Realisation Challenges of Optical Wavelength Division Multiplexed Signal Distribution System for Phased Array Radar Applications

Meena D[1], Durga R[1], LGM prakasam[1], Manisha Mathur[2], EktaTripathi[2], P K Gupta[2], Amarendra Kumar[3], TSN Murthy[3]
[1]Electronics and Radar Development Establishment (LRDE), CV Raman Nagar, Bangalore – 560 093, INDIA
[2]Bharat electronics Limited (BEL), Ghaziabad, INDIA
[3]CoreEl Technologies (I) Pvt. Ltd., Koramangala, Bangalore -560 034, INDIA
email: dmeenasatish@gmail.com

Abstract- Advancements in optical techniques and Microwave photonics (MWP) have made it possible to transmit both RF and digital signals over a single fiber simultaneously. This paper describes about an optical network for radar signal distribution in phased array radars. The work mainly emphasizes on certain realization aspects of WDM based distribution system and is supported with system performance analysis results.

Key Words - Wavelength Division multiplexing, non flat gain spectrum, EDFA transients

I. INTRODUCTION

Modern phased array radars consist of more number of low power transmit / receive modules typically of the order of thousands, than conventional high power transmitter. This demands the distribution of different kind of signals to these modules for normal mode of radar operation. Local Oscillator (LO) signals are required at the mixer stages for up/down conversion of signals during transmit and receive operations. Similarly clock and other control signals in digital nature are required for the synchronous operation of the modules. Additionally, during transmit operation of the radar system, the transmit waveform is required to distribute to all these modules which in turn distributes to all elements of the array. Thus signals of RF, low frequency analog and digital nature are required to distribute to all modules for normal mode of radar operation. This is conventionally done through RF cables and makes the systems bulky and prone to Electromagnetic Interference (EMI) issues. The advancements in the Optical techniques and Microwave Photonics (MWP) have made it possible the usage of fiber links for distribution of even high frequency Radio frequency (RF) signals in phased array radar systems [1],[2]. The transformation towards the optical domain helps in providing a low loss, less weight and EMI immune solutions to above problems. But latest improvements in MWP, helps in the transmission of multiple signals including RF signals over a single fiber by using Wavelength Division Multiplexed (WDM) technology [3]. But normally pedestal mounted phased arrays are not that much maintenance friendly from the access point of view. So such systems require additional circuitry for easy fault and detection analysis. Similarly usage of high power lasers as the optical signal sources demands to consider sufficient safety measures during the realization of the distribution systems.

II. DISTRIBUTION NETWORK CONFIGURATION

The work considers a hypothetical array consists of twenty four modules for distribution of maximum of five different signals. These signals include LO signals, radar transmit waveform, clock and synchronization signals. WDM technology enables the transmission of all signals through a single fiber by assigning different wavelengths to various signals. Figure 1. shows the block schematic of a generic WDM distribution network architecture, which can distribute different signals to twenty four modules. The distribution of signals to multiple modules will result in heavy splitting losses. So even though the distribution is required for a shorter span of array length, the losses due to splitters in the link requires additional amplifiers in the link. Basically this type of distribution system will have three sections like WDM Transmitter, section consisting of amplifier and splitter modules and WDM receiver modules along with safety and fault analysis circuitries.

III. REALIZATION CHALLENGES

In the case of present day radar systems, the number of modules can be as large as thousands [4],[5]. So the splitting loss also increases, due to the distribution of signals to multiple receiver modules and there is a need for an amplifier in the link for proper amplification of signals. But commonly used optical amplifier like Erbium doped fiber amplifier (EDFA) in the link operating in 1550 nm wavelength range will lead to issues that can affect the system performance. So the realization of this kind of distribution system should provide a less complex and less hardware intensive solution that can overcome these challenges.

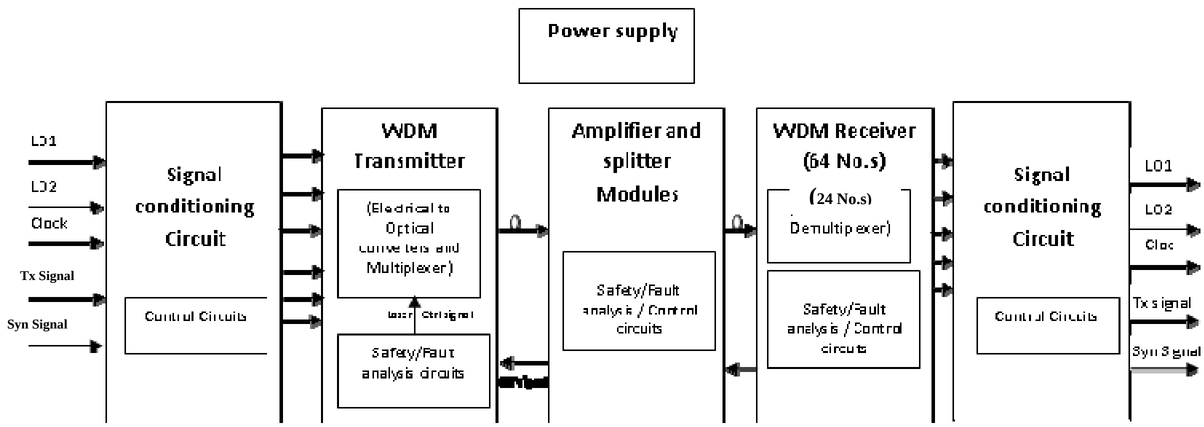

Figure 1 Optical distribution system –Block schematic

1 Choice of WDM channel spacing

The usage of WDM technology gives the option of usage of either Coarse WDM (CWDM) or Dense WDM (DWDM) systems. These two configurations differ in terms of channel spacing, where DWDM systems are having narrow spacing compared to CWDM systems. But as requirement of channel spacing is less, the complexity of the hardware increases. This is due to the fact that DWDM systems will have stringent temperature insensitive hardware requirement to attain laser wavelength stability. This is not essential in the case of CWDM systems and are easy to implement compared to DWDM systems. But the usage of CWDM configuration with amplifier in the link results in unequal power at the output for various wavelengths due to non flat gain spectrum of EDFA. These effects are discussed in the following section 3.

2 *Usage of External modulators for High frequency RF signal transmission*

As RF signal frequency to be transmitted is high, the signals get distorted due to chirp effects. So the usage of external modulator is very much essential for high frequency RF signal transmission rather than using direct modulation techniques [6]. So based on the frequency or bit rate of the signals, proper modulation method has to be selected.

3 EDFA effects in the link

In radar applications, equal power levels are expected at the receiver end irrespective of the selected wavelength. In the case of CWDM systems, the usage of single EDFA in the link for signal amplification causes wide variation in the output power level due to non flat gain spectrum of EDFA. So the usage of a combination of C and L band EDFAs is suggested in these cases to bring down the variations in power levels. But the DWDM systems, having signals separated with narrow wavelength spacing will not undergo prominent signal variation at the output after the amplification. But it invites additional requirement of having temperature insensitive circuits to maintain wavelength stability within tolerable limits.

This adds complexity of the system with additional hardware. Another option in CWDM system is to use separate EDFA for each of the channels for signal amplification. But again it requires additional hardware that increases the system complexity. In radar applications, gain flattening circuit can be avoided due to factors like weight and additional complexity. So simple circuitry with a combination of C and L band EDFAs can be considered that will minimize output power level variation [7].

Similarly the EDFA in the link may cause transient effects to digital signals that are critical to radar applications [8]. Normally synchronization signals are in digital format and are distributed to each of the modules as a reference for the generation of various timing and control signals. So these signals when get distributed through a link with an amplifier in the link may get distorted due to transient effects. This distortion in the original transmitted signal can be misinterpreted at the receiver end. But these challenges can be addressed by suitably selecting signal and pump power levels and by adjusting parameters that affects EDFA gain.

4 Fault Analysis circuitry

Modern radar systems are having multiple subsystems distributed spatially. So these subsystems are supported with built in test (BIT) features having a central monitoring facility. So even with optical distribution system, if any problem encounters at transmitter, receiver and amplifier or at splitter end should be reported. So each of the optical sub modules should have Local BIT(LBIT) features that help in fault detection and analysis process.

5 Human safety protection circuitry

The links operating with high power lasers may affect the safety of the operational personals. So especially when the distribution is happening to multiple modules which are in the order of thousands, it is mandatory to have some human safety measures in terms of protection circuits. These circuits can get activated on disconnect of any fiber link from respective connector points.

So during realization, an optimized solution that has overcome all these issues by suitably selecting the operational environment should be considered. The following section brings out some of the results obtained during the performance evaluation of such kind of optical distribution network after providing specific set of inputs as per the requirements.

IV. Results

Results are tabulated to show that at each of the sub module level, care has been taken to obtain the equalized link output power. The system under consideration uses CWDM wavelengths and assigned to different signals before multiplexing.

The WDM transmitter receives five signals in different format. i.e. four RF signals and a reference synchornisation signal in digital format. At the transmitter end, each of the signals are converted to optical domain by using either direct or external modulation techniques .

WDM Transmitter output power levels		
Signal	**Wavelength(nm)**	**O/P (dBm)**
TX Drive	1532.273	0.16
LO1	1553.704	-6.68
LO2	1573.806	-1.18
MCLK	1593.604	-2.09
SYNC	1610.968	-0.43

Table 1 WDM transmitter power level

Additionally, digital signal is analysed to ensure that signal is free from transient effects and delay is within the permissible limits. For this, a synchronization signal of frequency 100 MHz is used. A delay of 780 nsec is measured using an oscilloscope where input signal is used as reference(Figure 3).

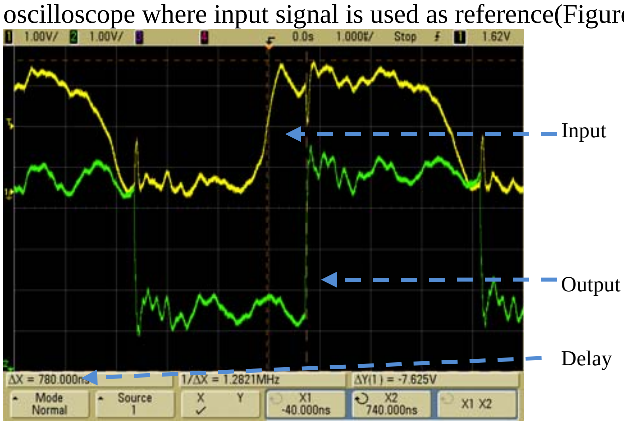

Figure 3 Delay measurement with digital signal

But RF signals are signal conditioned to match the input power levels of RF-to-Optical converters. The synchronization signal has a dynamically varying frequency and duty cycle. For the analysis purpose the upper frequency is limited to 20 kHz and duty cycle to 20%. One of the advantages of using the optical network is that the signals to be transmitted need not be generated at high power levels. This is because of the fact that input to RoF converter are of lower power levels. Table 1 shows the results obtained at the output of WDM transmitter unit. Here it can be observed that the output power levels of transmitter are adjusted with the help of compensating circuit to obtain equal link output power. The power at the transmitter need not be equal to obtain equal power at the link. For testing purpose, input power levels are set to a value of 27 dBm. It can also be seen that in the case of CWDM system, since wavelengths are widely spaced, stringent wavelength stability requirement is not there as in DWDM systems.

Figure 2 shows the Optical Spectrum Analyser (OSA) spectrum corresponding to Table 1 power levels.

Figure 2 OSA spectrum corresponding to Table 1 observations

Further the signal is passed through a splitter and amplifier section, where multiplexed signal gets amplified and splitted into 24 optical signals and fed to 24 detector stages. The control unit of this section monitors the status and controls the amplification and bias power of optical amplifier. It also monitors its own health and send request to receiver control unit to receive the health status from WDM receiver and consolidate along with its own status.

Table 2 shows the results obtained with various radar signals fed as input to the link. A dedicated control circuitry is used to adjust EDFA gain for a signal input of 6 dBm (with 27 dBm electrical signal input). This shows that circuitry is capable of adjusting over all link gain to provide necessary output signals at the receiver end. Table 3 with spurious measurements shows that second and third harmonics levels are within the limits. Figure 4 shows the snapshot of RF spectrum analyser output corresponding to first reading in Table 3 and all other readings are tabulated in the similar manner.

Input Signal(electrical)			Input Power to EDFA	Output Power dBm	Output Power at WDM receiver (dBm)
Signal	Frequency	Power			
Tx Drive	f_1 GHz	27 dBm	6dBm	20	0.07
		27 dBm	6dBm	21	1.84
		27 dBm	6dBm	19	-2
		27 dBm	6dBm	18	-1.14
LO1	f_2 GHz	27 dBm	6dBm	20	-0.3
		27 dBm	6dBm	21	1.8
		27 dBm	6dBm	19	-2.1
		27 dBm	6dBm	18	-4.2
MCLK	f_3 MHz	27 dBm	6dBm	20	5.61
		27 dBm	6dBm	21	6
		27 dBm	6dBm	19	4.2
		27 dBm	6dBm	18	2.6

Table 2 Link output level with various radar signals of 27 dBm input

Signal	Test Signal (RF)		WDMRX - RF Output Power (dBm)		
	Frequency	Power (dBm)	Main Frequency	2nd Harmonic	3rd Harmonic
TX Drive	f_{11} GHz	27	-1.41	6.20 GHz (-66.22dBc)	9.3 GHz (-75.99 dBc)
	f_{12} GHz	27	-0.28	6.4 GHz (-77.56 dBc)	9.6 GHz (-73.94 dBc)
	f_{13} GHz	27	0.28	6.6 GHz (-70.31 dBc)	9.9 GHz (-77.79 dBc)
LO1	f_{21} GHz	27	0.08	5.0 GHz (-82.06 dBc)	7.5 GHz (-78.96 dBc)
	f_{22} GHz	27	0.88	5.2 GHz (-83.52 dBc)	7.8 GHz (-80.05 dBc)
	f_{23} GHz	27	0.81	5.4 GHz (-83.68dBc)	8.1 GHz (-80.30 dBc)
LO2	f_3 MHz	27	3.23	1.08 GHz (-73.36 dBc)	1.62 GHz (-75.36 dBc)
MCLK	f_4 MHz	27	5.81	100 MHz (-61.19 dBc)	150 MHz (-69.05 dBc)

Table 3 Second and third harmonics measurement results with various radar signals

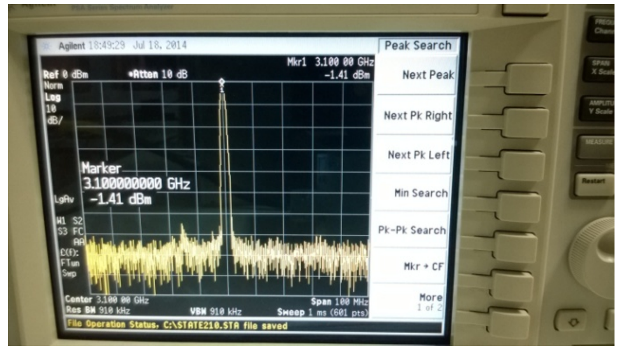

Figure 4 RF spectrum Analyzer Fundamental Output @3.1GHz

IX. Conclusions

The work mainly describes a typical optical distribution system for a hypothetical array consisting of 24 receiver modules. It also discusses various challenges to be addressed during the design phase of these distribution systems along with the results obtained after incorporating necessary preventive measures. It shows that with proper selection of pump and signal power and by adjusting EDFA gain, the EDFA transient effects can be completely avoided. Similarly proper assignment of wavelengths and necessary compensation mechanisms can provide almost equal link output power. The work also brings out that CWDM systems are having lesser hardware complexity than DWDM systems.

References

[1] J. Capmany, G. Li, C. Lim, and J. Yao, “Microwave photonics: Current challenges towards widespread application," *Optics express*, vol. 21, no. 19, pp.22 862-22 867, 2013

[2] J. Capmany and D. Novak, “Microwave photonics combines two worlds," *Nature Photonics*, vol. 1, no. 6, pp. 319-330, 2007.

[3] K. Xu, R. Wang, Y. Dai, F. Yin, J. Li, Y. Ji, and J. Lin, “Microwave photonics: radio-over-fiber links, systems, and applications [invited]," *Photonics Research*, vol. 2, no. 4, pp. B54-B63, 2014.

[4] T. Q. Ho, L. N. Hunt, C. Hewett, R. Mittra, W. Yu, T. G. Ready, D. Zolnick,M. Kragalott et al., “Analysis of electrically large patch phased arrays," in Antennas and Propagation Society International Symposium 2006, IEEE, 2006, pp. 1571-1574.

[5] M. Skolnik, Radar Handbook, Third Edition, ser. Electronics electrical engineering. McGraw-Hill Education, 2008.

[6] G. Agrawal, Fiber-Optic Communication Systems, ser. Wiley Series in Microwave and Optical Engineering. Wiley, 2012.

[7] L. Jordanova and V. Topchiev, “Amplification of the multi-wavelength signalby using edfa with constant gain," *IJCSNS*, vol. 9, no. 12, p. 38, 2009.

[8] M. Chen, Y. Song, and X. Zhang, ”Transient effect to small duty-cycle pulse in cascaded erbium-doped ber amplifier system," *Optical Engineering*, vol. 52, no. 2, pp. 025 006-025 008, 2013.

BIO DATA OF AUTHORS

Meena D. Graduated in E & C from NIT Calicut, Kerala, MBA from Bharathidasan university and just awarded doctoral degree from Indian institute of Science, Bangalore in "Optical networks for radar applications". She joined DRDO in 1996 and served at DRDO labs NPOL and CASSA. Prior to this, worked at Larsen and Toubro Pvt Ltd. and also served as lecturer. She is working at LRDE, DRDO as a scientist from 2001 onwards. Her areas of interest include Phased Array Radar systems, FPGA system design and Microwave photonics. Published more than 50 papers in both National, International conferences and journals.

L G M Prakasam: Born in 1961 at Tirunelveli (Dt), Tamilnadu, Graduated in E & C from Thaiagarajar College Of Engineering, Madurai in 1983, M.Tech in ICs & Systems from IIT Madras in 1986, MBA in Finance Management in 1996 from Annamalai university. Worked as Aero Engineer in HAL for two years, Lecturer for one year and is now working as Scientist in LRDE, Bangalore from Dec 1987 onwards. He was deputed abroad as part of development activities for duration of 18 months. He is heading a division responsible for development of Rotating Active Phased Radars with Digital Beam Forming. He is a recipient of award Scientist of the year 2014.

Durga R : Obtained AMIE degree and serving as Technical Officer at LRDE.

Manisha Mathur: received her B. E. Degree in Electronics and Communication Engineering from M.I.T.S. Gwalior, India (1990), M. Tech. Degree in Digital Communication from M.A.N.I.T. Bhopal, India (1992) .Presently, she is working as D.G.M. in Bharat Electronics Limited, Ghaziabad, India since 1992. Currently, leading a team for design and development of active aperture phased array radar. Her area of interest includes radar signal processing, radar system design and photonic systems.

P.K. Gupta: born in Oct 1964, joined Bharat Electronics Limited, Ghaziabad in Dec 1986.Presently, he is working in D&E-Radar as Sr.DGM. Currently, he is leading Arudhra & Mountain radar projects. He has a vast experience on radar systems like Indra-I, ASR & MSSR, SRE.

EktaTripathi: graduated in Electronics & Communication Engineering from Uttar Pradesh Technical University in the year 2008. Presently, she is currently working as a Senior Engineer in Bharat Electronics Limited, Ghaziabad D&E - Radar department since 2010. Her areas of interest are: Fiber Optics, Communication Systems, Control and Automation.

Amrendra Kumar completed AMIE in Electronics and Communication Engineering from Institution of Engineers (India) in 1995. He is presently working in CoreEl Technologies (I) Pvt. Ltd., Bangalore as a Hardware engineer in System Engineering Group. He has more than 15 years of experience in the field of System Design, high-speed board Design including photonics system design

TSN Murthy obtained his BE in Electronics & Communications Engineering from SV University, Tirupathi and PG Diploma from IISc, Bangalore. He is Senior Vice President and Director of CoreEL Technologies (I) Pvt. Ltd., Bangalore. He has over 33 years of hands-on experience in design and development of Single Board Computers, PARAM series of parallel processing systems, manufacturing automation systems, telecommunications products. Currently he heads Systems Engineering Group at CoreEL, designing and developing subsystems for RADARs & SONARs, Digital Video Processing and Telecommunication / Networking products.