5.1 Introduction

AESA radar antenna uses various RF and digital signals. These signals are transported from baseband circuit to antenna through rotary joints. Conventionally following schemes are followed for signal distribution in AESA radar:

1. **RF signal distribution through coaxial cables**: AESA radar has large number of T/R modules physically spread throughout the antenna array. Each transmit and receive module requires various RF signals. RF signals are required for frequency down conversion. Conventionally RF signals are distributed through coaxial cables. These coaxial cables are inherently lossy so it can be laid for few metres only considering high losses.

2. **Digital signals through twisted pair cables**: Digital signals required at each T/R module level are sent conventionally with the help of twisted pair shielded cable. These signals are required for synchronization and control of beam formation. There is again a limit of few metres when it comes to laying the cable.

3. **Issues with conventional scheme**: Some of the issues involved with conventional cables are as follows:
   
   i. Huge cabling due to size
   ii. Weight
   iii. Inherently lossy/ RF leakage
   iv. Limited RF signal bandwidth
   v. Poor immunity to electromagnetic interference
   vi. Poor reliability and maintainability
4 Advantages of transportation of RF signal over optical fiber: Optical fiber offers several advantages over conventional coaxial cables such as

i. Reduction in weight and complexity

ii. Immunity from EMI

iii. Higher bandwidth

iv. Higher data rate

v. Easy maintenance

vi. Use of optical rotary joint

vii. Less complex drive mechanism

5 WDM – WDM is a process of combining multiple wavelengths into a single fiber without any interference with each other.

6 CWDM – This is less complex than DWDM and is preferred when number of channels are less. The channel separation specified by International Telecommunication Union (ITU) for CWDM is 20 nm while for DWDM it is 2 nm. Another reason for complexity of DWDM is that laser is required to be cooled for operation.

5.2 Components for MWP in radar

Following are some of the major components used in the design of MWPN:

1. Laser – DFB lasers are single frequency laser. It is especially used when precise and stable wavelength is critical. DFB lasers are known for its narrow line width, tenability, low noise operation and fast to transmit data in optical world. The only disadvantage is safety involved during manufacturing. DFB lasers have been used in this work.
2. **Photo diode** – It is required for optical to electrical conversion. Current is generated when photons are absorbed in semiconductor material. The amount of current generated depends upon the responsivity of diode. A photodiode with responsivity 0.85 A/W will generate 0.85 A when 1 W of light impinge on it.

3. **Optical amplifier** – After the invention of optical amplifier the conversion in electrical domain for amplification is removed. Now each repeater station amplifies long distance optical signal in optical domain only.

4. **Optical multiplexer** – It multiplexes multiple wavelength sent via different lasers. It is passive form of mixing. The channels are virtually transparent to each other.

5. **Fiber connectors** – There are multiple types of optical connectors such as FC, LC, SC etc. Ruggedized connectors are available in MIL 38999 series. Multibeam rugged connectors are used in this design.

6. **Rugged optical cable** – Rugged optical cable which is rodent proof is used in this design.

**5.3 Proposed scheme for signal distribution**

Fig. 5.1 shows proposed scheme for RF and digital distribution in AESA radar. Four different RF signals and four digital signals are fed to Electrical to Optical converter which converts individual electrical channel into optical channel. These signals are fed to a multiplexer which works on WDM principle. The single optical fiber carrying all eight channels from baseband circuitry passes through optical rotary joint. As same RF signal is required at each T/R module, the signal is split into 64 channels to fed different T/R modules. The output of each splitter line is fed to individual T/R module after necessary de-multiplexing and Optical to Electrical conversion.
RF input is attenuated with the help of RF attenuators as the available RF signal is much higher than the required optimum input level for laser. It is kept at -24 dBm considering 1 dB compression point at -14 dBm as per manufacturer’s datasheet. Input signals are fed to 8 channels electrical to optical converter. This module is combined with isolators and mixers. Single optical fiber carrying 8 channels are fed to module 2 which de multiplexes incoming signal, amplify individually and sends the signal after multiplexing it. Third and final module is conversion of optical signal into necessary electrical signal for digital receivers.

Fig. 5.1 Proposed scheme of MWPN

Optical distribution scheme for active array radar covers broadly following steps:

i. Multiplexing of 8 channels at baseband

ii. Electrical to optical converter for RF and digital channel

iii. WDM for single optical fiber transmission

iv. Optical rotary joint to carry signals up to antenna

v. Optical amplifier EDFA for link gain

vi. Distribution of eight channels to individual T/R modules

Fig 5.2 shows use of signal conditioning cards to attenuate input RF signals. Four RF signals are passed through signal conditioning cards to match the level required for laser. Similarly 4 digital
signals are multiplexed and converted to optical signal using WDM. These signals are amplified and split into 64 identical chain for different receivers.

**Fig. 5.2: Interconnections of modules**

### 5.4 Spurious free dynamic range

SFDR comes out to be 106 dB as calculated in 3.4. This means with MDS at -161 dBm the input signal can well be tolerated up to -55 dBm without degraded performance. The selection of input power at DFB laser at -24 dBm justifies the calculations as shown in 3.4.

### 5.5 Modulation of light

The RF signal level with frequency less than 10 GHz can be modulated directly with IMDD technique. Fig. 5.3 shows the depth of modulation. The RF level changes the depth of modulation not the output optical power of laser. There is limit to user modulation depth of laser as it will lead to saturation of laser. Similarly small minimum value of RF signal is required to keep the modulation above noise level. Fig. 5.4 shows the circuitry preferred for IMDD of laser.
5.6 Experimental setup and results

Fig. 5.5 shows experimental setup for operational testing of MWPL. As performance degrades heavily due to presence of dust on optical connectors, an instrument to inspect cleanliness of connector end is used in this design. All cables are inspected with JDSU P5005i before making any connections. This instrument has a cleaning kit. It can be connected to computer to show magnified image of connector surface. As radar works on different spot frequencies, coaxial cables are calibrated prior to testing for frequency band from 2-4 GHz with input power 0 dBm. The design of the MWPL is zero dB gain. Also output of the MWPL is designed to have variation within 0 ± 1 dB for complete required band. The performance of all 64 channels is measured with the help of optical spectrum analyzer at the output of Tx module. Agilent Spectrum Analyzer PSA E4445A is used to
measure frequency response of received signal. The spectrum analyzer is set for video and resolution bandwidth of 910 Hz, for all channels. The gain block present at input and output of RF channel is used for measurement at spectrum analyzer. Signal conditioning cards are tuned with the help of tuning pots to keep RF within specified limits. This analysis is done for each channel and it is evident that each channel requires separate signal conditioning card at the input and output of RF channel. Thus total 8 signal conditioning cards are planned for 4 channels covering full RF band.

Due to cascading effects of performance of microwave components, variation in received power is observed for all channels. This is mainly attributed to splitter loss. This limits inter-operability of receiver modules. The desired performance will be achieved if 1:64 splitter is used in place of two 1:32 splitter. This happens due to non-uniform channel to channel separation of splitter. Electrical to optical Tx also shows performance variation of 4 dB. Signal conditioning cards are used to compensate this variation. As per the design of circuit, optical transceivers are planned to operate in linear region only. The output power level depends on responsivity of photodiode.

5.7 Installation precautions

After installation, optical time-domain reflectometer (OTDR) is used to ensure that none of the fiber in the cable had been damaged during installation. This device sends out a pulse of light along the fiber being tested and waits for a reflection to come back to the instrument, much like a SONAR system. Any break or lossy area will reflect some amount of light, and the timing and intensity of
reflections will allow pinpointing of any problems with a fiber. A typical precaution required while handling OTDR is that a bump is seen at trace display due to reflection of light back and forth at discontinuities in the cladding until it finally comes back to the instrument. This problem can be remedied by using a long (in excess of 1 km) patch fiber between the test set and the fiber under test. Since the cladding is more lossy than the core of the fiber and the light level in the cladding is reduced to a very low level after approximately 1 km. Although the “bump” can still be visible at approximately 200 meters but its level is reduced and accurate measurements can be made.

5.8 Characterization of MWP

MWPL is characterized for following checks

i. Power on checks
ii. Power measurements
iii. Harmonic measurement
iv. Noise floor measurement
v. Gain measurements
vi. Cable loss measurement
vii. Frequency measurement
viii. Effect of high temperature
ix. Effect of low temperature
x. Effect of wide bandwidth and temperature

It is difficult to design a MWPL for same performance on high and low temperature as well as for wide bandwidth operation. Hence the link is characterized for wide temperature range and wide bandwidth. As per the requirement of digital receiver of radar, all the RF outputs must be within $0 \pm 1$ dBm are required.
5.9 Effects of distortion on MWP

Distortion plays an important role in design of MWPL. It has following four major components:

1) **Harmonic distortion**- Suppose there is a single frequency, say $f$ travelling in any cable/fiber. Due to nonlinearity, it will have multiple frequencies. First harmonic is called $2f$ (twice the fundamental frequency), second harmonic ($3f$), third harmonic ($4f$) and so on. These multiple frequencies degrade spectrum.

2) **Gain compression**- Active devices like amplifier are linear in nature i.e. for an increase in input power, output will also increase. But this linearity is up to a certain range and beyond those devices operates in nonlinear/saturation region. Any increase in input doesn’t change the output. It defines 1db compression point. Compression point is the point below 1 db, till the device is linear.

3) **Intermodulation distortion**- Suppose a cable/fiber is carrying multiple frequencies. Then there is a possibility of frequency components generation like $f_1-f_2$, $f_1+f_2$, $f_1-2f_2$, $f_2-2f_1$. This generation of additional frequency components are called intermodulation distortion.

4) **Third order intercept**- Out of all intermodulation third order intercept is major concern as it falls in main band. Third order intercept is defined as $f_1-2f_2$ or $f_2-2f_1$, i.e. sum should be frequency 1 or frequency 2. TOI is an imaginary point where linearity of amplifier meets third order value. Designer prefers to operate the system below it. Noise floor decides dynamic range of photonic link. The minimum value is governed by noise floor while the maximum value is governed by saturation of laser.
5.10 Operational testing

Fig. 5.6 shows test setup for testing MWPL. Signal generators are feeding RF input at 16 dBm. Receiver modules are connected to spectrum analyser. A computer is also connected with ethernet link for monitoring the health and status of the link.

Fig. 5.6 Operational testing of MWPL

Fig. 5.7 shows actual setup of link testing. All the three modules i.e. RF to optical converter, Optical amplifier and splitter and optical to RF converter are seen along with its associated cables.
5.11 Conclusion

MWPL is tested for operational requirement and link characterization. Experimental results confirm the feasibility of transportation of multiple RF signals over single optical fiber. Its usage with respect to AESA radar is also verified for a single link.