Analytical method for studying a quasiperiodic disk loaded waveguide

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An analytic method to investigate a quasiperiodic disk loaded waveguide is presented. We rely on Cauchy residue theorem to formulate the transmission and reflection from a system composed of radial arms and grooves provided that the inner radius is kept constant; all the other parameters of the system can be arbitrarily changed. This method was successfully utilized to design the input and output section of a high power traveling wave tube which is very sensitive to reflections from both ends. We found this method particularly useful for the design of the output regions where breakdown imposes constraints on the geometry.

In many high power devices the electromagnetic energy is confined and guided by metallic surfaces. These surfaces play an important role in the interaction process of the electrons with the electromagnetic wave(s). A klystron, for example, consists of a metallic pipe to which two or more cavities are connected. The pipe is designed such that at the frequency of interest the electromagnetic wave is below cutoff and in the absence of the beam the cavities are isolated. In this kind of structure, power levels of 50 MW at 11.4 GHz were achieved at SLAC,¹ but since the interaction occurs in the close vicinity of the cavity gap, the gradients at the output cavity are high and the system is susceptible to rf breakdown.

This problem is less severe in a disk loaded traveling wave tube (TWT) which consists of a series of coupled cavities. These cavities are basically a short section of a periodic structure. In this case the interaction is no longer confined to the vicinity of the cavity, but it is distributed along the entire structure. The first experiments on high power TWT performed at Cornell² indicated that 100 MW at 8.76 GHz can be achieved before the system oscillates. Although no rf breakdown was observed in these kind of structures the fact that the input is no longer isolated from the output allows waves to be reflected backwards and this feedback may ultimately cause the system to oscillate.

In order to isolate the input from the output, the TWT was split in two sections separated by a sever.³ The second set of experiments on two stage high power TWT indicated that power levels in excess of 400 MW are achievable with no indication of rf breakdown.³ In this case, however, the output spectrum was 300-MHz wide and a significant amount of power (up to 50%) was measured in asymmetric sidebands. The latter observation was investigated theoretically⁴ and it was concluded that it is a result of amplified noise at frequencies selected by the interference of the two waves bouncing between the ends of the last stage. In fact we have shown⁵ that what we call amplifier and oscillator are the two extremes of possible operation and any practical device operates somewhere between the two extremes depending on the degree of control we have on the reflection process. We have suggested⁶ a method to eliminate the problem of reflections by designing a structure in which the time it takes the first reflection to reach the input end is of the same order of magnitude as the electron pulse length, thus by the time the reflection becomes relevant there are no more electrons to interact with. This method was successfully demonstrated⁷ experimentally and power levels of 200 MW were achieved at 9 GHz. The spectrum of the output signal was less than 50 MHz and the passband of the periodic structure is less than 200 MHz—for this reason we call it the narrow band structure (NBS). The 200 MW power levels, generated with the NBS were accompanied by gradients larger than 200 MV/m. Although we did not experience rf breakdown for any further increase in the power levels it will be necessary to increase the volume of the last two or three cells in order to minimize the electric field on the metallic surface—thus the system becomes quasiperiodic.

To summarize, the main two problems of an extraction section based on a quasiperiodic disk loaded structure are (1) minimize the reflections at both ends of the structure in order to avoid oscillation at high power levels and (2) taper the output section in order to avoid breakdown and optionally compensate for the velocity decrease of the electrons. In order to optimize these two conflicting requirements we have developed an analytical technique which permits us to design a quasiperiodic structure. This is a model which takes into account the input region, a section of a uniform structure, and the output region. In this letter we shall discuss only the pure electromagnetic problem and the analysis of an active device is left for an extended article. Although we are highly motivated here by the high

FIG. 1. The schematic of the system under consideration. The external radius $R_{ext}$, the groove/arm width $d$, and the separation between any two cavities can be arbitrary. The internal radius $R_{int}$ has to be maintained the same. $z_c$ indicates the center of the groove/arm.