A NOVEL TECHNIQUE TO REALIZE SMSK CONVERSION AND MATCHED FILTERS AT MICROWAVE FREQUENCIES

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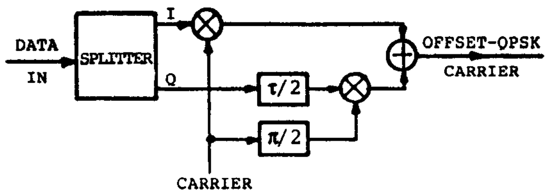
Abstract

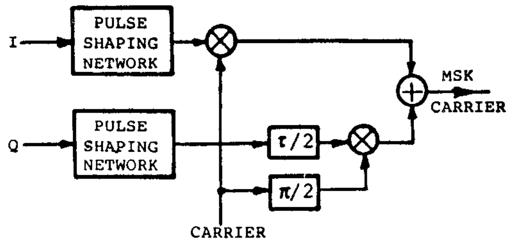
In modern, high-capacity satellite systems Serial Minimum-Shift Keying (SMSK) has been recently proposed as a valid alternative to PSK digital systems.
The well known low-sidelobe, constant-envelope properties of MSK, very attractive in Time Division Multiple Access (TDMA) environment (as they limit the Adjacent Channel Interference (ACI) and phase distortion) do in fact join with quite simple on-board hardware if Serial Demodulation is foreseen on-board the satellite.
SMSK modems are essentially constituted by Binary PSK (BPSK) modems and particular transmitting (Conversion) and receiving (Matched) Filters. These filters represent a crucial point in the design, as they perform the proper spectrum shaping which allows exploiting the MSK capabilities.
The paper presents a novel, easy technique to realise Conversion and Matched filters directly at microwave frequencies. This technique is satisfactorily applicable to medium/high bit rate SMSK systems.

1. INTRODUCTION

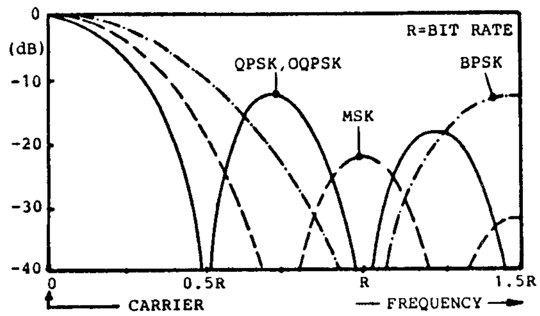
Minimum-Shift Keying (MSK) is one of the most popular Continuous Phase Modulation (CPM) digital techniques, which has the advantage of almost constant-envelope, resulting in a low degree of distortions in non-linear environments [1][2][3][4] .
It can be generated using a general Offset-QPSK modulator provided with a couple of pulse-forming networks to transform the full-length rectangular (modulating) pulses into half-length sinusoidal ones, as indicated in fig. 1(a) and (b). The spectrum of such pulses (and thus the modulated MSK spectrum) has considerably lower sidelobes, even if the mainlobe is larger (see fig. 1(c)).
This causes much less envelope fluctuation with respect to QPSK, and thus lower signal distortion caused by nonlinearities.
On the contrary, the BER characteristics of MSK are the same as QPSK.
MSK is also referred to as "Fast Frequency Shift Keying" (FFSK). In effect, it is precisely a two-tone frequency modulation with modulation index (separation between the tones, Δf, divided by the bit rate R) equal to 0.5. Therefore, a MSK signal can also be generated using the scheme shown in fig. 1(d) if a direct microwave generation is envisaged. The two voltages corresponding to the data stream are suitably set in order to keep the ratio $\Delta f/R$ at the VCO output equal to 0.5. The reference signals are derived by two crystalic-stability signals, injected into the VCO in order to lock its instantaneous frequency with the specified stability ("Injection locking" technique) [4] .



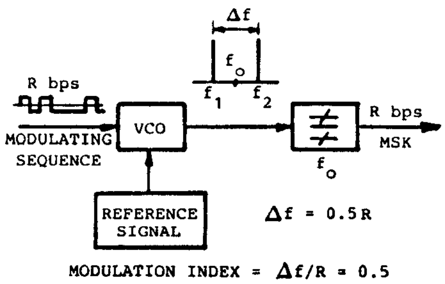
(a) Offset-QPSK(OQPSK) Modulator



(b) MSK Modulator



(c) Power Spectra of BPSK, QPSK, Offset--QPSK and MSK



(d) Direct RF generation of MSK as two-tone Frequency Shift Keying.

FIG. I. OFFSET-QPSK AND MSK.

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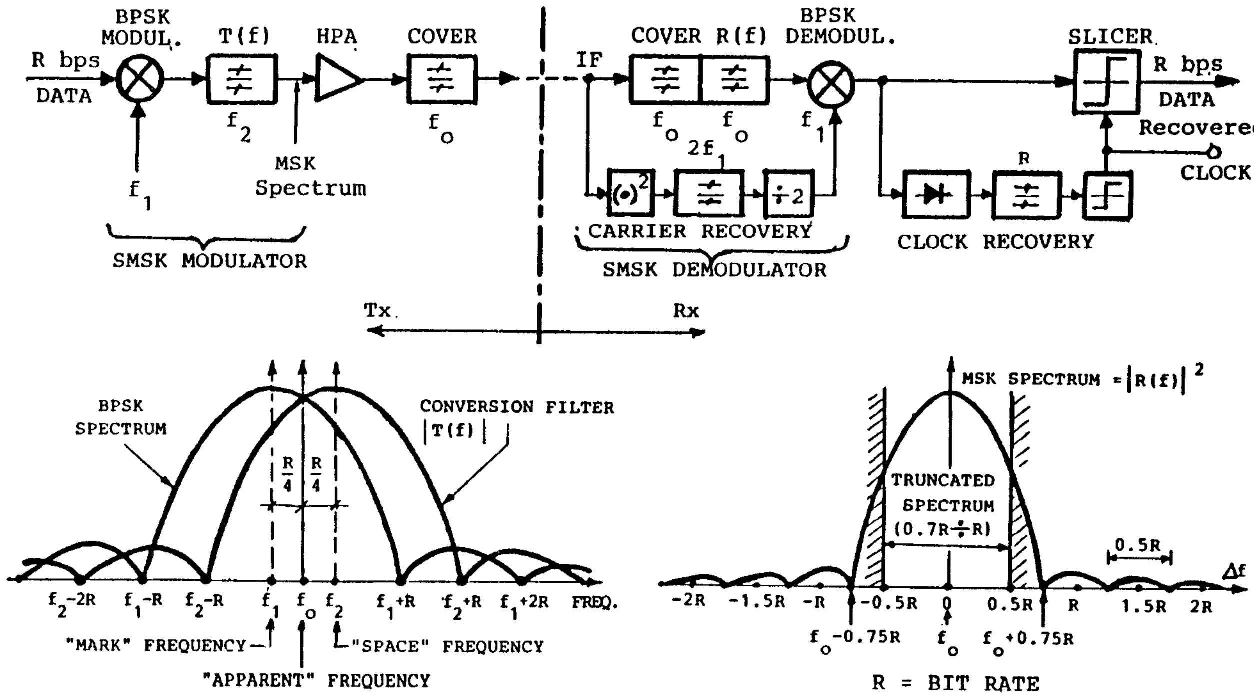

FIG. 2. SMSK TRANSMISSION SYSTEM.

The most advanced realisation of MSK modems utilizes a serial scheme (Serial-Minimum Shift Keying, SMSK), as indicated in fig. 2. Binary Phase Shift Keying (BPSK) modems -well proven technology - are present in this (coherent) scheme, together with suitable Conversion and Matched Filters, which represent a critical point in the design of SMSK systems, as they have to turn a BPSK modulation into a MSK one, and viceversa.
However, such a serial scheme tolerated a phase error ϕ in the recovered carrier much higher than in a (coherent) quadrature QPSK demodulator, the C/N degradation at a given BER value being proportional to ($1 - \sin\phi$) for quadrature demodulators and to ($\cos\phi$) for binary demodulators (SMSK). A requirement for 0.2 dB maximum degradation at BER $= 10^{-6}$, for instance, calls for $|\phi|$ less than about 3° using QPSK, and less than about 15° using SMSK [5][6].
Thus, SMSK is very promising if Time Division Multiple Access (TDMA) is employed, typical of modern, high-capacity satellite systems.
Due to the "burst" operation, the Carrier and Bit Timing recovery must be done very rapidly at the beginning of each burst in a short "preamble". It is quite hard to obtain a low phase noise in such a fast acquisition if on-board demodulation is envisaged (regenerative repeaters), thus a modulation technique insensitive enough to the phase error is very attractive.
Moreover, the carrier acquisition system can be composed by a times-2 multiplier (instead of times-4 in QPSK), enabling a halved microwave frequency to be handled within this system, thus simplifying the hardware on-board the satellite if RF or high IF demodulation is utilised.
The last advantage of SMSK (as binary modulation) is the possibility to use Differential Detection with a small C/N degradation (about 0.5 dB instead of 2.3 dB for a quaternary system). Thus, a further on-board demodulator hardware simplification can be attained, the carrier recovery circuit being constituted by a one-bit, temperature-stable delay line, the microwave realisation of which is not a problem now [7][8][9].
As far as SMSK filters are concerned, the theoretical frequency responses of Conversion - T(f) - and Matched - R(f) - filter have no bandlimitation, whilst in a practical system both transmitting and receiving filters must have finite bandwidth, in order to limit the channel spacing and the receiver noise as well.
Thus, a suitable MSK spectrum truncation is called for, resulting in a RF band of roughly 0.75 - to - 1.0R (see fig. 2).
In the following, a new technique, particularly interesting in medium/high bit rate applications is presented to easily implement Conversion and Matched filters.

2. THEORETICAL BACKGROUND

Fig. 3 shows a possible easy way for implementing a microwave selective network, constituted by a resistor in parallel to a convenient length of short-circuit transmission line.

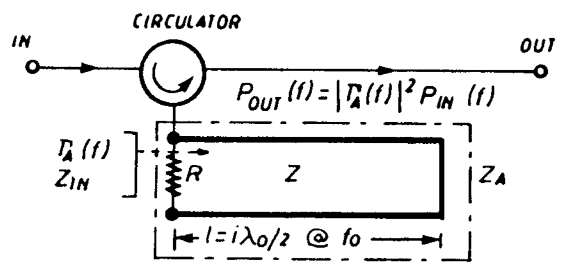

FIG. 3. MICROWAVE SELECTIVE NETWORK.

It is evidently:

(1) $V_{OUT}(f) = \Gamma_A(f) V_{IN}(f)$

(2) $P_{OUT}(f) = |\Gamma_A(f)|^2 P_{IN}(f)$

Thus, the phase shift is equal to the reflection coefficient phase, and the insertion loss (IL) is given by (neglecting the circulator losses):

(3) $IL(dB) = 10\log_{10}\left|\frac{1}{\Gamma_A(f)}\right|^2 = -20\log_{10}|\Gamma_A(f)|$

coinciding with the Return Loss (RL) of the network Z_A.
If the line is long enough, it is possible to obtain a "bell-shaped" frequency response within a not too wide frequency range, as exposed in [10] (where an open-circuit line has been considered) and sketched in fig. 4. A suitable choice of the value of R and Z allows alterating the shape of the "bell", without changing the frequencies at which IL minima and maxima occur.

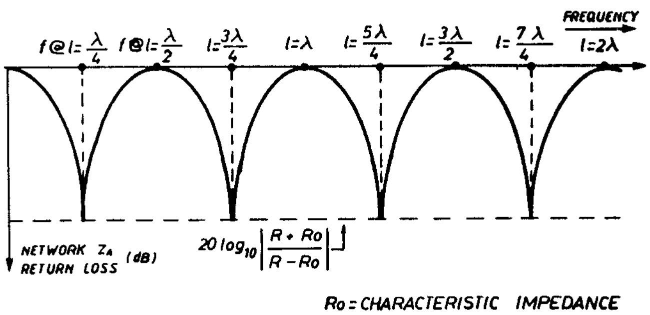

FIG.4. AMPLITUDE RESPONSE OF FIG.3 NETWORK.

Hence, the combined choice of l, R and Z assures a very good (easily implementable) approximation of whichever "bump-type "frequency response.
By explicitating some trivial mathematics, it is straightforward to derive the network Z_A reflection coefficient amplitude (return loss) and phase, which correspond respectively to the insertion loss and phase-shift of the complete "filter" sketched in fig. 3 (apart from circulator contribution):

(4)
$$IL(dB) \simeq \left[RL(dB)\right]_{NETWORK\ Z_A} = 10\log_{10} 1/|\Gamma_A(f)|^2 = 10\log_{10}\frac{(1+Z_oG)^2 + (YZ_o\cot\beta l)^2}{(1-Z_oG)^2 + (YZ_o\cot\beta l)^2}$$

(5)
$$\phi = \angle\Gamma_A(f) = \tan^{-1}\frac{2YZ_o\cot\beta l}{1-(Z_oG)^2-(YZ_o\cot\beta l)^2}$$

where: Z = 1/Y = characteristic impedance of the line
Z_o = system characteristic impedance
G = 1/R
$\beta = 2\pi/\lambda$
l = line length

As far as the insertion loss is concerned (eq. (4), which mathematically represents the behaviour shown in fig. 4), the line eletrical length, βl, gives the filter the frequency selectivity, whilst Y, Z_o and G - i.e. R, Z_o and Z - "weight" the shape of the frequency response.
On the other hand, the phase shift - eq. (5) - remains linear enough, at least in a 5% - 10% fractional bandwidth, depending on the line length and values of involved impedances.
As an example, fig. 5 refers to the case $R \simeq Z_o$, $l = 5\lambda_o/2$ at a generic frequency f_o.
This last property of the fig. 3 selective network makes it very attractive for realizing flat group delay filters, as required in digital telecommunication systems applications.

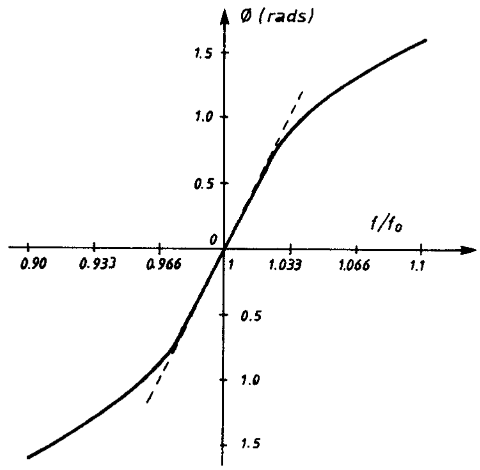

FIG.5. PHASE RESPONSE OF THE FIG.3 NETWORK WITH $R=R_o$ AND $l=2.5\lambda_o$ AT f_o.

3. APPLICATION EXAMPLE

From Ref. 6 the frequency responses of Conversion and Matched Filters in a SMSK system are:

(6)
$$T(f) = T\frac{\sin\pi T(f-f_2)}{\pi T(f-f_2)}$$

(7)
$$R(f) = \frac{4T}{\pi}\frac{\cos 2\pi T(f-f_o)}{1-16T^2(f-f_o)}$$

the "mainlobe" width - see fig. 2 - being 2 R and 1.5 R, respectively, where R is the digital link bit rate (= 1/T).
It is important to recognize that, to realize these two types of filters with the fig. 3 scheme, the system bit rate cannot be too low, unless we adopt rather long transmission lines.
However, the amplitude responses (6) and (7) can be satisfactorily approximated by the insertion loss expression (4) with suitable choice of parameters.
Let us consider, as an example, a digital transmission system having R = 400 Mbit-per-second.
Fig. 6 shows how good this approximation is (about 0.5 dB bandcenter dissipative loss has been removed). The agreement is very good and no trimming optimization has

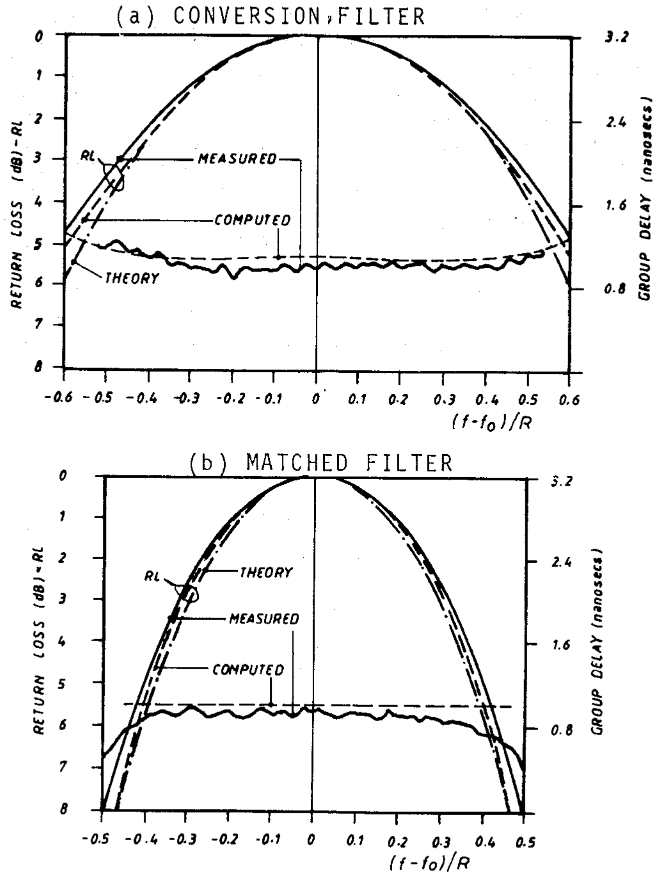

FIG.6. SMSK FILTERS FOR A 400-Mbps SYSTEM.

been done on the physical circuit itself. Some preliminary simulation activity has been undertaken to assess the Bit Error Rate (BER) performance of the ideal SMSK link with the previoulsy exposed Conversion and Matched filter. Only 0.6 dB degradation at 10^{-6} has been observed upon substitution of the theoretical filters with the proposed solution, truncated at $\pm$ 0.5 R or $\pm$ 200 MHz.
Fig. 7 shows a picture of the network Z_A prototype relative to the 400 Mbit/sec Conversion Filter realised on a 1" x 1" PTFE substrate (DUROID 6010, $\varepsilon_r \simeq 10$) without any particular attempt to reduce the size.

4. CONCLUSIONS

A novel, easy technique has been presented to implement microwave Conversion and Matched Filters for Serial-Minimum Shift Keying systems. Theoretical and experimental investigation has proven the practical feasibility of the exposed solution. However, due to the significant length of the involved transmission line, some care has to be taken to assure the necessary temperature stability, if required by the system (e.g. in satellite applications). As already pointed out, the microwave realization of temperature-stable transmission lines is sufficiently developed at present [7] [8] [9].
For instance, one could realize the transmission line on two cascaded substrates (e.g. alumina and some titanate) having temperature coefficients very similar but opposite in sign.

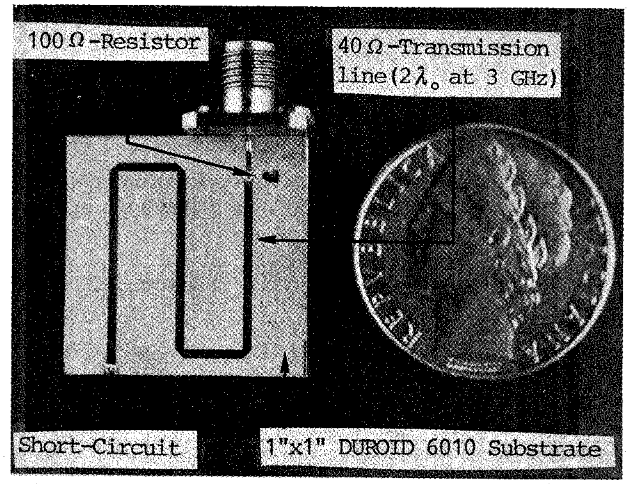

FIG.7. CONVERSION FILTER FOR A 400-Mbps SYSTEM ON A 1"x1" DUROID SUBSTRATE.

The technique exposed in this paper results very flexible, as SMSK filters can be implemented with good properties of amplitude response and group delay flatness across a discrete set of microwave frequencies.

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