stage. The system efficiency does not degrade with such operation.

In mobile systems it is common to subdivide the various radar units into transportable modules. A system composed of a chain of amplifier stages naturally adapts itself to the mobile concept with a minimal interstage connecting circuitry. It further permits an "add on" module concept that can either upgrade or derate a given chain to fit varied requirements without major modification. Typical configurations that have been established successfully in field use are shown in Fig. 1.

The reproducibility of the CFA adapts itself readily to applications having multiparallel amplifier stages, as in a transmitter driving a phased array. The modes of operation available are with the tubes either in parallel with power combined at the outputs, or separately feeding the antenna. The parallel feature also makes possible designs in which flexibility of approach exists by added combinations of stages.

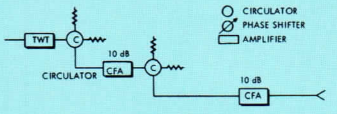
Raytheon crossed field amplifiers offer performance characteristics that make them ideal for use in chains of two or more tubes to maximize power and gain while minimizing size and weight. The versatility of CFA's also permits paralleling of tubes, using feed-through modes, and frequency shifting within the RF pulse. Wide electronic bandwidth can be used effectively for phasing purposes.

Chains utilizing more than two CFA's and/or incorporating Raytheon TWT's as drivers can also be designed to meet particular operating requirements. For example, an X-band chain (one TWT and two CFA's) produces over 70 db of gain at a tube weight of 45 pounds and a typical efficiency of 50%. This is by far the lightest-weight, most efficient, coherent 500 kW peak power source at X-band.

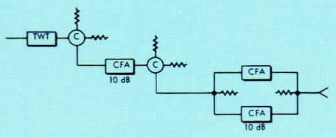
Crossed Field Amplifiers

Band	Tube Type	Freq. Range (MHz)	Avg. Power (kW)	Peak Power* (MW)	Peak Anode Current (A)	Typical Peak Anode Voltage (kV)	Pulse Width (μsec)	Peak RF Drive (kW)	Heater	Weight (lb)	Driver Tube
L (D)	QKS1319	1250-1350	3.0	0.1	20	10.5	1-250	4.5	none	50	—
	QKS1181	1250-1350	3.9	5.0	130	72-85	1.8	400	50 A preheat	120	5J26
	RK7577/ QKS653	1280-1350	3.6	5.3	98	94-105	1.8	400	50 A preheat	120	5J26
	QKS642	1280-1350	8.0	5.0	125	73-86	6.0	588	70 A	180	
S (E, F)	QKS1267	2905-3085	1.32	0.06	4.0	22-27	35	1.6	18 A max.	50	
	QKS1449	2900-3100	3.6	.120	5.0	28-30	30	7.0	none	50	—
	QKS1484	3170-3260	0.72	0.06	4.0	26-28	30	2.4	none	50	—
	QKS1380	3000-3200	22	1.2	33	51-55	80	110	none	120	—
	QKS1540	2900-3100	8.25	0.666	20	45-55	30	48	none	110	QKS1267, 8128
	QKS1541	2900-3100	14	2.6	62	44-56	28	550	none	110	QKS1540
	QKS1646	3100-3500	3.0	0.125	15	14-18	100	10.0	none	150	10 k W TWT
	QKS1606	3100-3500	75.0	0.8	70	32-36	100	75	none	200	QKS1646
C (G)	QKS1130	5400-5600	3.2	0.60	21	42	0.5	15	none	55	
	QKS1343 Driver	5400-5900	6.3	0.63	25	45-51	37	60	none	70	7C k W TWT
	QKS1343 Final	5400-5900	7.2	1.25	39	46-52	35	250	none	70	QKS1343
	QKS1570	5400-5900	6.0	0.60	40	23-30	50	50	none	115	60 k W TWT
X (I)	QKS1350	8900-9600	0.13	0.01	1.7	16	6.5	1.5	6. 3 A 1.6V	9.5	—
	QKS1539	9400-9700	0.3	0.015	2.0	19	5	1.5	none	11	—
	QKS1442	9200-9500	0.11	0.01	2.3	13	0.25	1.5	1.3 A at 6.3V	9.5	—
	QKS1443	9200-9500	0.7	0.25	19	31	0.2	10	10 A at 5.5V	35	QKS1442
	QKS1244	9500-9700	0.15	0.25	4.0	16	2.2	1.5	6.3 A at 1.6V	8.5	—
	QKS1243	9500-9700	0.7	0.5 0.25	26 16	37	2.0	25	none	35	QKS1244
	QKS1611	9000-9200	1.2	0.30	19	32	1.0	10	none	32	—
	QKS1705	9500-10,000	0.5	0.5	35	32	2.0	30	none	28	—

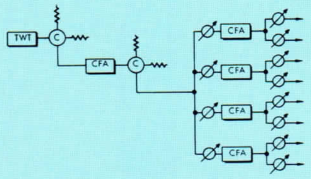
**Specification minimum value*



CASCADE CHAIN WITH INTERPULSE FEEDTHROUGH CAPABILITY



PARALLEL FINAL STAGE FOR UPGRADED POWER CAPABILITY



CORPORATE FEED WITH PHASE SHIFTERS

FIGURE 1.—Typical CFA Configurations

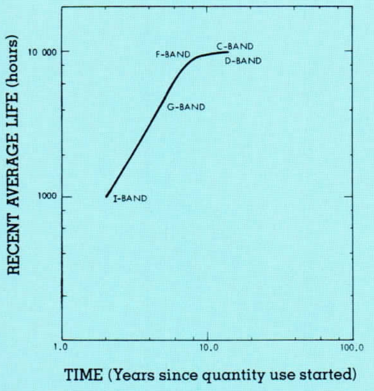


FIGURE 2.—Recent Average Tube Life as a Function of Years in Service.

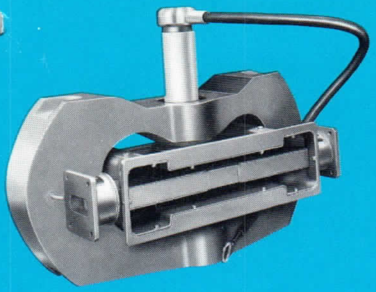
Environmental Factors

CFA's manufactured by Raytheon Company have had field experience in fixed, land mobile, shipborne, airborne, and space applications. Environmentally, the principal design consideration has revolved around the shock and vibration resistance of the cathode structure and the magnet—the cathode because it commonly has a cantiliver construction, and the magnet because of its weight. Designs have been achieved which meet varied environmental requirements together with the necessary thermal and electrical requirements, and which provide high reliability and good field experience. The small-size and low-voltage features of CFA interaction have enabled tubes to have physical designs that readily conform to environmental requirements, with the main design effort concentrated on the two areas noted.

Life

The average tube life in systems experienced in recent years is shown in Fig. 2 as a function of years in service. The lower frequency types have been in service longer, as indicated on the curve, and have acquired more history than the higher frequency types. The best life, as with all microwave tube types, also correlates with the lower frequencies where the tubes are large and understressed. Noteworthy, however, is the average life at 3 GHz where the tubes are relatively small but the peak and average power are appreciable. All data are for high-voltage operating time, since filament life is not applicable to operation of most CFA's.

Reference: "The Continuous-Cathode (Emitting-Sole) Crossed-Field Amplifier" by J. F. Skowron. Proceedings of the IEEE, Volume 61, Number 3 (March 1973).



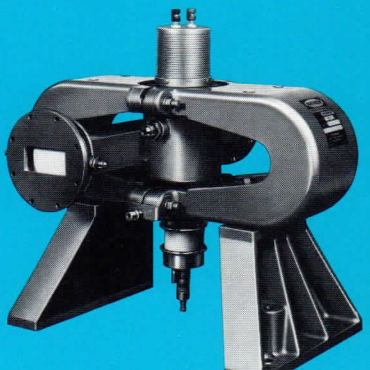
QKS1611

QKS1343

QKS1267

QKS1539

QKS1319



QKS1541

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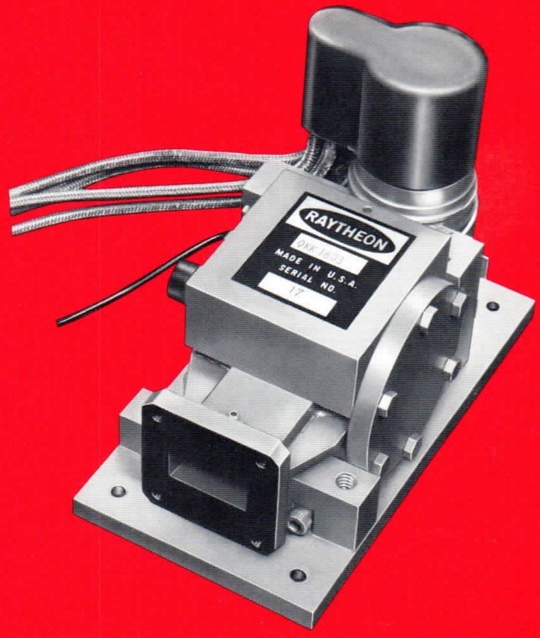
RAYTHEON KLYSTRONS



Raytheon Company offers a variety of two-cavity CW klystron oscillators and three-cavity and four-cavity CW klystron amplifiers for radar, illuminator and communication service, as well as a complete line of low power reflex klystrons for communications and local oscillator service.

The ratings and descriptions given in the following pages represent only some of the currently available, non-classified types. If your specific requirements are not found in these listings, please contact your nearest Raytheon Sales Office.

RAYTHEON

Klystrons

Introduction

Low power reflex klystrons, while being replaced by solid state devices in many applications, continue in widespread use and are still preferred in certain situations that require reliable operation together with low cost and/or wide mechanical tuning.

Currently available Raytheon klystrons in this category are listed on the following pages. Raytheon recognizes that your particular application may require different performance parameters than those listed, and is willing to provide new designs based upon your specific needs. For further information, please contact your nearest Raytheon Sales Office.

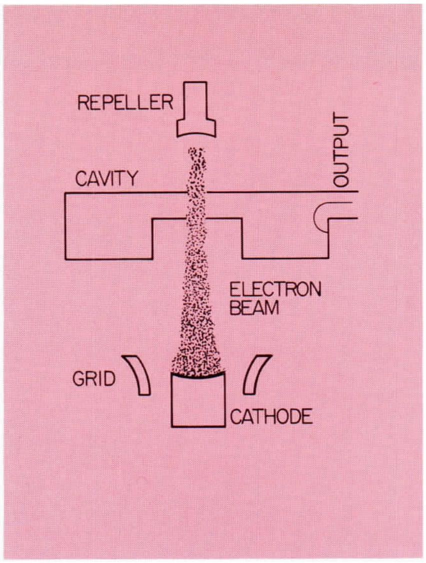


Figure 1.—Reflex Klystron Operation.

Reflex Klystron Operation

Figure 1 is a diagrammatic representation of a typical reflex klystron. In any given tube, oscillation may be obtained with several combinations of resonator and reflector voltages at a given frequency. The regions where oscillations occur within the reflector voltage range are referred to as voltage modes. Figures 2 and 3 show characteristics of a typical local oscillator tube (in this case, the 2K25) in the recommended modes. These modes have been chosen because they represent the best compromise between optimum power and wide electronic tuning range.

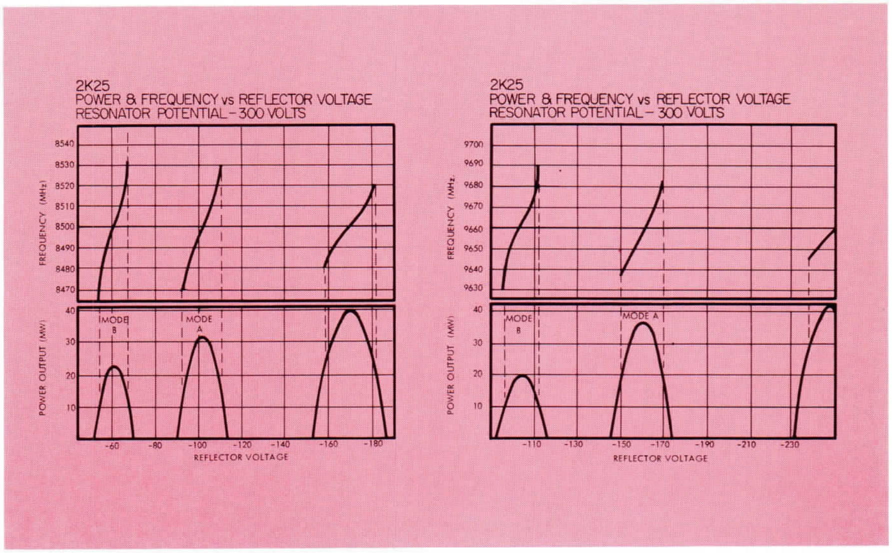
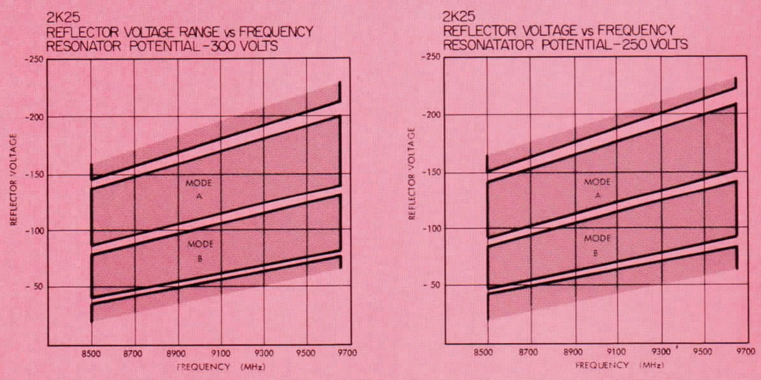


Figure 2.—Average Characteristics of Tubes Designed for use in Modes A or B.



THE EXACT VALUE OF REFLECTOR VOLTAGE, PRODUCING MAXIMUM OUTPUT AT A CERTAIN FREQUENCY, VARIES FROM TUBE TO TUBE, THE VOLTAGE FOR ALL TUBES, AT EACH MODE, WILL FALL WITHIN THE SHADED AREA INDICATED ABOVE.

Figure 3.—Average Characteristics of Tubes Designed for use in Modes A or B.

CW Klystrons

In addition to low power communications and local oscillator klystrons, Raytheon also designs and manufactures CW oscillator and amplifier klystrons for radar, illuminator, and communication service. Diagrammatic representations of these types of klystrons are shown in Figures 4 and 5.

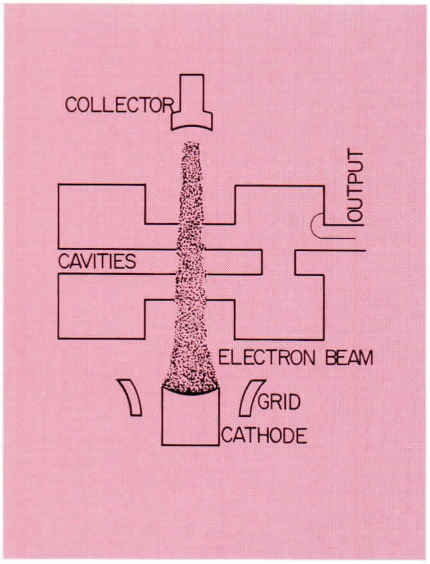


Figure 4.—A 2 Cavity Klystron Oscillator.

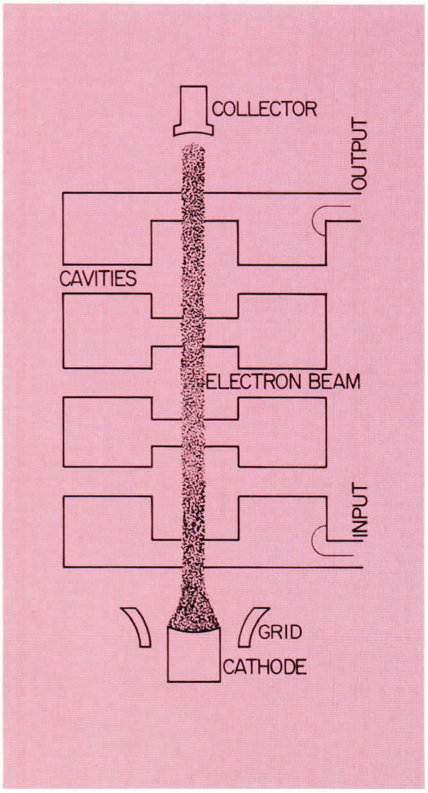


Figure 5.—A 4 Cavity Klystron Amplifier.

Two-Cavity CW Oscillators

Raytheon X-band two-cavity klystron oscillators display very low AM and FM noise sidebands and low thermal coefficients. The rugged, lightweight construction of these compatible, long life tubes provides highly-reliable operation under the most stringent environmental conditions. All tubes are electrostatically focused.

Data on representative non-classified two-cavity oscillators are given below. Other types, both classified and non-classified, are available. You are invited to contact your nearest Raytheon Sales Office for further information.

QKK1802

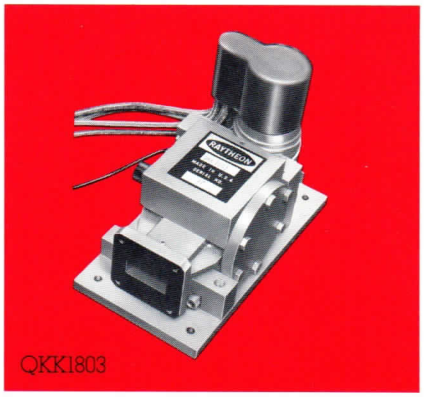
QKK1466

QKK1106

CW Amplifiers

Raytheon offers three-cavity and four-cavity klystron amplifiers with high gain and CW output power up to 5 kilowatts. Tubes are available in the C and X frequency bands.

Raytheon has designed and qualified compact, liquid-cooled, permanent magnet focused amplifiers for service in military radar, illuminator, and communications transmitters. Additional designs are being developed, and existing tubes can be quickly adapted for specialized applications. Raytheon's staff of experienced microwave engineers is ready to assist you in meeting your specific requirements.



QKK1803

QKK1102

CW Oscillators

Tube Type	Frequency (GHz) min.	Frequency (GHz) max.	Power Output (Watts) min.	Power Output (Watts) max.	Beam Voltage (kVdc) min.	Beam Voltage (kVdc) max.	Beam Current (mAdc) max.	Heater Voltage (Vdc) nom.	Heater Current (Amp) nom.	Temp. Coeff. (kHz/°C) nom.	Cooling	Weight Approx. (lbs.)	Tuning
QKK1802	9.2	9.4	0.25	0.5	3.60	4.10	30	6.3	0.7	15	Cond.	15.0	Fixed
QKK1803	9.7	9.9	0.6	1.5	4.32	4.38	35	6.3	0.7	15	Cond.	15.0	Fixed
QKK1106	9.6	10.6	1	5	3.6	4.2	30	6.3	3.2	3.0	Cond.	1.3	Fixed
QKK896	9.6	10.6	50	100	10		100	3.3	6.0	250	Liquid	2.5	Fixed
QKK1102	9.9	10.3	50	100	10		100	3.3	6.0	250	Liquid	3.0	Mech 2.5%
QKK1466	9.9	10.3	180	300	13.6		160	3.5	6.3	250	Ebullient	10	Mech 2.5%
QKK974	10.0	10.3	180	—	13.2	14.0	185	3.3	6.3	250	Ebullient	2.5	Fixed

Communications Klystrons

All tubes operate with 750V on the beam. Adequate cooling is accomplished by air cooling, by use of a heat sink adaptor, or by use of the QK1320A vapor cooling jacket. Very low temperature coefficients result when the probe output klystrons are operated in the QK1320A jacket.

Complete band coverage is also offered with klystrons incorporating a control electrode. Used in an AFC circuit, this electrode can compensate for slow frequency changes with time without introduction of distortion.

All types have a probe output.

Tunable Freq. (MHz)	Tube Type	Tube Type (control electrode)	Coupling Waveguide	Min Power Output (W) Non-control Electrode	Min Power Output (W) Control Electrode
3700-4200	**QKK1288**		WR-229	1.5	
4400-5000	**QKK1289**		WR-187	1.5	
5925-6425	**QKK754A**	**QKK965**	RG-50/U	1.5	1.0
6575-6875	**QKK755A**	**QKK910**	RG-50/U	1.5	1.0
6575-6875	**QKK755B**		RG-50/U	3.0	
6875-7125	**QKK756A**		RG-50/U	1.5	
7125-7750	**QKK758A**	**QKK967**	RG-51/U	1.5	1.0
7750-8400	**QKK759A**	**QKK968**	RG-51/U	1.5	1.0
10700-11700	**QKK1235**	**QKK878**	WR-75	1.0	0.5
11700-12200		**QKK879**	WR-75		0.5
12200-12700	**QKK833A**	**QKK978**	WR-75	1.0	0.5
12700-13250	**QKK1237**		WR-75	1.0	
14400-15200		**QKK882**	RG-91/U		0.5

Communications Klystrons

TYPICAL OPERATION

Tube Type	Mode	Resonator Voltage (V)	Cathode Current (mA)	Reflector Voltage (V)	Power Output (W)	Elec Tuning (MHz)	Ref Mod Sens (MHz/V)	Avg Temp Coeff* (kHz/°C)
QKK754A	2¾	750	68	−280 to −350	2.5	40	0.4	5.0
QKK965	2¾	750	68	−280 to −360	1.3	35	0.35	—
QKK1235	3¾	750	75	−450 to −550	1.2	40	0.45	10.0

* *Tested in QK1320A vapor cooling jacket over temperature range of —30°C to +60°C*

QK1320A VAPOR COOLING JACKET – For use with QKK755B, QKK1288, QKK1289, QKK754A-759A, QKK1235-1239 and QKK833A. With 1½ W tubes a maximum frequency change of 600 KHz is specified for ambient change of —30° to +60°C.

External Cavity Klystrons

For use in coaxial cavities for CW or pulsed operation over wide frequency ranges of an octave or more. Ideally suited for signal generator and special local oscillator applications. Special control grid permits low voltage pulsed operation. Freely circulating or forced air cooling. Long life, low replacement cost.

Tube Type	Frequency Range (MHz)	Power Output (mW typ)	Reflector Transit Mode	Resonator Voltage (V)	Resonator Current (mA)	Reflector Range (V)	Control Grid Cutoff (V)	Control Grid Voltage (V)
6BM6	600-3800	50	1¾ 2¾ 3¾	325	25	—20 to —355	—	—
6BM6A*	600-3800	50	1¾ 2¾ 3¾	325	25	—20 to —355	—	—
RK5837*	600-3800	50	1¾ 2¾ 3¾	325	26	−15 to —575	−10	+10
RK5836*	1600-6500	70	1¾ 2¾ 3¾	300	25	−25 to −550	−10	+10
6BL6	1600-6500	70	1¾ 2¾ 3¾	300	25	−25 to −550	—	—
RK6133*	1800-4000	100	2¾ 3¾	300	30	−50 to −250	—	—
2K28	1800-4000	100	2¾ 3¾	300	30	−50 to −250	—	—
RK6236/QKK1316*	3800-8000	60	2¾	1250	20	−140 to −375	−15	+12
RK5721	4000-11000	60	2¾ 3¾ 4¾	1250	20	—50 to −625	−15	+12
RK6390*	6800-11000	60	3¾ 4¾	1250	20	−140 to −375	−15	+12

* *Recommended for pulsed applications.*


QKK754A


QKK882


RK5721


2K28

Thermally Tuned Klystrons

For remote or automatic electrical tuning over complete frequency ranges. Coupling directly into waveguide through suitable transducers. Freely circulating air provides cooling. Low replacement cost. Wide use in automatic search equipment.

Tube Type	Frequency (MHz)	Power Output (mW typ)	Resonator Voltage (V)	Resonator Current (mA)	Reflector Voltage (V)	Elec. Tuning Range (MHz)	Tuner Power Diss. (W)	Thermal Tuning Time (sec)
2K45	8500-9660	30	300	25	−65 to −145	75	7	6
RK6116	8500-9660	30	300	25	−60 to −145	100	8	2
RK6940	8500-9660	30	300	25	−60 to −145	100	8	2

Low Cost Local Oscillator Klystrons

Low-cost, long-life integral cavity CW reflex klystrons. Particularly suited for local oscillator service in microwave receivers, spectrum analyzers, and as rf source for test purposes. Tunable over wide ranges by simple mechanical means. Vernier or special purpose electronic tuning obtainable. Usually require no more than freely circulating air for cooling. Probe output couples to coax or waveguide transducer.

Tube Type	Frequency Range (MHz)	Power Output (mW typ)	Resonator Voltage (Vdc)	Resonator Current (mA typ)	Reflector Voltage (Vdc)	Electronic Tuning (MHz)	Filament Voltage (V)	Design Feature
RK5981	1245-1460	70	225	35	−45 to −145	5	6.3	Extended frequency cycling
726C	2700-2960	140	300	25	−45 to −165	35	6.3	Occasional frequency adjust.
2K29	3400-3960	110	300	25	−75 to −150	35	6.3	Occasional frequency adjust.
2K56	3840-4460	100	300	25	−85 to −150	35	6.3	Occasional frequency adjust.
2K22	4240-4910	115	300	25	−75 to −235	35	6.3	Occasional frequency adjust.
RK6115A	5100-5900	100	300	25	−85 to −205	35	6.3	Occasional frequency adjust.
RK5976	6200-7425	125	300	25	−75 to −250	35	6.3	Occasional frequency adjust.
2K25	8500-9660	40	300	25	−85 to −200	50	6.3	Occasional frequency adjust.

Rugged Waveguide Klystrons

For use in radar applications where conditions of shock, vibration and sustained acceleration are encountered. No special provisions are ordinarily required for cooling. The waveguide output may easily be fitted with gaskets and inserts capable of insulating the tube from the coupling guide.

Tube Type	Freq. (MHz)	Power Output (mW typ.)	Resonator Voltage (Vdc)	Resonator Current (mA)	Reflector Voltage (Vdc)	Filament Voltage (V)	Base
RK6312	8500-10000	40	300	28	−85 to −225	6.3	Flying Leads
QKK1022	9500-10900	125	350	35	−200 to −300	6.3	3 Pin Pee Wee

Local Oscillator and 100mW Transmitter Klystrons

Operate at 300 V or 400 V resonator voltage. No cooling required at 300 V. Simple heat sinks are adequate for cooling at 400 V. These tubes are also capable of reliable operation at higher voltages for increased power operation or at lower voltages where specified voltage is not available.

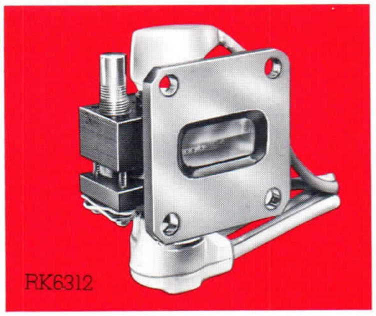
Tunable Frequency* (MHz)	Tube Type	Coupling Waveguide	Min. Power Output (mW)	
			Transmitter Mode	Local Oscillator Mode
4300-5000	**QKK1313****	WR-187	—	30
5925-6425	**QKK549**	RG-50/U	90	40
6200-7425	**RK5976**	RG-50/U	90	40
6575-6875	**QKK531**	RG-50/U	90	40
6875-7125	**QKK532**	RG-50/U	90	40
7125-7650	**QKK623**	RG-50/U	90	40
7125-7750	**QKK752**	RG-51/U	90	40
7750-8400	**QKK753**	RG-51/U	90	40
10700-11700	**QKK826**	WR-75	90	35
11700-12200	**QKK869**	WR-75	90	35
12200-12700	**QKK822**	WR-75	80	35
12700-13250	**QKK877**	WR-75	75	30

** Frequency range is greater than that shown for local oscillator (low power) mode to accommodate typical IF frequency separation.*
*** For local oscillator service only*

TYPICAL OPERATION

Tube Type	Mode	Resonator Voltage (V)	Cathode Current (mA)	Reflector Voltage (V)	Power Output (mW)	Elec. Tuning (MHz)	Reflector Modulation Sensitivity (MHz/V)	Avg Temp Coeff (KHz/°C)
QKK531	2¾	300V	26	−200 to −280	150	25	0.5	.14
	3¾	300V	26	−70 to −150	100	40	2.0	.14
QKK822	3¾	400V	37	−180 to −280	140	35	1.0	.20
	4¾	400V	37	−60 to −160	80	45	2.0	.20


RK5981


RK6312


2K25

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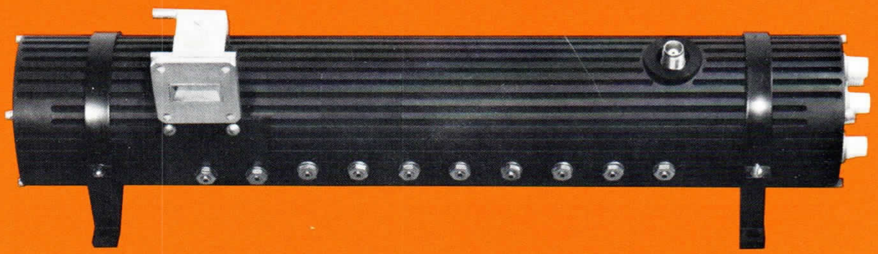
RAYTHEON
TWT'S



Raytheon Company offers extensive experience in research, development and manufacturing of traveling wave tubes for radar, ECM and communication systems. These TWT's cover the frequency range from UHF through millimeter.

RAYTHEON

Traveling Wave Tubes

Introduction

The traveling-wave tube (TWT) is an electronic amplifying device that accepts a weak r-f input signal and amplifies it many thousands of times. In this respect it performs the same basic function as its principal competitors, the triode, crossed field amplifier, and klystron. Unlike these other tubes, however, the TWT can amplify an r-f signal over an extremely wide frequency range. Figure 1 shows a collection of TWT's from Raytheon's product line, including large UHF-Radar tubes with power levels in excess of 200 kW, a 2 KW L-band CW TWT with octave bandwidth, and a variety of small ECM, radar and missile TWT's which represent the state-of-the-art in bandwidth, power output and duty cycle performance.

The basic form of the TWT has changed very little since its invention by R. Kompfner in 1944. The tube, however, saw little practical utilization until the first stable TWT was developed by J. R. Pierce and L. M. Field at Bell Telephone Laboratories about 1945. From 1945 to 1950 most of the theoretical fundamentals for traveling wave tubes were laid down at BTL and at Stanford University.

Bell Telephone Laboratories was interested in the TWT because of its potential application in the communication field. The U.S. Navy, on the other hand, was interested in potential military applications for TWT's in both radar and ECM, since the development of sophisticated deception and jamming techniques. An effective anti-jamming radar, for instance, must be able to shift frequency quickly and, if at all possible, over a wide frequency range, a requirement that TWT's meet admirably. In ECM systems, the TWT's broadband capabilities are needed to amplify wideband noise or to deceptively re-transmit the radar pulse to offset the radar's frequency shift tactics.

The TWT is a most useful amplifier for communications since it operates over wide frequency ranges and can therefore transmit a large number of information channels simultaneously. The quality of this amplification process, in terms of basic signal distortion parameters, is more than adequate for most existing communication requirements.

At the present time, more and more military radar and electronic counter-measure systems, as well as communication systems, are utilizing traveling-wave tubes because of the ever increasing demand for higher power levels, higher frequencies, and wider bandwidths that only the TWT is able to meet successfully. Figure 2 shows a group of missile TWT's for application in the SAM-D and the Active Standard Missile (ASM). A modern octave bandwidth I, J-band ECM TWT is shown in Figure 3, and Figure 4 shows a TWT chain, consisting of a driver tube, isolator, and output tube.

This discussion of traveling-wave tubes was written by Dr. Uwe-Jens Pittack, manager of linear beam tube development of Raytheon's Microwave and Power Tube Division. Dr. Pittack has extensive experience in plasma physics, gas lasers, and spectroscopy as well as in the design and development of microwave tubes. He holds MS and PhD degrees in Physics from the University of Kiel, West Germany.

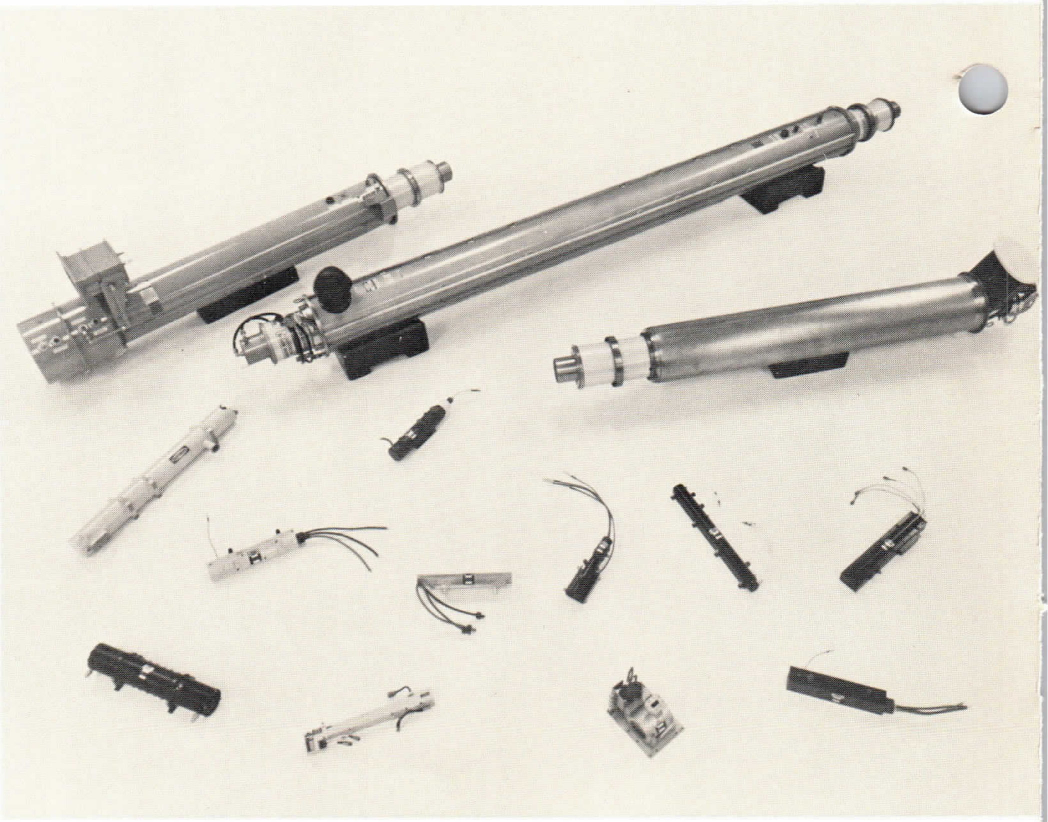


Figure 1.

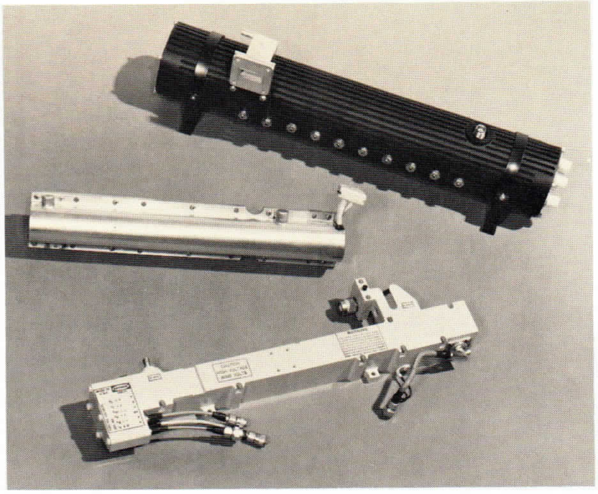


Figure 2.

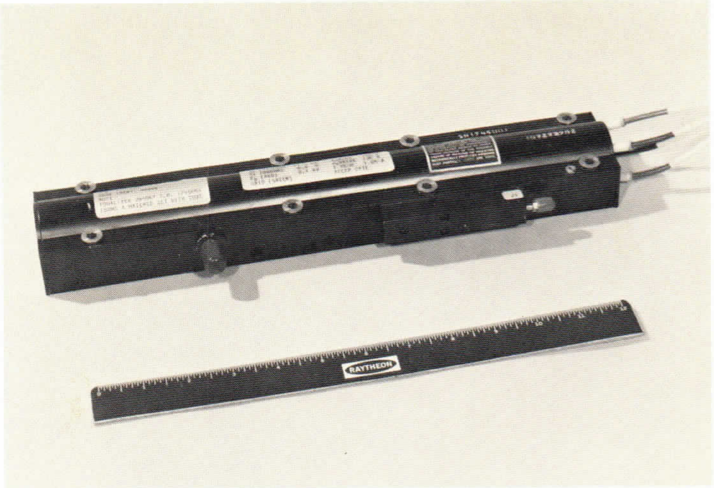


Figure 3.

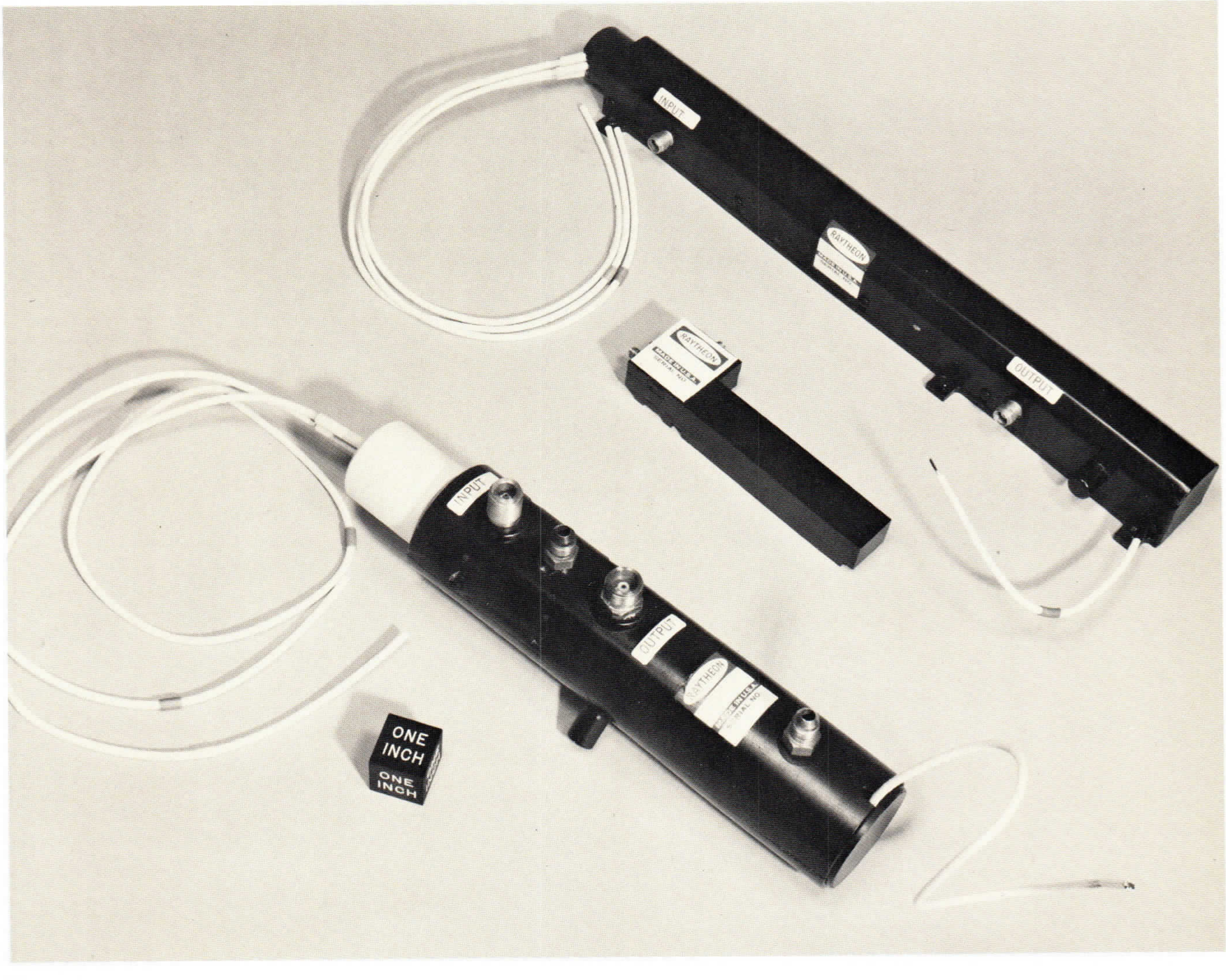
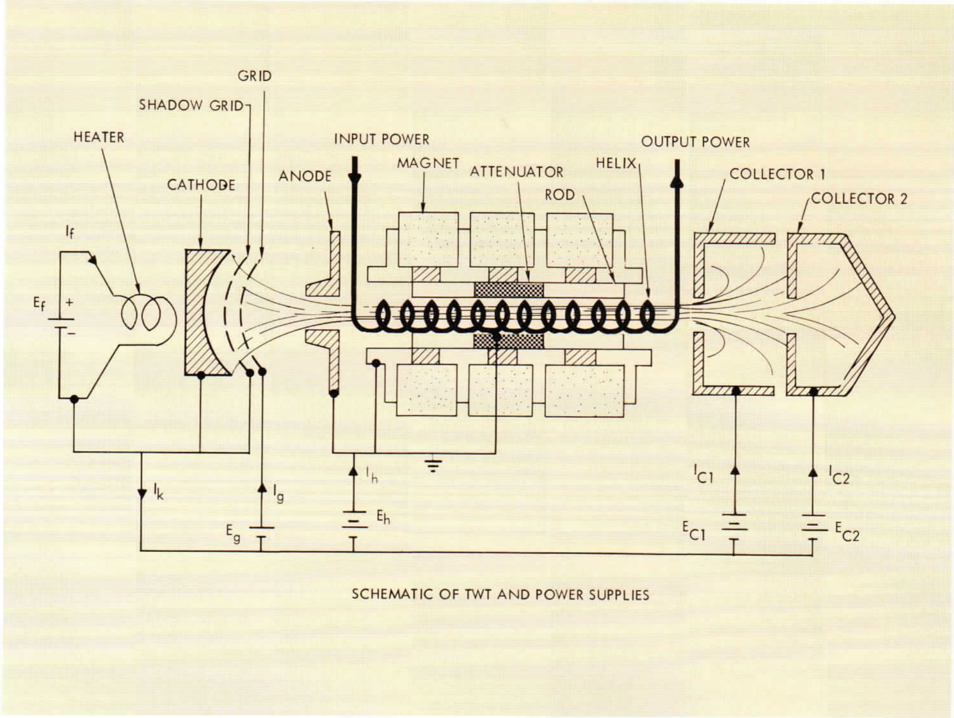


Figure 4.

Traveling Wave Tube Basics

The amplification process in a TWT is an interaction between an electron beam and an r-f circuit wave, both traveling at nearly the same velocity. This type of interaction process, or exchange of energy from moving electrons in an electron beam to the propagating circuit wave, is common to all microwave linear beam tubes. Because of the continuous nature of the electron slow wave structure used, the amplifying process is an accumulative one, beginning at the input of the TWT and continuing throughout the length of the circuit until the output is reached. The non-resonant structure of this interaction circuit, in combination with the cumulative interaction process, results in the extreme wideband capability of the TWT.

The basic elements of a TWT, as shown in Figure 5, are: (1) an indirectly-heated electron gun to create a cylindrical electron beam. (In this case the gun has a grid for pulse operation); (2) An r-f slow wave structure, in this case a helical delay line, to provide an electromagnetic traveling wave for interaction with the electron beam; (3) a focusing system to keep the electron beam from diverging and intercepting the helix. (In this case, a periodic permanent magnet (PPM) system); and (4) a collector to collect the spent electron beam. (In this case, a double depressed collector in order to increase the overall efficiency). Figure 5 also shows the schematic of the power supply components necessary to operate the TWT. Figure 6 shows the actual parts and subassemblies of a typical pulse TWT having a shadow gridded electron gun and four support rods.



SCHEMATIC OF TWT AND POWER SUPPLIES

Figure 5.

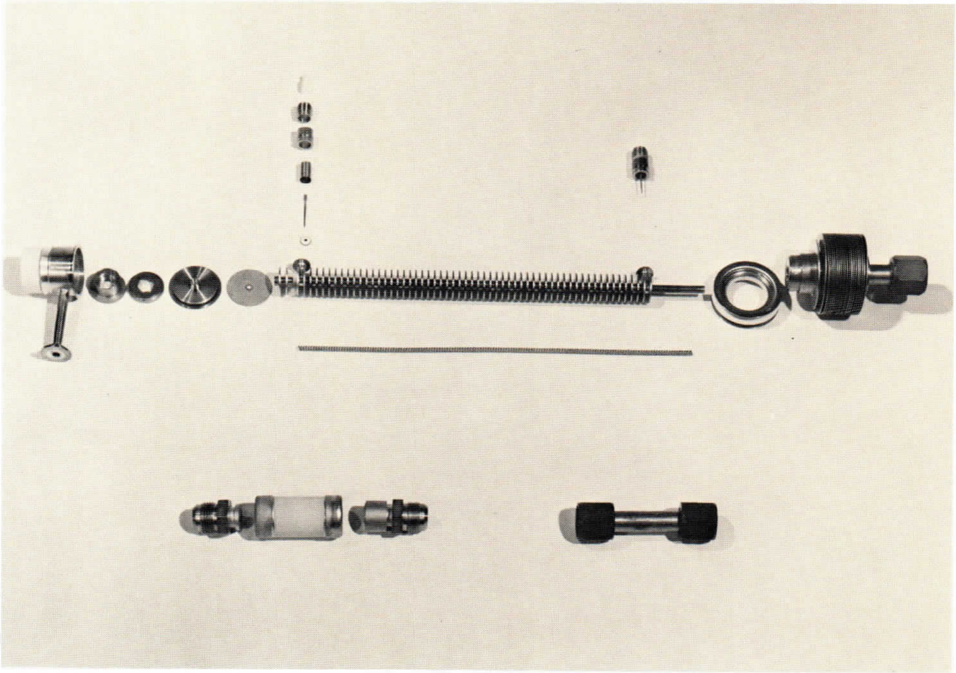


Figure 6.

Electron Beam Formation

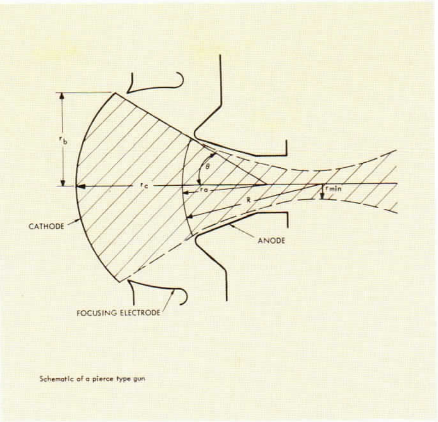
The electron beam necessary for the amplification process is created in the electron gun, which consists of a heater element that indirectly heats a cathode of normally spherical geometry. Heaters are generally made of tungsten wire wound in a bi-filar fashion to prevent heater created magnetic fields from interfering with the electrons leaving the cathode. Heaters are also normally coated with aluminum oxide to prevent an electrical short with the cathode itself.

The purpose of the electron gun is to create an electron beam with a circular cross-section having a certain electron density, and in which all electrons preferably have a uniform velocity. In most traveling-wave tubes this is achieved with the so-called Pierce electron gun, which is based on the electro-optical characteristics of two concentric spheres, as shown in Figure 7.

The design of the Pierce gun is derived from a spherical diode. A core section is removed from the diode, and an aperture is placed at the point where the electrons converge. To keep the electron flow free of transverse motion, the focus electrode is shaped and placed so that it produces field lines along the beam edge that are identical to those of a closed spherically symmetric geometry. The Pierce gun thus produces a rectilinear electron flow through an aperture.

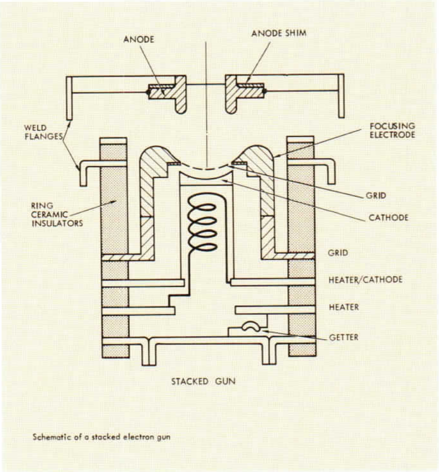
Until recently, development of a Pierce gun required the painstaking accumulation of experimental data obtained primarily through the operation of an electrolytic tank. Use of accurate high speed computer programs has now, for the most part, replaced tedious tank design procedures.

Now let us examine the influence of the anode aperture upon the beam. The anode hole acts as a diverging lens, with the focal length depending on the anode voltage. The convergence of the electron beam when entering the anode hole, and the convergence after passing through the anode entrance are both very important parameters in determining the electron beam minimum cross-section and position, which in turn allows the proper matching of the electron gun to the PPM stack. The beam minimum position and the beam minimum radius, or beam waist, are a function of the ratio of cathode to anode radius and of the initial beam radius at the cathode surface. For instance, leaving the cathode radius constant and moving the anode closer to the cathode will increase the diameter of the anode aperture in order to pass the beam through it, and will, in turn, shift the beam minimum position closer to the anode and increase the minimum beam radius. In the opposite case, moving the anode further away from the cathode results in a smaller anode hole, a smaller beam minimum radius, and a beam minimum position further away from the anode. The basic Pierce-type gun has been modified over the years to meet the requirements of modern TWT's, which often use very sophisticated electron gun and grid configurations such as shadow grid beam control or dual mode operation.



Schematic of a pierce type gun

Figure 7.



Schematic of a stacked electron gun

Figure 8.

A typical gun construction is illustrated in Figure 8. The different electrodes are stacked up together with ceramic insulator rings and then brazed. The basic operation of the electron gun is as follows: The heater is electrically insulated from the cathode and can be operated with either dc or ac current. The cathode is normally at negative voltage with respect to the grounded TWT body. The control grid has a cut-off mode (where it is negative with respect to the cathode) and an operating mode (where it is positive with respect to the cathode).

The function of the grid is to control the quantity of electrons which will pass through the aperture. This is accomplished by first applying a fixed negative bias to the grid, which repels the negatively charged electrons. The electrons are thus "cut-off" from the anode so that no electrons enter the aperture. The second step applies a positive voltage to the grid, opening the door for the electrons to pass through the grid and into the anode aperture. It is the amount of grid voltage (relative to the anode voltage) necessary to allow a certain number of electrons to pass through the anode that determines the "μ-parameter" often referred to in TWT gun design. There is always a certain amount of cathode current intercepted on the grid, normally around 10-15%. This intercepted grid current can heat the grid to an extent where the grid starts to emit electrons itself or can even be damaged.

To prevent grid damage, high power TWT's with high intercepting grid currents operate with so-called shadow grids, an isometric view of which is shown in Figure 9. The shadow grid is located between the cathode and the control grid, and is at cathode potential. The control grid and the shadow grid are geometrically identical, and electrons trying to avoid the shadow grid at cathode potential will not intercept the control grid. Intercepting grids or shadow grids are the most popular methods of controlling the electron beam in pulsed TWT's, since they allow control of the beam with a relatively low positive or negative voltage.

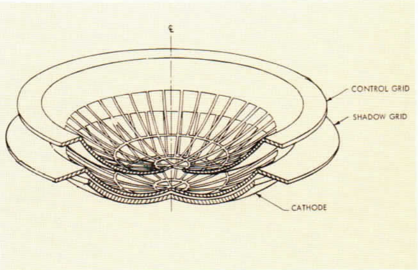


Figure 9.

In the case of non-gridded operation, the electron beam can be turned on or off with the focusing electrode or the anode. This method is used in some CW TWT's. However, a relatively high negative voltage with respect to the cathode is required to turn the electron beam off or on. Some CW tubes also apply a positive voltage to the anode during operation. This positive voltage on the anode prevents positive ions, which are created in the slow wave structure or the collector of the TWT, from returning back into the gun area and poisoning the cathode.

The electron gun, and especially its cathode, is the most important element of a traveling-wave tube since it is the dominant internally active element in the tube and, in most cases, also the life-limiting element.

Cathodes for Electron Guns

The requirements for modern high reliability traveling-wave tubes demand cathodes capable of high cathode current loading combined with long life. Best results can be obtained by using the following types of cathodes; oxide-coated, nickel-matrix, coated nickel-powder, and impregnated tungsten. The recently developed nickel-powder cathode (CPC) is a modified and improved oxide-coated cathode very well suited for use in traveling wave tubes.

Oxide cathodes operate at temperatures between 700-800°C. The basic electron emitting materials are barium and strontium oxides. Cathode current loadings of up to 500 milliamps per square centimeter in continuous operation can be achieved with oxide cathodes. The oxide cathode is very sensitive to the quality of the tube vacuum, and can easily be poisoned by residual gas particles in the tube.

The impregnated tungsten cathode is made of a porous tungsten body which is impregnated with barium and strontium oxides. These impregnated (or dispenser) cathodes can be operated up to 10 amps per square centimeter in continuous operation, and operate at temperatures between 1080-1160°C. The impregnated tungsten cathode is the most rugged type of cathode available since it cannot easily be poisoned by residual gas in the tube vacuum. However, the "dispensing" mechanism of the emitter results in the diffusion of cathode material onto other tube elements, and this may limit tube life.

The CPC cathode is basically an oxide cathode, where the oxide particles are coated with a nickel film and then processed. This coating process results in a partly porous metal structure which helps the cathode to operate at higher currents, and at the same time greatly increases its resistance to poisoning effects. The operating temperature of this type of cathode is between 800-900°C, and cathode current densities of up to 1.2 amps per square centimeter can be drawn continuously. The CPC cathode is utilized in a family of very high reliability, high power radar TWT's, where it provides an operating life of over 50,000 hours.

Under normal operating conditions, the life of a TWT is limited by the life of the cathode. The life of the cathode is, in turn, limited by the operating temperature. Higher current loading requires higher operating temperature, and thus shortens the life of the TWT. For example, a TWT for satellite communication system, where a very long life of up to 10 years is required, operates the cathode with a very low current loading and a very low cathode temperature. Typical loading and temperature values for a cathode in a satellite TWT are 100 milliamps per square centimeter maximum at an operating temperature of 700°C. On the other hand, cathode for very short life missile TWT's can be loaded up to 10 amps per square centimeter because the life of the missile tube is sometimes only a few minutes.

Most missile tube applications require a cathode with a warm-up time less than 3 seconds. These fast warm-up cathodes are derived from regular cathodes by making the operation very efficient from a heat transfer point of view, which can be done by keeping the mass of the cathode to an absolute minimum and by careful selection of the materials involved.

One basic design problem associated with electron guns lies in the fact that every electronic component or device tends to shrink in size with increasing frequency of operation. On the other hand, there is an ever increasing demand for higher frequency which, in turn, results in high power and current densities. For instance, let us compare an S-band TWT with a Ku-band TWT, both at the same r-f output power level. Since its operating frequency is lower, the S-band TWT has the larger r-f structure which, in turn, results in a larger electron beam. In order to achieve the same r-f output power for both tubes, the electron current in the beam has to be the same. To maintain the same electron current in the Ku-band TWT, either the cathode loading or current density has to be increased, or the size of the cathode has to be increased. Both solutions have their limitations. A too high area compression (ratio of cathode area to beam area) will result in a low quality electron beam which can only be focused with great difficulty. Normally, area compression ratios run between 10 and 30 to 1. Area compressions in the range of 50 to 100 to 1 are achievable, but very difficult to realize.

Electron Beam Focusing

The electron beam is the prime power source required for operation, and must be focused with high transmission through the r-f structure of the TWT. If the electron beam is not focused, the repelling forces of the electrons will cause the beam to diverge. In any focusing system, a minimum field is required to keep the electrons within a certain maximum distance from the tube's axis. In other words, the tendency of the electrons to spread out due to radial electric fields must be exactly balanced by the inward force of the axial magnetic field. This equilibrium condition is called Bullouin flow.

There are basically two schemes of confining the electron beam, electrostatic focusing or the more common magnetic focusing. Two magnetic focusing schemes are used — solenoid focusing and periodic permanent magnet (PPM) focusing. Figures 10 and 11 show an unpackaged PPM-focused pulse TWT and a solenoid-focused CW tube respectively. The solenoid focusing system can provide a higher quality of focusing, but it has the disadvantages that an additional d-c power supply is needed and that the volume and weight are high when compared with a PPM system. In most cases, also, a separate solenoid cooling system must be provided.

Solenoid focusing is commonly used on high-power ground-based TWT's, where the total efficiency of the system is not as critical as in, for instance, airborne or satellite applications. There are two practical solenoid focusing formats for TWT's: the integral solenoid with coils of wire or foil wrapped directly on the TWT body, and the independent external solenoid, which remains in the system. For mobile and marine radar systems, the choice of solenoid format normally favors the integral solenoid tube. This is often only half as heavy and requires less than half of the focusing power of the external solenoid combination. On the other hand, overall life cycle costs for large multi-tube radars may dictate the use of specially designed solenoid modules which accommodate more than one tube.

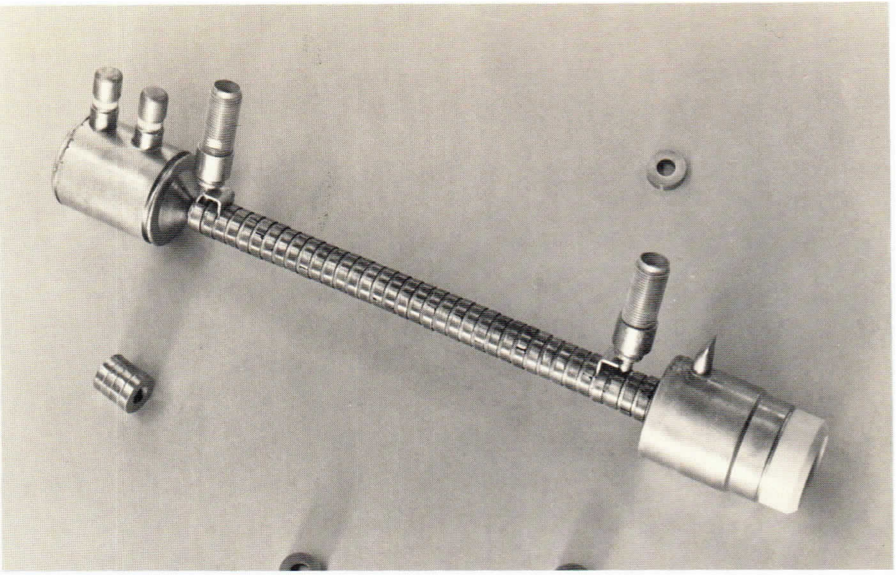


Figure 10.

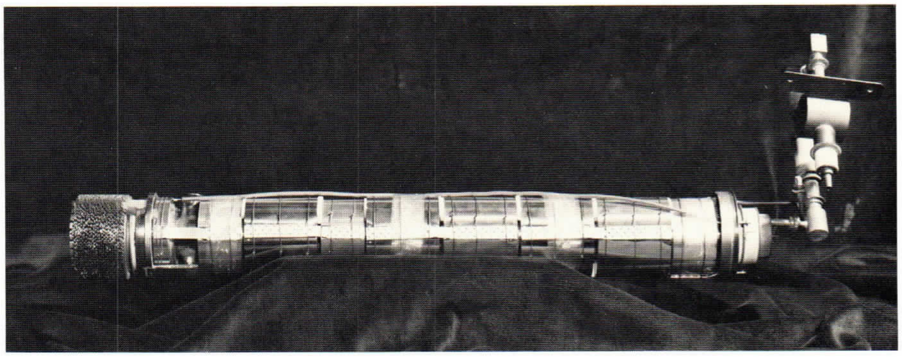
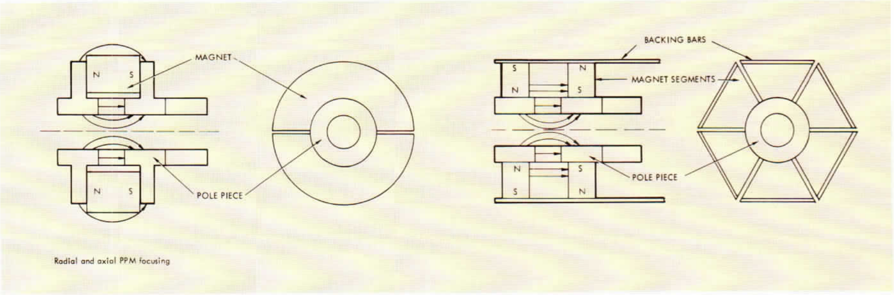


Figure 11.



Radial and axial PPM focusing

Figure 12.

For most modern TWT applications, the PPM system is the preferred focusing scheme. There are two basic PPM focusing structures, axial and radial, as shown in Figure 12. In both approaches the TWT barrel is made up of pole pieces and spacers, and represents part of the vacuum envelope of the tube. The radial focusing scheme uses magnet segments that are mounted to backing bars, while the axial scheme uses split magnet rings. The required magnetic field on the axis of a well designed TWT PPM-stack depends upon the operating frequency and the electron beam voltage and current, which determines the electron beam diameter. (In other words, the electron beam perveance.)

Figure 13 explains a special situation for octave bandwidth TWT's, showing the limits for the most commonly used magnet materials in the two different kinds of PPM focusing structures. For instance, a TWT with a center frequency of 12 GHz and a perveance of 0.3 can be focused by using Alnico 8 magnets or any of the other magnet materials shown. A TWT with a center frequency of 12 GHz and a microperveance of 1.5, however, can only be properly focused by using samarium cobalt magnets. The principal advantage of the radial approach is that lower energy product magnets such as Alnico 8 can be used to achieve higher magnetic fields than in an axial structure. This advantage is somewhat offset by the additional complexity of the assembly and magnetization, and the lack of shunting area when compared with an axial scheme.

It is obvious that the advent of the new samarium cobalt and other rare earth type magnet materials has considerably advanced the state-of-the-art of TWT's. One disadvantage of samarium cobalt is its temperature sensitivity. Heating up a samarium cobalt magnet for the first time results in a certain irreversible loss, while consecutive temperature cycles result only in a certain reversible loss depending on the temperature. If a TWT has to operate over a wide temperature range, compensators have to be used to minimize the magnetic field change due to reversible magnet loss. The quality, or energy product, of samarium cobalt magnets has reached such a high level that the TWT design limitations that were formally found in the energy product of the magnets are now found in the pole pieces. This is because the very high energy product of the magnets tends to saturate the TWT pole pieces so that the field on the axis of the TWT (in other words, the effective magnetic field which focuses the electron beam) is limited by this pole piece saturation. Since TWT requirements are moving upward in frequency and power, it can be seen from Figure 13 that there is a need for higher and higher magnet energy products, since an increase in TWT output power means an increase in beam perveance.

Two basic PPM-focusing structures for a coupled cavity TWT are illustrated in Figure 14. In one case the cavity structure and the iron pole pieces are combined, forming the vacuum envelope of the TWT. This scheme brings the magnetic field closer to the electron beam. A portion of the cavity walls are made from iron that is copper plated to reduce r-f losses. In this configuration a very high magnetic field can be produced on the axis of coupled-cavity TWT's.

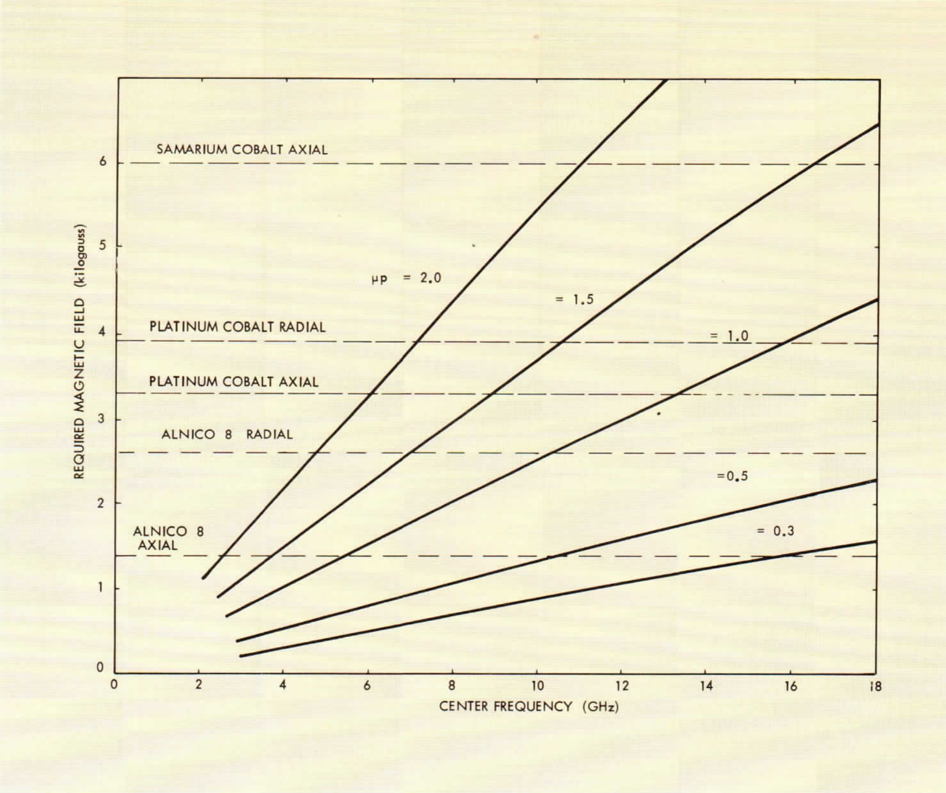


Figure 13.

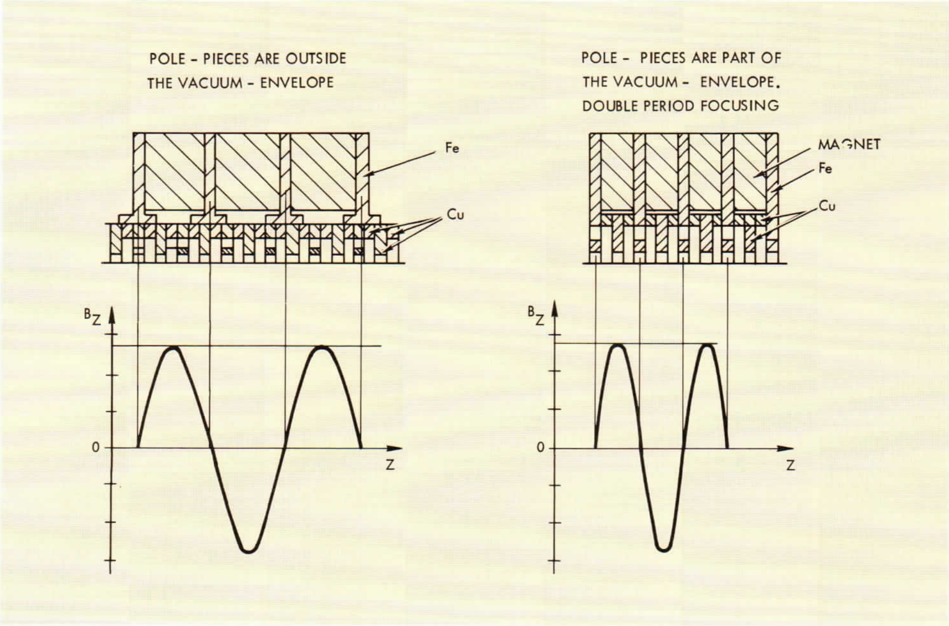


Figure 14.

Collecting the Electron Beam

After the electron beam has passed through the r-f structure, the spent beam is allowed to diverge into the collector. The energy of the beam is transferred into heat by the impact of the electrons on the inner surface of the collector. This transformation creates most of the thermal problems in TWT's, since a proper heat path must be provided to conduct the heat from the inner surface of the collector to a heat sink.

The heat created by the impact of the electrons on the collector surface can be reduced by collector depression, that is, by operating the collector at a potential intermediate between ground and cathode. Collector depression decreases the impact velocity of the electrons hitting the collector surface, which in turn results in less heat. Since depressed collector operation transfers less beam energy into heat, it therefore increases the overall efficiency of operation.

The scheme of depressed collector operation can be extended to dual or triple stage collectors, achieving overall efficiencies as high as 60%. Since electron backstreaming out of the collector has to be minimized, the slowest electrons in the spent beam determine the practical limit for the collector depression. Thus high efficiency tubes, which normally have a large amount of slow electrons in the spent beam, cannot be operated with collectors where all electrodes have large depression values.

Various schemes have been suggested for velocity-sorting of the spent beam to enable efficient collection of electrons with different velocities at electrodes with different potentials. Some schemes use electrostatic fields, others resort to magnetic forces, and still others employ a combination of electric and magnetic fields for velocity sorting. Two very common types of dual stage collector geometries are shown in Figure 15, the deep bucket type and the straight collector. In both configurations the electrons enter a geometry where the electrical field is appropriately shaped such that slow electrons are collected close to the entrance, while fast electrons penetrate deeply into the decelerating field. The limit of collector depression is reached when large amounts of primary or secondary electrons are returned to the interaction space, essentially retracing their original trajectories and causing heat dissipation problems or interference with electron interaction.

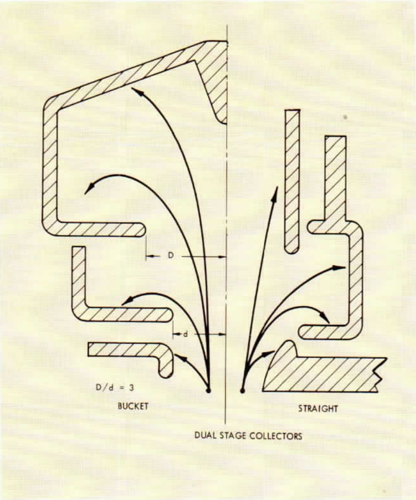


Figure 15.

TWT Slow-Wave Structures

Thus far we have examined three basic parts of the TWT; the electron gun which creates the electron beam, the focusing system which guides the electron beam through the slow wave structure, and the collector which collects the spent electron beam.

The TWT is a velocity synchronous device. That is to say, interaction between the natural electron waves on the electron beam and the microwaves requires that both of these waves travel at nearly identical velocities. The electron beam moves at a velocity of between 0.1 and 0.4 times the speed of light, depending upon the design voltage of the tube. Microwaves, on the other hand, propagate at the speed of light unless they are fed into a propagating structure designed to slow them down. Hence the designation slow-wave structure. With proper beam to microwave velocity mating, wave growth and amplification can take place.

There are basically two types of slow-wave structures; the helix and the coupled cavity, both shown in Figure 16. Several other slow-wave structures have been derived from these two basic concepts and are used successfully in special applications.

The helix circuit is the most useful, as it is able to produce much wider bandwidths than any other slow-wave structure. Bandwidths of two octaves (4:1) have been achieved with helix type TWT's. Many derivatives of the helix circuit, such as ring-bar and ring-loop structures, have been developed. The ring-bar circuit has the advantages of higher coupling impedance (which allows for greater efficiency) and more effective backward-wave oscillation suppression. It has the disadvantages of being more dispersive (thus operating over a narrower bandwidth) and having higher resistive loss per unit length.

The helix, however, is still the optimum wide-band circuit. Since helix geometry does not involve large opposed metal surfaces, the stored energy per unit length is lower than in any other circuit. This means that the helix circuit provides a maximum axial electrical field for interaction with the electron beam, a prerequisite for high conversion efficiency. A drawback of this circuit, when compared with the more massive

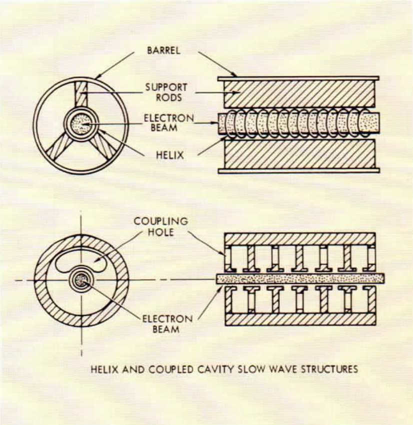


Figure 16.

coupled-cavity structure, is its power handling capability.

The helix is made of either molybdenum, tungsten, or copper tape, and is supported inside the barrel by rods made out of dielectric materials such as alumina, beryllia, boron nitride, quartz, or, very recently, diamond. The slow wave structure is assembled by mounting the support rods on the helix and inserting this helix-rod bundle into the TWT barrel.

Several types of assembly techniques have been developed, such as the triangulation technique, where the TWT barrel is deformed into a triangular shape and the helix support rod bundle is slipped into the barrel. When the pressure on the barrel is released, the barrel springs back into the round configuration, forming a very tight compression fit between the helix and support rods. Another assembly technique is the heat shrink method, where the TWT barrel is placed in an oven and heated to high temperature so the ID is expanded. The premounted helix and rod bundle is then slipped into this expanded barrel which shrinks tightly around the helix support rod structure when cool. For extremely high average power TWT's, the support rods are metalized and brazed to the barrel and helix.

The coupled cavity slow-wave structure, one of the most significant developments in the TWT field, uses basic waveguide mode resonators coupled together by means of capacitive or inductive apertures, as shown in Figure 16. Originally these coupled cavity structures provided a frequency bandwidth on the order of 10-15%. Recently, however, means have been developed to increase the bandwidth to up to 40% and more. The coupled cavity circuit has small bandwidth when compared with the helix, but has the advantages of high power handling capability and mechanical ruggedness.

The coupling element between the cavities is the coupling iris. Coupling from one cavity to another is done by the magnetic component of the electro-magnetic traveling wave. As a result of this, the passband of the coupled cavity circuit becomes a function of the coupling hole size. The larger the hole, the wider the passband. The drift tube for the electron beam is provided by the re-entrant part of the cavity, and its diameter and length are determined by the beam size and operating frequency of the tube. The coupled cavity structure can be manufactured by machining half-cavity sections and brazing them together in a stack. Cooling of the circuit is provided by cooling channels along the structure. Even though the coupled cavity structure is large compared with the helix, the electron beam can still be focused with a periodic permanent magnet structure.

Other important parts of the TWT circuit are the input and output windows. Depending on the tube application and power level, two r-f transitions used: coaxial and waveguide. These r-f input and output windows are a very critical part of every TWT, since they have to fulfill three functions: they are part of the vacuum envelope of the TWT, they have to provide a very good match between the external load and the slow-wave structure inside the TWT, and they must have power handling capability. The most commonly used window materials are alumina and beryllia.

The Amplification Process

Let us now examine what happens if the electron beam travels through a slow-wave structure in synchronism with a sinusoidal r-f signal applied to the TWT input. The sinusoidal input signal travels along the helix structure in the form of a traveling wave, providing an electric field component parallel to the direction of the electron motion. Since the wave and the electrons travel at nearly the same velocity, each electron experiences a force, originated by the electronic field, that travels with the electron. If this interaction process is sustained over a long period of time, it is possible to obtain very high amplification To understand this continuous interaction process, visualize a constant amplitude traveling wave of electric field as shown in Figure 17. Positive E means that the force (F) on an electron is to the left of Figure 17, and negative E means the force is to the right. A uniform distribution of the electrons is visualized, traveling at exactly the same velocity (V) and direction as the wave. If one now imagines oneself as traveling with the wave and the beam, it can be seen that between A and C all electrons will move to the right, and between B and C all electrons will move to the left. Thus within one wave period, from A to B, there will be a tendency for the electrons to form a bunch at C. Similarly, electrons in the half periods on either side of A are moving away from A, which causes an absence of negative charge at A. The process of bunch formation is a cumulative one in that the longer the electrons are subjected to the field, the denser a bunch they form. The charge density of the bunches grows as the square of the distance traveled from the input of the tube, where the electrons are first subjected to the field. The physical picture of the bunching process is also shown in Figure 17.

A bunched beam moving inside an r-f circuit of the type we are considering will, in turn, induce a field on the circuit. The function of the traveling-wave tube amplifier is to extract energy from the electron beam and transfer this energy into the circuit wave, thus making it grow in ampliutude. This process is just the opposite from that of a linear accelerator, where the circuit wave energy is extracted and transferred into the electron beam to accelerate the beam electrons to higher and higher velocities.

The interaction process between the electron beam and the slow wave structure as it has been described so far does not give the complete picture of the modes of propagation that are possible in this type of amplifier. Since the modulation of the electron beam

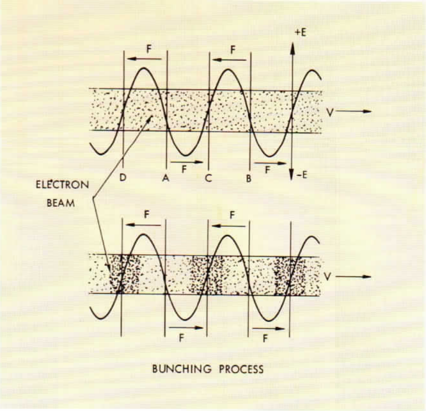


Figure 17.

creates a changing electron density along the electron beam, space charge waves are created. In addition there are also circuit waves that travel along the helix. A cylindrical electron beam surrounded by a slow-wave structure, such as a helix or coupled cavity circuit, predominately supports two space charge waves; one with a phase velocity less than the average electron velocity, and the other with a phase velocity greater than the electron velocity. These two space charge waves are called the slow space charge wave and the fast space charge wave respectively. Each space charge wave has a group velocity equal to, and in the same direction as, the electron beam velocity.

In addition to the space charge waves, a helix traveling-wave tube slow-wave structure also supports two circuit waves. One is traveling in the direction of the electron beam, and is called the forward circuit wave. The other, traveling in the opposite direction from the electron beam, is called the backward circuit wave.

The two space charge waves and the two circuit waves are called the modes of propagation. These modes of propagation can couple to each other. The space charge waves of the electron beam can couple to one another, or to one of the two circuit waves. In a high power TWT the space charge fields are quite intense, causing the velocity of the two space charge waves to be widely separated. As a result, the traveling circuit waves couple strongly with one of the space charge waves and only weakly with the other. A qualitative explanation of the TWT interaction mechanism between electron beam and circuit wave may be given by considering the interaction of these waves in pairs. For instance, the TWT amplification mechanism is based on the interaction of the forward circuit wave with the slow space charge wave, while the backward-wave oscillator or amplifier relies on the interaction of the backward circuit wave with the slow space charge wave.

Helix TWT's, especially those with higher beam voltages, are often plagued by undesirable backward wave oscillations. These oscillations are a serious limitation in achieving higher r-f output power levels. Recently developed fast-wave BWO suppression techniques, which rely on a certain interaction of two propagating modes in order to cancel these BWO oscillations, may help to overcome the currently existing output power limitations.

Other major instability problems associated with high power broadband traveling-wave tubes are forward wave oscillations and resonant circuit oscillations. Circuit instabilities generally arise when the passband of the unwanted oscillation mode is near the operating frequency band of the tube. Since the oscillation modes become higher in frequency as the circuit dimensions decrease, special attention has to be given to circuit design dimensions in high frequency, high power tubes. The prevention of circuit oscillation is generally a trade-off with tube gain and efficiency.

Forward wave oscillations are of the regenerative type, caused by reflected energy within the tube or by external feedback mechanisms. To suppress these oscillations, the impedence matches at the input and output end of the tube and the match of the internal attenuator have to be designed very carefully in order to avoid the reflection of excess energy that can start the oscillation. Oscillations can also be carried externally by improper shielding of a depressed collector, or internally by returning electrons from the collector, which carry the r-f information back to the input of the tube.

There is one item not discussed so far that is also a very important part of the slow wave structure in a TWT, the internal attenuator. An ideal TWT would not require an internal attenuator since it would not have any mismatches on input or output, or internally on the slow wave structure itself. In the real world, these various mismatches exist and we have to provide an internal attenuator in order to provide microwave separation between the input and the output. Attenuators are fabricated by coating the support rods in the helix TWT with a thin layer of carbon that is carefully matched in order not to create any reflections inside the tube. These attenuators completely separate the input from the output so that r-f information is transmitted through the attenuator region by means of the electron beam rather than by the circuit wave. A typical growth of the r-f wave along the tube is shown in Figure 18. Without an internal attenuator, a TWT will oscillate when the gain at the tube exceeds approximately 10 db. The presence of such attenuators has no significant effect on the operation of a well designed TWT except to provide the desired operating stability. The only drawback in incorporating an attenuator is the additional length of tube structure required.

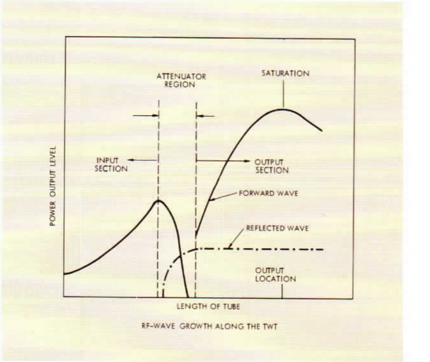


Figure 18.

TWT Characteristics

With an understanding of the interaction processes, let us now examine what happens if we drive the TWT with an r-f input signal. At low r-f drive levels a faithful reproduction of the input signal is found at the output of the TWT, except that there has been a considerable increase in power. The TWT amplifier in this case is a linear device, where the output signal grows in direct proportion to the applied input signal. Above a certain power level, however, an increase in r-f input power will no longer result in a corresponding increase in output power. The TWT's amplification process is then said to be in saturation. If we apply even more input power to the TWT beyond the saturation level, the output power will actually start to decrease. This typical gain characteristic of the TWT can be seen in Figure 19.

The greatest advantage of the TWT in comparison with other microwave tubes, is its extremely wide bandwidth capability. However, there is a limitation to the wide band capabilities of the TWT due to the dispersive nature of the helix structure. In order to make the interaction process between the traveling r-f wave and the electron beam the most efficient, the electron beam velocity is adjusted to be about 10% faster than the r-f wave at midband frequency. from this midband design point, the phase velocity of the r-f wave changes, and the wave and beam start falling out of synchronism. Figure 20 explains this TWT characteristic for both the wideband helix and the narrow band coupled cavity structure. It can be seen that the phase velocity of the helix circuit deviates less from the midband velocity than the phase velocity of the coupled cavity circuit. The de-synchronization of wave and electron beam results in a less efficient interaction, because the electron bunches are not tight and have the tendency to fall apart, with a resulting loss in efficiency and r-f output power.

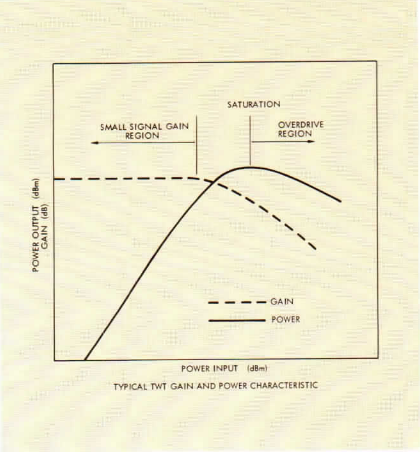


Figure 19.

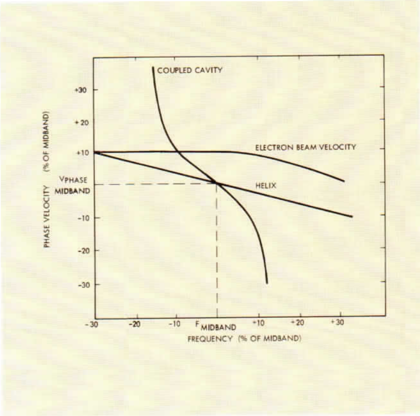


Figure 20.

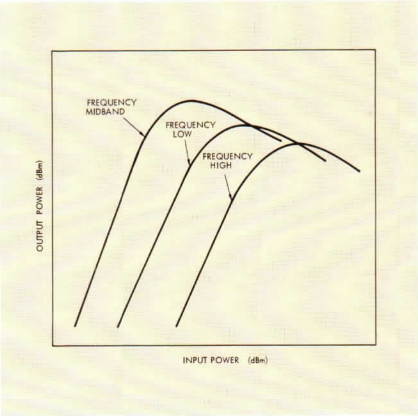


Figure 21.

Another bandwidth limiting effect is due to the variation of the coupling impedance over wide frequency bands. The coupling impedance has to be as high as possible in order to achieve an efficient TWT interaction process. In an octave bandwidth TWT, the coupling impedance can vary by a factor of 10 between the low and the high frequency end. The effect of the de-synchronization between wave and beam and the change in coupling impedance upon the output versus input power characteristic can be seen in Figure 21. Three different curves, for mid, low and high frequency are shown. It can be seen that the saturated output power is highest at midband and lowest at the high frequency end. It can also be seen that a certain specified output power level can only be achieved over a certain drive range, since the gain of the TWT drops sharply when approaching the high frequency end.

TWT Efficiency

Thus far, we have discussed the gain and output power characteristics of TWT's. There is another very important tube parameter, the efficiency, which involves the energy conversion process between the electron beam and the circuit wave.

There are three steps in the process of converting the dc energy of the power supply to the r-f output power of a traveling-wave tube. The electron beam is first accelerated to a specified level of kinetic energy. Next, the electron energy is converted to circuit energy. In this step, the r-f signal to be amplified produces in the slow-wave structure a growing traveling wave that interacts with the electron beam. The electron beam becomes modulated so that a part of its kinetic energy is converted into r-f energy. Finally, the kinetic energy of the spent beam is reduced by depressing the collector potential below that of the slow wave structure. The electrons are decelerated and the beam is collected at a lower potential. The resultant power saving provides additional efficiency enhancement.

It is possible to optimize the design of a traveling-wave tube for maximum efficiency. However, an optimum efficiency design cannot always be achieved in combination with all other requirements, such as power, bandwidth and frequency. As with any design parameter, certain tradeoffs must be considered. A highly efficient tube, for example, requires a high perveance, low convergence gun (which is, in itself, most difficult to obtain).

With respect to improving TWT efficiency, several methods have been devised to overcome a basic limitation of traveling-wave tube interaction. This limitation is the loss of synchronism between circuit wave velocity and average beam velocity in the final stage of the interaction. At large signal levels the power extraction from the electron beam, and consequently the beam's average velocity reduction, becomes so large that the required synchronism between circuit wave and beam is no longer maintained. It is therefore possible to improve the efficiency by re-synchronizing the beam and circuit at large signal levels. One method is to reduce the phase velocity of the circuit wave along the axis at the same rate that the average beam velocity is reduced at the output end of the tube. This circuit phase velocity tapering can be applied continuously if the slow wave structure is a helix circuit, or in several steps in a coupled cavity structure. Velocity reduction in a helix TWT, for instance, can be achieved by reducing the circuit pitch. The effect of a single-step reduction in helix pitch is shown in Figure 22.

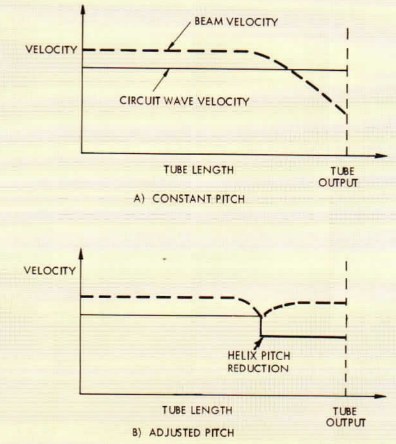


Figure 22.

TWT Signal Qualities

We have seen that the TWT is able to amplify a given signal over an octave frequency range or more, with gain of up to 70 dB and efficiencies of up to 50%. Next let us consider possible signal distortions. A very high signal quality is required for TWT's in communication systems. Most signal distortions are related to phase shift phenomena and the creation of harmonic signals in the TWT, and both are the result of a non-linear behavior at large signal levels.

A TWT slow wave structure has a circuit phase length that is many wavelengths long. This is illustrated in Figure 23A. In an actual helix TWT the circuit can be several tens of wavelengths long, and there are, of course, a larger number of wavelengths on the circuit with increasing frequency of operation. Figure 23B shows the linear relationship between the phase length of the tube and the increase in operating frequency, showing that with increasing frequency the phase length is increasing. The TWT circuit in a tube is not a perfect circuit and therefore does not show a linear dependency of phase length and frequency. The imperfections on a helix circuit, such as pitch variation or attenuator discontinuity, lead to mismatches and wave reflections which cause the phase length to vary as shown in Figure 23C. These perturbations are more or less pronounced depending on the amount of internal reflections and the gain of the tube. The result at the output end of the TWT is a change in phase length that in turn results in a gain ripple across the band, as shown in Figure 23D.

Another factor that influences the phase length of the TWT is the beam voltage. A small change in beam voltage can cause a considerable phase change due to the fact that the helix circuit contains such a large number of wavelengths. This dependency is shown in Figure 24 for two different TWT types. The beam voltage causes the largest contribution to the phase shift, but is not the only voltage that can cause phase variations. Voltage variations such as the grid voltage in a pulse TWT or the anode voltage in a CW TWT can cause the beam current to fluctuate and also cause phase shift.

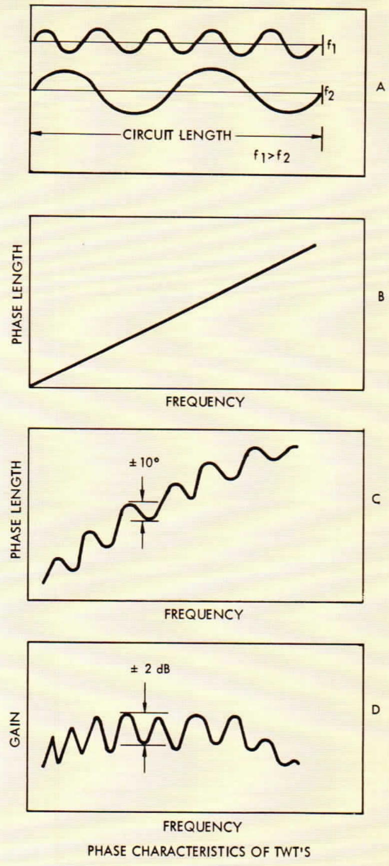


Figure 23.

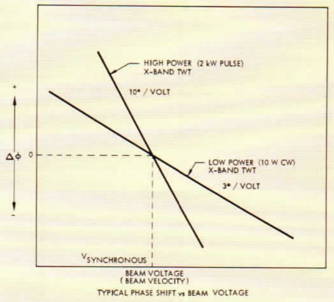


Figure 24.

Another parameter that effects the phase characteristic is the change in input drive power level. The drive power level directly effects the velocity distribution of the electron bunches and therefore result in a phase change. This phase change can be seen as a relative phase shift when comparing the input phase with the output phase of the TWT. This relative phase shift is small in the small signal region of the tube and grows as the saturation level is approached. This is to be expected, since the greatest velocity change of the electron bunches occurs in the large signal area, which in turn results in the strongest effect on the phase shift. A typical phase shift curve versus input power is shown in Figure 25, in comparison with the output power versus input power. Typical phase shift occurs at a rate of 3-5°/dB change of input power when the TWT is operating in the linear region.

Phase shift in TWT's leads to AM/PM conversion, which is the ratio of amplitude modulation to phase modulation. Any amplitude modulation that is imposed on the input signal will also appear on the output signal, and is accompanied also by phase modulation. A typical AM/PM curve versus input power level is shown in Figure 26. It can be seen that the maximum AM/PM conversion normally occurs about 6 to 7 dB below saturation.

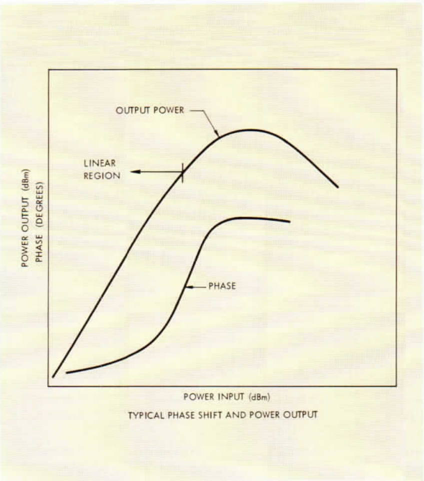


Figure 25.

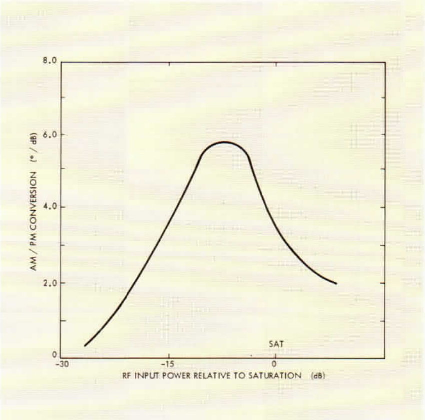


Figure 26.

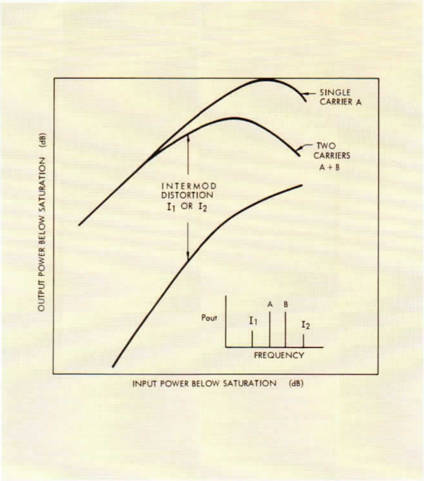


Figure 27.

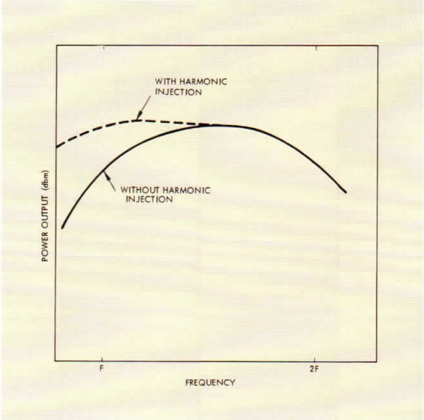


Figure 28.

It was pointed out before that the TWT is a non-linear amplifier, and that its non-linearity increases when approaching saturation. This leads to two other unwanted phenomena, harmonic signals and intermodulation distortion. Harmonic signals, which are frequency multiples of the fundamental signal to be amplified, are generated with increasing amplitude when the TWT is operated in the non-linear region. In the small signal region, the harmonics are negligible. The harmonic power generated can sometimes exceed the fundamental power, and the tendency to generate harmonics is strongest at the low frequency end of a wideband TWT. The generation of harmonic power, especially second harmonic power, is generally an unwanted effect. However, if harmonic power is introduced with the r-f signal at an appropriate phase and amplitude, the efficiency of the TWT can be improved. This process is called harmonic injection, and is basically a cancellation process where the injected harmonic signal is 180° out of phase with the harmonic signal created by the non-linear behavior of the TWT. The result of harmonic injection is an increase in fundamental output power of the TWT and a decrease of harmonic power output. In a broadband TWT, this injection process is only important and effective at the low frequency end, since only the harmonic frequency of the low end frequencies lies inside the amplification band. The effect of a properly adjusted harmonic injection method on an octave bandwidth TWT can be seen in Figure 27.

Another unwanted effect, created by the non-linear behavior of the TWT, is intermodulation distortion. The intermodulation process takes place when two or more signals are amplified simultaneously, resulting in intermodulation products that are displaced in frequency on the high and low side of the original carriers. The power level of these intermodulation products depends upon the drive level of the TWT, or, in other words, on the degree of the non-linearity of the power output versus drive curve. For the case of two equal amplitude carriers, the intermodulation distortion is shown in Figure 28. In order to avoid excessive intermodulation products, which is of great importance for communication TWT's, the tube has to be operated in the small signal region. The supression of excessive intermodulation products can be done by a method similar to the harmonic injection process. Again, a signal which is 180° out of phase and has the proper amplitude can be injected at the frequencies of the intermodulation products. A reduction in the intermodulation power level will permit operation of the TWT closer to saturation with higher useful conversion efficiency.

In addition to signal distortions and harmonic power generation, there is also noise generated by the TWT. This noise is broadband, or white, noise and is generated by thermal velocity distributions, beam fluctuations, and current distributions on the delay line. The measure of noise contributed by a given TWT is called its noise figure, which is the ratio of the signal to noise ratio at the input compared with the signal to noise ratio at the output. Low noise TWT's have a noise figure of less than 10 dB; communication TWT's with low temperature cathodes have a noise figure of 20 to 25 dB, while TWT's with high temperature impregnated tungsten cathodes have noise figures of 35 to 40 dB.

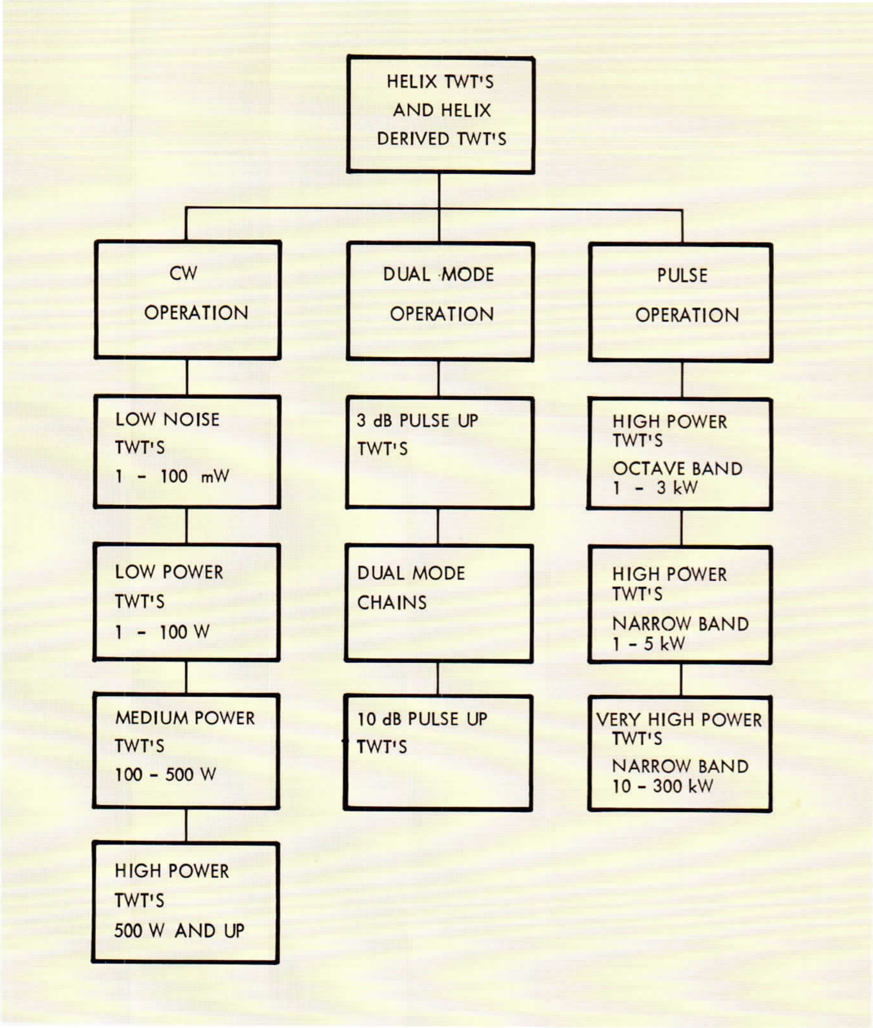


Figure 29.

Present State-of-the-Art in TWT's

Over the years the TWT tube type family has grown extensively in reaction to given system requirements. It is difficult to make up charts that clearly show the state-of-the-art of all TWT's with respect to output power, frequency, gain, efficiency, etc. With some simplifications, however, certain groups of TWT's can be discussed and the state-of-the-art of these groups can be shown. It is convenient to divide the tubes into coupled-cavity TWT's and helix TWT's, and then group them together according to their application, such as ECM, radar, or communications.

Figure 29 shows the basic members of the helix TWT family. In this family we have the pure helix TWT and also those TWT's which are derived from the helix circuit, such as folded helix TWT's, ring bar, or ring loop structures. Helix TWT's can be subdivided according to their mode of operation; CW, pulse, and dual mode.

The CW group of helix tubes starts out with the low noise tubes. These tubes cover the frequency range from one to forty GHz and operate over an octave bandwidth with power levels between one and one hundred mW. The tubes have wide dynamic range and, of course, a noise figure that is as low as possible. Noise figures of 7 dB can be achieved in the 4 to 8 GHz frequency range, but as frequency increases, the noise figure also increases. A low noise TWT in the frequency range from 18 to 26 GHz has a noise figure of approximately 18 db. Low noise TWT's are usually PPM focused and conduction cooled. Their major application is in preamplifiers for ECM systems, communication systems, and related types of applications.

The CW low-power TWT group has its major application as driver tubes for high power ECM TWT's or in communication applications. Most of the TWT's used in satellite communication systems are low power CW tubes of 1 to 20 watts, with power outputs of 20 watts at X-band and 4 watts at 30 GHz. Low power CW tubes are able to cover an octave frequency range if the application is in ECM, or a smaller band if the application is in a communication system.

Most are PPM focused and conduction cooled. Tubes of this type for satellite communications are available with lifetimes exceeding 10 years.

The next category of CW tubes is the medium power TWT group. Tubes in this group have power output levels between 100 and 500 watts, depending on their frequency of operation. They are used mostly as final amplifiers for high power noise in ECM systems. These tubes normally cover an octave bandwidth and have wide dynamic ranges. The state-of-the-art in this group is around 200 watts in I, J band, with higher power levels available at lower frequencies. Medium power TWT's are PPM focused and conduction cooled. The state-of-the-art is shown in Figure 30.

High power CW TWT's, from 500 watts and up, are also used in ECM systems. These tubes are solenoid focused and liquid cooled in order to handle an electron beam that can produce power levels of up to 2 kW CW (Figure 31). The state-of-the-art for these tubes is also shown in Figure 30.

It can be seen from Figure 30 that the higher power tubes are solenoid focused, and also that the efficiency of these tubes drops with increasing frequency. The expected future state-of-the-art for these tube categories is shown with a dashed line.

On the other side of the helix tube family is the high-power pulse TWT. This type can be broken down into three groups; the high-power octave bandwidth TWT, the high-power narrow band TWT, and the very-high-power narrow band TWT. The high-power pulse TWT with octave bandwidth coverage is able to achieve peak power levels between 1 and 3 kilowatts. This tube is generally PPM focused and conduction cooled, and its major application is in deception ECM systems. The narrow-band version of this octave bandwidth, high power tube was developed for radar and missile applications. Since these TWT's do not have to cover a full octave bandwidth, the peak power level can be extended

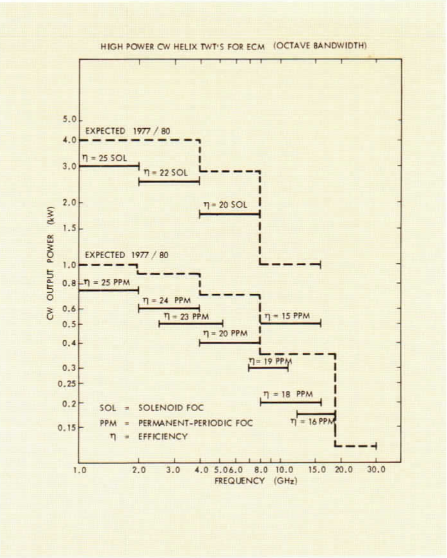


Figure 30.

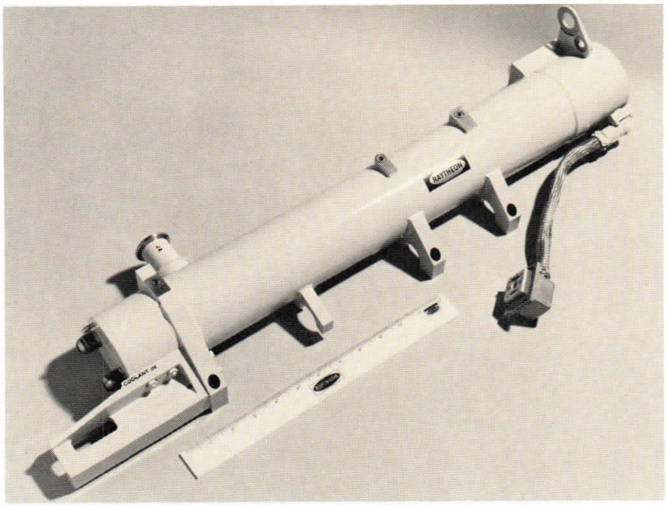


Figure 31.

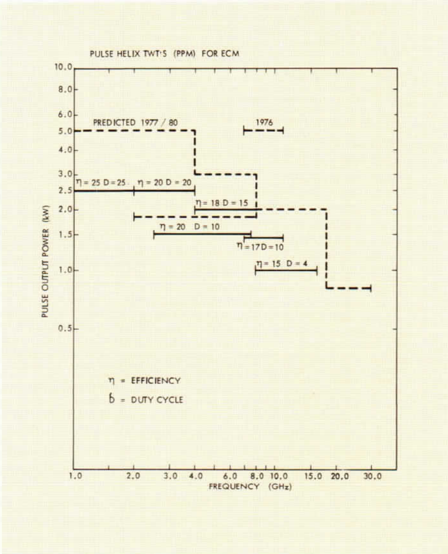


Figure 32.

up to 5 kilowatts. Ring bar and ring loop circuits are also included in this category. These tubes are conduction cooled and PPM focused. The state-of-the-art for high-power pulsed helix TWT's is shown in Figure 32. It can be seen that this tube type has a decreasing efficiency and duty cycle with increasing frequency. Predictions on output power with frequency for this tube group are shown in Figure 32 by a dashed line. Some typical pulse TWT's are shown in Figure 33.

Another important group of pulse TWT's is the very-high-power TWT with output power levels from 10 to 300 kilowatts (Figure 34). These tubes utilize ring bar or ring loop circuits, and are solenoid focused. They have been developed to meet the stringent phase stability and 30,000 hour MTBF reliability requirements of very large array-type systems. Their bandwidth, gain, and efficiency have made them directly applicable to sophisticated shipboard and transportable systems.

Certain ECM systems require both CW noise output power and high peak pulsed power for deception service. This requirement has been accommodated in the past by using "chains" of tubes. The principal dual mode chains are shown in Figure 35. There are basically two types of chains. The first uses a CW TWT and a pulse TWT in parallel, combined in a hybrid. The other uses a CW TWT in series with, and isolated from, a transparent TWT that has a gain of only 10 db.

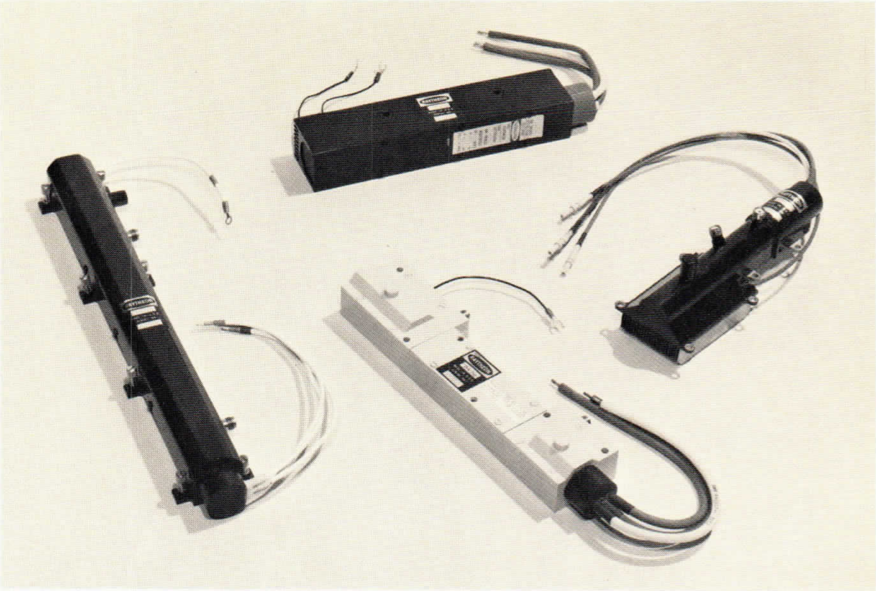


Figure 33.

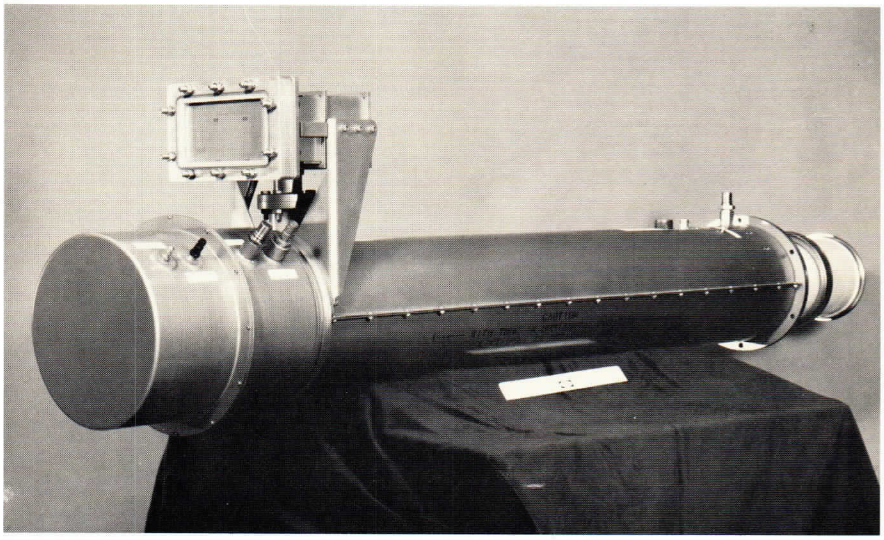


Figure 34.

In order to avoid the complexity of these dual mode chains, attempts are under way to develop a single helix-type TWT that is capable of running in the CW mode and also in the pulse mode. This so-called dual mode TWT requires 3 significant new developments: First, a slow wave circuit that offers octave bandwidth coverage in both the CW and the pulse mode. Second, an electron gun which, through low voltage changes, can provide an electron beam that can be focused efficiently at the two greatly different beam current levels required for dual mode operation. And third, a 10 db pulse-up capability.

Even though a 10 db pulse-up capability seems to be required, at the present state-of-the-art the industry can supply only 3 db pulse-up TWT's. For instance, the state-of-the-art in octave bandwidth coverage in G, H-band for dual mode operation is presently 150 watts CW and 300 watts pulsed.

Pulse-up capability and power level increase with decreasing frequency. In the frequency range

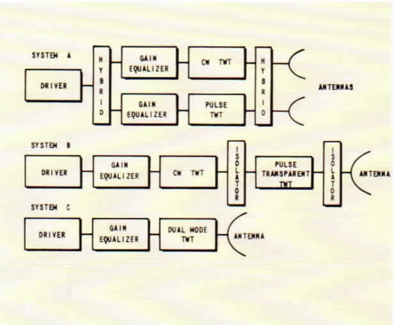


Figure 35.

from 2 to 4 GHz, 4 db pulse-up capability from 400 watts CW to a kilowatt pulsed is available. Dual mode TWT's with a 10 db pulse-up capability are expected to be available in three to four years. In the meantime, the dual mode chain is still very attractive to systems designers. The state-of-the-art in dual mode chains can be characterized by tubes in the I, J-band frequency region which have a pulse-up capability of 10 db running at power levels of 1 kilowatt to 10 kilowatts.

The coupled cavity TWT family can be divided into three major groups: PPM focused, solenoid focused CW, and millimeter, as shown in Figure 36. In comparison with the helix TWT, the coupled cavity tube is generally heavier and bigger and also runs at considerably higher beam voltages, which makes the power supply more complex. The coupled cavity TWT is restricted in bandwidth, even though 40 to 50% bandwidths have been achieved. On the other hand, the coupled cavity TWT is able to handle much higher average power than the helix tube. Coupled cavity tubes are used in ECM systems, airborne radar systems, ground-based satellite communications stations, and, in general, in almost every type of radar, ECM, or communication system.

Figure 37 shows the state-of-the-art for PPM focused, coupled cavity TWT's. For the application of this TWT it is important to have available both as much peak power and as much average power as possible. The curves in Figure 37 are shown for extremely high beam voltages, 60 to 70 KV. If the beam voltage on this type of coupled cavity TWT is lowered, the output power versus frequency curve shifts in the direction indicated by the arrows.

The state-of-the-art for CW coupled cavity TWT's that are solenoid focused is shown in Figure 38.

The state-of-the-art for the third group of coupled cavity TWT's, the millimeter tubes, has been advanced considerably over the last few years. These coupled cavity tubes have been built at 150 GHz with peak power levels of over 1 kilowatt, and at 100 GHz with 1 kilowatt of average power.

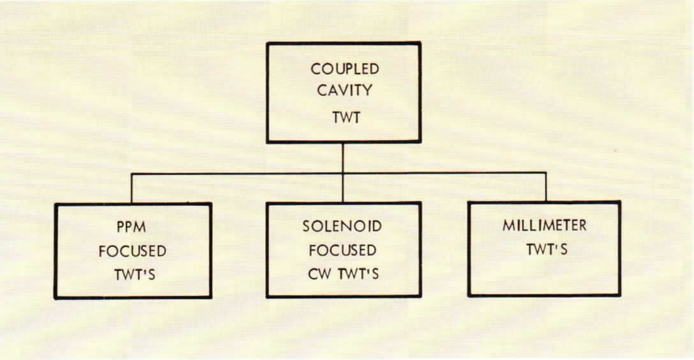


Figure 36.

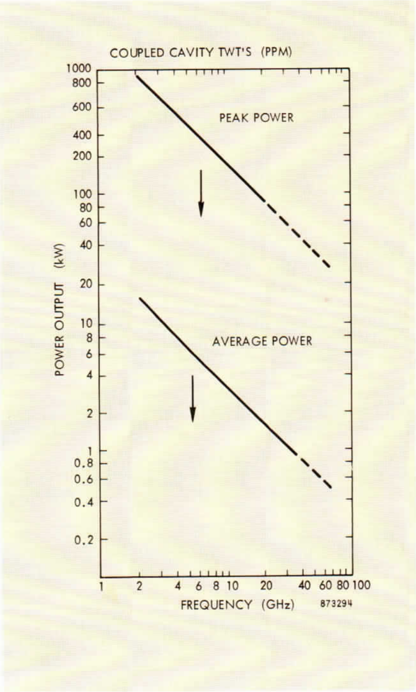


Figure 37.

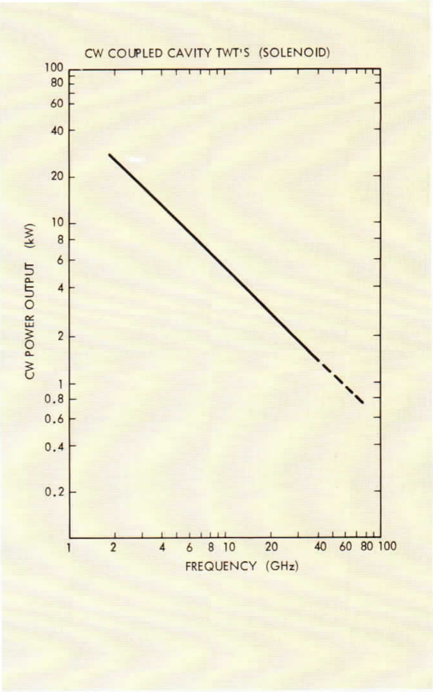


Figure 38.

The Future

There are several areas in which the state-of-the-art of helix TWT's will be advanced in the near future. These advances will be achieved by using new ideas and technologies developed at Raytheon. For instance the Fast Wave BWO Suppression technique will allow the designer to push the high power pulse, octave bandwidth TWT's into the 10 KW output power range in I, J-band.

New helix support materials such as diamonds will create high average power and CW TWT's with octave bandwidths and output power levels of several KW CW in J-band and several hundred watts CW in K-band.

The pulse up performance of dual mode TWT's will be improved to 10 db and move over octave frequency ranges with dual mode TWT's presently under development at Raytheon.

Inquiries about these developmental tubes should be directed to Raytheon Company, Microwave Tube Operation, 190 Willow St., Waltham, MA 02154.

Broad Band TWT Amplifiers

Band	Tube Type	Freq. (GHz)	Peak Power* (kW)	Max. Duty (%)	Min. Gain (db)	Focusing	Modulating Electrode
L (D, E)	QKW1643	1.45- 2.55	1.7	CW	30	SOL	MA
S (F, G)	QKW1633	2.7 - 5.4	1.0	3.0	40	PPM	IG
X (I, J)	QKW1634	2.7 - 5.4	8.0	3.0	10	PPM	IG
	QKW1600	7.0 -11.0	20.0	5.0	10	SOL	NIG
	QKW1704	7.0 -11.0	3.0	10.0	60	PPM	NIG
	QKW1784	7.0 -11.0	5.0	4.0	50	PPM	NIG
	QKW1458	7.0 -12.0	1.5	2.0	40	PPM	IG
	QKW1734	7.0 -12.0	2.5	2.0	60	PPM	IG
	QKW1389	7.4 -12.0	2.5	4.0	10	PPM	IG
	QKW1652	9.1 - 9.9	2.5	1.5	60	PPM	IG
	QKW1668	8.0 -16.0	2.0	4.0	45	PPM	IG
	QKW1810	8.0 -18.0	1.5	4.0	50	PPM	NIG

**Specification minimum value*

Modulating electrode:

IG — intercepting grid
NIG — non-intercepting grid
MA — modulating anode

Focusing:

PPM — periodic permanent magnet
SOL — solenoid

High Power TWT Amplifiers

Band	Tube Type	Freq. (GHz)	Peak Power* (kW)	Duty Cycle	Pulse Width (μsec)	Min. Gain (db)	Beam Voltage (kV)	Beam Current (A)	Length (in.)	Nom. Dia. (in.)	Weight (lbs.)
UHF (B)	QKW1630	0.42-0.48	240	.05	500	40	41	16	128	10	350
L (D)	QKW1518	1.2 -1.4	160	.036	200	45	40	13	74	10	110†
	QKW1671A	1.2 -1.4	160	.036	200	45	40	13	75	12	240
	QKW1815	1.25-1.4	200	.034	100	46	43	16	75	12	260
S (F)	QKW1593	3.1 -3.5	125	.02	500	50	40	12	55	15	120

**Specification minimum value*
†Plus solenoid

NOTE: Heater power, all types, 110 watts
Integral solenoid all types except QKW1518, external

The ratings and descriptions given represent only some of the currently available, non-classified types.

If your specific requirements are not found in these listings, please contact your nearest Raytheon Sales Office.

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RAYTHEON LOW & MEDIUM POWER TWT'S

Raytheon now offers the complete RCA line of low and medium power TWT's, including loop tubes and miniaturized TWT's, to meet a wide variety of ECM and communications applications.

RAYTHEON

Low & Medium Power TWT's

As an addition to its long-established capabilities in higher power TWT's, Raytheon now offers the complete RCA line of low and medium power TWT's, including loop and miniaturized tubes. These TWT's are specifically designed to meet a wide variety of ECM and communications applications, and are backed by complete engineering and production facilities devoted exclusively to these tubes.

Miniaturized TWT's

The Raytheon line of miniaturized Traveling-Wave-Tubes (MINI-TWT's), incorporates samarium-cobalt magnets and features outstanding performance as well as small size and weight. Volumes are as low as 3 cubic inches and weights are as low as 7 ounces. Intended for airborne applications as amplifiers in EW systems, where size and weight are critical considerations, Raytheon MINI-TWT's provide 10 to 50 watts of RF power output in the frequency range of 2.5 to 18 GHz and have bandwidths greater than one octave.

The miniature tubes use depressed collector operation for improved overall DC-to-RF efficiency, and have a conduction-cooled heat sink. Specifically designed for side-by-side operation with minimum interaction between adjacent tubes, they are particularly suited for applications in phased-array systems. A typical tube has a cross-section only one-half inch in width and one inch in height, including the RF coupler housing.

Raytheon has made a major effort to obtain improved reliability, thermal stability, and tube-to-tube consistency in the MINI-TWT line. This includes the ability to obtain full DC-to-RF operation without noticeable power fade even at the 30-watt RF power output level. Such capability is achieved with only a modest cost increase (in production quantities) over standard traveling-wave tubes.

Loop Tubes

Traveling-wave tubes for loop-memory subsystems must provide RF storage capability while operating with the required passive delay components in the feedback loop. To accomplish this, it is necessary for the traveling-wave tube to meet the following prerequisites:

1. Produce small-signal gain contour which complements the delay line loss.
2. Maintain excess gain spread and gain contour with temperature variation over operating environment.
3. Provide storage operation over the memory period with ±5% variation in helix voltage and ±5% variation in collector voltage, over the normal range of temperature variation.
4. Meet the requirements mentioned above over a wide input pulse power range.
5. For the in-line loop, meet the specific system interface characteristics as an amplifier between the input and final traveling-wave tubes in the chain as well as RF storage.

Raytheon offers a wide variety of both "in-line" and "off-line" traveling-wave tubes that meet these requirements.

Major Application Areas

ECM Systems: Raytheon specializes in providing traveling-wave tubes for the low-level input amplifier stage, recirculating rf memory (loop) stage, and the driver stage of electronic counter measure systems. Raytheon medium-noise traveling-wave tubes meet the diverse and opposing requirements of low noise and wide dynamic range for the input amplifier stage of ECM systems. These tubes cover the L-Ku frequency band and have noise figures from approximately 12 to 20 dB. Where desirable, tubes can be prepackaged with delay lines, power dividers, and integral power supplies as complete subsystems.

Communications Systems: Recent developments in X and Ku common carrier and Community Antenna Distribution systems have led to the production of a family of 10- and 20-Watt communication TWT's. These tubes incorporate the latest design advances to assure long life and reliability at an economical price.

Subsystems: Raytheon can provide solid-state power supplies (designed to MIL-E-5400) integral with traveling-wave tubes or as separate units. The power supplies can be either of the field or depot repairable form, depending on the application. Controlling the interface between the traveling-wave tube and the power supply can reduce the total cost for the system and/or result in improved tube performance. Power alarm and monitoring circuits can be customized to your specific needs with quick reaction capability.

Typical Operating Characteristics of Loop Tubes

Performance Mode	Frequency Band	Storage Time	Power Level	SS Gain
In-Line	S	5 μsec approx.	∿1 - 4 W	35 dB
In-Line	C	5 μsec approx.	100 mW - ½ W	40 dB
In-Line	X	5 μsec approx.	100 mW - ½ W	40 dB
In-Line	X-Ku	5 μsec approx.	½ W	60 dB

Miniaturized Traveling-Wave Tubes

Raytheon Type Number	Replaces RCA Type	Frequency Range GHz	RF Output Saturated W	Gain Small Signal dB	Noise Figure dB	Heater		Collector		Helix	
						Voltage V	Current A	Voltage V	Current mA	Voltage V	Current mA
QKW1930	A1485	2.6- 5.2	24	40	35	6.3	1.0	1200	120	2100	8.0
QKW1931	A1483	4.0- 8.0	10	40	35	6.3	1.3	2000	60	2100	6.0
QKW1932	A1464	5.0-10.0	5	35	30	6.3	1.25	2300	50	2200	4.0
QKW1934	A1481	5.2-10.4	26	40	35	6.3	0.6	1300	100	2500	8.0
QKW1935	A1487	7.0-17.0	10	50	35	6.3	0.4	1700	70	3000	5.0
QKW1936	A1465	8.0-16.0	10	30	30	6.3	1.25	2400	60	3800	1.0
QKW1937	A1484	8.0-18.0	10	45	35	6.3	0.35	1700	60	3300	6.0
QKW1938	A1478	8.0-18.0	16	40	—	6.3	0.4	2000	75	3000	8.0
QKW1939	A1486	10.4-18.0	20	40	35	6.3	0.5	1800	95	3000	8.0
QKW1940	A1480	11.0-18.0	20	40	—	6.3	0.3	1800	75	3200	8.0
QKW1941	A1497	4.6- 5.4	45	45	35	6.3	1.25	1600	110	2350	16.0

NOTES: 1. All tubes ceramic metal construction. 2. RF connectors, all tubes: SMA. 3. Tubes normally furnished with flying leads. 4. All tubes periodic-per
P — Phased Array. E — ECM.

Medium-Power Traveling-Wave Tubes (10W and above)

Raytheon Number	Replaces RCA Type	Frequency Range GHz	RF Output (Saturated) W	Gain (Small Signal) dB	Noise Figure dB	Heater		Collector		Helix	
						Voltage V	Current A	Voltage V	Current mA	Voltage V	Current mA
QKW1924	A1317	0.75- 1.0	20	30	23	6.3	1.3	1550	60	1650	0.5
QKW1901	7642	1.7 - 2.3	18	28	—	6.3	1.3	2000	70	2250	0.7
QKW1922	4054	1.7 - 2.7	17	29	—	6.3	1.3	2000	70	2250	0.1
QKW1921	4079	10.7 -11.7	10	41	28	6.3	0.9	2400	45	3700	0.5

NOTES: 1. All tubes periodic-permanent-magnet focusing. 2. Tubes normally furnished with flying leads.

Low-Power Traveling-Wave Tubes (9.9 watts and less)

Raytheon Type Number	Replaces RCA Type	Frequency Range GHz	RF Output Saturated W	Gain (Small Signal) dB	Noise Figure dB	Heater		Collector		Helix	
						Voltage V	Current A	Voltage V	Current mA	Voltage V	Current mA
QKW1903	A1381	2.0 - 3.85	0.02	35	—	6.3	0.7	550	4.0	400	1.0
QKW1904	A1384	2.0 - 3.85	1.0	37	—	6.3	1.4	1200	34.0	1000	2.0
QKW1923	A1310	2.0 - 6.0	3.0	40	30	6.3	1.3	900	45.0	1600	0.5
QKW1927	A1468*	2.5 - 8.5	2.0	38	28	6.3	1.0	1500	30.0	2100	2.0
QKW1926	A1358	3.0 - 8.0	2.0	35	30	6.3	1.3	900	45.0	2000	2.0
QKW1905	A1382*	3.85- 7.4	0.003	30	20	6.3	0.24	650	0.3	470	0.3
QKW1906	A1385	3.85- 7.4	0.1	38	—	6.3	0.29	950	8.0	830	1.0
QKW1916	A1360*	4.0 - 8.0	0.01	35	15	6.3	0.24	720	1.0	670	0.1
QKW1929	A1379	7.0 -11.0	0.03	30	—	6.3	0.24	1350	3.0	1200	2.8
QKW1919	A1438*	7.0 -16.0	0.003	35	15	6.3	0.20	1150	0.5	1050	0.1
QKW1907	A1383*	7.4 -12.0	0.005	33	20	6.3	0.24	1050	0.5	900	0.1
QKW1908	A1386	7.4 -12.0	0.2	40	—	6.3	0.2	950	12.0	1800	0.5
QKW1920	A1476*	8.0 -16.0	0.5	55	—	6.3	0.3	2300	11.0	2300	1.0
QKW1918	A1360V2	4.0 - 8.0	0.01	35	15	6.3	0.24	720	1.0	670	0.1
QKW1917	A1301V3	2.0 - 4.0	1.0	35	—	6.3	1.4	1200	34.0	1000	4.0
QKW1915	A1301V4	2.0 - 4.0	1.0	35	—	6.3	1.4	1200	34.0	1000	4.0

NOTES: 1. Types marked with asterisk (*) are ceramic-metal construction. 2. All tubes periodic-permanent-magnet focusing. 3. Tubes normally furnished with
L — Loop.

In addition to the tubes listed herein, Raytheon is developing new types to supplement the existing former RCA line. Information on classified types to meet specific program requirements is also available upon receipt of proper security clearance and evidence of need to know.

Complete details of any of the Raytheon line of low and medium pow obtained thr Raytheon sa the back pa

Anode Voltage V	Control Grid	Dimensions (Excludes Connectors) inches L	W	H	Weight Approx. lbs.	Application
3800	Yes	10.0	0.75	1.0	1.0	P, E.
2400	Yes	10.0	1.0	1.0	0.8	
2250	No	8.0	1.0	1.0	1.0	
3500	Yes	8.0	0.6	0.85	0.6	P, E.
2900	No	10.0	0.5	1.0	1.0	P, E.
2450	No	8.0	1.0	1.0	1.0	
2300	Yes	9.0	0.63	1.35	0.75	
2900	Yes	7.0	0.5	1.0	0.6	
3400	Yes	7.0	0.6	0.85	0.6	P, E.
2800	Yes	7.0	0.5	1.0	0.6	P, E.
1150	Yes	11.87	0.95	0.98	1.0	E.

nanent-magnetic focusing.

Anode Voltage A	Control Grid	RF Connectors	Dimensions (Excludes Connectors) inches L	W	H	Weight Approx. lbs.
1400	No	N	20.0	2.19	2.13	5.0
1375	No	N	20.5	3.12	3.88	6.5
1400	Yes	N	19.0	3.12	3.88	6.5
2250	No	WR-75	13.3	3.75	3.8	9.2

Anode oltage V	Control Grid	RF Connector	Dimensions (Excludes Connectors) inches L	W	H	Weight Approx. lbs.	Application
200	Yes	SMA	12.3	1.56	1.56	2.0	
1100	No	SMA	13.0	1.69	1.31	3.0	L
1300	No	TNC	15.4	1.87	2.0	3.0	
1600	Yes	SMA	14.0	1.5	1.65	3.3	
1000	No	TNC	15.2	1.87	2.0	3.0	
300	Yes	SMA	12.0	1.5	1.5	1.6	
800	No	SMA	13.0	1.25	1.25	1.6	L
300	No	TNC	12.0	1.5	1.6	2.0	
350	Yes	½ RG-320	13.0	4.0	2.5	5.0	L
350	Yes	SMA	12.0	1.25	1.25	1.6	
350	Yes	SMA	12.0	1.5	1.5	1.6	
1050	No	SMA	13.1	1.25	1.25	1.6	L
1000	Yes	SMA	14.0	1.0	1.0	1.6	L
300	No	TNC	12.0	1.25	1.6	2.0	
1050	No	SMA	13.0	1.6	1.31	3.0	L
1050	No	TNC	13.0	1.6	1.31	3.0	L

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