R. Bracht, E. K. Miller and T. Kuckertz (1997), "Using an Impedance-Modulated Reflector for Passive Communication," IEEE AP-S International Symposium, The Queen Elizabeth Hotel, Montreal, Canada, July 13-18, pp. 1070-1073.

USING AN IMPEDANCE-MODULATED REFLECTOR FOR PASSIVE COMMUNICATION

Roger Bracht, Los Alamos National Laboratory, Los Alamos, NM
Edmund K. Miller, Santa Fe, NM*
Thomas Kuckertz, Pajarito Scientific Corporation, Los Alamos, NM

INTRODUCTION

The idea of using modulated reflectors for communicating is not new. A 1948 IRE Proceedings article [Stockman (1948)] considered this possibility, envisioning however that the modulation would need to be achieved by mechanical means, stating that "Modulation (of a reflector antenna) usually requires mechanical oscillation of large masses, joined into a rigid system by members of insufficient stiffness; thus the upper modulation cutoff frequency becomes unduly low." In this summary we discuss the alternative of using electronic modulation of its terminating impedance to vary the reflectance of a passive-node antenna (PNA) and demonstrate its practical feasibility in a real system.

The system described here was developed specifically to use an impedance-modulated reflector (IMR) as the PNA in a medium range (up to 10s of km), low power (a few watts at the active node), slow-scan video surveillance application using compression technology to permit it to utilize narrowband satellite and telephone channels. An advantage of an IMR in this application is that it is inherently covert and therefore hard to detect. The passive-node hardware can also be made small, lightweight, rugged, reliable and power parsimonious (only a small amount of power is needed to operate the ancillary electronics). The active node in our system uses a Doppler radar as is discussed further below.

SIMULATING DOPPLER REFLECTIONS USING VARIABLE REFLECTIVITY

For the application being considered here, the "target" is not a moving aircraft but is instead a stationary reflecting antenna whose reflectivity is caused electronically to vary in time, i.e., the IMR, to produce a Doppler-like signal. The variable reflectivity results in some of the reflected power being shifted into time-varying sidebands, Δf, producing a signal suitable for processing using Doppler-radar circuits, using a time-varying load at the PNA. Any variation of the terminating impedance from Z_o will change the reflected power in magnitude and phase by an amount determined by $Z_o - Z_t$, where Z_t is the termination impedance.

Varying Z_t electronically is relatively easy and requires little input power, using a voltage-controlled diode, for example. The frequency of the incident or illuminating field at the IMR is controlled at the active node with the reflected signal determined by $Z_t(t)$, whose time variation is in turn established by the signal information and the specific kind of modulation being used (e.g., sinusoidal, square wave, random, etc.). The information thus encoded on the reflected signal is recovered at the active-node antenna (ANA) by known radar demodulation techniques. Because only an extremely small portion of the transmitted power may, ultimately, return to the ANA, coherent detection techniques (i.e., where the local receive oscillator is phase-locked with the transmit oscillator) are probably the best way to detect and extract information arriving from a passive node.

Some results showing the kinds of spectra produced by reflection of a CW plane wave at broadside incidence on a half-wavelength-long dipole antenna obtained from solving a time-domain integral equation for the problem [Miller and Landt (1980)] are illustrated in Fig. 1. The reflected field in the broadside direction for a 16-GHz incident wave is shown in Fig. 1a, where the finite width of the spectra results from performing the computation over a finite time window. The reflected spectrum for this same antenna when it has a resistive load at its center which is varied sinusoidally in time at a modulation frequency f_m = 20 GHz between 0 and 1,000 ohms is shown in Fig. 1b. The amplitude of the reflected field is reduced by about a factor of about four (12 dB) at the 16-GHz peak with sidebands produced at frequencies given by $f_t \pm nf_m$, m = 1, 2, . . . These particular parameters are chosen for illustrative purposes; using other parameters would change the specific result but not the general outcome.

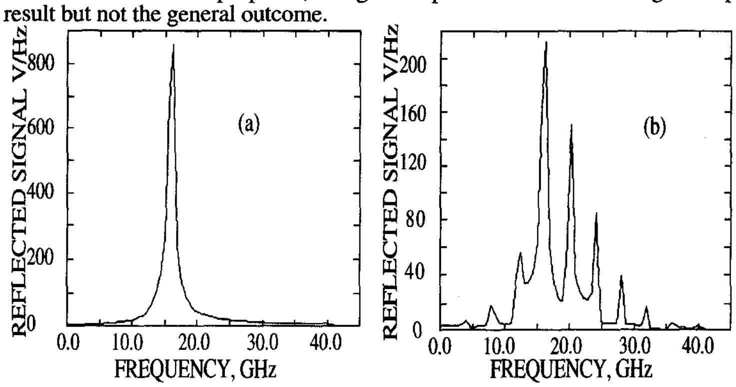

Figure 1. The broadside, unmodulated return for a 16 GHz unit-amplitude plane wave normally incident on a dipole with its electric field parallel to the dipole axis as shown in (a) is changed to the spectrum in (b) when a resistive load at the dipole's center varies as $R[1 + \sin(2\pi f_m t)]$, with a modulation frequency of 4 GHz and R = 1,000 ohms. The locations of the spectral peaks depend on the incident-wave frequency, the modulation frequency and the modulation type being used. These spectra may be considered to be short-time "snapshots" of the instantaneous spectrum that would be caused by a variable modulation frequency.

SOME THEORETICAL ISSUES IN MODULATED-REFLECTOR COMMUNICATION USING DOPPLER RADAR

A typical continuous-wave (CW) Doppler radar, with some straightforward modifications, can be used to recover modulated-reflector information. The Doppler radar cancels out the carrier frequency, detecting the sidebands as frequency differences from which it extracts the encoded information. In practice, a more complex system must be used to handle some problems that are unique to an IMR system. Using digital data, rather than trying to maintain a linear operating range in frequency change that would be needed for analog signals, is probably the best way to maximize signal-to-noise ratio. A pin diode switch provides an effective means of modulating the impedance of the IMR. The pin diode also permits very high modulation rates to be achieved, while further providing a good modulation efficiency.

The maximum working range, R, of an IMR system is similar to that for a radar, being derivable from the basic radar range equation [Levanon (1988)], and can be expressed, with the subscripts t and r denoting transmit and receive quantities, respectively, as

$$R = \sqrt{\frac{G_t G_r}{4\pi}}\lambda\left[\frac{P_t e_m}{P_r}\right]^{1/4} = \frac{\sqrt{A_t e_t A_r e_r}}{\lambda}\left[\frac{P_t e_m}{P_r}\right]^{1/4}.$$

where P_t is the average radiated power from the active node; G and A are the antenna gain and aperture, respectively; λ is the wavelength; e is the antenna efficiency; e_m is the modulation efficiency, and P_r is the minimum detectable received power. The latter is determined by a number of factors including the thermal-noise floor, system loss, the minimum detectable signal-to-noise ratio and atmospheric attenuation. Taking all of these factors into account, the system performance we obtained is similar to that for which Fig. 2 was developed.

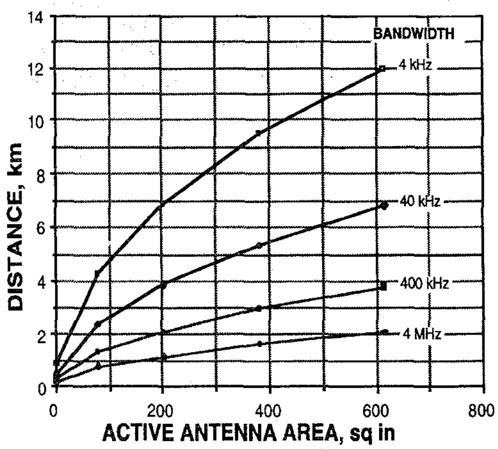

Figure 2. The effective communication range for an IMR system depends on the bandwidth and ANA area as shown here, where a 4-watt transmitter power and PNA area of 64 square inches are assumed.

IMPLEMENTATION CHALLENGES

Some significant challenges need resolution before a practical IMR system can be built:

1) Compensating for the receive nulls that occur every half wavelength due to destructive interference as the path length changes.

2) Reducing the effect of interfering Doppler return signals that can easily desensitize, or saturate, the receiver so that it cannot recover the desired signal.

3) Minimizing the bandwidth needed for the video surveillance.

Our design objectives were to develop a fieldable system that: 1) required no rf power source at the passive node to demonstrate the feasibility of using IMR for practical communications; 2) achieved a usable range of 2 to 5 km; was compatible with narrow-band satellite and phone-line transmission; and 3) was modular, lightweight and portable for practical field use.

The problem of the receive nulls was solved by using an in-phase and quadrature (IQ) demodulator in the Doppler radar. The effect of Doppler interference was eliminated by using $f_m = 192$ kHz, well above any likely other Doppler reflections. Digital modulation was chosen to maximize the signal-to-noise ratio, and system dynamic range was maximized to reduce the problem of receiver saturation caused by Doppler interference. The bandwidth requirement was achieved by using a slow-scan TV system that provided low-resolution, 128 x 128 black-and-white video imagery at a rate of 0.5 frames per second, or better.

The demodulator is attached to the back of the ANA which consists of two separate microstrip antennas approximately 13 x 13 inch in size, one for transmission and one for reception, mounted side-by-side on a single backplane. These antennas, as well as the PNA, were made by Ball Communications. The system employs a center frequency of 10.4 GHz while permitting a ±200 MHz frequency variation and generates about 2 watts of output power. A simplified block diagram of the overall system is shown in Fig. 3.

DISCUSSION

A wide variety of other applications can be envisioned using this proven technology. One possibility would be to use a single, active-node, central station to provide communication links between a large number of widely dispersed passive nodes using an electronically scanned ANA and time sharing. For channels having real-time, voice-bandwidth capacity, communication distances of 10s of kms could be achieved using a few watts of power at the active node.

Another application of this technology would be to electronic tagging. One kind of electronic tag beginning to appear at freeway toll booths, on railroad rolling stock and in similar applications uses a completely passive tag without even the minimal battery power needed for our design. This limits the current range of such tags to just a few meters. By adding the miniature, on-board battery used in our system, the tag-reading range could be increased to many times this distance with little or no increase in system complexity.

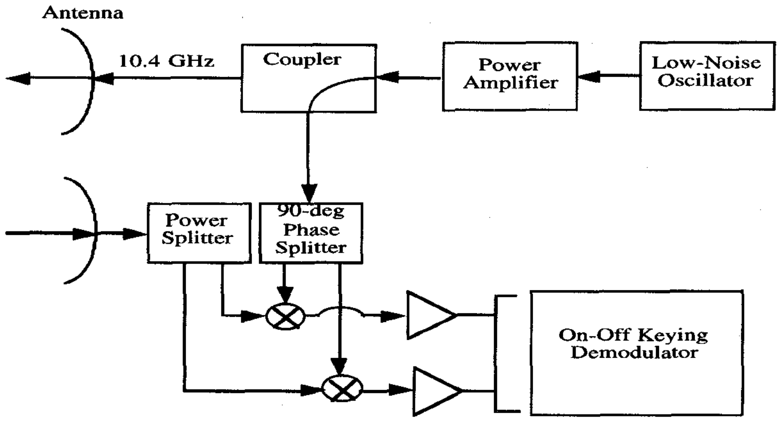

Figure 3. Radar and demodulator block diagram. The microstrip antennas are approximately 13 in square and the system output power is about 2 watts.

REFERENCES

Levanon, Nadav (1988), "Radar Principles," John Wiley & Sons, NY, p. 5.

Miller, E. K. and J. A. Landt (1980), "Direct Time-Domain Techniques for Transient Radiation and Scattering from Wires", Invited Paper in *Proceedings of the IEEE*, **68**, pp. 1396-1423.

Stockman. Harry (1948), "Communication by Means of Reflected Power," Proceedings of the IRE, October, pp. 1196-1204.