Microwave Photonic Links: Models, Measures and Limits of Performance **Instructor: Cox**

Conveying information, whether in analog or digital form, over microwave optical links is becoming an important technology for a number of new applications. Examples include radar, wide bandwidth communications and high speed digital data.

The majority of microwave optical links employ intensity modulation of the optical carrier. In this talk we present the electro-optical signal models for two principal intensity modulation methods: direct and external. We then discuss four of the most common measures of performance for microwave optical links: gain, bandwidth, noise figure and intermodulation-free dynamic range (IMFDR). We give examples of the state of the art performance that has been achieved in each of these measures. We also examine two limits on performance: noise figure with passive matching and IMFDR under linearization.

One of the reasons for studying links in detail, is that a link is a basic building block for may applications, beyond the basic point-to-point link. Consequently with the above as background, we conclude by examining two of these broader applications of links. The beamformer example highlights the impact of additional optical loss on link performance, not all of which can be recovered with an optical amplifier. The frequency conversion link example highlights the tradeoffs of incorporating additional functionality into a link.

Outline

1. Introduction, including an overview of performance achieved to date

2. Link models for intensity modulation, direct detection via two principal methods
    - 2.1 Direct modulation
    - 2.2External modulation

3. Principal link measures of performance for microwave optical links
    - 3.1 Intrinsic Gain, i.e. the transducer power gain of an amplifierless link
    - 3.2 Bandwidth and the tradeoffs with gain as set by the Bode -Fano limits
    - 3.3 Noise Figure and how the record low values have been achieved
    - 3.4 Dynamic Range, both intermodulation -free and signal-to-noise

4. Limits on performance
    - 4.1 Noise figure
    - 4.2 Linearization

5. Links in context
    - 5.1 Impact of optical loss; beamforming example
    - 5.1 Impact of additional function: frequency conversion link example

5.1 Impact of optical loss, beamforming example

5.1 Impact of additional function; frequency conversion link example

6. Summary

Charles Cox, president of Photonic Systems, Inc., is one of the founders of the field that is now generally referred to as analog or RF photonics. Immediately after receiving the ScD from MIT, Dr. Cox joined MIT Lincoln Laboratory, where he worked for almost 20 years in the Applied Physics and Applied Photonics groups. His incremental modeling approach to analog links led to the prediction of photonic links with gain, which he first demonstrated in 1987. This led the way to significant reductions in the link noise figure as well, and to an understanding of the performance limits of analog links.

He has participated in 8 government-industry studies in the area of photonics, served on the committees of 16 conferences in a variety of roles including general chairman and technical program chair. He holds 6 US patents, has given 45 invited talks on photonics and has published over 70 papers. He has written a textbook, *Analog Optical Links*, which is due to be published this year, has co-edited another book and has written chapters in two other books. He is a fellow of the IEEE and a member of both Sigma Xi and the Optical Society of America.