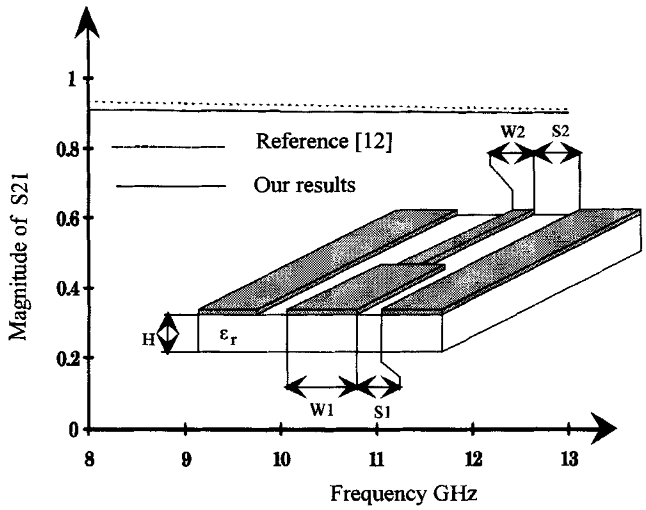

Figure 6 Transmission coefficient of a CPW discontinuity. $W_2 = 0.3$ mm, $W_1 = 1.5$ mm, $S_2 = 1.2$ mm, $S_1 = 0.6$ mm, $H = 0.635$ mm, $\varepsilon_r = 9.6$

measured with the help of numerical magnetic matched loads placed at each port of the discontinuities. We demonstrate thus that this method may be applied in the case of magnetic-current-defined structures, as well as in the case of microstrip lines defined with the presence of electric current densities. The different advantages of this method permit us now to consider simulating some hybrid, more complicated structures, where both magnetic and electric current densities must be taken into account.

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PERFORMANCE ANALYSIS OF CELLULAR MOBILE COMMUNICATONS OVER MULTISTAR RING FIBER-OPTIC / COAXIAL CATV NETWORKS

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KEY TERMS

Cellular mobile communication, cable TV network, fiber optics, coaxial cable

ABSTRACT

The embedded hybrid fiber-optic / coaxial CATV network can provide cellular mobile communications with a star ring fiber-optic network to distribute broadcasting cable TV programs and to provide the transmission of a bidirectional wireless signal. There are two lasers at the head end. The down-link laser is split into two parts. One part is the local oscillator for the up-link coherent detection, and the other part is externally modulated by the combined TV and wireless signals. The up-link laser is connected to the ring network with the cascaded phase modulators scheme. For the location neighborhood and frequency reuse, we may apply the multistar ring CATV cellular network with the distance between the head end and the first-level hub of 5 km and the distance between the first-level hub and the second-level hub of 0.5 km. The total hub number of 42 for the multistar ring system can support 34,860 wireless users for the IS-54 system with frequency reuse number of 7 covering an area of radius 5 km. © 1995 John Wiley & Sons, Inc.

1. INTRODUCTION AND SYSTEM DESCRIPTION

There is increasing interest in the provision of integrated CATV and telephone services, such as an integrated service using a system based on CT-2 (second-generation cordless telephone) [1, 2]. A passive optical/coaxial hybrid network (POCN) can be designed, providing video as well as enhancing telephone and data services, while providing all of the customers with an optical/coaxial cable architecture [3]. The introduction of a microcellular system reduces power consumption and the size of the handset. However, acquiring suitable real estate for the establishment of an antenna tower in a city is currently serious problem. Therefore we need to design a small cost-effective antenna tower with an optical-fiber microcellular distribution system [4–7].

We propose a star ring fiber-optic network to distribute broadcasting cable TV programs and to provide simultaneously duplex transmission of wireless signals. This network employs the star topology for the down link with the direct detection and the ring structure for the up link with coherent detection as shown in Figure 1. The proposed system has some benefits:

1. It can provide wireless bidirectional communication via the existing hybrid optical-fiber/coaxial CATV network.
2. A fiber to the hub system with M subscribers and X wireless users sharing the same photodetector and phase modulator.
3. A hybrid fiber-optic/coaxial system is more economical.
4. While transmitting the wireless signals to and from the hub based on the common rf band, up-down frequency-converting techniques for the transmission of the multiple hubs' wireless signals with the same fiber cable between the head end and hubs can be used.

There are two lasers at the communication head end (as shown in Figure 2). The down-link laser has power P_D and the up-link laser has power P_U. A 1×2 coupler is connected to the output of the down-link laser to split the light into two parts. One part is used as the local oscillator for up link by coherent detection. The other part is externally modulated by the combined TV and wireless signals, then distributed via a $1 \times N$ star coupler to N hubs. The up-link laser is connected to the ring network to provide an optical carrier to all hubs for up-link signals. The optical signal carrying the upstream messages from the other side of the ring is mixed with the

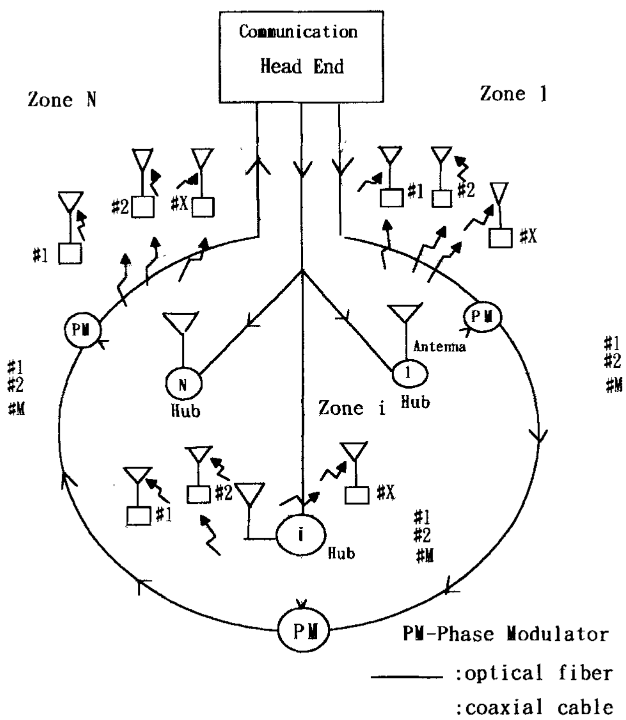


Figure 1 Schematic diagram of the star ring fiber-optic CATV network

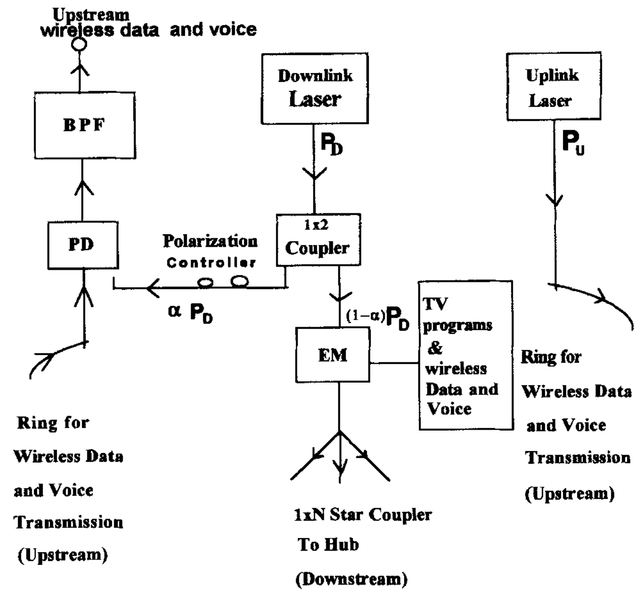


Figure 2 Communication head end structure

local oscillator and detected by the photodetector to recover the messages. Each hub uses a photodetector to detect the TV programs and down-link wireless messages via subcarrier multiplexing (SCM) [8], and distributes the TV programs by coaxial cable to subscribers and wireless messages by antenna to wireless users. The hub utilizes a phase modulator to transmit the up-link wireless data from an antenna via the fiber ring network with the cascaded phase modulators scheme [9].

In order to transmit the dedicated signals to the destination hub, we use the up-down frequency converter. For example, we transfer the wireless signal band into the ith hub frequency, $f_{\text{hub}i}$, by up converter and transmit these up-converting signals into the down-link fiber star network. At the destination hub, it receives those down-link signals (TV programs and wireless signals). After the down converting, we can obtain the corresponding wireless signals at the output of the down converter, then transmit those wireless signals to the antenna. On the other hand, we have collected the wireless up-link signals from the antenna and up-converted them into the up-link fiber ring network.

2. ANALYSIS

2.1. Carrier-to-Noise Ratio for Up Link. For the up link, we use coherent detection:

$$i_U(t) = 2R\sqrt{P_S P_{\text{LO}}} \cos(2\pi f_{\text{IF}} t + \theta_U(t)), \tag{1}$$

where R is the responsivity of the photodetector and f_{IF} is the frequency difference between down-link and up-link lasers. P_S and P_{LO} are the received optical signal power and local-oscillator power given as $P_S = P_U/(L_{\text{PM}}^N L_R)$ and $P_{\text{LO}} = \alpha P_D$, respectively. α is the power ratio of the local oscillator laser over the down-link laser. $\theta_U(t)$ is the up-link wireless signal given as

$$\theta_U(t) = \sum_{i=1}^{N} \sum_{j=1}^{X} \beta_{U_{i,j}} \sin\left(2\pi f_{U_{i,j}} t + \psi_{U_{i,j}}(t)\right), \tag{2}$$

where $\beta_{U_{i,j}}$, $f_{U_{i,j}}$, and $\psi_{U_{i,j}}$ are the modulation index, the subcarrier frequency, and phase for the up-link wireless signals. $10\log_{10} L_{PM}$ is the insertion loss of the phase modulator, assumed to be 3 dB. L_R is the propagation loss of the up-link fiber for ring topology, assumed to be $(2\pi r + 2r)\alpha_{fiber}$ dB. r is the radius between the head end and hub. α_{fiber} is the fiber loss.

Assuming the upstream signals are a single-octave system (because the AMPS system's up-link band is from 824 to 849 MHz) then the carrier-to-noise ratio (CNR) at the upstream receiver is given by [10]

$$\mathrm{CNR}_U = \frac{0.5R^2P_{LO}P_S\beta_U^2}{(\sigma_{sh}^2 + \sigma_{th}^2)B_U + h_3K_3R^2P_{LO}P_S\beta_U^6/32}, \quad (3)$$

where $J_1(\beta_U)$ and $J_0(\beta_U)$ have been approximated by $\beta_U/2$ and 1, respectively. Thermal and shot noises are given, respectively, by $\sigma_{sh}^2 = 2eRP_{LO}$ and $\sigma_{th}^2 = NFkT/R_L$. e is the electron charge, B_U is the transmission bandwidth for up-link wireless signals, NF is the amplifier noise figure (3 dB), k is Boltzman's constant, T is the temperature (300 K), and R_L is the load resistance. The largest number of the third intermodulation distortion (IMD_3), which falls on the central channel [11], is given as

$$K_3 = NX(NX/2 + 1)/4 + ((NX - 3)^2 - 5)/4, \quad (4)$$

where NX is taken to be even. h_3 is the effective factor of IMD_3 power within the desired signal band and is equal to 0.66 [10]. The optimal modulation index for the up-link wireless signal is

$$(\beta_U)_{opt} = \left(\frac{16(\sigma_{sh}^2 + \sigma_{th}^2)B_D}{h_3K_3R^2P_{LO}P_S}\right)^{1/6}. \quad (5)$$

2.2. Carrier-to-Noise Ratio for Down Link. For the down link, the detected photocurrent at the hub is given by

$$i_D(t) = RPr(1 + \sin\theta_D(t)), \quad (6)$$

where Pr is the received DC optical power as, $Pr = (1 - \alpha)P_D/(L_BL_CL_S)$. $10\log_{10} L_B$ in decibels is the insertion loss of the BBI modulator [12], and $10\log_{10} L_S$ is the propagation loss of the fiber link for star topology. Both are assumed to be 3 dB and $r\alpha_{fiber}$ dB, respectively. $10\log_{10} L_C$ (dB) is the splitting loss of the $1 \times N$ star coupler, with L_C being equal to N. $\theta_D(t)$ is the combined TV programs and wireless signals for the down link with the total number of P channels and NX wireless users, respectively, as given by

$$\theta_D(t) = \sum_{l=1}^{P} \beta_l \sin(2\pi f_{TV_l}t + \psi_{TV_l}(t)) + \sum_{i=1}^{N}\sum_{j=1}^{X} \beta_{Di,j}\sin(2\pi f_{Di,j}t + \psi_{Di,j}(t)), \quad (7)$$

where $(\beta_l, \beta_{Di,j})$, $(f_{TV_l}, f_{Di,j})$, and $(\psi_{TV_l}, \psi_{Di,j})$ are the modulation index, the subcarrier frequency, and the subcarrier phase for the down-link TV and wireless signals, respectively. In general, the modulation indices for all channels within TV programs and wireless users are chosen to be the same as $\beta_l = \beta_{TV}$ and $\beta_{Di,j} = \beta_D$, respectively. For simplicity, we rewrite $\theta_D(t)$ as

$$\theta_D(t) = \beta_{TV}\sum_{l=1}^{P} \sin(2\pi f_T V_l t + \psi_l(t)) + \beta_D\sum_{k=1}^{q}\sin(2\pi f_{Dk}t + \psi_{Dk}(t)), \quad (8)$$

where $q = NX$ and $(f_{Dk}, \psi_{Dk}(t))$ is one-to-one mapped into $(f_{Di,j}, \psi_{Di,j}(t))$. Then we can express $\theta_D(t)$ in terms of Bessel-function extension as,

$$\begin{aligned}\sin\theta_D(t) = \sum_{n_l=-\infty}^{\infty} \cdots \sum_{\Sigma n_{l_i} + \Sigma u_{k_i} = ODD} & J_{n_{l_1}}(\beta_{TV})\cdots J_{n_{l_p}}(\beta_{TV})J_{n_{k_1}}(\beta_D)\cdots J_{n_{k_q}}(\beta_D) \\ & \times \sin\Big\{n_{l_1}[\omega_{TV_1}t + \psi_{TV_1}(t)] + \cdots + n_{l_p}\big[\omega_{TV_p}t + \psi_{TV_p}(t)\big] + n_{k_1}[\omega_{D_1}t + \psi_{D_1}(t)] + \cdots \\ & + n_{k_q}\big[\omega_{k_q}t + \psi_{D_q}(t)\big]\Big\}. \end{aligned} \quad (9)$$

Here the TV signal band is away from the wireless signal band; therefore their cross talk can be ignored. For example, the CATV band is from 50 to 550 MHz, and the downlink of the AMPS system is from 869 to 894 MHz. The approximations $J_0(x) \approx 1$ and $J_1(x) \approx x/2$, for $x \ll 1$, are used. We use the BBI (balanced bridge interferometer) modulator [12] as the external modulator. The BBI modulator uses two optical output ports in the modulator for solving the modal matching problem of the MZ (Mach-Zehnder) device and for eliminating the MZ intrinsic loss. For the BBI modulator biased at the quadrature points such that composite second-order distortion becomes negligible [12], the CNR for down-link wireless and TV signals [10] is given as

$$\mathrm{CNR}_D = \frac{R^2Pr^2\beta_D^2/2}{\left(\sigma_{sh}^2 + \sigma_{th}^2 + \sigma_{RIN}^2\right)B_D + h_{D3}K_{D3}R^2Pr^2\beta_D^6/32}, \quad (10)$$

where B_D, h_{D3}, K_{D3}, and B_{TV}, h_{TV_3}, K_{TV_3} are the transmission bandwidth, IMD_3's power ratio, and IMD_3's number for down-link wireless and TV signals, respectively. $\overline{\sigma_{sh}^2} = 2eRPr$. $\sigma_{RIN}^2 = \mathrm{RIN}\ R^2\ Pr^2$. RIN represents the relative intensity noise of laser. (Here it is -165 dBc/Hz for Nd:YAG laser [12].) And the CNR_{TV} of TV signals are the same as the above equation, except that β_D, B_D, h_{D3}, and K_{D3} are replaced with β_{TV}, B_{TV}, h_{TV_3}, and K_{TV_3}, respectively. The largest numbers of the third intermodulation distortion (IMD_3), which falls on the central channel [10], are given, respectively, as

$$K_{D3} = N_D(N_D/2 + 1)/4 + \left((N_D - 3)^2 - 5\right)/4, \quad (11)$$

$$K_{TV_3} = N_{TV}(N_{TV}/2 + 1)/4 + \left((N_{TV} - 3)^2 - 5\right)/4, \quad (12)$$

where N_D and N_{TV} are the number of down-link wireless signals and TV programs, respectively.

The optimal modulation index for the down-link wireless signals is

$$(\beta_D)_{\text{opt}} = \left(\frac{16\left(\overline{\sigma_{\text{sh}}^2} + \sigma_{\text{th}}^2 + \sigma_{\text{RIN}}^2\right)B_D}{h_{D3}K_{D3}R^2Pr^2} \right)^{1/6}. \quad (13)$$

3. NUMERICAL RESULTS AND DISCUSSIONS

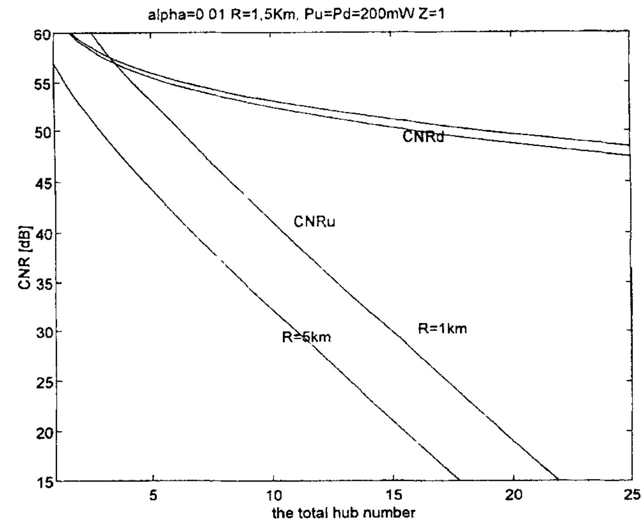
There are two kinds of conditions for breaking the total hub number N into groups with the number Z.

1. Some hubs located in the same area may be considered as one group with their corresponding star ring subnetwork to interconnect the up and down links.
2. Owing to the frequency reuse scheme, we may transmit the same frequency into different groups of the subnetwork. Therefore the whole network consists of multistar ring subnetworks with the number of Z.

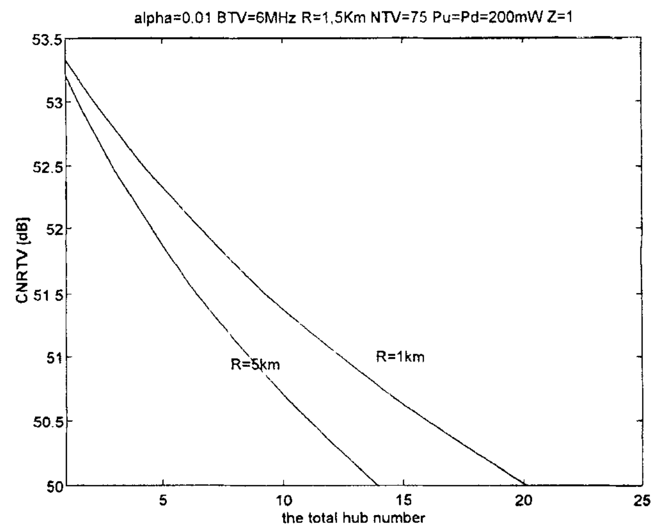
Consider a system with the following parameters: up- and down-link lasers with optical power of 200 mW, the 1-km radius for the microcellular systems and 5-km radius for the macrocellular system, respectively. Now take the IS-54 system [13] as an example, with an up-link frequency band from 869 to 894 MHz, and a down-link frequency band from 824 to 849 MHz for channel spacing of 30 KHz. That is, the corresponding system parameters are $X = 830$ (wireless users per hub) with a transmission width of 30 KHz. In Figure 3, we have obtained the total hub number versus the CNR of up link, down link, and TV, respectively. The results show that the total hub numbers are 20 and 14 for $r = 1$ and 5 km, respectively.

In Figure 4, we have shown the multistar ring CATV cellular structure with $Z = 6$. The distance between the head end and the first-level hub is 5 km, and the distance between the first- and second-level hubs is 0.5 km. The first-level hubs received the optical TV and down-link wireless signals by the photodetector, then distributed those signals to the second-level hubs by coaxial cable. The second-level hubs collected the up-link wireless signals by the fiber-ring subnetwork together with the cascaded phase modulators, then concentrated at the first-level hubs for transmitting toward the head end by one single pair of fibers. In this example, as shown in Figure 4, we must utilize one down-link laser (200 mW) to provide six first-level hubs and two up-link lasers (200 mW), each supporting 21 hubs (3 first-type hubs and 18 second-type hubs). Therefore, the number of the total hubs in Figure 4 is 42 and this multistar ring system can support 34,860 wireless users with a frequency reuse number of 7 to cover an area 5-km radius.

In our network we may use the fiber hub (up link and down link both by fiber cable), the semi-fiber-hub (up link by fiber cable and down link by coaxial cable), and the coaxial hub (up link and down link both by coaxial cable). Because the fiber hub and the semifiber hub are more expensive than the coaxial hub by using the phase modulator for up-link transmission, we can extend the system capacity in this economical way. For example, there are six fiber hubs and 36 semifiber hubs in Figure 4. Therefore, we may apply the coaxial hubs for the systems in Figure 4 to increase the total number of hubs and wireless communication users.



(a)



(b)

Figure 3 (a) The CNR versus the total hub number for down-link and up-link wireless data transmission. (b) The CNR versus the total hub number for the down-link TV programs

4. CONCLUSION

A proposed star ring fiber-optic network to distribute broadcasting cable TV programs and simultaneously provide bidirectional transmission of wireless signals is investigated. This system employs the star topology together with an external modulator for down-link direct detection and a ring structure with cascaded phase modulators for up-link coherent detection. At the head end, there are two lasers, the down-link laser being split into two parts (one being the local oscillator for the up-link coherent detection and the other being externally modulated by the combined TV and wireless signals); the up-link laser is connected to the ring network with the cascaded phase modulator schemes.

In consideration of the location neighborhood and frequency reuse, we may apply the multistar ring network. The multistar ring CATV cellular structure is shown in Figure 4 with the distance between the head end and the first level hub being 5 km, and the distance between the first- and the second-level hubs being 0.5 km. The total number of hubs in

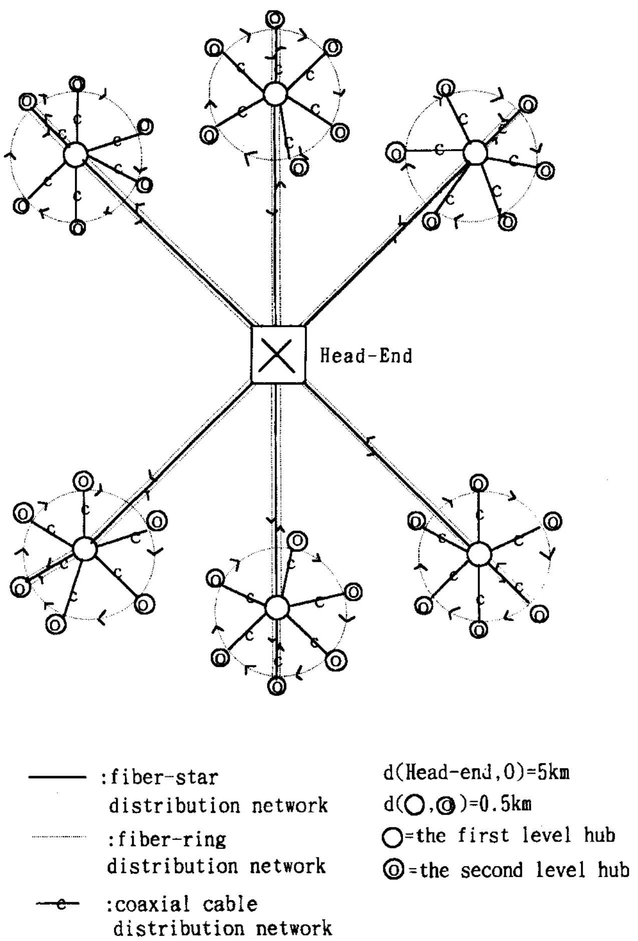


Figure 4 Multistar ring CATV cellular structure

Figure 4 is 42, and this multistar ring system can support 34,860 wireless users for an IS-54 system with a frequency reuse number of 7 to cover an area of 5-km radius.

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GENERALIZED STOKES RELATIONS AND THE PROBLEM OF REVERSIBILITY IN CRYSTAL ACOUSTICS

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KEY TERMS

Crystal, acoustics, optics

ABSTRACT

This article is devoted to an operator generalization for elastoanisotropic case well known in optics of isotropic media: the scalar Stokes relations. The generalized relations connect Fresnel reflection and transmission operators, which apply to problems of the direct and inverse incidence of a plane wave on a plane interface of two semi-infinite linear homogeneous gyroanisotropic media. The tensor of surface impedance for the piezocrystals is introduced. Using the operator impedance method, feasibility conditions for stated relations are analyzed for oblique and normal wave incidence on the anisotropic layer. © 1995 John Wiley & Sons, Inc.

1. INTRODUCTION

Stokes considered the reflection of light on a plane interface of two media, each transparent, homogeneous, and isotropic. For incident beam oscillations parallel and perpendicular to the plane of incidence, Stokes found coupling between scalar Fresnel coefficients of the reflection r, r' and transmission t, t' of the boundary [1]. Values with a prime relate to the inverse beams. These scalars are the simplest examples of the scattering (coherent) operators of a plane wave on a plane