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TRAVELLING WAVE TUBE DESIGN FOR SURVEILLANCE AND SECURITY OPERATIONS IN NIGERIA

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ABSTRACT

This paper concerns the adaptation and engineering design analysis of various types of Travelling Wave Tubes (TWTs) and their applications for intelligence and security operations. The major adaptive designs and their applications include the RADAR TWT design that requires high peak power, moderate bandwidth, and cooling fan that can be achieved by helix or coupled cavity slow-wave structures. The Electronic Counter Measure design requires high peak power, high continuous wave and a bandwidth wider than RADAR TWT. It uses coupled cavity circuit when the power requirement exceeds the capability of helix-type circuits. The Missile TWT design requires minimal size and weight, moderate bandwidth, high efficiency and reliability that utilize unique cathode heater designs. The instrumentation TWT design for laboratory and test equipment incorporates a control grid that can be used to turn ON and OFF TWT beam current. The Communication TWT design needs high reliability, efficiency, linearity, moderate power output and bandwidth that has helix slow-wave circuit, multiple stage depressed collector and conduction cooling. This design showed that the acceleration can be caused by the interactions with the helix and it allowed the TWT to produce a very low noise output. Again, these designs are less sensitive which allowed the TWT to operate over a wider variety of frequencies. These various designs of TWT can be used to monitor, track, block, arrest and attack terrorists, arm robbery, kidnapping, and other types of insurgences speedily, successfully and accurately.

Keywords: Travelling Wave Tube, Era of Terrorism, Engineering Design, Surveillance, and Security Operation.

INTRODUCTION

The Travelling Wave Tube (TWT) is a high-gain, low-noise, wide-bandwidth microwave amplifier. It is capable of gains greater than 40dB with bandwidths exceeding an octave. The wide-bandwidth and low-noise characteristics make the TWT ideal for use as a radio frequency amplifier in microwave equipment.

The Travelling-wave Tube (TWT) (A. Choffrut et al., 2003) is a microwave tube of special design using a broadband circuit in which a beam of electrons interacts continuously with a guided electromagnetic field to amplify microwave frequencies.

Microwave frequencies are generally identified as frequencies above 500MHz. At microwave frequencies the familiar circuit theory concepts no longer apply and it is necessary to use electromagnetic theory to describe the electric and magnetic fields that exist in electromagnetic waves. The operation of the TWT depends on the interaction of a beam of electrons with an electromagnetic wave.

The TWT contains an electron gun which produces and then accelerates an electron beam along the axis of the tube. The surrounding magnet provides a magnetic field along the axis of the tube to focus the electrons into a tight beam (I.I. Ezebuiro et al., 2015). The helix, at the center of the tube, is a coiled wire that provides low impedance transmission line for the radio frequency (RF) energy within the tube. The radio frequency input and output are coupled onto and removed from the helix by waveguide directional couplers that have no physical connection to the helix. The attenuator prevents any reflected waves from travelling back down the helix.

The electron beam bunching already starts at the beginning of the helix and reaches its highest expression on the end of the helix. If the electrons of the beam were accelerated to travel faster than the waves traveling on the wire, bunching would occur through the effect of velocity modulation. Velocity modulation would be caused by the interaction between the traveling wave fields and the electron beam.

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Bunching would cause the electrons to give up energy to the traveling wave if the fields were of the correct polarity to slow down the bunched (W.E.Garrigns et al., 1975). The energy from the bunched would increase the amplitude of the traveling wave in a progressive action that would take place all along the length of the TWT.

The Travelling wave tube amplifier (TWTA) (A. S. Gilmour, 2011) is TWT integrated with a regulated power supply and protection circuit. It is used to produce high power radio frequency signals. The bandwidth of a broadband TWTA can be as high as one octave with operating frequencies range from 300 MHz to 50 GHz. Broadband TWTAs generally used a helix TWT, and achieve less than 2.5 KW output power. TWTAs using a coupled cavity TWT can achieve 15 KW output power, but at the expense of bandwidth.

All these configurations can be adapted and designed for warfare systems for intelligence and security purpose such as the radar, Electronic Counter Measure (ECM) space surveillance and missiles for tracking, monitoring, jamming and attacking.

LITERATURE REVIEW

The basic form of the TWT has changed very little since its invention by in 1944, although the performance of these devices today is at least an order of magnitude better in all attributes.

The history of microwave technology is a history of progressive advances in the techniques used to generate, amplify, and process signals at microwave frequencies (J. Copeland et al., 2015). Operation at the threshold of the microwave region was provided by triodes that employed special geometries to minimize transit time effects. This was followed by the magnetron and other crossed-field devices, then by the klystron and today by the travelling-wave tube (TWT) (A. S Gilmond 2011). Unique combination of bandwidth, power output, and gain from electronic warfare to space exploration and to the relaying of home-video signals, the TWT has expanded the microwave horizon.

The TWT is not a new device. Its remarkable capabilities and some of its potential applications have been known for nearly fifty years. It was invented during the latter part of World War II by an Austrian refugee while working on microwave tubes for the British Admiralty (M. Chodorow et al., 1964).

The TWT was not utilized during that war and remained an experimental laboratory device until the first practical tube was developed at the Bell Telephone Laboratories (BTL) in 1945. The first details were published in the IRE Transactions of February 1947.

From 1945 to 1950, most of the development work was done at BTL and Stanford University. By present-day standards, these efforts were relatively low key. BTL, in particular, was interested in the TWT because of its potential application in the communication field.

The military services had other potential applications in mind, radar and electronic counter measures. The development of radars during World War II had been rapidly followed by the development of counter measure techniques to deceive and jam them. The evolution of new radars has, therefore, been partially the result of a continuous need to stay ahead of any new counter measure tactics which might compromise the radar's effectiveness and vice versa. The trend in search radar has been toward much higher powers and towards new techniques which would have the effect of increasing visibility even while being jammed good anti-jamming radar must be able to shift frequencies over a wide bandwidth quickly to avoid dwelling at the jammer's source frequency.

THEORY

The Travelling Wave Tube is a microwave device operating at a high frequency range of electromagnetic radiation (A. S. Gilmour, 2011).

Microwaves exhibits several properties of visible light; they travel in straight lines at the speed of light and are only minimally refracted by the earth's atmosphere and they can be focused into narrow beams which are subject to complete reflection when they impinge upon a conducting surface. These properties make microwave especially useful for radar and telecommunications systems. There are also devices called microwave amplifiers.

Within the frequency range of interest, two technologies (M. Steer 2010), (vacuum tube and solid-state electronics) are used to generate and amplify microwaves. Each offers advantages for specific applications within the performance domain of radio frequency (RF) systems (see Figure 1).

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Microwave power tubes (the principal product derived from RF vacuum electronics) are preferred for applications requiring both higher frequency and higher power. Electron transport in a vacuum conveys so many advantages to microwave power tubes such features as wide band performance, efficiency, high gain, thermal robustness, and radiation hardness. Alternatively solid-state power amplifiers combine the power from many transistors. The advantages of charge transport in a solid state media result in compact devices, competitive efficiency and bandwidth at lower frequency and power. Figure 2 shows the various vacuum devices in the industry within the Microwave Tube general family.

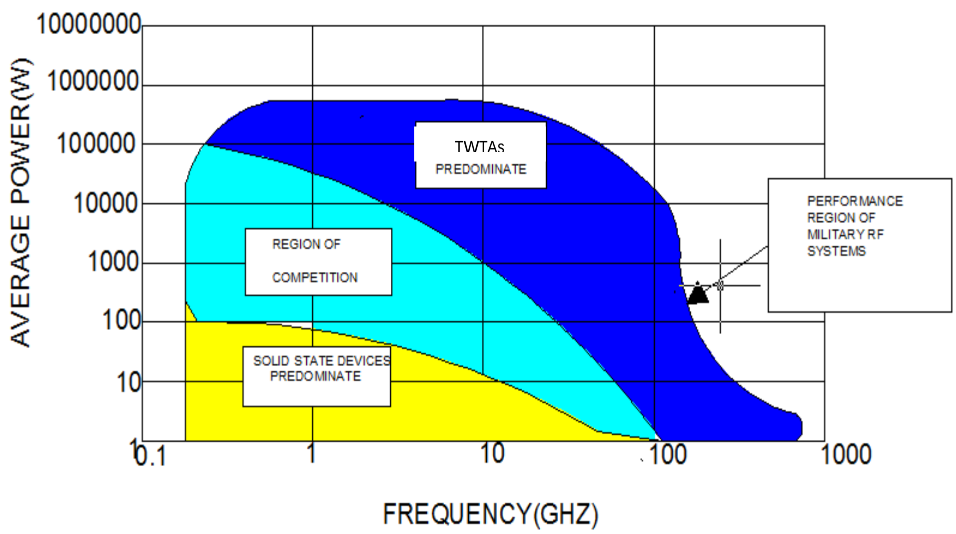

Figure 1: Ranges of applications of microwave TWTs and TWTAs and solid state power amplifiers (SSPA)

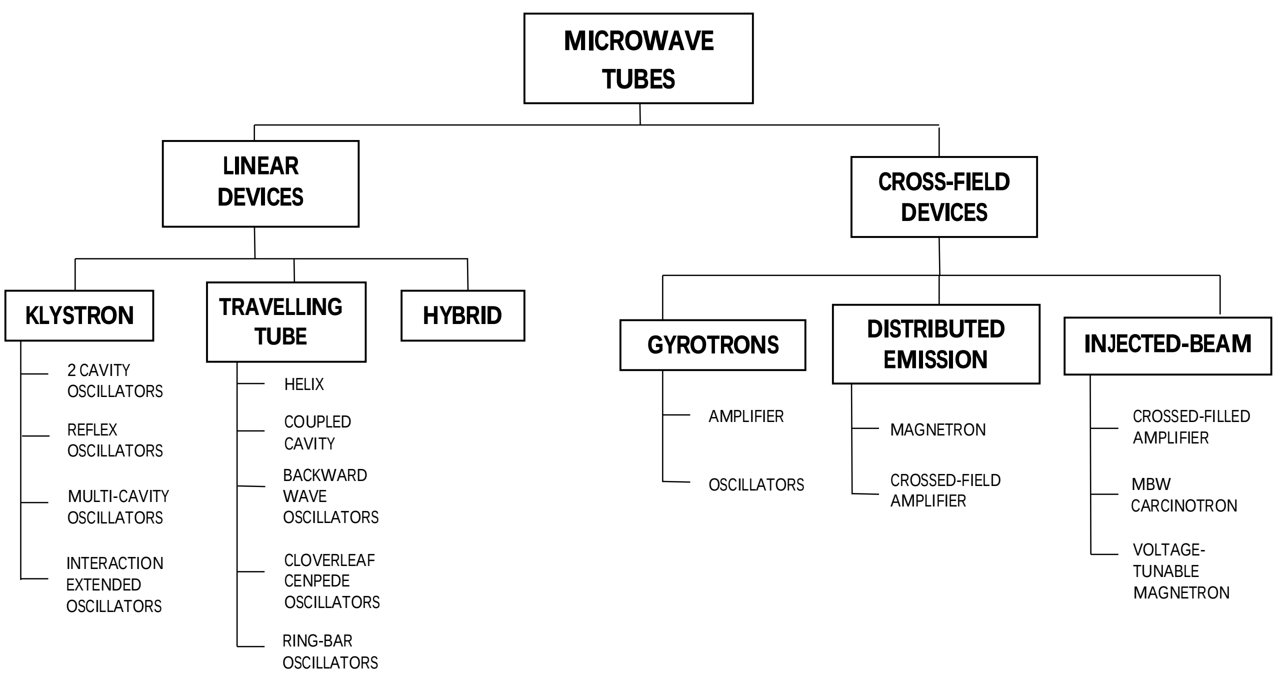

Figure 2: The summary of various types of microwave tube families

Travelling Wave Tube Design for Surveillance and Security Operations in Nigeria

MATERIALS AND METHODS

The materials, design and operation of the TWT are now presented.

MATERIALS

All TWTs components (A.S. Gilmour, 1994) possess four subassemblies as follows:
An electron gun that produces a high density electron beams.
A microwave slow-wave circuits that supports a travelling wave of electromagnetic energy with which the electron beam can interact.
The collector that collects the spent electron beam emerging from the slow-wave circuit.
The TWT package, which provides points for attachment to the using system, providing cooling for power dissipated within the TWT, and in some cases, includes all or part of the beam focusing structure. Other functions may also be included as required.

SCHEMATIC DESIGN OF THE TRAVELLING WAVE TUBE

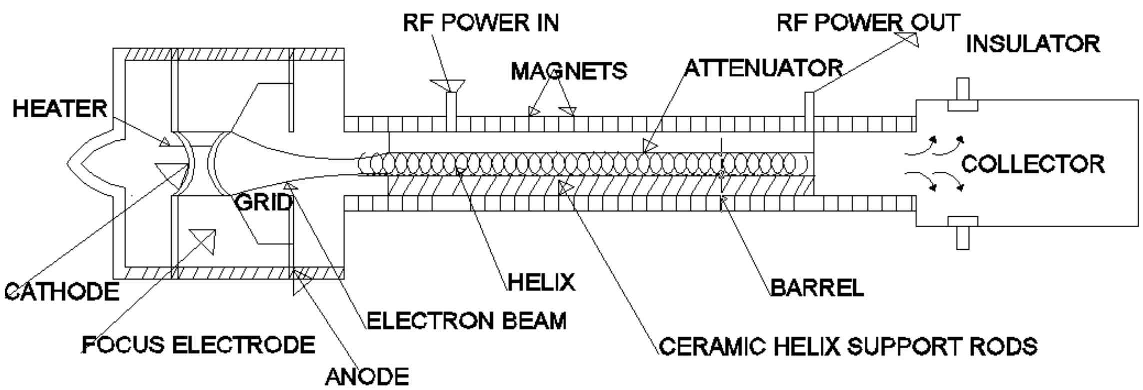

Figure 3: Simplified TWT schematic

OPERATION OF THE TRAVELLING WAVE TUBE

Amplification (C. Brain et al., 2008) in a TWT is attained by causing an electromagnetic RF wave to travel along a propagating structure in close proximity to an electron beam, as indicated in Figure 3.
At the left of this simplified diagram is an electron gun assembly. The cathode, when heated, emits a continuous stream of electrons. These electrons are drawn through an aperture in the anode and are then focused into a well-defined cylindrical beam by a magnetic field. The beam is therefore caused to travel inside the slow-wave circuit for the length of the tube. The electrons are finally collected and their kinetic energy is dissipated in the form of heat in the collector.
At the same time that the cylindrical electron beam is moving along the length of the tube axis, the RF signal to be amplified is fed into the slow-wave structure consisting, in this case, of a coiled wire called a helix. The RF energy travels along the helix wire at the velocity of light. However, because of the helical path, the energy progresses along the axial length of the tube at a considerably lower axial velocity, determined primarily by the pitch and diameter of the helix.
The phase velocity of the RF wave (the speed at which the phase fronts of the energy appear to move along the length of the tube) is made slightly slower than the velocity of the electron beam. This near-synchronism results in a continuous interaction between the electron beam and the RF signal. Some of the electrons in the beam are slowed by the RF field, while others are accelerated.
As the "velocity-modulated" electrons move down through the helix they form bunches. This bunches, in turn, overtake and interact with the slower helix RF wave, surrendering kinetic energy to the wave on the helix. The result is a cumulative amplification of the RF signal. Single TWTs have been built with power gains of more than 10,000,000 (70 dB).

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CONTROLLING THE BEAM

The electron gun functions somewhat like the lens in a projector. The object is to get as much electron current as possible flowing within a concentrated beam without distortion. Good gun design is extremely important since the gun is the source of electrons for the beam. A wide variety of gun designs have been developed effort to provide well-behaved electron beams that can be readily adapted to new TWT types.

ANALYSIS OF DESIGNS AND APPLICATIONS

The design of a TWT originates with the requirements to provide certain amount of gain and power over a certain frequency band. The final design of the TWT usually results from a trade-off study that includes considerations involving the power supply, sometimes called the the Electronic Power Conditioner (EPC) and interfaces between the TWT and the using system. These considerations lead to trade-offs that affect each of the major subassemblies of TWT. Those considerations include:

- The type of slow-wave circuit to be used in meeting the power and bandwidth requirements, including the selection of cathode voltage and current to be used in meeting those requirements. It is important to note that the higher thermal dissipation capability in coupled-cavity TWT circuits can provide two orders of magnitude greater power output capability than availability from TWTs having helix circuits, at the penalty of increased size and weight.
- The method to be employed for focusing the electron beam.
- The method to be used for varying the beam current, including the method used for turning the TWT on and off as well as any modulation required during TWT operation.
- The environmental conditions under which the TWT will operate (ambient pressure, ambient temperature, shock and vibration levels)
- The type of cooling available.
- Size and weight limitations.
- Cost.

The final design of the TWT can be affected as much by the priorities assigned to the design considerations as by the considerations themselves. It is not uncommon to find that TWTs designed for similar frequencies and power levels may differ widely in design (C. Ar et al., 2008). For example, consider a TWT designed for use in an aircraft where dielectric cooling fluid is available. The TWT might well use that fluid both for cooling and as a dielectric around high voltage regions. Alternatively, that same design could not be used in an application where the cooling fluid is not available or is not a good dielectric.

The major applications for TWTs include:

- Radar TWTs for airborne and sea level applications.
- ECM TWTs for airborne and sea level applications.
- Missile TWTs for terminal seekers.
- TWTs for space applications, especially for communications satellites but also for radar and space probe applications.
- Instrumentation TWTs for laboratory and test equipment.

SPECIAL DESIGNS

DESIGN 1: RADAR TWTs FOR AIRBORNE AND SEA LEVEL APPLICATIONS

The features that influence the design of these TWTs include:

- High peak power with moderate average power
- Moderate bandwidth
- Cooling can usually be conduction, forced air, or circulating liquid
- Operation at altitude usually requires that high voltage leads are encapsulated or enclosed in dielectric fluid.
- Operation in extreme environments requires rugged construction.

These requirements are usually met by using TWTs that have either helix or coupled-cavity slow-wave structures and solenoid focusing, although the latest available magnetic materials are allowing some of these devices to utilize periodic-permanent-magnet (PPM) focusing structures.

DESIGN 2: ELECTRONIC COUNTER MEASURE (ECM) TWTs FOR AIRBORNE AND SEA LEVEL APPLICATIONS

ECM TWTs (J.R. Pierce et al., 2009) tend to fall into two categories, those that require high peak power and those that require high CW (continuous wave) or average power. In most cases, the bandwidth must be wider than for radar TWTs because the exact frequency of operation is not defined until the threat is identified. Helix or helix-derived circuits are essential for those applications requiring octave or multiple octave bandwidths. Coupled-cavity circuits are required when the power requirement exceeds the capability of helix-type circuits and the reduced bandwidth can be tolerated. Permanent magnet focusing is widely used in these devices. This design is very useful for air and sea surveillance, airborne and sea level operation, counter measures and attacks.

DESIGN 3: THE TWT IN SPACE COMMUNICATIONS (TWTs FOR SPACE APPLICATIONS)

Features that influence the design of these TWTs include:

- Long life and high reliability
- High efficiency
- Moderate power output (usually less than 300W)
- Moderate bandwidth (1 percent to 5 percent)
- Low phase and gain distortion (high linearity)
- Well-controlled manufacturing facility and manufacturing documentation

These features usually dictate that the TWTs have helix slow-wave circuits (usually with a velocity taper to improve both linearity and efficiency), high area compression ungridded electron guns, PPM focusing, multiple stage depressed collectors, and conduction cooling (in some applications, collector is cooled by direct radiation into free space). The use of a linearizer is often dictated by the linearity requirements. Linearized Travelling Wave Tube Amplifiers (LTWTAs) (M. Steer, 2010) represent as integrated design where in the designs of the TWT, EPC and linearizer are closely coordinated.

DESIGN 4: MISSILE TWTS FOR ACTIVE SEEKERS

Features that influence the design of these TWTs include:

- Minimal size and weight
- Narrow to moderate bandwidth
- Off to fully operational turn-on times of 1 second or less
- High efficiency
- High reliability after long inactive storage periods

These TWTs are normally of the Periodic-Permanent Magnet (PPM) (S. Yngvesson, 1991) focused helix variety. They normally utilize unique cathode-heater designs to provide the very fast warm-up required. They typically have multiple stage depressed collectors with conduction cooling.

DESIGN 5: INSTRUMENTATION TWTs FOR LABORATORY AND TEST EQUIPMENT

The features that influence the design of these TWTs include:

- Fold back protection
- Bright 4 line by 20 character alphanumeric display
- Existence remote status
- Control through a GPIB (IEEE 488) interface

These features are always considered by using travelling wave tube (TWT) incorporating a control grid that can be used to turn on and off the TWT's beam current. The TWT acts as an RF amplifier (C. Brain et al., 2008) only when the beam is turned on. Turning the beam off when no RF output is needed results in a significant reduction in power consumption, and hence reduces the amount of heat to be dissipated.

SUMMARY AND CONCLUSION

Travelling wave tube could be adapted and designed for various intelligence surveillance and security operations; such as the Electronic Counter Measures (ECM) and missile applications, especially for electronic warfare which is in a military action to take advantage of the enemies' use of electromagnetic spectrum or deny its use to him. Others include the Radar TWT and for airborne and sea level operations that would check terrorist on the air, land and illegal bunkering/oil theft in the seas. Criminals such as arm robbers and kidnappers would be check and surveillance to check other insurgences such as illegal immigrants entering Nigeria rail, road, air and many more.

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