A Novel Method for Frequency Discriminators Construction based on Balanced Gray Code

E. M. F. de Oliveira[1]*, M. S. Coutinho[1], T. L. Pedrosa[1], M. T. de Melo[1] and I. Llamas-Garro[2]
[1]Departamento de Eletrônica e Sistemas, Universidade Federal de Pernambuco, Recife, Brazil
[2]Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Barcelona, Spain
*Corresponding author: eliasmarques@outlook.com

***Abstract*—** This paper discusses the use of multi-band-stop filters for application as frequency discriminators. A novel design method is presented (multi-band-stop filters based on the balanced gray code) and compared to the straightforward method (traditional gray code). The novel method increases individual rejected bands fractional bandwidth, while assuring that each filter possess the same amount of rejected sub-bands. For a frequency span, it is also shown that the sub-bands fractional bandwidth relative standard deviation is reduced.

***Keywords*—** *frequency discriminators; multi-stop-band filters; balanced gray code.*

I. INTRODUCTION

In Instantaneous Frequency Detection, a *frequency discriminator* is a frequency-sensitive device that allows the system to infer the frequency of an unknown incoming signal.

A way of implementing Digital Instantaneous Frequency Detection Systems is using a set of interferometers along with power detectors that create a unique combination of output words to represent the detected frequency.

However, a group of interferometers can be substituted by a set of filters that mimic its frequency response, allowing the use of much more developed implementation techniques.

As a natural solution, these filters ended mimicking the code in which the interferometers are built: the traditional gray code.

This paper presents a method for defining the characteristics of a set of filters for application as frequency discriminators based on the balanced gray code. Also, a comparison between both methods is present, showing average sub-band fractional bandwidth along with standard deviation and variation coefficients.

II. MICROWAVE FREQUENCY DISCRIMINATORS

Historically, interferometers have been used in analogue Instantaneous Frequency Measurement Systems (IFM) as frequency discriminators. A microwave interferometer operates similarly to an optical one, splitting an incoming signal into two equal parts, guiding each one into different paths. When combining the signals, the phase shift between them produces a pattern that allows the recognition of the signal frequency. [1].

From this method, a straightforward solution to implement a digital IFM is to attach microwave detectors along with voltage comparators [2, 3]. If a certain detected signal's voltage level is higher than a predefined threshold, the output bit is '1' (or '0' otherwise).

To increase resolution, multiple interferometers can be utilized. Since the frequency response of an interferometer is periodical, the output bits will present a periodical pattern with respect to the input signal frequency. Thus, the output code (composed by the individual bits) has to respect such pattern.

The traditional gray code is perfectly suited for this application since its bits sequences are composed by a sequence of '0's followed by the same number of '1's, therefore being easily implemented with interferometers. Another advantage from the use of this code is that its consecutive words differ by only one bit, preventing spurious results in the band transition proximities. [4]

Below, is the 4-bit traditional gray code:

0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1

0 0 0 0 1 1 1 1 1 1 1 1 0 0 0 0

0 0 1 1 1 1 0 0 0 0 1 1 1 1 0 0

0 1 1 0 0 1 1 0 0 1 1 0 0 1 1 0

A. Frequency Discriminators Using Multi-band-reject Filter Responses based on Traditional Gray Code.

The use of filters as frequency discriminators emerge from the concept that any couple of microwave network will perform the same function as long as their frequency responses are equal.

Nonetheless, microwave filter design techniques are far more advanced when compared to microwave interferometers', what makes the choice for the previous very appropriate.

Some solutions employ filters as frequency discriminators utilized multi-band-reject filters for this task [5]. In [6] the filter design was chosen to mimic the interferometers' frequency response. In this example, all filters were implemented using square ring resonators that while being suitable for implementing the narrowest sub-bands, requires a large number of rings for implementing the widest ones.

Also, as predicted by the use of the traditional gray code, every subsequent filter sub-bands bandwidth is half the size of its predecessor. In order to increase the system resolution, more filters have to be added with even narrower sub-bands.

B. *Frequency Discriminators Using Multi-band-reject Filter Responses based on Balanced Gray Code*

The balanced gray code is a variation of the traditional gray code that while maintaining its characteristics, reduces the number of transitions, therefore, allowing the filters' rejected bands to be less narrow when compared to their traditional counterparts.

The key concept behind this choice is that the set of n filters will still keep its key requirements: producing 2^n output words, while two consecutive words differing by a bit only. Nonetheless, the filter design can benefit from this choice in the form of the shape of its sub-bands and quantity of sub-bands per filter.

Below, is the 4-bit balanced gray code:

0 1 1 1 1 1 1 0 0 0 0 0 0 1 1 0

0 0 1 1 1 1 0 0 1 1 1 1 0 0 0 0

0 0 0 0 1 1 1 1 1 0 0 1 1 1 0 0

0 0 0 1 1 0 0 0 0 0 1 1 1 1 1 1

III. Comparison Between Traditional and Reconfigurable Discriminator Designs

Considering multi-band-reject filters, one possible way to construct such devices is by the combination of sub-filters that individually reject each sub-band. Implementing a set of filters mimicking the traditional gray code will result in disproportion in the number of sub-bands per filter. As an example, using the 4-bit traditional gray code, filters 1 and 2 will possess 1 rejected sub-band, while filter 4 will possess 4 rejected sub-bands.

The balanced gray code, however, grants that each filter has the same quantity of sub-bands. On the 4-bit balanced gray code, every filter has the same amount of rejected sub-bands, i.e. 2 rejected sub-bands per filter. This impacts directly on the filter size uniformity, since each filter will be constructed with the same amount of sub-filters.

For a better understanding of the concept, let us define $\Delta f'$ as the resolution of an IFM system of n bits, given by:

$$\Delta f' = \frac{f_2 - f_1}{2^n} \tag{1}$$

where f_2 and f_1 are respectively the maximum and minimum frequencies of the IFM system.

Considering a rejected sub-band belonging to a multi-band-stop filter, its limiting frequencies will be apart from each other by a multiple of the system's resolution, as shown in Fig. 1.

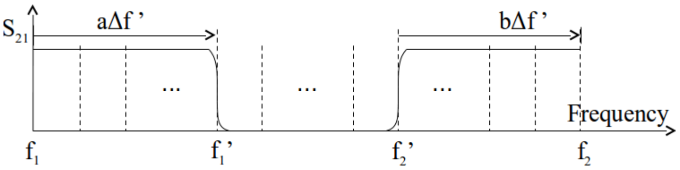

Fig. 1 – A filter Individual Rejected Sub-band

In this representation, a and b are integers and represent how far from the maximum and minimum frequencies the sub-band cutoff frequencies are; while f_1' and f_2' are the rejected sub-band cutoff frequencies.

The fractional bandwidth of a filter individual sub-band can be expressed in terms of this representation by:

$$\text{FBW}' = \frac{f_2' - f_1'}{f_c'} = 2\frac{(f_2 - f_1) - (a+b)\Delta f'}{(f_2 + f_1) + (a-b)\Delta f'} \tag{2}$$

As a comparison, let us choose $f_2/f_1 = 2$, the values of a and b give the fractional bandwidth for each sub-band, as shown on Table 1. (Note that the variables considered are those of a 4-bit system). The results show that for the same number of bits, the average fractional bandwidth is greater, while the standard deviation is smaller.

Table 1 – Fractional Bandwidth Comparison for $f_2/f_1 = 2$

Traditional Gray Code					Balanced Gray Code				
Filter	Band	a	b	FBW'	Filter	Band	a	b	FBW'
1	1	8	0	0.2857	1	1	1	9	0.3000
2	1	4	4	0.3333	1	2	13	1	0.0667
3	1	2	10	0.2000	2	1	2	10	0.2000
3	2	10	2	0.1429	2	2	8	4	0.1538
4	1	1	13	0.1111	3	1	4	7	0.2222
4	2	5	9	0.0909	3	2	11	2	0.1053
4	3	9	5	0.0769	4	1	3	11	0.1000
4	4	13	1	0.0667	4	2	10	0	0.2069
Average:			0.1634		Average:			0.1694	
Standard Deviation:			0.1003		Standard Deviation:			0.0774	

Fig. 2 shows the average fractional bandwidth vs. f_2/f_1 for both traditional and balanced gray code. Having a greater fractional bandwidth means that the filter implementation can be done easier because the sub-bands are relatively wider.

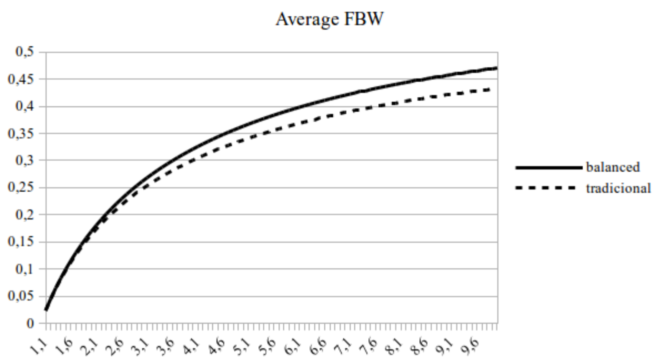

Fig. 2 – Average Fractional Bandwidth versus f_2/f_1

Fig. 3 presents the relative standard deviation of the fractional bandwidths. Having a smaller relative standard deviation means that the sub-bands fractional bandwidths are closer. Therefore, a same technology will be suitable for all rejected sub-band individual filter implementation.

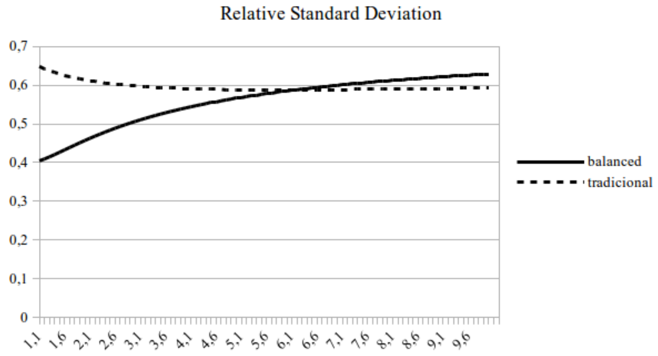

Fig. 3 – Fractional Bandwidth Relative Standard Deviation versus f_2/f_1

IV. CONCLUSION

In this paper, it is demonstrated that the use of balanced gray code for the definition of sub-bands in a multi-band-stop filter increases the average fractional bandwidth of the individual rejected bands while assuring that each filter will possess the same amount of rejected sub-bands.

Also, it is shown that, for a specific frequency region, the rejected sub-bands bandwidth relative standard deviation is also reduced, which means that it is easier to construct all filters using the same technology.

AKNOWLEDGEMENTS

This work was supported by the North Atlantic Treaty Organization (NATO/OTAN), project SfP 984809. Spanish Ministry of Economy and Competitiveness project TEC2014-58341-C4-4-R, NRF-Korea project NRF-2014R1A1A2055653. Part of this work has been supported by the Generalitat de Catalunya under grant 2014 SGR 1551.

REFERENCES

[1] East, P. W. “Fifty years of instantaneous frequency measurement,” IET Radar, Sonar, and Navigation, Vol. 6, No. 2, pp. 112-122, 2012.

[2] De Oliveira, B. G. M.; de Melo, M. T.; Machado, G. G.; Llamas-Garro, I.; “Compact Coplanar Interferometers for a 5-6 GHz IFM System”, International Journal of Applied Electromagnetics and Mechanics, Vol. 45, No 1-4, April 2014, pp 235-240.

[3] M. T. De Melo, M. J. Lancaster and J. S. Hong, "Coplanar strips interdigital delay line for instantaneous frequency measurement systems," Advanced Signal Processing for Microwave Applications (Digest No.: 1996/226), IEE Colloquium on, London, 1996, pp. 1/1-1/4.

[4] L. Wang; Z. Wang; Q. Huang; M. Zhang, "Balanced Gray Codes with Flexible Lengths," in IEEE Communications Letters , vol.PP, no.99, pp.1-1.

[5] B. Lu, W. Pan, X. Zou, L. Yan and B. Luo, "Photonic Microwave Frequency Measurement With High-Coding-Efficiency Digital Outputs and Large Measurement Range," in IEEE Photonics Journal, vol. 5, no. 5, pp. 5501906-5501906, Oct. 2013.

[6] De Souza, M. F. A.; e Silva, F. R. L.; de Melo, M. T.; and Novo; L. R. G. S. L., “Discriminators for Instantaneous Frequency Measurement Subsystem Based on Open-Loop Resonators,” IEEE Transactions on Microwave Theory and Techniques, Vol. 57, No. 9, September 2009, pp. 2224-2231.