SUPERFISH

Don W. Reid, Alex Harvey, and Gary W. Rodenz AT-5 (MS 827)
Los Alamos National Laboratory, Los Alamos, New Mexico 87545

Ronald F. Holsinger
Field Effects, Inc., Carlisle, Massachusetts 01741

Summary

The computer code SUPERFISH was developed to calculate various parameters associated with rf fields in axially symmetrical cavities of arbitrary shapes. The development of the code has been well described[1,2]. Since the introduction of the code in 1976, it has been in continuous use at Los Alamos National Laboratory. Over the intervening years there have been numerous utility improvements, and several technical additions to the program. This paper describes these modifications and additions, and reviews the basic capabilities of SUPERFISH.

What SUPERFISH Is

SUPERFISH is a computer code that determines the electromagnetic resonance frequency of, and evaluates the electromagnetic fields in, rf cavities with axial symmetry. Recently an intensive effort has been undertaken at Los Alamos to develop a computer code that will extend the capabilities of SUPERFISH to azimuthally asymmetric modes. This code is called ULTRAFISH and is described elsewhere in this conference.[3]

There have been a number of computer codes that deal with the rf cavity problem.[4,5] These early programs used an overrelaxation method to solve a set of homogeneous linear-field equations. For large diameter-to-length ratios, or for modes other than the fundamental mode, the convergence rate is small; or in some cases, the solution may not converge at all with typical methods for overrelaxation-factor optimization. SUPERFISH, on the other hand, uses a direct, noniterative method to solve a set of inhomogeneous field equations.

The details of the method used are well described and only a brief summary will be presented here. The fields, inside the structure, are described by the azimuthal magnetic-field strength, H. Maxwell's equations are represented by one difference equation for H at each mesh point on the surface of, and inside, the structure. One of the mesh points is arbitrarily chosen and H is set equal to 1. The difference equation for that point is thus eliminated. The resulting set of inhomogeneous linear equations is solved with a noniterative Gaussian block-elimination and back-substitution process.

At the point previously chosen, H is calculated from the known values of H at the neighboring mesh points. In general, this value of H will be different from the original value of 1. This difference can be interpreted as the current I of circulating magnetic charges necessary to drive the cavity to the field value of 1 at the chosen point. The coefficients of the original set of difference equations depend on frequency. As a result, I also depends on frequency and on the coefficient k. Resonance is characterized when I = 0.

To find resonance, I is not used directly, but the normalized quantity, $D = 2\pi R_1\, kI/H^2 dv$, is used. The quantity R_1 is the distance of the arbitrarily chosen point from the axis, and k is the angular frequency divided by c. This technique simplifies the root-finding procedure because it can be shown that, at every resonance, D = 0 and $dD/dk^2 = -1$. Between every two resonances, D = 0 once and $dD/dk^2 = +1$.

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Using SUPERFISH

SUPERFISH is the major program in a series of four programs with pre- and postprocessors that enable the user to input data in a reasonable fashion and to get answers in a usable format. The initial program is AUTOMESH. AUTOMESH understands the physical dimensions of the cavity and regenerates the cavity outline. The program can draw straight lines between points and can draw arcs that are tangent to straight lines. An AUTOMESH-generated plot of one quadrant of a drift-tube linac cavity is shown in Fig. 1.

AUTOMESH generates a file that is read by the next program in the series, LATTICE. This file fills the cavity outline with a series of interconnected triangles, as shown in Fig. 2. By proper choice of input data, it is possible in AUTOMESH to specify the size of the triangle and to have several areas of different mesh density within the cavity. This feature has obvious impact on computation time. It also enables the user to do the initial calculations with a gross matrix and then to complete them with a more exact approximation.

A recent addition to LATTICE is the ability to put materials into the cavity with relative permeability and relative permittivity other than 1. This new capability allows standard cavity values (resonant frequency, power dissipation, etc.) to be calculated. Test cases have been run, but the capability has not been tested extensively.

LATTICE generates a file that can be fed into the program SUPERFISH. From this file, SUPERFISH calculates the various cavity parameters by the methods previously described. A typical output from SUPERFISH is shown in Fig. 3.

Although several output options are available, the summary shown in Fig. 3 has proved to be the most useful. Several points are noteworthy:

- The power dissipated, energy stored, etc., all are normalized to an electric field of 1 MeV/m. All SUPERFISH numbers must be adjusted to the operational level of the resonant system.

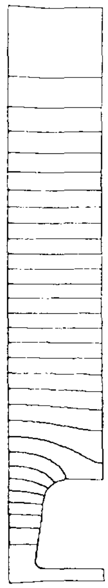

Fig. 1. One quadrant drift-tube-linac cavity with electric fields, as drawn by AUTOMESH.

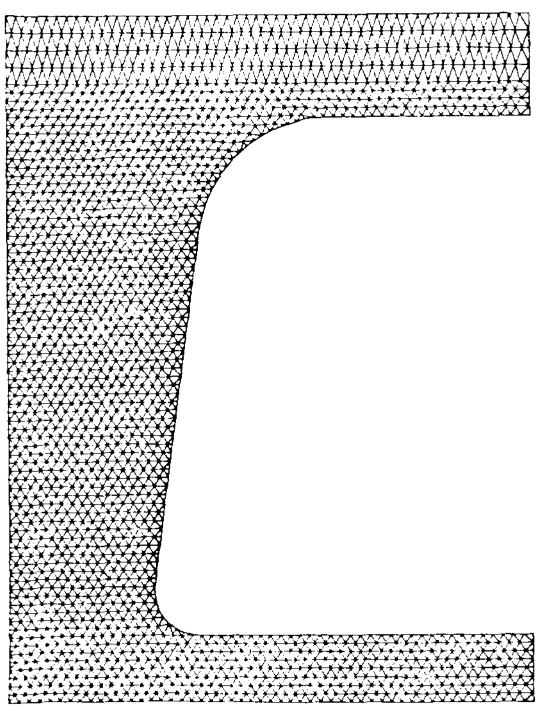

Fig. 2. Mesh configuration around drift-tube-linac nose, as drawn by LATTICE.

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SUPERFISH OUTPUT SUMMARY        09.45.21  23-SEP-8
PROBLEM NAME =425ALV75 CELL 40
CAVITY LENGTH  =   7.272 CM     CAVITY DIAMETER  =   47.334 CM
     D.T. GAP  =   7.272 CM         STEM RADIUS  =    1.000 CM
FREQUENCY (STARTING VALUE = 425.000)             =  424.896 MHZ
BETA =  0.1031                    PROTON ENERGY  =    5.023 MEV
NORMALIZATION FACTOR   (EO=1 MV/M)       ASCALE  =   4791.2
STORED ENERGY (MESH PROBLEM ONLY)                =   0.0083 JOULES
POWER DISSIPATION (MESH PROBLEM ONLY)            =   376.69 WATTS
T,TP,TPP,S,SP,SPP  =   0.813   0.055   0.006   0.469   0.057   0.008
Q  =   58775                  SHUNT IMPEDANCE  =    96.52 MOHM/M
PRODUCT Z*T**2                            ZTT  =    63.87 MOHM/M
MAGNETIC FIELD ON OUTER WALL                     =     1271 AMP/M
MAXIMUM ELECTRIC FIELD ON BOUNDARY               =    4.804 MV/M
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ISEG	ZBEG (CM)	RBEG (CM)	ZEND (CM)	REND (CM)	EMAX (MV/M)	POWER (W)		D-FREQ (DELZ)	D-FREQ (DELR)
4	0.000	23.667	3.636	23.667	0.00024	233.5	WALL	0.0000	-1.4076
8	3.636	4.250	2.288	4.250	1.21865	37.4	WALL	0.0000	-0.0691
9	2.288	4.250	1.336	3.415	3.48806	23.9	WALL	2.0819	1.6706
10	1.336	3.415	1.006	0.867	4.36774	8.9	WALL	3.9130	0.5074
11	1.006	0.867	1.328	0.500	4.80449	0.0	WALL	0.3023	0.1112
12	1.328	0.500	3.636	0.500	0.59347	0.0	WALL	0.0000	0.0016
					TOTAL	303.8	WALL		
-5	3.636	23.667	3.636	5.000	0.73681	68.5	STEM	0.5383	0.0000

Fig. 3. SUPERFISH output summary.

- Typically, one quadrant of the cavity is drawn because of axial symmetry. Hence, the calculated power dissipation must be multiplied by 2.
- The cavity losses are calculated assuming copper in all cavity walls.
- Experience has shown that good rf assembly practices can achieve only about 85% of the theoretical value of Q calculated by SUPERFISH.
- SUPERFISH divides the cavity boundary into segments and calculates the power dissipation in each segment, which is very useful when determining water cooling, temperature gradients, etc.; the length and number of segments of the cavity boundary can be specified.

Unconventional Uses

SUPERFISH, in its present form, also can be used with an arbitrary cross section in the x - y plane assuming infinite length in the orthogonal z direction. A radio frequency quadrupole (RFQ) for example, with a cross section as shown in Fig. 4, does not lend itself to cylindrical coordinates; therefore modifications in the program have been made to enable the user to specify rectangular coordinates. In effect, these modifications make the cavity straight and infinitely long. Note that in cases such as RFQs, where the cavity's resonant frequency is critically dependent on the spacing between vane tips, extreme care should be taken in selection of mesh size and beginning point of the mesh construction.

Another special case is that of a cavity partially loaded with dielectric material. In this case, it is

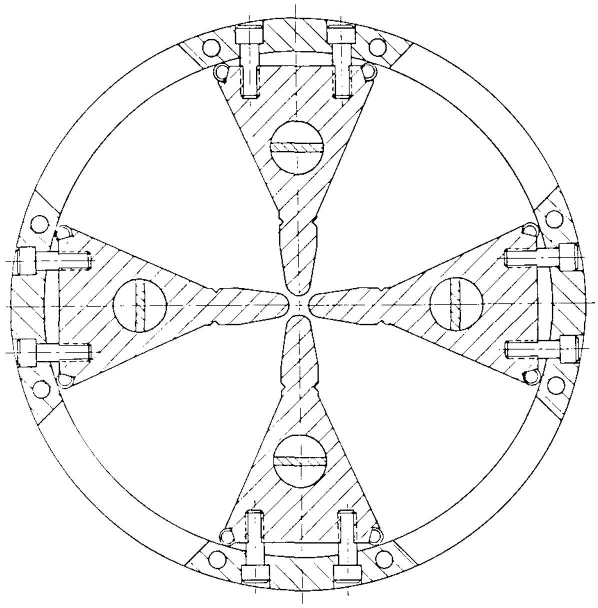

Fig. 4. Typical RFQ cross section.

assumed that the material is isotropic; that is, the permittivity and permeability is independent of the field orientation in the material. It is possible to specify the region that contains the dielectric and to have several regions, each containing a material with a different dielectric constant.

Conclusion

The computer code SUPERFISH has been used for several years at Los Alamos. Improvements in the utility and capability of the code have been made, the most notable of which is the ability to calculate the cavity parameters with a dielectric or ferrite material in the cavity, and the ability to set the problem up in x - y coordinates. The problem of adding azimuthally asymmetric mode capability has recently been completed and is described elsewhere.[3]

It is anticipated that work will continue on updating and modifying SUPERFISH. Among the planned activities is further test-case work on ULTRAFISH, modification of the field-normalization routine, extensive testing of the dielectric capability, and updating of the user's manual. Baseline SUPERFISH, on magnetic tape suitable for running on either VAX or a large computer Fortran-based operating system such as LTSS can be obtained from Los Alamos National Laboratory. Further details may be obtained from the authors.

Acknowledgments

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