HIGH-PERFORMANCE FIBER-OPTIC LINKS FOR MICROWAVE APPLICATIONS

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Abstract

There have been significant improvements in the performance of fiber-optic links over the last four years. We will review some of the advances that have been made since our previous comparsion between directly and externally modulated links [3]. We will also present new data on additional link parameters for both types of links.

Introduction

Considerable progress has been made over the last four years in fiber-optic links using both direct and external modulation. The improvements in directly modulated links stem mainly from the introduction of distributed feedback (DFB) diode lasers, which have higher linearity in their optical power vs. current (P-I) curve and 15 to 20 dB lower relative intensity noise (RIN). Externally modulated links have benefited primarily from an improved understanding of the scaling of link gain and noise figure with average optical power [5]. In Tables 1 and 2 we have listed a sampling of recently published experimental-link results for directly and externally modulated links, respectively. For comparison we also list the results from the earlier work of Stephens and Joseph [16] which used Fabry-Perot lasers for the directly modulated link and low optical power for the externally modulated link. We will comment briefly on several common link parameters as well as a couple of other parameters that are particularly important in many microwave-link applications.

Gain and Frequency Response

The gain of directly modulated links depends on the slope of the laser P-I curve; since this slope did not improve with the change to DFB lasers, neither did the link gain. The maximum modulation frequency for diode lasers is determined by the laser's relaxation frequency. This frequency has increased due to factors other than the DFB structure; the present record is 28 GHz [12]. On the other hand, the maximum frequency of external modulators is determined by material properties, and is probably about 500 GHz for lithium niobate. An external modulator operating at 94 GHz has been demonstrated [4]. Externally modulated link gain increases as the square of the link average optical power so the reduced link loss of recent links is largely due the fact that these links now operate with 10 mW on the photodetector whereas previously the maximum power was 100 μW.

Noise Figure

The RIN of DFB lasers is 15 to 20 dB less than that of Fabry-Perot lasers and the RIN of solid state lasers is 20 dB less than that of DFB lasers. These RIN values are midband values since, for both DFB and solid state lasers, there are peaks in RIN vs. frequency. The peaks occur at the relaxation frequency — typically 10 GHz for diode lasers and 200 kHz for solid state lasers, and at the longitudinal mode spacing — usually 300 GHz for diode lasers and 4 GHz for solid state lasers. The intermodal RIN peaks can be essentially eliminated by using lasers that are predominately single frequency, such as DFBs and single-frequency solid state lasers. Although the RIN peaks may often be out of the link passband, they can still cause problems because they will appear as amplitude-modulated sidebands around an inband signal. The higher noise figures of direct modulation will be difficult to reduce, especially without sacrificing other laser parameters such as linearity. Thus it appears that direct-modulation links will always need a preamplifier, which may be a problem in applications where dc power is difficult to deliver.

Intermodulation-free (IM-free) Dynamic Range

The sinusoidal transfer function of the most common external modulator is less linear than the DFB P-I curve. Thus, at a fixed optical modulation depth (OMD), directly modulated links have lower-

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amplitude harmonic and inter-modulation signals than do externally modulated links. However, the lower RIN of solid state lasers means that externally modulated links can be operated at lower OMDs than directly modulated links which results is the wider IM-free dynamic range for external modulation seen in comparing the respective columns of Tables 1 and 2. Two other differences in distortion between these two modulation methods should also be noted. The more common external modulators have transfer functions which have odd symmetry about their bias point, thus second-order distortion is often negligible; diode lasers usually have both second- and third-order distortion. The distortion of external modulators is independent of frequency, whereas diode-laser distortion peaks at the relaxation frequency and, to a lesser extent, at half the relaxation frequency. In many applications both types of links have larger signal-to-noise ratios (SNRs) than required. Consequently numerous lineraization schemes have been developed which trade some of this excess SNR for improved IM-free dynamic range [see for example refs 10 and 13].

Cancellation Ratio

In applications where the output of two or more links will be combined by a signal processor, it is often important that there be a good match between the frequency response of the links involved. A measure of the narrow-band match between the frequency response of two links is the cancellation ratio CR. We have recently measured the CR between pairs of both types of links around 100 MHz. Directly modulated links have CRs of -65 to -70 dB whereas externally modulated links can have CRs only as low as -50 dB. All these results are for a CR over a 100 kHz bandwidth. However this later value requires considerable effort to suppress the bulk piezoelectric (acoustic) modes of the lithium niobate — without such suppression the CR can be as high as -20 dB. At higher frequencies the acoustic modes become negligible so the CR of external modulators is expected to approach that of direct modulation.

AM/FM Noise

Some applications require that signals close to a CW carrier be detected. There are a number of link noise processes, such as the laser RIN peaks discussed above, that can appear as sidebands around a CW carrier thereby potentially masking the desired signals. One particularly troublesome noise is interferometric intensity noise IIN. This intensity noise arises from the interference between the main optical wave and a portion of the main wave which has been twice retro-reflected so that it is now traveling in the same direction as the main wave. IIN can appear in both types of links. Its severity depends upon the number and magnitude of the reflecting planes as well as the linewidth of the laser spectrum. Externally modulated links, with their extra modulator component have more potential reflection sites. However the solid state laser lines are narrower than diode lasers which helps reduce IIN. Initial measurements [17] indicate that the AM noise of directly modulated links is about 20 dB lower than externally modulated links, at least for carriers around 100 MHz.

Conclusions

We have examined directly and externally modulated fiber-optic links using a number of parameters of importance in microwave applications. Both modulation methods have made significant progress and each has better performance in certain parameters. Although both types of links are beginning to find real applications, additional work is needed to permit fiber-optic links to expand into additional applications.

Acknowledgement

This work was sponsored by the Department of the Air Force.

Table 1
Directly Modulated Link Experiments

Center Frequency (GHz)	Bandwidth (GHz)	Gain (dB)	Noise Figure (dB)	IM-free Dynamic Range (dB-Hz$^{2/3}$)	Reference
12	0.8	-13	48	96	8
11.1	9.7	-46	>60		9
9	18	-40	59	98	11
0.8	1.5	-5	33	91	7
4.4	0.6	-37	92	84	16

Table 2
Externally Modulated Link Experiments

Center Frequency (GHz)	Bandwidth (GHz)	Gain (dB)	Noise Figure (dB)	IM-free Dynamic Range (dB-Hz$^{2/3}$)	Reference
20	5.2	-34	41	108	2
10	16	-49	51	102	15
3.9	0.5	-21	36	109	14
7	10	-67	128		16
(MHz)	(MHz)				
900	50	0	21	117	1
300	600	0			6
60	10	11	6	113	3

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