

# An Automated Software Suite for Determining Electrical Characteristics of Travelling Wave Tubes

*David Dyson*

TMD Technologies Limited, Swallowfield Way, Hayes, Middlesex, UB3 1DQ UK

## 1. Introduction

Travelling wave tubes are vacuum devices with electron beams that couple to a microwave frequency electromagnetic signal (loosely termed 'r.f.' in the trade) propagating in the direction of the beam. Energy is transferred to the microwave signal, and the device generally behaves as an amplifier.

Since the electron beam must obviously travel slower than the speed of light, there must be some means of slowing down the forward velocity of the electromagnetic wave. This is done by means of a slow wave structure (sws), on which the electromagnetic wave propagates. This sws forces the microwave signal to effectively meander back and forth across the beam, slowing down its forward motion to a point where it is in approximate synchronism with the electron beam.

Recent purchases of software, particularly Vector Fields' Opera3d and CST's microwave studio allow the 3d modelling of complicated slow wave structures to determine their r.f. characteristics. Approximate analytical methods and experience were previously used to estimate the characteristics of ring-loop, ring-bar, and helix slow wave structures, prior to prototype building. In combination with modern fast computers, these electromagnetic software codes can render accurate solutions to 3d models in very short times.

The value of accurate design tools to TWT development is immense. However the building of the models could be very time consuming, sometimes taking several days for each geometry requiring solving, with several geometries needing to be tried before the correct predicted performance was achieved. This 'software suite' project aimed to

make them available to non-specialist users, thereby expanding their application.

Using Compaq Visual Fortran (Vector Fields themselves use this to design, write, and compile their own codes), it is now possible to perform all stages of analysis at the same level, and interlink results from one piece of software with those of another. Thus the opportunity presented itself to write overriding software codes which could run a set of programs from different sources in turn and generate accurate results for complicated geometries in very short times. The slowest link in this chain is the human user who has had to determine how to construct the models and proceed to do it in laborious fashion. However both CST and Vector Fields, in their forward thinking, allowed the possibility of writing parameterised command sequences, the parameters being set by the user just before the time of use.

The possibility of complete automation was first realised, and successfully demonstrated, using TMD's standard type of ring-loop sws. This type had required much analysis over the previous 3 years, and this need was destined to continue. The automation routines had begun to be set up gradually as part of a number of previous PV's (private ventures) which included S band TWT feasibility, cost down sws modelling, and ku band TWT design, and also included IT strategy.

## 2. Basic Operation

A dialogue box allows user modification of the most recently used set of dimensions. A second dialogue box allows the user to set the operating conditions, ie the electron beam voltage, current, and diameter. The computer then proceeds, completely automatically, to generate models (with different boundary conditions), solve them

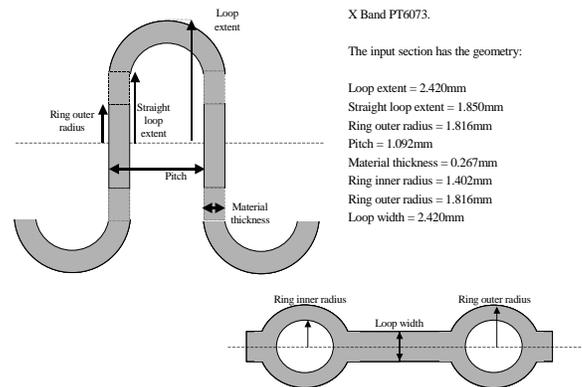
(eigenvalues), analyse them (process the field patterns in terms of total energy and fields on axis to compute interaction impedance), fit the results to polynomials (both the eigenvalues and the impedances are fitted to polynomials – differentiation of the eigenvalue polynomial is needed to determine the group velocity of the travelling wave as part of the calculation of impedance), calculate small signal gain (ssg) per unit length and output power, and proceed to plot fully annotated graphs of dispersion, ssg, output power and impedance over the range of interest. The results can be printed out and /or stored. The entire routine takes just under 5 minutes on a 2 GHz Pentium computer, and this represents a saving of around 4 days, or a factor of 360 in speed. This one automated routine alone enables ring-loop sws design or modification to be performed in a minimum of time by a user with no experience of finite element modelling or any other type of software coding. However, it is beneficial for the user to be experienced with TWT's of this type and be able to interpret and understand the results.

The basic routine outlined above, is shown in the flow chart in Appendix A

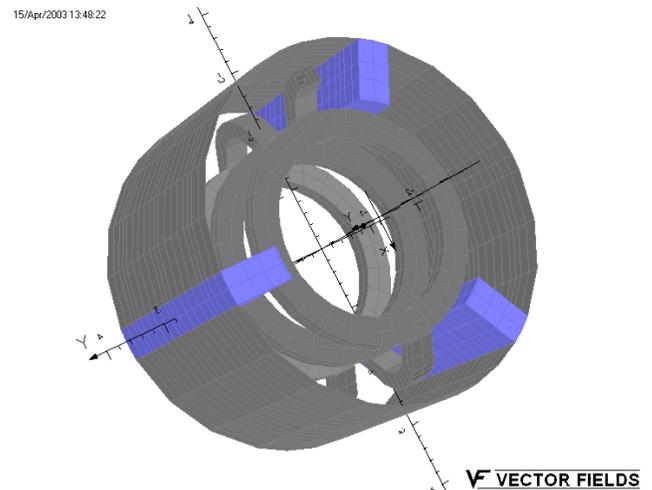
There are a number of sequences of modelling and analysis for various tube types, which have since been automated. The main sequence for sws design is similar to the ring loop sequence, however several different parameterised models have been created. These include 2 types of ring-bar, and helix designs, with an assortment of dielectric support configurations. The helix models, and one of the ring-bar types are created in CST's microwave studio.

The following figure shows a schematic of a ring-loop sws and indicates some of the parameters which should be defined by the user of the software suite.

### X Band TWT – Input section



The software suite transforms the schematic ring-loop in the figure above, along with dielectric support bars and outer sheath into a proper 3d model in the Vector Fields software. The 3d model is 3 pitches long and, with different boundary conditions, allows eigenvalue solutions with phase shifts from  $\pi/6$  upwards with  $\pi/6$  spacing



### 3. Extra Features: Empirically derived calculation of loop folding characteristics

One of the dimensional parameters required to generate a ring-loop model is the extent by which the loop projects from the sws, or in other words, it's proximity to the outer sheath.

The radial extent of the loop is quite critical in determining the frequency and operating voltage because of capacitive coupling between it and the outer sheath.

The ring-loop sws is physically created by bending a flat preformed strip. Thus the radial extent of the loop depends on the stretching characteristic of the material. The inside of the loop could be compressed whereas the outside of the loop is stretched, and there would be some null point in between.

An additional Fortran program, not shown on the flowchart, based on an empirically derived location for zero stretching, has been incorporated into the software suite. This calculates the maximum loop extent from certain of the other parameters, in particular the material thickness, and pitch between rings before folding.

#### 4. Extra Features: Construction/Analysis of a Complete TWT

In practice a travelling wave tube is made up of several sections of sws with slightly different dimensions and characteristics. This is done in order to enhance efficiency and avoid risk of oscillation.

Each type of section can be analysed separately using the 1<sup>st</sup> part of the software suite. Characteristics files are saved individually. Another part of the suite allows these sections to be built up and analysed as a whole. In this case information such as total gain and total phase length is generated.

#### 5. Extra Features: Different slow wave structures

As mentioned earlier, the software suite is set up to automatically create and analyse ring-bar and helix type sws's. The methodology is very similar to that used for ring-loop, and again complete tubes can be built up from the data files from individual sections.

#### 6. Extra Features: Variation of beam size and phase pushing with grid drive and cathode voltage

It is a simple matter to run the total tube model with different applied voltages to determine phase pushing, a very necessary characteristic as it links in with the tube's power supply design and the maximum values are often dictated by the customer.

TMD uses 2 basic designs of guns for it's X band TWT's – a hexagonally meshed intercepting grid, and a non-intercepting grid pair with spider's web form. These 2 guns are used with a variety of grid drives and cathode voltages in order to produce electron beams for a number of X band TWT's.

One input parameter required for small signal gain analysis is the size of the electron beam - both electron guns/focusing systems have previously been modeled in Opera3d, and the beam size found to vary with both grid drive and cathode voltage.

By running the gun models with a range of voltages, an empirical relationship has been derived for beam size variation, and is of the following form:

$$\text{Beam radius} = k\sqrt{V}(1+\alpha|vg|)$$

Where: V is the cathode voltage

vg is the grid drive voltage

k, α, β are constants depending on the grid geometry (ie different for the 2 types of gun)

In addition, a relation for beam current was determined, and seen to follow the form expected, i.e the famous 3/2 power law for a diode with an offset determined by the mu of the grid ( the effective penetration of the anode voltage through the grid cells):

$$\text{Beam current} = c(vg+V/\lambda)^{3/2}$$

Where:  $c$  and  $\lambda$  are constants depending on the grid geometry (again different for the 2 types of gun)

Although the beam current for any standard TWT is known (by simple measurement), beam radius is not.

The overall gain, output power and phase pushing of the TWT depend on the beam radius. The software suite has been upgraded with the empirically derived radius formula and the inverse of the beam current formula. Users can select to enter their own beam radius or have the software calculate it for them.

## 7. Practical Use of the Software

A good deal of use has been made already of the automated ring-loop software, for example optimisation of existing tubes and responding to many customer enquiries.

The way the suite is set up allows trying out different dimension combinations in an almost 'while u wait' manner. The user can then see which of the options is best suited to a customer requirements from the point of view of limited available space or efficiency.

The modular form of the suite also allows for an experienced user to break in at any point, modify a data file, and continue executing the remaining sequence of codes.

For example, where a proposed design contains features not in the topology of the ring-loop model in the automated suite, two models can be run, straddling either side of the true topology, and then an interpolated data file can be formed corresponding to the actual topology. This interpolated file can then be used to perform the final analysis.

Another example relates to compensating for manufacturing processes. One type of structure is made by a photoetching process, ie in a different manner to the normal punched structures of the standard range of X band tubes. This process is known to cause cusping and with past experience is judged to reduce the dispersion characteristic by 1.5%. Although the automatically generated model does not contain this feature, the resultant r.f. data file can be modified part way through the automated routine, and the frequency and phase velocity columns reduced by 1.5%, without any change to the impedance column. We have seen that when the full tube data files were assembled and run through the gain program, the gain profile maximum agreed perfectly with experiment results for all tested voltages. This gave great confidence in trusting the software

## 8. Conclusion

A suite of software has been created, which allows very fast automated analysis of some types of travelling wave tube. The software has given results very consistent with experiment. It is continually being refined and extended and, in fact, TMD has an ongoing PV to automate electron gun design to add to it.

The software is used on a virtually daily basis at the moment to address numerous customer enquiries.

**Appendix A** **Flowchart for**  
**Determination Of R.F. Characteristics in**  
**Single Ring-Loop Section**

