A Novel Planar Contiguous Diplexer DC-67-100 GHz Using Organic Liquid Crystal Polymer (LCP)

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Abstract — **This article describes a novel contiguous, planar Suspended Stripline (SSL) diplexer covering up to 100 GHz, implemented using Organic Liquid Crystal Polymer (LCP) for the first time. The diplexer design enables sharp & symmetrical roll-off. The lowpass and highpass channels cover ultra-wide bandwidth of DC-66 GHz and 66-100 GHz respectively. The synthesis, design and simulation of the diplexer is done using closed form analytical model in AWR's iFilter and optimized using 3D simulation.**

Index Terms — Liquid Crystal Polymer, Suspended Stripline, contiguous diplexer, soft-board, recessed cavity, lowpass filter, highpass filter, millimeter wave diplexer.

I. Introduction

Emerging applications of mm wave technologies require new and higher performance components and test equipment. These applications include Broadband wireless, high-speed wired, Automobile Radars, Imaging and sensors. 5G wireless systems are expected to take full advantage of wide bandwidths available in mm wave region. Test equipment needs to keep ahead of the devices under test. All these applications require components with small-size and excellent electrical performance [1]. Stringent requirements need to be imposed on the underlying material technologies. In order to satisfy material and design requirements, Liquid Crystal Polymer (LCP) was chosen as a candidate to implement diplexer design. This diplexer is used as a key component in the mm-Wave frond-end for a real-time 100 GHz oscilloscope design as shown in fig 1[2].

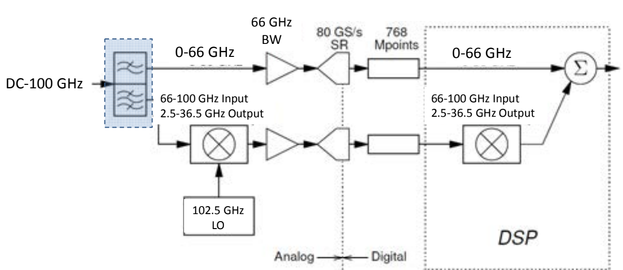

Fig. 1. Digital Bandwidth Interleaving (DBI) System Block Diagram

The diplexer in fig. 1 separates the incoming signal DC – 100 GHz into two frequency bands (DC to 66 GHz and 66 GHz to 100 GHz.) The higher frequency band is block down-converted to a frequency range suitable for acquisition by digitizing channels. In DBI systems, the digitized bands (higher and lower) are then stitched back to re-create the time domain signal [2].

The diplexer's construction includes distributed lowpass and highpass circuitry, which is printed on a 0.002 in. thick LCP substrate. The substrate is symmetrically suspended between top and bottom ground planes of the SSL structure. SSL technology performs with better temperature stability, less dispersion, flatter group delay, and low loss over a wider frequency bandwidth than the conventional microstrip and stripline technologies.

A. LCP material

The planar substrate used for the diplexer is Roger's Ultralam 3850 material with dielectric constant of 2.9, and effective dielectric constant is closer to 1 due to SSL structure. The substrate thickness is only 0.002 in. With such low substrate thickness, implementing high Q and low capacitance values on broadside coupled sections becomes more practical due to SSL, especially at millimeter-wave frequencies.

LCP offers low moisture absorption and excellent dimensional stability due to its woven glass free homogeneous properties, which enables broadband millimeter-wave frequency performance. The attenuation characteristic of the LCP exhibits 2 dB/cm at 100GHz. Figure 2 represents the real and imaginary parts of the effective dielectric in a pure TEM mode of propagation over entire frequency range in microstrip transmission line. The real part of ϵ_{eff} for the vast majority of the frequency range varies by only 0.12 [1].

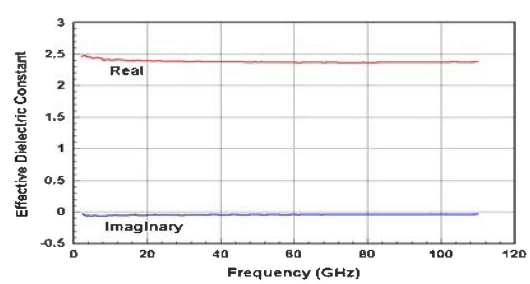

Fig. 2. Real and Imaginary Effective Dielectric response of LCP[1]

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Flat group delay response is critical in any planar filter design. This is possible if the phase velocity is stable theoretically constant across the band of interest in any given dielectric material. Stable phase velocity is the result of flat effective dielectric constant ϵ_{eff}. LCP offers stable dielectric constant up to millimeter-wave frequencies.

B. SSL Design and Higher Order Modes

Figure 3 shows a cross-sectional view of a single-side metallized SSL structure, which has 0.002 in. dielectric substrate housed in a proportional recessed air cavity enclosed in a shielded rectangular waveguide. The lowpass section of the diplexer is implemented using single-sided (top) conductor on the substrate as shown in figure 3. While the highpass section of the diplexer is realized with metallization on opposite sides of the substrate forming broad-side coupled sections (quasi-lumped capacitors) as shown in figure 4.

The height ($=h_1 + h_2 + h$) and width (w_1) of the SSL cavity are optimized such that the higher order TE and TM hybrid modes are suppressed below the intended frequencies of operation [3].

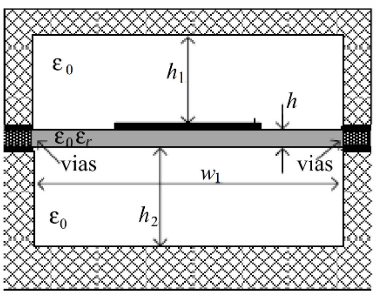

Fig. 3. Cross-section of SSL structure

For the dominant mode to be quasi TEM in the SSL structure, the cut-off frequency of loaded SSL is set to be above 100 GHz and can be computed from equation below:

$$f_c = \frac{c}{2w_1}\sqrt{1 - \frac{h}{b}\left(\frac{\epsilon_r - 1}{\epsilon_r}\right)} \quad (1)$$

Where w_1 is the channel width, b is the channel height ($=h_1 + h_2 + h$), c is the speed of light and h is the substrate height.

II. FILTER DESIGN

A. Diplexer model and synthesis

The initial synthesis of the lowpass and the highpass filter of the diplexer model is completed using closed form admittance inverter equations that require parameters of Tchebyschev low-pass prototype.

B. Lowpass Filter

The Tchebyschev lowpass section of the diplexer is modeled and synthesized using iFilter feature in AWR. The lowpass 13th order stepped impedance design is implemented using series λ/8 high impedance and shunt λ/2 low impedance resonators. The cutoff frequency of the filter is set to 35 GHz with pass-band ripple of 0.1 dB.

C. Highpass Filter

The LC lumped element prototype circuit of the Tchebyshev 11th-order highpass is synthesized again using iFilter (AWR) for the corner frequency at 35 GHz. The series capacitances of the highpass are implemented using broadside coupled strip elements on either side of the substrate. The shunt inductances are implemented using short-circuited step impedance line resonators with a nominal electrical length of λ/2 [4]. Physical lengths of the resonators and overlap sections of the highpass filter are finely optimized in 3D EM software for the required performance.

D. Simulation

The diplexer design specifications are shown in the table below

TABLE I
DESIGN SPECIFICATIONS

Parameter	dB	Frequency range (GHz)
$\|S_{11}\|$	≥ 10	DC – 100 GHz
$\|S_{22}\|$	≥ 10	DC – 66 GHz
$\|S_{33}\|$	≥ 10	66 – 100 GHz
$\|S_{21}\|$	≤ 3	DC – 66 GHz
$\|S_{31}\|$	≤ 4	66 – 100 GHz
$\|S_{21}\|$ = $\|S_{31}\|$	≤ 7	At 66 GHz (cross-over)
$\|S_{21}\|$ & $\|S_{31}\|$	≥ 20	At ± 2 GHz from cross-over

The layout of the synthesized Low Pass and High Pass filters are transferred to 3D EM software and optimized for required performance. The junction shown in Fig.4 was optimized for broadband match and cross over phase linearity. Figures 4 and 5 show the layout and simulation response of the diplexer.

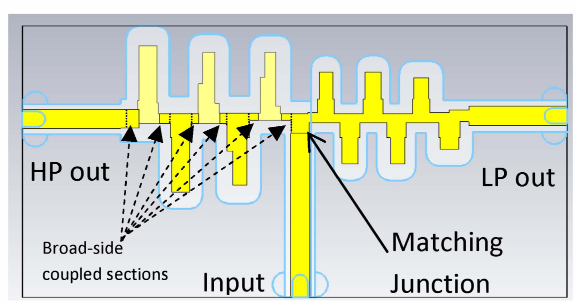

Fig. 4. 2D circuit model of the diplexer

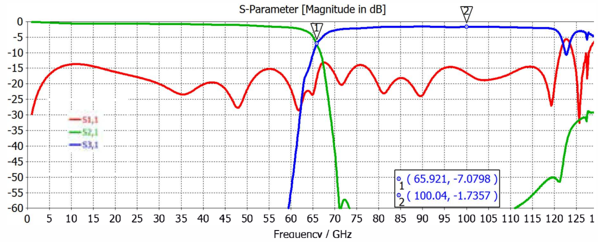

Fig. 5. Simulated Log Magnitude S-Parameter response of the diplexer

E. Fabrication

Gold-plated brass was used for the mechanical housing and recessed cavities. High accuracy in mechanical dimensions and PCB etching is required for high-frequency devices [2]. Therefore, machining tolerance for the housing was held better than 0.0002. PCB etching tolerances of better than 0.0005 in. was held with 1/4 ounce Cu metal thickness to achieve good co-relation between simulated and measured results. Figure 6 shows complete assembly of the diplexer circuit using the LCP substrate. Provision for sapphire tuning rods as shown in Fig. 6 below was implemented to fine tune the measured response.

Anritsu's W1-103F two hole flange 1.00 mm connectors were used on all three ports. Diplexer circuit fabricated on LCP material is shown in Figure 7. Implementation of the Coaxial to SSL transition using 1 mm connector was one of the major challenges. The mismatch at the transition was overcome primarily by performing capacitive and inductive compensation.

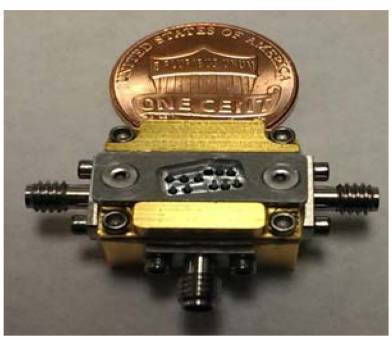

Fig. 6. Complete diplexer assembly

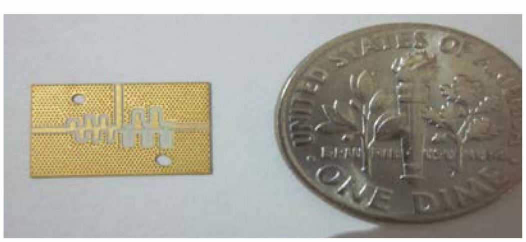

Fig. 7. Diplexer Circuit fabricated on LCP

III. Measured Results

The measured result shown in figure 8 displays excellent agreement between simulation and measured data. The passband ripple is less than 1 dB with 3dB loss in the mid band of High pass response and 5 dB loss at 100 GHz. Crossover was measured at 66.5 GHz with an insertion loss of 7.0 dB. Both the LPF and HPF show very high rejection in the reject band. The measured response in fig. 8 is shown with final post tuning. The shift in frequency of the cross-over is caused manly due the limitation of the etching tolerance of the PCB.

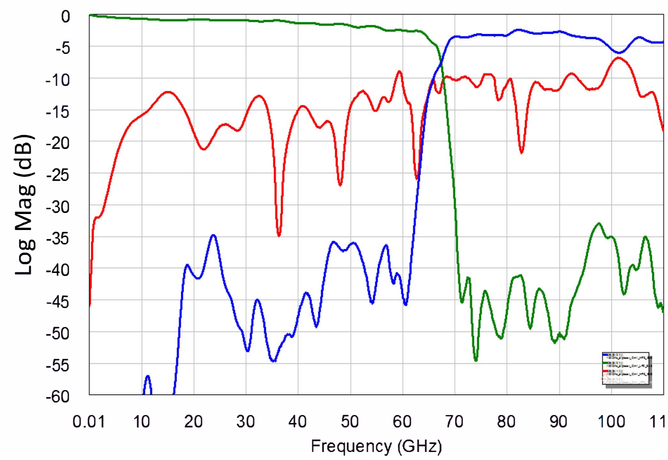

Fig. 8. Post tuned measured Log-Mag S-Parameter Response of LCP 100GHz Diplexer

The diplexer exhibits flat group delay across the band as shown in figure 9 and 10. Figure 9 displays the measured group delay of the lowpass filter section and is about 100 picoseconds except at the cross over. The variation in the lowpass group delay from cross-over frequency (66.5 GHz) to the mid band (35 GHz) is less than 60 picoseconds.

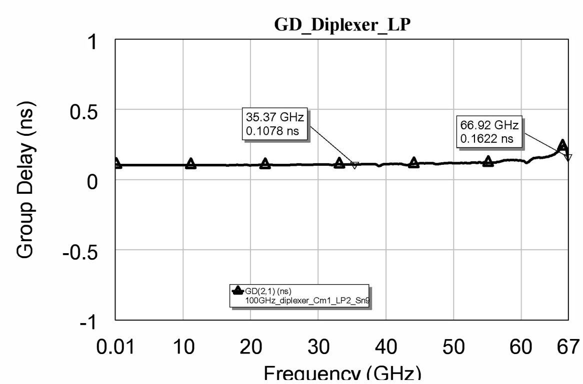

Fig. 9. Measured Group Delay response from DC to 67 GHz of the LowPass section of the diplexer

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Figure 10 shows group delay of highpass filter section of the diplexer and is measured to be about 120 picoseconds between 65GHz to 100 GHz except at the cross over. Slight peaking in group delay around the crossover region from 65.5 GHz to 67.5 GHz is due to the abrupt phase and quality factor variation when transitioning from lowpass to highpass. The deviation in the group delay from cross-over frequency (66.5 GHz) to the mid band (87 GHz) is less than 100 picoseconds.

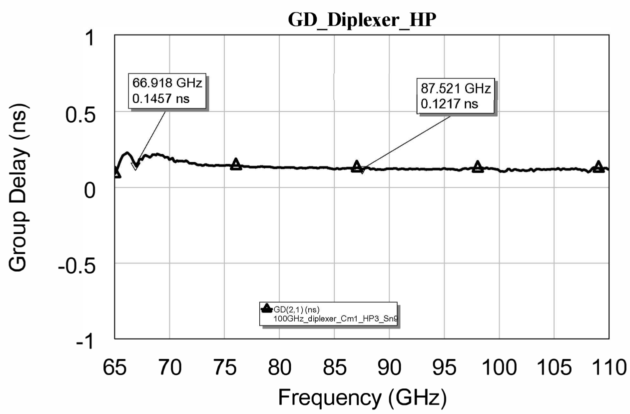

Fig. 10. Measured Group Delay response from DC to 67 GHz of the HighPass section of the diplexer

IV. Conclusion

A novel high-performance planar contiguous diplexer (covering DC to 66 to 100 GHz) implemented using organic LCP material is presented. Excellent flatness and steep roll-off sharpness is achieved. Return loss better than 10 dB was measured across the band. Excellent correlation between simulated and measured results was realized. It was demonstrated that LCP enables high performance and practical implementation capability of passive filters in mm-wave bands up to 100 GHz and beyond.

Acknowledgement

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