Novel Arbitrary Angle Leaky-Wave Reflector using Heterodyne Mixing

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***Abstract* — A novel leaky-wave reflector using heterodyne mixing is proposed and demonstrated experimentally. This reflector uses a unique antenna element and is capable of reflecting an incoming signal to any arbitrary angle by controlling an LO frequency in real time. It may be fully integrated and refined for several commercial and military applications.**

I. INTRODUCTION

Conventional retrodirective reflectors are antenna arrays redirecting an incoming signal toward the source without a priori knowledge of the incoming signal [1]-[4]. They fundamentally require the presence of *several* antenna elements and usually do not allow angles toward other targets than the interrogator.

In this paper we present a novel leaky-wave reflector consisting of a *single* antenna element and is capable of radiating the outgoing signal under *arbitrary angles* controlled by an LO frequency. The antenna element used here is the Composite-Right/Left-Handed (CRLH) leaky-wave antenna, presented in [5] and further explained in [6]. Thanks to the full-space scanning characteristic of this antenna, full-space operation can be achieved in our reflector, while conventional leaky-wave structures would restrict the range of angles to half-space only [7]-[8].

II. PRINCIPLE OF THE LEAKY-WAVE REFLECTOR

The measured angle versus frequency relation of the CRLH leaky-wave antenna of [5] is shown in Fig. 1. In this design, full-space scanning is achieved in the frequency range from *3.2 GHz* to *6.0 GHz*, with backward (*-90° ~ 0°)* radiation in the left-handed (LH) range (*3.2GHz ~3.9GHz*) and forward (*0° ~ 90°*) radiation in the right-handed (RH) range (*3.9GHz ~ 6.0 GHz*).

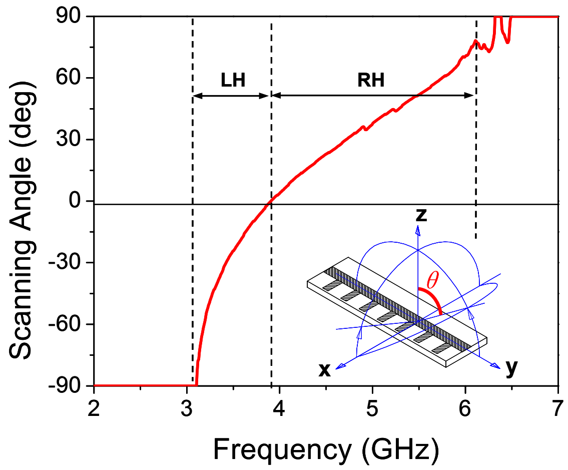

Figure 1 Measured angle versus frequency relation for the CRLH leaky-wave antenna of [5]. The backfire-to-endfire scanning range is 3.2 to 6.0 GHz.

The principle of the proposed reflector, using a CRLH leaky-wave antenna, is shown in Fig. 2. An incoming signal with angle θ_{in} at frequency f_{in} is converted by way of mixing to a signal of frequency f_{out} corresponding to a desired output angle θ_{out}. Any arbitrary output angle can be obtained by varying the output frequency according to the specification of Fig. 1.

A circulator is used to separate and isolate the incoming and outgoing signals. Two identical band-pass filters with pass-band covering the full frequency range of the antenna (*3.2-6.0 GHz*) are used to suppress undesired incoming signal (f_{in} filter) and harmonics / intermodulation products (f_{out} filter). For full-space operation (arbitrary incoming/outgoing angles), two mixers are required from the fact that the incoming and outgoing frequency ranges are identical, in order to avoid spurious beams to be created by the incoming signal (e.g. If $f_{in} = 3.9GHz$, corresponding to $\theta_{in} = 0^\circ$, and an output angle of $\theta_{out} = +30^\circ$ is desired, requiring $f_{out} = 5.0GHz$, using a single mixer would induce a spurious output beam at $\theta = 0^\circ$ because of leakage of the incoming $3.9GHz$, which is not filtered out). The first mixer down-converts the incoming signal to an intermediate signal f_m, which is amplified by an IF amplifier to compensate for the conversion loss of the passive mixer used, and the second mixer up-converts f_m back to the frequency range of the antenna. The LO,1 frequency must be chosen such that f_m be in the operating range of the IF amplifier in the whole range of the reflector, i.e. $f_{\min} - f_{LO,1} < f_m < f_{\max} - f_{LO,1}$.

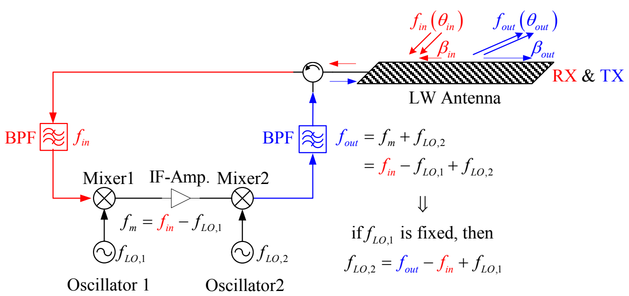

Figure 2 Schematic of the proposed leaky-wave reflector. For a given fixed $f_{LO,1}$, $f_{LO,2}$ is adjusted to provide the desired output angle according to the angle-frequency lookup graph of Fig. 1.

If the LO,1 frequency is fixed, then the LO,2 frequency is given by

$$f_{LO,2} = f_{out} - f_{in} + f_{LO,1} \quad (1)$$

as shown in Fig. 2. The LO,1 frequency must be chosen so that both f_m and $f_{LO,2}$ be positive, i.e. $f_{\max} - f_{\min} < f_{LO,1} < f_{\min}$. Different incoming/outgoing angles cases are illustrated in Tab. 1.

In the table 1, several cases are shown at $f_{LO,1}$ *=3GHz*, which corresponds with the requirement for LO,1 frequency. Cases 1 and 2 will be demonstrated experimentally in the next section, and cases 3 and 4 show that LO,2 range extends from *0.2* to *5.8GHz*.

CASE	Incoming frequency (f_{in})	Outgoing frequency (f_{out})	LO2 frequency ($f_{LO,2}$) from (1)
1	3.9 GHz	3.3 GHz	2.4 GHz
2	3.9 GHz	4.3 GHz	3.4 GHz
3	3.2 GHz (*fmin*)	6.0 GHz (*fmax*)	5.8 GHz
4	6.0 GHz (*fmax*)	3.2 GHz (*fmin*)	0.2 GHz

Table 1 Examples if LO2 frequencies required at the fixed $f_{LO,1}$*=3GHz* for different (f_{in},f_{out}) pairs.

III. Measurement Results

The measured bistatic RCS of the reflector is shown in Fig. 3 for cases 1 and 2 of Tab. 1. Two horn antennas were used for transmitting and receiving in the far-field of the DUT (~1.2m). The transmitting antenna was placed at *0°* and excited at *3.9GHz* for maximum DUT sensitivity at this angle according to Fig. 1. An LO,1 frequency of *3.9GHz* was chosen in the appropriate range prescribed in the previous section $6.0 - 3.2 = 2.8GHz < f_{LO,1} < 3.2GHz$.

The outgoing angles were arbitrarily chosen to be *-45°* and *+15°*, corresponding to the output frequencies *3.3 GHz* (LH range) and *4.3GHz* (RH range), respectively. It can be seen that the measured reflected angles agree well with predictions from the antenna characteristics of Fig. 1, despite the fact that this measurement was not performed in an anechoic chamber where it would have been cleaner.

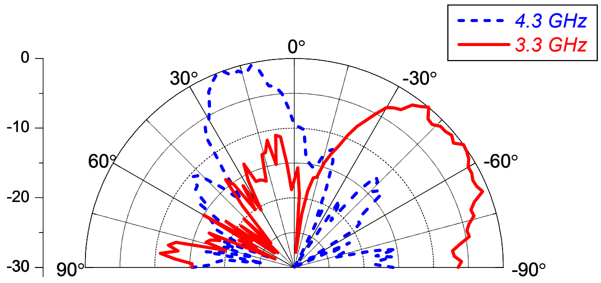

Figure 3 Measured normalized bistatic RCS at f_{in} = *3.9 GHz* ($\theta_{in} = 0$) for cases 1 and 2 in Tab. 1.

VI. CONCLUSION

A novel leaky-wave reflector using heterodyne mixing has been proposed and demonstrated experimentally. This reflector uses a unique antenna element and is capable of reflecting an incoming signal to any arbitrary angle by controlling an LO frequency in real time. It may be fully integrated and refined for several commercial and military applications.

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REFERENCES

1) L. C. Van Atta " Electromagnetic Reflector", U.S. Patent no. 2 908 002, October 6, 1959
2) C.Y. Pon, "Retrodirective Array Using the Heterodyne Technique", *IEEE Trans. Antennas Propagation*, Vol. AP-12, pp.176-180, March 1964
3) Y. Chang, H. R. Fetterman, I. L. Newberg and S.K. Panaretos, "Microwave Phase Conjugation Using Antenna Arrays", *IEEE Trans. Microwave Trans. Theory Tech.*, vol. 46, no. 11, pp 1910-1919, November 1998.
4) R.Y. Miyamoto, Y. Qian and T.Itoh, "An Active Integrated Retrodirective Transponder for Remote Information Retrieval-on-Demand", *IEEE Trans. Micr. Trans. Theory Tech.*, vol.49, no.9, pp.1910-1919, September 2001.
5) L. Lei, C. Caloz and T. Itoh, "Dominant mode leaky-wave antenna with backfire-to-endfire scanning capability", *Electron. Lett.*, vol. 38, no.23, pp. 1414-1416, November 2002.
6) C. Caloz, and T. Itoh, "Application of the Transmission Line Theory of Left-Handed (LH) Materials to the Realization of a Microstrip LH Transmission Line," *IEEE-APS Int'l Symp.*, vol. 1, pp. 412-415, San Antonio, TX, June 2002.
7) W. Menzel, "A New Traveling-Wave Antenna in Microstrip", *Arch. Elektron. Ubertragungstechnik*, vol. 33, no. 4, pp. 137-140, April 1979.
8) A. A. Oliner, "Leakage from Higher Modes on Microstrip Line with Application to Antennas", *Radio Science.*, vol. 22, no. 22, pp. 907-912, November 1986.