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The Anglet: An E/H-plane Bent, 90-Degree Twisted, $\mathrm{TE}_{101}/\mathrm{TM}_{110}$-Mode Singlet Building Block

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***Abstract*—In this work, a subclass of the singlet building block is defined. Termed the *anglet*, a waveguide cavity-based structure is demonstrated that combines a bend, a 90-degree polarization rotation, and produces one pole and one transmission zero. The anglet is defined due to its unique ability to be viewed as either a TE_{101}-mode singlet or a TM_{110}-mode singlet based on the users coordinate point of view together with the requirements for the bend direction and polarization rotation. Two types of anglets are demonstrated by simulation and a third-order filter is demonstrated for the incorporation of an anglet in a practical design. Emphasis on its unique capabilities are highlighted due to its nature as a fundamental-mode resonator with evanescent bypass coupling. Furthermore, an accurate approximation for the source-load coupling is described and a prototype filter is fabricated and measured in order to validate the concept.**

***Index Terms*—Anglet, bandpass filter, nonresonating mode, passive components, singlet, twist component, waveguide bends**

I. INTRODUCTION

The use of nonresonating modes in filter applications has become a powerful design tool and has been applied to many well-known filter topologies to improve both the electrical and physical characteristics. In [1], the first reported example of a nonresonating-mode path was described with the use of inductive-iris coupled cavities. Since this time, many structures such as the singlet and doublet have been explored for their inherent abilities to produce transmission zeros without the use of physical cross couplings. In the case of the singlet, the most basic structures can be viewed in the form of rectangular cavities with: asymmetric irises, where the resonating mode is TE_{101} and the nonresonating mode is TE_{20} (evanescent), an oversized H-plane cavity, where the resonating mode is TE_{201} and the nonresonating mode is TE_{10}, and a TM-mode cavity, where the resonating mode is TM_{110} and the nonresonating mode is TE_{10}.

The singlet is recognized for its ability to generate a transmission zero either above or below the center-frequency position of the pole, where the relative position of the transmission zero is determined by the sign of the bypass coupling. In [2], the limitations of the most basic singlet type – asymmetric irises; [1], [3], [4] – is discussed and highlights the shortcomings of this type of design; that being, the transmission zeros are limited to the upper stopband and are located relatively far away from the passband. For this structure, the physical geometry can only support a weak bypass coupling which is carried by the TE_{20} mode and whose energy decays along the length of the cavity. This observation is important to note as it widely limits the use of this type of singlet.

On the extensive use of nonresonating modes in cavity filters, [2], [5] highlight three fundamental design rules in order to achieve a high level of design flexibility and control over the singlet's transmission-zero location:

- the nonresonating modes should be propagating along the longitudinal direction of the filter,
- the structure must possess design parameters controlling the ratio between the energy carried by the resonating and the nonresonating modes,

and

- the structure must possess design parameters that enable it to invert the bypass coupling sign.

However, if we are to disregard the first axiom proposed above, a special case of the singlet can be defined based on the identification of an E/H-plane bent, 90-degree rotated topology that functions similar to the previously described asymmetric irises that utilize a TE_{101} resonating mode and an evanescent TE_{20} mode for bypass coupling. This special case is of interest due to its unique physical profile, where depending on the use of port 1 or port 2, the resonating mode will be in the form of either TE_{101} or TM_{110} and the evanescent bypass coupling will be in the form of either a TE_{20} or TM_{12} nonresonating mode, respectively, and inherently introduce an E-or-H-plane bend and a 90-degree polarization rotation. In this regard, we term this special case as an *anglet*.

The anglet can be further defined with the following properties which are appended to the previous design criteria:

- function as an E-plane/H-plane bend,
- produce a 90-degree polarization rotation,

and

- retain the properties of a singlet; one pole and one transmission zero.

Table 1 is provided as a summary of basic rectangular waveguide cavities using nonresonating modes. However, it can be noted that other geometries such as slanted ridges [6], triangular resonators [7], and circular waveguides [8], have also been demonstrated in conventional singlet configurations.

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TABLE I. Summary of basic rectangular waveguide cavities utilizing nonresonating modes.

Cavity Structure	Resonating Modes	Nonresonating Modes	Topology
Asymmetric Irises	TE_{101}	TE_{20} (evanescent)	Singlet
E/H-plane Bend & Twist	$\mathrm{TE}_{101}/\mathrm{TM}_{110}$	$\mathrm{TE}_{20}/\mathrm{TM}_{12}$ (evanescent)	Anglet
Oversized H-plane	TE_{201}	TE_{10}	Singlet
TM Single Mode	TM_{110}	TE_{10}	Singlet
TM Dual Mode	TM_{120} & TM_{210}	TM_{11}	Doublet

II. ANGLET DESIGN

The anglet takes the form of a single resonator with two orthogonal irises. Two profiles are proposed: the first being a rectangular cavity, and the second being an L-shaped cavity. Fig. 1 presents the topology of the anglet which takes the form of a singlet, however, it must be noted that depending on the orientation of the structure, either the TE_{101} or TM_{110} mode will be defined as the resonant mode while the TE_{20} or TM_{12} mode will act as the bypass. To signify this, we have added a half window frame symbol to the center of the well-known singlet topology. This symbol now indicates an angular (E-plane or H-plane) change, as well as a polarization rotation. Fig. 2 is provided for the reader in order to view both types of anglets with a front-view where the bend and twist motion ends in the H-plane direction. Alternatively, the anglet can be re-orientated and viewed with the bend and twist motion in the E-plane direction.

The characteristic response of an anglet can be described by a $3x3$ coupling matrix in the form:

$$[m] = \begin{bmatrix} 0 & M_{S1} & M_{SL} \\ M_{S1} & M_{11} & M_{1L} \\ M_{SL} & M_{1L} & 0 \end{bmatrix} \tag{1}$$

and follows from the design equations outlined by [6], [9]–[11] with

$$Q_{e_{Sii}} = \frac{\pi \cdot f_{\tau_{Sii}} \cdot \tau_{Sii}(f_{\tau_{Sii}})}{2} \tag{2}$$

where τ_{Sii} is the group delay and $f_{\tau_{Sii}}$ is its associated center frequency for $i = 1, 2$. Moreover, we propose a solution for the source-load coupling as

$$M_{SL} = \frac{M_{S1} M_{1L}}{\Omega_Z}, \tag{3}$$

where Ω_Z is the normalized transmission-zero frequency.

In order to demonstrate control over the transmission zero location, four cases are illustrated in Fig. 3 where the transmission zero is moved above and below the center frequency location.

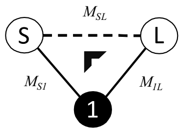

Fig. 1. Topology of the anglet; the half window frame symbol is used to indicate the use of an anglet in schematic form. The resonating node is black and the source/load nodes are white. Solid lines indicate the direct-coupling paths and the dashed line indicates the bypass-coupling path.

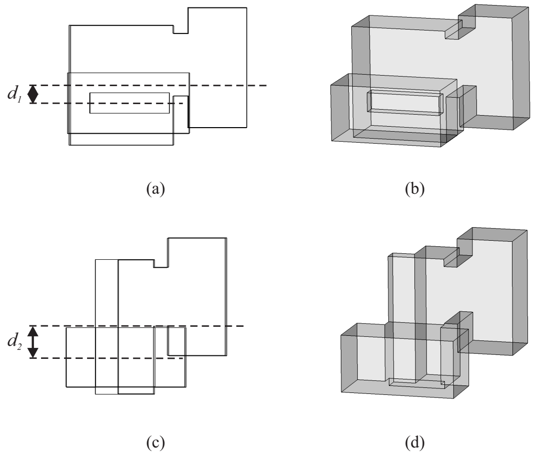

Fig. 2. Fundamental mode anglets; front (a) and perspective (b) views of a rectangular cavity anglet, and the front (c) and perspective (d) views of an L-shaped cavity anglet.

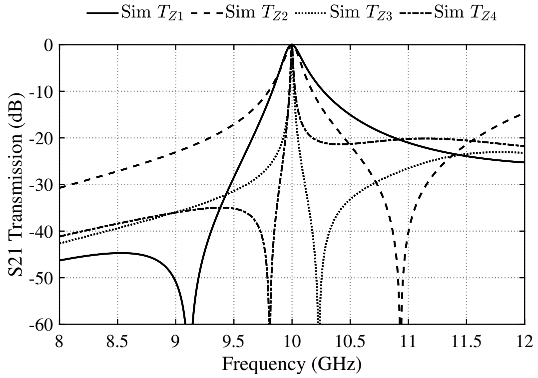

Fig. 3. Simulated transmission response of a rectangular resonator anglet as outlined in Fig. 2(a); the transmission zeros (T_{Zi} for $i = 1, 2, 3, 4$) are varied by adjusting the port position via d_1.

III. DESIGNING FILTERS WITH ANGLETS

To demonstrate its versatile nature as a filter building block, a third-order filter is designed for approximately 3% fractional bandwidth at 10 GHz using an L-shaped resonator similar to that of Fig. 2(d) with two rectangular iris-coupled resonators on either side. The vacuum-shell layout of the filter is depicted in Fig. 4 while the topology of the filter with the previously defined anglet symbol is provided in Fig. 5. The use of the anglet symbol in this case helps to differentiate the quasi-

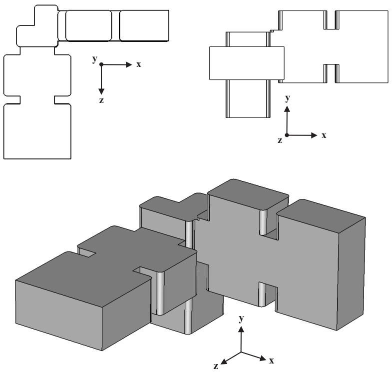

Fig. 4. Vacuum shell of the proposed 3% FBW third-order (quasi-triplet) filter; the structure contains two rectangular resonators and an L-shaped anglet as the interconnect.

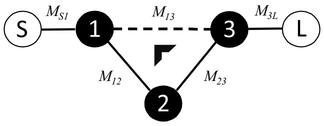

Fig. 5. Topology of the quasi-triplet filter utilizing an anglet. Resonating nodes are black and the source/load nodes are white. Solid lines indicate the direct-coupling paths and the dashed line indicates the bypass-coupling path.

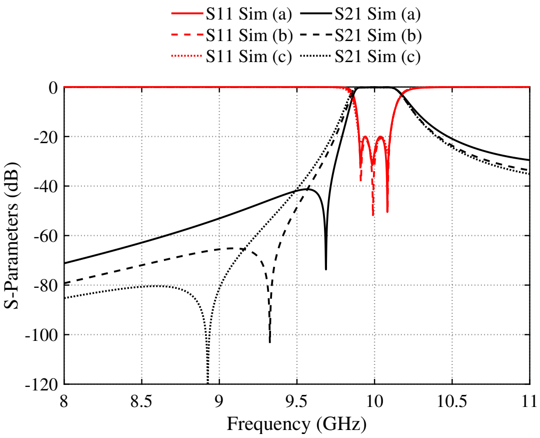

Fig. 6. Simulated results of the 3% FBW quasi-triplet filter; the transmission zero is varied below the passband as demonstration. For simulations (a-c) the transmission zero is varied by adjusting the port position via d_2.

triplet example at hand from the typical triplet-type filter that utilizes a physical cross-coupling between resonators 1 and 3.

A demonstration of the filtering characteristics are shown in Fig. 6 where three simulated versions are given in order to highlight the versatile control of the transmission zero in the lower rejection region while retaining a 20 dB return loss within the specified passband. The transmission zero is controlled by varying the position of the port along the dimension d_2, as shown in Fig. 2(c).

A. Fabrication and Measurement

A prototype has been designed for X-band operation in aluminum alloy. The filter is designed in a shifted E/H-plane split-block configuration in order to allow the filter to be milled and assembled from two pieces. Fig. 7 depicts one of the two milled component halves and the fully assembled filter. Once assembled, the filter was tested using a Rohde & Schwarz ZVA24 network analyzer. Fig. 8 presents a comparison of the simulated and measured results over 8.0 GHz to 12.0 GHz. This direct comparison demonstrates good measured results; the measured return loss is better than 20.0 dB throughout the passband and the measured insertion loss is on the range of 0.24 dB to 0.41 dB. A close-up view of the passband insertion loss is given in the inset of Fig. 8 over the range of 9.8 GHz to 10.2 GHz. Analyzing the filter's response, the unloaded quality factor is found to be approximately $Q_u \approx 2600$. As for the physical properties, the size of the component in terms of L·W·H is approximately 75.1·79.1·71.7 mm^3 and weights approximately 1150 g.

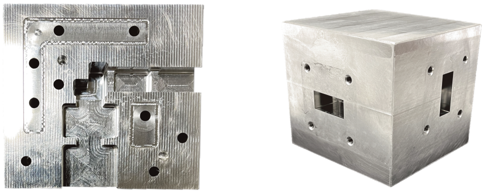
(a) (b)

Fig. 7. Fabricated X-band prototype; (a) The internal filter cavities of one half section, and (b) the fully assembled filter.

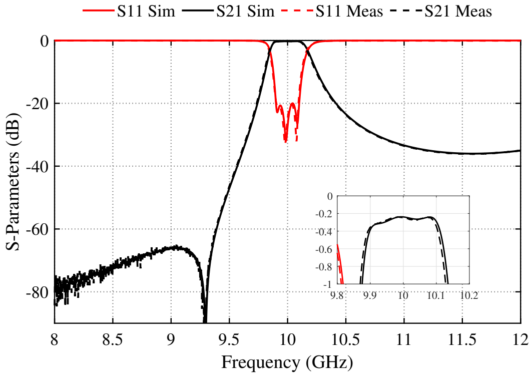

Fig. 8. Simulated versus measured results of the 3% FBW quasi-triplet filter. Effective conductivity is taken as 9.0 MS/m.

IV. CONCLUSION

A new subclass of the singlet building block has been defined and termed the *anglet*. The anglet is comprised of a waveguide cavity based structure that is capable of combining a bend, a 90-degree polarization rotation, and producing one pole and one transmission zero. Two versions of the anglet have been presented and a third-order filter concept has been demonstrated by both simulations and prototype measurements. The prototype exhibits the versatility of the new building block and demonstrates that it can be readily applied in larger filter-based assemblies.

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