

A Survey on Dual-Band Polar Transmitter Architecture for Railroad Wireless Communication

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Abstract— In this study, we briefly introduce a novel concept of dual-band polar transmitter design based on digital quadrature modulation techniques for the application of railroad wireless communication (e.g., TRS & GSM-R) to reduce the bandwidth of dual-band PM (phase modulation) signal. We show that the complex signal processing at low frequency effectively utilizes the polar transmitter which is susceptible to the bandwidth of PM signal. Also, we evaluated the zero-crossing rate of two different schemes. There is the remarkable reduction of zero-crossing rate, compared to the conventional scheme.

Keywords— Polar transmitter, Dual-band transmitter, Complex signal processing, SDR

I. INTRODUCTION

Regarding various wireless communication technologies and standards (e.g., GSM, WCDMA, LTE, WLAN), multi-band & multi-standard transceiver systems on various frequency bands are basic elements necessary to realize the software-defined radio, as shown in [1-5]. Because most of various communication systems have used different frequencies, a few studies on the wideband or dual-band RF design for realizing SDR was carried out [6-7]. Especially the multi - band digital IF for W-CDMA transceiver using two-stage digital complex quadrature modulation (DCQM) technique is implemented in [8]. And multi-standard & dual-band polar transmitter for the 900 MHz and the 2.4 GHz band was introduced in [9]. In this paper, we introduce a novel concept of dual-band polar transmitter design based on DCQM technique briefly in Section II, and explain the result of computer simulation in Section III, and finally conclude in Section VI.

II. DUAL-BAND DIRECT CONVERSION TRANSMITTER

A. Dual-Band over Single RF chain

Conventional RF transmitter often does not include two RF signals at the same time, because it is difficult to make it satisfied with wideband characteristics, and it costs higher to satisfy the spectral mask of each RF output. Moreover, recently it is possible to put a number of the RF chain to a single RF chip, such as Figure 1. However, RF transmitters are getting more and more integrated and miniaturized gradually

and enabled to increase the transmission bandwidth as compared to the sampling rate. Thus the needs of the multi-band transmitter techniques in a digital part will increase more than before, as shown in Figure 2.

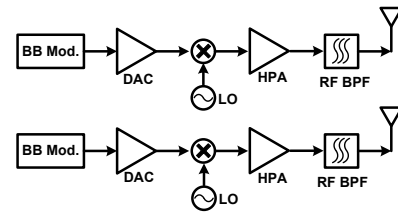


Figure 1. A couple of RF chains in single chip

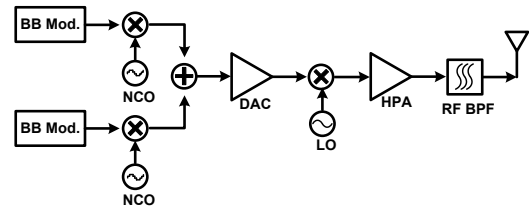


Figure 2. Single RF chain for dual-band transmission

B. Generation of Dual-Band Low-Pass Signal

Unless two kinds of baseband modulated signals as an input of single RF chain share the same digital modulation schemes, then it should be converted into dual band-pass digital signals on low frequencies. The frequency responses of these dual band-pass signals at the low frequency could be expressed as follows:

$$S_{HT}^{+}(f) = \begin{cases} S_{+}(f), & f > 0 \\ 0, & f = 0 \\ -S_{-}(f), & f < 0 \end{cases} \quad (1)$$

$$S_{HT}^{-}(f) = \begin{cases} -S_{+}(f), & f > 0 \\ 0, & f = 0 \\ S_{-}(f), & f < 0 \end{cases} \quad (2)$$

The spectra of (1) and (2) are shown in Figure 3.

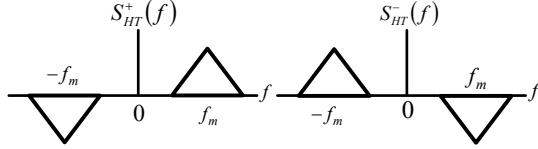


Figure 3. Conceptual spectra for two Hilbert transformed signals

These particular spectra can be expressed by Hilbert transformer as follows:

$$S_{HT}^+(f) = jH(f)S(f) \quad (3)$$

$$S_{HT}^-(f) = -jH(f)S(f) \quad (4)$$

$$\text{where } H(f) = \begin{cases} -j, & f > 0 \\ 0, & f = 0 \\ j, & f < 0 \end{cases}$$

From (3) and (4), two different spectra which have the negative frequency and positive frequency are expressed respectively as follows:

$$S_+(f) = S(f) + S_{HT}^+(f) \quad (5)$$

$$S_-(f) = S(f) + S_{HT}^-(f) \quad (6)$$

If two spectra of (5) and (6) are cascaded linearly, then dual band-pass signal at low frequencies can be generated, as shown in Figure 4 (a). These low frequency band-pass signals have relatively narrow bandwidth as follows:

$$W_{lf} = f_n + \frac{W_b}{2} \quad (7)$$

where f_n is the frequency of NCO (Numerically Controlled Oscillator) in Figure 2, W_b is the bandwidth of the baseband modulated signal. On the other hand, Figure 4 (a) shows the spectra of the two-stage conventional band-pass signals whose frequencies are f_{l1} , f_{l2} .

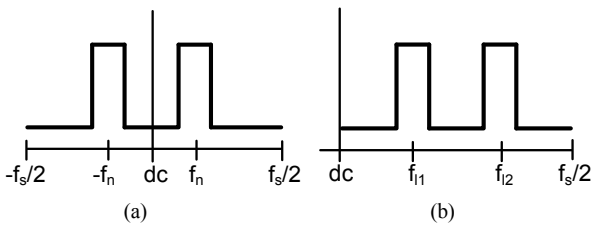


Figure 4. Two kinds of dual-band spectrum at low frequencies

These positive frequency band-pass signals have the bandwidth as follows:

$$W_{lf} = f_{l2} + \frac{W_b}{2} \quad (8)$$

Since f_{l2} is relatively higher than f_n , the required bandwidth of RF transmitter in Figure 4 (a) is smaller than that in Figure 4 (b).

C. Polar Transmitter

Polar transmitter has been interesting as the most suitable structure in the multi-mode RF transmitter and multi-band transmission. It also provides a high efficiency by using a switched mode RF power amplifiers, such as E-Class power amplifiers for the synthesis of the PM signal and the AM (amplitude modulation) signal. For these reasons, it was applied to the communication systems, such as WCDMA. And many researches of its application are still on going. Figure 5 shows the structure of a typical polar transmitter briefly, which consists of Cartesian-to-Polar converter, amplitude modulator, and phase modulator. Cartesian-to-Polar converter serves to convert a complex baseband I/Q signals to a combination of the amplitude signal and the phase signal, as expressed in (9) and (10). It is easily implemented using the CORDIC (coordinate rotation digital computer) algorithm.

$$A(t) = \sqrt{i^2(t) + q^2(t)} \quad (9)$$

$$\theta(t) = \tan^{-1} \left(\frac{q(t)}{i(t)} \right) \quad (10)$$

$\theta(t)$ is phase-modulated by using the VCO (voltage-controlled oscillator) and PLL (phase-locked loop). This phase-modulated signal is given to the input signal of the power amplifier. $A(t)$ controls the current or voltage of the power amplifier. Polar transmitter amplifies the input signal using these PM and AM signals. PM signal is the direct input of the amplifier by using the control voltage of the VCO, and AM signal controls the Vcc / Vdd of the power amplifier as shown in Figure 5. Therefore, since PM signal has a fixed amplitude, nonlinear switching mode power amplifier such as Class-D, E, F could be used to improve power efficiency of the amplifier without consideration of nonlinearity problem.

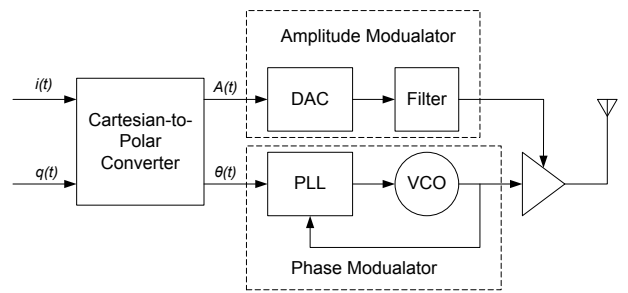


Figure 5. Architecture of Polar transmitter

D. Dual-Band Polar Transmitter

As mentioned above, low frequency band-pass signal processing using two-stage DCQM has the advantage of relatively small bandwidth, and polar transmitter has the advantage of high power efficiency with nonlinear amplifier.

Hence, we propose the dual-band polar transmitter scheme which consists of these two technologies, as shown in Figure 6.

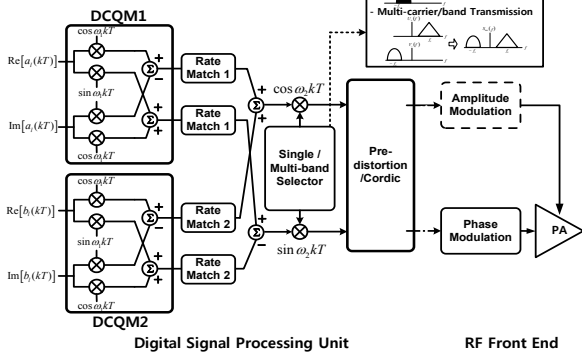


Figure 6. Structure of dual-band polar transmitter

This dual-band polar transmitter using two-stage DCQM processing could reduce the bandwidth of PM signal, and the zero-crossing rate at given sampling rate of digital to analog converter.

III. SIMULATION RESULTS

Figure 7 shows a two-stage DCQM processing procedure in the Simulink simulation tool.

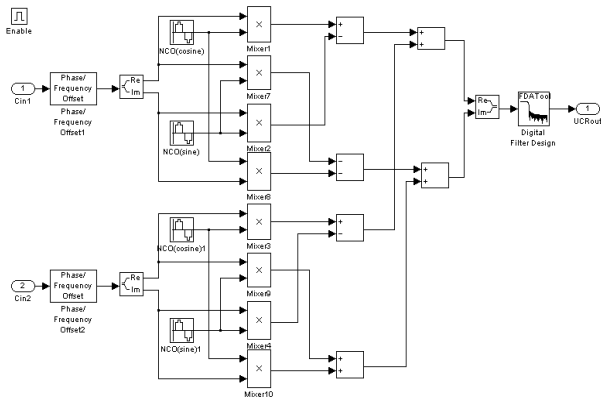


Figure 7. Simulation of two-stage DCQM

Table 1 shows simulation parameters of two RF signals, which have a symbol rate of 5 MHz and 1.5 MHz respectively.

TABLE 1. SIMULATOR PARAMETERS

Parameter	Characteristics of two RF signals	
	Baseband signal #1	Baseband signal #2
Symbol rate	5 MHz	1.5 MHz
Modulation	QPSK	64 QAM
Sampling rate	480 Msps	480 Msps
RF Freq.	1 GHz	1.01-1.07 GHz (step size: 10 MHz)

Figure 8 shows the RF spectrum of simulation result which have RF carrier frequencies of 1 GHz, and 1040 MHz. Thus

the carrier frequency spacing of two RF signal is 40 MHz, as shown in Figure 8.

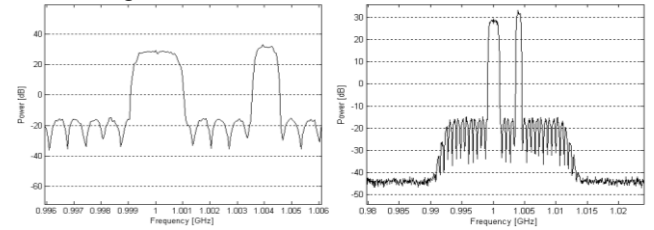


Figure 8. RF spectra of simulation results

Figure 8 shows a spectral regrowth around the main spectrum. This phenomenon happens when the analog low-pass filters are applied to the PM and AM signals generated by CORDIC function. This spectral regrowth problem can cause not only a distortion of the signal, but also the performance degradation of the communication link. If effective bandwidths of two RF signals are all 3.75 MHz, and the frequency spacing is 20 MHz, the spectral regrowth could happen according to the cutoff frequency of low-pass filter, as shown in Figure 9.

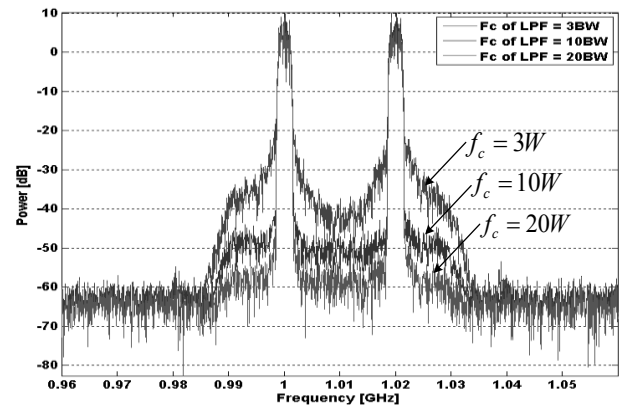


Figure 9. Spectral regrowth of dual-band polar transmitter

As a result of observation in Figure 9, we can see that the bandwidth of the PM signal reaches tens of times than those of baseband signal, and this spectral regrowth problem cannot be easily solved by low-pass filters.

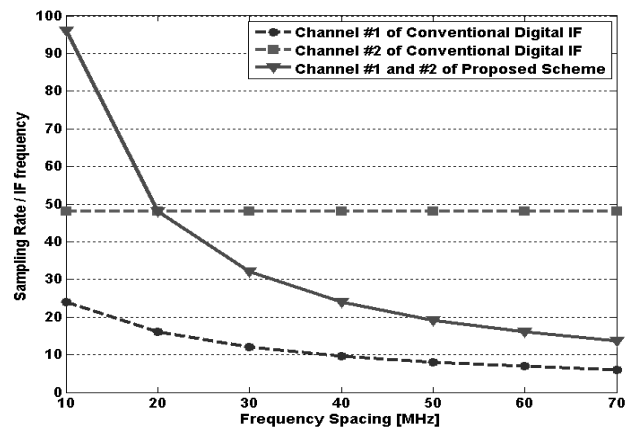


Figure 10. Comparison of the required sampling rates

Figure 10 shows the comparison of the required sampling rates between the conventional low-pass signal of Figure 4 (b), and dual-band low-pass signal using two-stage DCQM of Figure 4 (a). We can see that the latter gets relatively lower sampling rate required, and that is to say it has a relatively narrower bandwidth of PM signal compared to the former.

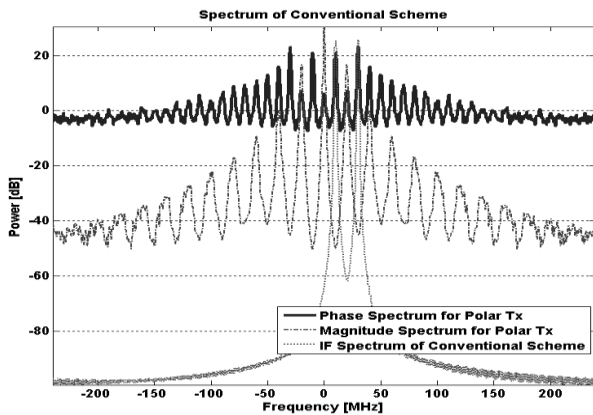


Figure 11. Spectra of the conventional low-pass signal

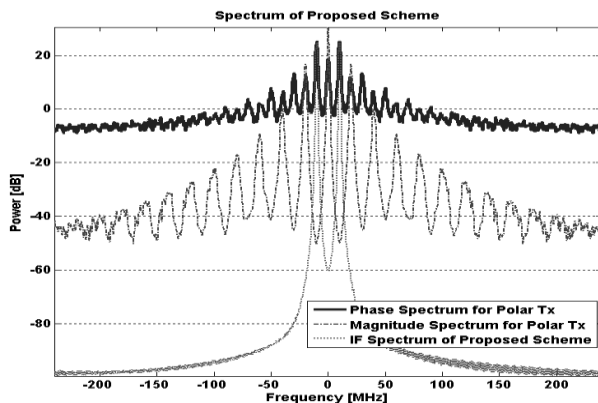


Figure 12. Spectra of the low-pass signal from two-stage DCQM

Figure 11 and 12 show the spectra of PM and AM signal of two different low-pass signals respectively.

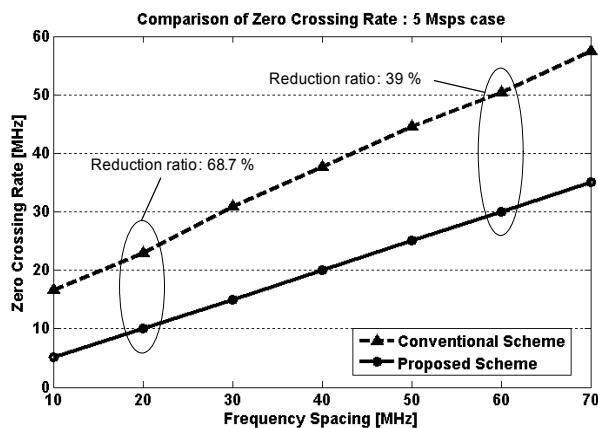


Figure 13. Comparison of zero-crossing rates

Figure 13 shows the comparison of zero-crossing rates at polar transmitter. Note that zero-crossing rate is proportional to the frequency spacing of two RF signals, and the proposed scheme reduced zero-crossing rate by about 35 % to 70 % compared to the conventional scheme. Hence, in order to reduce the zero-crossing rate of the polar transmitter, and the distortion caused by polar transmitter, it is quite efficient to reduce the bandwidth of low-pass signal at low frequency. And we confirm that it can be possible by the proposed scheme via these computer simulations.

IV. CONCLUSIONS

In this paper, we propose the dual-band polar transmitter scheme which has the cascaded two-stage DCQM to reduce the bandwidth of dual-band PM signal. Our solution, based on complex signal processing, effectively utilizes the polar transmitter which is susceptible to the bandwidth of PM signal. We further provided the comparison of the required sampling rates about two kinds of the band-pass signal processing.

Also, we evaluated the zero-crossing rate of two different schemes. There is the remarkable reduction of zero-crossing rate compared to the conventional scheme. In particular, we are currently studying on the delay-time discordance of AM and PM signal at dual-band polar transmitter, and compensation techniques on it.

ACKNOWLEDGMENT

This work was supported by the IT R&D program of MKE/KEIT. [K1001869, Research on environment-adaptive autonomous technologies for mobile wireless access].

REFERENCES

- [1] H. Liu, et. al., "Quad-Band Bandpass Filter Using Quad-Mode Stub-loaded Resonators," *ETRI Journal*, vol. 36, no. 4, pp. 690-693, 2014.
- [2] F. Jondral, "Software-Defined Radio – Basics and Evolution to Cognitive Radio," *EURASIP J. on Wireless Communications and Networking*, pp. 275-283, 2005.
- [3] U. Kim, et. al., "A Fully-Integrated Penta-Band Tx Reconfigurable Power Amplifier with SOI CMOS Switches for Mobile Handset Applications," *ETRI Journal*, vol. 36, no. 2, pp. 214-223, 2014.
- [4] R. Bagheri, et al., "An 800MHz to 5GHz software-defined radio receiver in 90nm CMOS," in *Proc. ISSCC*, 2006.
- [5] Y. Seo, et. al., "3-Level Envelope Delta-Sigma Modulation RF Signal Generator for High-Efficiency Transmitters," *ETRI Journal*, vol. 36, no. 6, pp. 924-930, 2014.
- [6] J. N. Lee, et al., "Design of Dual-Band MIMO Antenna with High Isolation for WLAN Mobile Terminal," *ETRI Journal*, vol. 35, no. 2, pp. 177-187, 2013.
- [7] Y. Liu, et al., "Miniaturization of Dual-Band PIFA for Wireless LAN Communication," *ETRI Journal*, vol. 35, no. 3, pp. 530-533, 2013.
- [8] W. C. Lee, et al., "SDR-based digital IF for multi-band W-CDMA Transceiver," in *Proc. ICICS-PCM*, 2003, pp. 1737-1741.
- [9] J. H. Mueller, et al., "A low complexity multi standard dual band CMOS polar transmitter for smart utility networks." in *Proc. SOCC*, 2014, pp.426-430.