OPTICAL ANALOG CATV SYSTEM CONVEYING 100 CHANNELS IN A 1.5 GHZ SUB CARRIER USING THE AM-VSB FORMAT

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Resumo: Sistemas ópticos analógicos de CATV usando o formato AM-VSB são introduzidos. Através de uma subportadora no intervalo 1 - 2 GHZ, o espectro de CATV é transladado para a região das baixas frequências de microondas. Este espectro deslocado AM modula um laser semicondutor. O sinal resultante é então introduzido numa fibra óptica. Na extremidade da recepção ocorre a detecção e a conversão de frequência para baixo. Vantagens e pontos críticos deste esquema são discutidos. Um diodo laser comercial é rigorosamente modelado e usado para várias situações de simulação sistêmica. O papel desempenhado pelo amplificador a microondas que modula o laser é discutido. Mostra-se que, sobre uma única fibra, é possível alcançar a capacidade de 100 canais, de maneira econômica, enquanto preservando o desempenho desejado.

Abstract: Optical analog CATV systems using the AM-VSB format are introduced. By using a subcarrier, in the 1-2 GHz range, the CATV spectrum is upconverted to a low microwave region. This shifted spectrum AM modulates a semiconductor laser. The resulting optical signal is then introduced in an optical fiber. At the reception end occurs the detection and the downconversion. Advantages and critical points of this arrangement are discussed. A commercial laser diode is rigorously modeled and used for several system simulation situations. The role played by the microwave amplifier that drives the laser is discussed. It is shown that, over a single fiber, it is possible to reach the 100 channel capacity, in an economic way, while preserving the desired performance.

Key Words: CATV by optical fiber, laser modeling, sucarrier multiplexing, SCM, lightwave TV system.

1. INTRODUCTION

Nowadays, it is commomplace to speak about the significant increase in home entertainement services offer. Several companies are aiming at obtaining a strong position in the TV distribution business. The competition between telephone and cable TV companies, which is occuring not only in US but also in several other countries, is a good example of how demanding this market is. Within this scenario, the TV distribution by optical fiber is a very important issue, as it is a quite economical way of massive TV distribution.

The classical CATV system uses a coaxial cable for distributing some 60 TV channels, which are alocated in the 50-550 MHz range, in a FDM way. The coaxial cable is not practical for higher frequencies (or larger bandwidths) than this last mentioned figure. By using higher frequencies in a cable system, the attenuation calls for a shorter distance between the bridger and/or line extender amplifiers. By increasing the number of amplifiers, the intermodulation distortion is also increased. Very soon, a practical limit is reached [1].

Due to its low attenuation, the optical fiber is able to beat this limit. It is then possible to long-distance transmit a great number of TV channels in an arrangement similar to the conventional CATV [2]. The SCM AM-VSB (*SubCarrier Multiplexed Amplitude Modulated-Vestigial SideBand*) TV by optical fiber is appearing as a natural evolution of the classical CATV. In these very large capacity systems, the optical fiber may be regarded as a data-bank, as far as TV channels are concerned; the so called *supertrunk* [3]. At specific areas, according to market decisions, certain channels are routed from the supertrunk to local area networks, by simple frequency translation.

The ability to handle analog signals with arbitrary modulations in photonics systems, in a quite economical way, is a relatively new development. It has started in the late 80's, when some manufactures put in the market semiconductor devices specially tailored for these applications [4]. Laser diodes with 5 GHz modulation capability and photodiodes with 10 GHz detection bandwidth, were then introduced.

Presently, there are not well established standards for carrying TV by optical fiber. Some experts have suggested the use of subcarrier, in the 1-2 GHz as a satisfactory trade-off [5]. Several attempts have been done for modulating this subcarrier in a digital [6,7] or FM [8] way. Apparently, the best modulation format solution is the one which uses the subcarrier in the 1-2 GHz band and still keeps the original AM-VSB format of the conventional CATV. By doing so, several advantages become apparent. The relative bandwidth occupation at the 1-2 GHz range is smaller than at the 50-550 MHz range. Much of the intermodulation distortion is avoided. Electronic circuitry becomes simpler. By keeping the CATV format, the compatibility with respect to the tuning circuits of each domestic TV set is preserved. This last procedure will save costs in all customer points. Finally, the AM modulation of laser diode is obtained in a quite straigthforward process: the transmitter system may be also implemented in a more economical fashion. In this way, the SCM AM-VSB format will be here adopted. Being more specifical, the used subcarrier will be the one centered at 1.5 GHz The organization of this paper, describing the different subjects that will be focused in each section, is now presented.

In section 2 it is discussed what migth be called a conventional SCM AM-VSB CATV system. A critical point is there detected. This is the inneficient coupling between the amplifier which drives the laser and the laser itself. It is shown that this coupling ineficiency renders to an increase of the total system intermodulation and/or to an increase of the system costs

A broadband planar matching circuit is introduced between the laser and the drive amplifier, in section 3. The coupling between these two devices is then improved. The intermodulation distortion is reduced, the system capacity may be increased and/or the costs may be reduced.

In section 4 a recent commercially available laser diode is rigorously modeled. Although this laser is intented, as suggested by the manufacturer, to convey 40 CATV channels at the conventional baseband level, it is shown that it has the potential ability to reach the 100 channel target using an 1.5 GHz subcarrier.

Alternatives for SCM AM-VSB TV systems are discussed in section 5. An elegant approach is used for exploring maximum system capacity, given the performance goals. With the previously mentioned circuit in place and taking other design parameters into account, it is shown that is possible to reach the 100 channel capacity in an economical and efficient way.

2. CONVENTIONAL APPROACH FOR OPTICAL SCM AM-VSB TV SYSTEM

Although there is not a standard approach for CATV by optical fiber, a reasonable configuration for a system using the SCM AM-VSB alternative, could be the one depicted in Fig. 1.

The baseband CATV spectrum is initially upconverted to a low microwave frequency range, by means of a local oscillator (LO) and an (upper) single sideband mixer (USSB).This shifted spectrum is then introduced in a microwave amplifier drive amplifier (hereafter called as amplifier) for superimposing the desired signal onto the laser bias current. The microwave amplifier is usually designed for presenting an output impedance level of 50 ohm, while the dynamical input impedance of the laser diode is usually much more lower: tipically 5 ohm [9]. For matching purposes, an ~ 45 ohm resistor is then placed between these two last devices. Next , the optical spectrum is routed to a monomode fiber. At the reception end, a photodiode recovers the electrical signal, although still displaced in frequency, due to the subcarrier action. A final downconversion, by means of another LO and mixer, replaces the spectrum in the CATV baseband.

By using the matching resistor, it is easy to see that the amplifier drives the laser with a substantial power penalty. With the pair 45/5 ohm, quite typical values, the power penalty is $p(\mathrm{dB}) = 10 \log_{10}[(45 + 5)/5] = 10$ dB. In other words, 90% of the amplifier output power is lost in the matching resistor.

As it will be shown later, to keep an acceptable performance, the intermodulation distortion introduced by the amplifier must be kept in an quite low level. Consequently, in a practical system, the designer must use an an amplifier which operates either with a substantial backoff or with a linearizing scheme. Anyhow, in any case, backed off or linearized, the amplifier costs are increased, as it is also increased either the dissipated heat (backoff) or the physical size (linearized). Both situations work against the integration of the amplifier together with laser in a single assembly; an ever desired manufacturing feature. For circumventing these disagreable situations a quite elegant solution is now offered.

3. AN UPGRADED OPTICAL SCM AM-VSB TV SYSTEM

Here, a broadband all-planar matching circuit is placed between the amplifier and the laser, instead of a lossy resistor. The previously mentioned power penalty disapears. From a system view, the role played by the matching circuit is to emulate an amplifier with a higher power, without the corresponding cost, intermodulation or heat.

The advantanges and new possibilities derived from the use of this matching circuit, instead of the matching resistor, may be mentioned as follows:

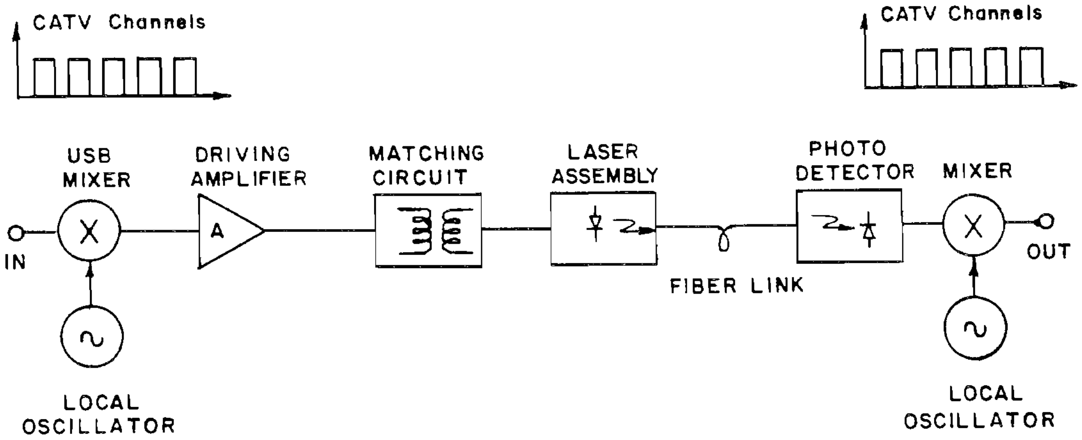

Fig. 1 - Configuration of a Typical AM-VSB SCM TV Lightwave System

The advantanges and new possibilities derived from the use of this matching circuit, instead of the matching resistor, may be mentioned as follows:

i) For keeping the same system performance level, the 1 dB output power compression level of the amplifier, P_{1dB}, may be derated by the correspondent power penalty derived from the resistor use.

ii) If, instead of derating the amplifier, the previous level is kept, then the system will work with a better intermodulation margin.

iii) Same as before, however, the excess in the intermodulation margin is traded by an increase of the system capacity.

The suggested matching circuit is an impedance transformer capable of matching the low laser input impedance to the 50 ohm amplifier output. It is an all-planar transmission-line-derived device, capable of covering a bandwidth in excess of a decade. The structure, which presents a high pass response, may be obtained with simple printed circuit techniques over commercially available substrates. If an $e_r = 38$ substrate is used, a device operating from 1 GHz is obtained with a total lenght of just 2 cm. This circuit, which has been previously presented by one of the authors for fast pulses photonics applications [10], is shown schematically in Fig. 2, for both sides of the substrate.

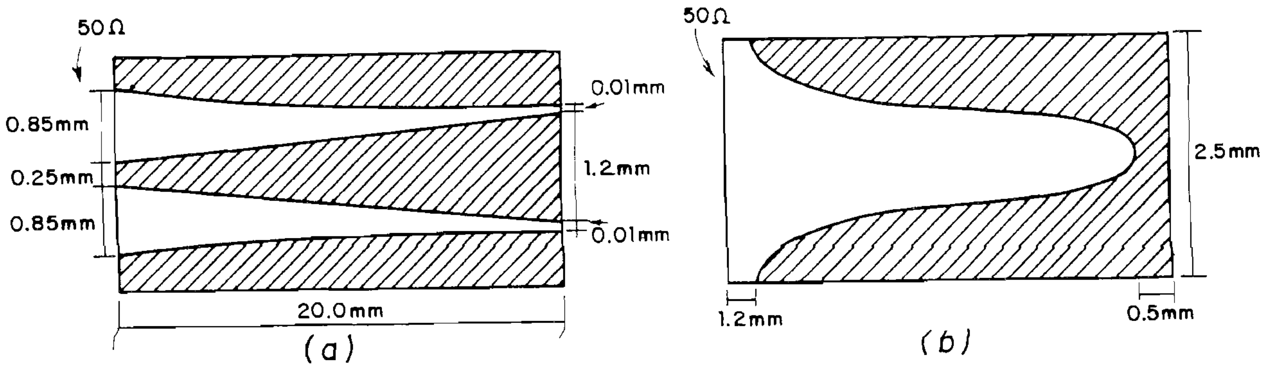

Fig. 2 - An All-Planar Circuit for Matching the Drive Amplifier with the Laser Substrate Faces: (a) upper; (b) bottom

4. MODEL FOR A DFB LASER AND SIMULATIONS

The laser that is being focused is a recent semiconductor DFB one, by Ortel, Model 1610A CATV, for 1300 nm. It is suited for analogic applications, delivering more than 4 mW into a monomode fiber and recommended for conveying 40 TV AM-VSB in the baseband region. Nothing is suggested for its operation under a subcarrier mode. In respect to subcarrier use, it may pointed out that Darcie, Tucker e Sullivan [11], using measured results, have shown that the total nonlinear distortion, which is obtained from a given laser, is governed mainly by the total modulation index, m, at which the laser is driven, provided the relaxation oscillation frequency of this laser, f_r , is kept substantially higher than the highest modulation frequency, fm_{max} , ie: $f_r > 2fm_{max}$. It will be shown latter that the focused laser possess $f_r \sim 10$ GHz. Therefore, using a given modulation index, essentially the same intermodulation level will be obtained if it works with 40 TV channels located at the baseband (with $fm_{max} \sim 500$ MHz), or if these channels are shifted by an 1.5 GHz subcarrier (with $fm_{max} \sim 1.7$ GHz).

Before introducing the laser, a brief description of the available software, which will be used for modeling the laser and later for evaluating the complete system, will be given.

4.1 Software Description

The available software, is an upgrade of a microwave system analysis one, which has been extented for taking into account photonics devices and the microwave-photonics combination.

For microwave devices and systems, the software furnishes the input, output and transmission complex (magnitude and phase) coefficients of devices and their association. The devices may be passive, active, linear, nonlinear, lossless, lossy or dispersive. The input and output signals may be defined, or obtained, both in the time and frequency domain.

For photonics devices the same system-oriented approach was used. However, a very accurate approach was used for the laser and for the monomode optical fiber.

For the laser, the large signal rate equations are numerically solved, in the time domain. For the optical fiber, the propagation equations are solved taking into account dispersion effects for b_1 (group velocity), b_2 (group velocity dispersion) and b_3 (dispersion slope).

4.2 Laser Model

Using the mentioned software and some parameters furnished by the manufacturer, the laser has been modeled. Table 1 is furnishing the most relevant parameters.

Table 1 - Typical Parameters for Laser ORTEL Model 1610A CATV

Active Volume V_a	4.3 mm^3
Spontaneous Emission Factor b	1.0×10^{-4}
Optical Confinement Factor p	0.5
Optical Gain Slope Constant g_o	3.0×10^{-12} m^3 s^{-1}
Optical Gain Compress. Factor e	2.2×10^{-23} m^3
Diff. Quantum Efficiency h	0.16 mW/mA
Internal Losses a_{int}	20 cm^{-1}
Facet Refractivity Index	0.32
Carrier Density at g = 0 N_o	1.0×10^{24} m^{-3}
Carrier Lifetime t_n	0.45 ns
Photon Lifetime t_p	1.93 ps
Emission Wavelenght l_o	1310 nm
Threshold Current	22 mA
Bias Current	80 mA

Three tests are performed for evaluating the validity of the obtained model, with respect to manufacturer's measured data: relaxation frequency, DC output and CTB (composite triple beat).

The first one is testing for the relaxation frequency. A low-level frequency-swept electrical signal is superimposed to the laser bias. The output photon density is observed at the frequency domain. The results show that the relaxation frequency increases with the bias level. At 80 mA, the relaxation frequency was found to be 10 GHz. This result is in accordance with the those furnished by the manufacturer, namely < 9.5 GHz.

The second test is for the DC output. The laser DC curve is obtained. At the 80 mA bias level, the light power output is shown to be 18.6 mW. Additionally, one must consider that for launching light into a monomode (9/125) fiber, a coupling lens is needed. This last presents a typical effenciency of 35%. Consequently, a value of 6.5 mW entering the fiber is obtained This value is quite consistent with the one provided the manufacturer which is > 4 mW.

The third test is for verifying an important dynamic condition: the third order intermodulation test known as CTB. For doing so, the laser is first biased at 80 mA. Two equal-amplitude carriers, at f_1 and f_2 , are introduced in the laser, in a way that the total modulation index m = 22%. This last figure is equivalent to 40 carriers at individual modulation indexes m_i = 5%. Next, the resulting spectral lines, occuring at $2f_1 - f_2$ and at $2f_2 - f_1$, are observed in the frequency domain and compared with the carrier amplitudes. Several situations were studied with the carriers assuming several frequency positions within the 100-300 MHz range. The CTB results present different values according to the carriers positions. They vary from -67 to -73 dBc, with -68 dBc being a typical value. This is quite consistent with the CTB specification provided by the manufacter which is better than -65 dBc.

4.3 Laser Simulations for Conveying SCM AM-VSB TV Channels

The first simulation is a baseline for testing a consistency with a similar case provided by the manufacturer.

Simulation #1: 40 Channels at the SCM Level - The manufacturer provides CTB for 40 channels at baseband level. Here, instead, it will be tested for total harmonic and intermodulation distortion for N = 40 channels at the subcarrier level. The conceptual difference between the two cases is not so dramatic as it may seem to be. First, consider that at subcarrier level the relative band occupancy for 40 channels will be substantially lower than an octave, typically 40%. Consequently, all integer-derived harmonics (composed second order, composite third order and the the others) will fall out of the useful band. Therefore, the observable distortion will be CTB, associated with some less significant higher-order difference-derived components like composite fifth order, seventh order and so on.

For 40 channels, the laser drive is, as the manufacturer suggests, an individual modulation index m_i = 5% , which corresponds m = 22%, ie: $m = m_i \ (N/2)^{1/2}$, for N > 10.

The Fig. 1 shematic is used, where all components, exception done to the laser, are considered as ideal. A 25 ohm resistor is used for matching circuit as this specific laser presents an input impedance of 25 ohm. A total of 41 carriers, alocated from 50 up to 450 MHz and equally spaced by 10 MHz, are introduced in the mixer. The LO is set to 1.25 GHz. The upconverted spectrum will span from 1.3 to 1.7 GHz. Next, one carrier, the central one, is suppressed. The output is observed at the frequency domain, at the photodetector output level. Three observation windows are used: i) 10 MHz below the spectrum, ii) the central notch, where the carrier has been suppressed and iii) 10 MHz above the spectrum.

The observed results may be seen at Fig. 3. At the first window is seen a value of -70 dBc, a value of -67 dBc is obtained at the central one and -65 dBc is observed at the third window. The manufacturer has obtained the figure of -65 dBc for pure CTB. Even considering that here the obtained values are somewhat corrupted by other less significant terms, it is believed to be a consistent experiment.

This simulation has shown that there is not such a great difference between operating a lightwave system at the baseband level or at the subcarrier level, provided the previously mentioned conditions are kept.

A Brief System Consideration - Before starting the 100 channel simulation, some system considerations must be discussed, for providing performance guidelines.

The industry measures the performance of a TV system by evaluating noise, CTB and CSO. If all these contributions are considered to be as a kind of *noise*, than a CNR (carrier to noise ratio) may be defined. It is not well established which is the accepted level for this total noise. It seems that a future accepted value will be within the interval CNR > 50 to 55 dB [12]. Arbitrarily, here will be addopted CNR > 52 dB. In this paper, CNR takes into account, all kind of nonlinearities like CTB, CSO, which also include those derived from laser clipping, and, which will be genericaly called as NLD. CNR is also including those that are indeed noise-derived as shot-noise (ShN), intensity-noise (IN) and thermal-noise (ThN).

Saleh has dealt with fundamental limits of a semiconductor laser lightwave system [12]. An interesting suggestion has been there presented. It is said that for achieving a desired goal perfomance, the approach may be so that the contribution derived from the nonlinearities should be about the same of those noise-derived. In other words: if NLD corresponds to the total power contribution derived from nonlinearities, SN corresponds to the total power contribution of different noise sources and C to the total carrier power, then a (quasi) optimum design condition will occur when (C/NLD) ~ (C/SN). Within this scope, and assuming CNR = [C/(NLD + SN)] > 52 dB, this optimum situation is (C/NLD) ~ (C/SN) > 55 dB.

This brief discussion was necessary for establishing a performance limit for the 100 channel simulation which will be now presented.

Simulation #2: 100 Channels at the SCM Level - Consider the discussion of the last paragraph where a criteria of C/NLD > 55 dB was announced. Compare with the results obtained with the first simulation where NLD ~ -65 dBc has been obtained. It is easy to see that the above case, with 40 channels, is well beyond the system limit, if only the NLD criteria is considered. It is fair to attemp to increase the system capacity. This is done by increasing the number of channels to 100, however, reducing the individual modulation index to 3.2%. With this last figure, the total modulation index is still kept: m = 32%. Still using ideal components at Fig. 1 scheme, except for the laser, the number of carriers is increased to 101. At the baseband level the carriers use the 50-1050 MHz band and the local oscillator is set to 0.95 GHz. Again, the central carrier is suppressed and NLD is observed in the same three correspondent windows.

The obtained results are shown in Fig. 4. It is obtained -59, -65 and -58 dBc for the three windows. This simulation is showing that this laser may withstand 100 channels with an acceptable NLD level.

It may seem that decreasing the individual modulation index is the ever successful way of increasing the system capacity, as this procedure indeed reduces NLD. However, those who are familiar with lightwave system design, are aware that this reduction will contribute to corrupt the CNR figure, through the shot-noise side; as it will become clear further in this paper. The design of a lightwave analog system presents difficulties from a number of sides.

Although this last simulation is encouraging, still remains the central problem. This is the one of demonstrating an acceptable performance in a complete lightwave system considering other NLD contributions, those last mainly derived from the amplifier, and still other contributions derived from detector shot-noise, laser intensity noise and detector thermal noise, just to mention a few.

For doing so, at this point, a complete lightwave system will be introduced, where each component should present a realistic characteristics. Next, the complete system will be evaluted.

5. A 100 CHANNEL SCM AM-VSB LIGHTWAVE SYSTEM

The description of how the software deals with the different devices used for simulating a complete lightwave system will be now presented. For doing so, refer to Fig. 1 components.

5.1 The System Components

* USSB Mixer - as this mixer is working with a low-level signal, the software looks to it as a linear device. The only action performed, from input to output, is to shift the input spectrum, in the frequency domain, in the upper direction, by a value given by the LO.

*Local Oscillator - it is supposed to be noiseless. It governs the frequency spectrum translation provided by the mixer.

*Amplifier - the low-signal gain and the 1 dB output power compression gain, P_{1dB}, are entered as parameters. The amplifier nonlinearity, towards saturation, is taken into account through a time-domain third degree polynomial transfer function, which is an adequate assumption [13] when the amplifier operates at least 6 dB from P_{1dB}, the 1dB compression point. This function is such that settles the third order intercept point, P_{3IMP}, 10 dB above the P_{1dB} level.

*Matching Circuit - this block may be configurated as desired. For the purposes of this paper, it either assumes the role of a lumped 25 ohm resistor or the one of the taper described in Fig. 2. When it represents the taper, the propagation effect in all kind of transmission lines which constitues the device is considered, including the losses and dispersion effects; as the taper lines are not TEM mode ones. Specifically, the tapered lines are considered to be a cascade association of 100 sections of elementar lines of different widhts.

*Laser - the role of the laser has been already preliminarily described in Section 4.1. Now, it must be stressed that the large signal rate equations are numerically solved without any simplification, in a quite rigorous way. This approach takes into account all nonlinearities, including those derived from clipping. This is also different from some other previous papers where some sort of simplification is used [14,15], or an equivalent circuit is used [16,17], in spite this corresponds to a diverse physical phenomenom. In the semiconductor laser block, the optical power and the chirping response to the current weaveform I(t) is determined by means of numerically solving, in the time domain, the large signal rate equations, which describe the interrelations of the photon density, carrier density and optical phase within the laser cavity, as follows:

$$dN/dt = I/(qV_a) - (A_{nr} + BN + CN^2)\,N - g\,(N - N_g)\,(1 - eS)\,S$$

$$dS/dt = Gg\,(N - N_g)\,(1 - eS)\,S - S/t_p + GbBN^2$$

$$df/dt = 1/2\ a\,[Gg\,(N - N_g) - (t_p)^{-1}]$$

where N and S are, respectively, the electron and photon densities in the active layer and f is the optical phase. I(t) is the amplitude of the injected current. The only physical constant above is $q = 1.6 \times 10^{-19}$ C, which is the electron charge. All other quantities are laser parameters: V_a is the active layer volume, A_{nr} is the the nonradioactive recombination rate, B is the radioactive recombination coefficient, C is the Auger recombination coefficient, g is the active layer gain coefficient, N_g is the electron density at transparency, e is the gain compression factor, G is the mode confinement factor, t_p is the photon lifetime, b is the fraction of the spontaneous emission coupled into the lasing mode and a is the linewidth enhancement factor.

*Coupling Lens - although this device does not appear in Fig. 1, it is used and represented by a flat frequency domain scale factor, which represents the lens efficiency. Here it will be adopted the value of 35%.

*Optical Fiber - although the software has sophisticated mechanisms to deal with dispersion, in this paper they were not used, as in 1310 nm the standard monomode fiber presents negligible dispersion effects, mainly in a 12 Km link, as it will be used here. What has been used, solely, was a loss effect assumed as 0.35 dB/Km.

*Photodetector - the photodetector model is a flat frequency scale factor (from mW to mA), representing its responsivity, associated with a time constant , where R and C may be specified.Here, R = 50 ohm and C is such that the frequency response goes up to 10 GHz.

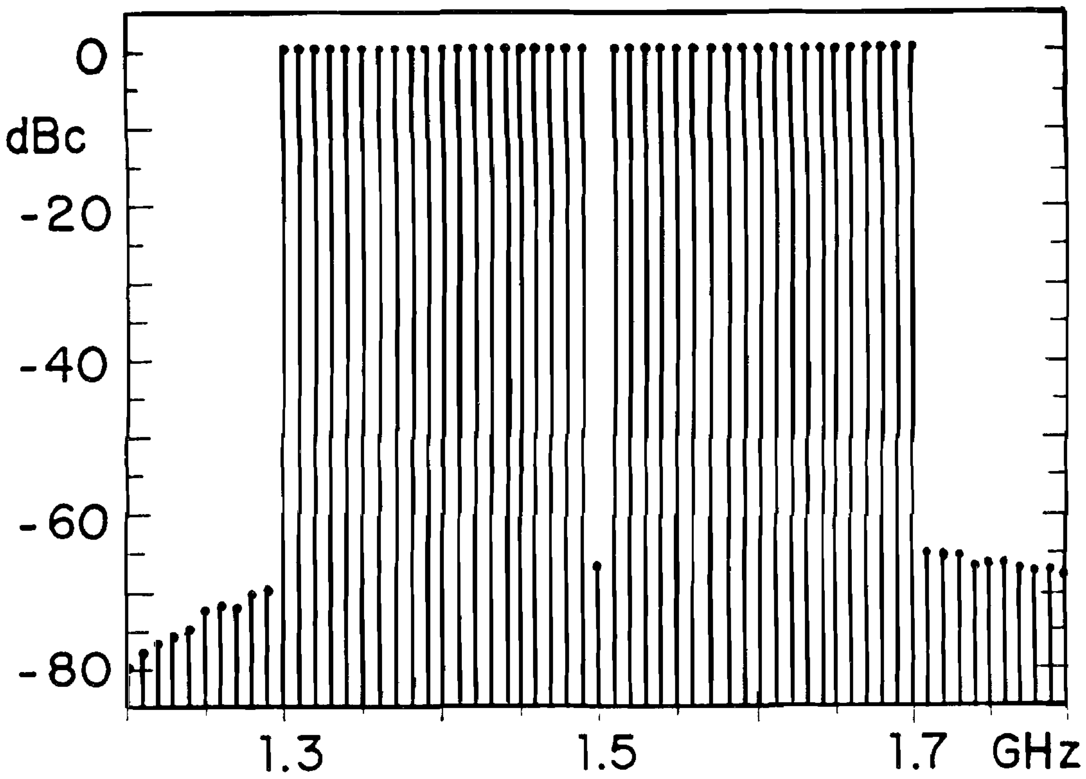

Fig. 3 - Laser Non-Linear Distortion Obtained with 40 TV Channels

5.2 Noise and CNR

All noise computations, thermal, shot and intensity noise are also considered by the software. Thermal noise will not be here considered, as this kind of system will operate with a moderate (~1 mW) reception level. Shot and intensity noise follow classical models, as follows:

$$C/ShN = r\, m_i^2\, P_o / 4\, q\, B \quad (1)$$

$$C/IN = m_i^2 / 2\, RIN\, B \quad (2)$$

where r is the photodetector responsitivity, here assumed as r = 0.65, m_i the modulation index per channel, P_o the average detected power, q the electron charge, RIN the laser relative intensity noise, here assumed flat with the frequency and with a value of RIN = -155 dB/Hz, as given by the manufacturer and B the bandwidth, assumed here to be B = 4 MHz, as this value is the one of a domestic TV set, the ultimate link of a TV system chain.

Additionally, it must be mentioned that due to nonlinearities, the evaluation of the average detected power P_o, mentioned in (1), is not so easy as it might seem to be at first glance. The software performs this task rigorously.

The association, in a RMS sense, of NLD, ShN and IN leads to CNR. In a formal way it is obtained:

$$CNR = C / (NLD + ShN + IN) = [\, (C/NLD)^{-1} + (C/ShN)^{-1} + (C/IN)^{-1}\,]^{-1} \quad (3)$$

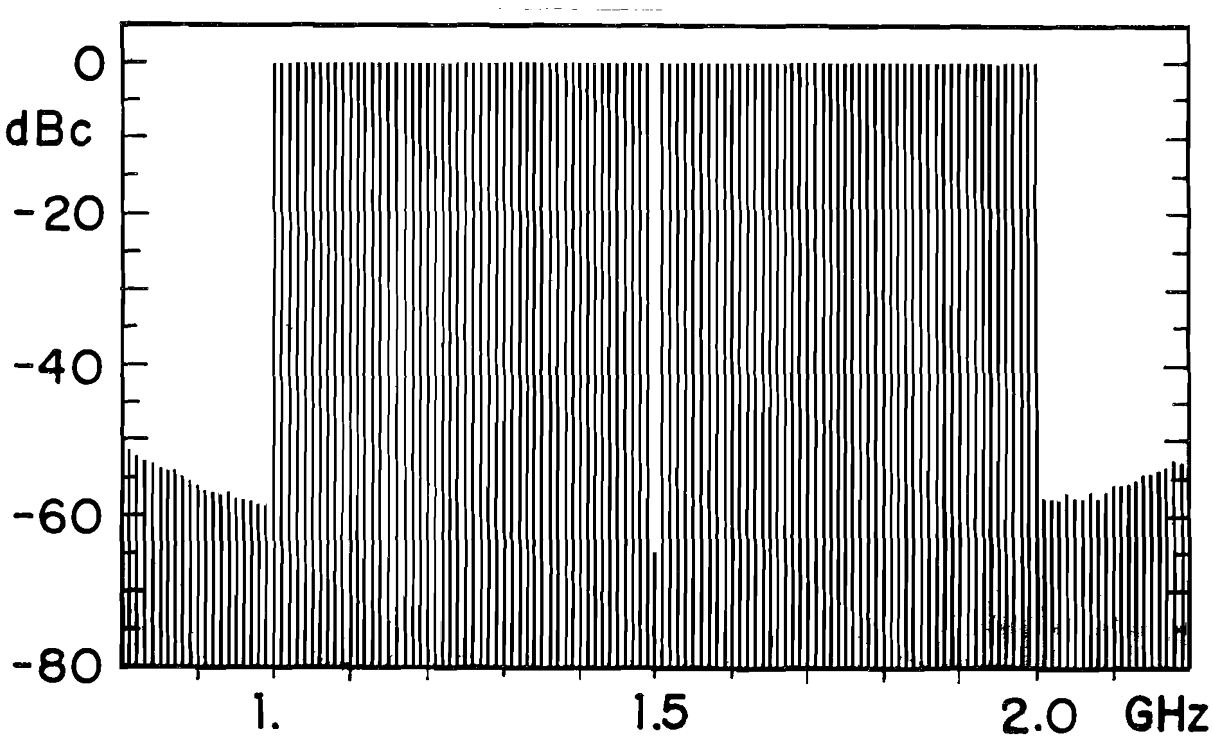

Fig. 4 - Laser Non-Linear Distortion Obtained with 100 TV Channels

5.3 Performance as a Function of the System Parameters

In the design of an analog lightwave system it is suposed that is often desired to increase N, the number of channels and L, the system lenght, while preserving the performance. For doing so, the designer faces a multi-parameter problem, which, indeed, is not an easy task. Here, quite obviously, it not offered a general solution. However, if the lenght and the equipment are given, the procedure here presented will lead to a quite satisfactory solution. The problem which is being proposed to be solved is: given the hardware, to choose the right modulation index for achieving a desired performance, while maximizing the number of channels.

The system length will be defined as 12 Km; a reasonable one for an analog system, to be used in a medium to moderate-large urban center. The equipment has already been defined above, with some exceptions which will be given now. First, observe that the focused laser presents an 25 ohm input impedance. The power penalty for driving it, from a 50 ohm amplifier, with an 25 ohm matching resistor is 3 dB. This is not so severe as the 10 dB mentioned before. However, the present 25 ohm laser input impedance is not the typical case. Consequently, a taper is used for matching 50 to 25 ohm. The amplifier is specified as having P_{1dB} = 300 mW, which implies, by previous assumptions P_{3IMP} = 3 W. Its terminations are 50 ohm. If the taper were not used, than this amplifier should be rated as 600 mW, with all the next results being the same.

Refering again to Fig. 1, a total of N+1 equal-amplitude carriers are introduced in the system. As before they are equally spaced by 10 MHz. Their allocation in frequency and the LO frequency are such that the shifted spectrum will always be centered in 1.5 GHz. The central carrier is suppressed. The amplitude of the carriers are variable, and, for each case, the corresponding modulation index per channel is noted. The number of carriers is also variable. In other words, the universe m_i x N is swept. Each pair (m_i , N) corresponds to a case. For each case, NLD is observed, like in Figs. 3 and 4. The worst value, among the three observation windows, is kept. For each case, ShN and IN are also computed, like described in (1) and (2). The final CNR, for each case, is obtained, as given in (3). From a great number of cases, Fig. 5 results, using the individual modulation index as a parameter.

In Fig. 5 it is observed that in the lower capacity region, the most significant contributions to CNR are derived from ShN and IN, as these are not affected by the total modulation index, rather by the individual one. Consequently, in this region, the curves are practically horizontal.

When the number of channels is increased, the NLD contribution increases in a dominant way, as the total modulation index is progressively increased. The CNR degrades.

For very low individual modulation indexes, m_i < 2.4, it is not possible to achieve the desired performance, CNR > 52 dB, for any capacity. The almost fixed contributions derived from ShN and IN are already dequalifying high.

The Fig. 5 pictures beatifully the existing trade-off between the capacity N and the individual modulation index m_i . It is often desired to increase N. However, by increasing N, the total modulation index also increases, as increases NLD. This last deteriorates CNR. Consequently, one must reduce the individual modulation index for achieving the desired CNR. This last procedure reaches very soon a limit settled by the very low individual modulation indexes, where ShN and IN predominates.

For achieving high capacity (N > 50) the working region is limited 2.5 % < m_i < 5.5 %. Finally, for this specific system, the marked point at N = 100 is suggesting that is possible to reach the 100 channel capacity, with m_i = 3.5%, equivalent to m = 25%, taking into account all relevant contributions, and still obtaining a CNR > 52 dB. This point is now examined in detail

5.4 - A Complete 100 Channel SCM AM-VSB TV System

The LO is settled for 0.95 GHz and the amplitude of each of the 100 carriers are such that an individual modulation index of 3.5% is obtained. Similarly to previous cases, NLD is observed in the three windows. The results are -56, -58 and -57 dBc. The value of the detected average power is P_0 = 1.8 mW, the shot noise computation leads to -59 dBc and the intensity noise to -57 dBc. The final result is CNR = 52.5 dB

This last results are showing that, for the focused system, the 100 channel capacity target is achievable. However, one must also remember that a simulation is not able to take into account all effects of a real field test. Some other effects would then appear. For instance, the multiplicity of reflections throughtout the splices and connectors of the link would somewhat enhance the intensity noise. Another consideration, also dealing with intensity noise, is the one that RIN has been assumed to be flat, at the -155 dB/Hz level. This flatness is quite true for moderate (up to 300 MHbandwidths. For an 1 GHz bandwidth, like used in the last simulation, this assumption should be somewhat revised. In any case, it should be mentioned that the result, concerning the intensity noise, obtained for the last simulation, possesses a safety margin. This was to adopt the RIN figure provided by the manufacturer, which has been obtained with a 65 mA bias, and to run

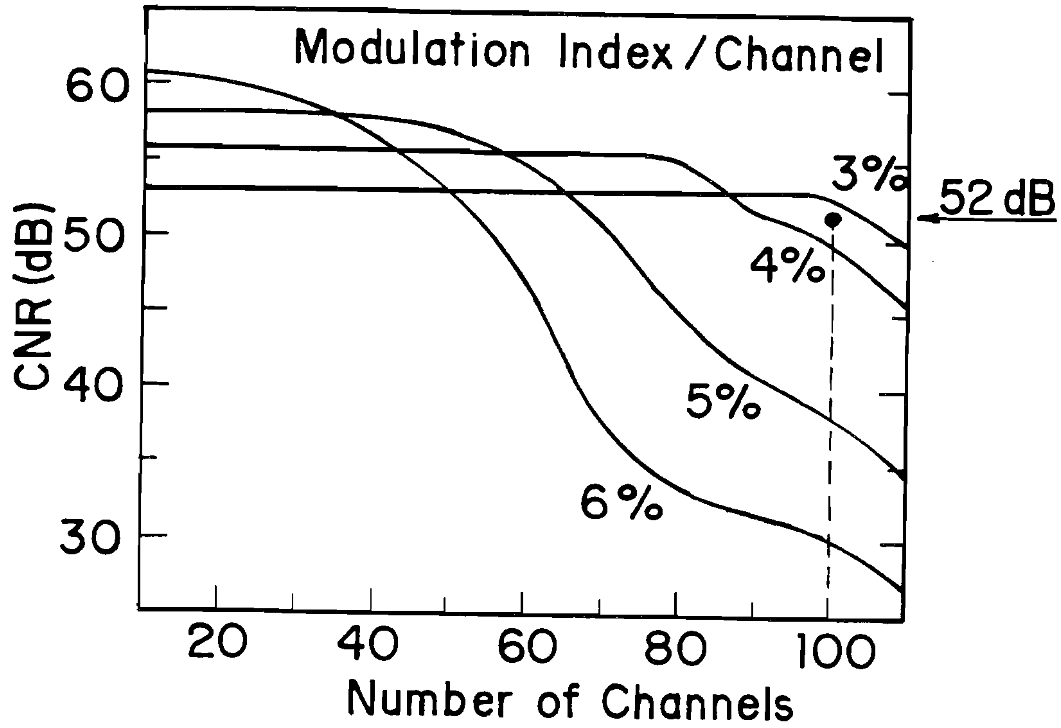

Fig. 5 - Obtained System Carrier-to-Noise Ratio with Respect to the System Capacity for Several Individual Modulation Indexes

simulations with a heavier bias condition (80 mA). Remember that RIN decreases with the third power of the bias power. Consequently, the intensity noise figures obtained provide for counterbalancing those aditional phenomena

6. CONCLUSIONS

The AM-VSB format, using an 1-2 GHz range subcarrier, is supposed to become a preferential way of massive distributing TV by optical fiber. Some advantages of this arrangement have been presented: the circuitry is simpler than those for FM or digital modulation, the use of a relative bandwidth of less than an octave avoids much of the harmonic distortion and the AM-VSB may use the tuning circuits of the commercial TV sets. Additionally, in the 1-2 GHz range, the used circuitry is still quite simple, economical and may be easily adjusted.

Linearity, on the other hand, is a critical point for analog systems. This paper has shown that although the laser is the most significant device, as far as linearity is concerned, care must be taken with the driving amplifier too. For the laser, it was shown, in Simulation #2, that a commercial and economic device is already available capable of withstanding a 100 TV channel capacity in a AM-VSB format in the SCM mode. For the amplifier, it was shown that the use of a matching circuit is capable of reducing its requirements. Specifically, the matching circuit here suggested is an all-planar one, capable of being integrated in the transmitter module.

The 100 channel system configuration presented, in section 5.4, is composed by easily available devices and their assumed performances are quite realistic. The 12 Km system lenght is a convenient one for being use in TV distribution in medium to moderate-large urban centres.

The measured results, obtained by Darcie, Tucker and Sullivan [11], might lead one to ask if the 100 channel capacity here obtained might be also reached by using other type of laser, provided the same modulation indexes are used and the laser relaxation frequency is also near 10 GHz. In this case, care must be exercised as the Darcie, Tucker and Sullivan conclusions apply only to intermodulation results. Here, the favorable obtained system results are due, in part, to the exceptionally low RIN level of the focused laser.

A significant contribution of this work is offered by Fig. 5, where the desired parameters for achieving a desired performance are easily obtained.. This is suggesting that in a multi-parameter problem, like a lightwave system design, a convenient approach is to display a large region of the universe to be explored. Next, seeking a small region near optimum conditions becomes an easy task. However, one must remember that this large region was only able to be displyed thanks to the availability of an efficient software. This last condition played an important role in this paper.

Additionally, observe that Fig. 5 could be similarly generated for fixed N and seeking for maximum lenght system L, or for optimizing the performance with respect with any other desired parameter.

The most significant contribution of this work was the one of suggesting that a 100 TV channel system is possible to be implemented in an economical way, achieving a satisfactory performance. Although this work is a simulation effort, it is believed to be rigorous enough in order to stimulate reaching in a practical situation the above described capacity. Note that this capacity, over a single fibre, as far as the authors are aware, has not been previously related.

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