AN X-BAND PHASED ARRAY MIROWAVE/PHOTONIC BEAMFORMING NETWORK

S. K. Banerjee, G. Zimmer, H. P. Feldle, P. Marten*, L. P. Schmidt**

Deutsche Aerospace, Ulm, Germany
*** Daimler-Benz, Ulm, Germany**
**** Fachhochschule Frankfurt, Frankfurt, Germany**

ABSTRACT

In the following contribution an X-band microwave/-photonic phased-array radar demonstrator is described which is at present under development at Deutsche Aerospace in Ulm. The paper will present an experimental study of all critical components associated with a microwave/photonic beamforming network.

INTRODUCTION

Future radar and microwave communication systems will be using active phased-array beamformer to fulfill the demand on higher fidility, flexibility and transparency. The requirements in wide bandwidth immunity to EMI, conformality and reduction in size and weight have reached the limits in the conventional waveguides signal distribution technique. The use of single-mode optical fibre network in conjunction with optical fibre amplifier for signal distribution offers a number of advantages and thus promises to overcome the hurdles of a conventional microwave distribution network.

X-BAND PHASED ARRAY BEAMFORMING NETWORK

Beamforing Network

Figure 1 shows the X-band phased array/photonic beamforming network at present under developement. The demonstrator consist of an intensity modulated DFB laser at microwave frequency, an optical isolator (isolation > 50 dB) at the output of the laser to reduce far end reflection back into the laser, an optical fibre amplifier to boost the optical modulated signal, an optical power splitter of five single mode fused biconic couplers and the T/R modules with optical frontends.

In the Tx-mode laser is modulated with the radar Tx-signal. The modulated light wave is then distributed to the T/R modules, where it is reconverted into the microwave frequency. In the Rx-mode a local oscillator signal with required frequency offset is used for modulating the laser. The light wave is then distributed along the same network and reconverted into a microwave LO signal for down converting the received radar signal to an intermediate frequency. Which may be transmitted to the base band radar receiver in form of a analog IF signal or as digital data via an optical communication network.

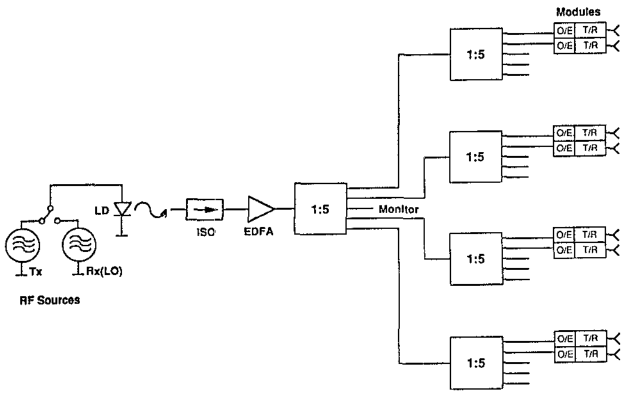

Figure 1: Optical signal distribution system for phased array antenna

Laser Module

In order to asses the state of the art DFB laser diodes for analog microwave transmission of radar-signals an optical link was set up. The normalized transfer function $H(j\omega)$ of a laser for small sinusoidal modulation current ΔI and resulting optical intensity variation ΔP can be expressed as [1]:

$$H(j\omega) = \frac{1}{1 - (\frac{\omega}{\omega_r})^2 + j\frac{\omega}{\omega_d}} \quad (1)$$

From the above equation, the small signal frequency response of a laser mainly depends on two parameters: one of them is relaxation resonance frequency $f_r = \omega_r/2\pi$ and the other is damping frequency $f_d = \omega_d/2\pi$. In order to examine the maximum obtainable modulation bandwidth of the laser, the small signal transfer function of the laser was measured as function of the laser bias current. A curve fit to the measured transfer function yield the parameters f_r and f_d of the used laser. While the damping frequency remains constant with a value arround $f_d = 11GHz$ the relaxation resonance frequency steadly increased with increasing bais current and reaches a maximum measured value of about $10GHz$. Using the above measured values a maximum theoretical modulation bandwidth of $15GHz$ was deduced.

In an intensity modulated optical transmission system the maximum signal to noise ratio (SNR) that can be obtained depends on the intensity noise of the used laser. This important parameter was measured with an optical frontend HP-Spectrumanalyser. The intensity noise of the laser showed to decrease steadly with increasing bias current reaching a minimum of $-135dB/Hz$ at a bias current of $I_L = 80mA$.

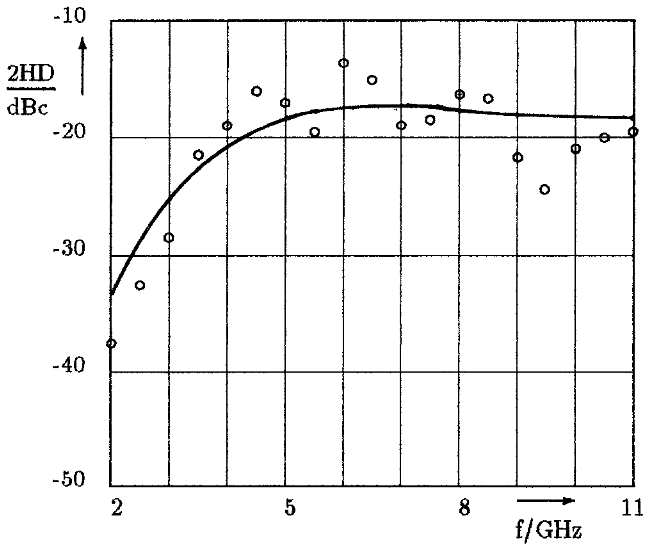

Figure 2: Second harmonic distortion

When designing an analoge microwave distribution network, it is also important to consider the nonlinear modulation characteristic of an optical transmission link. The figure 2 shows the measured 2nd harmonic distortion (2HD) as a function of modulation frequency at an optical modulation depth of 46% and laser bias current $I_L = 80mA$ (2.6 times the laser threshold current). Circles denote the measured values while the solid line represents the theoretical values according to equation (2) [2].

$$\frac{2HD}{C} = m\frac{\omega^2}{\omega_r^2 H(j2\omega)} \tag{2}$$

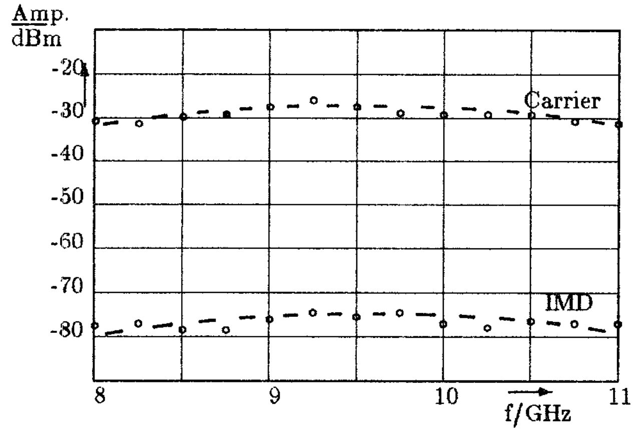

Figure 3: Carrier und IM-distortion

The measured amplitude of the carrier (C) and the intermodulation distortion (IMD) as a function of carrier frequency is shown in figure 3. The intermodulation distortion was more than $45dB$ below the carrier for the measured frequency range, the corresponding optical modulation depth for each frequency and the laser bias current I_L were 46% and $80mA$ respectivley.

Erbium-doped fibre amplifier

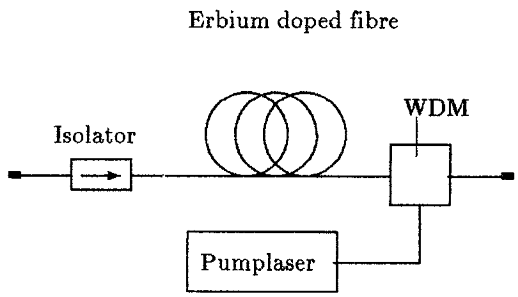

Figure 4: Schematic of the EDFA

Due to their high gain, low noise, negligible crosstalk and compatibility with fibre networks the erbium-doped fibre amplifier (EDFA) is a very attractive system component for many fibre optic applications. The Figure 4 shows the principle set up of our first EDFA. It consists of a $16.8m$ long erbium-doped fibre (EDF) with ends terminated to eliminate optical feedback. The EDF is pumped by a high power semiconductor laser source operating at a wavelength of 1460nm. The pump power is injected in counter direction to the signal wave using a precision polarisation insensitive wavelength division multiplexing (WDM) fibre optic coupler.

Figure 5 shows the measured small signal gain variation against the optical input power at a pump power of $35mW$. At the desired system input power level of $-3dBm$ a gain of $16dB$ is available which is 3dB below the saturation limit of $16dBm$.

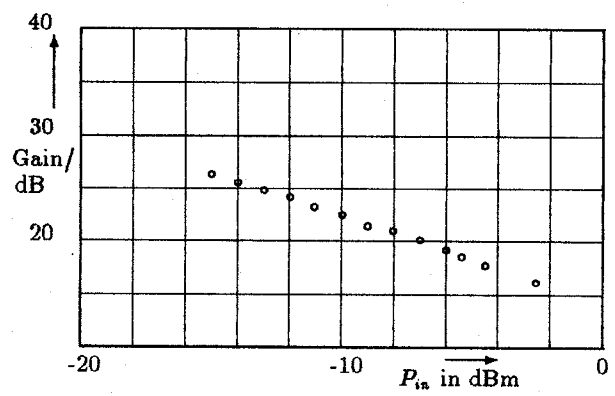

Figure 5: Measured gain of the amplifier

The noise figure shown in figure 6 was measured using the signal of a sinusoidal intensity modulated DFB laser. It shows a value of $5dB$ at the specified input power.

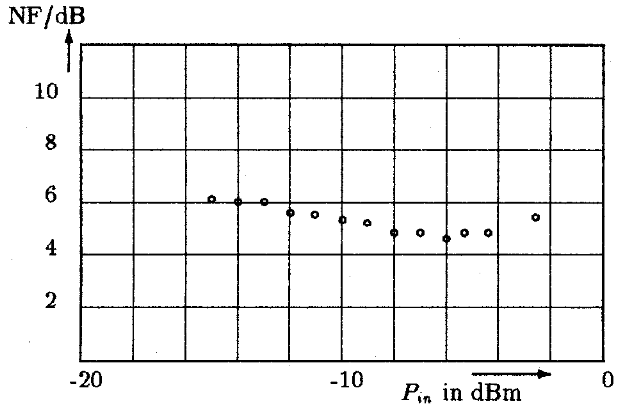

Figure 6: Measured noise figure of the amplifier

To reach the 3dB theoretical predicted quantum limit the set up of the EDFA has to be changed according to refrence [3], where a noise figure of 3.1dB has been achieved.

Optical power splitter

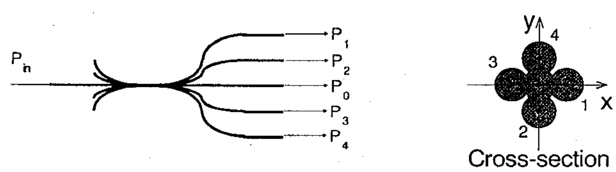

Figure 7: Prinziple of 1:5 optical power splitter

The principle of 1 to 5 coupler is shown in figure 7. The five fibres are fused and drawn automatically. This fused fibre junction produces a multimode optical waveguide. The coupling into the fibres takes place due to interference of the excited modes.

During the drawing process the coupling ratio is automatically measured and compared with the required setting. When the set values are reached the process is stoped automatically. The measured data of the 1:5 power is given below:

coupling coeffient	$20 \pm 1\%$
polarisation variation	$< 1\%$
variation due to temperatur $(-40^{\circ} ... +120^{\circ})$	$< 1\%$
insertion loss	$0.2dB$
directivity	$> 60dB$

T/R Modules

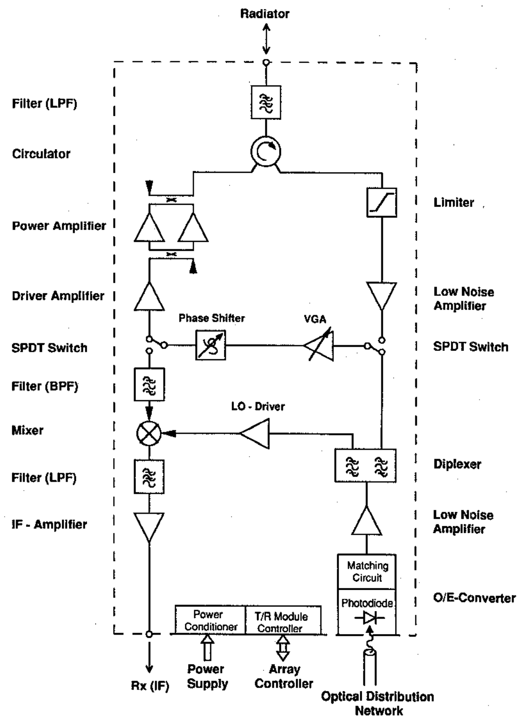

Figure 8: Prinziple layout of the T/R modules

The T/R Modules are based on a common leg architecture. The RF signal forming for Tx/Rx mode is achieved by an attenuator and a phase shifter. This key element [4] provides the phase control necessary for pattern generation, beam forming as well as polarization setting. Essential requirements on this phase shifter are high phase resolution, low insertion loss with lowest variation and good input/output VSWR. The realized 6-Bit phase shifter is of the switch filter type suitable for broadband applications $(9 - 11GHz)$ and requiring a minimum of chip area $(3.5mm \times 2.5mm \times 0.15mm)$. The wafer process employs $0.25\mu m$ recessed gate MESFET technology and uses MOCVD grown epitaxial layers for the FETs and resistors. All bits are controlled by two complementary signals, $0V$ and $-5V$.

The T/R moduls including the optical frontend use integrated components (MMICs, ASICs) and utilize an advanced multilayer structure, which results in a volume compatible with a half wavelength grid spacing to realize a two dimensional array antenna.

System's SNR prediction

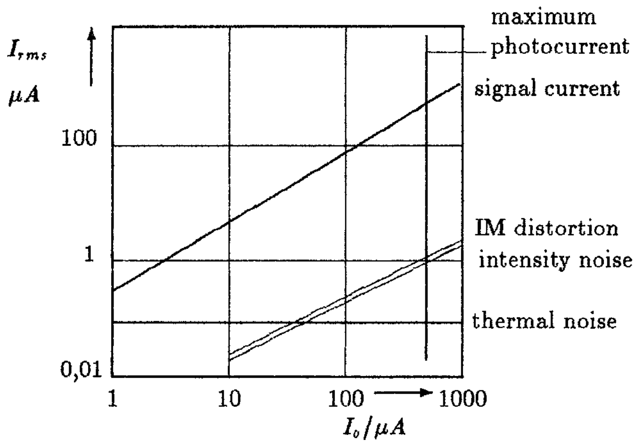

Figure 9: Factors affecting the system's SNR

Figure 9 shows the rms value of the signal current, the thermal noise current, the noise current due to intensity niose of the laser and the current due to intermodulation distortion as function of the mean detector current on the assumption of a simple theoretical model of the network with a systembandwidth of 100 MHz. It can be seen from the above diagram that the currents due to the intensity noise and intermodulation distortion are of the same order of magnitude and will limit the maximum reachable SNR with a value of about 45dB. The incorporation of the EDFA in the system will further reduce the SNR to a value of approximatly 40dB.

CONCLUSIONS

The critical components associated with a microwave/photonic beamforming network has been experimentally studied. Measured parameters of DFB laser and EDFA for analog modulation are in good agreement with the theory. Using a simplified analytical system model with incorporation of a EDFA, it has been shown that for a system bandwidth of $100MHz$ and a modulation index of 46% the maximum reachable SNR is approximatly $40dB$. Further detailed studies considering real radar signals have to be carried out to decide whether the laser intensity noise or the intermodulation distortion is the system performance limiting factor.

Acknowledgement

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