PERFORMANCE IMPROVEMENTS IN FIBER-OPTIC LINKS FOR MULTI-CARRIER TV TRANSMISSION

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ABSTRACT

In broadband networks, there is an increasing need for the transmission of more and more television channels. For this purpose the fibre-optic link proved to be one of the best solutions. However, when the number of TV channels is very high a significant intermodulation distortion will arise.

The intermodulation distortion can be reduced by improving the modulation linearity of the laser or by applying a more appropriate modulation method. In this paper both solutions will be discussed in detail. The linearity has been significantly improved by applying an active matching technique. The sensitivity of QPSK TV transmission to disturbing intermodulation has been investigated. A new "group modulation" method offers a better approach for optical multi-carrier TV transmission.

INTRODUCTION

In broadband networks, there is an increasing need for the transmission of more and more TV (television) channels. For this purpose the fibre-optic link proved to be one of the best solutions. The fibre-optic link offers a very wideband transmission with adequate signal-to-noise ratio [1]. However, when the number of TV channels is very high a significant intermodulation distortion will arise because of the nonlinearities in the fibre-optic link [2-5].

The intermodulation distortion can be reduced by improving the modulation linearity of the laser or by applying a more appropriate modulation method. In this paper both solutions are discussed in detail. The different system arrangements are compared.

The linearity has been significantly improved by applying an active matching technique. The sensitivity of QPSK TV transmission to disturbing interference has been experimentally investigated. A new "group modulation" method offers a better approach for optical multi-carrier TV transmission.

IMPROVEMENTS IN THE TRANSMITTER LINEARITY

At the transmitter side, a linear transfer is needed from the microwave input to the optical output. In the generally used cases, at the input of the transmitter dozens of TV channels are multiplexed utilizing individual subcarriers. Thus its band lies in the UHF frequency range, the spectrum is confined to a band of several hundred MHz. When the number of TV channels is to be increased, the band is extended into the microwave region as well. However, the spectrum has no components below a few hundred MHz. Thus the complete transmission band is not wider than an octave.

The nonlinearity of the transmitter provides the most significant contribution to the nonlinearity of the complete fiber-optic link. Therefore, any improvement in the transmitter linearity has a great significance [6]. The linearity of the transmitter is influenced by the modulation characteristic of the laser and the transfer function of the driving circuit. The laser linearity is dependent mainly on its inner construction. Thus the transmitter linearity can be improved significantly by the proper choice of the laser construction. However, this paper will be concentrated on the improvements achieved by a more appropriate driving circuit.

LASER INPUT IMPEDANCE

For improving the linearity of the transmitter, the microwave input impedance of the semiconductor laser has been measured from 0.3 to 500 MHz at two bias currents. The result is plotted in Fig. 1 in the form of Smith charts. As seen in this figure, the imaginary part of the input impedance does not depend on the bias current of the laser, however, the real part is decreased with increasing laser current. The simplest equivalent circuit for the microwave input impedance of the laser contains a linear inductance and a nonlinear resistance.

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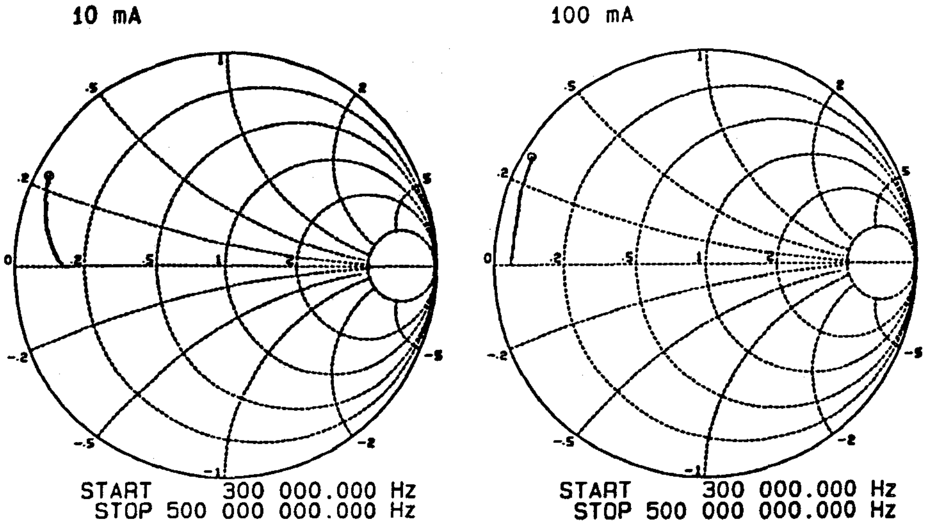

Fig. 1 The microwave input impedance of a semiconductor laser with 10 and 100 mA bias currents

The level dependence of these elements has been investigated based on further measurements. That is depicted in Fig. 2 where the inductance and the resistance are depicted as functions of the laser current. As seen the inductance is nearly constant, however, the resistance exhibits a reduction when the current is increased. The nonlinear input resistance contributes significantly to the nonlinearity of the modulation characteristics of the laser if the usual passive matching techniques are applied [7,8]. Therefore, an active matching technique has been developed to obtain a better linearity.

DRIVING CIRCUIT

The active matching has been performed by a new driving circuit applying a microwave MESFET amplifier. The main task of that driving circuit is to provide a good transfer from its voltage driven input to its current driven output for the laser diode. This goal has been achieved by the active matching technique what is needed because the load of the driving circuit, i.e. the microwave input impedance of the laser is nonlinear as seen in Fig. 2 As that impedance is frequency dependent as well the proper frequency response of the driving circuit is also necessary for a better linearity. Utilizing these matching processes, a significant improvement has been attained in the modulation linearity of the laser.

Thus the driving circuit contains a microwave FET amplifier with appropriate feedback, and input-output matching circuits. The design goal is to provide a current source at the output of the driving circuit and the current of the source has to be linearly proportional to the input voltage. It is very important to keep the output impedance of the driving circuit as close to open circuit as possible. This way, the current flowing through the laser will not depend on its microwave input impedance which is highly nonlinear.

The bias current of the laser has to be chosen properly as well. The most linear section of the modulation characteristic is used and special care is needed to keep the bias current unchanged under a high level modulation as well.

The linearity of the transmission is also dependent on the width of the band to be transmitted. Another parameter is the driving range. The input level exhibits a fluctuation around an average level. If this fluctuation is less then a higher linearity can be attained for this smaller driving range.

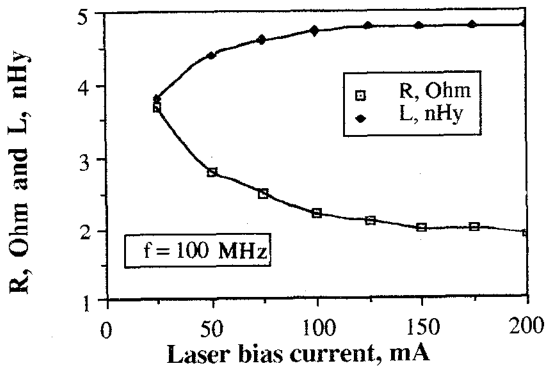

Fig. 2 The input inductance and resistance versus the laser bias current

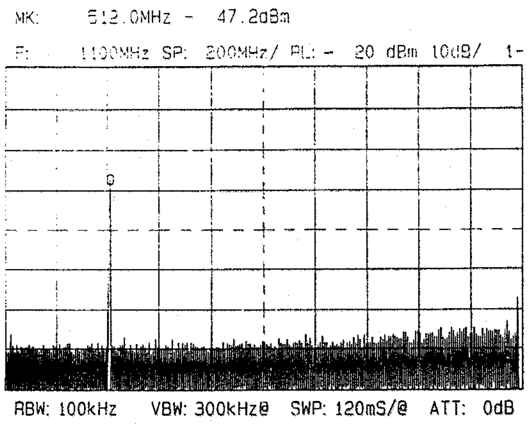

Fig. 3 The output spectrum of the modulated laser

MEASUREMENT OF LINEARITY

Many well established methods are available to measure the nonlinearity or its result. The nonlinearity gives rise to the distortion in the channel and the interference between the channels.

One of the possible methods measures the transfer function of the laser transmitter. A more precise evaluation is obtained when the slope of the modulation characteristic, i.e. the modulation sensitivity is measured at different bias currents.

In an other method, the intermodulation products are measured directly. For that purpose, two measuring signals with a small frequency difference are applied at the input of the optical transmitter, and the level of the third order mixing product gives the information on the nonlinearity.

The nonlinearity can be characterized by the harmonic components as well. First of all, the second and third harmonics are relevant. A spectrum analyzer is used for that measurement. This method is advantageous because it is very sensitive to the nonlinearity.

The harmonic measurement method has been applied to determine the linearity as a function of the modulating signal level. The harmonic content of the output spectrum has been measured for that purpose. The result is plotted in Fig. 3 showing the output spectrum of the laser modulated with a 500 MHz signal. As seen the second, third and fourth harmonics are below the noise level, i.e. at least 43 dB below the level of the fundamental frequency component. This very pure output signal means that the modulation characteristic is highly linear.

MORE APPROPRIATE MODULATION METHODS

The linearity requirement can be less stringent when a more appropriate modulation method is used. In the widely used arrangements, the TV channels are transmitted in their original form containing AM (amplitude modulated) video and FM (frequency modulated) sound channels. For combining several tens of TV channels subcarriers are applied and the combined signal is then used to modulate the optical transmitter.

A significant improvement can be obtained if a frequency or phase modulation is applied for the individual video channels. The frequency or phase modulation is less sensitive to the nonlinearities.

A further approach offers a good transfer for digitalized TV signals. Thus a QPSK (quadrature phase shift keying) modulation can be used because it is also not sensitive to the nonlinearities.

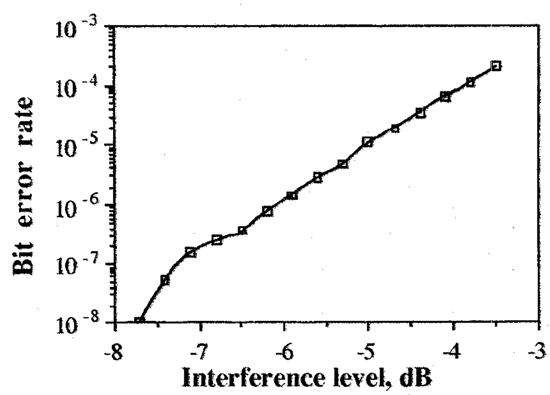

Fig. 4 Bit error rate as a function of the distorting signal level

In our experiments, the optical transmission of a pseudo-random QPSK signal with a bit rate of 34 Mbit/s was measured concerning the interference effects. The impairment in the bit error rate was measured as a function of the distorting signal level obtained from other signals via the nonlinear conversion. That is shown in Fig. 4 where the bit error rate is plotted as a function of the distorting signal level. As seen in this Figure the distorting signal is at a very high level when the impairment in the bit error rate is noticeable.

By an appropriate allocation of the subcarrier frequencies, the distortion due to the intermodulation can be reduced significantly.

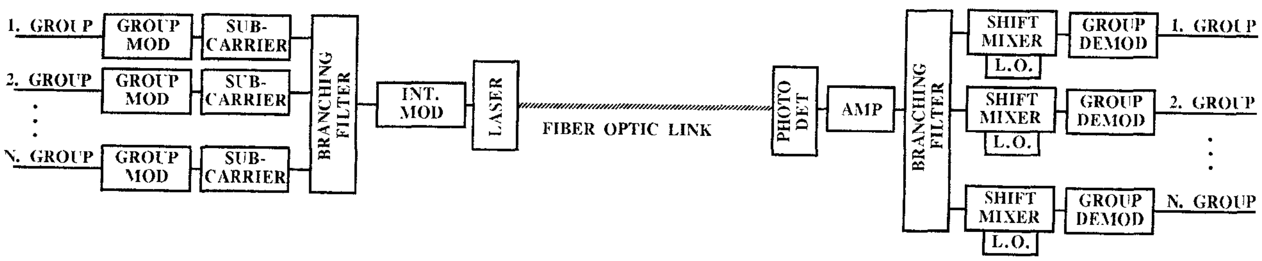

Fig. 5 Block diagram of an optical link applying the group modulation

GROUP MODULATION

Now another new approach is presented which will be called "group modulation". In this case, 5 to 10 TV channels with different subcarriers create a group, and this group is put on a second subcarrier modulating its frequency. That is shown in Fig. 5 providing the block diagram of a complete optical link applying the new group modulation technique. In a group the analog or digital TV channels are combined by having different subcarriers. The output signals of the group modulators with the second subcarriers are led via a branching filter to the laser diode which is modulated in intensity. At the receiver side after the optical detection group discriminators are used to regain the TV signals with the first subcarriers.

The group modulation is more advantageous because the linearity requirement in a group is less stringent and it can easily be fulfilled by the group modulator and demodulator. Further, the frequency modulated groups are much less sensitive to the nonlinearity of the optical transmission considering the interference problems. Creating the groups offers new possibilities: the proper choice of the frequency bands for the groups assures a lower interference level.

The linearity requirement can also be reduced by the application of proper modulation schemes. A spectrum containing discrete lines create higher interference than a continuous spectrum. Therefore the subcarriers have to be suppressed significantly even when there is no modulating signal.

The group modulation is a good approach to reduce the linearity problems when the number of TV channels is very high. The reason is that the modulation nonlinearity of the group modulator can be kept at a very low level. This technique has another advantage: the groups can be separated by branching filters which makes possible a more flexible operation.

CONCLUSIONS

The demand for higher transmission capacities is based on the need for more available TV channels, and also on the wish for improving the quality of the TV picture. In the future, more and more HDTV programs will be distributed which require a wider bandwidth. Another trend is the application of digital modulation for the transmission of TV channels which also needs a wider band.

The increase in the capacity of the fiber-optic links obtained by improved linearity or by applying a new modulation method can be exploited for the transmission of more analog or digital TV or HDTV channels. That will be a relevant requirement in the near future.

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