Over-Moded Operation Of Waveguide-To-Coax Transition
At 60 GHz

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Abstract
In the design of a 57-63 GHz MMIC amplifier, a hermetic waveguide-to-coax transition was involved. A relatively large-diameter coaxial glass bead had to be employed, allowing the TE$_{11}$-mode to propagate from 52 GHz upwards. Measurements showed transmission blocked around 60 GHz, which could be explained as a resonance of the TE$_{11}$-mode. Conditions for blocking-free operation were analysed and an improved transition was designed, realized and tested which shifts the frequency of the TE$_{11}$ resonance upward outside the band.

Introduction
In a project in cooperation with TESAT Spacecom GmbH in Backnang/Germany a preamplifier for satellite TWT power amplifiers was designed. Three MMIC chips CHA2157 supplied by UMS were cascaded in a hermetic housing which incorporated transitions from microstrip to coax and coax to waveguide and featuring two waveguide flanges of WR15 size.

Fig.1: 57 – 63 GHz MMIC amplifier module inside view

Fig.1 shows the amplifier housing opened and exhibits the MMICs and connecting microstrip-line ceramic substrates in a narrow upper compartment together with a hybrid circuit for the d.c. supply regulation in a large, lower compartment. The first and last ceramic substrate microstrip-lines are connected to the center conductors of hermetic coaxial glass beads placed inside the gold-plated aluminium housing to the left and to the right. The other side of the center conductors probe into the input- and output waveguide ports, which are milled into the block from the other side.

Coaxial-to-Waveguide Transition
The coax-to-waveguide transition employed in the amplifier module is of conventional design, employing a soldered coaxial hermetic seal (Corning Gilbert Y007-L) "glass bead". The center conductor probe is tuned together with the back-short distance to give good impedance match. The other end of the center conductor reaches through a coaxial drill hole until it connects to the microstrip-line conductor inside the MMIC module. The details of the design were optimized by electromagnetic simulation using HFSS [1] and the resulting construction is seen in Fig.2. We realize that the inside coaxial transmission line made-up by the drill hole and the center conductor is smaller in outer diameter than the glass bead. This is necessary in order to keep the characteristic impedance constant (50 Ohm). However, the 1.65 mm outer diameter of the glass-filled coaxial line (glass bead) is relatively large with respect to the frequencies of operation intended: Based on a relative dielectric constant of 3.8, the cut-off frequency of the TE$_{11}$-mode is calculated at 52 GHz, which normally would exclude this glass bead hermetic seal from being used for our purpose in order to avoid any problems from moding.

Analysis of Coax-to-Waveguide Transition
In a first step, the mechanism leading to the blocking of transmission through the transition was investigated. Field theoretical simulations of the modal behaviour of the coaxial structures involved were performed using the µ Wave Wizard [2]. One result is indicated in Fig.3: The TE$_{11}$-mode reflection coefficient at the discontinuity from the glass-filled volume to the unfilled and smaller-diameter coaxial transmission line (far below cut-off), with good approximation, exhibits the character of a short-circuit. The reflection coefficient looking-in from the waveguide-side is then found to result from a TE$_{11}$-mode transmission line of length L which is short-circuited at the other end. Introducing the length L=1.4 mm for our glass bead and looking at the frequencies close to 60 GHz, it is found that the glass bead represents a TE$_{11}$-mode quarter-wave transmission line and that the TE$_{11}$-mode input impedance is an open circuit.

When we look from inside the glass bead into the waveguide,
the discontinuity is represented by impedance $jX_{11}$ which is inductive close to open-circuit and thus will not considerably modify the open-circuit resonance condition. It then can be assumed that the blocking of the transmission through the transition is due to an open-circuit impedance of the TE$_{11}$-mode inside the glass filled volume and that an equivalent circuit should appropriately model the behaviour by series connecting the TEM-waveguide and the TE$_{11}$-waveguide. Such an equivalent circuit can be derived as a refinement of the classical discontinuity model dating back to [3] and is given in Fig. 4:

A calculation of the quarter-wave resonance frequency using the approximate cut-off wave number $k_c = 2/(a+b)$, e.g. [4], yields a simple formula for the upper frequency limit of a glass bead used in a coaxial-to-waveguide transition as

$$f_{\text{max}} \approx \frac{300}{\sqrt{\varepsilon_r}} \left[ \frac{1}{4L/\text{mm}} + \frac{1}{\pi(a+b)/\text{mm}} \right]^2$$

In our given case, this approximation gives a frequency limit which is about 2% to low in comparison with the exact calculation (using exact cut-off wave number).

### Improvement of Coax-to-Waveguide Transition

Based on the above understanding of the blocking phenomenon due to TE$_{11}$-resonance, a simple modification of the transition geometry was investigated with the aim of shifting the resonance frequency upwards. Since it is not advisable to grind the hermetic seal to smaller length $L$, we can only modify the discontinuities at both sides of the glass bead. One simple and efficient measure was found as depicted in Fig. 6: A metal ring was soldered over the glass bead at the waveguide side, forming a concentric iris at the transition. Its TE$_{11}$-mode reactance $X_{11}$ was found to be inductive, varying between near short-circuit (small inner diameter) and near open-circuit (large inner diameter) and shifting the resonance frequency upwards as a result from the shunt connection of $jX_{11}$ modelled in Fig. 4. With a diameter of 1.3 mm and after readjustment of the probe dimensions, the TE$_{11}$-mode resonance condition of the glass bead coaxial section was moved up in frequency to 63.5 - 65 GHz so that unobstructed operation of the amplifier module was achieved over its specified operating frequency range.

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### References