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# Development of a Dual-Circular Polarizer for the KVN Receivers

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## Abstract

A stepped septum polarizer has been designed and fabricated for the 43 GHz band KVN receiver system. The dual-circular polarizer converts left and right hand circularly polarized signals into linear polarizations in two separated rectangular waveguides. Measurements show that the performance of the designed septum polarizer covering 42-48 GHz frequency band is adequate to meet the requirement of KVN receivers. Especially, a polarizer for the KVN receiver of 85-95 GHz frequency band can be fabricated by scaling the dimensions of the septum polarizer developed in this paper.

*Keywords*: receiver, dual-circular polarization, septum polarizer, E-plane split-block

## 1. Introduction

A polarizer is one of the most critical components in microwave and millimeter-wave communication systems. One can find many applications of polarizers in radio astronomical observations, too. There have been several attempts to make observations of CMB (cosmic microwave background) polarizations with ground-based and satellite-based radio telescopes such as WMAP and Planck (Chattopadhyay et al. 1998, Jarosik et al. 2003). The measurement of the polarization angular power spectrum of the CMB needs a receiver system capable of separating two orthogonal polarizations of signals. In addition, radio interferometric array systems like Korean VLBI Network (KVN) require dual-circular polarization observations generally (Middelberg & Bach 2008). Thus, a device capable of discriminating dual circular polarizations is essential for such a kind of polarization observation receiver as shown in Figure 1. In the KVN receivers of 22 GHz and 43 GHz frequency bands, commercially available polarizers have been used in the receiver system because only narrow bandwidth is needed for the current specifications of the KVN receiver. But it is difficult to find custom designed polarizers in the millimeter-wave industry for the KVN receivers of 86 GHz and 129 GHz frequency bands because there are very few applications of polarizer at such high frequencies except radio astronomical observation. It leads to attempt on development of a dual-circular polarizer for the KVN receiver system.

Quasi-optical method or waveguide structures can be used for the dual-circular polarization. But waveguide-based polarizers are generally compact and robust and such polarizers can be inserted into the cryogenically cooled receiver dewar in order to reduce the receiver noise temperature.

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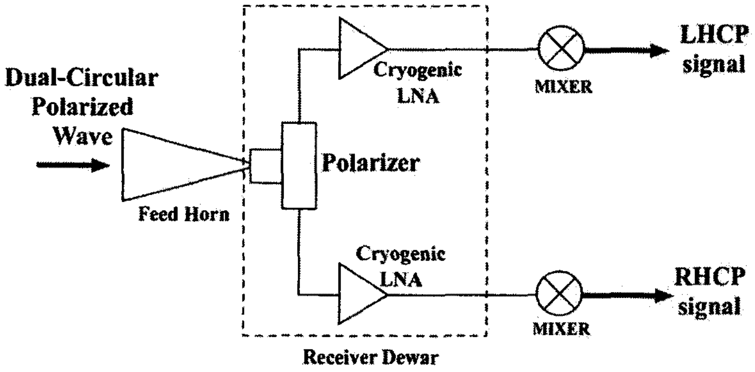


Figure 1. A simplified schematic for a dual-circular polarization receiver.

Relatively narrow bandwidth of the KVN receiver system enables us to choose a septum polarizer for a prototype polarizer of the KVN receivers. The septum polarizer is simple and easy to be fabricated at lower frequencies even though it shows narrow-band performance compared to other types of polarizers such as corrugated waveguide phase shifter (Arndt et al. 1984). A necessity of fabrication and alignment of a very thin septum makes it difficult for a septum polarizer to be employed at very high frequencies but the recent progress of micromachining technology allows the application of septum polarizer around 100 GHz frequency band (Biber et al. 2004).

The aim of this paper is to demonstrate the design and fabrication of a prototype polarizer for better fitting with the KVN receiver's specifications. Intensive 3D electromagnetic simulations using a commercially available software tool have been carried out to optimize and predict the performance of the designed septum polarizer. In this paper, the calculated and measured performances of the prototype polarizer for the 42-48 GHz band will be presented.

## 2. Design and Simulation

The septum polarizer is a 4-port waveguide device as depicted in Figure 2, because the square waveguide connected into the circular waveguide as the input port actually represents two ports in terms of the electromagnetic signals. A stepped septum located inside the square waveguide couples a circularly polarized field propagating through the square waveguide to one of the rectangular waveguide ports. Electric field components parallel (TE10) and perpendicular (TE01) to the septum transform into two odd-mode and even-mode signals in the rectangular waveguide (Chen & Tsandoulas 1973, Davis et al. 1967). The odd-mode signal propagates at a slower phase velocity than the even-mode signal. If the phase difference between the odd-mode and even-mode signals is 90 degrees at the end of septum, the resulting electric fields cancel each other out or add according to the sense of circular polarizations. Thus, LHCP (Left-Hand Circular Polarization) and RHCP (Right-Hand Circular Polarization) fields couple only to the port 3 and 4, respectively. The length and shape of the stepped septum must be determined in order that the phase difference between the horizontal and vertical polarization fields become 90 degrees and the return loss in the common input port be minimum across the operation frequency band.

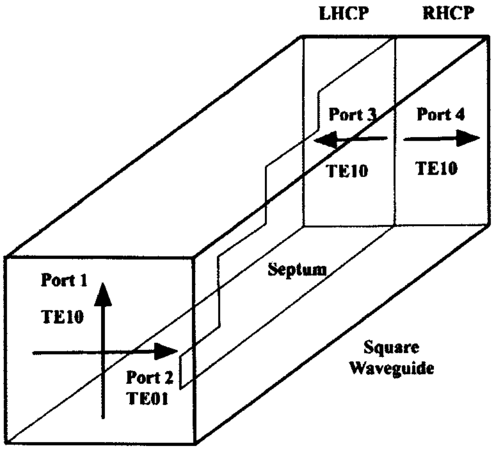


Figure 2. Stepped septum polarizer.

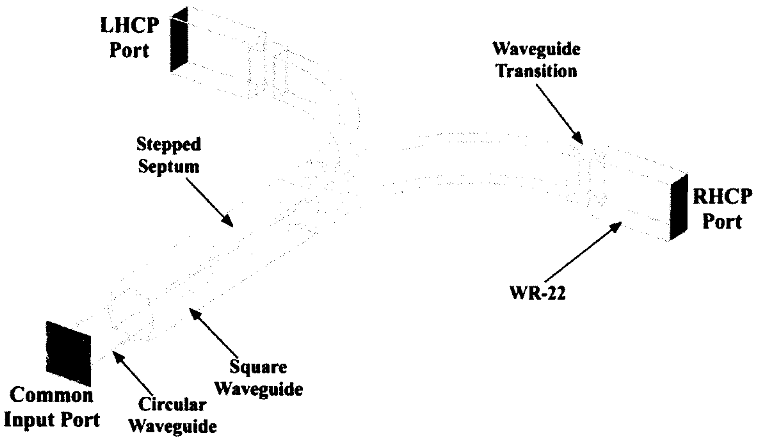


Figure 3. Structure of the designed stepped septum polarizer.

The most crucial part in the design of septum polarizer is a stepped septum. Since it is nearly impossible to use an analytical method for the design of septum, the design of septum strongly relies on the three-dimensional electromagnetic simulation (Monorchio et al. 2004). The 3D EM simulator used in this paper is CST MWS (Microwave Studio, CST, Inc. 2008), which is a time domain electromagnetic software tool based on FIM (finite integration method) algorithm. In addition to the septum, there are also waveguide components to be designed such as circular-to-square waveguide transition and rectangular waveguide impedance transformer. The dual-circular polarizer is generally attached to the feed horn of which the output port is a circular waveguide. A transition must be located between the circular and square waveguides to minimize the RF power reflected from

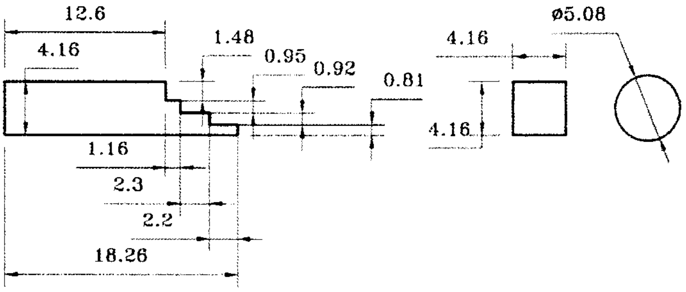


Figure 4. Dimensions of the septum polarizer parts (thickness of stepped septum is 0.6 mm and all dimensions are in millimeter).

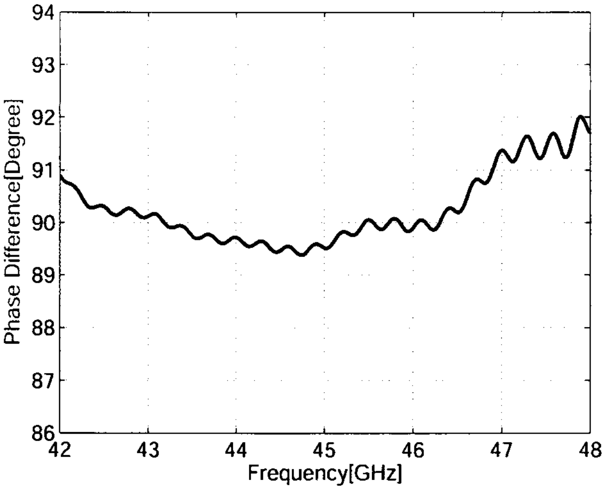


Figure 5. Phase difference between the horizontal and vertical polarization waves of the septum polarizer.

the common input port of polarizer. It is found out that a careful selection of the size of the square waveguide and the diameter of the circular waveguide eliminates the transition or adapter and the square waveguide can be directly attached to the circular waveguide with no significant RF power reflection. The two output ports of the septum polarizer are the rectangular waveguide, which is a standard waveguide, WR-22. The thin stepped septum divides the square waveguide into two identical rectangular waveguides, which are LHCP and RHCP ports. Since the cross section of these rectangular waveguides is different from the output port of WR-22, a waveguide impedance transformer is necessary at the output port of polarizer for having smaller insertion losses. This part is also designed by using the 3D EM simulator. The designed structure of septum polarizer is shown in Figure 3. The current frequency band of the KVN 43 GHz receiver is 42-44 GHz but the design frequency band is extended into 42-48 GHz. The dimensions of the essential components in the

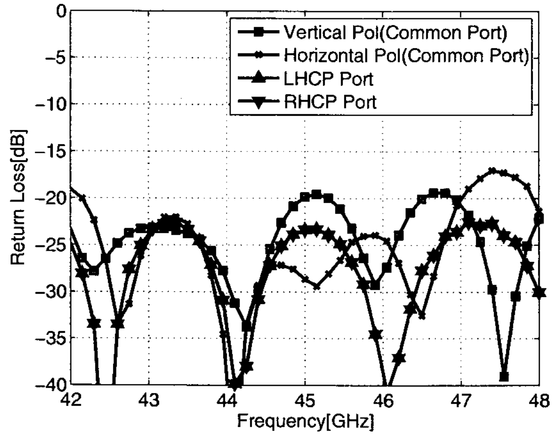


Figure 6. Return losses of the common input, LHCP and RHCP ports of the septum polarizer.

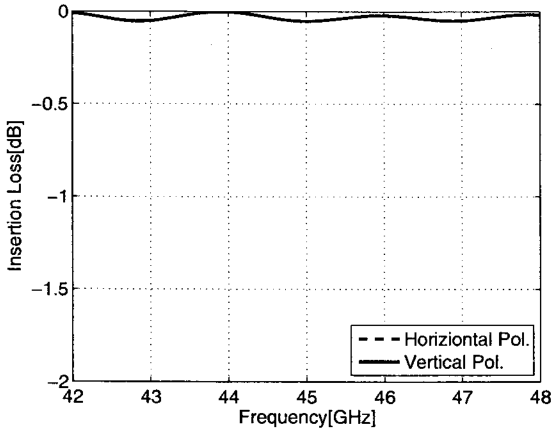


Figure 7. Insertion losses from the common input port to the rectangular output port.

stepped septum polarizer are shown in Figure 4.

Figure 5 shows the simulation result of phase difference between the horizontal and vertical polarized fields. The phase difference must be 90 degrees to discriminate the LHCP and RHCP signals. It can be seen that the calculated result of the phase difference is 90 ± 2 degrees.

The return losses and insertion losses of the common input port, LHCP and RHCP output ports are depicted in Figures 6 and 7. The calculated return losses except the horizontal polarization at the common input port are approximately less than –20 dB. The return loss of the horizontal polarization signal of the common input port is somewhat worse than –20 dB at both edges of the design frequency band. In addition to the 42-48 GHz frequency band polarizer, a simulation of the

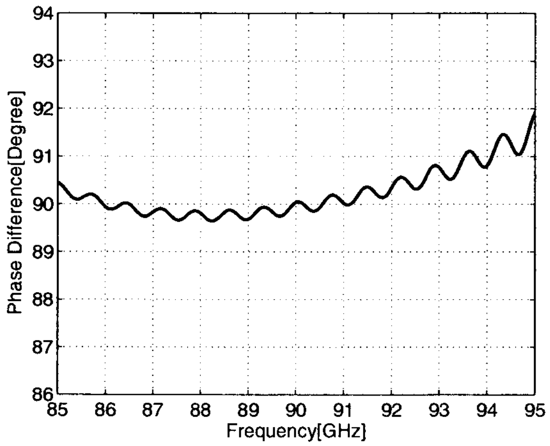


Figure 8. Phase difference between the horizontal and vertical polarized fields of 85-95 GHz frequency band septum polarizer.

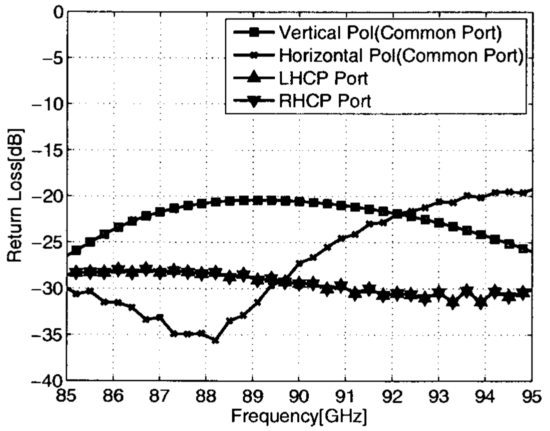
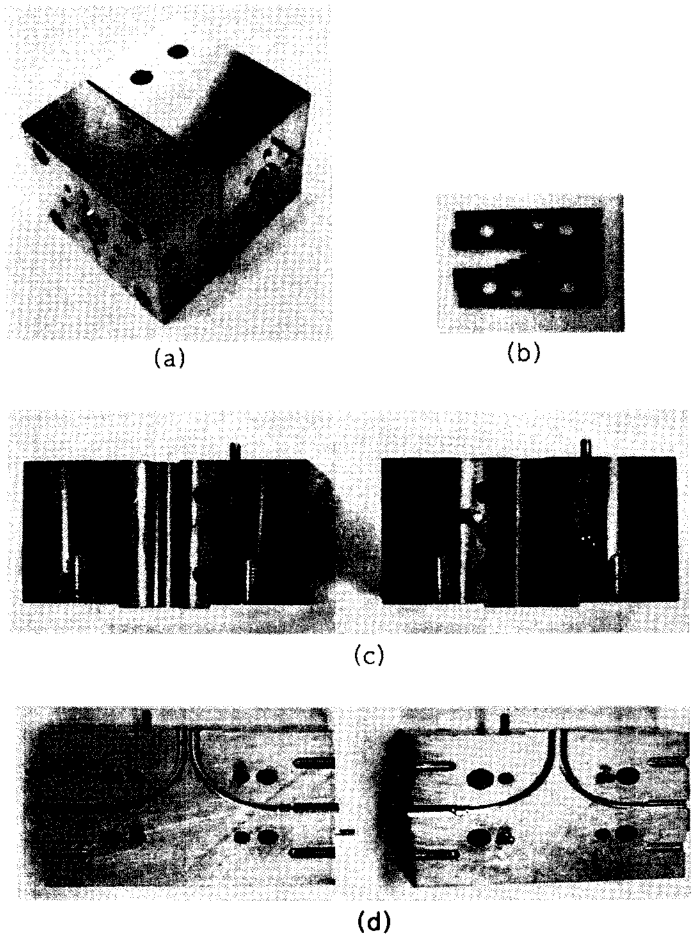


Figure 9. Return losses of the common input, LHCP and RHCP ports of 85-95 GHz frequency band septum polarizer.

septum polarizer for 85-95 GHz frequency band has been performed. Due to the scale invariance of the Maxwell equations without currents and charges, scaled structures have the same frequency response if the spatial dimensions are inversely proportional to the frequency. Thus, the dimensions of septum polarizer for 85-95 GHz frequency band are scaled down to half the designed septum polarizer for 42-48 GHz frequency band. In principal, the two septum polarizers should have the similar performances. Figures 8 and 9 show the calculated phase difference and return losses of the septum polarizer for 85-95 GHz frequency band.



(a) (b) (c) (d)

Figure 10. Fabricated E-plane split-blocks of the 42-48 GHz frequency band septum polarizer: (a) assembled septum polarizer, (b) stepped septum piece, (c) split-block for square waveguide, and (d) split-block for E-plane waveguide bends and waveguide transitions.

## 3. Fabrication and Measurements

A stepped septum polarizer for the 42-48 GHz frequency band KVN receiver was fabricated using E-plane split-block technique. The components for the septum polarizer can be seen in Figure 10. The fabricated septum polarizer consists of two modules. One module shown in (c) of Figure 10 contains a thin metal stepped septum that divides the square waveguide into two rectangular waveguides and another module depicted in (d) of Figure 10 has two E-plane waveguide bends and waveguide transitions for each polarization output port that mates with WR-22 waveguide. The block halves for the two modules were machined from brass and gold plated subsequently. The metal stepped septum piece was also made of brass and gold-plating was then applied to the surface. Gold-plating and surface roughness of the waveguide circuit may become more important for RF

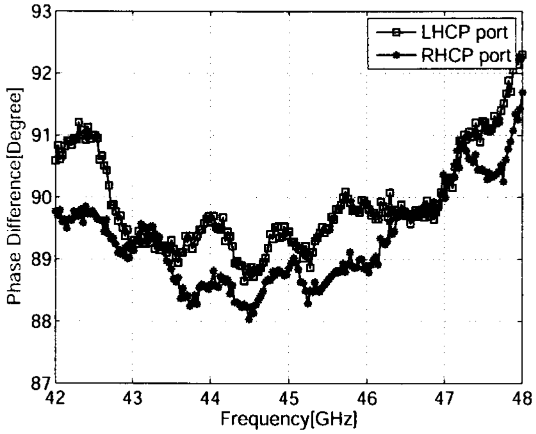


Figure 11. Measured phase difference between the horizontal and vertical polarized fields.

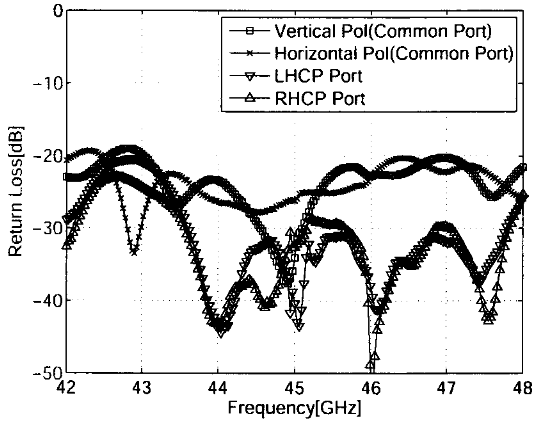


Figure 12. Measured return losses of the common input, LHCP, and RHCP ports.

loss at higher frequencies.

The phase differences and the return losses for the horizontal and vertical polarization fields and the insertion losses were measured using an HP 8510 vector network analyzer. The measured phase differences between the horizontal and vertical polarization waves are shown in Figure 11. The phase measurements between the common input port and LHCP, RHCP ports are performed through the circular-to-WR-22 waveguide transition and 90-degree waveguide twist for each polarization. If the horizontal and vertical polarization fields have the equal amplitude, the axial ratio of polarizer can be defined as follows (Srikanth 1997).

$$AR(dB) = 10 \log \frac{2 + \sqrt{2 + 2\cos(2\theta)}}{2 - \sqrt{2 + 2\cos(2\theta)}} \tag{1}$$

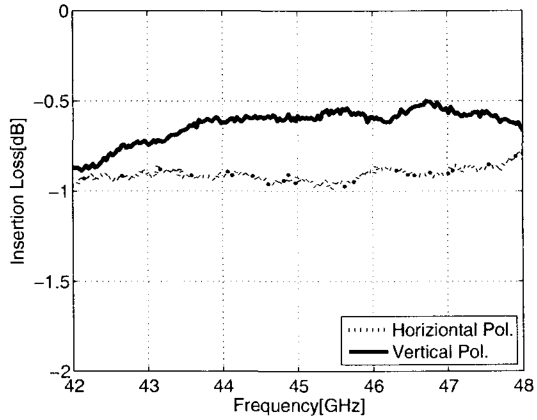


Figure 13. Measured insertion losses from the common input port to the rectangular output port.

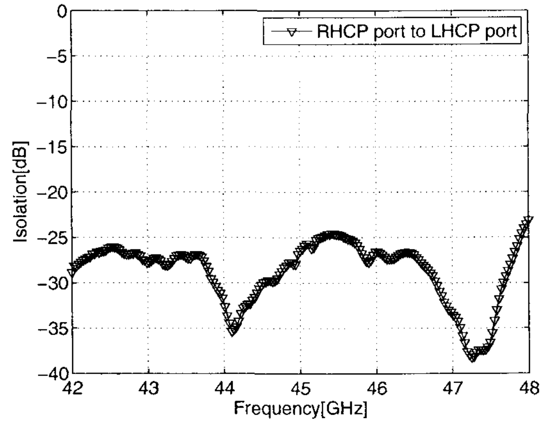


Figure 14. Measured isolation between LHCP and RHCP ports.

where $\theta$ is the phase difference between the two orthogonal polarizations. According to Eq. (1), the axial ratio of the fabricated septum polarizer is less than 0.5 dB across 42-48 GHz frequency band. The measurement result of return losses is depicted in Figure 12. The measured return losses are approximately better than –20 dB over the design frequency band except lower edge of the frequency band where the return losses of the vertical and horizontal polarizations rise slightly.

As shown in Figure 13, the measured insertion losses for both polarizations are considerably higher than simulation results. It is thought that this discrepancy may be caused by lossier waveguide inner surface than the theoretical one and gold-plating composition on the waveguide surfaces. Some alignment errors when mating of the machined split-block haves shown in Figure 10 can also lead to higher insertion loss than expected. In addition, the insertion losses for the horizontal and vertical polarizations are different. The misalignment or defect of the stepped septum inside the square waveguide can be one of such causes. The isolation between LHCP and RHCP ports was measured to be less than −25 dB over the designed frequency band in Figure 14.

## 4. Conclusions

A stepped septum polarizer for the KVN receiver system of 42-48 GHz frequency band has been built and tested. Measurement and simulation results of the designed septum polarizer show a good agreement. Measured phase difference across the design frequency band is within 90 ± 2 degrees, which corresponds to the axial ratio less than 0.5 dB if the imbalance between the amplitudes of the orthogonal polarizations is negligible. In addition, the return loss of the septum polarizer was measured to be better than 20 dB across almost 42-48 GHz frequency band. For a performance comparison, a dual-circular polarizer (AMC1233) currently employed in the KVN 43 GHz receiver has the return loss and the axial ratio that are around −16 dB and 0.9 dB over the operating frequency band, respectively (Test data sheet provided by Atlantic Microwave Corp. 2003).

The reasonably good agreement between measurement and simulation confirms that the designed structure of polarizer for 42-48 GHz frequency band can be used for the KVN 85-95 GHz frequency band polarizer by scaling of the polarizer dimensions. It will enable us to reduce the manufacturing cost and time for the development of polarizer over 85-95 GHz frequency band because measurement and fabrication of a septum polarizer at lower frequencies are relatively easy and cost-effective.

## References

Arndt, F., Tucholke, U., & Wriedt, T. 1984, Electron. Lett., 20, 458

Biber, S., Schür, J., Hofmann, A., & Schmidt, L.-P. 2004, Proc. 5th International Kharkov Symposium on Physics and Engineering of Microwaves, Millimeter and Submillimeter Waves, p.26

Chattopadhyay, G., Philhour, B., Carlstrom, J. E., Church, S., Lange, A., & Zmuidzinas, J. 1998, IEEE Microwave & Guided Wave Letters, 8, 421

Chen, M. H. & Tsandoulas, G. N. 1973, IEEE Trans. AP, 21, 389

Davis, D., Digiandomenico, O. J., & Kempic, J. A. 1967, G-AP Symp. Dig., p.26

Jarosik, N., Bennett, C. L., Halpern, M., Hinshaw, G., Kogut, A., Limon, M., Meyer, S. S., Page, L., Pospieszalski, M., Spergel, D. N., Tucker, G. S., Wilkinson, D. T., Wollack, E., Wright, E. L., & Zhang, Z. 2003, ApJS, 145, 413

Middelberg, E. & Bach, U. 2008, Rep. Prog. Phys., 71, 066901

Monorchio, A., Manara, G., Grassi, P., & Arena, D. 2004, Electromagnetics, 24, 49

Srikanth, S. 1997, IEEE Microwave & Guided Wave Letters, 7, 150