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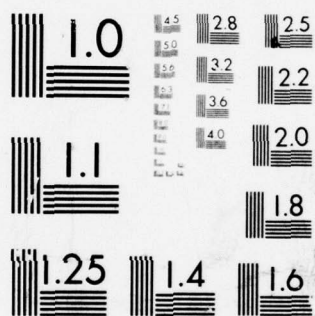
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SPECTRA AND WAVEFORMS OF BOTTOM REFLECTED PULSES

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Edward S. Eby

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ABSTRACT

A mathematical model considering reflection as a reradiation phenomenon has been constructed. The model allows computation of the spectrum and waveform of a reflected pulse in terms of the incident plane wave pulse or its spectrum, the reradiation characteristics of the reflector, the incident direction and the reradiation direction. Bottom reflection of sonic pulses in an isovelocity medium has been considered in terms of this model and temporal and spectral distortions have been calculated. The theory of Cron and Nuttall (J. Acoust. Soc. Am., 37, 486-492(1965)) is shown to be a special case of the present theory.

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1. This Memorandum consists of the abstract, test and slides of a paper read to the Seventy-first Meeting of the Acoustical Society of America in Boston, Massachusetts, on 2 June 1966.
2. This abstract has been previously published in The Program of the Seventy-first Meeting of the Acoustical Society of America, Boston, Massachusetts, 1-4 June 1966.

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SPECTRA AND WAVEFORMS OF BOTTOM REFLECTED PULSES

E. S. EBY

INTRODUCTION

IN THIS PAPER,
SOME RESULTS DERIVED FROM A MATHEMATICAL MODEL
CONSIDERING BOTTOM REFLECTION AS A RERADIATION PHENOMENON
ARE PRESENTED.

THE PULSES BEING REFLECTED
ARE TRANSMITTED FROM A DIRECTIONAL SOURCE
AND RERADIATED FROM THE BOTTOM.

THEORETICAL RESULTS WILL BE DISCUSSED FIRST.

IT WILL BE SHOWN
THAT FOR A UNIFORMLY RERADIATING BOTTOM,
ONLY SPECULAR REFLECTION
AND SNELL'S LAW REFRACTION OCCUR.
HOWEVER, FOR NONUNIFORM RERADIATION,
ENERGY IS RERADIATED IN OTHER DIRECTIONS AS WELL.

THIS THEORY IS THEN APPLIED
TO A TWO SHIP SITUATION
WHERE THE SOURCE SHIP HAS A DIRECTIONAL TRANSMITTER.

IT WILL BE SHOWN
THAT MOTION OF THE SOURCE SHIP
CAUSES PERTURBATIONS OF THE RECEIVED SPECTRUM
AS WELL AS PULSE SHAPE DEGRADATION
AND TIME SMEARING.

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SLIDE 1

IN THIS SLIDE, THE BASIC SITUATION IS SHOWN.

THE VECTORS Λ , m , n REPRESENT THE NORMALS

TO THE INCIDENT PLANE WAVES,

THE BOTTOM,

AND THE RERADIATED PLANE WAVES,

RESPECTIVELY.

THE PLANE OF THE BOTTOM

IS ASSUMED TO BE THE PLANE $x_3 = 0$

FOR CONVENIENCE IN CALCULATION.

IT HAS ALSO BEEN ASSUMED

THAT THE PULSE TRANSMITTED BY A DIRECTIONAL SOURCE

LOCATED AT THE UPPER LEFT,

OFF THE SLIDE,

CAN BE SEPARATED INTO TWO PARTS:

THE TRANSMITTED WAVEFORM,

AND THE PROJECTION OF THE BEAM PATTERN OF THE SOURCE

ONTO THE BOTTOM WHICH IS CALLED THE RERADIATION FUNCTION.

THE RERADIATION FUNCTION

IS ASSUMED TO BE NORMALIZED,

AGAIN FOR CALCULATIONAL CONVENIENCE.

SINCE THE BOTTOM IS THE PLANE $x_3 = 0$

THE RERADIATION FUNCTION IS ACTUALLY A FUNCTION

ONLY OF x_1 AND x_2 .

THE SOUND SPEED IN THE UPPER MEDIUM IS c .

THE PLANE WAVES RERADIATED IN THE DIRECTION N
TRAVEL WITH VELOCITY v .
IF N IS DIRECTED INTO THE UPPER MEDIUM
THEN v IS EQUAL TO c ,
BUT IF DIRECTED INTO THE LOWER MEDIUM,
 v WILL DIFFER FROM c .

SLIDE 2

IF THE TRANSMITTED WAVEFORM IS $f(t)$
AND THE RERADIATION FUNCTION IS DENOTED BY $w(x)$,
THEN THE AMPLITUDE OF A PARTICULAR RERADIATED PLANE WAVE
IS OBTAINED BY SUMMING THE CONTRIBUTIONS
FROM THE PULSE INCIDENT ON THE BOTTOM
TO A PLANE TRAVELING WITH VELOCITY v IN DIRECTION N
WEIGHTED BY THE RERADIATION FUNCTION.
THIS AMPLITUDE IS EXPRESSED BY $g(t, P)$ AS SHOWN.
THE VECTOR P IS INTRODUCED TO SIMPLIFY THE NOTATION
AND REPRESENTS THE COMBINED EFFECTS OF THE INCIDENT DIRECTION,
THE RERADIATED DIRECTION AND THE CORRESPONDING VELOCITIES.
THEREFORE WE SEE THAT THE RERADIATED WAVEFORM CAN BE EXPRESSED
AS A CONVOLUTION OF THE INCIDENT PULSE WITH THE RERADIATION FUNCTION.

WE LET $F(\omega)$ AND $G(\omega, P)$ BE THE STANDARD FOURIER TRANSFORMS
OF THE INCIDENT WAVEFORM,

AND THE RERADIATED WAVEFORM.

WE DEFINE THE TRANSFER FUNCTION OF THE BOTTOM
TO BE THE "FOURIER" TRANSFORM, CAP $W(\omega, P)$,
OF THE RERADIATION FUNCTION, $w(x)$, AS SHOWN HERE.
WE ALSO DEFINE THE IMPULSE RESPONSE OF THE BOTTOM $w(t, P)$
TO BE THE TIME FUNCTION OBTAINED
FROM A STANDARD FOURIER INVERSION
APPLIED TO THE FREQUENCY FUNCTION CAP $W(\omega, P)$.

NOTE THAT THE QUANTITIES ON THE LEFT HAND SIDES OF THESE EQUATIONS
ARE DEFINED BY THE EXPRESSIONS ON THE RIGHT-HAND SIDES.

USING THESE DEFINITIONS
OF TRANSFER FUNCTION AND IMPULSE RESPONSE
IT CAN BE SHOWN
THAT THE USUAL THEOREMS FROM COMMUNICATION THEORY SHOWN HERE
HOLD IN THIS MODEL.
THESE THEOREMS SHOW
WE CAN STUDY THE EFFECT OF A DIRECTIONAL SOURCE
BY STUDYING THE PROPERTIES
OF THE TRANSFER FUNCTION AND IMPULSE RESPONSE.

IF, IN ADDITION TO THE BEAM PATTERN EFFECTS WE HAVE DISCUSSED,
THE BOTTOM INTRODUCES
THE PHASE SHIFT AND ATTENUATION TERM
DISCUSSED IN THE PRECEEDING PAPER,
THE TRANSFER FUNCTION MUST BE MULTIPLIED
BY THE TERM $e^{j\epsilon \operatorname{sgn}(\omega) - b(\omega)}$
AND THE IMPULSE RESPONSE
MUST BE CONVOLVED WITH THE CORRESPONDING TIME FUNCTION.

SLIDE 3

IF THE PROJECTION OF THE BEAM PATTERN ONTO THE BOTTOM

IS THIS ELLIPTIC PARABOLOID,

THEN THE TRANSFER FUNCTION

IS $8 \frac{J_2(k\omega)}{(k\omega)^2}$.

THE PARAMETER k HERE

EXPRESSES THE EFFECT

OF THE BOTTOM AREA ILLUMINATED

AS WELL AS THE DIRECTIONS AND VELOCITIES.

THE LIMIT AS a_1 AND a_2 GO TO INFINITY,

IS THE TRANSFER FUNCTION

FOR A UNIFORMLY RERADIATING BOTTOM.

THE LIMIT IS UNITY

IF THE FIRST TWO COMPONENTS

OF THE VECTOR P ARE ZERO

AND ZERO OTHERWISE.

IF WE NOW GO BACK

TO THE DEFINITION OF THE VECTOR P

AND SEE WHAT THE CONDITIONS $p_1 = p_2 = 0$ IMPLY,

WE FIND THAT THESE CONDITIONS

ARE EQUIVALENT TO SPECULAR REFLECTION

OR SNELL'S LAW REFRACTION,

DEPENDING ONLY ON WHETHER THE RERADIATION DIRECTION

IS UPWARD OR DOWNWARD.

THIS IS THE CASE
FOR WHICH PHASE SHIFT
AND ATTENUATION EFFECTS OF THE BOTTOM
HAVE BEEN CONSIDERED BY CRON AND NUTTALL.

THE ELLIPTIC PARABOLOID SHOWN HERE
IS THE RERADIATION FUNCTION ASSUMED
FOR THE SITUATION SHOWN IN THE NEXT SLIDE.

SLIDE 4

THE SOURCE AND RECEIVING SHIPS ARE POSITIONED
SO THE TRANSMITTED PULSE WILL ARRIVE BY SPECULAR REFLECTION

FOR A 30° DEPRESSION ANGLE.

THE DIRECTIONAL SOURCE
HAS A 6° HORIZONTAL BEAM WIDTH
AND A 10° VERTICAL BEAM WIDTH.

THE RECEIVING TRANSDUCER IS OMNIDIRECTIONAL
TO AVOID EFFECTS OF RECEIVING SHIP MOTION.

WE NOW WILL SHOW THE EFFECT
OF A GENTLE ROLL,
ONLY 5°
ON A 200 MILLISECOND RECTANGULAR PULSE ENVELOPE.

A 0° ROLL GIVES SPECULAR REFLECTION
AND IS SHOWN IN WHITE.

THE BEAM FOR a- 5° ROLL
IS SHOWN IN BLUE
AND FOR $+5^{\circ}$, IN RED.

THIS COLOR CODING IS USED
IN THE SLIDES WHICH FOLLOW.

THE ROLLING MOTION OF THE SOURCE
IS ASSUMED TO BE SUFFICIENTLY SLOW

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THAT THESE THREE SITUATIONS
CAN BE CONSIDERED STATIC
AND DYNAMIC EFFECTS ARE IGNORED.

SLIDE 5

THE UPPER CURVES ARE THE TRANSFER FUNCTIONS
FOR THE ROLL ANGLES OF 0° AND $\pm 5^\circ$
AND ARE SEEN TO CHANGE RATHER DRASTICALLY.

HOWEVER, FROM THE BOTTOM FIGURE
WE SEE THAT THE SPECTRA OF THE RECEIVED WAVEFORMS
ARE NOT APPRECIABLY CHANGED
EXCEPT THAT THE HIGHER FREQUENCY COMPONENTS
ARE EFFECTIVELY MISSING
FROM THE TRANSMITTED SPECTRUM.
OF COURSE, THE ZERO ROLL CURVE
IS EXACTLY THE TRANSMITTED SPECTRUM.

SLIDE 6

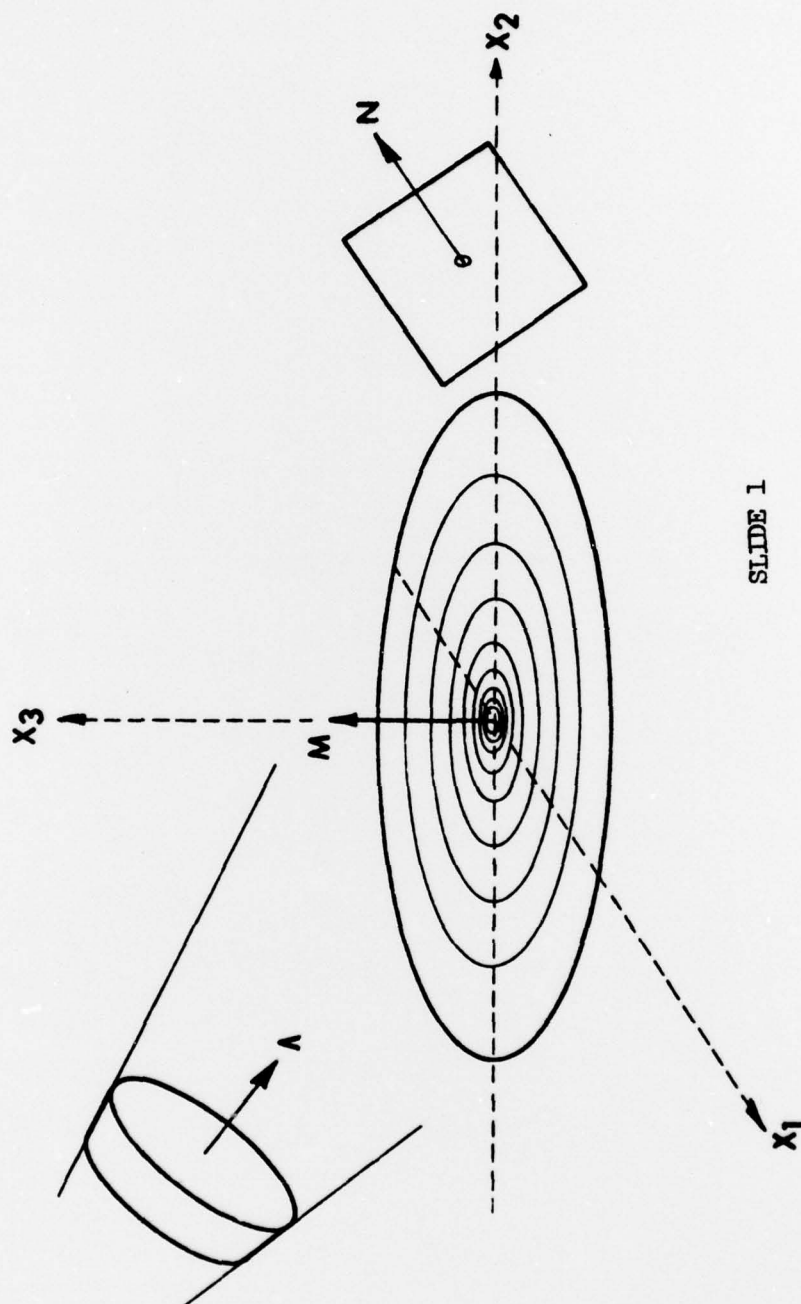
THIS FIGURE SHOWS THE CHANGE IN WAVESHAPE
OF THE RECEIVED SIGNALS
AS A FUNCTION OF ROLL ANGLE.
THE PULSE SHAPES FOR NON-SPECULAR RERADIATION
ARE DEGRADED AND SHOW A LARGE TIME SMEAR.
THE PULSES RECEIVED FOR -5 AND $+5^{\circ}$ ROLLS
HAVE DURATIONS OF 341
AND 574 MILLISECONDS
COMPARED TO THE TRANSMITTED PULSE DURATION
OF 200 MILLISECONDS.

THIS CORRESPONDS
TO AN UNATTENUATED -ZERO DEGREE PHASE SHIFT
IN TERMS OF THE PRECEEDING PAPER.

SLIDE 7

THE LAST SLIDE
SHOWS THE ADDITIONAL PULSE SHAPE DEGRADATION
FOR AN UNATTENUATED - 60° PHASE SHIFT
ASSUMING THE RESULTS OF CRON AND NUTTALL.

IN SUMMARY, WE SEE THAT
THIS RERADIATION POINT OF VIEW
ALLOWS THE COMPUTATION OF SPECTRA AND WAVEFORMS
RECEIVED FROM A DIRECTIONAL SOURCE
WHICH SHOWS THE TIME SMEAR AND PULSE SHAPE DEGRADATION
CHARACTERIZING PULSES RECEIVED IN EXPERIMENTAL SITUATIONS.



SLIDE 1

RERADIATED WAVEFORM:

$$g(t, P) = \int_B f\left(t - \frac{X \cdot P}{c}\right) w(X) dx$$

TRANSFER FUNCTION:

$$W(\omega, P) = \int_B w(X) e^{-j\frac{\omega}{c} X \cdot P} dx$$

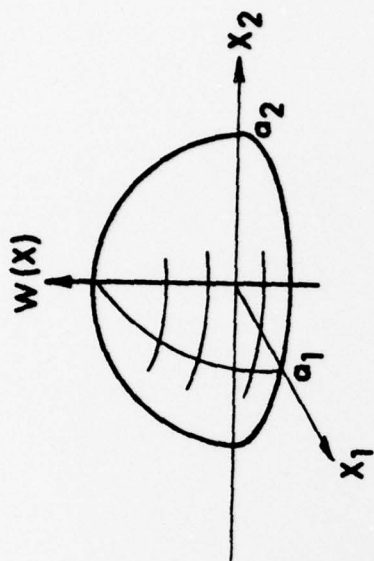
IMPULSE RESPONSE:

$$w(t, P) = \frac{1}{2\pi} \int_{-\infty}^{\infty} W(\omega, P) e^{+j\omega t} d\omega$$

THEOREMS:

I. $G(\omega, P) = F(\omega) W(\omega, P)$

II. $g(t, P) = \int_{-\infty}^{\infty} f(\tau) w(t - \tau, P) d\tau$

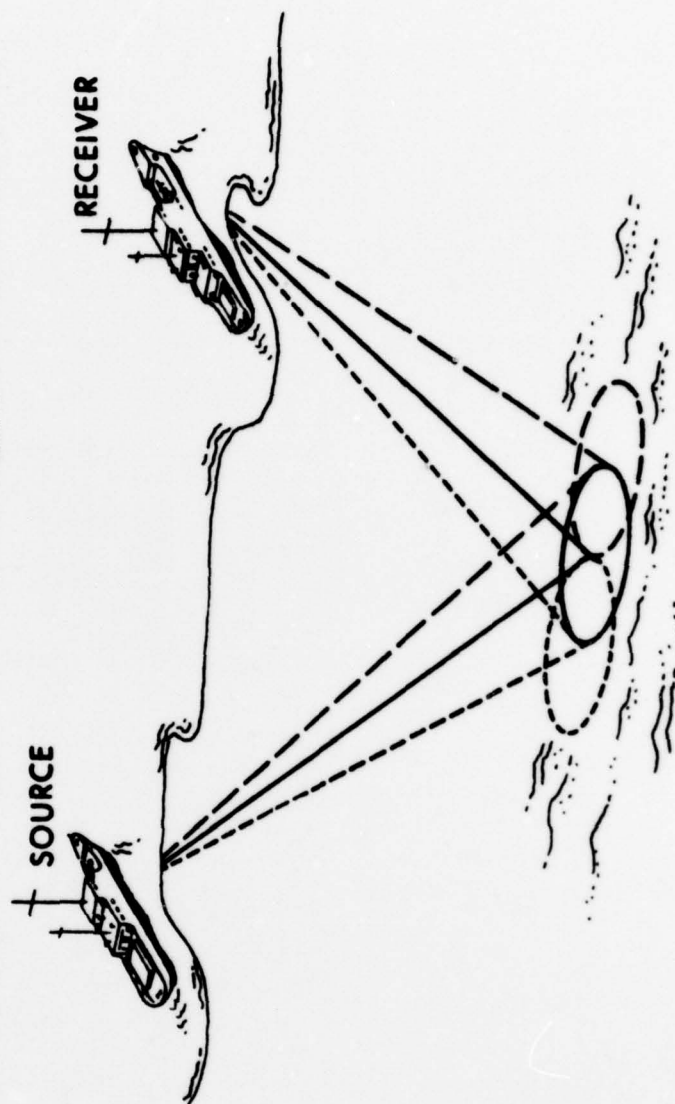


TRANSFER FUNCTION:

$$W(\omega, P) = 8 \frac{J_2(k\omega)}{(k\omega)^2}$$

UNIFORMLY RERADIATING BOTTOM:

$$\lim_{\substack{a_1 \rightarrow \infty \\ a_2 \rightarrow \infty}} W(\omega, P) = \begin{cases} 1, & P_1 = P_2 = 0 \\ 0, & \text{OTHERWISE} \end{cases}$$

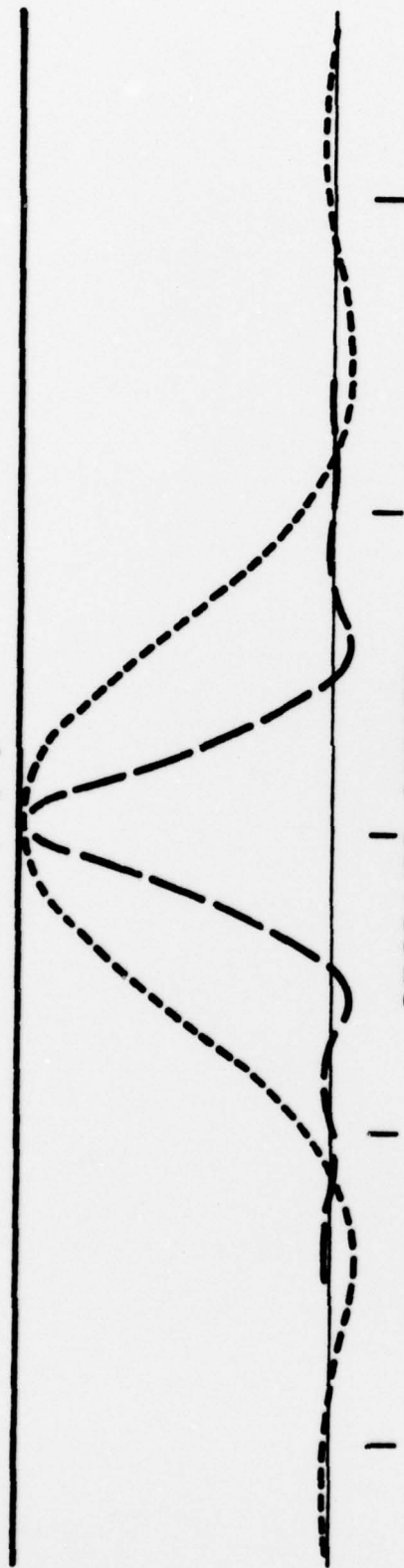


SLIDE 4

ROLL ANGLE
 - - - - - -5°
 ———— 0°
 - - - - - $+5^\circ$

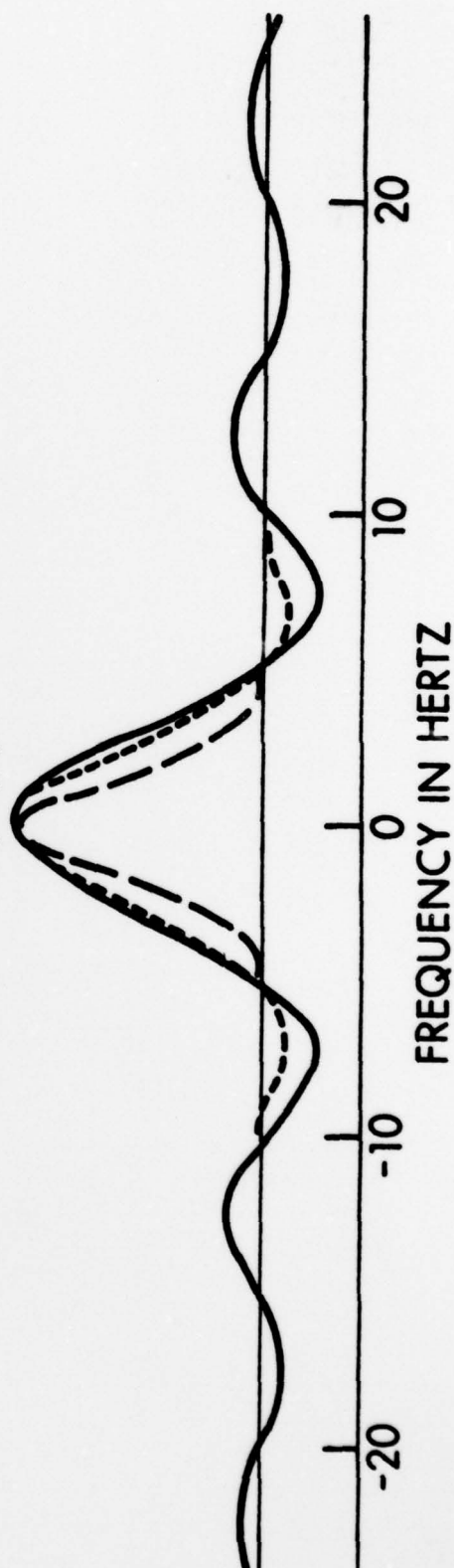
TRANSFER FUNCTIONS

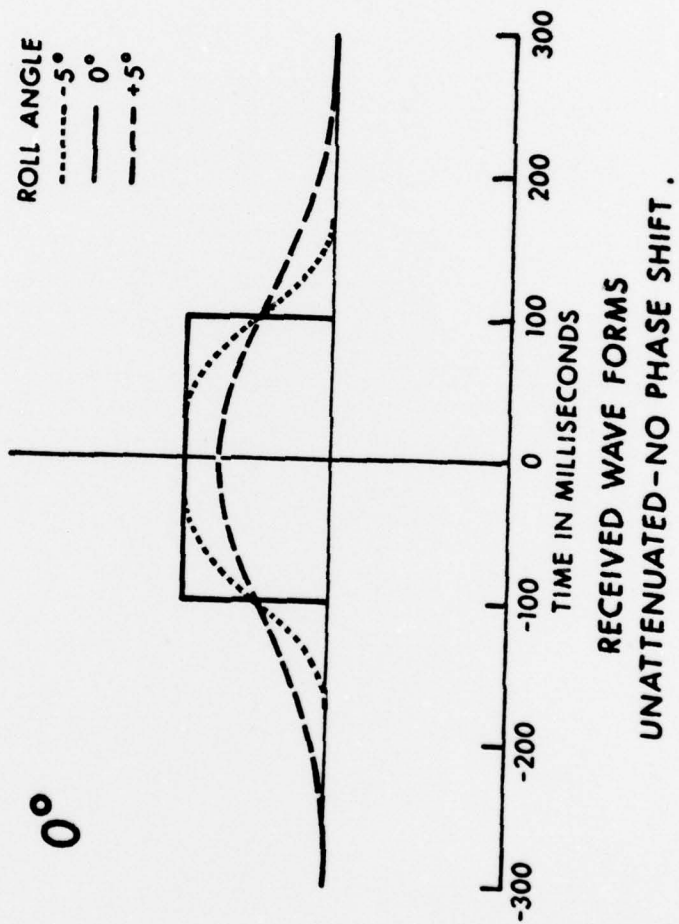
$W(\omega, P)$



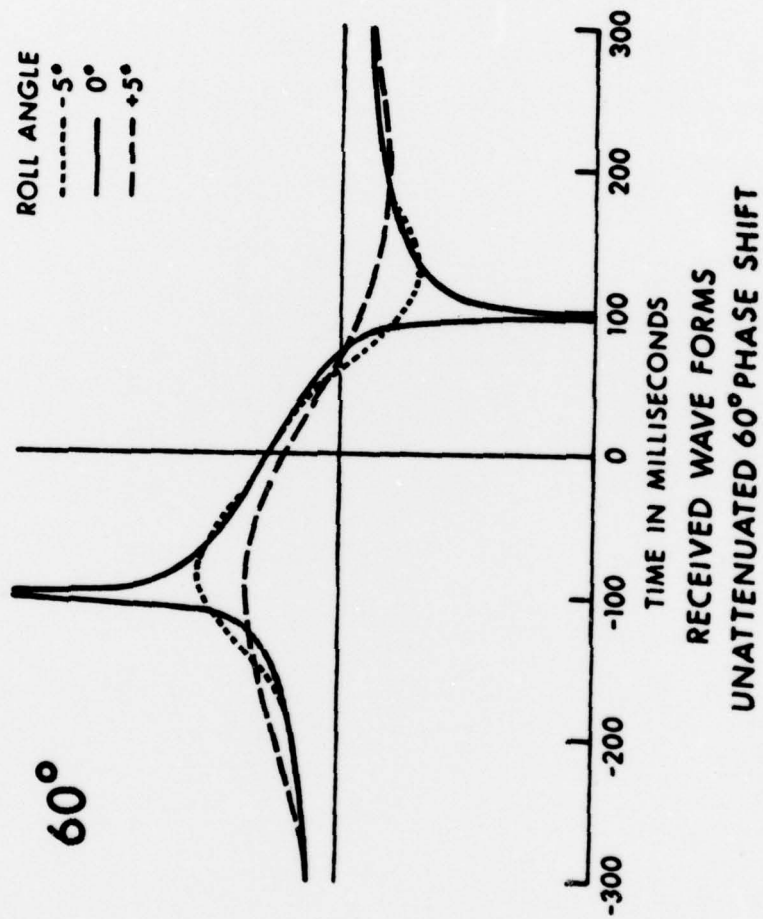
RECEIVED SPECTRA

$G(\omega, P)$





SLIDE 6



SLIDE 7