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Quadrature Signal Splitting Technique Offering Octave-Band Performance

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Abstract: *An analogue signal quadrature-phase splitting technique is introduced that offers enhanced amplitude and phase balance over a wider bandwidth than that available from transformer or branch-line methods. Both simulated and measured results are presented and a performance comparison is made with existing commercial products. Gain and phase balances of $\pm 1^\circ$ and $\pm 0.3\text{dB}$ over a 71% bandwidth have been achieved, additionally an extremely low component count make the technique simple to implement.*

Introduction

The trend for flexibility in radio transceiver systems leads to a requirement for wide-band phase-quadrature signals over frequency ranges up to the 5GHz region. These signals are generally generated by a parallel mixing process resulting in two quadrature channels. A quadrature LO is required for this process, the quality of which has a direct bearing on the overall system performance.

There are two options when generating a quadrature analogue LO for a flexi-standard transceiver: The gain and phase balance may be assumed from a passive and accurate generation process or monitored and adjusted by an active intelligent process. This paper presents a technique applicable to the former of these options. The accuracy of the quadrature relationship has a direct effect on transceiver performance, for example in Error Vector Magnitude and image suppression. In order to maintain EVM below 9%, gain and phase errors of less than 0.3dB and 3° respectively are required between the I and Q channels. The same accuracy within a direct conversion transceiver will result in an image suppression of no greater than 30dB.

Transformer-based solutions to this requirement are beset by parasitic reactance at such frequencies, leaving branch-line devices as the only viable alternative to date. However, the authors have investigated an alternative, passive and reciprocal technique for quadrature signal splitting [1], which offers considerably enhanced performance over commercially available products.

Theoretical Description

If a single magnitude response null is effected in the frequency domain transfer characteristic of a passive two-port analogue network of zero electrical length, the following will be observed. The phase response moves from zero towards $-\pi/2$ radians as frequency increases towards the null, is undefined at the frequency of the null, and tends from $+\pi/2$ radians to zero as frequency further increases. Extending this to the case where two nulls exist separated by a frequency band; it can be shown that the phase response passes through zero at a particular rate of phase shift/frequency. The location of this zero-phase crossing is dependent on both the symmetry of the nulls and their absolute position in the frequency domain.

If the resonant device causing each of the two response nulls exhibits a symmetrical phase response, the zero-phase crossing point will occur equidistant from the pair.

Now, if the transfer response of this network is referenced against a second two-port passive network comprising a group delay element designed to match the rate of change of phase with frequency at the

zero-phase crossing point, an absolute phase difference will be seen. This phase difference can be exploited in the construction of a non-equal-phase splitter.

A three-port non-equal-phase splitter can be realised from a zero-phase splitter, multi-zero network and a compensating delay. The implementation is given in Figure 1.

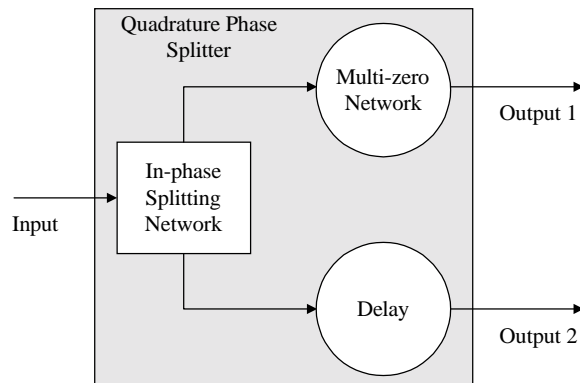


Figure 1: Quadrature Phase Splitter Implementation. An in-phase symmetrical splitter is cascaded with a compensated multi-zero network.

Simulated and Practical Results

For analysis, the implementation of the multi-zero network was chosen to be a comb filter. Theoretically, this device effects an infinite number of nulls equi-spaced in the frequency domain, each of which offers the desired symmetrical gain/phase response with no attenuation at the centre of any consecutive pair.

The theoretical simulation of a quadrature splitter using this implementation is given in Figure 2; as the analysis is purely mathematical the frequency units are undefined. The solid line denotes the power gain difference and the broken line denotes the phase difference. Signal splitting operation can lie within any region where the gain difference is small and the phase difference is approximately constant with frequency.

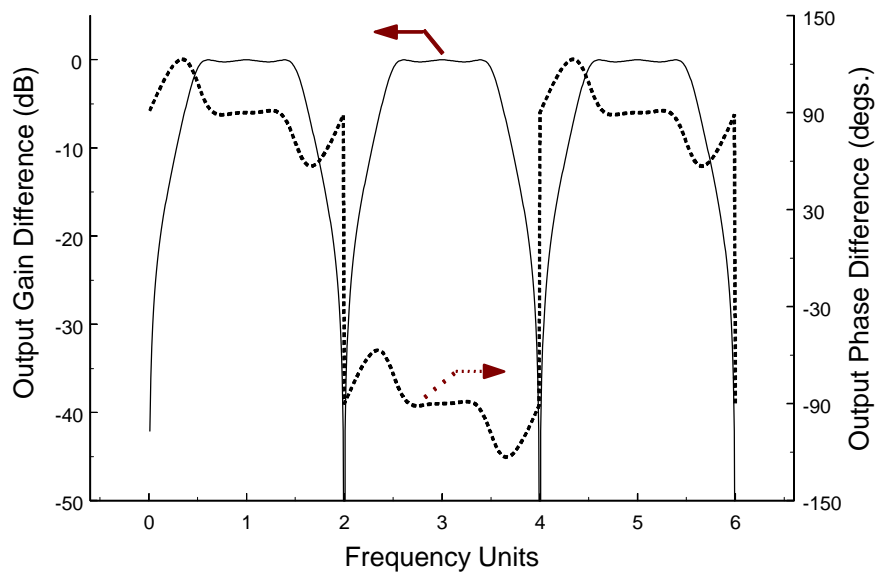


Figure 2: Quadrature Splitter - Theoretical Performance. The solid line denotes the power gain difference and the broken line denotes the phase difference between the two outputs.

The practical implementation of the quadrature splitter for analysis comprised three elements; a Wilkinson-type zero-phase power splitter, a delay-line and a shunt-stub comb filter. All of these components can be implemented in planar microstrip or any other form of transmission-line. There is a single discrete component in the design: a resistor in the zero-phase power splitter. This may be omitted at the expense of bandwidth performance and port isolation.

Because the zero-phase-splitting device is symmetrical, the output signals vary in a complementary manner, as the frequency diverges from the centre design value. This important quality facilitates the wide-band capability of the overall network. A resistive splitter could be used in its place at the expense of transfer loss, isolation and parasitic reactance. A Wireline-based, transformer-based or transmission-line directional coupler could not be used, since these devices do not exhibit the required complementary output variance with frequency.

The measured performance of the implemented device is given in Figure 3. Here, the use of a Wilkinson splitter is significant, the operational bandwidth of this device confines the performance of the network to one of the inter-null zones shown in Figure 2. The frequency units are now significant and are GHz. Importantly, the device can be scaled to suit any centre frequency within the capability of the transmission medium employed, in the same manner as a branch-line splitter.

The gain and phase balance of the two quadrature outputs within the operating region can be seen in the detail insert graph within Figure 3. The performance of this technique is summarised in Table 1, where a $1^\circ / 0.3\text{dB}$ balance over a range in excess of an octave is shown. Also stated are examples of what can be expected of the other appropriate technologies for this function.

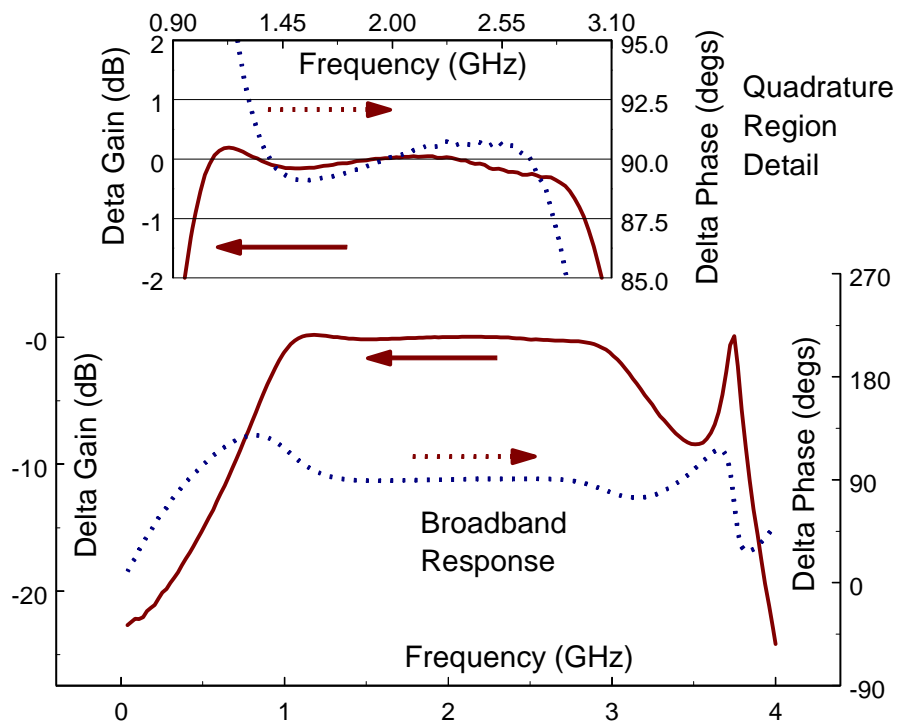


Figure 3: Quadrature Splitter - Measured Performance. The solid line denotes the power gain difference and the broken line denotes the phase difference between the two outputs. The detail insert graph shows the system performance at the operating region.

The table shows, by example, that branch-line technology exceeds the performance of transformer-type quadrature splitters and that the delay-compensated multi-zero technique exceeds the performance of both. Comparing these latter two, for a similar output balance performance, delay-compensated multi-zero operates over an additional 16% of bandwidth and for similar bandwidth, delay-compensated multi-zero offers four times the output balance accuracy.

Device Technology	Centre Frequency (GHz)	B/W (%)	Phase balance (Degrees)	Power balance (dB)	Data Reference
Transformer	1.5	13	5	1.0	[2]
Branch line	1.5	67	3	1.2	[3]
Branch line	3	67	4	1.2	[3]
Delay Compensated Multi-zero	2	71	1	0.3	Figure 3
		75	2	0.3	
		79	3	0.4	
		81	4	0.4	
		83	5	0.5	

Table 1: Comparison of the delay compensated multi-zero quadrature phase splitter with that of other appropriate technologies.

Conclusion

A technique has been demonstrated that offers quadrature power splitting/combination over bandwidths up-to and over an octave; Delay-compensated Multi-zero. The theoretical operation of the device is described, and both simulated and practical results are given. It is shown, by example, that the device performance exceeds what can be expected from both transformer and branch-line techniques. The observation is made that the quadrature-phase splitting balance accuracy of this technique exceeds that commercially available by a factor of four.

References

- [1] J. Domokos, 'Microwave Power Divider', UK patent GB 2170358 B.
- [2] Minicircuits Device RPQ-1495, Full data available from <http://www.minicircuits.com/2way90.htm>.
- [3] Pulsar devices from QS2 range, Full data available from <http://pulsarmicrowave.com/index2.html>

Captions