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PERFORMANCE STABILIZATION OF STEEP GAIN GRADIENT CLASS ULTRA-WIDEBAND DIRECT CONVERSION IFM RECEIVER OF HOMODYNING BASED SYSTEMS

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Abstract:-

This article explains finding of power issues and the methodology of giving a suitable solution for performance stabilization of an ultra-wideband very high gain receiver with steep gain gradient. The origin of this problem lies in homodyning down conversion technique itself. Its LO is derived from input RF source. Varieties of frequency band limited equalizers like RC, RL and RLC are examined to overcome initial gain fluctuations at low frequencies as well as region based gain humps to reduce slope gradient. Thereby at the same time it helps to enhance practically achievable gain against theoretical gain at around highest frequencies by reducing power distribution among all harmonic and spurious components caused by lower frequency elements.

Keywords: – *Homodyning down conversion, Instantaneous Frequency Measurement (IFM), Direction Finding (DF), Direction of Arrival (DOA), Gain slopes and Domain based equalizers.*

I. INTRODUCTION

Evolution of ultra-wideband receiver design and development techniques have been developed over time and are already available in the market like homodyning, super heterodyning methodology etc. Modern ESM system design follows few basic concepts like homodyning or heterodyning down conversion respectively, Base Line Interferometer (BLI) technique based Direction Finding (DF), Detector Log Video Amplifier (DLVA) based amplitude measurement and Delay line based instantaneous frequency measurement (IFM) etc. Performance stabilization of a very high gain receiver with steep gain gradient is a challenging task especially for ultra-wideband spectrum. In the book [1] discuss interactions between the noise and the nonlinearities of the cascaded system and the intermodulation products (IP) that are produced by noise or by noise like signals. It build ideas of nonlinearity effects on even and odd order IP and harmonics which in terms affect power level of high frequency spectrum. In the paper [2] a brief study on direct conversion heterodyne receiver and image-reject topologies are carried out. It has also studied few effects and design techniques of direct-conversion architecture such as dc offset, I and Q mismatch, I and Q calibration even-order distortion, flicker noise, and oscillator leakage are analyzed. The complexities of homodyne receiver design are; it not only identifies phase information (frequency extraction) but also calculates direction finding information. Thereby its design technique is very complex in nature and bulky in size indeed. Unlike homodyne receiver design principle, super heterodyne receiver has different LO generation scheme (external LO) and also its end output type. Thus it's apparently less complex compared to homodyne receiver to design as the present scope of work. Present ultra-wideband receiver is a subset of homodyne receiver with LO derived from intercepted signal and having only phase information (I and Q) video signal at outputs. Its digital processing is done separately in another single board housed in the same housing. Here concept of delay line implementation and mixing techniques differ totally from existing homodyne receiver. Electronic Support Measurement (ESM) class system always offers such challenges especially for homodyning based systems due to its wide effective operating bandwidth in nature. Zero-intermediate frequency receiver design technique is explained in paper [3] where advantages and disadvantages concerning integratability and performance of IF and zero-IF receivers are discussed. Here technique is explained for telecommunication domain. The origin of this problem lies in homodyning based down conversion technique itself as LO is derived from the same input RF source. Mixer requires a sufficient LO drive to be fully operational. LO channels receives very weak signal from antenna. Thereby sufficient gain needs to boost the power is obvious for multichannel LO paths. Amplifiers which are readily available in the market with high P1dB (about18 ~ 20 dBm) having considerable gain slope comprising typical gain (about 15 ~ 20 dB) over wideband spectrum. It means cascading of several such devices required to build very high gain (about two fold amount of gain from typical receiver needs) at higher frequencies. While doing so it ends up with very high gain variation form lowest to highest frequency of operation respectively. Such high gain requires for homodyning based IFM receiver to tackle heavy losses due to various splitting, filtering, coupling and passive delay line circuitry. Basic problems happens with such chain of amplifiers are several viz. abrupt gain slope, matching issues between sections, gain mismatch and depreciation of power due to harmonics effects etc. [4]. Localized gain humps at low frequency thereby cause harmonics issues at higher frequencies [6]. It results less power to the mixers at the highest frequency of operation. This short fall of power at this frequency (although theoretical gain is enough) reduces LO drive to the mixer. Additionally it imposes unexpected low as well as high intensity oscillation issues over the spectrum.

II. STABILIZATIONTECHNIQUES

There are several theories provided by well-established literature are available to address those issues. Gain equalization is one of the basic techniques to solve few of the above mentioned issues [7]. There are varieties of equalizer design techniques. Basic RC, RL, RLC etc [8]. Are followed to overcome initial gain fluctuations at low frequencies as well as region based gain humps to reduce slope gradient at the same time to equate practically achievable gain against theoretical gain at around highest operating frequency. Gain (or especially power) would not reach to its expected level at higher frequencies due to power distribution among all harmonic and spurious spectrum components produced by lower frequency spur without equalization circuitry. Nonlinearity of any component can be described by equation (1) [5].

$$g(v) = g_0 + \sum_{j=1}^{j=n} g_j v_{in}{}^j(t) \qquad (1)$$

Where $v_{in}(t)$ =A cos $(\omega_c t)$, $g(v)$ is output considered, g_0 threshold, g_j coefficient of nonlinearity, g_0 component's threshold value and $v_{out}(t)$ can be calculated by equation (2). Final harmonic components are shown in equation (3)

$$v_{out}(t) = g_0 + g_1 \mathrm{A}\cos(\omega_c t) + g_2 \mathrm{A}^2\cos^2(\omega_c t) + A^3 g_3 \cos^3(\omega_c t) \ldots \qquad (2)$$

$$= g_0 + g_2\frac{A^2}{2} + \left(g_1 + \frac{3g_3A^3}{4}\right)\cos(\omega_c t) + \frac{g_2A^2}{2}\cos(2\omega_c t) + \frac{g_3A^3}{4}\cos(4\omega_c t) \ldots \qquad (3)$$

It happens due to very high gain at lower frequency region harmonic components get sufficient level at higher frequency. Power taken out from fundamental by the harmonic components is necessary to assess for this particular problem. For an amplifier gate to source voltage waveform is

$$v_{gs}\big|_{inst} = v_{gs} + A\cos(\omega_c t) \qquad (4)$$

Therefore the distortion of drain current waveform by nth harmonic component is

$$HD_n = 20\log\left|\frac{A}{4(v_{gs}-v_t)}\right| \qquad (5)$$

Ratio of power of an nth harmonic component to the fundamental component power is

$$HD_n = 10\log\left(\frac{P_n}{P_c}\right) = \sqrt{\left(\frac{v_2}{v_c}\right)^2 + \left(\frac{v_3}{v_c}\right)^2 + \dots + \left(\frac{v_n}{v_c}\right)^2} \quad (6)$$

Intermediation distortion components for any active module using nonlinearity equation (1) is written below

$$v_0(t) = g_0 + g_1A(\cos\omega_1 t + \cos\omega_2 t) + g_2A^2(\cos\omega_1 t + \cos\omega_2 t)^2 + g_3A^3(\cos\omega_1 t + \cos\omega_2 t)^3 \dots \quad (7)$$

Another disadvantage of cascaded linear gain blocks is to reduce power level with higher gain slope often happens after reaching to saturation with increasing input power level. These all components having cumulative effect of reducing gain from higher frequency fundamental components. Equalization technique stabilizes the low frequency gain variation and by doing so it improves the spurious level performance by keeping them down. Thereby it enhances power level of real higher frequency components by 5 to 7 dB which is very crucial at that frequency band. By doing so it improves the low intensity oscillation at higher frequencies. RF channeling and covering are another aspect of this kind of dense populated RF layouts to improve isolation and high intensity oscillations as it kills the main purpose of such ultrawideband highly sensitive receiver design.

Normal gain equalizer is used to maintain the gain slope with lumped components is shown here [9]. Input impedance of the R-L-C network is written in equation (8).

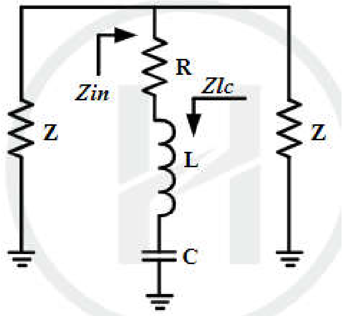

Fig-1 Single element R-L-C equalizer circuit model representation

$$|Z_{in}| = \sqrt{R^2 + \left|\frac{1-\omega^2LC}{\omega C}\right|^2} \qquad (8)$$

Where R, L and C are the shunt resistance, inductance and capacitance respectively. Transfer function of the n section equalizer can be written by equation (9).

$$H_{total}(\omega) = \sum_{i=1}^{i=n}\frac{2(j\omega C_iR_i - \omega^2L_iC_i + 1)}{j\omega C_iZ + 2(j\omega C_iR_i - \omega^2L_iC_i + 1)} \quad (9)$$

Where Z, is the load impedance and angular frequency respectively. When it interacts with nonlinear active module (treated as arbitrary load) its combined matching and slope flatness also changes as per equations (10) and (11) [10].

$$S'_{1,1}(f) = \frac{A_1^*}{A_1}\frac{\{1-\Gamma_L(f)*S_{1,1}(f)\}\{S_{1,1}(f)-\Gamma_S^*(f)\}}{D}*$$

$$\{\Gamma_L(f) * S_{1,1}(f) * S_{2,1}(f)\} \quad (10)$$

$$S'_{2,1}(f) = \frac{A_1^*}{A_1} \frac{S_{2,1}(f)(1 - |\Gamma_L(f)|^2)}{D} \quad (11)$$

where

$$D = [\left(1 - \Gamma_S(f) * S_{1,1}(f)\right)\left(1 - \Gamma_L(f) * S_{2,2}(f)\right) - \Gamma_S(f) * \Gamma_L(f) * S_{1,2}(f) * S_{2,1}(f)] \quad (12)$$

$$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} \quad \& \quad \Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (13)$$

$$A_1 = \frac{1 - \Gamma_S^*(f)}{|1 - \Gamma_S(f)|} \sqrt{1 - |\Gamma_S(f)|^2} \quad (14)$$

$$A_2 = \frac{1 - \Gamma_L^*(f)}{|1 - \Gamma_L(f)|} \sqrt{1 - |\Gamma_L(f)|^2} \quad (15)$$

Where , are source and load impedances respectively. S parameters are normalized to characteristic impedance ( ). Maintaining , ( ) over operating spectrum by ticking R, L and C parameters are main challenge. Thus the final output can be written as below by equation (16).

$$F_{final}(\omega) = f\{v_{out}(t), HD_n, H_{total}(\omega), \ldots\} \quad (16)$$

III. HARDWARE IMPLEMENTATION

Homodyning based IFM receiver requires almost 70 to 75 dB net gain in the LO path to ensure more than 10 dBm drive to the mixers. It's obvious challenging to make sure equal power for multi-channel mixers with effective gain flatness. Thereby total gain is divided into few stages to cater equal power without any distortion.Fig-2 shows a typical LO channel arrangement. First stage with common medium gain stage with lower P1 dB devices plus highest slop equalizers, intermediate maximum gain stages having medium P1 dB devices with low frequency and localized zone oriented equalizers and last gain stage with maximum P1 dB device without equalizers.

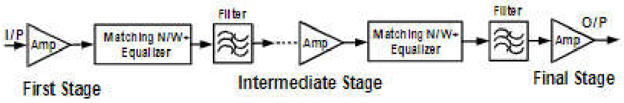

Fig-2 Schematic of a single channel gain blocks and equalizers circuit

Pictorial representation of a typical five channel LO distribution path is shown in the Fig-3. Challenge lies to build gain over the band for each channel thereby equalizers have been used with different topology and sections respectively to cope up with gain gradient. Each channels are placed very closely. Thereby inter channel isolation or leakage between channels are responsible for low intensity oscillation, chaotic noise floor, uneven phase variation, etc. Thus intensive care have been taken to arrest signal leakage. Each mixer generates sine and cosine term as homodyning mixing technique is adopted with same RF and LO frequency on IQ (In phase, Quadrature phase) mixer.

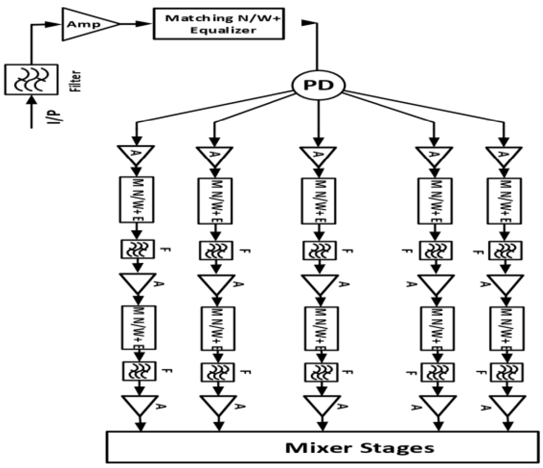

Fig-3 Schematic diagram of a multi-channel LO distribution circuit; A: gain block, E: equalizer, F: low pass filter, M N/W: matching network, PD: power divider

IV. RESULTS

Ultra-wide band receiver has successfully been developed and tested. LO distribution channels are responding well over the full dynamic range. At lowest power level LO power reaching about 10 dBm. At higher power the channel to channel leakage varies thereby a very low intensity oscillation still observed in much nearby channels. Care has been taken to improve such issues. Figure 4 shows an amplifier and two section RL equalizer of ultra-wideband IFM receiver. Equalizer is used to suppress high gain at low frequency and boost gain at higher frequency.

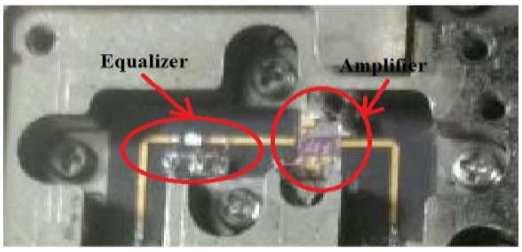

Fig-4 Developed single section amplifier with two section RL equalizer of IFM Receiver

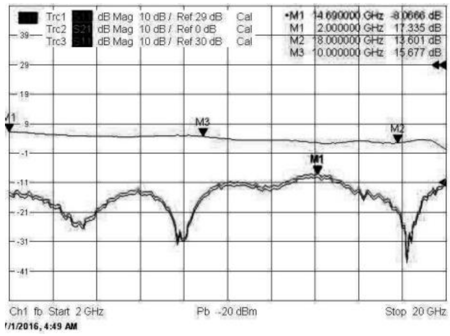

Fig-5 Measured response of a Gain blockwithout equalizer

Fig-5 and Fig-6 shows the measured responses of amplifier without and with equalizer respectively. From Fig-5 gain variation over 2 to 18 GHz is around3.8 dB and matching is less than 10 dB.

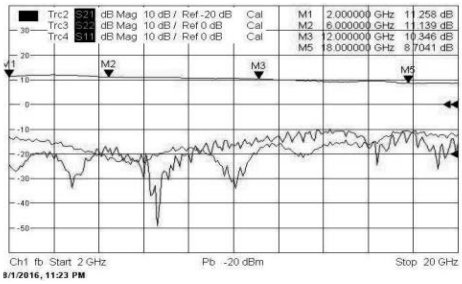

Fig-6 Measured response of a Gain blockwith equalizer plus other passive circuits.

Gain flatness becomes 2.5 dB over 2-18 GHz bandwidth with two sections equalizer is used and matching also improved better than 10 dB. Gain flatness can be improved by adding more sections of equalizer. In the case of multi-section amplifiers used in intermediate stage two types of equalization circuits have been used. Fig-7 shows multi-section equalizer with two gain blocks at input and output side of the equalizer. Fig-8 shows response is 47.7 dB to 35.8 dB i.e. having almost 12 dB gain slope. At higher frequency region gain roll off is very fast.

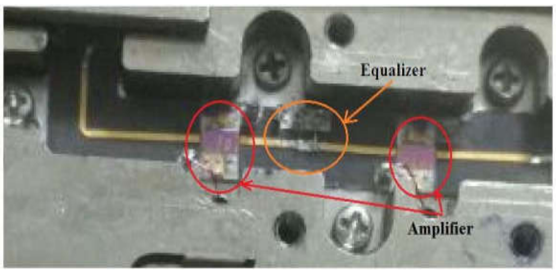

Fig-7 Developed Gain block with equalizer section of IFM Receiver

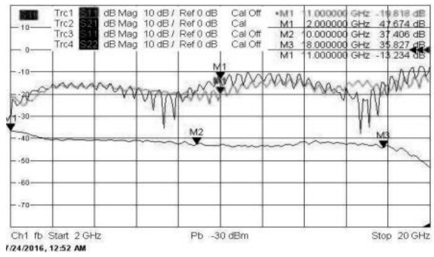

Fig-8 Measured response of intermediate Gain blockswithout equalizer

This issue has been solved by using low frequency sharp roll off equalizer and band limited equalizers. Thus Gain improved at higher frequency from 35.8 dB to 41.1 dB at 18 GHz shown in Fig-9. Gain flatness is now less than 4 dB unlike 12 dB in without equalizer being used.

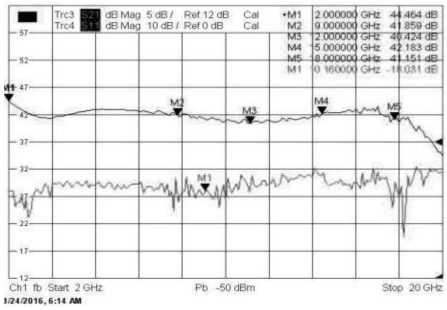

Fig-9Measured response of intermediate Gain blockswith equalizer

Hence gain shortfall due to harmonics effect is oppressed by using the above mentioned technique. Low intensity oscillation due to high gain at low frequency region is also improved. RF channeling of mechanical housing is another aspect to arrest inter-channel leakage and obvious low intensity oscillation.

V. CONCLUSION

Ultra-wide band receiver based on homodyning technique is designed and developed. Different types of equalization techniques have successfully been experimented to control the gain slope at lower frequencies and gain boost at higher frequencies. Special care has been taken while channelizing different LO paths. Specially designed cover plates solved the issues.

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REFERENCES

[1] W. F. Egdan, “Practical RF System Design”, Wiley-IEEE Press, 2003
[2] B. Razavi, "Design considerations for direct - conversion receivers, " IEEE Trans Circuits System-II, Analog and Digital Signal Processing, vol. 44, pp. 428-435, June 1997
[3] J. Crols, M.S. Steyaert, "Low-IF topologies for high-performance analog front ends of fully integrated receivers," IEEE Trans Circuits Syst. -II, Analog and Digital Signal Processing, vol. 45, pp. 269-282, March 1998.
[4] J.C. & Carvalho, N.B. “Designing Multisine Excitations for Nonlinear Model Testing, IEEE Transactions Microwave Theory and Techniques, Vol. 53, No. 1, pp. 45- 54, January 2005, ISSN: 0018-9480, 2005.
[5] J. C. and Carvalho, N. B. “Intermodulation Distortion in Microwave and Wireless Circuits”, Artech House, ISBN 1-58053-356-6, Norwood, USA, 2003
[6] P. I. Mak, S. P. U, and R. P. Martins, “Transceiver architecture selection: Review, State-of-the-Art Survey and Case Study”, IEEE Circuits and Systems Magazine, vol. 7, 2nd quarter 2007, pp. 6-25.
[7] Zhou, T.-F., Y. Zhang, and R.-M. Xu, “Research on the millimeter wave gain equalizer," IEEE International Conference on Microwave echnology & Computational Electromagnetics (ICMTCE), 180-182, May 2011
[8] Thornber M., “Amplitude Equalizer Flattens Gain from 50 MHz to 7 GHz” Microwaves & RF, Vol. 46, No. 10, October 2007.
[9] H Wang, B. Yan, Z. Wang, and R. Xu, “A Broadband Microwave Equalizer” Progress In Electromagnetics Research Letters, vol. 33, pp. 63 – 72, 2012.
[10] G. Gonzalez, “Microwave Transistor Amplifier Analysis and Design”, Prentice Hall Inc, 1994.