DEMODULATION BY A NON-LINEARITY

There has been interest here in "hypersound" as a beamed source of modulated untrasound that carries and distributes ordinary audio. The basic concepts are not new: Beaming of sound (audible or ultra) is not new. Modulation is not new, nor is demodulation. [In fact, demodulation by a non-linear process is not new – that's how even the original "crystal-set" radios worked.] What is new is a practical realization that seems to work but initially seemed unlikely, and possible suggestions that it could be extended to beams of microwaves.

Fig. 1 shows a modulation example – ordinary Amplitude Modulation (AM) as was first used in radio.

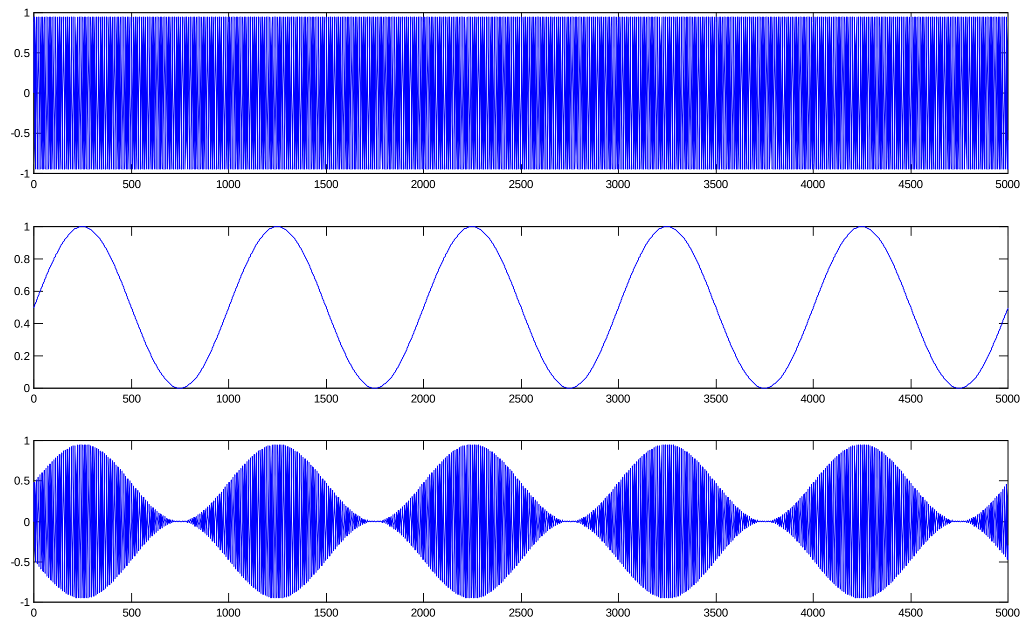

Fig. 1 Ordinary AM

Here the top panel is the carrier, a frequency of 1/10. It is a sinusoid but is impossible to see in the clutter of so many cycles. It corresponds to the Radio Frequency (RF) carrier, like 550 kHz to 1,600 kHz for AM radio. The middle panel is the "program" or modulating signal, which would be Audio Frequency (AF) in AM radio. Note well that while it is AF, it is NOT audio (sound), but rather an electrical signal (usually a voltage) that is an analog of the sound (typically obtained by a microphone). Here the program signal varies from 0 to +1, so when we multiply the top two panels (giving the bottom panel), the modulation is 100%. Here is the Matlab code for this plot:

```
t=0:4999;
xm=(1+sin(2*pi*t/1000))/2;
xc=sin(2*pi*t/10);
x=xc.*xm;
figure(1)
subplot(311)
plot(t,xc)        %Top panel, Fig. 1
subplot(312)
plot(t,xm)        %Middle panel, Fig. 1
subplot(313)
plot(t,x)         %Bottom panel, Fig. 1
figure(1)
```

In AM radio, it is the modulated carrier that is intercepted, and we desire to recover the electrical signal (de-modulate) and convert that back to sound with a earphone of loudspeaker. The top panel of Fig. 2 is just the absolute value of the bottom panel of Fig. 1 (thus the rectified modulated carrier) while the lower panel in Fig. 2 is a low-passed version of the top. The filter is just a simple length-10 moving average for illustration. This does a good job of recovering the program signal. In the crystal-set radio, the rectifier was a galena crystal (a diode) and the low-pass was the mechanical inertia of the transducer (the diaphragm of the earphone) and/or the frequency limits of the ear (the earphone performing a dual function of converting electrical to audio and of low-pass filtering).

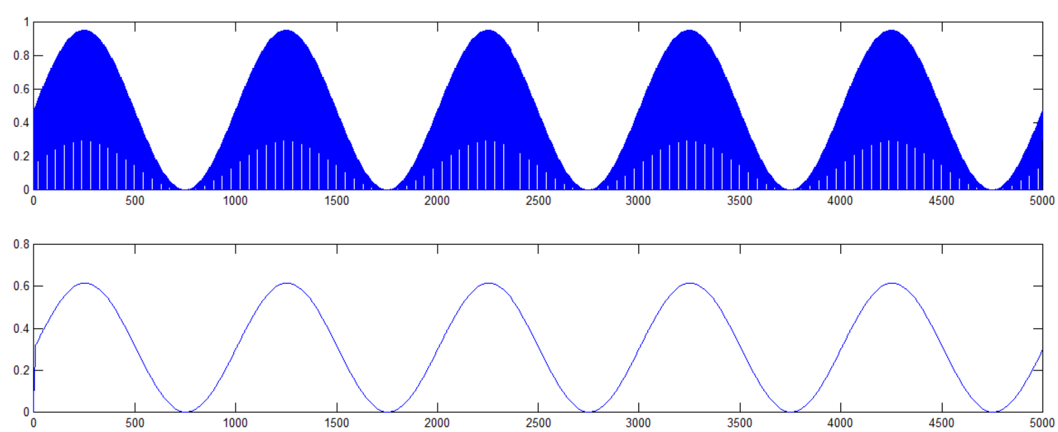

Fig. 2 De-Modulation with Rectifier/Low-Pass

The Matlab code for Fig. 2 is here:

```
%
xd=abs(x);
xdlp=filter((1/10)*ones(1,10), 1, xd);      % length 10 moving average
figure(2)
subplot(311)
plot(t,xm)
subplot(312)
plot(t,xd )           % Top panel of Fig. 2
subplot(313)
plot(t,xdlp)          % Bottom panel of Fig. 2
figure(2)
```

Finally we want to illustrate the de-modulation possible with a non-linearity. [Wait a minute – we just did. The absolute value is a sever non-linearity.] It is common practice to investigate a nonlinearity startling with a power series. Here we will use x replaced by $x + 0.1x^2$. This is shown in the top panel of Fig. 3. Note the slight upward displacement of this relative to the modulated waveform (bottom Fig. 1) but far less than the absolute value (top Fig. 2). It is probably clear enough that if we only used x^2, we would have a purely positive result. The low-pass filtered (same filter as above) version of the non-linearity is shown in the bottom panel of Fig. 3. [Here, and above, the low-pass filter amplitude depends on several factors not central here.] The bottom panel is noisy-looking, but does suggest that credible de-modulation has occurred.

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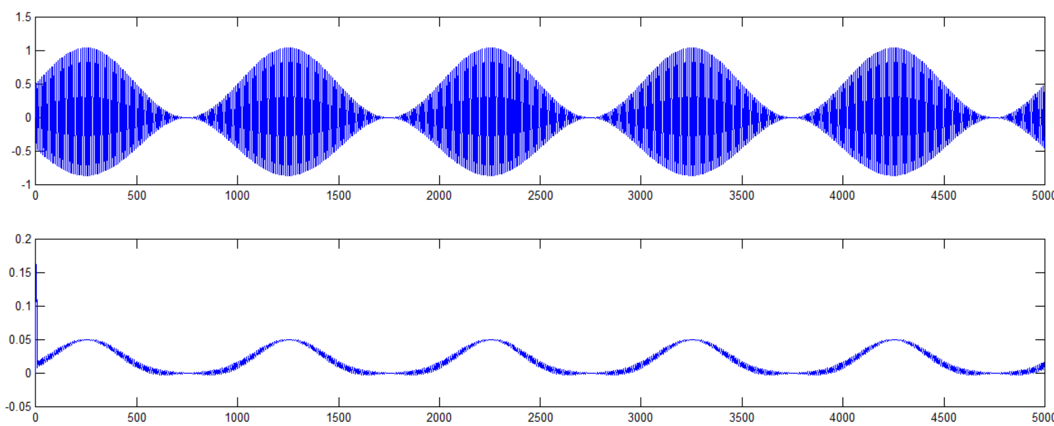

Fig. 3 De-Modulation with Non-Lineariaty ($x \rightarrow x + 0.1x^2$)

The code for Fig. 3 is here:

```
%
xnl = x + 0.1*x.^2;
xnllp=filter((1/10)*ones(1,10), 1, xnl);
figure(3)
subplot(311)
plot(t,xm)
subplot(312)
plot(t,xnl )                  % Top panel of Fig. 3
subplot(313)
plot(t,xnllp)                 % Bottom panel of Fig. 3
figure(3)
```

If we interpret the results of Fig. 3 as being an ultra-sonic carrier and an audio program signal, we can enquire about the nature of the processes. The modulated (AM) signal would be obtained by using the audio signal (electrical analog from a microphone, etc,) to control the amplitude of an ultra-sound oscillator/transducer which then enters the air as ultrasound. We would expect this to be inaudible. We need a demodulator – in this case, the non-linearity. That is, the higher pressure of the assumed very loud ultra-sound produces a non-linear response. The corresponding low-pass filter is nothing more than the fact that the ear hears only the lower component caused by the non-linearity.

The “beaming” (beam-forming) is all in the transducer array for the ultra-sound. The demodulation is due to the high loudness of the ultrasound (non-linearity – requiring a lot of energy). No “transducer” is required, since the lower audio is there for the ear to interpret directly. High marks for those who actually made this work. Note as well that the difficulties were in engineering – not particularly with theory.

What About Microwaves?

Can an audio signal modulate a microwave beam? Of course: for decades (before fiber) this was how long-distance telephone was implemented once the limitations of land-lines needed to be overcome. Can microwaves be amplified into a non-linear region. Certainly: the circuitry can be driven to “clipping”. BUT- you can’t drive the MEDIUM (the metaphorical “aether”) to non-linearity the way you can air. And the medium is not going to be its own transducer. You need demodulation circuitry, electrical signals to sound. And it needs to be precise technology on the receiving end, and intentional.

Could microwaves be transmitted, even beamed by a satellite in space? Of course. Likely much of your communications comes from this. It's low-energy stuff however. Can vast amounts of energy (intense beams) be beamed to thousands of individuals on the surface? Of courses not. How would you get enough energy (in space) to drive your disruptor? It's hard enough to get the TV pictures down even with very sensitive receivers and lots of signal processing on the ground.

Hypersound does not translate to microwaves.