Efficient Signal Generation for High-Power Dual-Spacecraft Command

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This article describes a frequency multiplex scheme that is potentially 1.6 times as efficient (+2 dB) as the one currently under consideration, without exceeding the peak voltage rating of the Klystron.

I. Introduction

The possibility of transmitting to two spacecraft simultaneously from a single antenna has arisen in the forthcoming Viking 1975 Project that will place two orbiters and two landers at Mars. Two of the spacecraft will be simultaneously controlled from the ground. Therefore, there is a requirement to send two command signals (on two separate carrier frequencies) from a single transmitter, comprised of a single Klystron power amplifier and antenna. In this article, we describe a frequency multiplex scheme that is potentially 1.6 times as efficient (+2 dB) as the one currently under consideration, without exceeding the peak voltage rating of the Klystron.

II. Discussion and Description

We are concerned about amplifying two phase-modulated carrier signals

$$S_1(t) = \sin(\omega_1 t + \theta_1)$$

$$S_2(t) = \sin(\omega_2 t + \theta_2)$$

without exceeding the peak voltage limit $\sqrt{2P_{max}}$ on the Klystron, where P_{max} is the maximum rms power rating.

If we blindly add the two signals, the result is

$$\sqrt{2P}S_1(t) + \sqrt{2P}S_2(t) = 2\sqrt{2P}\sin(\omega_+ t + \theta_+)\cos(\omega_- t + \theta_-) \leq \sqrt{2P_{max}} \quad (1)$$

where

$$\omega_+ = \frac{1}{2}(\omega_1 + \omega_2); \qquad \theta_+ = \frac{1}{2}(\theta_1 + \theta_2)$$

$$\omega_- = \frac{1}{2}(\omega_2 - \omega_1); \qquad \theta_- = \frac{1}{2}(\theta_2 - \theta_1)$$

Obviously, from (1), the value of P is limited to

$$P \leq \frac{1}{4} P_{max}$$

and the total power output is at most 50% of the Klystron rating, since

$$2P \leq \frac{1}{2} P_{max}$$

The scheme proposed next can achieve an output efficiency of ~80%, and should be "easy" to implement.

The idea is to biphase-modulate $\sin(\omega_+ t + \theta_+)$ by the squarewave $\sqsubset\text{os}(\omega_- t + \theta_-) = \text{sgn}[\cos(\omega_- t + \theta_-)]$, amplify, and then filter to remove undesired frequencies, as shown in Fig. 1.

Note that ω_- is several orders of magnitude less than $\omega_+ = (1/2)(\omega_2 + \omega_1)$: $\omega_- \approx 1$ to 10 MHz, while $\omega_+ \approx 2$ GHz. Also observe that $(4/\pi)\cos(\omega_- t)$ is the fundamental of the unit amplitude squarewave $\sqsubset\text{os}(\omega_- t)$. With the above in mind, we next note that

$$z_0(t) = \sqrt{2P_{\max}} \sin(\omega_+ t + \theta_+) \sqsubset\text{os}(\omega_- t + \theta_-) \leqq \sqrt{2P_{\max}}$$

for all t. But

$$\sqsubset\text{os}(\omega_- t + \theta_-) = \frac{4}{\pi} \sum_{k=0}^{\infty} \frac{(-1)^K}{2K+1} \cos[(2K+1)(\omega_- t + \theta_-)]$$

Therefore,

$$z_0(t) = \frac{2}{\pi}\sqrt{2P_{\max}} \sin(\omega_1 t + \theta_1) + \frac{2}{\pi}\sqrt{2P_{\max}} \sin(\omega_2 t + \theta_2)$$

+ higher harmonics of ω_- on ω_+ that can be filtered. It is crucial to note that this filtering must take place after the signal has been amplified. For example, the nearest two sidebands to the desired signal are at $\omega_+ \pm 3\omega_-$, hence at $2\omega_2 - \omega_1$ and at $\omega_1 - 2\omega_2$, and are each about 9.5 dB down. Suitable bandpass filtering will attenuate them and their higher- and lower-frequency brethren to negligible proportions. Since the filtering is on the Klystron output, the filters must be capable of dissipating approximately 20% of $P_{\max}$ or about 80 kW for a 400-kW tube.

To summarize, the signal $\sqrt{2P_{\max}} \sin(\omega_+ t + \theta_+) [(\omega_- t + \theta_-)]$ satisfies the voltage rating of the amplifier, but contains many undesirable intermodulation products that can be filtered out with some effort. The resulting benefit is an increase in output power to

$$\left(\frac{2}{\pi}\right)^2 P_{\max} \sim 0.4 P_{\max}$$

for each signal, which is only 1 dB below the maximum 50% limit for each command link and ~2 dB better than the linear multiplex scheme previously mentioned.

Incidentally, time multiplexing of the two carriers with a switching frequency of the order of ω_- also produces intermodulation products of the same size and has none of the advantages of the present scheme.

III. Implementation

Filtering of the high- (as opposed to the low-) frequency harmonics of $\sqsubset\text{os}\,\omega t$ can be accomplished at low power levels in the exciter because absence of the higher harmonics places only a small ripple onto the squarewave, thus having a negligible effect on efficiency. Thus, referring to Fig. 1, starting with two signals at about 66 MHz which will be multiplied up to 2 GHz in the $\times 32$ multiplier, we have first the desired command signals at 66 MHz:

$$e_1 = \sin\left(\frac{\omega_1 t + \theta_1}{32}\right) + \cos\left(\frac{\omega_2 t + \theta_2}{32}\right)$$

Their hard limited version becomes

$$e_2 = \text{sgn}[e_1(t)]$$

and prefiltering yields

$$e_3 = \text{bandpass filtered } e_2(t)$$

bandwidth of, say, 5 MHz centered at 66 MHz, so that

$$e_3(t) = \sin\left(\frac{\omega_+ t + \theta_+}{32}\right) \sqsubset\text{os}\left(\frac{\omega_- t + \theta_-}{32}\right)$$

where $\sqsubset\text{os}(\omega t/32) = \sqsubset\text{os}(\omega t/32) -$ harmonics greater than 5 MHz. After frequency multiplication, the result is

$$e_4 = \sin(\omega_+ t + \theta_+) \sqsubset\text{os}(\omega_- t + \theta_-)$$

where $\sqsubset\text{os}(\omega_- t) = \sqsubset\text{os}(\omega_- t) -$ harmonics greater than 160 MHz. After amplification in the Klystron,

$$e_5 = \sqrt{2P_{\max}}\, e_4$$

Finally, high-power filtering yields

$$e_6 = e_5$$

filtered to remove all but ω_1 and ω_2.

IV. Conclusions

Further studies of the high-power filter required to demonstrate this efficient dual-carrier multiplex scheme are in progress, including the question as to whether such filtering is needed at all. This last point is based on the fact that the harmonics that can cause interference in the receiver, which is about 200 MHz removed, are eliminated before amplification, while the high-power harmonics radiated by the antenna can be blocked by the front end of the spacecraft receiver.

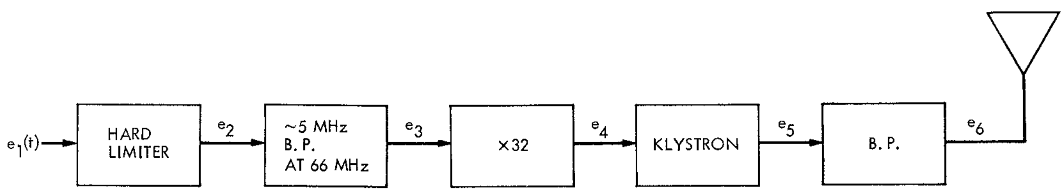

Fig. 1. Dual-carrier multiplex scheme