Novel Tunable Waveguide Backshort for Millimeter and Submillimeter Wavelengths

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***Abstract*—A new tunable waveguide backshort with low loss and reliable performance has been designed. Based on a fixed short and dielectric phase shifter, it has a simple structure which is easy to design and fabricate. These properties make it a sound alternative for millimeter- and submillimeter-wave applications. A W-band (75–110 GHz) backshort has been designed and tested showing excellent performance with a return loss of less than 0.21 dB.**

***Index Terms*—Dielectric slab, millimeter-wave, submillimeter-wave, tunable, waveguide backshort.**

I. Introduction

MANY millimeter- and submillimeter-wave devices such as detectors, mixers, multipliers, and oscillators comprise waveguide structures where impedance tuning is required. In many cases, tuning is realized with a movable waveguide backshort (short circuit). Several types of contacting and noncontacting waveguide backshorts with various properties and advantages exist.

A contacting backshort is usually made of springy metal which makes direct contact with the broad walls of the waveguide. Although it is simple and frequency-independent, the quality of the RF contact becomes a problem in small waveguides at high frequencies. Moreover, it suffers from mechanical wear which further degrades the performance.

To avoid these problems, different noncontacting backshorts have been designed, e.g., [1]–[3]. In [1] and [2], a metal bar insulated from waveguide walls with a thin dielectric layer is applied. The power reflection is accomplished with a low-pass filter constructed from low- and high-impedance sections (grooves [1] or holes [2] in the metal bar). Instead of the metal bar, a planar metal structure is used in [3]. In order to be applicable to submillimeter designs, the structures in [2] and [3] need complex photolithography techniques. Furthermore, misalignment or a defect in the insulation can degrade the reflection performance.

In this letter, we propose a new alternative for a tunable waveguide backshort at millimeter and submillimeter wavelengths. The proposed structure is easy to design and fabricate while it still has low loss and good reliability.

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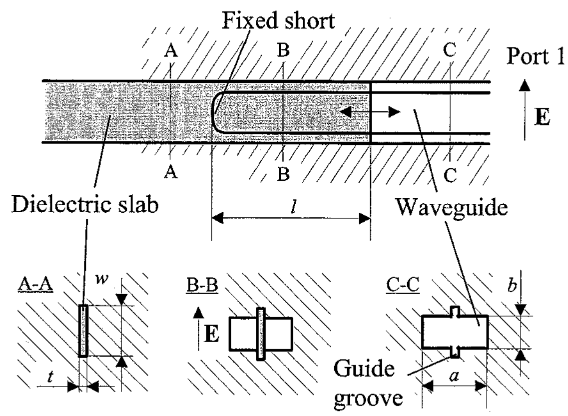

Fig. 1. Structure of the new tunable backshort.

II. Design

In the proposed design (Fig. 1), a dielectric slab is moved in a shorted waveguide to create a shorted variable phase shifter, i.e., a tunable waveguide backshort. Referring to Fig. 1, a wave propagating into the input port at right travels through a straight waveguide section and reflects back from a shorted waveguide end. The effective electrical length of the waveguide and, thus, the plane of the electrical short can be varied by changing the extent l of intrusion of the dielectric slab inside the waveguide. The slab is supported and aligned by a guide channel and grooves at the center of the E-plane. Accordingly, width w of the guide channel is made slightly larger than height b of the waveguide. Whereas height t of the channel is made small enough to prevent propagation of the TE_{10} mode.

Inside the waveguide, the dielectric slab changes the propagation factor and characteristic impedance in that waveguide region. If the change in the impedance and attenuation is assumed negligible, the shift in the phase of the reflection coefficient can be estimated as $\Delta\phi \approx 2l(\beta_2 - \beta_1)$, where β_1 is the phase constant in the waveguide and β_2 is the phase constant in the waveguide section containing the slab. Thus, the length of the slab needed for a phase shift of full 360° is approximately $l \approx \pi/(\beta_2 - \beta_1)$. With the permittivity ϵ_r and thickness of the slab known, β_2 can be determined, e.g., with the transverse resonance technique.

III. Experimental Results

To demonstrate the validity of the novel design, a W-band (frequency range 75–110 GHz) backshort was tested. By using the split-block technique, a 10 mm long WR-10 waveguide (cross-section 2.54 mm × 1.27 mm) and guide channel (cross-section 1.4 mm $\times$ 0.2 mm) for the dielectric slab were milled in two halves of a brass block which were gold-plated afterwards. The slab was a 1.4 mm wide and 120 μm thick piece of fused quartz ($\varepsilon_r = 3.8$). Fused quartz was selected because of its good rigidity and low loss.

The magnitude and phase of the reflection coefficient S_{11} at the input port were measured with an HP-8510 network analyzer as a function of l. l was varied from 0 to 9.5 mm with 0.5 mm steps. Fig. 2(a) shows the measured and simulated magnitude of S_{11} for $l = 0$ and 9.5 mm. $l = 9.5$ mm results in $\Delta\phi \approx 360°$ at 92.5 GHz. The return loss is less than 0.21 dB over the whole measurement bandwidth. The large-scale ripple in the results is caused by multiple reflections, summing of waves reflected from the fixed short and discontinuities of the structure and losses. The maximum peak-to-peak amplitude variation results when l is increased to the maximum required length, corresponding to $\Delta\phi = 360°$ at 75 GHz and is estimated from the measurements to be under 0.2 dB. Figs. 2(b) and (c) show the measured and simulated phase of S_{11} for $l = 0$ and 9.5 mm. Further, Fig. 2(d) illustrates the produced phase shift $\Delta\phi$ at 92.5 GHz as a function of l. As shown by the figures, the performance can be accurately predicted with the finite element method.

The performance was also studied beyond the standard waveguide band which may be important for the design of active circuits [1]. The simulated magnitude of the reflection coefficient over a wide frequency range (70–230 GHz) is shown in Fig. 3. The average return loss in the W-band is 0.14 dB which is congruent with the measured results [Fig. 2(a)] with $l = 9.5$ mm. Above the waveguide band, part of the power reflects at higher order waveguide modes. In the simulated frequency range, coupling to the TE_{30} mode is significant. In addition to ohmic and dielectric losses, the reflected power attenuates at higher frequencies due to small leakage to the guide channel through the higher order modes. The simulation does not take into account the metal surface roughness which increases the loss.

In the simulations, the structure was accordant with Fig. 1 with the waveguide as the input port and the guide channel as an output port. Electrical conductivity of $4.1 \cdot 10^7$ S/m and a loss tangent of 0.001 were used for gold and quartz, respectively.

IV. Features of Design

The proposed backshort design has the following advantages.

1) *Simple Design*: Only the dimensions of the dielectric slab have to be designed. The slab becomes long if it is thin or made of low permittivity material.
2) *Simple Fabrication*: Complicated mechanical parts are not required. Two halves of the backshort block can be fabricated easily in association with other parts of a device by applying the split-block technique. Also, the rectangular-shape slab is easy to cut.
3) *Easy Tuning*: The plane of the electrical short is tuned by changing the effective electrical length of the waveguide, i.e., by moving the slab over a long path. Thus, only a moderate tuning mechanism is needed.
4) *Low Losses*: In single-mode operation, the losses result from the finite conductivity and surface roughness of the

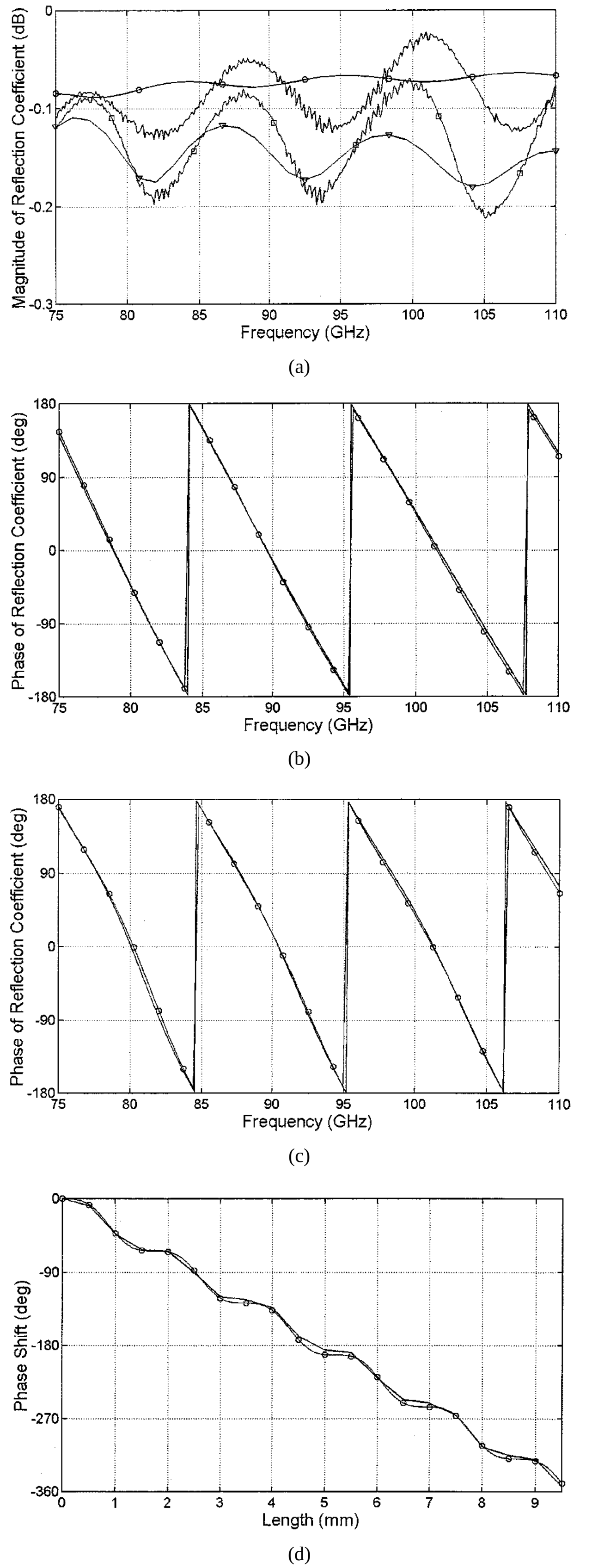

Fig. 2. Reflection coefficient S_{11}. (a) $|S_{11}|$ for $l = 0$ (measured: solid line; simulated: line with circles) and for $l = 9.5$ mm (measured: line with squares; simulated: line with triangles); (b) measured and simulated (line with circles) phase for $l = 0$; (c) measured and simulated (line with circles) phase for $l = 9.5$ mm and (d) Measured and simulated (line with circles) $\Delta\phi$ as a function of l at 92.5 GHz.

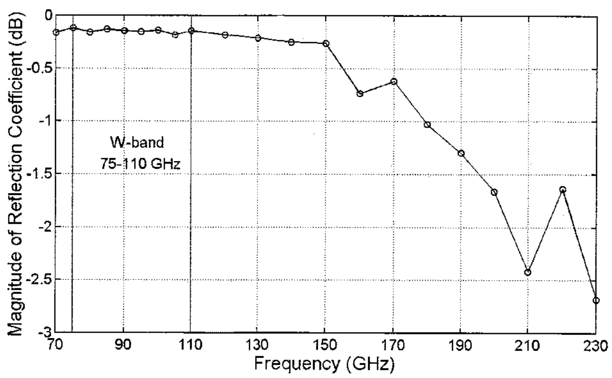

Fig. 3. Simulated magnitude of the reflection coefficient S_{11}.

metal walls of the waveguide and from the dielectric material. These can be minimized with a proper selection of materials. If the required $\Delta\phi$ is small, the losses can be further reduced. This design is not disposed to any losses due to bad alignment or poor contact.

5) *High Reliability*: The performance of the backshort is well repeatable with a proper tuning mechanism. There is no risk of bad alignment or wear of contact or the insulation. Due to the guide channel, the device is inherently robust and stable. Possible wear of the slab does not affect the magnitude of the reflection but only increases phase uncertainty.
6) *Readiness for Scaling*: Since the structure does not involve any parts hard to machine, it is scalable and suitable also for submillimeter wavelengths.

Since there has to be a waveguide section of a certain length to allow room for tuning, the phase variation is inherently large, which may limit the applicability of the backshort to narrow band applications. This is the major drawback. However, if the required $\Delta\phi$ is small, the length of the backshort can be reduced and the drawback minimized. The minor drawback is the nonlinearity of the phase variation as a function of the frequency [Fig. 2(c)] and also as a function of l [Fig. 2(d)].

V. CONCLUSION

A new tunable waveguide backshort has been introduced. It comprises a fixed short and movable dielectric slab for tuning the effective phase constant of a waveguide section. The validity of the new structure has been demonstrated by designing and testing a W-band backshort. Advantages of the design are the simplicity and low loss. A measured return loss of less than 0.21 dB in the whole waveguide band (75–110 GHz) indicates the excellent performance of this design. The main disadvantage is the frequency dependency, i.e., large phase variation. However, in devices where that is not critical, e.g., detectors and oscillators, the new backshort is an alternative to be reckoned with.

REFERENCES

[1] M. K. Brewer and A. V. Räisänen, “Dual-harmonic noncontacting millimeter waveguide backshorts: Theory, design and test,” *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 708–714, May 1982.

[2] T. M. Weller, L. P. B. Katehi, and W. R. McGrath, “Analysis and design of a novel noncontacting waveguide backshort,” *IEEE Trans. Microwave Theory Tech.*, vol. 43, pp. 1023–1030, May 1995.

[3] T. Newman and K. T. Ng, “Planar noncontacting short circuits for millimeter-wave and submillimeter-wave applications,” *IEEE Microwave Guided Wave Lett.*, vol. 2, pp. 412–412, Oct. 1992.